A Compact UWB Printed Monopole Antenna with Triple-Band Notched Characteristics

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Abstract **─** A compact triple band-notched printed monopole antenna for ultra-wideband (UWB) application is presented. By inserting two triangular-shaped notches in both sides of the ground plane of microstrip feed line, additional resonances are excited and the bandwidth is increased up to 160%. Three sharp notched frequency bands at 3.8 GHz, 5.5 GHz, and 7.5 GHz are achieved by embedding a pair of rectangular-shaped slits in the ground plane and two pairs of modified bow-shaped slits in the patch. This novel monopole antenna has ultra-wide frequency bandwidth for input impedance, compact size (24 mm × 20 mm), low cost fabrication and Omni-directional H-plane radiation pattern which makes it suitable for ultra-wideband applications. The measured results reveal that the presented triple band-notched monopole antenna is a promising candidate for UWB communication systems to avoid interference with WiMax band (3.3-3.7 GHz), some C-band (3.7-4.2 GHz), WLAN (5.15-5.825 GHz) bands and some C-band satellite communication systems (7-8 GHz).

Index Terms **─** Bow-shaped slits, printed monopole antenna, rectangular-shaped slits, triangular-shaped notch.

I. INTRODUCTION

Ultra-wideband technology has undergone many significant developments in recent years. However, there still remains many challenges in improving this technology to its full potential [1]. Several printed monopole antennas have been proposed recently [2-6], to cover the UWB frequency band 3.1 GHz to 10.6 GHz allocated by the Federal Communications Commission (FCC) for UWB applications [7]. However, this will cause interference to other existing wireless systems WiMAX (3.3-3.7 GHz), WLAN (5.15-5.825 GHz), terrestrial microwave and satellite communications in C-band (3.7-4.2 GHz). Hence, UWB antennas with band-notches are required to avoid harmful interference to other existing communications systems. Some UWB antennas with band-notch have been reported in the literature [8-12]. A recently reported antenna has been designed by making use of two split resonant rings (SRR) to obtain dual band-notch characteristic [13]. In [14], dual band-notch is achieved by using a U-slot in the ground plane and an E-slot in the radiation patch. In [15], the dual notched bands are achieved by embedding a pair of Γ-shaped stubs in the radiation patch and a modified G-slot defected ground structure in the feed line.

The dual band-notch characteristic is achieved by etching a single tri-arm resonator below the patch in [16]. The F-shape feed line is designed to achieve dual notch band characteristic in [17]. In [18], by inserting a novel parasitic strip in trapezoidal slot and a pair of L-shaped slots in metallic ground, dual band-notched characteristics

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are obtained. In [19], for a notched frequency band, two L-shaped slits are embedded on the ground plane. In [20], the desired band-notch antenna is achieved by etching a narrowband triple complementary split-ring resonator into the radiating element of an existing UWB antenna. However, most of the existing antennas can generate no more than two notched bands.

In this paper, in addition to increase the bandwidth of the UWB monopole antenna, a novel triple band-notched monopole antenna is proposed. To increase the bandwidth, two triangular-shaped notches are inserted on the ground plane. Three notched frequency bands are achieved by embedding two pairs of modified bow-shaped slits in the radiation patch and a pair of rectangular-shaped slits in the ground of microstrip feed line. The simulation results using the Ansoft-HFSS show that for VSWR<2, this antenna covers 2-18 GHz frequency band with three notched band of (3.3-4.2 GHz), (5.15-5.95 GHz), and (7-8 GHz). Section 2 presents the details of the antenna structure. Full wave analysis of the proposed antennas in frequency domain is obtained by using Ansoft HFSS which is based on Finite Element Method. The VSWR and far field results obtained are presented in Section 3.

