Compact Planar Microstrip-Fed Printed Antenna with Double Band-Filtering for UWB Application

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Abstract **─** In this paper, a new design of dual band-notch printed monopole antenna for UWB applications is proposed. The antenna consists of a circular disc radiating patch with a protruded anchor-shaped strip, a feed line with an inverted U-ring slot and a ground plane structure, which provides a wide usable fractional bandwidth of more than 125% (2.69-12.53 GHz) with dual band-stop performance around of 3.3-4.2 GHz and 5-6 GHz. In the proposed structure, by using a protruded anchor-shaped strip in the radiating patch, a single frequency band-stop performance can be achieved. Also, in order to create the second notched frequency, an inverted U-ring slot was cut at the feed line. Simulated and measured results obtained for this antenna show that the proposed monopole antenna offers two notched bands, covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX and 4-GHz C-band range. The proposed antenna has a small dimension of 12×18×1.6 mm^3.

Index Terms **─** Anchor-shaped strip, inverted U-ring structure, UWB applications.

I. INTRODUCTION

There has been more and more attention in ultra-wideband (UWB) antennas ever since the Federal Communications Commission (FCC)'s allocation of the frequency band 3.1-10.6 GHz for commercial use [1-2]. 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 [3-4].

There are many narrowband communication systems which severely interfere with the UWB communication system, such as the wireless local area network (WLAN) operating at 5.15-5.35 and 5.725-5.825 GHz, international telecommunication union operating from 8.025 to 8.4 GHz, and etc. Therefore, UWB antennas with band-notched characteristics to filter the potential interference are desirable. Nowadays, to mitigate this effect many UWB antennas with various band-notched properties have developed [5-6].

All of the above methods are used for rejecting a single band of frequencies. To effectively utilize the UWB spectrum and to improve the performance of the UWB system, it is desirable to design the UWB antenna with dual band rejection. It will help to minimize the interference between the narrow band systems with the UWB system. Some methods are used to obtain the dual band rejection in the literature [7-8]. In this paper, a new dual band-notched monopole antenna is presented. In the proposed structure, single band-notched function is provided by using a rectangular slit with a protruded anchor-shaped strip in top of the circular disc radiating patch, and dual band-notched characteristic is obtained by cutting an inverted U-ring slot inside the feed line. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

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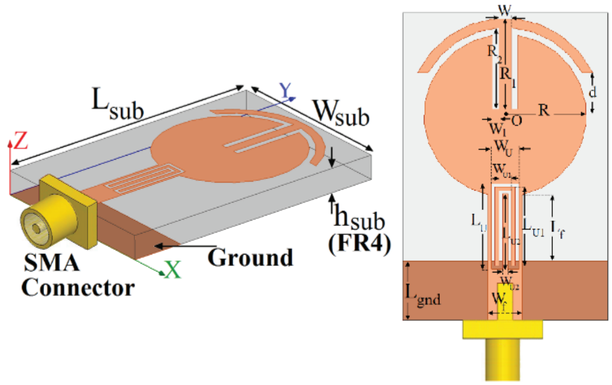
II. ANTENNA DESIGN

The presented small monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on an *FR4* substrate of thickness of 1.6 mm, permittivity of 4.4, and loss tangent of 0.018.

Microstrip feed line is one of the easier methods to fabricate as it is just a conducting strip connecting to the patch and therefore can be considered as an extension of radiating patch. It is simple to model and easy to match by controlling the inset position. In the microstrip-fed technique, a conducting strip is made contact directly to the edge of the radiating patch or microstrip patch. The conducting strip is having minimum in width as compared to the radiating patch.

The proposed antenna is connected to a 50-Ω SMA connector for signal transmission. The circular disc patch has a radial of *R*. The radiating patch is connected to a feed line with width of W_f and length of L_f .The width of the microstrip feed line is W_f=2mm. On the other side of the substrate, a conducting ground plane of is placed.



