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Design and Parametric Analysis of Beveled UWB Triple Band Rejection Antenna

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Abstract—A novel beveled triple band rejection UWB monopole radiator is presented. The reference UWB antenna incorporate a beveled radiator and partial ground structure for achieving UWB bandwidth from 2.73 to 11.05 GHz. For rejecting 3.78–4.36, 5.15–5.45, and 7.2–7.9 GHz for C, lower WLAN, and X-band applications, the reference UWB element is freighted with an inverted U-shaped slot etched into a radiating patch. A symmetrical split ring resonator pair (SSRRP) is proximate to microstrip feed, and a C-shaped parasitic stub is embedded on top of defected ground plane. The antenna is designed on an FR-4 substrate with $30 \times 32.5\,\text{mm}^2$ size, having a realized average gain of 3.72 dBi and is nearly stable across the entire UWB excluding at three rejected bands.

1. INTRODUCTION

In 2002, U.S. Federal Communications Commission (FCC) allocated 7.5 GHz bandwidth ranging 3.1–10.6 GHz for unlicensed commercial UWB radio systems [1]. The frequency range allocated for UWB spectrum is different in different countries. In China, UWB spectrum is allocated from 6 to 9 GHz, whereas in Korea from 3.1 to 4.8 GHz for the lower and from 7.2 to 10.2 GHz for the upper UWB band. In UWB systems, information is broadcast by generating short duration pulses at specific intervals of time to ameliorating multipath fading effects. Recently, in the field of wireless communications, UWB technology has gained several advantages due to low power spectral density, low loss penetration, low cost, fading robustness, high data transmission rate, fidelity, secured communication, and single chip architecture. The preeminent limitation of UWB radiator is electromagnetic interference (EMI) with narrow band systems like 3.3–3.6 GHz (WiMAX), 3.7–4.2 GHz (C-band), and 5.15–5.825 GHz (WLAN). To mitigate EMI, UWB antennas are designed with multiple rejection bands. In recent years, to eliminate this interference, a number of antennas are designed with band rejection capability. Initially, microwave filters are used for band rejection, but this method is complex and costly [2]. Thus, instead of using filters, UWB antennas are designed with band rejection feature by introducing slots into radiator or ground structure [3, 4], parasitic elements on either sides of substrate [5, 6], SRR [7, 8], CSRR [9], and EBG [10]. Moreover, UWB antennas are designed with single [11], double [12], triple [13], multiple [14, 15] band notch characteristics, and an array of UWB elements with side lobe suppression are reported [16, 17].

In this paper, a bevel-shaped UWB antenna with triband rejection using a U-shaped slot for C band, SSRRP for lower WLAN, and a C-liked parasitic stub for X-band rejection is presented. The designed radiator has −10 dB impedance bandwidth of 2.73–11.05 GHz with triple band notches ranging from 3.78 to 4.36 GHz for C-band, 5.15 to 5.45 GHz for lower WLAN, and 7.2 to 7.9 GHz for X-band applications. The antenna is optimized by altering parameters such as the length of the U-shaped slot, angle and gap (G) of SSRRP, and thickness of parasitic stub to achieve desired band notch functions.

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2. ANTENNA DESIGN

2.1. Antenna Geometry

The proposed antenna is fabricated on a low cost FR-4 substrate ($\varepsilon_r = 4.3$, $\tan\delta = 0.02$) fed by a microstrip line.

The structure consists of a bevel shaped radiator and a partial ground with a slot, SSRRP, and a parasitic stub as depicted in Figure 1.

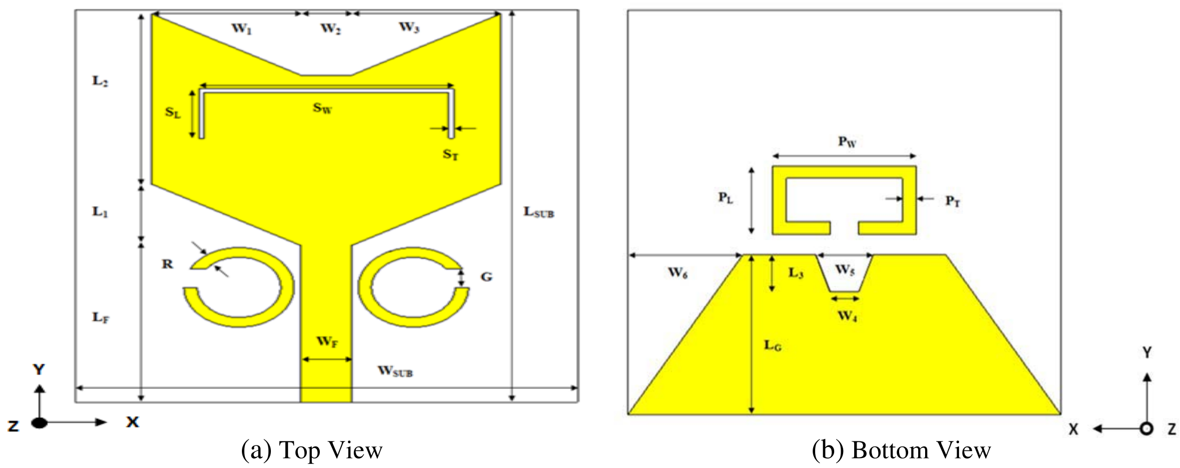


Figure 1. Proposed beveled antenna. (a) Top side. (b) Bottom side.