II. ANTENNA DESIGN

The configuration of the proposed ultra-wideband antenna is depicted in Fig. 1. The basic monopole antenna structure consists of a circular patch, a microstrip feed line, and a ground plane. The design of the proposed antenna starts by choosing the dimensions of the designed antenna. This antenna is printed on an FR4 microwave substrate with a size of $W_{sub} \times L_{sub} = 20 \times 24$ mm^2, thickness of 1.6 mm, and relative dielectric constant of 4.4. In the next step in the design of the proposed antenna, the radius of the circular patch is calculated. Radius of the circular patch has a lot of effects on the antenna bandwidth. As this parameter decreases, so does the antenna bandwidth, and vice versa. This parameter is approximately $\lambda_{lower}/4$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the monopole width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated. The patch is connected to a 50 Ω microstrip feed line of width W_f. The width of the microstrip feed line W_f is fixed at 2 mm. The final step in the design of the proposed antenna is to choose the length of the band-notch slots. The circular radiating patch has two pairs of modified bow-shaped slits. On the other side of the substrate, a conducting ground plane with two triangular notches and a pair of rectangular-shaped slits is placed. In this design, the optimized length L_{notch} is set to band-stop resonates at $0.25\lambda_{notch}$.

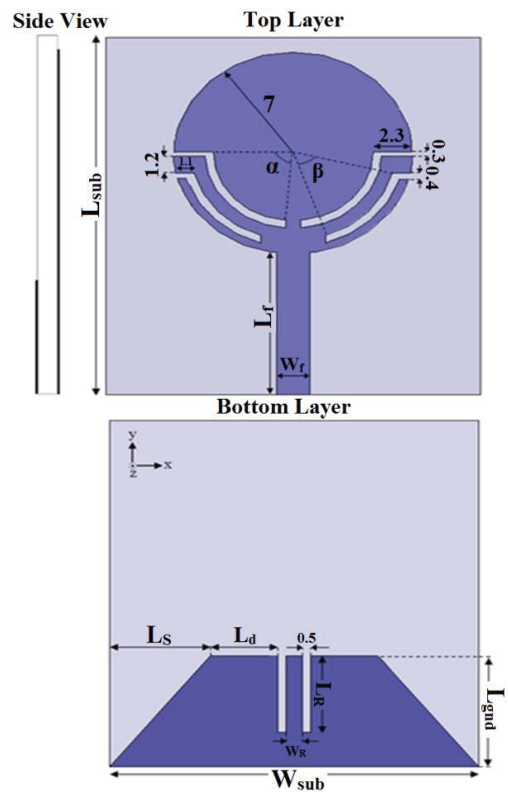

Fig. 1. Configuration and parameters of the proposed antenna (unit: mm).

By inserting two triangular-shaped notches in both sides of the microstrip feed line on the ground plane, additional resonances are excited and hence the bandwidth is increased up to 160%. The improvement in impedance matching over its entire bandwidth is attributed to the phenomenon of defected ground structure (DGS) with slits that creates additional surface current paths in the antenna. Moreover, this ground-plane structure changes the inductive and capacitive nature of the input impedance, which in turn leads to changes in bandwidth [4].

To achieve triple notches at central frequencies of 3.8 GHz, 5.5 GHz, and 7.5 GHz, two pairs of bow-shaped slits on the radiating patch and rectangular-shaped slits in the ground plane are adopted. The antenna is symmetrical longitudinally. The optimal dimensions of the designed antenna are as follows: L_{sub} = 24 mm, W_{sub} = 20 mm, L_f = 9 mm, α = 85^0, β = 60^0, L_R = 6 mm, W_R = 1 mm, L_S = 6 mm, and L_d = 3 mm. The width of the arms at bow-shaped slits in the radiation patch is set at 0.5 mm. The height of the feed gap between the main patch and the ground ($d = L_f - L_{gnd}$) is also an important parameter to control the impedance bandwidth [21]. The radiating patch has a distance of 1 mm to the ground plane with a length of L_{gnd} = 8 mm printed on the back surface of the substrate.

III. RESULTS AND DISCUSSIONS

The parameters of proposed antenna are studied by changing one parameter at a time and fixing the others. To fully understand the behavior of the antenna and to determine optimal parameter values, the antenna was analyzed using Ansoft's high-frequency structure simulator (HFSS™).