(a) (b)

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

In this work, we start by choosing the dimensions of the designed antenna. These parameters including the substrate is $W_{sub} \times L_{sub}$=12×18 mm^2 or about 0.15λ×0.25λ at 4.8 GHz (the first resonance frequency of the ordinary monopole antenna). We have a lot of flexibility in choosing the radios of the radiating patch. This parameter mostly affects the antenna bandwidth. As R 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 last and final step in the design is to choose the length of the band-stop filter elements. In this design, the optimized length L_{notch} is set to band-stop resonate at $0.5\lambda_{notch}$, where $L_{notch1}=R_1+0.5R_2+0.5$ for 3.9 GHz notched frequency and $L_{notch2}=L_{U1}+0.5W_{U1}+0.25L_{U2}$ for 5.5 GHz notched frequency. λ_{notch1} and λ_{notch2} corresponds to first band-notch frequency (3.9 GHz) and second band-notch frequency (5.5 GHz), respectively.

In this study, the protruded anchor-shaped strip in the radiating patch perturbs the resonant response and also acts as a half-wave resonant structure [4]. At the notched frequency, the current concentrated on the edges of the interior and exterior of this structure [7]. Additionally, the inverted U-ring slot inside the feed line act as a filtering element to generate another notched frequency, because it can create additional surface current path. As a result, the desired attenuation near the notched frequencies can be produced. Final values of the designed antenna parameters are indicated in Table 1.

Table 1: The final dimensions of the antenna

Param.	mm.	Param.	mm.	Param.	mm.
W_{sub}	12	L_{sub}	18	H_{sub}	1.6
L_f	7	W_f	2	W	7
R	4.75	W_1	0.4	R_1	5.5
R_2	5	W_U	1.1	L_U	5
W_{U1}	0.5	L_{U1}	4.6	W_{U2}	0.2
L_{U2}	4.4	d	2.25	L_{gnd}	3.5

III. RESULTS AND DISCUSSIONS

In this Section, the microstrip monopole antenna with various design parameters were constructed. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [9].

A. UWB monopole antenna

In the proposed structure, in order to increase the upper frequency bandwidth, we use a modified circular disc structure instead of square structure in radiating patch of the antenna [7]. By properly tuning the length of R in the radiating patch, the antenna can actually radiate over a very wide frequency band based on a coupling condition.

Figure 2 shows the effects of circular disc radiating patch with different values of radial sizes on the impedance. It is found that by applying a circular disc structure of suitable dimensions at the radiating patch much wider impedance bandwidth can be produced, especially at the higher band [3-6].

The simulated current distributions for the ordinary monopole antenna with a circular-disc radiating patch at the resonance frequencies are presented in Fig. 3. It can be observed in Figs. 3 (a) and 3 (b) that the directions of surface currents at the circular-disc radiating patch are reversed in compared to each other, which cause the antenna impedance changes at 4.8 and 11 GHz due to the resonant properties of the top layer structure.

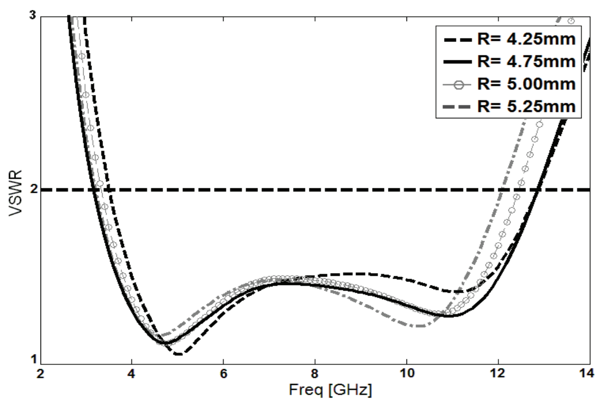


Fig. 2. Simulated VSWR characteristic with different values of R .

