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Design of Quad Band Operational UWB Antenna with Triple Notch Bands Using Meander Line Slot

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Abstract—A novel ultra-wideband (UWB) antenna with triple band rejection capabilities operating in quad bands is presented. The proposed UWB antenna is derived from a planar rectangular shaped monopole antenna. In order to improve the bandwidth of the antenna, a partial ground is maintained with a slot at centre along with truncated slots made at bottom two corners and a rectangular slot at top side centre of the radiating patch. In order to achieve the required triple notch characteristics and the multiband operation, a single meander line slot is made in the middle of the patch. The dimensions of the meander line slot are varied to change the notch band characteristics of the antenna. The proposed UWB antenna rejects triple bands 3.29 GHz–4.83 GHz (WiMAX), 5.15 GHz–6.84 GHz (WLAN), & 7.94 GHz–8.49 GHz (X-band satellite uplink). The operational bands of the UWB antenna with triple notch bands are as follows, 2.38 GHz–3.29 GHz, 4.83 GHz–5.15 GHz, 6.84 GHz–7.94 GHz, and 8.49 GHz–13.15 GHz. The measured peak gains at 2.7 GHz, 5 GHz, 7.3 GHz, 8.7 GHz, and 11.5 GHz are 3.4 dBi, 2.8 dBi, 3.6 dBi, 3.3 dBi, & 3.88 dBi respectively. The step-by-step implementation of the triple notch band UWB antenna and the comparative analysis is presented. The proposed antenna performance is presented with the help of reflection coefficient, VSWR, gain, field distributions, and radiation pattern curves. The simulated and measured analysis comparison shows good agreement making the designed antenna a good candidate for UWB applications that require multiband operations with selected bands rejection.

1. INTRODUCTION

In recent years, the demand for antennas having multiband operations or with higher data rate capability has increased drastically. Ultra-wideband (UWB) antennas proved their importance in such cases due to their advantage of large bandwidth. The Federal Communication Commission (FCC) has allocated the frequency band from 3.1 GHz to 10.6 GHz for low power emission applications. While several types of antennas are there, like aperture antennas, wire antennas, conical antennas, etc., microstrip antennas have gained more attention due to their low profile, easy fabrication, and low-cost capabilities. However, these microstrip antennas suffer from some disadvantages of narrow bandwidth issues, and they need special design adjustments to achieve higher bandwidth ratio. Over the years, several researchers have introduced different kinds of antennas to achieve the larger bandwidth ratio. These UWB antennas can be designed using different techniques, and planar wideband antennas, fractal based compact UWB antennas, metamaterial inspired UWB antennas, UWB antennas for wearable applications, and multiband UWB antennas which have band notch capabilities have been developed by incorporating various methods into the design [1–10]. Due to the size advantages, several fractals based UWB antennas are being developed for compact size wireless communication devices [11–14].

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While these UWB antennas are designed, one of the major problems is having interference issues with other nearby communication systems which utilize the frequency of operation within the UWB coverage. Filtering these interfering unwanted bands is referred as band rejection or filtering or band notch capabilities. Different kinds of UWB filters have been investigated and presented by several researchers, and these filters have the capability of rejecting single band to multibands with good selectivity [15–19].

Similar to UWB filters, antennas capable of band rejection of selected bands have been developed using different methods. These antennas with notch characteristics can be developed by using slots, metamaterial inspired structures like meander lines, parasitic elements, electromagnetic bandgap structures (EBG), frequency selective surfaces (FSS), resonator structures, etc. These antennas can be developed to reject single or multibands [20]. The selectivity of the rejection bands depends on the effectiveness of the techniques incorporated.

