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Planar Ultrawideband Monopole Antenna with Tri-Notch Band Characteristics

Sai K. Venkata, Muktikanta Rana, Pritam S. Bakariya*, Santanu Dwari, and Manas Sarkar

Abstract—In this article, a compact ultra-wideband (UWB) planar monopole antenna with the triple notched band is proposed. The antenna consists of a semicircular radiating patch and a modified ground plane with two bevels at upper edge. By etching two round shape slots in radiating patch the notch characteristics are achieved at WiMax band (3.3–3.7 GHz) and WLAN band (5.15–5.875 GHz). In order to realize notch band at X-band downlink satellite communication band (7.1–7.76 GHz) a pair of rotated V-shape slot are etched on the ground plane. The measured operating impedance bandwidth of proposed antenna ranges from 2.9 to 10.9 GHz having return loss less than 10 dB with triple notched bands. The proposed antenna exhibits a nearly omnidirectional radiation pattern in the H-plane, and a dipole-like radiation pattern in the E-plane for the ultra-wideband. The effects of each individual slot on band-notch characteristics are also investigated. The measured gain of the proposed triple band notched antenna is relatively stable across the operating frequency band except notched bands and thereby making the proposed antenna suitable for practical UWB applications. Proposed antenna has a compact size of $27 \times 25\,\mathrm{mm}^2$.

1. INTRODUCTION

Planar monopole ultrawideband (UWB) antenna has drawn wide interest from the researchers for increasing the data rate in wireless communication, since the Federal Communications Commission (FCC) released 3.1 to 10.6 GHz as an unlicensed band for radio communication. Due to many attractive features, such as simple structure, small size, light weight, and low cost, printed monopole antennas are the most frequently used antennas for UWB applications [1–4]. However, the planar monopole antenna design for UWB communication system is still facing many challenges. The UWB communication system has allowed very low power emission level, thus it could be easily interfered by nearby communication systems such as WiMax communication system operating at 3.5 GHz (3.4–3.7 GHz), WLAN system such as IEEE 802.11/a operating at 5.2 GHz (5.15–5.35 GHz, 5.725–5.875 GHz) and X-band downlink communication frequency operating at 7.5 (7.1–7.76 GHz). So the interferences of these narrowband communication systems with UWB systems should be avoided for better performance. To avoid interference, band-stop filer can be used. However, the use of band-stop filter requires more space to integrate, and it also increases the cost and complexity of the system. A better way to avoid interference is using UWB antenna with band-notch characteristic.

In the last few years, various UWB antennas with band-notch characteristics have been reported. The most general method is to etch slots of different shapes either on radiating patch or in the ground or in microstrip, adding circuit stub, using metamaterial resonator [5–8]. Using these techniques, many antennas have been reported to achieve single notch band [9–14], dual band notch [15–20] and triple notch band [21–24] in UWB region.

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* Corresponding author: Pritam Singh Bakariya (pritam.gs@gmail.com).
The authors are with the Department of Electronics Engineering, Indian School of Mines, Dhanbad, Jharkhand 826004, India.

In this article, a novel UWB printed monopole antenna with triple bands notched characteristics is proposed. The band-notch characteristics are obtained by two round shape slots etched on radiating patch and a pair of rotated V-shape slot [25] in the ground plane. The length of each slot has been taken about half of the guided wavelength at their respective notched band frequency. The position of each notched band can be controlled individually according to requirements of the system by changing the dimension or position of their respective slot. The effect of each slot has been optimized and discussed in detail. The proposed antenna exhibits a nearly omnidirectional radiation pattern in the H-plane and a dipole-like radiation pattern in the E-plane for the entire UWB. In comparison to the antennas in [21–23], this antenna is compact in size, and in comparison to [24], the radiation pattern is more stable at passband of the ultrawideband renge. Moreover, the cross polarization level of the proposed antenna is better than that of [24].

2. ANTENNA DESIGN AND ANALYSIS

Figure 1 shows the geometry and configuration of the proposed monopole antenna. The antenna has a compact size of $27 \times 25\,\text{mm}^2$. This antenna is printed on FR4 substrate of 0.8 mm thickness with a dielectric constant of 4.4 and loss tangent of 0.02. It is composed of a 50-Ω microstrip feed line, a planar radiating patch with two round shape slots and rectangular ground plane with a pair of rotated V-shape slots. Several aspects were considered to optimize the final design like the overall impedance bandwidth of the antenna, the bandwidth of the notched bands, and the level of band rejection at notched frequency. The optimal antenna parameters are obtained as follows: $L = 27\,\text{mm}$, $W = 25\,\text{mm}$, $d = 5.5\,\text{mm}$, $R_1 = 6\,\text{mm}$, $R_2 = 4.5\,\text{mm}$, $R_3 = 12\,\text{mm}$, $W_1 = 0.2\,\text{mm}$, $W_2 = 0.4\,\text{mm}$, $L_1 = 2\,\text{mm}$, $L_2 = 2.5\,\text{mm}$, $L_3 = 5.1\,\text{mm}$.