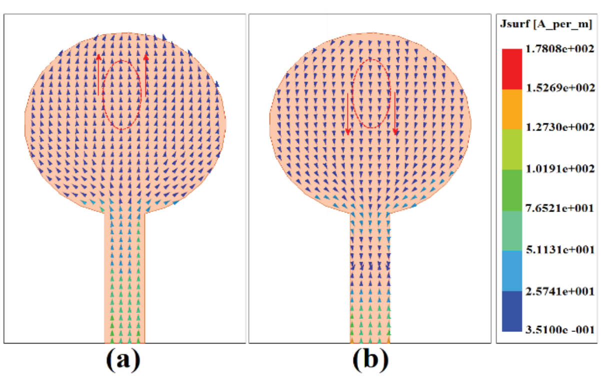


Fig. 3. Simulated surface current distributions for the circular antenna at: (a) 4.8 GHz, and (b) 11 GHz.

B. Dual band-notched UWB antenna

The structure of the various antennas used for simulation studies are shown in Fig. 4. VSWR characteristics for the ordinary circular disc monopole antenna [Fig. 4 (a)], circular disc monopole antenna with a Protruded anchor-shaped strip in the rectangular slit at radiating patch [Fig. 4 (b)], and the proposed antenna structure [Fig. 4 (c)] are compared in Fig. 5.

As shown in Fig. 5, to generate a single frequency band notch function (3.3-4.2 GHz), we insert a rectangular slot with an anchor-shaped strip protruded inside the rectangular slot in the radiating patch of the ordinary circular disc monopole antenna, and also by using an inverted U-ring slot at feed line, the dual band-notched function can be achieved.

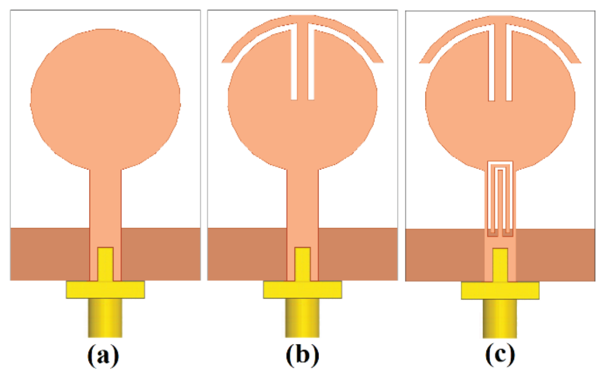


Fig. 4. (a) Basic structure, (b) antenna with a protruded anchor-shaped strip inside rectangular slot, and (c) the proposed antenna.

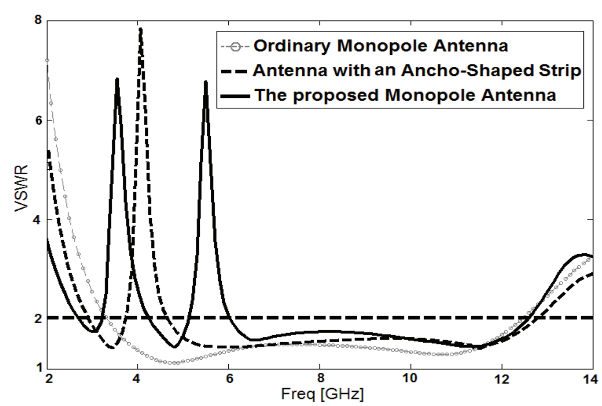


Fig. 5. Simulated VSWR characteristics for the antennas shown in Fig. 2.

In order to know the phenomenon behind the dual band-notched performance, the simulated current distributions on the circular disc radiating patch for the proposed antenna at 3.8 GHz are presented in Fig. 6 (a). It can be observed in Fig. 5 (a), that the current concentrated on the edges of the interior and exterior of the protruded anchor-shaped strip at 3.8 GHz.

Other important design parameter of this structure is the inverted U-ring slot use in the feed line. Figure 6 (b) presents the simulated current distributions on the feed line at the second notched frequency (5.5 GHz). As shown in Fig. 6 (b), at the second notched frequency the current flows are more dominant around of the inverted U-ring shaped slot. As a result, the desired high attenuation near the second notched frequency can be produced [10].