Figure 2 shows the effects of two triangular-shaped notches on the VSWR characteristics of the ordinary antenna. As illustrated in Fig. 2, the value of the L_S is playing an important role in the wideband characteristics and in L_S = 6 mm much wider impedance bandwidth is produced. L_S can adjust the inductive and capacitive nature of the input impedance, and improves impedance bandwidth without any cost of size or expense. It is observed from the Fig. 2, that the designed antenna without the filter structures exhibits wideband performance from 2.2 GHz to 17.5 GHz for VSWR<2, covering the entire UWB frequency band.

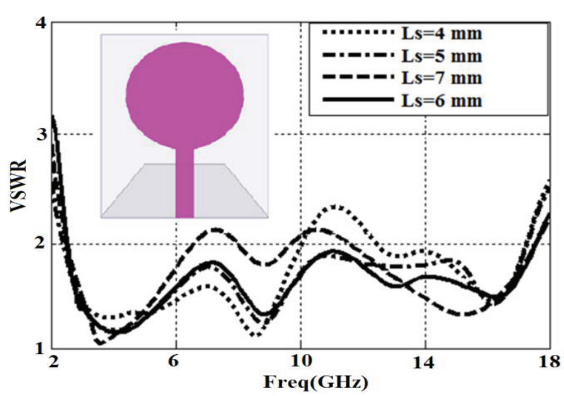

Fig. 2. Simulated VSWR characteristics of the ordinary antenna with different values of L_S.

Triple notched frequency bands are achieved by embedding two pairs of modified bow-shaped slits in the radiation patch and a pair of rectangular-shaped slits in the ground plane. As shown in Figs. 3 (a), 3 (b) and 3 (c), at the notch frequency, current flows are more dominant around the filter and are in opposite directions at interior and exterior edges. Hence, the resulting radiation fields are canceled out and high attenuation near the notch frequency is achieved. This means that the antenna does not radiate efficiently.

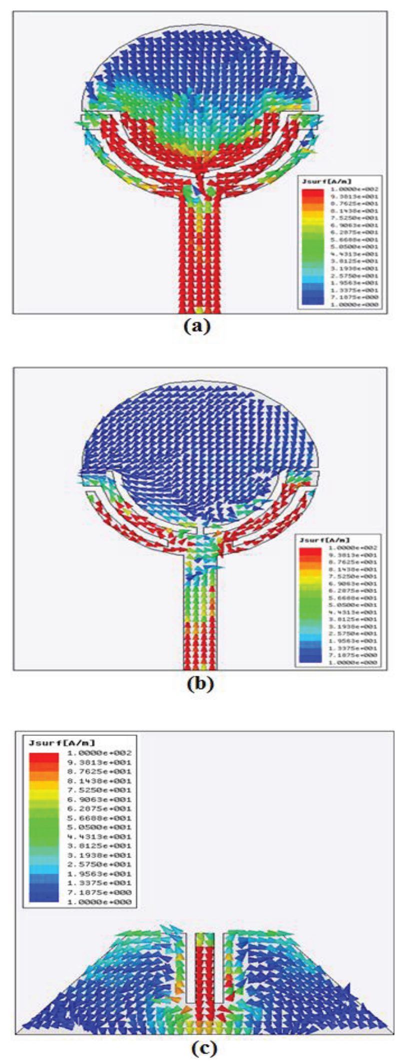

Fig. 3. Simulated surface current distributions on the radiating patch and ground plane for the proposed antenna at: (a) 3.8 GHz, (b) 5.5 GHz, and (c) 7.5 GHz.