In [21], dual meander line slots are etched in ground plane to turn it into defective ground surface to achieve quad band notch capabilities. Multiple slits and slots are utilized to develop a triple band notch MIMO antenna with high isolation in [22]. A Π-shaped slot in radiating patch and EBG based resonator slots in ground plane are made to develop the dual notch UWB monopole antenna in [23]. In [24], two C slots are made on radiating element to achieve the rejection of bands at 3.5 GHz and 7.5 GHz. Similarly, a spiral-shaped slot is etched on the feed line to achieve another notch at 5.8 GHz, achieving a triple band notch UWB antenna using slots. A combination of split ring and complementary split ring resonator-based slots, along with defective ground surface, is used to achieve the penta-notched UWB antenna in [25]. New EBG models are created by making meander line slits in a complementary way and placed near the feed line to achieve the dual notch UWB antenna in [26]. In [27], a rectangular slot is made in feed line, and vertical stubs are placed inside to implement single notch and dual notch UWB antennas. Three rectangular slots are made on radiating element to develop a dual notched CPW antenna in [28]. In [29], WiMAX and WLAN bands are notched by adding two stubs to the modified ground plane. A U shaped slot is made on patch element, and a split ring resonator model is attached at back side of the antenna to achieve a dual band notch UWB antenna in [30]. In [31], two short circuited folded step impedance resonator circuits are placed near the feed line to achieve the dual notch characteristics. Dual bands centred at 5.3 GHz and 7.5 GHz are rejected by a quasi-complementary split ring resonator slot in feed line in [32]. In [33], an elliptical slot in radiating element and a split ring resonator (SRR) structure at back side are used to achieve a triple band notched UWB antenna. A combination of SRR and EBG structures is used to implement a triple band notched UWB antenna in [34]. Three U-shaped slots are made on radiating element, and a meander line EBG structure is placed near the feed line to develop a quad band notched UWB antenna in [35]. Similarly, in [36], a combination of three slots along with one split ring resonator model is used to achieve the quad band rejection characteristics for a UWB antenna.

Band notch antennas usually require to have multiple slots at patch, ground, or additional stubs in order to achieve multiple band notch characteristics, and in some cases metamaterial inspired slots help in achieving band notch characteristics at more than one band. Our work is based on an inter digital capacitance model achieved from making a meander line based slot helped in achieving the quad band notch characteristics, and this slot occupies a major part of the radiating element which achieves similar miniaturization equivalent to incorporating multiple periodic slots or fractal slots. The dimensions variation of the meander slot and its position can shift the notch bands

2. ANTENNA CONFIGURATION

2.1. Antenna Model

The proposed triple notch UWB antenna is presented in the following Figure 1. To improve the bandwidth of the antenna, the radiating element edges at bottom corners are etched with truncated slots, and at top side of the patch a rectangular slot is made, making it look like U shape. The ground of the antenna is maintained partial with a slot at centre below the strip line. The proposed partial ground is designed similar to the UWB antenna depicted in [37]. The antenna is fed by a microstrip line. The multiband operation with triple band rejection is achieved by making a meander line slot at centre part of the radiating patch. Varying the dimensions of this slot can change the notch bands range. An

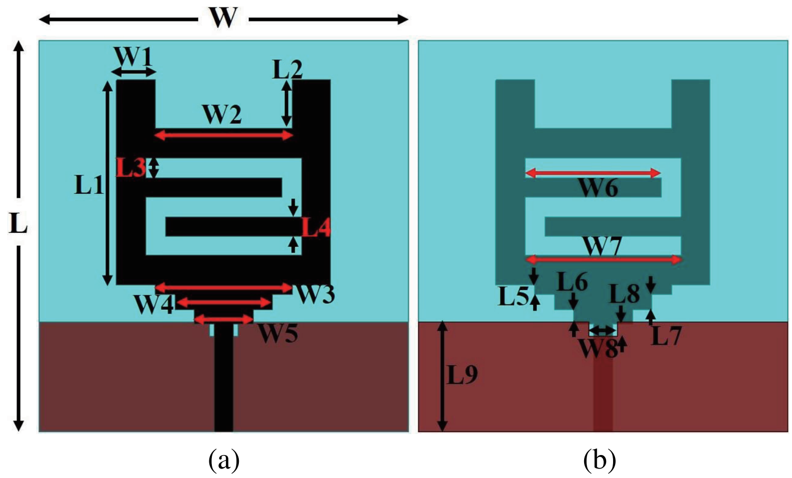


Figure 1. Structure layout of the proposed triple notch UWB antenna: (a) Top view; (b) Bottom view.

