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EBG and SRR loaded triple band notched UWB antenna

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KEYWORDS
SRR loaded antenna;
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UWB antenna;
Slot loaded antenna.

Abstract. A compact triple band-notched Ultra-Wideband (UWB) monopole antenna is presented in this paper. Split Ring Resonator (SRR) structure is exploited in various forms, like the Complementary Split Ring Resonator (CSRR), Split Ring Resonator Pair (SRRP), and CSRR on Electromagnetic Band Gap (EBG) structure, to produce triple band-notched characteristics in UWB spectrum. The proposed antenna produces triple band-notched functions with the integration of all three types of SRR on the primary antenna. The parametric analysis of each form of SRR is presented, along with their current distribution effects on the triple band-notched antenna. The proposed antenna prototype is fabricated, and measured results are compared with the simulated ones to understand the discrepancies. The measured and simulated results are presented to investigate the band-notching characteristics of the suggested antenna in terms of Voltage Standing Wave Ratio (VSWR) and radiation characteristics.

1. Introduction

Wireless communication is the fastest-growing technology and has evidenced the most advancement in the last two decades. After the announcement by the Federal Communication Commission (FCC) regarding Ultra-Wideband (UWB) as an unlicensed band for commercial uses [1], planar antennas like microstrip have become auspicious for designing compact wireless communication systems due to their undisputed advantages. Microstrip antennas have some distinct features which make them suitable for designing UWB-printed antennas at a low cost and are compatible with various fabrication technologies [2]. UWB technology shares the spectrum with other existing narrowband applications like WiMAX, WLAN, and C-Band satellite communication (downlink). The narrowband applications cause electromagnetic interference in UWB systems

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which degrades the performance of this popular technology. To overcome the electromagnetic interference challenges, numerous approaches have been presented by researchers, among them designing an antenna with band filtering features is the most popular [3]. Currently, scholars have suggested several techniques to make an antenna with band filtering features, such as slots etched from the metallic patch or on the finite ground plane, DGS, slots in the feed line, stub methods, split-ring resonators, and many more. However, in literature, many kinds of Electromagnetic Band Gap (EBG) configurations have been recommended, like EBG over CPW-fed antenna [4], Mushroom EBG (M-EBG) and modified EBG near the antenna feed line for band-notched features [5], slot-loaded M-EBG in [6], M-EBG for dual band-stop features in [7], C and reverse C slot-loaded EBG near feed line [8], a general EBG configuration for band-stop application in [9], a reconfigurable EBG structure with diagonal chamfered structure [10], square EBG near feed line in [11], and double via EBG with slot in [12]. Furthermore, Split Ring Resonator (SRR) structure has been implemented for band notch in [13], a dual-band SRR slot on radiating patch in [14], U-shaped resonator and inverted U-shaped slots implemented for band-notched features in [15], an Electric Ring Resonator (ERR) on the backside of the substrate used to produce band-notched characteristics in [16] and a resonating stub used to create band-notched characteristics in [17]. The integrated slot method is also used in [18,19] to produce triple band-notched features, whereas along with slots on the patch, open-ended stubs are used in [20]. A multilayered Complementary Split Ring Resonator (CSRR) topology is implemented in [21] for multifunctional UWB features. The authors in [22] designed a MIMO configuration for slit and slot-loaded UWB antenna for band-notched features. In [23,24], authors have etched alphabetic letter-shaped slots to produce band-notches, whereas in [25], a folded resonator is used to produce band-notches as a resonating element as well as a slot on the patch or ground. The concept of EBG is used to produce band-filtering characteristics in UWB antennas by authors in [26]. In literature, it is proven that the SRR produces negative permittivity, and the same concept is used by [27] to produce band-notched features with Jeong et al. UWB antennas.

The presented work has an analysis of SRR inspired structures to produce band-notching characteristics in the UWB spectrum, which significantly minimizes the electromagnetic interferences due to applications like WiMAX, WLAN, and X-band. A CSRR slot is etched on the radiating patch to create band-stop functions for WiMAX applications, a pair of SRRs near the feed line to produce notch characteristics for X-band, and a pair of CSRRs integrated with EBG structure for band-filtering characteristics in the WLAN band. The EBG technique is one of the most general procedures to make an antenna with band-filtering features. However, in this paper, EBG integrated with CSRR structure is investigated to produce band-notch features without changing the EBG dimensions. The proposed antenna has a pair of SRRs near the feed line which splits at 75° to produce band-notch at the X-band, and it is novel in comparison to conventional SRR structures for band-notching. The SRR approach enhances the antenna characteristics along with minimizing the electromagnetic interferences from narrowband applications.

2. Triple band notch antenna design and analysis

The proposed antenna design and its characteristics analysis have been completed with the commercially available EM simulator Ansoft's HFSS 13. The evolution of the proposed triple band-notched antenna is presented in Figure 1. It also exhibits the integration of band-filtering structures. The dimensions and necessary design variables of the proposed antenna are exhibited in Figure 1, and the fabricated sample of the antenna is depicted in Figure 2. The presented antenna is fabricated with the cost-effective dielectric material FR-4, with a substrate height of 1.6 mm, $\varepsilon_r = 4.4$, and a loss tangent of 0.02. The primary antenna has followed the design equations discussed in [28] to resonate at the UWB lower-end frequency.