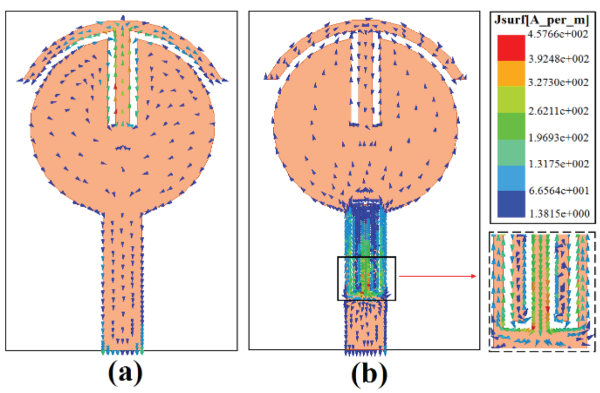


Fig. 6. Simulated surface current distributions on the radiating patch for: (a) the circular disc antenna with a protruded anchor-shaped stub at 3.9 GHz (first notched frequency), and (b) the proposed antenna at 5.5 GHz (second notched frequency).

The simulated VSWR curves with different values of $d\&L_U$ are plotted in Fig. 7. As illustrated, when the interior width of the anchor-shaped strip and the length of the inverted U-ring slot increase from 3.5 to 5.3 mm and 2 to 2.5 mm respectively, the center of notched frequencies decrease from 6.2 and 4.2 GHz to 5 and 3.5 GHz. From these results, we can conclude that the notched frequencies are controllable by changing the length of the embedded structure.

Another main effect of the anchor-shaped and inverted U-ring structures occurs on the filter bandwidth. In the proposed structure, the lengths of $R_1\&W_{U1}$ are the critical parameter to control the filter bandwidth. Figure 8 illustrates the simulated VSWR characteristics with various lengths of $R_1\&W_{U1}$. As the interior width of the $R_1\&W_{U1}$ increases from 5.3 to 5.7 mm and 0.4 to 0.6 mm respectively, the filter bandwidth is varied from 0.7 to 1.5 GHz. Therefore the bandwidth of notched frequencies is controllable by changing the length of $R_1\&W_{U1}$.

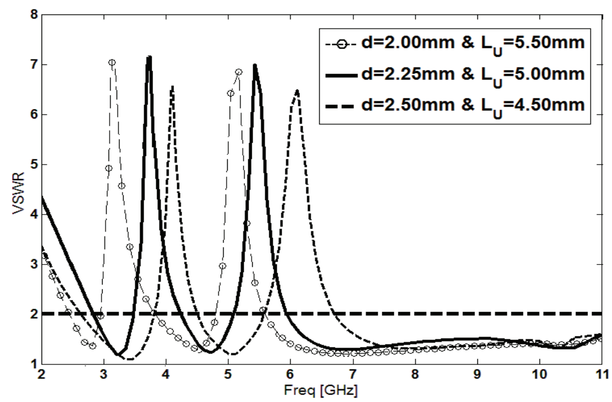


Fig. 7. Simulated VSWR characteristic with different values of $d\&L_U$.

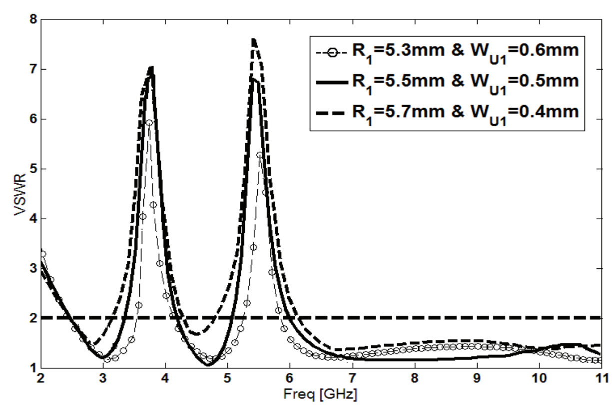


Fig. 8. Simulated VSWR characteristics for the proposed antenna with different values of $R_1\&W_{U1}$.