Parametric analysis is made to further understand the antenna's behavior. The effects of

L_S, α, β, and L_R parameters are studied in the bandwidth and notch band variations. Simulation results show that the bandwidth and notched frequencies are controllable by changing the length of these parameters. Various notched bands can be achieved by properly changing the parameters of the filter. The notch characteristics are mainly determined by α, β, and L_R. By adjusting the lengths of slots to about a quarter-wavelength at the center frequency of the desired notched-frequency band, the proposed UWB planar monopole antenna becomes non-responsive at that frequency band [21].

In the proposed structure, to increase the bandwidth and achieve triple notches at central frequencies of 3.8 GHz, 5.5 GHz, and 7.5 GHz, two triangular-shaped notches in both sides of the microstrip feed line on the ground plane and two pairs of bow-shaped slits on the radiating patch and rectangular-shaped slits in the ground plane are adopted. Each slots act as a resonator at their resonance or notch frequency. Resonant slot length, which is a multiple of quarter-wavelength, can be calculated approximately by $L_{total} \cong n\,\lambda_g/4$. For a desired notch frequency the wavelength is given by $\lambda_g = \lambda/\sqrt{\varepsilon_r}$, which λ is the free space wavelength. In this design, a good start point for the length L_{notch} is $\lambda_{notch}/4$, where λ_{notch1}, λ_{notch2} and λ_{notch3} corresponds to first band-notch frequency (3.8 GHz), second band-notch frequency (5.5 GHz), and third band-notch frequency (7.5 GHz) respectively. As shown in Figs. 4 (a) and 4 (b), the first and the second notch frequencies depend on the values of α and β, respectively. As illustrated in Fig. 4 (a), by increasing α from 60° to 88°, while maintaining other parameter values, the first notched band moves to a lower frequency. As shown in Fig. 4 (b), when β increases from 50° to 75°, the center frequency of 5.5 GHz notch band changes from 6 GHz to 4.4 GHz.

Figure 5 illustrates the simulated VSWR characteristics with various lengths L_R, and also shows that small changes in L_R significantly affects the center frequency of 7.5 GHz notch band. As L_R is increased from 3.5 to 7 mm, the center frequency of the notch band is changed from 12.7 GHz to 6.3 GHz. Hence, we conclude that notch frequencies are controllable by carefully choosing the values of α, β, and L_R. The results indicate that the antenna is a promising candidate for UWB communication systems to avoid interference with WiMax band (3.3-3.7 GHz), some C-band (3.7-4.2 GHz), WLAN (5.15-5.825 GHz) bands and some C-band satellite communication systems (7-8 GHz).

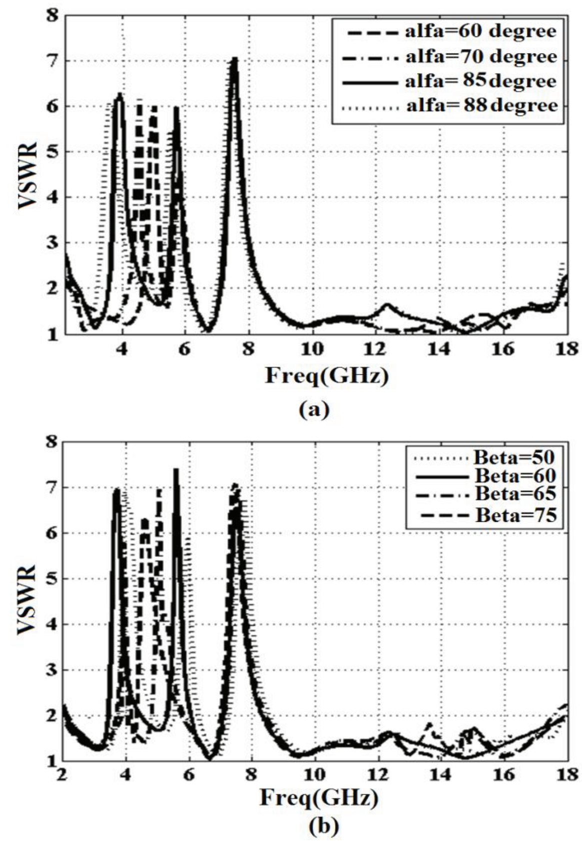

Fig. 4. Simulated band-rejection characteristics of the proposed antenna with notched bands for different values of α (a), and β (b).