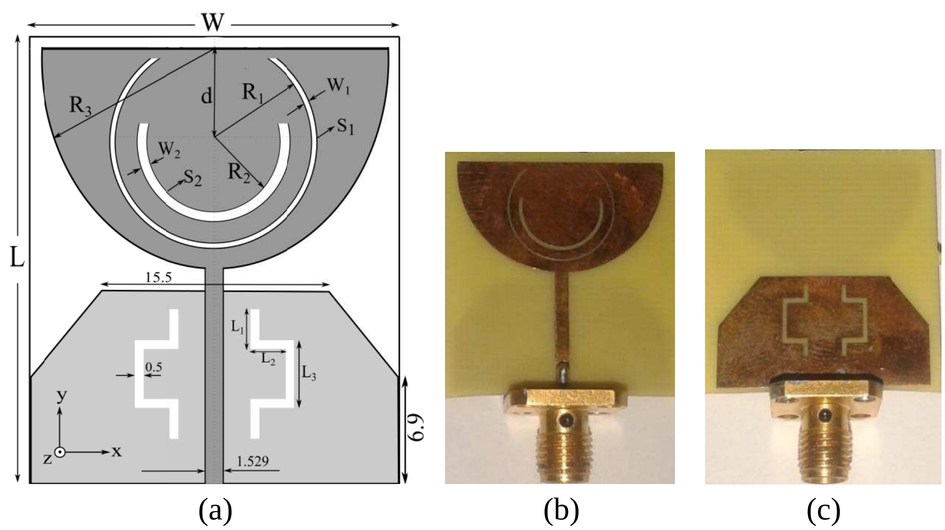


Figure 1. (a) Schematic of proposed antenna. (b) Front view of fabricated antenna. (c) Bottom view of fabricated antenna.

Commercial simulation software Ansoft HFSS 14 was used to perform the parametric study of proposed antenna. The individual effect of different parameters of each slot like slot length, width and their position have been investigated. To create a band-notch characteristics within the UWB there are two round shape slots S_1 and S_2 etched on the radiating patch and a pair of rotated V-shape slots S_{3a} and S_{3b} etched in the ground plane as shown in Figure 1. The length of each slot has been taken about half of the guided wavelength.

Figure 2 shows the effect of different parameters of slot S_1 etched in radiating patch. The length of slot S_1 is taken about half of the guided wavelength at a center frequency of WiMax band 3.5 GHz (3.3–3.7 GHz). The slot length optimization is shown in Figure 2(a), and it is observed that as it decreases, the center frequency shifts toward higher frequency, while it increases the response shifts toward lower frequency. It is due to the increase of resonant frequency of the slot when the slot length decreases and vice versa. In Figure 2(b), the effect of changing the width W_1 of slot S_1 on return loss is shown, with other parameters fixed. To see this effect, the inner radius R_1 of slot S_1 was decreased gradually, so the effective width of slot S_1 increases. Its effect is observed in shifting notched band toward higher frequency with a slight increase in bandwidth and reflection coefficient. It is due to the decrease of distributed shunt capacitance of the slot line when the width of slot increases. In Figure 2(c), the effect of slot position is shown while keeping the length and width fixed. It is observed from Figure 2(c) that as the slot shifts from downward to upward or near to away from the microstrip line, both the magnitude and bandwidth decrease keeping center frequency almost constant. Therefore, from the above discussion it is concluded that the first notched band for WiMAX is controlled by the slot S_1 without affecting the other notch bands. Therefore, from the above parametric study, it is observed that length variation has a dominant effect to change the center frequency of the notch, and position of the slot has a dominant effect in changing the bandwidth of the notch band.

The notched band at WLAN band is achieved by cutting another slot S_2 in radiating patch. The shape of slot S_2 is similar as to S_1 so the effect of different parameter is same as discussed in the previous section, but because the slot location and slot length are different, band notch at WLAN band is achieved. The effect of slot S_2 and its optimization is shown in Figure 3. It shows that the bandwidth and position of WLAN bands can be controlled with WiMax band unaffected.