The proposed microstrip monopole antenna with final design as shown in Fig. 9 was built and tested, and the VSWR and return loss characteristics were 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).

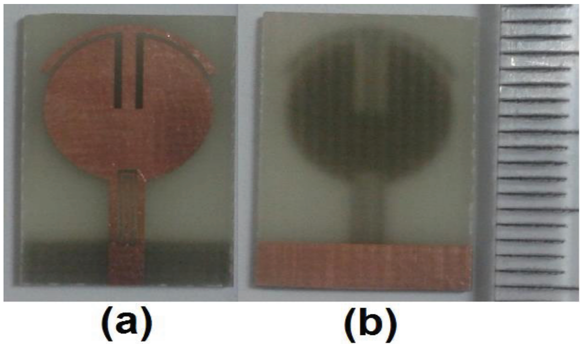


Fig. 9. Photograph of the realized antenna: (a) top view, and (b) bottom view.

Figures 10 and 11 show the measured and simulated VSWR and return loss characteristics of the proposed antenna, respectively. As illustrated, the fabricated antenna has the frequency band of 2.69 to over 12.53 GHz. However, as seen, there exists a discrepancy between measured data and the simulated results. This 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, the wide range of simulation frequencies.

In a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of a SMA connector and a microstrip line (the microstrip feed-line is excited by a SMA connector), whereas the simulated results are obtained using the Ansoft simulation software (HFSS), that in HFSS by default, the antenna is excited by a wave port that it is renormalized to a 50-Ohm full port impedance at all frequencies. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement processes need to be performed carefully.

Measured maximum gain of the proposed antenna in compared with ordinary structure is shown in Fig. 12. As illustrated, two sharp decreases of the maximum gain in the notched frequencies (3.9 and 5.5 GHz) are shown. For other frequencies outside the notched frequency band, the antenna gain with the filters is similar to this without them. As seen, the proposed antenna has sufficient and acceptable gain level in the operation bands [5-6].

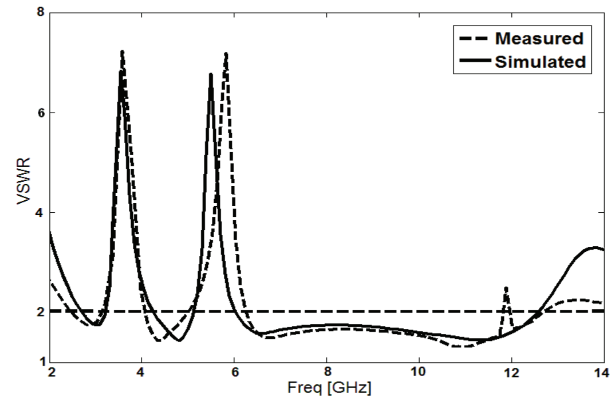


Fig. 10. Measured and simulated VSWR for the proposed antenna.

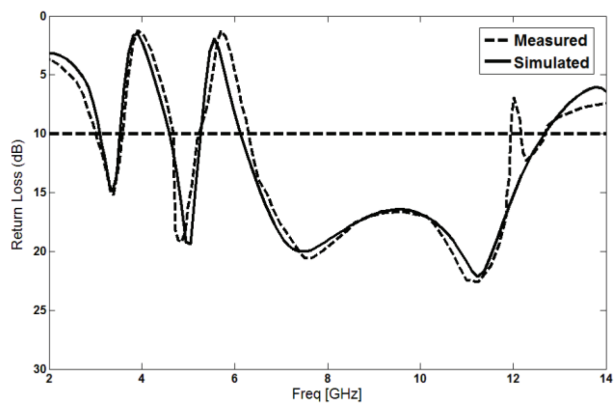


Fig. 11. Measured and simulated return loss characteristics for the proposed antenna.

