

Compact CSRR Etched UWB Microstrip Antenna with Quadruple Band Refusal Characteristics for Short Distance Wireless Communication Applications

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Abstract—This communication enlightens design, simulation, fabrication and testing of a novel compact CSRR etched ultra-wideband (UWB) patch antenna with quadruple band refusal characteristics. The planned antenna contains chamfered bevel slot rectangular radiating material with a complementary split ring resonator (CSRR) etched on one side and an incomplete ground plane on the other side of the substrate. To understand band rejection characteristics, four circular slots with different radii are etched on the radiating material as CSRR to reject bands at Worldwide Interoperability for Microwave Access (WiMAX) at 3.5 GHz, Indian National Satellite (INSAT) at 4.6 GHz, Wireless Local Area Network (WLAN) services at 5.8 GHz, and Wideband Global SATCOM (WGS) at 8.2 GHz. The rejected bands center frequencies are perfectly coupled at particular slots with different radii. This compact antenna is effective and useful for short areas and can be easily incorporated in small devices. The results show that the antenna has a bandwidth from 2.77 GHz to 13 GHz. This antenna gains a worthy harmony between the simulated and measured results.

1. INTRODUCTION

In real world of communication, high speed data transfer is a very important feature, and to achieve it many techniques have been adopted in wireless communication technology. Among those for short areas, ultra-wideband (UWB) is an effective and attractive procedure. In recent ages UWB grows widely in communication due to its ultra-high frequency bandwidth, low energy density, extremely low power transmission levels, great safe and excessive reliable communication solutions, unintended detection, and many others. UWB becomes more popular after Federal Communication Commission (FCC) allocated the bandwidth ranging from 3.1 to 10.6 GHz in February 2002 which can be used for short areas [1]. According to the literature many types of UWB antennas were stated time to time [2–4], and the bandwidth enhancement techniques such as chamfering, bevel and step shape designs of the radiating material and defective ground plane are reported [5–7]. Huge research on these systems carried some challenges including matching the impedance, low substrate size, low fabricating cost, etc. Different narrow bands are included in this UWB spectrum such as WiMAX at 3.5 GHz (3.3 GHz–3.7 GHz), INSAT at 4.6 GHz (4.5 GHz–4.8 GHz), WLAN services at 5.8 GHz (5.75 GHz–5.85 GHz), and WGS at 8.2 GHz (7.9 GHz–8.4 GHz), which create interference with the UWB system. To reject particular bands in the UWB spectrum various resonators for single band rejection characteristics [8, 9], double band rejection characteristics [10, 11], triple band rejection characteristics [12, 13], and quadruple band rejection characteristics [14–22] are studied. This research proposes a novel design of a compact CSRR etched ultra-wide bandwidth antenna with sensible rejected bands.

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2. ANTENNA DESIGN

The geometry and a photograph of the fabricated planned compact CSRR etched UWB patch antenna are shown in Figs. 1(a), (b), (c), and (d). By etching chamfered bevel slots on the bottom side of the radiating material supports the traveling wave from lower to higher frequencies. From Fig. 1(a), $L3$ and $W2$ represent bevel slot length and width, respectively, and $L4$ represents chamfering of the bevel slots. The proposed antenna is printed on an FR4 substrate with dielectric constant (ϵ_r) = 4.4, loss tangent ($\tan \delta$) = 0.02 having compact dimensions of $28 \times 18 \times 0.8 \text{ mm}^3$. The feed line and radiating material are attached to each other. They are printed above the substrate, and on the bottom side ground plane is printed.

In the presented design, a complementary split ring resonator (CSRR), with four slots, is etched on the patch to accomplish quadruple band rejection characteristics at WiMAX (3.5 GHz), INSAT (4.6 GHz), WLAN (5.8 GHz), and WGS (8.2 GHz) services. Four slots with different widths ($R1$, $R2$, $R3$, and $R4$) and different radii ($r1$, $r2$, $r3$, and $r4$) are nested one another to form CSRR. CSRR etched UWB microstrip antenna is most suitable to achieve quadruple band rejection characteristics because most of the current is concentrated near the feed line, and the current is perfectly coupled to the slots by etching different slots near feed line as shown in Figs. 2(a) to 2(d). VSWR vs frequency curve for various antenna configurations is shown Fig. 2(e).