Dimensions of the beveled antenna are optimized using CST Microwave studio ver. 2017 and are given in Table 1.

Table 1. Proposed antenna optimized parameters.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
W_{sub}	30	L_1	5.1	L_G	12.9
L_{sub}	32.5	L_2	14.1	L_3	3
W_F	3	R	0.8	W_4	2
L_F	12.95	G	1.5	W_5	4
W_1	8.925	S_L	4.1	W_6	8
W_2	3	S_W	15.2	P_W	10
W_3	8.925	S_T	0.3	P_L	5.5
P_T	1	-	-	-	-

2.2. Proposed Antenna Design Procedure

The flowchart for design steps of beveled antenna is shown in Figure 2. Initially, a simple rectangular patch of dimension $(W_1 + W_2 + W_3) \times (L_1 + L_2)$ is fed with microstrip feed line of $W_F \times L_F$ etched on top surface of an FR-4 substrate with $W_{sub} \times L_{sub}$. The patch is optimized by notching bevels at both lower and upper corners to increase the bandwidth. Further, to enhance the bandwidth a partial ground plane with $W_{sub} \times L_G$ is notched on bottom surface of the substrate and then beveled. The width of feed W_F affects the impedance matching, while the ground length L_G is more sensitive to

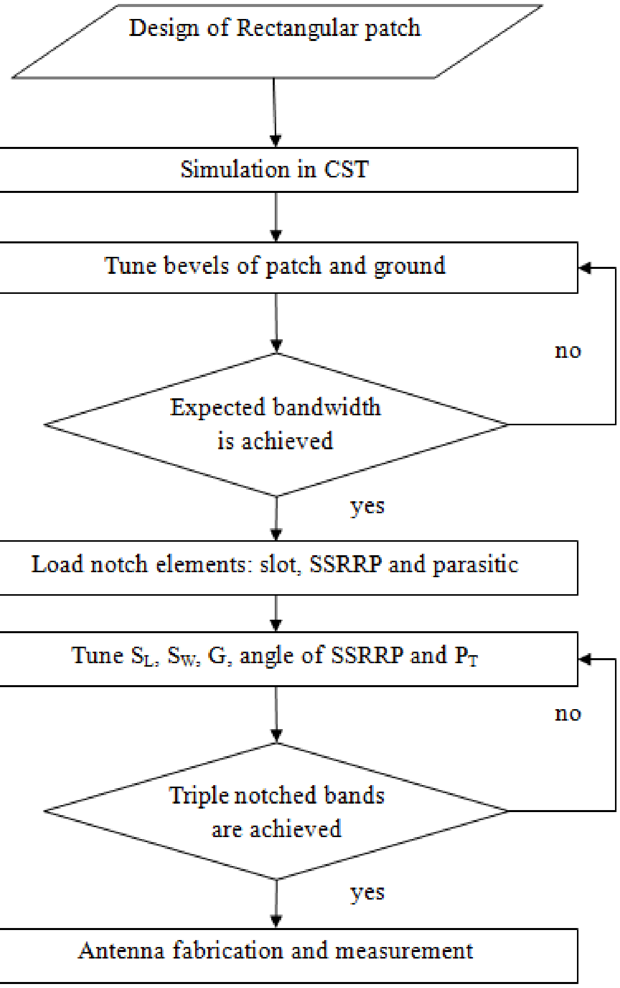


Figure 2. Proposed triple band notched UWB antenna design flow chart.

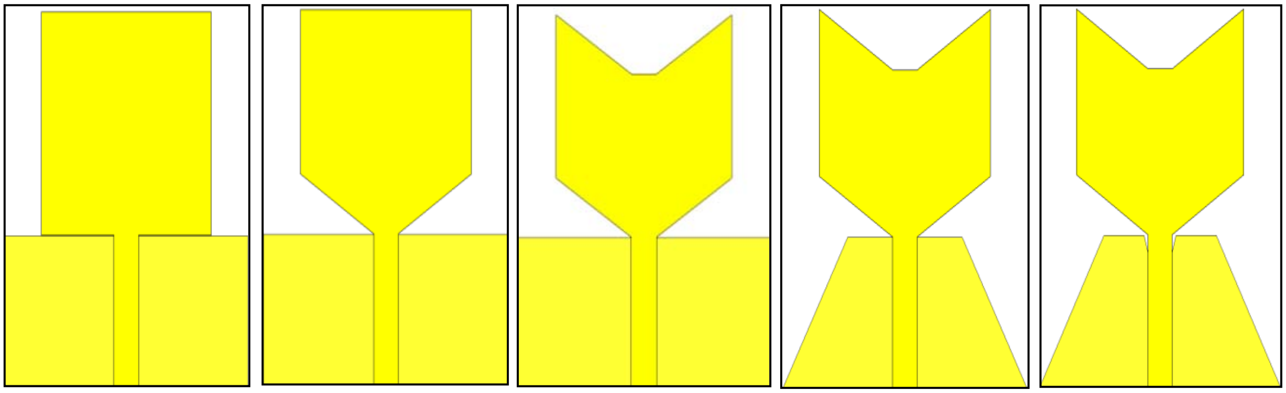
achieve desired impedance bandwidth. Later, to achieve required UWB bandwidth a beveled slot is introduced in middle of the partial ground structure.