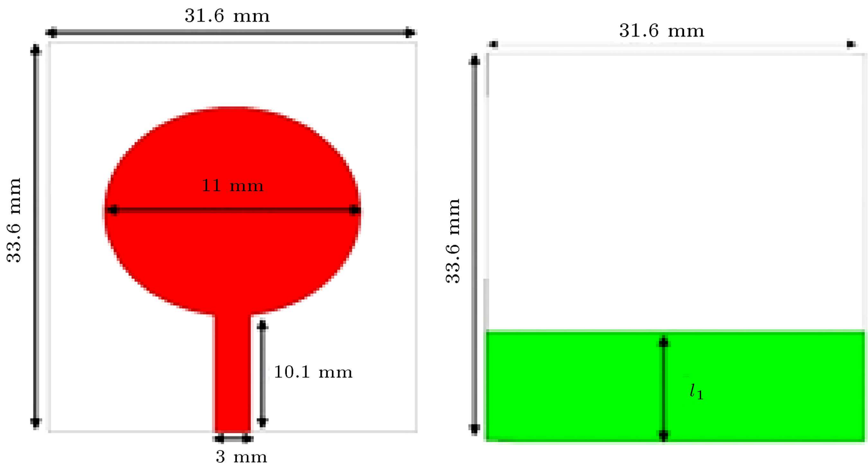
The suggested antenna produces triple band-notched characteristics which are achieved in three steps as discussed in Subsections 2.1, 2.2, and 2.3. The characteristic impedance of 50 Ω for the feed line is achieved through a 3 mm wide metallic strip. All the optimized dimensions of the proposed antenna are listed in Table 1.

2.1. CSRR-loaded antenna design (WiMAX-band notch)

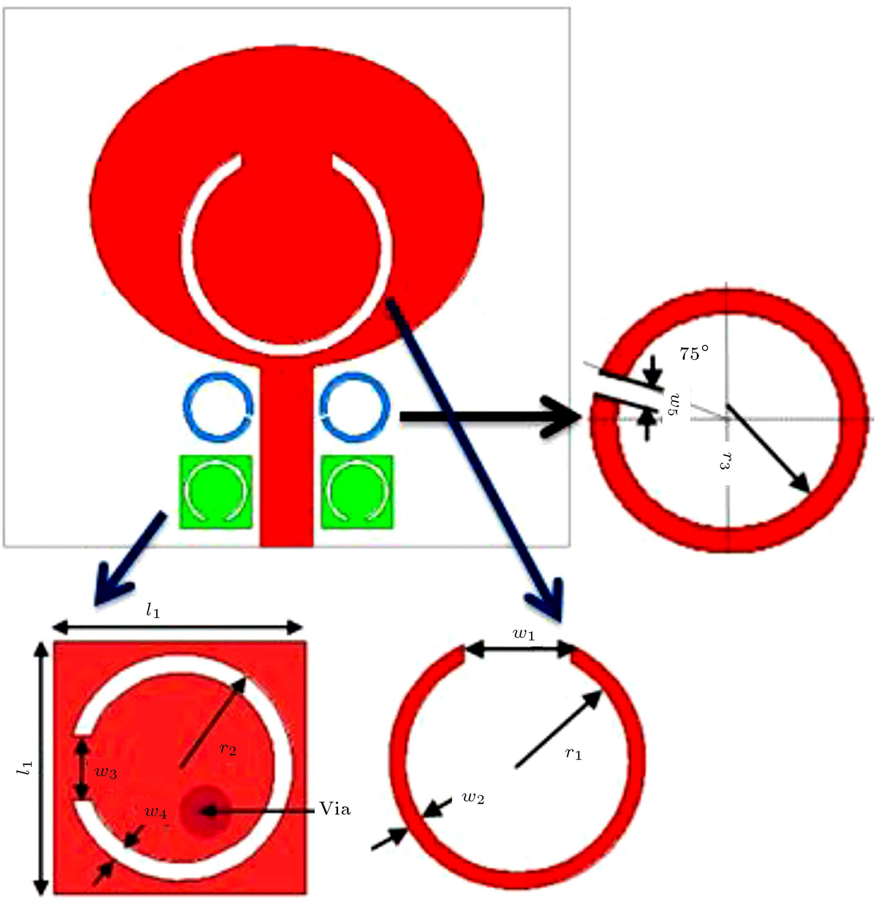
An SRR can resonate over a band of frequencies with respect to its designed size; here, a circular CSRR is etched on a metallic patch to produce band filtering characteristics. The proposed CSRR design on the primary antenna produces band-notch features for WiMAX band applications. The primary antenna

Table 1. Optimized dimensions of proposed antenna (mm).