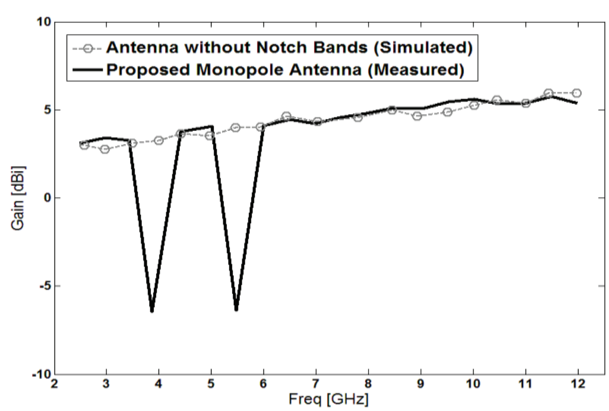


Fig. 12. Measured and simulated maximum gain characteristics for the proposed antenna.

Figures 13 and 14 depict the measured radiation patterns including the co-polarization and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane) at the resonance and notched frequencies, respectively. It can be seen that nearly omnidirectional radiation pattern can be observed on x-z plane over the whole UWB frequency range, especially at the low frequencies. The radiation patterns on the y-z plane are like a small electric dipole leading to bidirectional patterns in a very wide frequency band [7-8], [10].

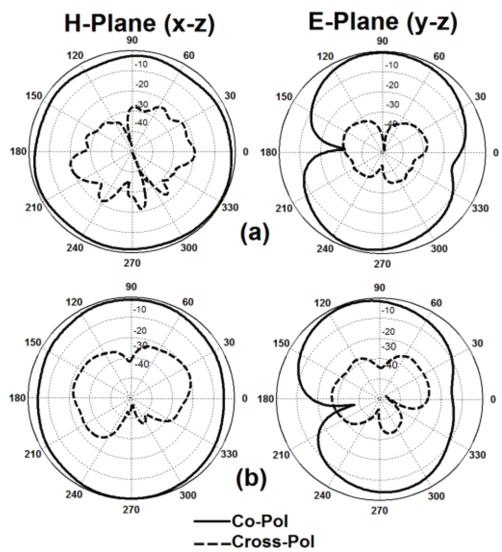


Fig. 13. Measured radiation patterns at resonance frequencies: (a) 4.8 GHz, and (b) 11 GHz.

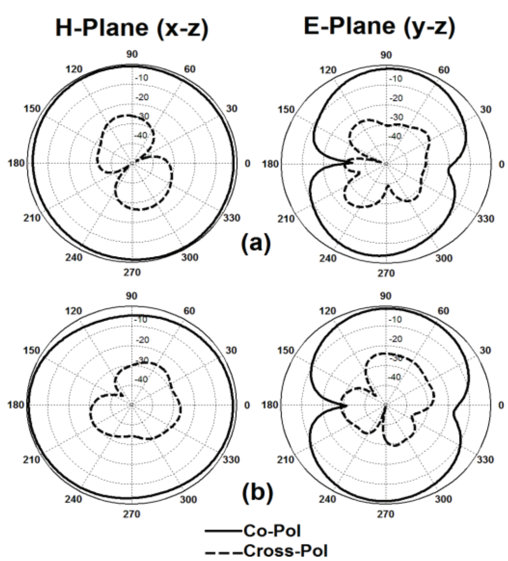


Fig. 14. Measured radiation patterns at notched frequencies: (a) 3.9 GHz, and (b) 5.5 GHz.

IV. CONCLUSION

In this paper, a compact planar monopole antenna (PMA) with single and dual band-notched characteristics has been proposed for various UWB applications. The fabricated antenna has the frequency band of 2.69 to over 12.53 GHz with two rejection bands around 3.3-4.23 and 5.07-5.96 GHz. By cutting a rectangular slit with a protruded anchor-shaped stub in the circular disc radiating patch, single band-notched characteristic is generated, and also by inserting an inverted U-ring slot inside the feed line, a good dual band-notched characteristic can be achieved. The proposed antenna has a simple configuration and small size.

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