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DUAL BAND-NOTCHED MONOPOLE ANTENNA WITH MULTI-RESONANCE CHARACTERISTIC FOR UWB WIRELESS COMMUNICATIONS

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Abstract—In this manuscript, a novel design of ultra-wideband (UWB) monopole antenna with dual frequency band-stop performance is proposed. The proposed antenna consists of an ordinary square radiating patch with a pair of rotated T-shaped slits, and a modified ground plane with an inverted Ω-shaped and a pair of rectangular-ring slots. In the presented structure, by cutting a pair of rectangular-ring slots in the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band that the antenna provides a wide usable fractional bandwidth of more than 140% (2.8–17.5 GHz). In order to generate single band-notched characteristic, we cut a pair of rotated T-shaped slits in the square radiating patch. Finally, by inserting an inverted Ω-shaped slot in the ground plane, a dual band-notched function is achieved. The measured results reveal that the presented dual band-notch monopole antenna offers a very wide bandwidth with two notched bands, covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX and 4 GHz C bands. The designed antenna has a small size of $12 \times 18\,\mathrm{mm}^2$. Good return loss, antenna gain and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

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1. INTRODUCTION

In the UWB communication systems, one of the 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. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated [1–5]. As important compact UWB antennas, printed monopole antennas with frequency notched function have attracted more and more attention [6–8].

Despite the advantages of UWB, the frequency range for UWB systems between 3.1 to 10.6 GHz will cause interference to the existing wireless communication systems, such as, the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands, WiMAX (3.3–3.6 GHz and C-band (3.7–4.2 GHz), so the UWB antenna with a single and dual band-stop performance is required [9–12]. In [9–11], different shapes of the slits (i.e., rectangular and Γ-shaped) are used to obtain the desired band notched characteristics. Conductor-backed plane structures are embedded in the ground plane to generate the single and multiple band-notched functions, respectively [10–12].

In this paper, to achieve all of the above purposes, such as the frequency range for UWB systems with respect to the multi-resonance performance and dual notched band characteristics (to avoid the interference between UWB and WLAN/WiMAX), at the first step of design algorithm by cutting a pair of rectangular-ring slots in the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, which leads to a bandwidth improvement and a complete coverage of the UWB frequency band. At the next step, in order to generate single band-notched characteristic, we cut a pair of rotated T-shaped slits in the square radiating patch. Finally, by inserting an inverted Ω-shaped slot in the ground plane, a dual band-notched function is achieved. The measured results reveal that the presented dual band-notch monopole antenna offers a very wide bandwidth with two notched bands, covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX and 4 GHz C bands. The proposed antenna is designed for UWB devices which mounted on wireless systems such as satellite receiver. The proposed antenna has a small size of $12 \times 18\,\text{mm}^2$, or about $0.15\lambda \times 0.25\lambda$ at 4.2 GHz (first resonance frequency), which has a size reduction of 28% with respect to the previous similar antenna [12, 13]. Good antenna gain and VSWR characteristics are obtained in the frequency band of interest.

Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications

2. 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 1.6 mm, permittivity 4.4, and loss tangent 0.018. The basic monopole antenna structure consists of a square patch, a feed line, and a ground plane. The square patch has a width W. The patch is connected to a feed line of width W_f and length L_f. The width of the microstrip feed line is fixed at 2 mm, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane with modified structure is placed. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission.