The third notch at X-band downlink satellite communication has been obtained by cutting a pair of rotated V-shaped slot in the ground having length of $2L_1 + 2L_2 + L_3$. The effect of ground slots and its optimization is shown in Figure 4. As the length L_2 increases, the notch band shifts from uplink satellite communication band to downlink satellite communication band with other notched bands unaffected. From the above discussion, it can be concluded that all notch bands at WiMax, WLAN, and X-band downlink satellite communication can be individually controlled by controlling the respective slot dimensions and position.

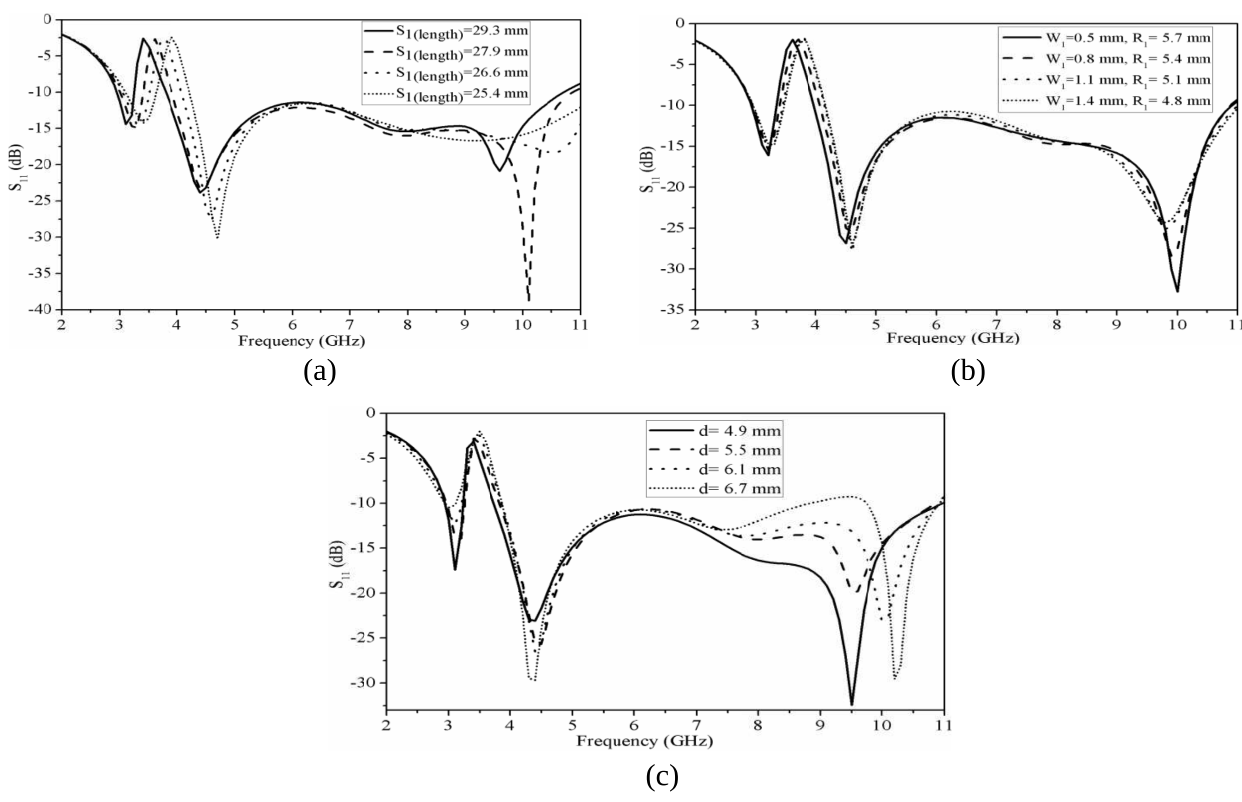
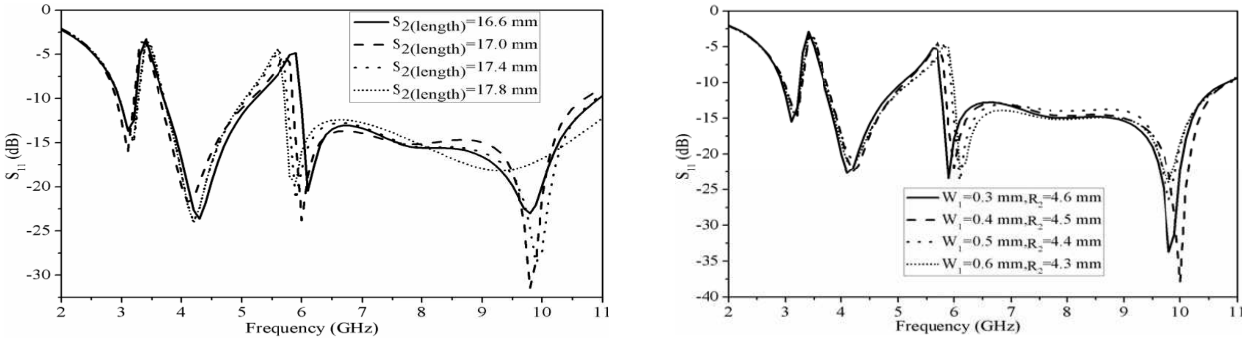