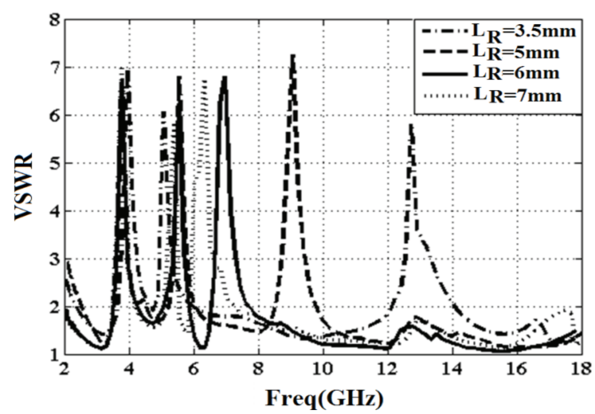

Fig. 5. Simulated band-rejection characteristics of the proposed antenna with notched bands for various L_R.

To verify the proposed design, a prototype of the antenna based on optimized dimensions has been fabricated, as shown in Fig. 6, which also shows the measured and simulated VSWR characteristics of the proposed antenna. Note that, there exists a discrepancy between measured data and the simulated results, which could be due to the SMA port.

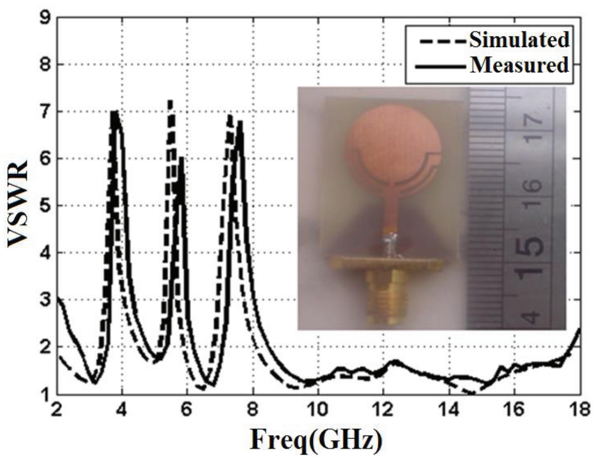

Fig. 6. Photograph of the fabricated prototype and comparison between measured and simulated VSWR for the proposed antenna.

In order to attain the VSWR characteristics for the designed antenna, the measurement and manufacturing processes need to be performed carefully. Note also that, the designed antenna with the filter structures exhibits three notch bands 3.3-4.2 GHz, 5.15-5.95 GHz and 7-8 GHz, which covers the 3.5/5.5-GHz (3.4-3.69/5.25-5.85 GHz) WiMAX bands, 5.2/5.8-GHz (5.15-5.35/5.725-5.825 GHz) WLAN bands and some C-bands, while maintaining wideband performance from 2 GHz to 18 GHz for VSWR<2, covering the entire UWB frequency band.

Figure 7 shows the measured radiation patterns of the fabricated antenna, obtained for the y-z plane (E-plane) and the x-z plane (H-plane) at 4, 7 and 10 GHz. The patterns in the H-plane are omnidirectional as expected, whereas in the E-plane, radiation patterns have a dumbbell shape. Cross-polarization levels are generally much lower than the co-polarization ones. Note that, the fabricated antenna actually radiates over a wide frequency band.