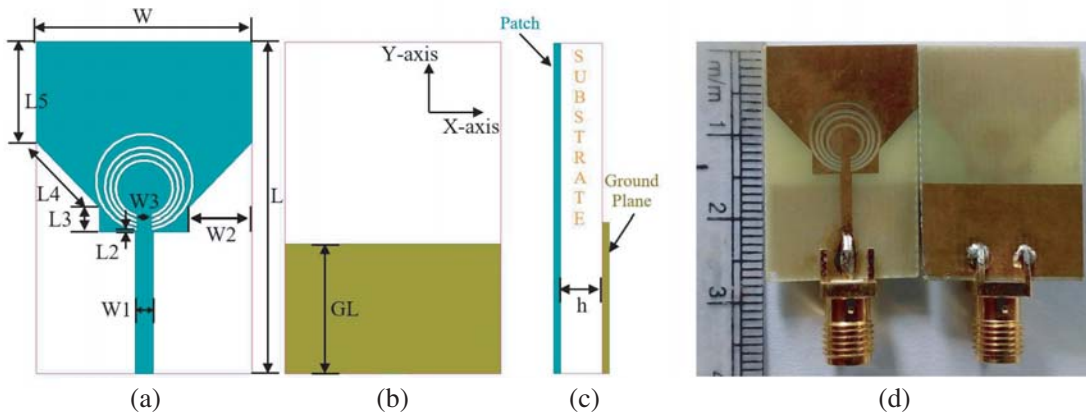


Figure 1. Structure of compact CSRR etched UWB microstrip antenna with quadruple band refusal characteristics. (a) Top view, (b) bottom view, (c) side view, (d) photograph of fabricated antenna. ($W = 18 \text{ mm}$, $W1 = 1.5 \text{ mm}$, $W2 = 5 \text{ mm}$, $W3 = 1.2 \text{ mm}$, $L = 28 \text{ mm}$, $GL = 11 \text{ mm}$, $L2 = 0.35 \text{ mm}$, $L3 = 2.8 \text{ mm}$, $L4 = 7.5 \text{ mm}$, $L5 = 7.7 \text{ mm}$, $R1 = 0.25 \text{ mm}$, $R2 = 0.25 \text{ mm}$, $R3 = 0.25 \text{ mm}$, $R4 = 0.25 \text{ mm}$, $r1 = 4.40 \text{ mm}$, $r2 = 3.40 \text{ mm}$, $r3 = 2.75 \text{ mm}$, $r4 = 2 \text{ mm}$, $h = 0.8 \text{ mm}$, $K1 = 8 \text{ mm}$).

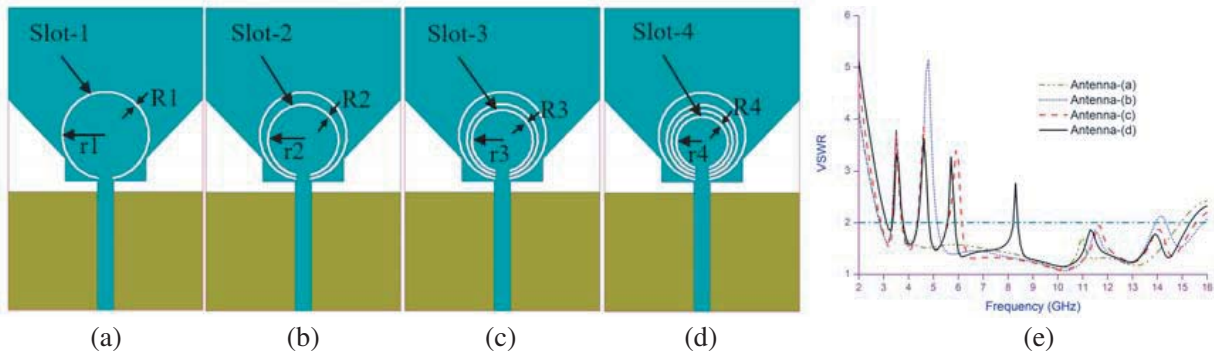


Figure 2. Various antenna configurations to form CSRR. (a) Antenna-a, (b) Antenna-b, (c) Antenna-c, (d) Antenna-d, (e) VSWR vs frequency curve for various antenna configurations.