FR4 substrate with dielectric constant 4.4 with loss tangent 0.02 is used for implementing the proposed triple band notched UWB antenna. The overall dimensions of the antenna are 40 mm×38 mm×1.6 mm. The EM simulation software ANSYS HFSS 18.0 is used to design and analyse the antenna parameters. The proposed antenna dimensions after parametric study are listed in Table 1.

Table 1. The dimensions of the proposed triple notch UWB antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	40	$L5$	1	W	38	$W5$	6
$L1$	21	$L6$	1.5	$W1$	4	$W6$	14
$L2$	5	$L7$	1.5	$W2$	14	$W7$	16
$L3$	2	$L8$	1.5	$W3$	14	$W8$	3
$L4$	2	$L9$	11.2	$W4$	10		

For the planar monopole antenna the fundamental resonant frequency is obtained by the following equation [38].

$$fr = \frac{144}{Lg + Lp + \dfrac{A1}{2\pi Lg\sqrt{\varepsilon_{re}}} + \dfrac{A2}{2\pi Lp\sqrt{\varepsilon_{re}}}} \tag{1}$$

where

Lg = Length of the ground plane = $L9$.
Lp = Length of the radiating patch = $L1 + L5 + L6 + L7 + L8$.
$A1$ = Area of the ground plane.
$A2$ = Area of the radiation patch.
ε_r = Effective dielectric constant.

2.2. Antenna Analysis

The step-by-step implementation of the triple notch UWB antenna is presented in the below Figure 2. The performance comparison for the steps involved in the triple notch UWB antenna is presented with

Figure 2. Stel-by-step implementation of triple notch UWB antenna (a) Step-1; (b) Step-2; (c) Step-3; (d) Step-4; (e) Step-5; & (f) Step-6.

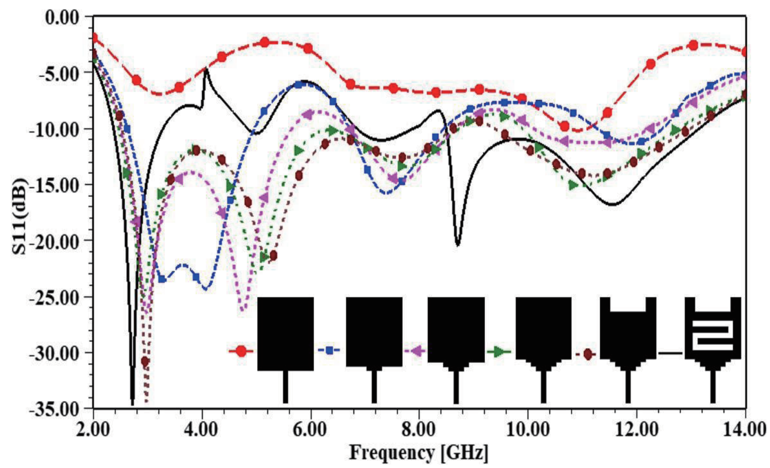


Figure 3. Reflection coefficient comparison for the steps mentioned in Figure 2.

the help of reflection coefficient curve in the following Figure 3. The operational and rejected bands comparison for the steps involved is listed in Table 2.

From Figure 3 and Table 2 data it can be seen how steps involved in the design of the proposed UWB antenna affected the operational and rejection bands coverage. The meander slot made on the patch helped in achieving the greater number of operational bands and the rejection bands than the remaining steps, and tuning this meander line slot can help in improving the selectivity of the rejection bands. The four operational bands of the triple band notch UWB antenna have bandwidths 910 MHz, 320 MHz, 1100 MHz, and 4660 MHz, respectively.