Variable	l_1	l_2	w_1	w_2	w_3
Size (mm)	4	9.58	5	0.75	1
Variable	w_4	w_5	r_1	r_2	r_3
Size (mm)	0.3	0.34	5.25	1.8	1.6



(a) Primary antenna front and back view



(b) Triple band notched antenna with proposed SRR configurations

Figure 1. Evolution of proposed antenna.

operates over the complete UWB spectrum and is used to implement CSRR as shown in Figure 1(a). The proposed CSRR length can be calculated from Eq. (1) as follows:

$$L_{eq} = 2\pi r_1 - w_1, \tag{1}$$

$$f_c = \frac{c}{2L_{eq}\sqrt{\left(\varepsilon_r + 1\right)/2}}, \tag{2}$$

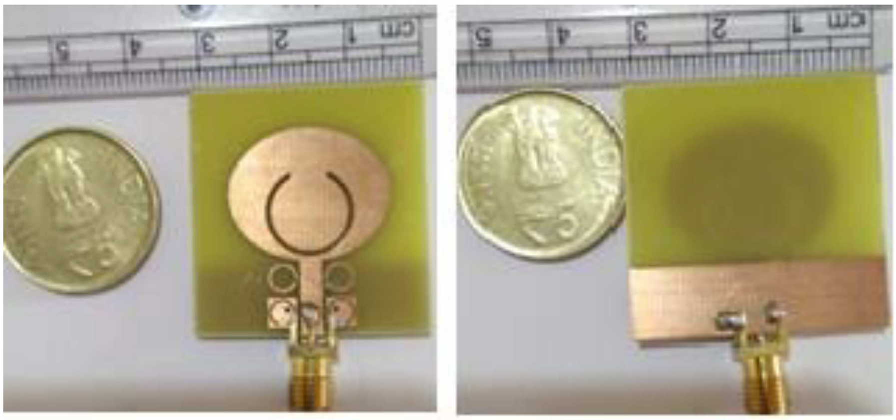


Figure 2. Front and back view of fabricated prototype of proposed antenna.

where L_{eq} is the equivalent length, r_1 is the radius of the ring, w_1 is the split gap, and c represents the speed of light.

The equivalent length, L_{eq}, can be modified and optimized to create a notch at the WiMAX band. The theoretical length of the CSRR is 25.66 mm (calculated at 3.5 GHz, which is half the guided wavelength for the structure), whereas the practical length is approximately 27.97 mm, calculated from Eq. (1). The discrepancy between the theoretical and real length of the CSRR is due to the mutual inductance coupling of the other resonators near the feed line.

2.2. SRR-loaded antenna (X-band notch)

The band-notch characteristic for X-band applications has been achieved through the SRR near the feed line. Here, a pair of SRRs is used whose impedance can be controlled through the length and split gap of the resonator. The practical length of the SRR is approximately 12.03 mm (calculated at 7.5 GHz, which is half the guided wavelength for the structure from Eq. (2), whereas the theoretical length is 11.97 mm, calculated from Eq. (3) as follows:

$$L_{eq} = 2\pi r_3 - w_5, \tag{3}$$

where L_{eq} is the equivalent length, r_3 is the radius of the ring, and w_5 is the split gap.

2.3. CSRR-loaded EBG pair antenna (WLAN band notch)

A pair of M-EBG cells near the feed line of the metallic patch, as displayed in Figure 1(b), is used for band-notched characteristics. To create a band notch at WLAN applications (5.1–5.8 GHz), an M-EBG cell is integrated with CSRR and grounded using via. The entire size of the M-EBG cell is 4×4 mm^2. A fabricated prototype of the proposed antenna is presented in Figure 2. The practical length of the CSRR can be calculated from Eq. (4) as follows:

$$L_{eq} = 2\pi r_2 - w_3, \tag{4}$$

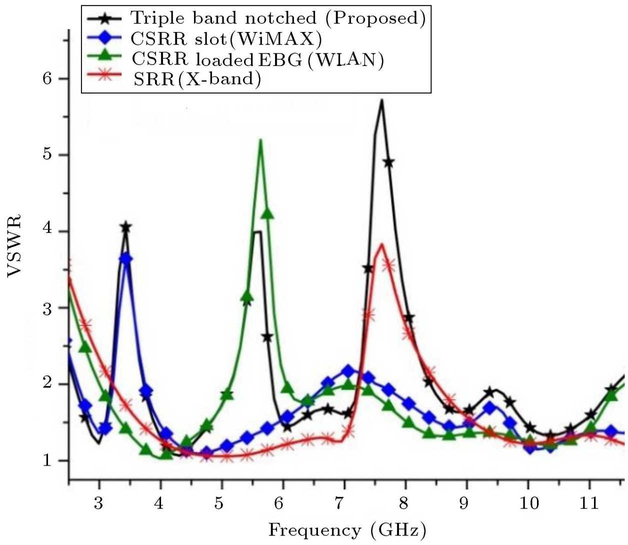


Figure 3. VSWR of proposed antenna step by step evolution.

where L_{eq} is the equivalent length, r_2 is the radius of the ring, and w_3 represents the split gap. The theoretical length of the resonator to create a band notch at 5.5 GHz is 16.3 mm, calculated from Eq. (2) as half the guided wavelength, whereas the practical length of the EBG resonator is 16 mm. Furthermore, this EBG patch is tuned using the complementary split ring slot on it.