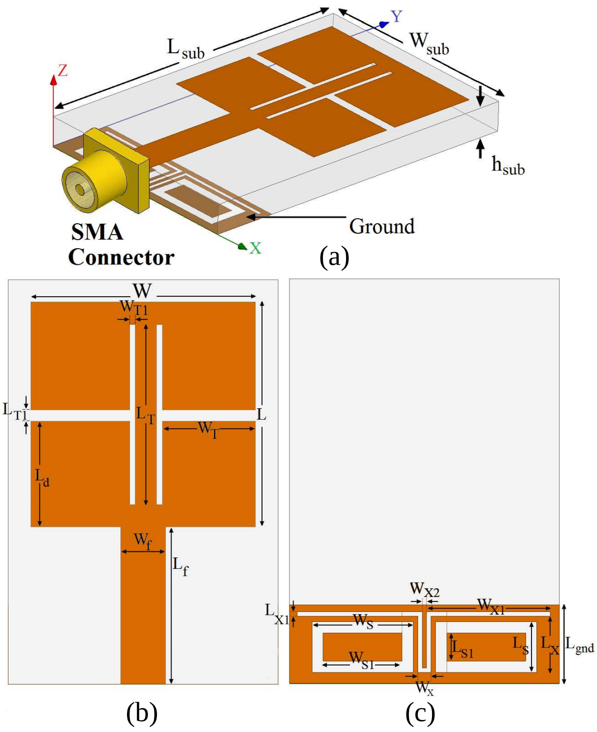

Figure 1. Geometry of proposed microstrip-fed monopole antenna. (a) Side view, (b) top layer, and (c) bottom layer.

In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, is $W_{Sub} \times L_{Sub} = 12\,\mathrm{mm} \times 18\,\mathrm{mm}$ or about $0.15\lambda \times 0.25\lambda$ at 4.2 GHz (the first resonance frequency). We have a lot of flexibility in choosing the width of the radiating patch. This parameter mostly affects the antenna bandwidth. As W decreases, so does the antenna bandwidth, and vice versa. Next step, we have to determine the length of the radiating patch L. This parameter is approximately $\frac{\lambda_{lower}}{4}$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the radiating patch width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated [8]. The important step in the design is to choose $L_{resonance}$ (the length of the resonators), L_{notch} (the length of the filters). $L_{third\,resonance}$ is set to resonate at $0.25\lambda_g$, where $L_{third\,resonance} = W_S + L_S$, and $L_{fourth\,resonance} = 0.5W_S + L_S$, λ_g corresponds to new resonance frequencies wavelength (11.5 GHz is the first notched frequency and 15.9 GHz is the second notched frequency. L_{notch} is set to band-stop resonate at $0.5\lambda_g$, where $L_{first\ notch} = L_T + 0.5(L_T - L_{T1} + W_{T1}) + W_T$, and $L_{second\,notch} = L_X + W_{X1}$, λ_g corresponds to notched band frequencies wavelength (3.9 GHz is the first notched frequency and 5.5 GHz is the second notched frequency).

The final values of proposed antenna design parameters are as follows: $W_{sub} = 12\,\mathrm{mm}$, $L_{sub} = 18\,\mathrm{mm}$, $W_f = 2\,\mathrm{mm}$, $L_f = 7\,\mathrm{mm}$, $W = 10\,\mathrm{mm}$, $W_S = 4.5\,\mathrm{mm}$, $L_S = 2.5\,\mathrm{mm}$, $W_{S1} = 3.5\,\mathrm{mm}$, $L_{S1} = 1.5\,\mathrm{mm}$, $W_X = 0.6\,\mathrm{mm}$, $L_X = 2.75\,\mathrm{mm}$, $L_{X1} = 0.25\,\mathrm{mm}$, $W_{X1} = 5.5\,\mathrm{mm}$, $W_{X2} = 0.2\,\mathrm{mm}$, $W_T = 4.25\,\mathrm{mm}$, $L_T = 8\,\mathrm{mm}$, $W_{T1} = 0.25\,\mathrm{mm}$, $L_{T1} = 0.5\,\mathrm{mm}$, $L_d = 4.75\,\mathrm{mm}$, and $L_{gnd} = 3.5\,\mathrm{mm}$.

3. RESULTS AND DISCUSSIONS

The proposed microstrip monopole antenna with various design parameters was constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The proposed microstrip-fed monopole antenna was fabricated and tested to demonstrate the effect of the presented. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement is obtained [14].