Table 2. The operational and rejection bands comparison for the design steps mentioned in Figure 2.

Step No	No of Operational Bands	Coverage of Operational Bands	No of Rejection Bands	Coverage of Rejection Bands
1	1	10.71–11.10	-	-
2	3 (2 in UWB, 1 out of UWB)	2.63–4.97, 6.71–8.46, 11.25–12.47	2	4.97–6.71, 8.46–11.25
3	3	2.5–5.66, 6.7–8.68, 10.08–12.25	2	5.66–6.7, 8.68–10.08
4	2	2.47–8.74, 9.89–12.77	1	8.74–9.89
5	2	2.53–8.62, 9.36–12.99	1	8.62–9.36
6	4	2.38–3.29, 4.83–5.15, 6.84–7.94, 8.49–13.15	3	3.29–4.83, 5.15–6.84, 7.94–8.49

2.3. Simulated Analysis

The designed triple notch antenna performance is compared with a basic planar rectangular monopole antenna of the same dimensions. The performance comparison is presented with the help of reflection coefficient curve, field, and the 3D radiation coverage. The proposed triple notch antenna reflection coefficient comparison with basic planar rectangular monopole antenna is presented in the below Figure 4. From Figure 4 data it can be seen that the proposed triple notch antenna has quad operational bands centred at 2.7 GHz, 5 GHz, 7.3 GHz, & last band resonances at 8.7 GHz and 11.5 GHz with return loss −34.66 dB, −10.45 dB, −11 dB, −20.46 dB, and −16.8 dB, respectively.

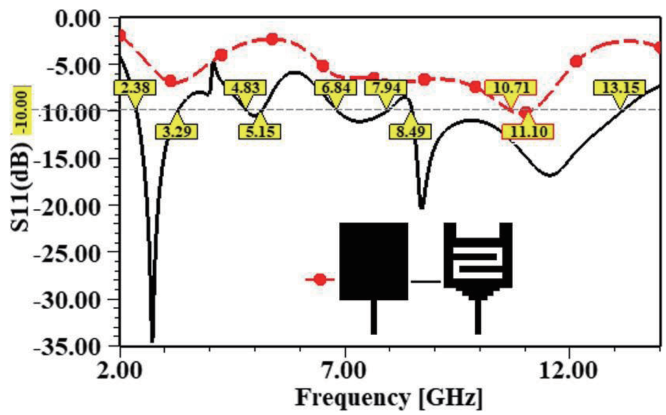


Figure 4. Reflection coefficient comparison between the basic planar rectangular monopole antenna and the proposed triple band notch UWB antenna.

The current distribution at 2.7 GHz is strong at feed line and the top side edges of the radiating patch. For 7.3 GHz the current distribution is weak in the patch area, whereas at 8.7 GHz the current distribution is concentrated at center strips in the place where meander line slot is made. Similarly at 11.5 GHz the current distribution is weak in the patch area, only strong at feed line and the edges of the staircase steps.