3. UWB ANTENNA WITHOUT NOTCHED BANDS

Antenna without band rejection characteristics are shown in this section. The proposal has 3 cases as shown in Fig. 3(a). Starting from case 1, the rectangular antenna was converted to chamfered bevel slot rectangular antenna, and the VSWR variation in Fig. 3(a) clearly shows that the antenna VSWR level is reduced from case 1 to case 3. From Fig. 3(b) it is noted that the bandwidth of the antenna goes below VSWR = 2 by reducing $K1$. It can be seen that by decreasing $K1$ the bandwidth of the antenna is increased without growing the length and width of the antenna.

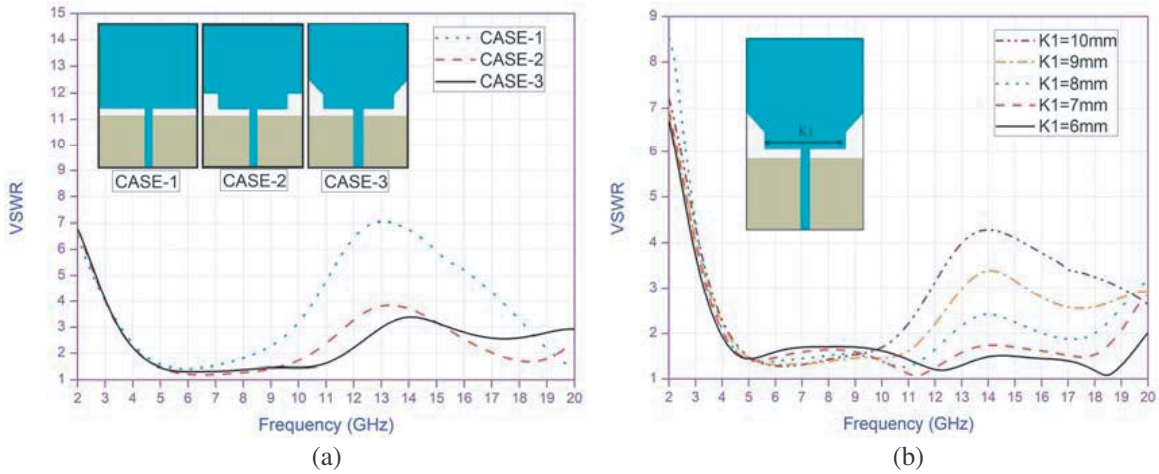


Figure 3. (a) Different cases to show conversion of rectangular antenna to chamfered bevel slot antenna, (b) VSWR vs frequency plot for different values of $K1$.

4. PARAMETRIC STUDY OF SLOT LENGTHS

The proposed antenna performance with CSRR is characterized by full-wave electromagnetic simulations which are carried out by high frequency structure simulator (HFSS) of Ansoft. The simulations are performed with finite element method (FEM). The total length of the slots at center frequency of rejected band in CSRR is calculated using

$$L_{\text{slot}} = \frac{C}{2f_i \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

where f_i is the center frequency of the rejected band. Table 1 shows the theoretical and practical slot lengths for different rejected center frequencies. There is good agreement between the theoretical and practical values with minimum error.

Parametric variation for CSRR etched quadruple band rejection antenna is studied by varying the radius of each slot keeping other values constant. In this study, arc length ($W3$) is removed, and slot

Table 1. CSRR slot lengths at rejecting frequencies.