A primitive antenna has been designed (an elliptical patch with an axial ratio of 9/11) which radiates for the entire UWB band with a Voltage Standing Wave Ratio (VSWR) less than 2, as presented in Figure 3. To produce triple band-notched features, all the discussed methods are integrated with the primary antenna, and their individual band-notched results are exhibited in Figure 3. The proposed antenna is an arrangement of all three approaches to produce band-notched features, and their respective VSWR has been exhibited in Figure 3.

The SRR metallic strip is used to produce band-

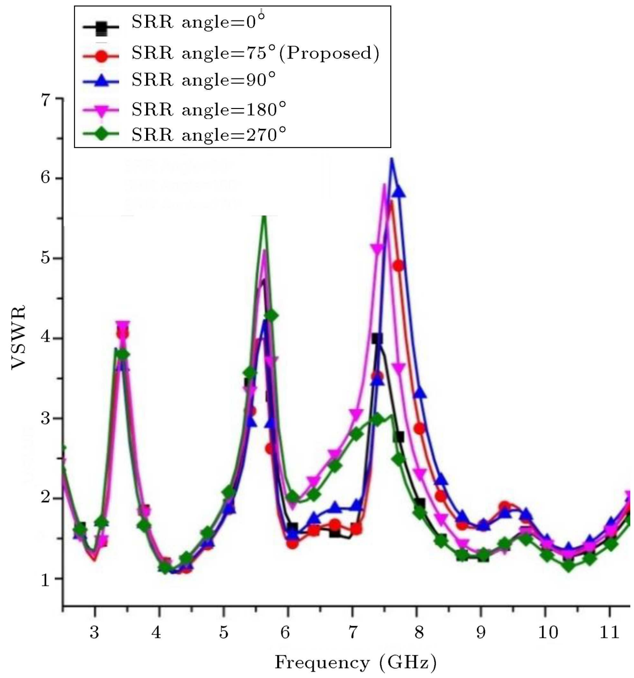


Figure 4. VSWR variation due to different split angles of SRR.

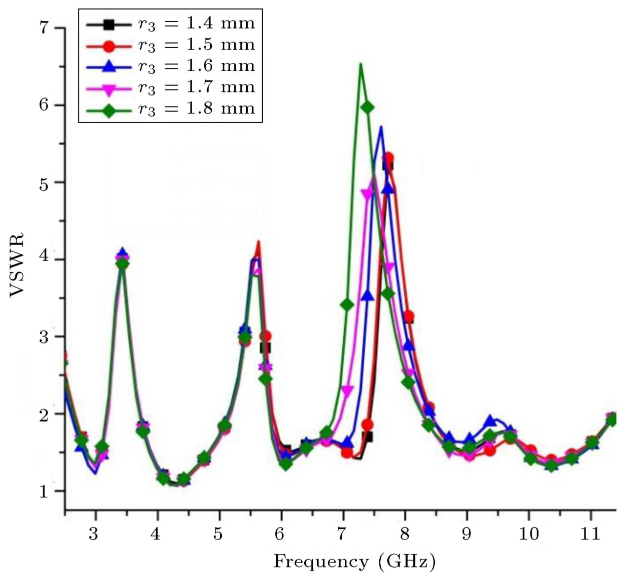


Figure 5. VSWR variation with SRR width (alteration in radius r_3 of SRR).

notch characteristics in the X-band. However, the resonator split angle also plays a key role in tuning the band-notched frequency. We varied the split angle from 0° to 270°, and the corresponding VSWR is presented in Figure 4. In Figure 4, it can be observed that the band-notch frequency changes with the split angle of the SRR. The proposed SRR is different from the conventional SRR, and the desired band-notched feature is achieved at a split angle of 75°.

The SRR width variation is presented in Figure 5.

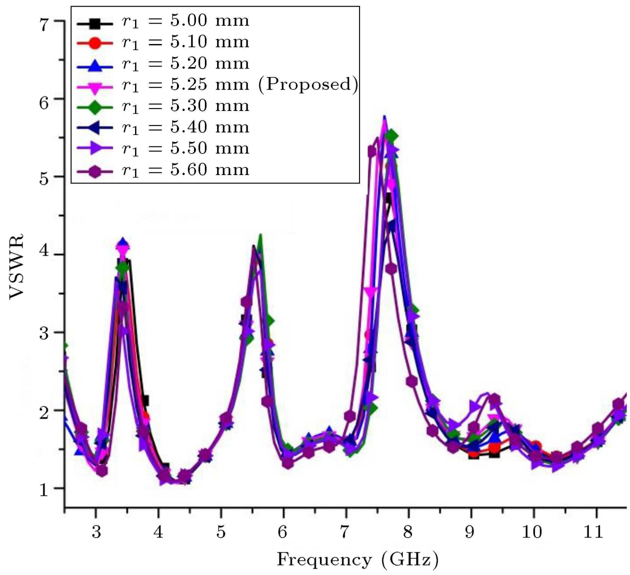


Figure 6. VSWR variation for r_1 (CSRR Slot width alteration).