3.1. UWB Antenna with Multi-resonance Characteristic

Figure 2 shows the structure of various antennas used for multi resonance performance simulation studies. Return loss characteristics for ordinary square antenna (Fig. 2(a)), with a single rectangular-ring slot in the ground plane (Fig. 2(b)), and with a pair of rectangular-ring slots in the ground plane (Fig. 2(c)) are compared in Fig. 3. As shown in Fig. 3, it is observed that by using these modified structures in the ground plane, third and fourth resonances are excited at 11.5 and 15.9 GHz and hence the bandwidth is increased. Also, Fig. 4 shows the Smith Chart results for proposed antenna with multi-resonance

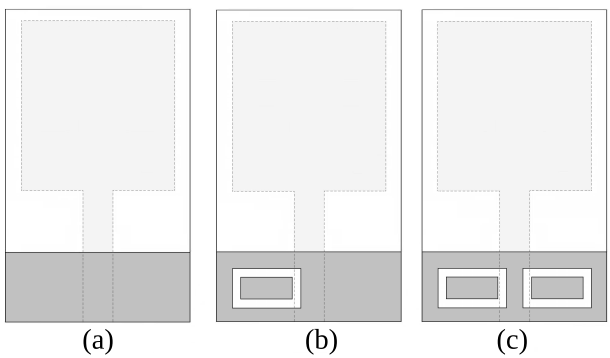

Figure 2. (a) Ordinary monopole antenna, (b) antenna with a rectangular-ring slot in the ground plane, and (c) with a pair of rectangular-ring slots in the ground plane.

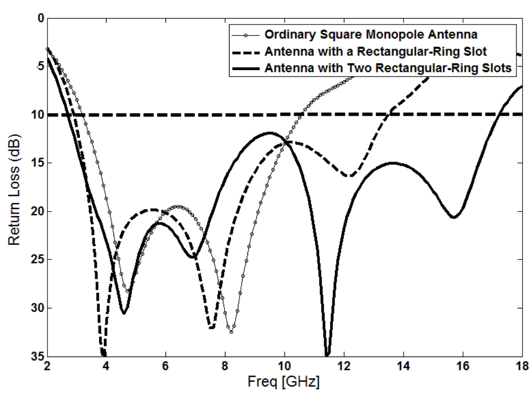

Figure 3. Simulated return loss characteristics for the various antenna structures shown in Fig. 2.

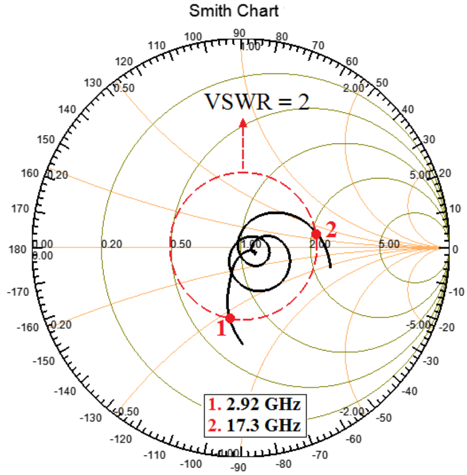

Figure 4. The simulated input impedance on a Smith Chart of the multi-resonance antenna structure shown in Fig. 2(c).

structure that was shown in Fig. 2(c).

As shown in Fig. 3, in the proposed antenna configuration, the ordinary square monopole can provide the fundamental and next higher resonant radiation band at 4 and 7.9 GHz, respectively. The upper frequency bandwidth is significantly affected by using the pair of rectangular-ring slots in the ground plane. This behavior is mainly due to the change of surface current path by changing the dimensions of the pair of rectangular slits as shown in Figs. 5(a) and 5(b).

As shown in Fig. 5, the current concentrated on the edges of the interior and exterior of the inverted coupled U-shaped conductor-backed plane at the extra resonances frequencies (11.5 and 15.9 GHz) [12, 13]. As shown in Fig. 5(a), at fourth resonance frequency (15.8 GHz), the current is mainly concentrated on the interior and exterior edges of the pair of rectangular-ring slots. This figure shows that the electrical current for the fourth resonance frequency (Fig. 5(b)) does change direction along the bottom edge of the ground plane and changes the antenna impedance at this frequency, as leads to an increase in the radiating power and bandwidth.