Notching element	Notching frequency	L theoretical (mm)	L practical (mm)	Error
Slot-1	3.5 GHz (WiMAX)	26.13	26.44 $((2\pi r1)-W3)$	0.31
Slot-2	4.6 GHz (INSAT)	19.89	20.16 $((2\pi r2)-W3)$	0.27
Slot-3	5.8 GHz (WLAN)	15.77	16.07 $((2\pi r3)-W3)$	0.30
Slot-4	8.2 GHz (WGS)	11.15	11.36 $((2\pi r4)-W3)$	0.21

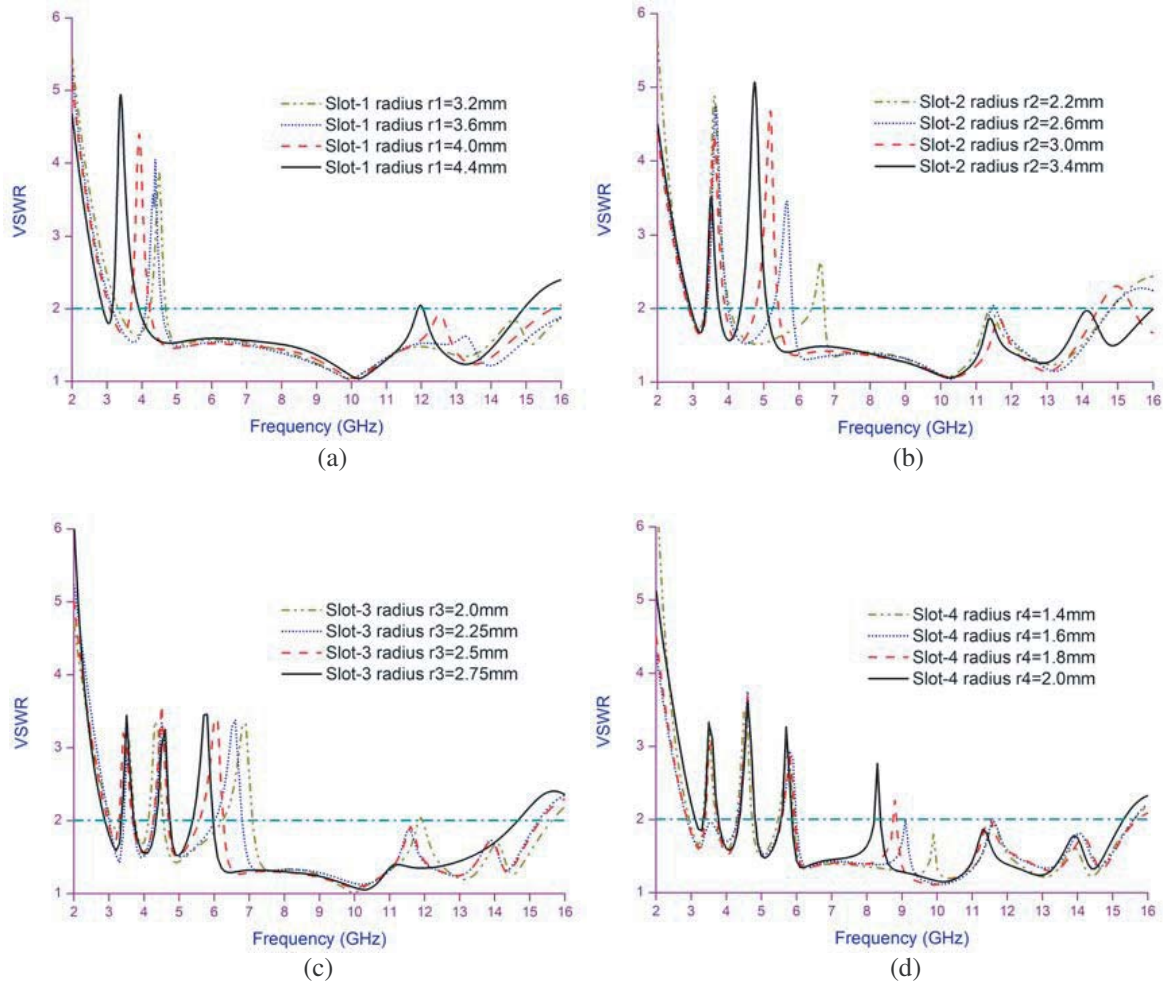


Figure 4. Parametric study for various radius values. (a) Slot-1 for WiMAX notch, (b) slot-2 for INSAT notch, (c) slot-3 for WLAN notch, (d) slot-4 for WGS notch.