Firstly, C-band is notched by introducing a U-structured slot on the patch and is optimized by varying the dimensions (S_L, S_W, and S_T). The variation in the dimensions of width S_T of the slot determines the bandwidth of the rejection band while length $2S_L+S_W$ contributes the notch band centre frequency. Secondly, to notch WLAN band, an SSRRP is etched on juxtaposition to the microstrip feed line and optimized by changing the dimensions of SSRRP (G and angle of SSRRP). The change in the dimension G of SSRRP shifts the rejected band centre frequency, and angle of SSRRP determines the frequency width of the WLAN band. Finally, optimizing the value of thickness P_T of C-shaped parasitic stub introduced on top of the defected ground plane shifts centre frequency of X-band notch.

2.3. Reference UWB Antenna

The evolution of reference UWB antenna in five stages is shown in Figure 3. In Figure 3(a), in the first stage, a rectangular patch of dimension $20.85 \times 19.2\,\text{mm}^2$ is fed with feed line of $3 \times 12.95\,\text{mm}^2$ etched on top surface of substrate and a partial ground plane of $30 \times 12.9\,\text{mm}^2$ on bottom side of the substrate. This structure of Antenna \$a will not create any resonance in UWB frequency range as depicted in Figure 4. Later in the second stage, when lower corners of patch are beveled, the $-10\,\text{dB}$ bandwidth ranges from 2.78 to 7.44 GHz for Antenna \$b.

In the third stage, when the upper corner of the radiating patch is beveled, the bandwidth changes



(a) (b) (c) (d) (e)

Figure 3. Progressive stages of reference UWB antenna. (a) Antenna \$a. (b) Antenna \$b. (c) Antenna \$c. (d) Antenna \$d. (e) Antenna \$e.

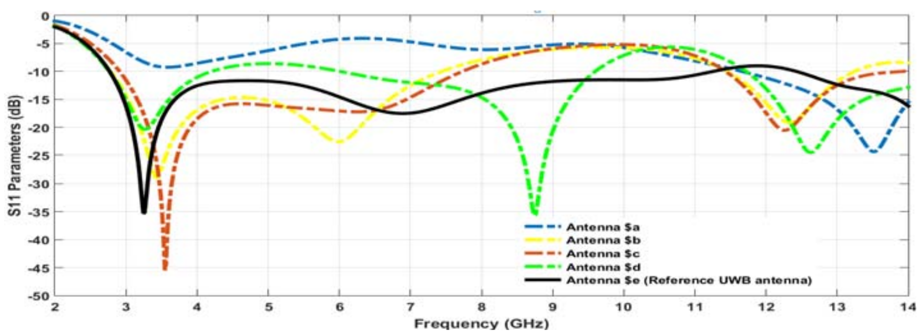


Figure 4. S_{11} parameter plot in different stages.

from 2.91 to 7.73 GHz for Antenna \$c. In the fourth stage, for Antenna \$d, when both sides of the partial ground plane are beveled, the antenna structure creates two resonant frequencies at 3.27 GHz and 8.74 GHz. In the final stage, when the partial ground plane is beveled in the middle, Antenna \$e achieves the required -10 dB impedance bandwidth of 2.77–11.25 GHz which covers the entire UWB as depicted in Figure 4.

2.4. Reference UWB Antenna with Individual Band Notch Formation and Parametric Study

The reference UWB Antenna \$e with an inverted U-shaped slot for C band (3.78–4.36 GHz) rejection, with SSRRP for lower WLAN band (5.15–5.45 GHz) rejection, and with a parasitic strip for X band (7.2–7.9 GHz) rejection is illustrated in Figures 5(a)–(c). To perceive the proper band rejection formation, the dimensions of individual notch elements are optimized.

The parametric study of the beveled antenna is depicted in Figures 6(a)–(d). For C-band rejection, the total length $2S_L + S_W$ of the inverted U-shaped slot is varied in steps of 21.4, 23.4, and 25.4 mm. The notched frequency of the proposed antenna is mathematically approximated by [18],

$$f_n \approx \frac{c}{\lambda_g \times \sqrt{\varepsilon_{eff}}} \approx \frac{c}{2L_n \times \sqrt{\varepsilon_{eff}}}; \quad \text{Here, } L_n = 2S_L + S_W \quad \text{here, } \varepsilon_{eff} = \frac{\in_r + 1}{2} \tag{1}$$

where C is the speed of light, and f_n is the notched frequency associated with total effective length, L_n, of the inverted U-shaped slot. Here, the total effective length of the slot, L_n, is equal to $\lambda_g/2$ (λ_g is the guided wavelength at f_n). Thus the proposed antenna works as a half wavelength resonator.