In order to investigate the effects of rectangular-ring slots on the bandwidth of the proposed antenna and impedance matching, the VSWR characteristics for various slot sizes were analyzed in Fig. 6. Four such rectangular-ring slots structures with different sizes are specified in Table 1 as cases 1, 2, 3 and 4. As shown in Fig. 6, it is found that by inserting the pair of rectangular-ring slots dimensions

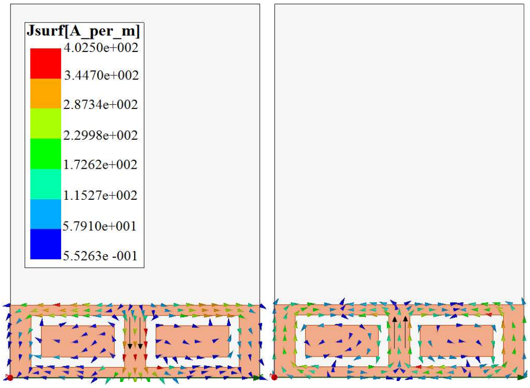

Figure 5. Simulated surface current distributions on ground plane for the proposed antenna, (a) at 11.5 GHz (first extra resonance frequency), (b) at 15.9 GHz (second extra resonance frequency).

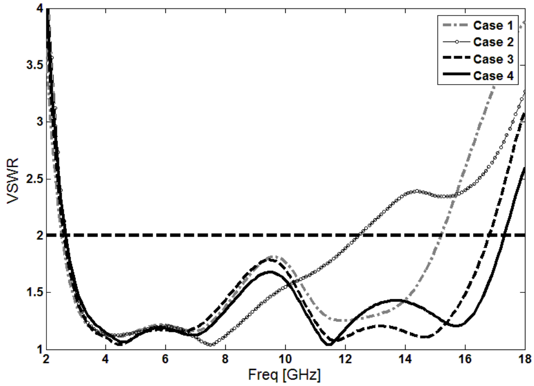

Figure 6. Simulated VSWR characteristics for the various sizes of rectangular-ring slots.

Table 1. Four cases of proposed UWB antenna structure with different values of rectangular-ring slots.

Case	W_S (mm)	L_S (mm)	W_{S1} (mm)	L_{S1} (mm)
1	3.5	2.5	2.5	1.2
2	4	2	3	1
3	4.5	2.5	2.5	1.5
4	4.5	2.5	3.5	1.5

in the ground plane additional resonances is excited and hence much wider impedance bandwidth with multi-resonance characteristics can be produced.

3.2. UWB Antenna with Dual Band-notched Function

To design a novel antenna, also in order to generate a dual band-notched characteristic, we insert a pair of rotated T-shaped slits at square radiating patch and also an inverted Ω-shaped slot was inserted in the ground plane, as displayed in Fig. 1. Geometry for

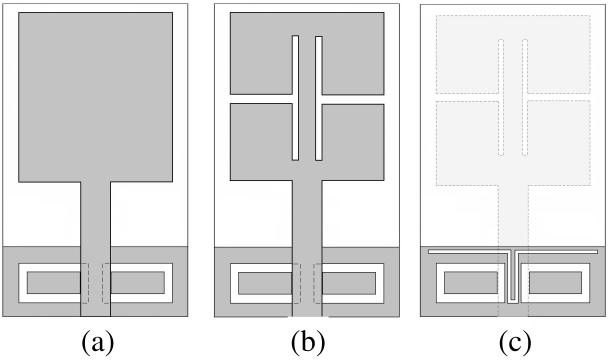

Figure 7. (a) Antenna with a pair of rectangular-ring slots in the ground plane, (b) and with a pair of rotated T-shaped slit at square radiating patch, and (c) the proposed antenna structure.