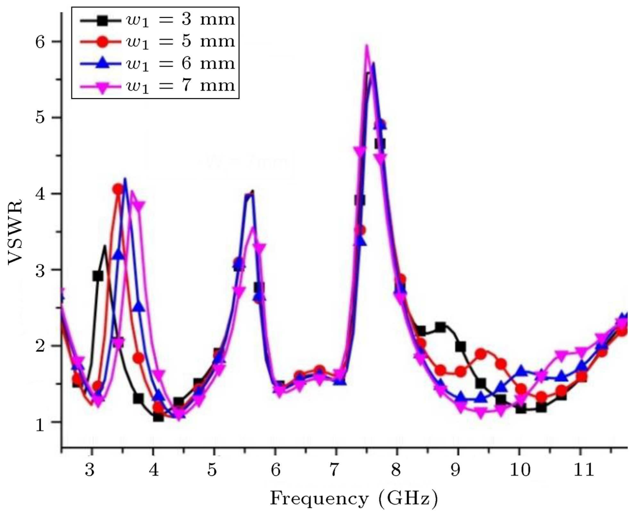


Figure 7. VSWR variation with W_1 (CSRR slot length alteration).

In Figure 5, it can be realized that the SRR width has a great impact on the frequency tuning of the proposed antenna. The width of the proposed SRR is a function of frequency. It can be verified from Figure 5 that the center frequency of the band notch inversely varies with the SRR width.

The dimensions of the CSRR can be changed and optimized by adjusting the split gap and width of the CSRR. The width W_2 of the CSRR slot can be varied with the radius r_1, and the length changes with variations in W_1. These parameters are optimized, and their effects on VSWR are presented in Figures 6 and 7, respectively.

In Figure 6, it can be observed that the effect of slot width can be used to tune the center frequency of

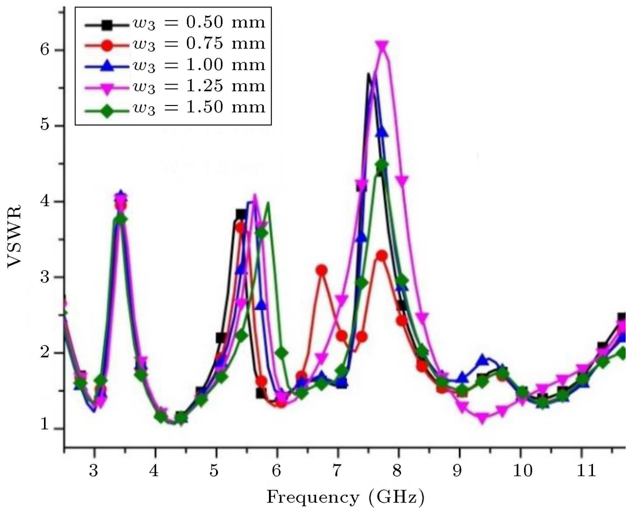


Figure 8. VSWR variation with W_3 (EBG-CSRR slot length alteration).

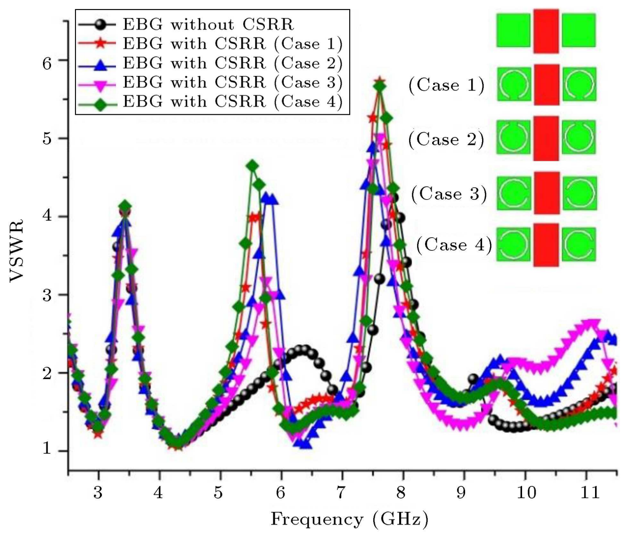


Figure 9. VSWR variation with CSRR orientation integrated on EBG patch.

the notched band; however, it has a negligible effect on other band-notched frequencies.

The modification in W_1 of slot length is optimized, and it highly affects the VSWR, as displayed in Figure 7. The length optimization shows that slot length has a negligible effect on WLAN frequencies.

A symmetrical CSRR slot integrated pair of square-shaped M-EBG is used to produce band-notched characteristics for WLAN applications. The integrated CSRR length can be varied with the split gap W_3 to tune the band-notched frequency of WLAN applications. The optimization effects on VSWR of CSRR integrated over EBG are presented in Figure 8.

The CSRR is integrated over EBG to produce the desired band-notched functions, as presented in Figure 9. The EBG structure integrated with CSRR in various circumstances verifies that the CSRR produces an effective capacitance to produce the desired band-notch frequency.

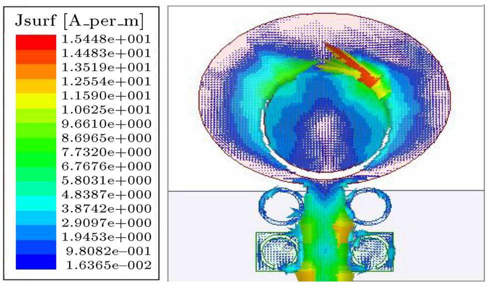
The effect of different types of band-notching structures on the metallic patch can be examined with vector current distributions. The vector current distribution on the suggested antenna at five different frequencies is exhibited in Figure 10. At passband frequencies like 4 GHz and 6.5 GHz, the circulation of the vector current is identical, as shown in Figure 10(b) and (d). Figure 10 (a), (c), and (e) represents the vector current distribution effects of CSRR, M-EBG integrated with CSRR slot, and SRR on the proposed antenna. In Figure 10(a), (c), and (e), it can be observed that a stronger current density is concentrated near the edges of the band-notching structures, which is necessary to create a band-stop feature.