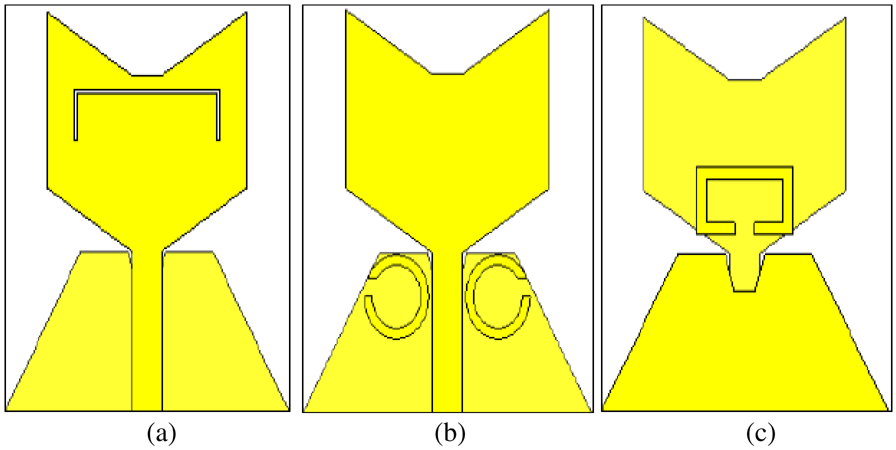


Figure 5. Antenna $e loaded with notch elements for (a) C band, (b) WLAN band, (c) X band rejections.

From Figure 6(a), it is noticed that when $2S_L + S_W$ is altered, the centre frequency of notch band is displaced. The centre frequency of C-band notch is at 4.6 GHz for $2S_L + S_W = 21.4$ mm, at 4.2 GHz for $2S_L + S_W = 23.4$ mm, and at 3.87 GHz for $2S_L + S_W = 25.4$ mm. The variation in length of SSRRP is a function of gap G; hence the parametric study is carried out by changing gap G in steps of 1, 1.5, and 2 mm. Increasing gap G results in decreasing the length of SSRRP, and hence the effective inductance also decreases, which results in increase in notched band resonant frequency as shown in Figure 6(b).

In Figure 6(c), the parametric study is carried out by rotating SSRRP with different rotation angles 0°, 90°, 180°, and 270°. As discussed in [19], the effective capacitance at 0° angle is due to both beveled patch and microstrip line resulting in resonant frequency of notch band at 4.48 GHz with notched band in between 4.85 and 5.65 GHz. Further, for rotation angles of 90°, 180°, and 270°, the effective capacitance due to microstrip line and SSRRP results in achieving notched band resonant frequencies 4.58, 4.62, and 5.07 GHz with notched bands ranging 4.92–5.44, 4.97–5.31, and 5.13–5.47 GHz, respectively.

Finally, the parametric study of the parasitic stub is carried out by changing thickness P_T in steps of 0.75, 1, and 1.25 mm to notch X-band as depicted in Figure 6(d). The parasitic stub acts as a half wavelength resonator. The centre notch frequency of X band is at 7.53 GHz for the optimized value of $P_T = 1$ mm. Thus, reference UWB antenna is successfully achieved with triple band notch characteristics. Moreover, the centre frequencies of notched bands are controlled independently.

2.5. Numerical Results and Discussion

The numerical results of the proposed beveled shape UWB antenna with triple band notches are measured by Anritsu MS2037C/2 network analyzer.

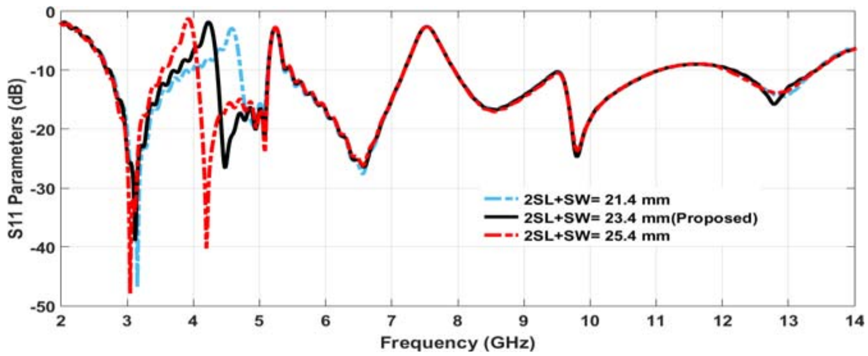
The prototype of the beveled antenna is shown in Figure 7.

The comparisons between simulated and measured results in terms of magnitude of return loss (S_{11}) and VSWR plots are depicted in Figures 8(a) and (b).