Figure 2. Optimization of slot S_1 for single notch. (a) Length optimization. (b) Width optimization. (c) Position optimization.



(a) (b)

Figure 3. Optimization of slot S_2 for dual notch. (a) Length optimization. (b) Width optimization.

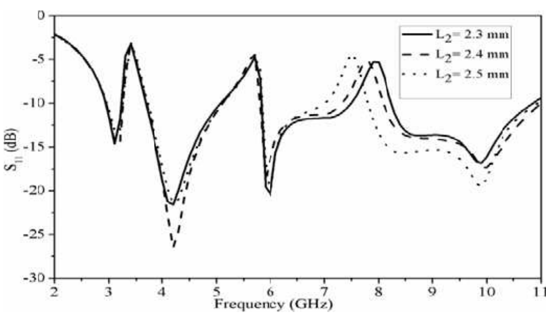


Figure 4. Optimization of slot S_3 position by changing L_2.

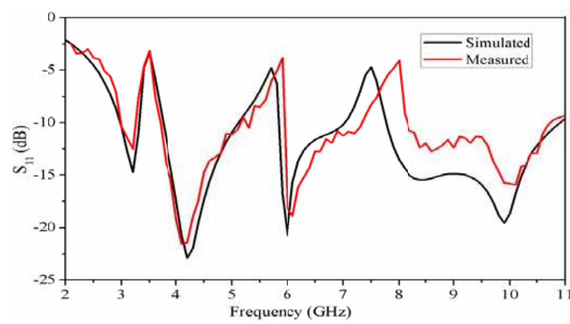


Figure 5. Simulated and measured reflection coefficient of the printed UWB antenna.

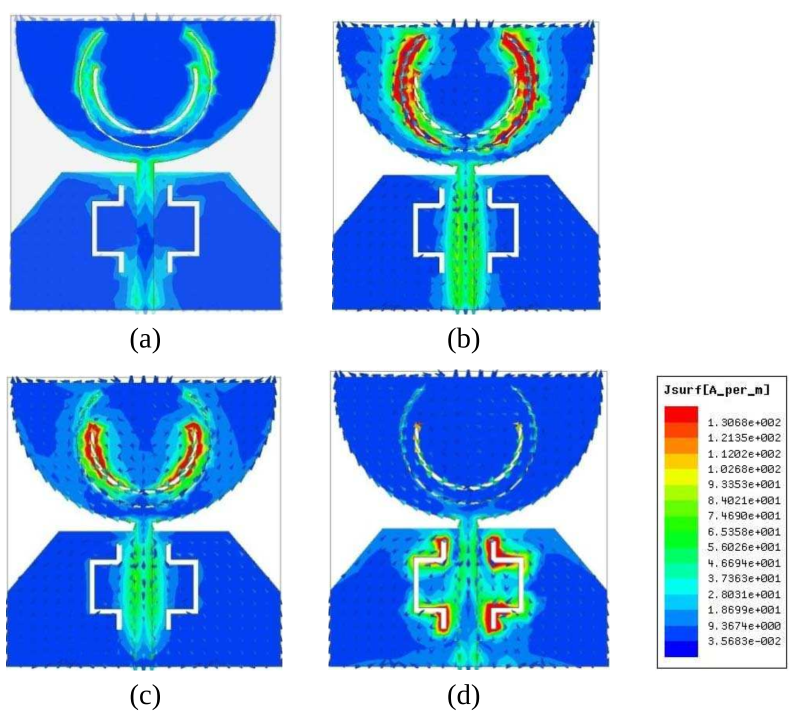


Figure 6. Surface current distributions on the radiating patch at (a) 4.5 GHz, and at the notch frequencies of (b) 3.5 GHz, (c) 5.5 GHz, (e) 7.5 GHz.