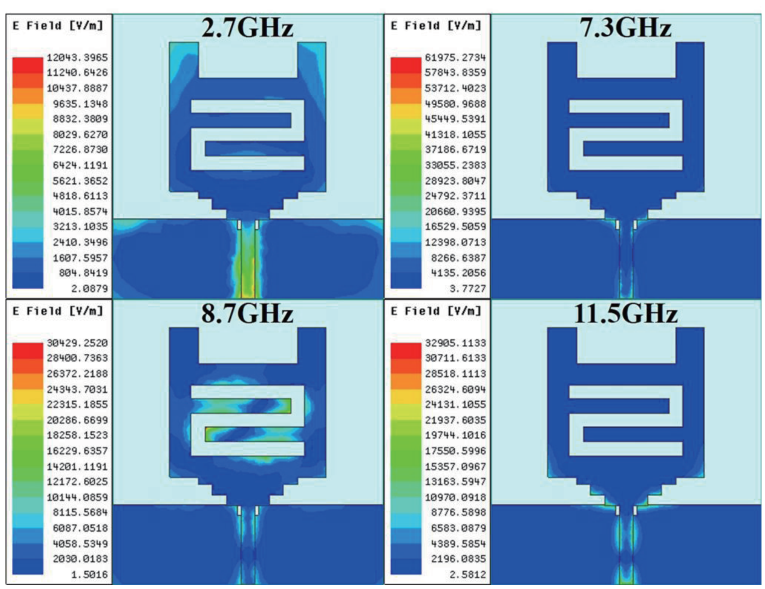


Figure 5. E-field distribution comparison between the basic planar rectangular monopole antenna and the proposed triple band notch UWB antenna.

Out of all the operation frequencies, the better resonance with return losses 2.7 GHz, 7.3 GHz, 8.7 GHz, and 11.5 GHz is analysed for field distribution and presented in Figure 5. Similarly for the same frequencies the 3D radiation coverage is presented in the following Figure 6. From which it can be observed that at these frequencies the proposed triple band notch UWB antenna exhibits peak gains of 1.4 dBi, 5.7 dBi, 3.7 dBi, and 6.5 dBi, respectively.

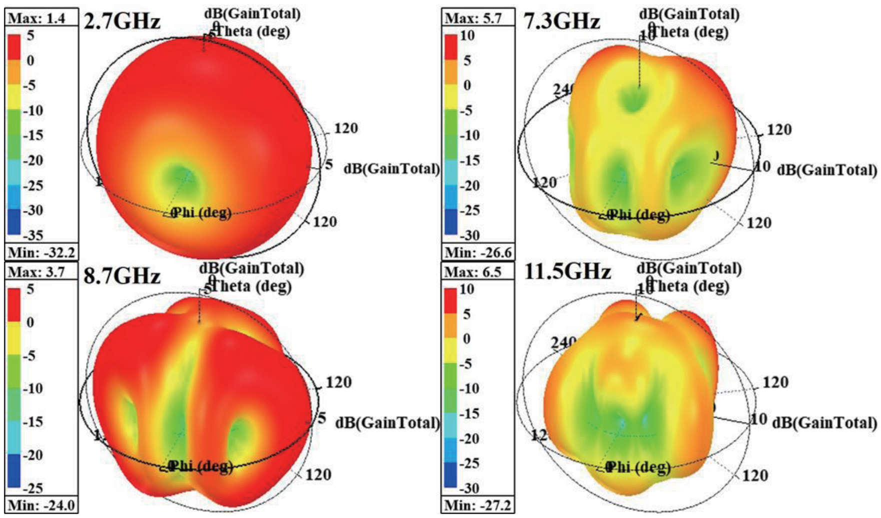


Figure 6. 3D radiation pattern comparison between the basic planar rectangular monopole antenna and the proposed triple band notch UWB antenna.