lengths are considered. It is observed from Figs. 4(a) to 4(d) that if the radius is increased, the notch frequency is shifted to lower frequency side because length of slots is inversely proportional to frequency as in Eq. (1). To understand the occurrence of quadruple band-rejected performance, the simulated current distributions on the radiating material are shown in Figs. 5(a) to 5(d). From Fig. 5 one can find that the current is mainly concentrated on the slots. From Fig. 5(a) it is shown that the current at 3.5 GHz is concentrated on slot-1. Fig. 5(b) shows that the current at 4.6 GHz is concentrated on slot-2. Fig. 5(c) shows that the current at 5.8 GHz is concentrated on slot-3. Fig. 5(d) shows that the current at 8.2 GHz is concentrated on slot-4. It is shown that the rejected band center frequencies are varied with respect to the variation in radius of the slots.

5. RESULTS AND DISCUSSION

The frequency domain investigation was passed on VSWR, radiation pattern, gain, and radiation efficiency of the proposed compact CSRR etched UWB microstrip antenna with quadruple band rejection characteristics. All the measurements in anechoic chamber were carried out using Rohde and Schwarz VZL network analyzer (9–13.6 GHz). Fig. 6(a) Shows the comparison of simulated and measured VSWR characteristics of the proposed antenna with a photograph of the fabricated antenna in an anechoic chamber. The antenna has VSWR below 2, over entire UWB range except at the rejected bands. Measured results follow the simulated results with minor variations. It is also observed that at lower

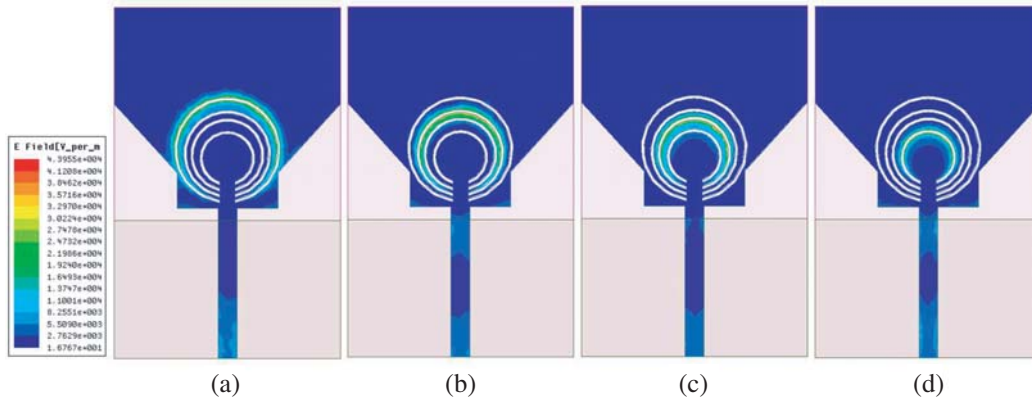


Figure 5. Surface current distributions at rejected frequencies. (a) 3.5 GHz, (b) 4.6 GHz, (c) 5.8 GHz, (d) 8.2 GHz.