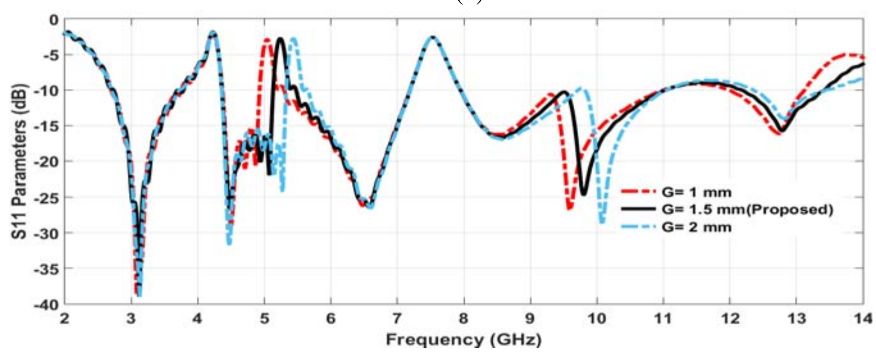
From measured results, the impedance bandwidth of proposed antenna is 2.73–10.95 GHz. The bandwidth of notched band observed for C band is 3.78–4.36 GHz, for lower WLAN band is 5.15–5.45 GHz, and for X band is 7.2–7.9 GHz. For the proposed antenna, the measured peak values of VSWR are 9.4 at 4.2 GHz, 6.4 at 5.24 GHz, and 6.8 at 7.53 GHz for C, Lower WLAN, and X-band notched characteristics.

The simulated and calculated radiation characteristics of the beveled antenna are depicted in Figures 9(a)–(d) at resonant frequencies 3.11, 4.48, 6.58, and 9.8 GHz. The antenna has distorted radiation patterns at high frequencies due to the increased effect of harmonics of higher order modes and distortion in electric field distribution [20].

The performance characteristics of proposed antenna can be better perceived by observation of surface current distributions at rejected band frequencies 4.23, 5.24, and 7.53 GHz as shown in



(a)



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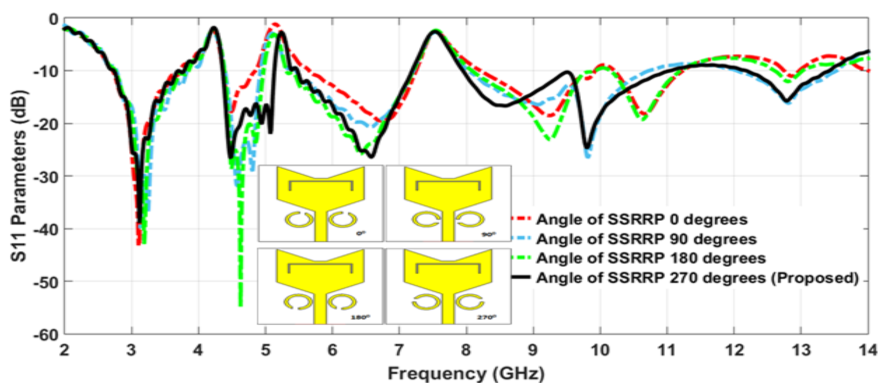
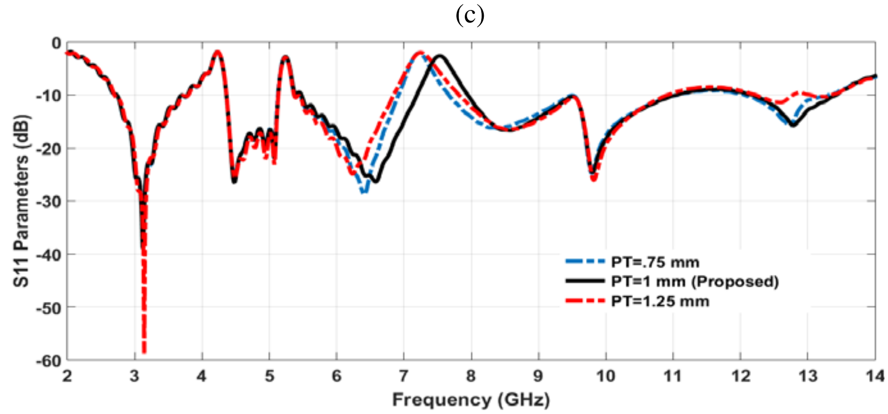


(c)