Figure 11 demonstrates the input impedance characteristics of the recommended antenna with frequency. The introduced antenna shows resistance approximately equal to 50 Ω for resonating frequencies and approximately 0 Ω of reactance. At band-notched frequencies, it can be seen that these values are not uniform. At band-notched frequencies like 3.5 and 5.5 GHz, it can be observed that the resistance is approximately 20 Ω and 75 Ω, respectively, whereas the reactance at both frequencies has a positive derivative, which indicates a series-type resonance to create the band-notch function. Likewise, at 7.75 GHz, it can be observed that the input resistance has a very high value of approximately 180 Ω, and the input reactance is a negative derivative that produces a parallel resonance and evidence to produce band-stop functions at the desired resonance frequency of the band notch.

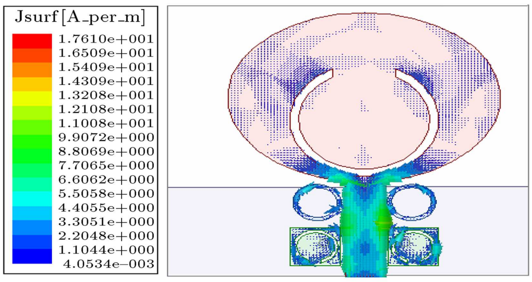
3. Measured results and discussion

The antenna characteristics, like the VSWR of the recommended antenna, were measured with "Keysight Vector Network Analyser," and radiation characteristics were assessed in an anechoic chamber for E and H plane patterns. Figure 12 shows the true measuring setup for the proposed UWB design. These measured results have acceptable similarities with the simulated results. The discrepancies between the measured and simulated results are because of inaccurate cable calibration and tolerance limits of the fabrication process, which also cause distortions in the results. However, these results fulfil the acceptance limit for UWB technology.

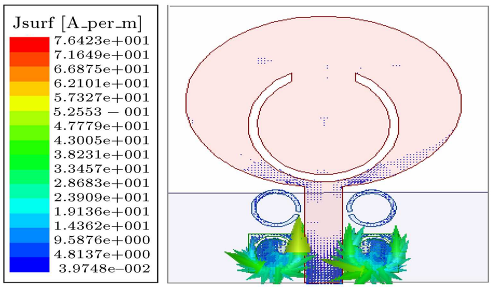
The measured VSWR result of the proposed antenna compared with the simulated one is displayed in Figure 13. The suggested antenna successfully produces triple band-notched characteristics and covers the UWB spectrum with the mandatory condition of VSWR less than 2 for frequencies other than



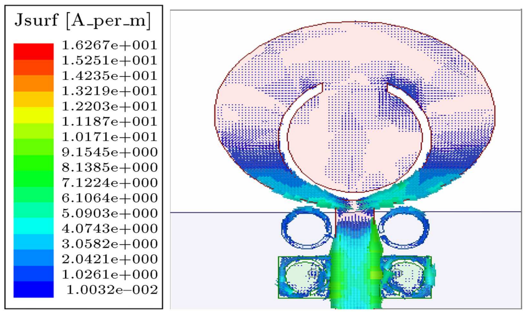
(a) 3.5 GHz (Notched band)



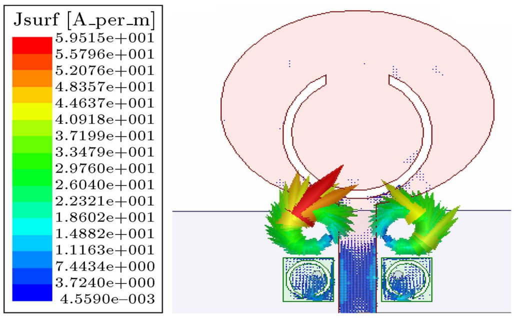
(b) 4 GHz (Pass band)



(c) 5.5 GHz (Notched band)



(d) 6.5 GHz (Pass band)



(e) 7.75 GHz (Notched band)

Figure 10. Vector current distribution on proposed antenna due to various band stop structures.

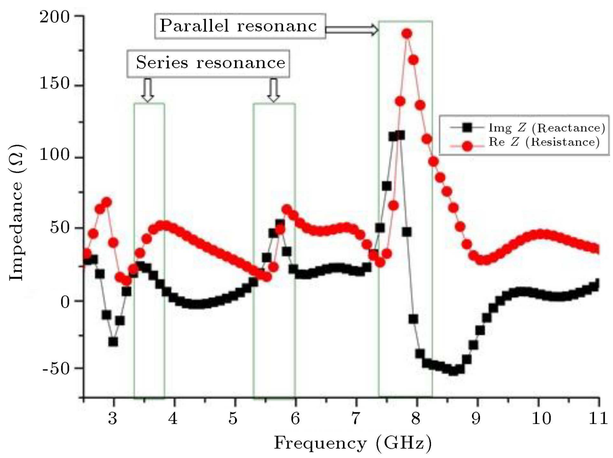


Figure 11. Input impedance characteristics of proposed antenna.