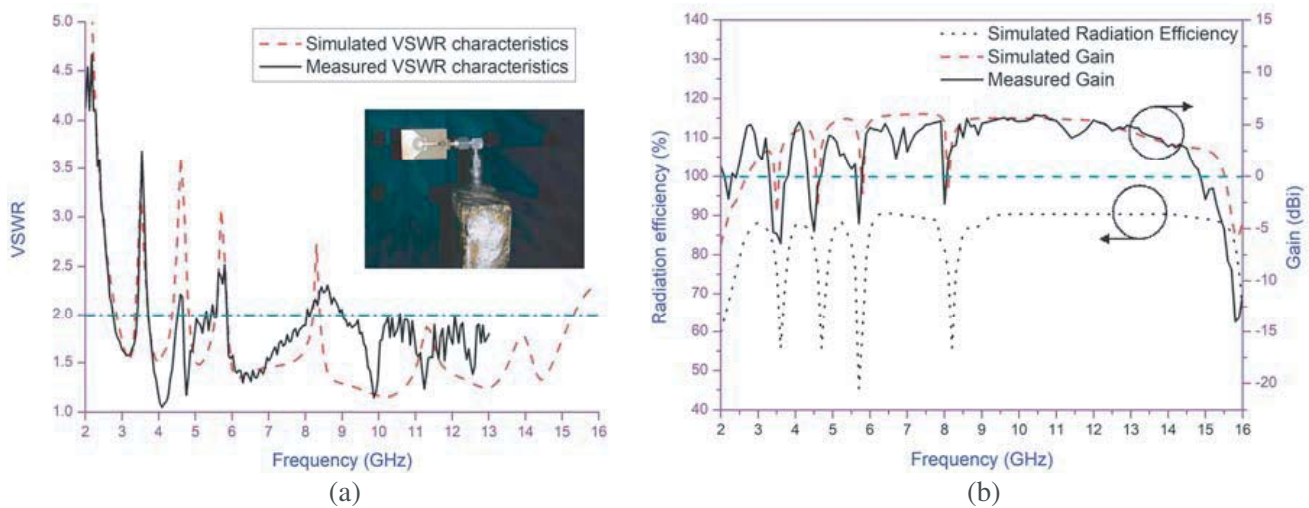


Figure 6. Characteristics of CSRR etched UWB antenna. (a) Simulated and measured VSWR, (b) simulated efficiency, simulated and measured gain.

frequencies the simulated and measured results show good agreement, but as the frequency increases, the measured result shows slight differences. The variation can possibly be due to imperfections of feed wires, over-etching, fabrication error tolerances in the dielectric constant of the substrate, SMA connector losses which are not considered during simulation, soldering effect, and some parametric alterations between the simulated and fabricated models. Fig. 6(b) shows the simulated and measured gains and simulated radiation efficiency of the proposed antenna. The antenna has gain above 2.5 dB and radiation efficiency above 85% over the entire UWB frequency range except at the rejected bands with the maximum gain of 6 dBi.

Figure 7(a) shows the Smith chart of the proposed antenna without band rejection characteristics, with the impedance bandwidth from 3.1 GHz to 15.5 GHz which is inside the $VSWR = 2$ circle. Fig. 7(b) shows the Smith chart of the proposed antenna with quadruple band rejection characteristics where impedance bandwidth is from 2.8 to 15.4 GHz which is inside the $VSWR = 2$ circle. It is also observed that all the four bands are rejected which are out of $VSWR = 2$ circle. Fig. 8 shows the E -plane and H -plane radiation patterns for the proposed UWB antenna at 4 GHz, 7 GHz, and 10 GHz. It is observed that the antenna radiates in omnidirectional pattern in H -plane, and in E -plane it has a dipole-like radiation pattern.

Previously reported band rejected UWB antennas are compared with this work in Table 2. The