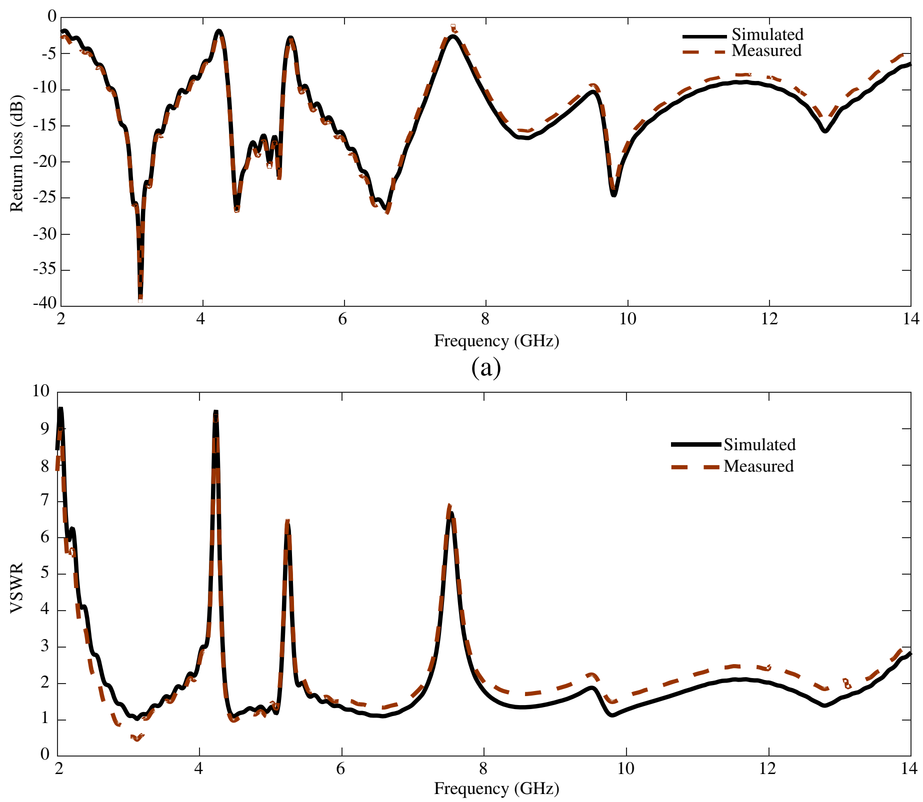


(d)

Figure 6. Magnitude of S_{11} of reference UWB Antenna $e for variation in dimension of notching elements (a) $2S_L + S_W$ for C band notch, (b), (c) SSRRP gap (G), angle for Lower WLAN band rejection, (d) P_T for X band rejection.

(a) (b)

Figure 7. Fabricated Antenna. (a) Top layer. (b) Bottom layer.



(b)

Figure 8. Simulated and measured. (a) Magnitude of S_{11} and (b) VSWR.

Figures 10(a)–(c). For three notched band frequencies, the concentration of surface currents is maximum and in reverse direction for inner and outer edges along the band notched elements. This is because a large amount of electromagentic energy is accumulated in each of the band rejected elements and behaves as non-radiator at relevant notch frequencies.

The measured input impedance of the beveled antenna is depicted in Figure 11. For C-band rejection, the inverted U-structured slot shows parallel resonance peculiarity noticed from the imaginary impedance curve. At C band notch frequency 3.9 GHz, the impedance of real part is 130 Ω, while the imaginary part of impedance swings from negative to positive. It reveals that the C-band rejection is indicated by parallel resonance circuit and is demonstrated [21] and that the input impedance of C-band notched antenna is analogous to the reference UWB antenna with input impedance Z_a.

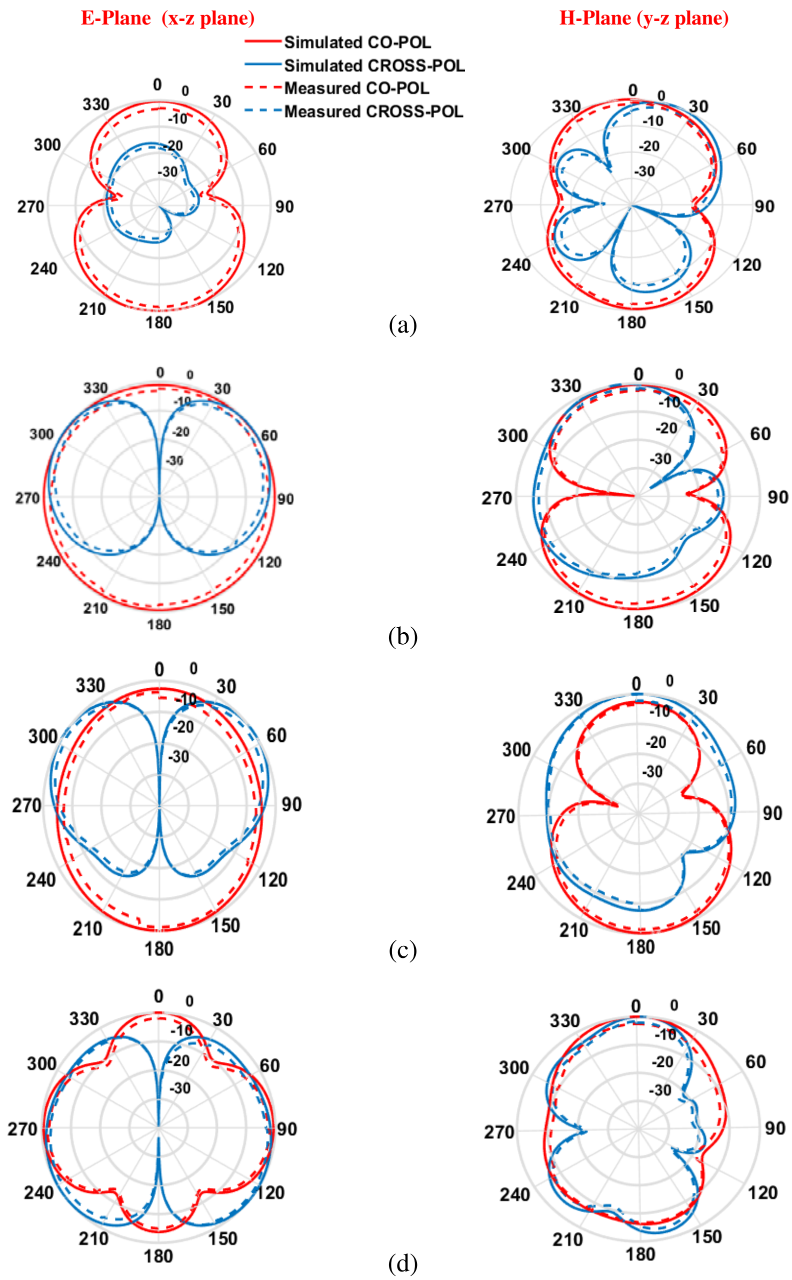


Figure 9. Radiation patterns at (a) 3.11 GHz, (b) 4.48 GHz, (c) 6.58 GHz, (d) 9.8 GHz.