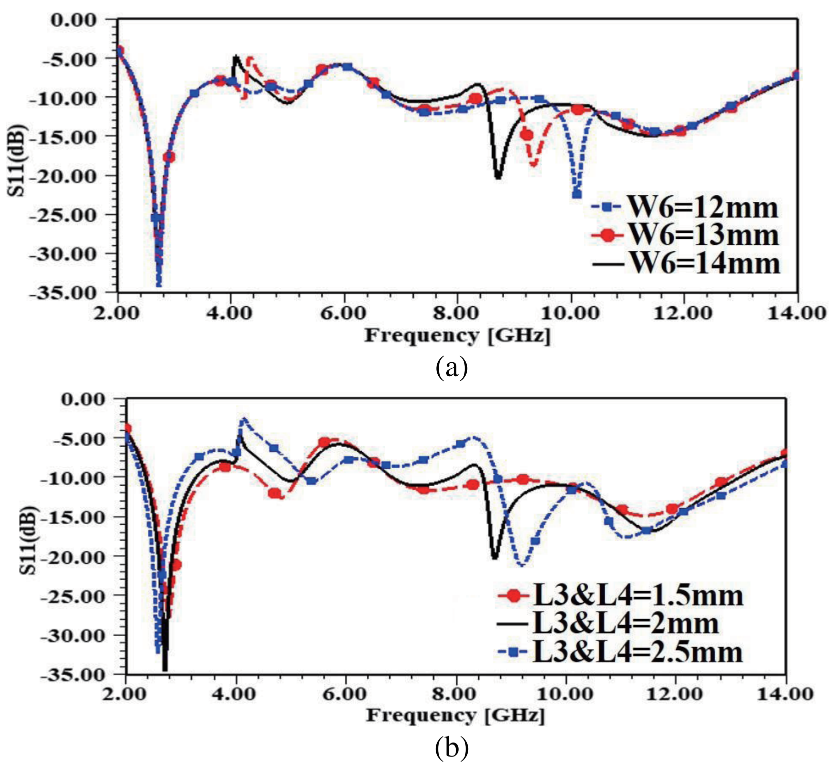


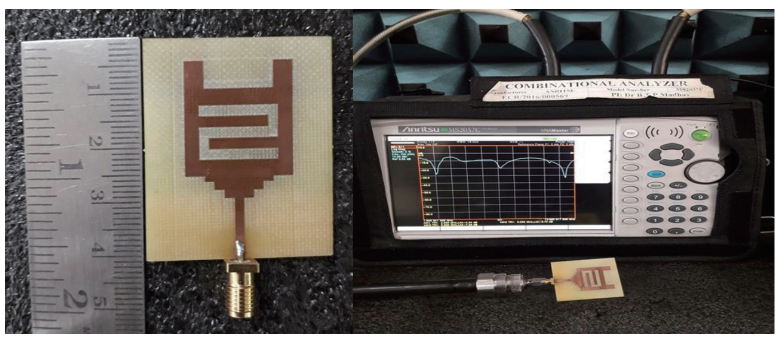
Figure 7. Parametric study comparison (a) $W6$ variation, (b) $L3$ and $L4$ variation.

3. PARAMETRIC STUDY

In the parametric study, a comparative analysis for different dimensions of the meander line strip width and slot width of the antenna is presented in Fig. 7. The parameters that significantly affect the antenna performance are the dimensions of the meander slot made at centre of the radiating element. The dimensions of the strip lines at center which formed the meander line $W6$ and the strip width and slot width of the meander line $L3$ and $L4$ are varied, and the comparative analysis is presented in the following Figures 7(a) and 7(b). Here for varying $L3$ and $L4$ the start of the meander line slot from top is kept in the same position while $L3$ and $L4$ values are maintained equal, i.e., the width of the strip line and the width of the slot are maintained same.