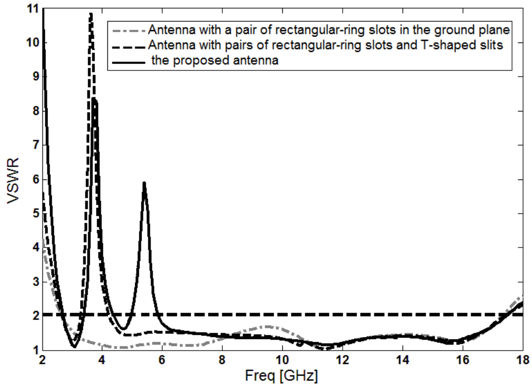

Figure 8. Simulated VSWR characteristics for the various antenna structures shown in Fig. 7.

the antenna with a pair of rectangular-ring slots in the ground plane (Fig. 7(a)), with pairs of rectangular rectangular-ring slots in the ground plane and rotated T-shaped slits at square radiating patch (Fig. 7(b)) and the proposed antenna structure (Fig. 7(c)) are shown in Fig. 7. VSWR characteristics for the structures that were shown in Fig. 8 are compared in Fig. 8 As shown in Fig. 8, in order to generate single band-notched characteristic (3.3–4.2 GHz C-Band and

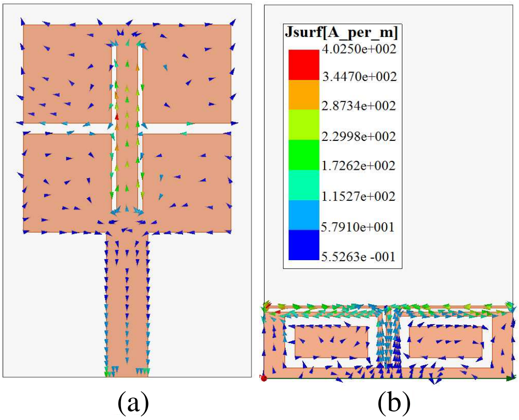

Figure 9. Simulated surface current distributions for the proposed antenna at the notched frequencies, (a) in the radiating patch at 3.9 GHz, (b) on the ground plane at 5.5 GHz.

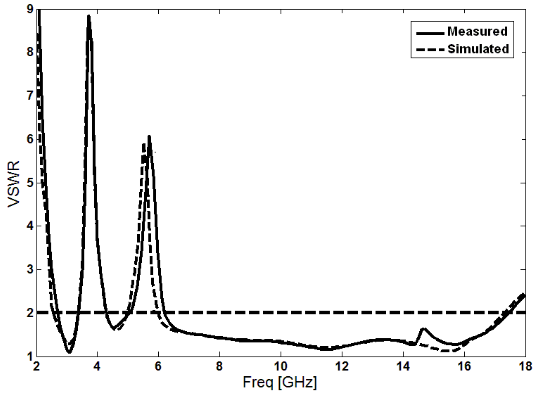

Figure 10. Measured and simulated VSWR characteristics for the proposed antenna.