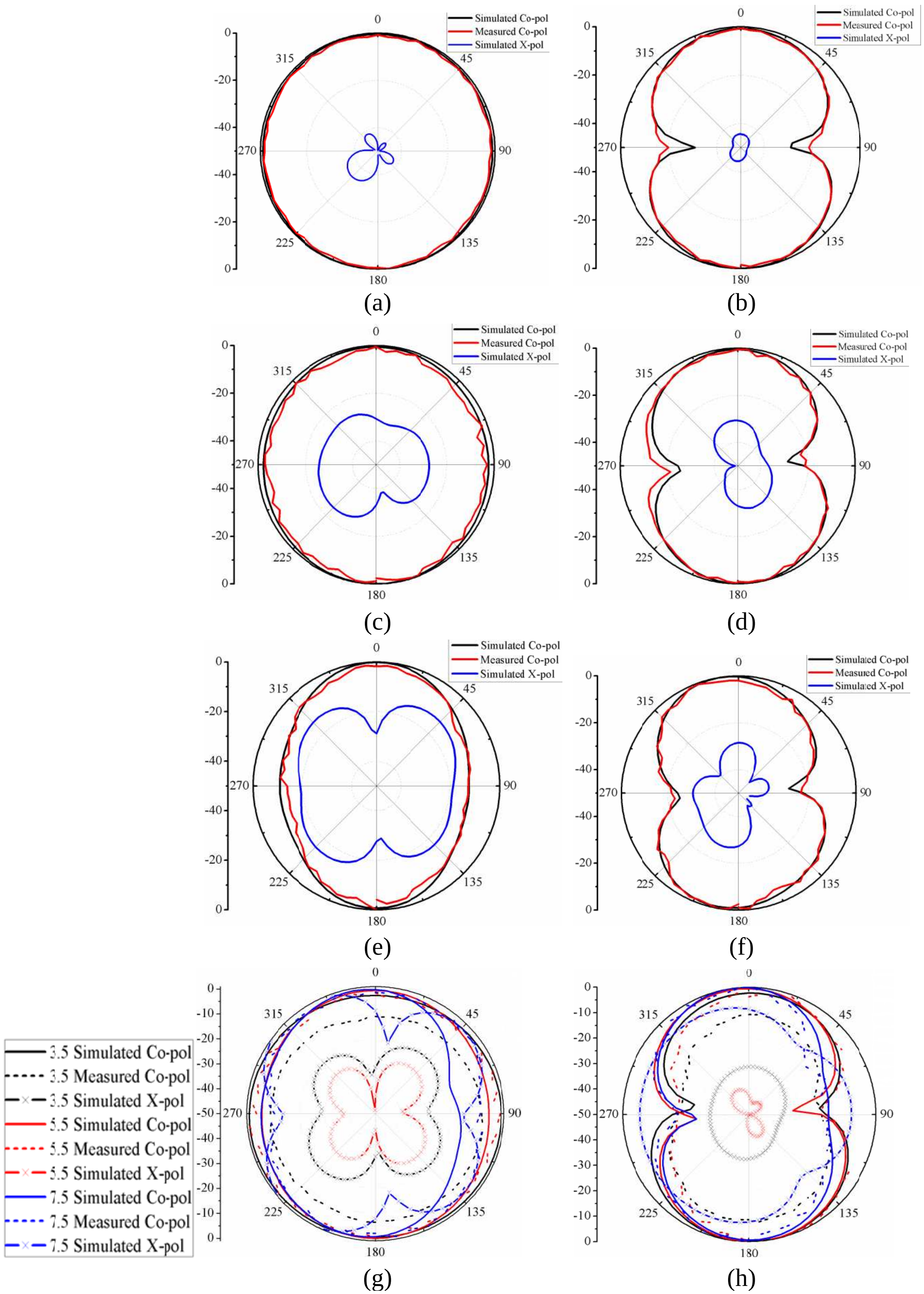


Figure 7. Simulated and measured normalized radiation pattern in (a), (c), (e), (g) H-plane and (b), (d), (f), (h) E-plane at (a), (b) 4 GHz, (c), (d) 6.5 GHz, (e), (f) 9 GHz, and (g), (h) stop band [3.5 GHz, 5.5 GHz, 7.7 GHz].