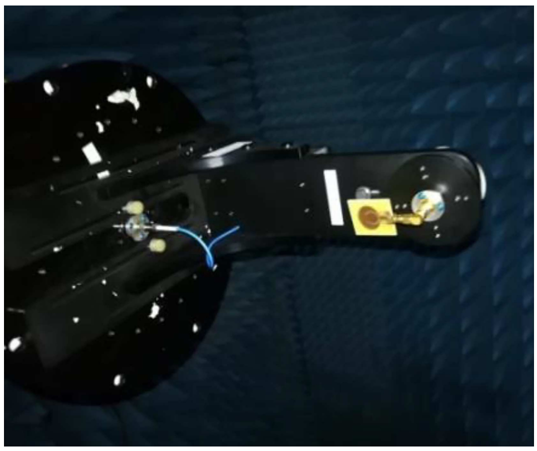


Figure 12. The true measurement setup of antenna in anechoic chamber.

the notched ones. The compared E-plane and H-plane patterns at 4.5 and 6.5 GHz for co and cross polarizations are displayed in Figure 14(a)–(d). The measured radiation patterns of the presented antenna show acceptable matching with the simulated results. However, some distortions exist in the radiation pat-

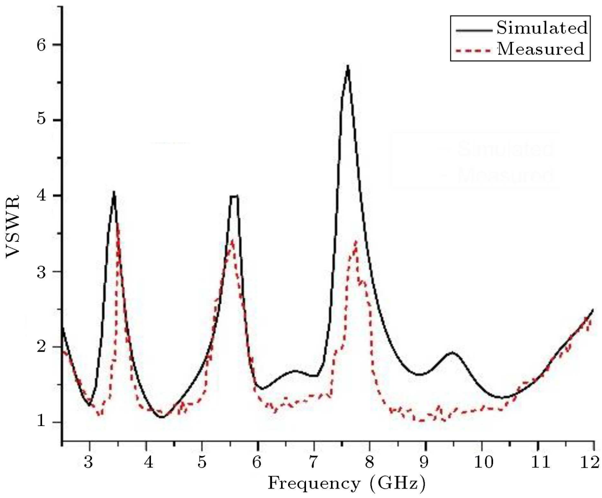
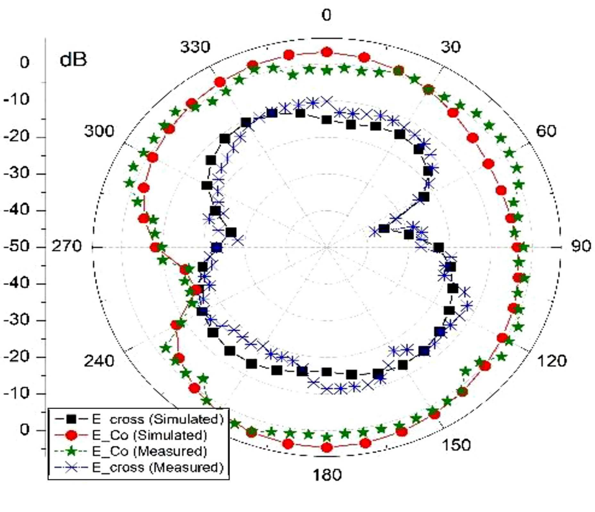


Figure 13. Measured and simulated VSWR of the proposed antenna.

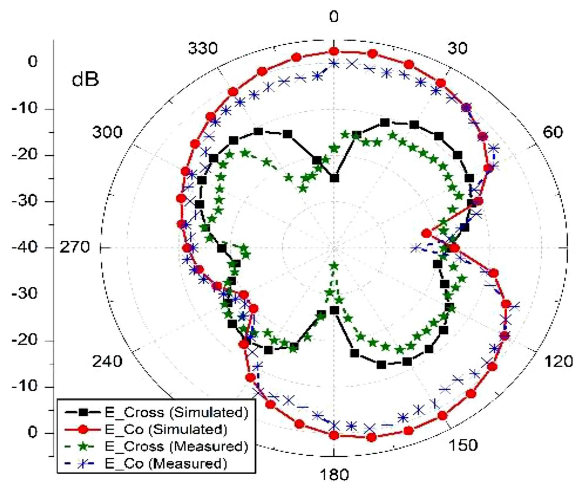
tern due to higher-order modes at high frequencies and cable losses during measurement. Figure 15 shows the antenna radiation efficiency and peak realized gain. It can be observed that the gain is approximately -2 dBi for the notched frequency band, whereas it is 4 dBi for other frequencies. Similarly, efficiency is approximately 20% for notched bands, which reflects that the antenna has successfully stopped the desired bands.