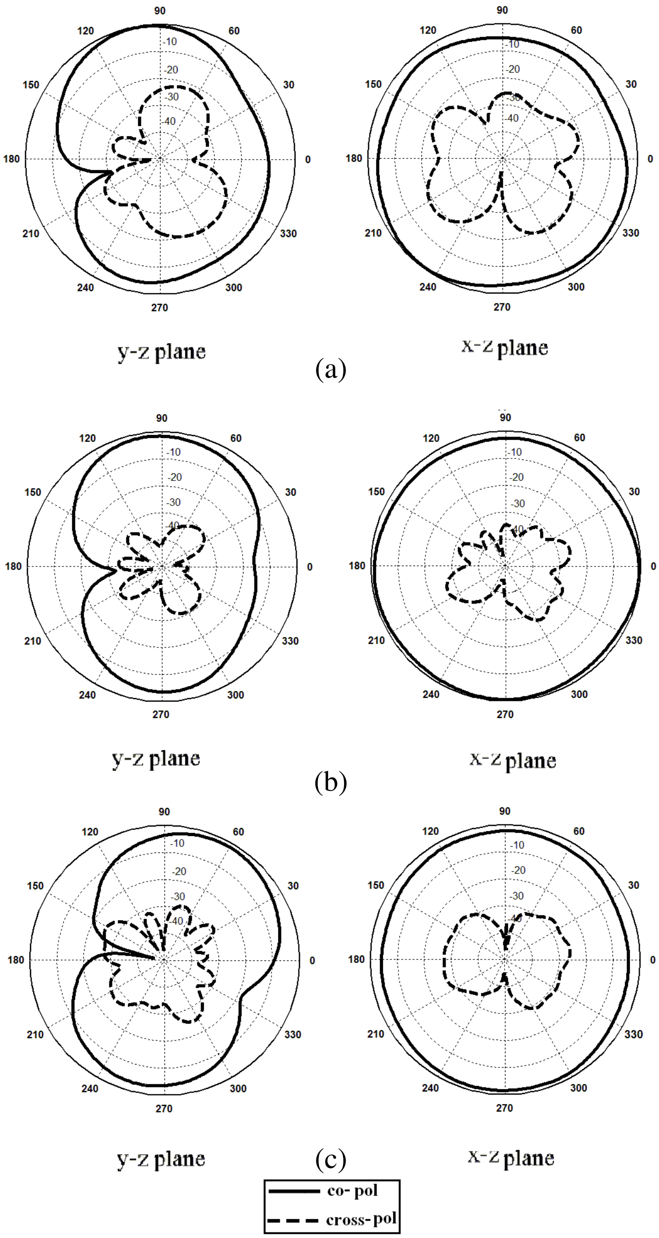

Figure 11. Measured radiation patterns of the proposed antenna. (a) 4.5 GHz, (b) 9 GHz, and (c) 13.5 GHz.

WiMAX), we use a pair of rotated T-shaped slits at radiating patch. By adding an inverted Ω-shaped slot in the ground plane, a dual band-notched function is achieved, that covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX and 4-GHz C bands.

In order to understand the phenomenon behind this dual band-stop performance, the simulated current distributions for the proposed antenna at the notched frequencies presented in Fig. 9. It is found at the notched frequencies the current flows are more dominant around of the inverted Ω-shaped slot s and a pair of T-shaped slits.

The proposed antenna with final design was built and tested. Measured and simulated VSWR characteristic of the proposed antenna were shown in Fig. 10. The fabricated antenna has the frequency band of 2.7 to over 17.5 GHz with two rejection bands around 3.32–4.23 and 5.05–5.95 GHz.

Figure 11 illustrates the measured radiation patterns, including the co-polarization and cross-polarization, in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that the radiation patterns in x-z plane are nearly omni-directional for the three frequencies.

Figure 12 shows the effects of the rotated T-shaped slits and also inverted Ω-shaped slot on the maximum gain in comparison to the ordinary UWB square antenna without them. As shown in Fig. 12, the ordinary square antenna has a gain that is low at 3 GHz and increases with frequency. It is found that the gain of the square antenna is decreased with the use of the rotated T-shaped slits and also inverted Ω-shaped slot It can be observed in Fig. 12 that by using these structures, a sharp decrease of maximum gain in the notched frequencies band at 3.9 & 5.5 GHz are shown. For other frequencies outside the notched frequencies band, the antenna gains with the filters are similar to those without them.

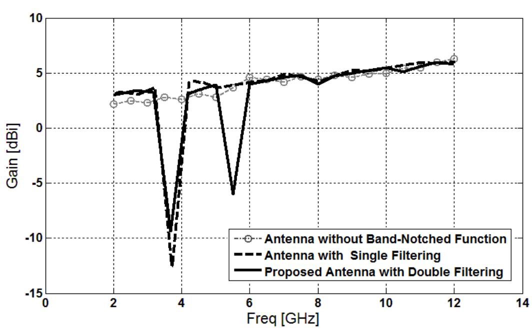

Figure 12. Measured maximum gain comparisons for the various structures of the proposed antenna.

4. CONCLUSION

A novel compact UWB monopole antenna with dual band-notched function has been presented. The basic monopole antenna structure consists of a square radiating patch, feed-line, and a ground plane. By cutting pairs of rectangular-ring slots and rotated T-shaped slits and also by embedding an inverted Ω-shaped slot in antenna configuration, two band-stop characteristics with additional resonances are excited and hence much wider impedance bandwidth can be produced. The proposed antenna can operate from 2.7to 17.5 GHz with two rejection bands around 3.3–4.2 GHz and 5–6 GHz. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB application.

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