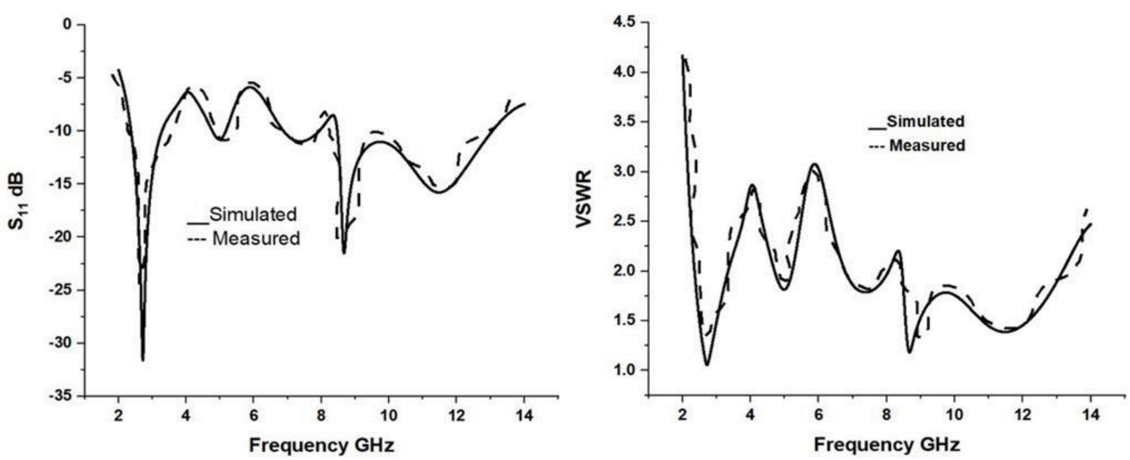
4. RESULTS AND DISCUSSION

As per the dimensions listed in Table 1, the proposed triple band notch UWB antenna is successfully fabricated and tested. The prototype of the fabricated antenna is illustrated in the Figure 8(a), and the S-parameters measurement setup inside an anechoic chamber is presented in Figure 8(b). The simulation and measurement comparison using reflection coefficient and VSWR is presented in Figure 9. Similarly, the gain vs frequency curve comparison for simulation and measurement is presented in Figure 10, and the data show that the designed antenna exhibits gains of 3.4 dBi, 2.8 dBi, 3.6 dBi, 3.3 dBi, & 3.88 dBi at frequencies 2.7 GHz, 5 GHz 7.3 GHz, 8.7 GHz, and 11.5 GHz, respectively.



(a) (b)

Figure 8. Proposed triple band notch UWB antenna: (a) Prototype; (b) $S11$ measurement setup.



(a) (b)

Figure 9. Simulated and measured comparative analysis (a) $S11$ vs Frequency, (b) VSWR.

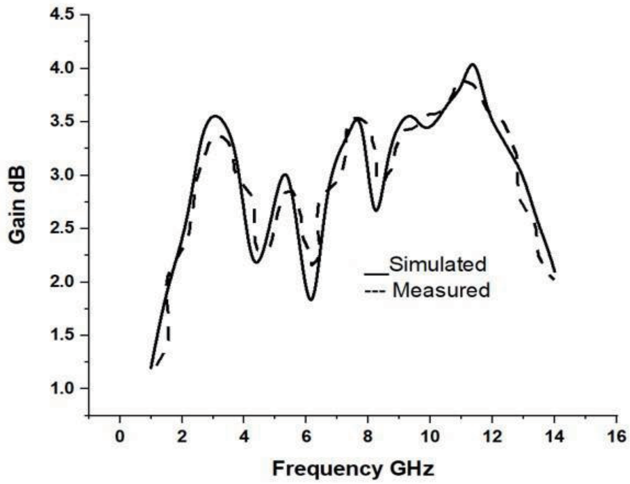


Figure 10. Simulated and measured comparison for gain vs frequency.