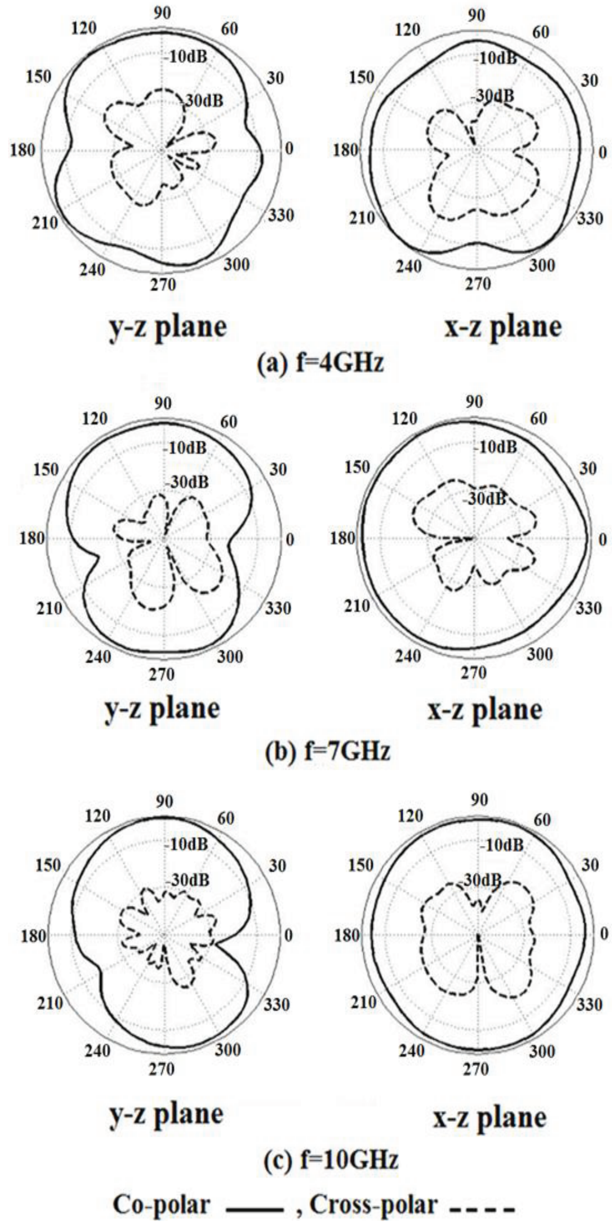

Fig. 7. Measured radiation patterns at frequencies: (a) 4 GHz, (b) 7 GHz, and (c) 10 GHz.

Figure 8 presents the measured peak antenna gain with and without filters. The figure indicates that the realized triple band notched antenna has good gain flatness, except in three notched bands. As desired, the antenna gain is decreased in the vicinity of 3.5 GHz, 5.5 GHz and 7.5 GHz. Outside the notch band, antenna gain is relatively constant (variations below 2.5 dB). Thus, the antenna exhibits stable gain across the operation band.

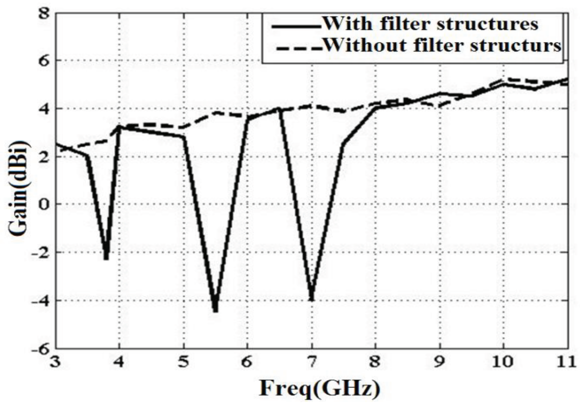

Fig. 8. Peak gain of the optimized UWB antenna with and without filter structures.

IV. CONCLUSION

A novel compact printed monopole antenna with triple band-notched characteristics, suitable for UWB applications was presented and analyzed. We showed that by inserting two triangular-shaped notches on the ground plane with proper dimensions, a wide impedance bandwidth is achieved. Triple band-notches are achieved by embedding two pairs of bow-shaped slits in the radiation patch and a pair of rectangular-shaped slits in the ground plane. The radiation pattern of this antenna shows good omni-directional pattern throughout the UWB frequency range. The gain of the proposed antenna is almost flat in the operation frequency band with sharp notched bands.

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