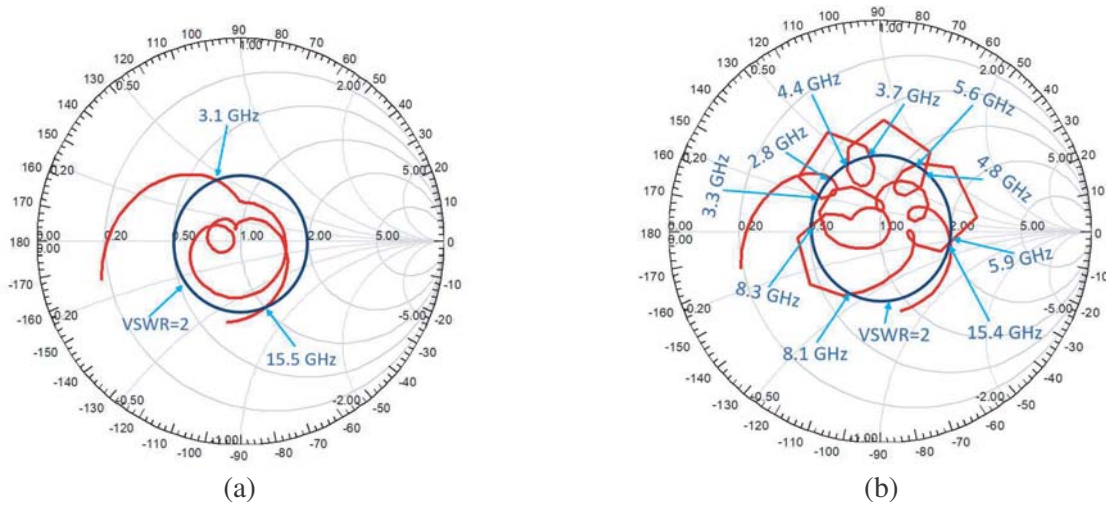


Figure 7. Simulated smith chart characteristics. (a) Without band rejected, (b) with band rejected.