3. RESULTS AND DISCUSSION

The return loss of the proposed antenna was measured using an Agilent N5242A vector network analyzer. The measured and simulated results for return loss are shown in Figure 5. The measured and simulated results show good agreement at lower frequencies, but with increases in frequency, the measured result shows slight variations. It may be due to some measurement or fabrication errors, or it may also be expected due to some parametric differences between the practical and simulated models.

The effect of different slots S_1, S_2 and S_3 in getting the notch band can also be clearly examined by surface current distribution. The simulated surface current distribution of proposed antenna on radiating patch at different frequency is analyzed as shown in Figure 6. In Figure 6(a), it is observed that at pass band frequency of 4.5 GHz the surface current is distributed uniformly over antenna. The current distribution at notch frequencies are shown in Figures 6(b)–(d) and these show very strong current distribution concentrated around slot S_1, S_2 and S_3 at a center frequency of notch band 3.5 GHz, 5.5 GHz and 7.5 GHz, respectively. The strong current distributions around slots at the notch frequency leads to near field radiation counteracted, due to which high energy is reflected back to the input port and the band-notched characteristics achieved [18]. It also can be noticed that in Figures 6(b)–(d) there are very low mutual coupling at the notch frequencies, which indicate that each rejected band can be controlled independently.

The measured and simulated far-field radiation patterns of the proposed antenna in H-plane (XZ-plane) and E-plane (YZ-plane) at pass-band frequency of 4 GHz, 6.5 GHz, 9 GHz and at the stop band of 3.5 GHz, 5.5 GHz, 7.5 GHz are shown in Figure 7. The antenna has a nice omnidirectional radiation pattern in H-plane and bidirectional pattern in E-plane. The cross polarization levels at notch band frequency are observed, which shows that at stop band frequencies, the cross polarization levels are increased in comparison to passband frequencies. The antenna exhibits stable radiation patterns throughout the UWB.

The measured and simulated gains of the proposed antenna against frequency are shown in Figure 8. The gain of the antenna was measured at far field in an anechoic chamber using substitution method where two calibrated antennas of known gain are used to find the unknown gain of 'antenna under test' (AUT). The AUT was used as the receiving antenna and placed on the positioner with required elevation and azimuth coverage. The transmit antenna was wideband quad ridged horn [from QRH11, by RF Spin] with calibrated gain. The test antenna was then replaced with the second wideband quad ridged horn antenna of calibrated gain and similar measurement was performed. Difference between measured powers reflects the gain difference between the two receiving antennas and the absolute gain of the test antenna is calculated. The measurement was repeated by changing the distance between transmit and receive antenna using the positioner movement and the average gain was considered as the final measurement. The results show that the proposed antenna perfectly performs band rejection in the range of 3.3–3.7 GHz, 5.1–5.875 GHz, and 7.1–7.8 GHz bands.

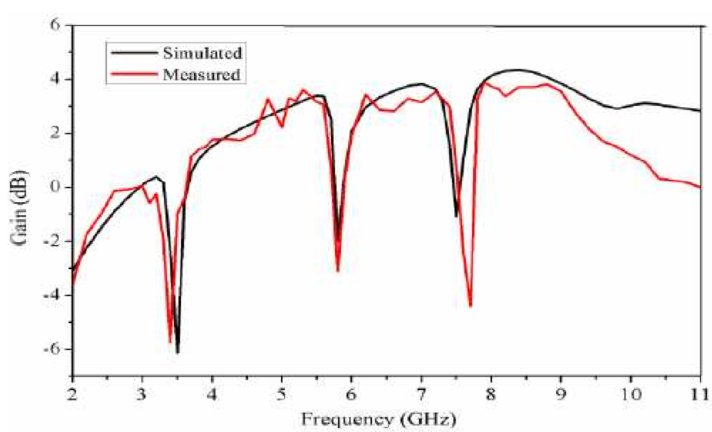


Figure 8. Measured and simulated gain.

4. CONCLUSION

A printed monopole antenna with three band notched characteristics is proposed for UWB applications. The band-notch characteristics are achieved by etching two round shape slots in radiating patch and a pair of rotated V-shapes at ground. The length of each slot has been taken about half of guided wavelength. It has been observed that by changing the dimension and location of different slots, each notched band can be controlled independently, without affecting the UWB performance, which offers a great freedom to select the notch frequency band for the band-notch antenna. The measured and simulated results reveal that the antenna has a stable far-field radiation pattern in H- and E-planes throughout the UWB. Stable gain has been observed, except at the notched frequency. The presented antenna is suitable for practical UWB applications.

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