For WLAN and X band rejection bands, the input impedance curves are approximately alike to the impedance of series resonance feature [22]. On this account, the conceptual circuit model of the proposed beveled antenna is as shown in Figure 12.

The calibrated peak gain of reference UWB antenna $e and proposed triband notch antenna are sketched in Figure 13. The average peak gain measured for reference antenna over the operating bandwidth is 3.72 dBi. In C band notch, the gain drops from 3.17 to −4.96 dBi, in WLAN band notch; the gain decreases from 2.51 to −1.96 dBi; and in X-band notch, the gain drops from 4.53 to −2.53 dBi. Hence, the proposed antenna effectively suppresses the interference due to C, WLAN, and X bands.

The parametric analysis of the beveled antenna is shown in Table 2.

The performance comparison of the prototype antenna with latterly outlined antennas [23–28] is stated in Table 3.

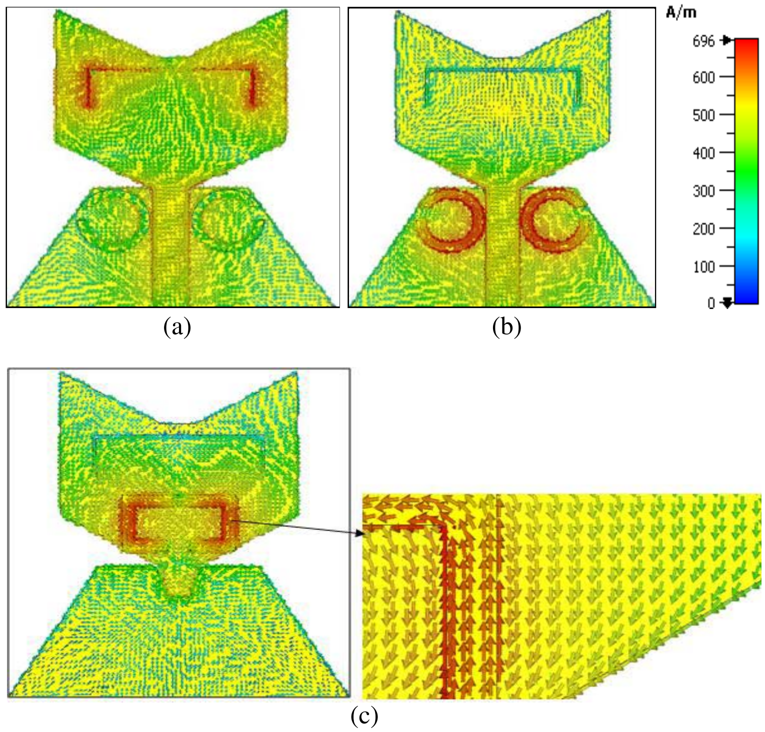


Figure 10. Surface current distributions at notched frequencies (a) 4.23 GHz, (b) 5.24 GHz, (c) 7.53 GHz.

Table 2. Parametric study of proposed antenna.

Parameter	Parameter value in (mm)	Centre of notch frequency, f_n (GHz)	Notched band resonant frequency (GHz)	VSWR at f_n	Actual Bandwidth, (GHz)	Achieved Bandwidth, (GHz)	Magnitude of band error, %
Slot length, $L_n = 2S_L + S_W$	$L_n = 21.4$	4.58	3.15	6.09	3.7–4.2 (C band)	3.98–4.71	7, 12.1
	$L_n = 23.4$ (proposed)	4.2	3.11	9.50		3.78–4.36	**2, 3.8**
	$L_n = 25.4$	3.92	3.04	13.81		3.52–4.06	4.8, 3.3
SSRRP Gap, G	$G = 1$	5.04	4.86	6.02	5.15–5.35 (Lower WLAN)	4.92–5.29	4.4, 1.1
	$G = 1.5$ (proposed)	5.24	5.07	6.38		5.13–5.45	**0.3, 1.8**
	$G = 2$	5.43	5.27	6.30		5.33–5.65	3.4, 5.6
Angle of SSRRP	0°	5.04	4.48	14.72		4.85–5.65	5, 5.6
	90°	5.09	4.58	6.02		4.92–5.44	4.4, 1.6
	180°	5.13	4.62	5.61		4.97–5.31	3.4, 0.74
	270° (proposed)	5.24	5.07	6.38		5.13–5.47	0.3, 2.2
Parasitic thickness, P_T	$P_T = 0.75$	7.22	6.41	8.49	7.25–7.75 (X-band satellite communication)	6.91–7.66	4.6, 1.6
	$P_T = 1$ (proposed)	7.53	6.58	6.70		7.2–7.9	**0.68, 1.9**
	$P_T = 1.25$	7.24	6.23	8.75		6.84–7.81	5.6, 0.77

Table 3. Comparison between proposed and recently reported antennas.