4. Conclusion

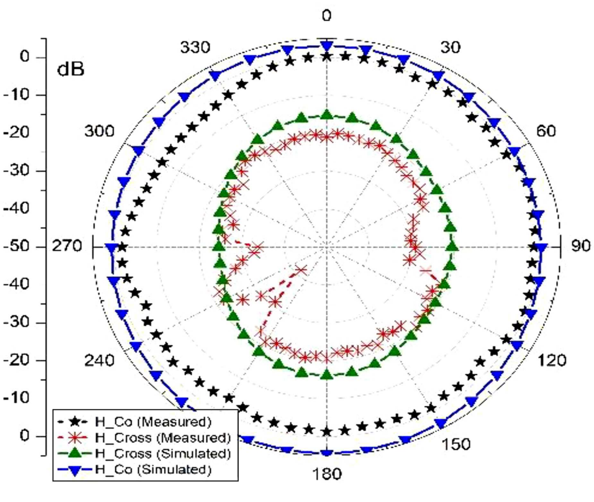
The proposed antenna covers the Ultra-Wideband (UWB) band and overcomes the interference problems from WiMAX, WLAN, and X-band applications. The Complementary Split Ring Resonator (CSRR), Split Ring Resonator (SRR), and SRRP integrated Mushroom EBG (M-EBG) structures have been successfully designed to produce triple band-stop filtering charac-



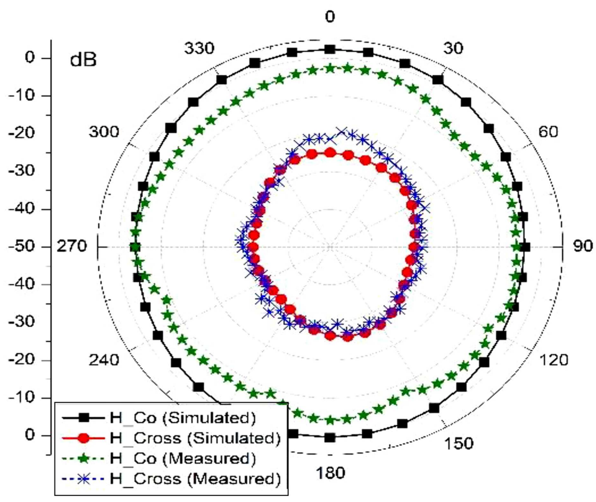
(a) 4.5 GHz, E-plane pattern



(c) 6.5 GHz, E-plane pattern



(b) 4.5 GHz, H-plane pattern



(d) 6.5 GHz, H-plane pattern

Figure 14. Measured and simulated E and H plane patterns of the proposed antenna.

Table 2. Comparison of the proposed antenna with reference antennas.

Ref.	Size	Permittivity (ε_r)	Notched band
[4]	$48 * 50 * 1$	2.65	WLAN, X-band
[5]	$42 * 50 * 1.6$	4.4	WiMAX, WLAN
[6]	$40 * 40 * 1$	2.6	X-band
[7]	$32 * 52 * 1.6$	4.4	WiMAX, WLAN
[8]	$35 * 39 * 0.813$	3.55	WLAN
[9]	$35 * 39 * 1.8$	3.38	WLAN
[11]	$38 * 40 * 1$	4.5	WLAN
[12]	$38 * 40 * 1.6$	4.4	ISM-band
[13]	$42 * 32 * 1.6$	4.4	WiMAX, WLAN
[14]	$36 * 16 * 0.8$	10.2	ISM and C-band
[15]	$54 * 554 * 1.59$	4.4	WiMAX, WLAN
[16]	$50 * 50 * 1.52$	3	WiMAX, WLAN, and X-band
[17]	$75 * 10 * 1.6$	4.4	5 G and WLAN
Proposed	$31.6 * 33.6 * 1.6$	4.4	WiMAX, WLAN, and X-band

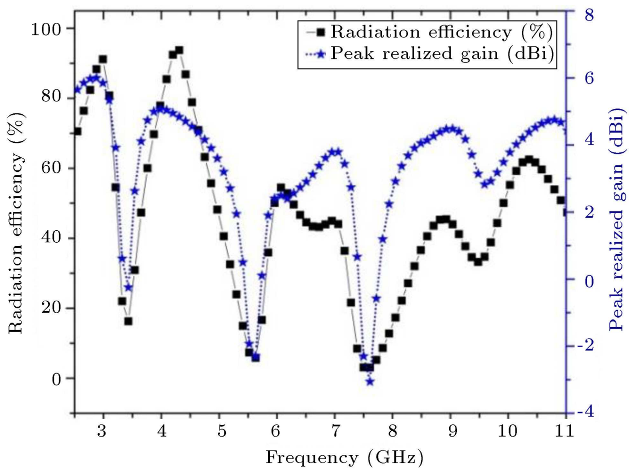


Figure 15. Measured gain and radiation efficiency.

teristics. The comparison of the proposed design with different designs existing in the literature is listed in Table 2. Simulated results are in good agreement with measured results. This antenna has a simple structure and compact size of 31.6×33.6 mm^2. The results and analysis of this antenna indicate that the SRR approach is better than the slot method to produce band notches at higher frequencies, such as X-band. It is a good candidate for miniature devices for UWB technology, with a simple design and compact size as an added advantage. The proposed SRR and CSRR integrated structure further can be used in metamaterial designs and frequency-selective surfaces applications.

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