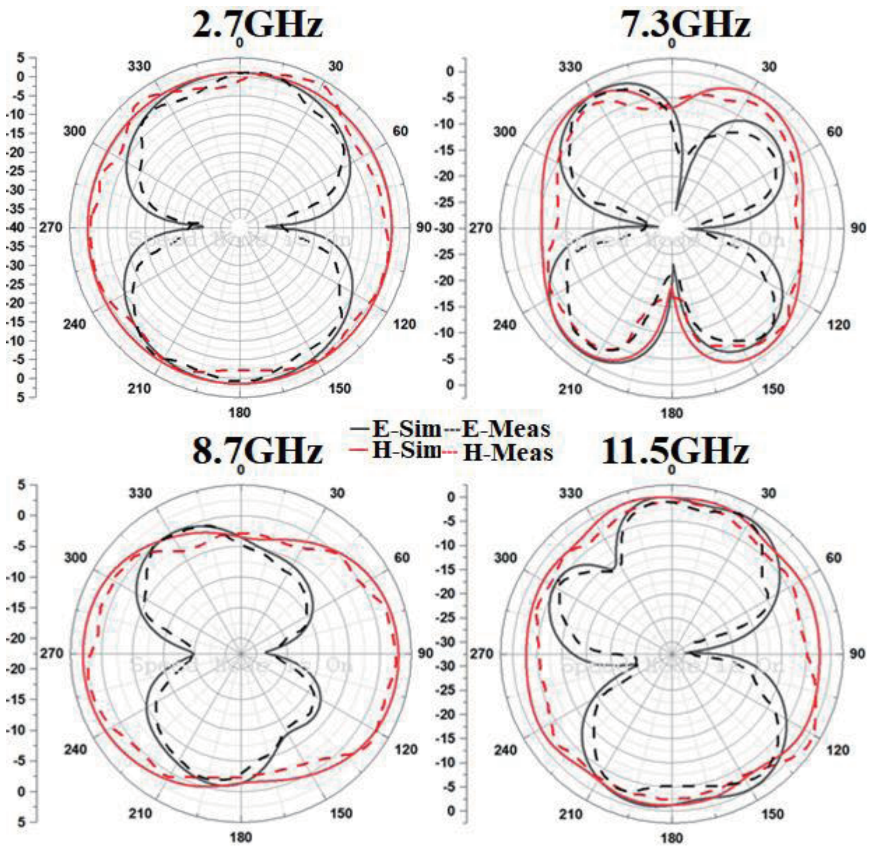


Figure 11. Simulated and measured 2-D radiation patterns comparison for the proposed triple notch UWB antenna 2.7 GHz, 7.3 GHz, 8.7 GHz and 11.5 GHz in E & H-planes.

The 2D radiation patterns at frequencies 2.7 GHz, 7.3 GHz, 8.7 GHz, and 11.5 GHz for co-polarization in E and H planes are presented in Figure 11, where the patterns are mostly maintained omni-coverage. The performance comparison of the designed antenna with previous literature is listed in the following Table 3.

Table 3. Performance comparison between the proposed triple band notched UWB antenna and previous work.

Antenna Design	Notch Technique	Dimensions (mm)	No of Notch Bands	Notch frequencies/bands
Proposed Work	Meander Slot	40×38×1.6	3	3.29–4.83, 5.15–6.84, 7.94–8.49
[28]	Rectangular slots	26×30×1.6	2	5.18–5.82, 7.25–8.39
[29]	Addition of stubs	25×30×1.6	2	3.4–3.69, 5.15–5.85
[30]	U slot, SRR, EBG	25×25×1.6	2	5.94–7.5, 8.02–10.46
[33]	Slot and Resonator	36×34×1	3	3.97–4.48, 5.79–6.57, 7.3–7.6
[34]	EBG and SRR	20×26×1.52	3	3.4–3.9, 5.15–5.825, 7.25–7.75
[35]	U slots and meander line EBG	34.9×31.3×1.6	4	2.53–3.15, 3.23–3.68, 3.92–4.30, 5.49–6.19
[34]	Slots and SRR	41.5×32×1.6	4	3.3–3.7, 5.15–5.35, 5.725–5.825, 7.25–7.75

5. CONCLUSION

In this paper, a compact triple band notched UWB antenna is presented for quad band applications. A meander line slot is used in the design to achieve the triple notch bands. The notched frequency bands are 3.29–4.83 (WiMAX), 5.15–6.84 (WLAN), 7.94–8.49 (X-band satellite uplink). It has been observed that by varying the dimensions and position of the meander slot, triple notched frequency bands have been obtained with maintaining the rest of the UWB response. From Figures 9 to 11 it can be seen that the experimental and simulated results are in good agreement for the designed triple notched UWB antenna. The proposed antenna is a good candidate for multiband UWB applications with its quad operational bands at 2.38 GHz–3.29 GHz, 4.83 GHz–5.15 GHz, 6.84 GHz–7.94 GHz, and 8.49 GHz–13.15 GHz.

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