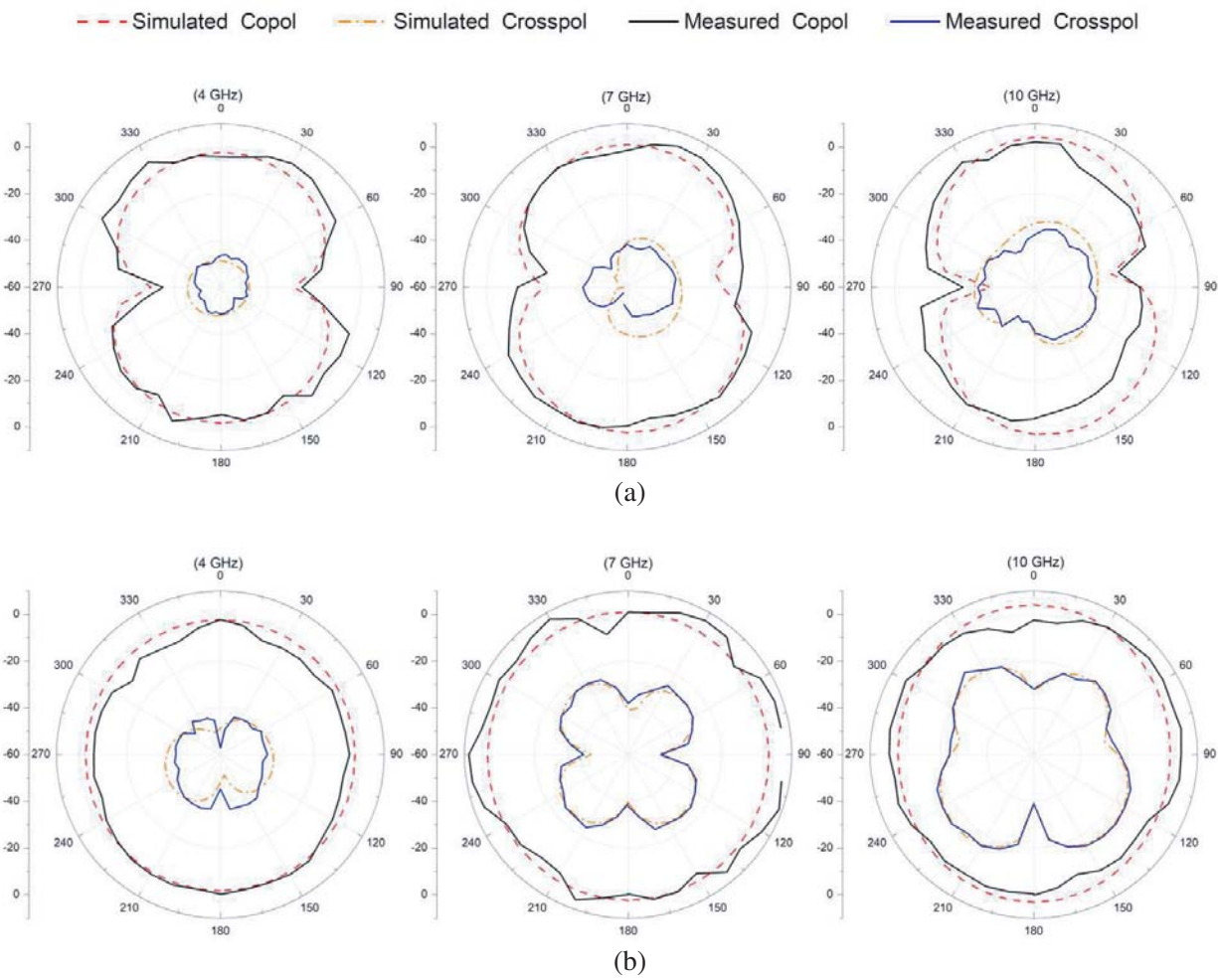


Figure 8. Simulation and measured radiation pattern of the antenna. (a) *E*-plane (*y-z* plane), (b) *H*-Plane (*x-z* plane).

Table 2. Proposed antenna comparison with reported antennas.

Ref.	Size (mm ²)	BW (GHz)	Notch bands (GHz)	NE	PG (dBi)
[15]	31 × 31	2.8–11.4	3.3–3.6, 5–5.4, 5.7–6, 7.6–8.6	3	5
[16]	44 × 35	2–12	2.32–2.7, 3.35–3.78, 5.02–5.45, 5.7–6.22	3	5
[17]	31 × 30	2.8–11	3.5–03.6, 4.5–4.8, 5.15–5.35, 5.725–5.825	4	5
[18]	40 × 34	2.35–12	2.44–2.77, 3.42–3.97, 5.45–5.98, 8–8.68	4	6
[19]	33.5 × 30	2.88–12.67	3.43–3.85, 5.26–6.01, 7.05–7.68, 8.08–8.87	4	6
[20]	38 × 20	2.8–13	4.5–5.5, 5.8–6.1, 8.5–8.9, 9.9–10.9	1	13
[21]	36 × 27	2.8–14	3.26–3.9, 4.35–5.05, 5.5–6.65, 7.95–9.35	4	6
P	28 × 18	2.77–13	3.3–3.7, 4.5–4.7, 5.6–5.9, 8–8.9	1	6

P-Proposed NE-Notching Element PG-Peak Gain

proposed antenna has a good bandwidth of 10.23 GHz, which covers the entire UWB (3.1 to 10.6 GHz) region, and even better bandwidth is achieved for future UWB applications. There is only one notching element (CSRR) which creates quadruple notched bands, so the complexity of the antenna is reduced. Peak gain of the proposed antenna is 6 dBi. With all these benefits the proposed antenna can be used in UWB applications.

6. CONCLUSION

This paper presents a compact CSRR etched UWB microstrip antenna with quadruple band refusal characteristics and a compact dimension of $28 \times 18 \times 0.8 \text{ mm}^3$, which covers the frequency range from 2.77 to 13 GHz (Tunable). Introducing a CSRR on the radiating material gives quadruple band rejection characteristics, at Worldwide Interoperability for Microwave Access (WiMAX) at 3.5 GHz, Indian national satellite (INSAT) at 4.6 GHz, Wireless Local Area Network (WLAN) services at 5.8 GHz, and Wideband Global SATCOM (WGS) at 8.2 GHz (Tunable). Good matching between simulated and measured results for VSWR is achieved. The designed antenna shows maximum gain of 6 dB. The proposed antenna is simple, compact, and gives excellent performance, so these antennas are used in various UWB systems for short distance wireless applications.

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