Ref. Antennas	Size (mm^2)	Area (mm^2)	Notch Bands (GHz)
[23]	40 × 40	1600	1.6–2.66, 3–4, 5.13–6.03
[24]	38.31 × 34.52	1322	3.28–3.82, 5.12–5.4, 5.7–6
[25]	35 × 35	1225	3.3–3.8, 5.15–5.85, 7.9–8.4
[26]	36 × 34	1224	3.3–3.9, 5.2–5.35, 5.8–6
[27]	30 × 35	1050	3.3–3.8, 5–6, 7.1–7.9
[28]	42 × 24	1008	3.3–3.7, 5.15–5.825, 7.1–7.76
This work	30 × 32.5	975	3.78–4.36, 5.15–5.45, 7.2–7.9

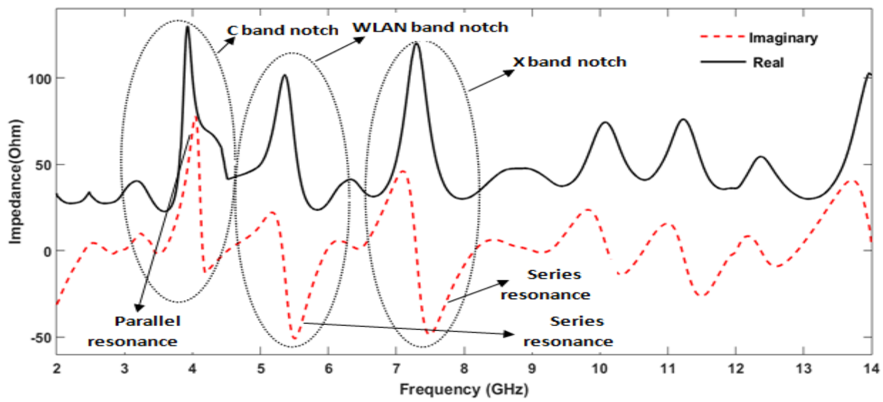


Figure 11. Measured input impedance of proposed antenna.

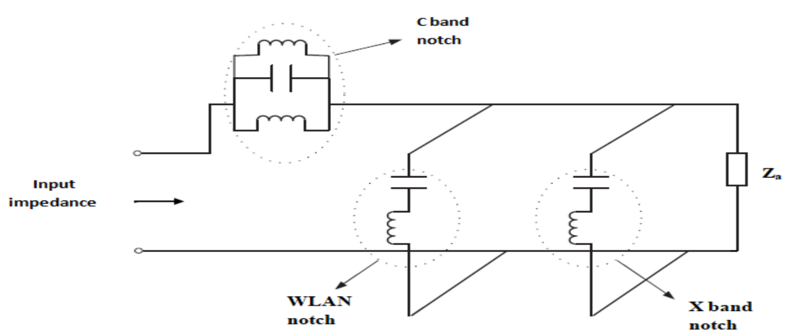


Figure 12. An equivalent conceptual model of beveled antenna.

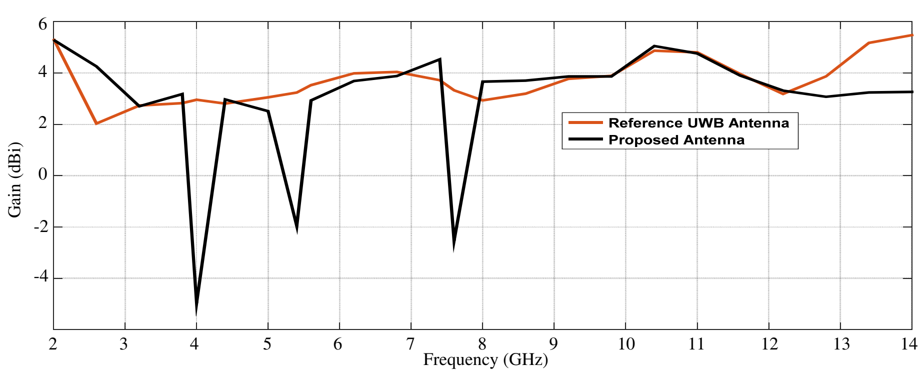


Figure 13. Measured Peak gain.

3. CONCLUSION

A beveled UWB monopole radiator with triband rejection peculiarity is proposed. The impedance bandwidth of antenna is from 2.73 to 11.05 GHz. Triple band notch characteristics are generated for C-band (3.78–4.36 GHz), WLAN-band (5.15–5.45 GHz), and X-band (7.2–7.9 GHz) by using a slot, SSRRP, and parasitic stub, respectively. It is observed that the triple band notch functionalities are controlled independently by variation in dimensions of parameters of band notched elements. The consistency in simulated and measured parameters shows that the bevel-shaped antenna is suitable for portable UWB applications.

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