Progress In Electromagnetics Research C, Vol. 110, 39–54, 2021

Split Ring Slot Loaded Compact CPW-Fed Printed Monopole Antennas for Ultra-Wideband Applications with Band Notch Characteristics

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Abstract—Compact CPW-fed ultra-wideband monopole antennas with band notch characteristics using Split Ring Slots (SRSs) are proposed in this manuscript. Initially, the antenna is designed by using a rectangular shaped patch, and it has been modified to obtain enhanced impedance bandwidth (VSWR $\leq$ 2) throughout the entire UWB frequency range. Further, the notch band element (split ring slot) has been introduced in the geometry of proposed antenna to generate the band rejection at WLAN frequency centered at 5.3 GHz (5.15–5.81 GHz). Another antenna has been designed by varying the dimensions of SRS to get the rejection of frequency at an X-band satellite communication system centered at 7.4 GHz (7.16–7.71 GHz). The overall size of proposed UWB antennas is compact ($18 \times 18\,\mathrm{mm}^2$), and it is designed on a low cost FR4 glass epoxy substrate with 1.6 mm thickness and 4.4 dielectric constant. The proposed antennas with and without a notch filter are designed by using HFSS V13 simulator and fabricated for the validation of simulated results. Experimental and simulated results are compared and found in reasonable agreement with each other.

1. INTRODUCTION

In the present era, human beings are highly influenced by the gigantic changes in communication technology. These changes are impossible without appropriate antenna designing. Various scientists and researchers have carried out their work in this direction and found that ultra-wideband (UWB) is most suitable for the wideband applications. UWB was first developed in USA for military applications, but later on it is publicized for commercial applications. In 1976, Dubost and Zisler proposed the first metallic strip monopole antenna [1]. UWB has attracted great interest from scientists, researchers, and academicians. Federal Communication Commission (FCC) in year 2002 allocated the UWB frequency range from 3.1 to 10.6 GHz for commercial use. It provides significant potential for long- and short-range communications [2]. Every year the demand for broadband wireless communication has been rising with higher data rate. UWB with huge bandwidth means that it is suitable for high data rate wireless applications [3]. UWB technology is mainly employed for indoor and outdoor applications. The expeditious growth in the wireless technology has raised the demand for ultra-wideband and multiband antennas with compact size and more operating bandwidth [4]. Researchers have given more attention to improving UWB antennas parameters like impedance bandwidth, matching characteristics, radiation patterns, and to decrease the size of antenna. However, UWB systems are very sensitive to electromagnetic interference of existing narrowband wireless communication systems. It is necessary to design antennas with multiband filtering characteristics to avoid the interference. The pre-existing

Received 24 December 2020, Accepted 28 January 2021, Scheduled 16 February 2021
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narrow bands are Worldwide Interoperability for Microwave Access (WiMAX) operating in 3.3–3.6 GHz, IEEE 802.11a, Wi-Fi (5 GHz), IEEE 802.11, IEEE 802.16, Wireless Local Area Network (WLAN) 5.15–5.825 GHz, X-band satellite communication system (7.2–8.4 GHz) (7.25–7.745 GHz) for uplink and (7.9–8.395 GHz) for downlink, etc. [5]. Several monopole structures such as circular, pentagonal, hexagonal, elliptical ones have been proposed recently on UWB antennas by researchers. These researchers have used filters or band notch characteristics to remove the unwanted frequency bands. To eliminate the interference from UWB range, the antennas with different band notch characteristics have been proposed including different types of slots such as L-shaped slot [6], U-shaped slot [7, 8], V-shaped slot [9] on the ground plane or on the radiating patch, stubs, parasitic elements, split ring resonator (SRR), complementary split ring resonator (CSRR), and etching on patch or ground plane [10]. The researchers have carried out extensive research on UWB band notched antennas using different techniques. Tak et al. used an FR-4 dielectric substrate, proposed a butterfly-shaped antenna for attaining single notch applicable to WiMAX band (3.5 GHz), and also proposed the modified U-shaped slot etched from a butterfly shaped patch of four arms [11]. Zhu and Su explained characteristics of a UWB single band notch antenna at WLAN frequency band. In this antenna design, a novel symmetric E-shaped slot was inserted into a rectangular patch to achieve the desired band [12]. Askarpour et al. demonstrated so-called tulip shaped antenna to achieve single notch band for WiMAX. The Pi-shaped slot is etched on a tulip-shaped antenna to attain the desired band [13]. Xu et al. anticipated a UWB polygon-slot antenna with WLAN band (5.3 to 5.9 GHz) notch characteristics. The one pair of I-shaped MTM unit cells were etched on the fork-shaped patch symmetrically to realize the desired band [14]. Cai et al. explained a UWB antenna which covered the bandwidth for UWB applications (3.4–12 GHz). The antenna designed with an I-shaped strip, an H-shaped strip, and a U-shaped strip on the radiating patch to achieve the desired band of 1 GHz (from 5 to 6 GHz) [15]. A cylindrical dielectric resonator UWB antenna with a U-shaped slot was introduced by Mohamed and Zoubir [16] for single band notch characteristics at WiMAX frequency point (3.2–3.8 GHz). Fazal et al. [17] designed a compact UWB coplanar waveguide (CPW)-fed antenna using an L-shaped slot for band rejection characteristics at WLAN frequency band from 4.9 to 6.2 GHz. A compact printed square-shaped UWB antenna was designed by Jha et al. [18] with WiMAX band rejection characteristics from the frequency range of 3 to 4.7 GHz. Capacitively Loaded Loop (CLL) resonators have been employed by Yao et al. [19] in a high gain Vivaldi antenna to generate the notched band at WLAN (5.15–5.825 GHz). Mishra and Sahu [20] demonstrated a circular shaped patch UWB antenna and obtained WLAN band notch characteristics by introducing SRR structures in the resonating patch. A rectangular notch band UWB antenna was designed by Abbas et al. [21], in which the notch characteristics are obtained by using EBG (electromagnetic bandgap) structures. The bandwidth of the notch was controlled by using two rectangular metallic conductors loaded on the back of the radiator, which is connected to the patch by shorting pins. Bakir et al. [22] designed frequency selective surfaces (FSSs) with U-shaped metallic elements for single and dual frequency band-stop filter applications in X and Ku-band frequency regions. In this design, the single and dual-frequency narrowband absorbances have been observed, and it can be utilized in sensing and biomedical applications. A broadband CPW-fed antenna was designed by Abdulkarim et al. [23], by incorporating organic solar cells with 100% insolation and can be used for Ku-band satellite communications. This antenna covers the frequency band ranging from 11.7 to 12.22 GHz with a realized gain of 6.30 dB. A neural network approach was used by Ozdemir et al. [24], to reduce the mutual coupling of the cross-dipole antenna for base station. The designed antenna resonated in the frequency range from 2.2 to 2.7 GHz. In this design, 48 different 6×6 resonator layers were formed and combined into the cross-dipole antenna to condense transmission and enhance isolation between antenna elements. Nazeri et al. [25] presented a new method called reflection only method for characterizing PEC-baked anisotropic materials by using waveguide higher order modes. Reflection coefficients of the TE10 and TE20 modes are reported for two different orientations of the MUT in the waveguide which maintains sufficient data for obtaining the unknowns.

In this manuscript, compact monopole antennas are designed, and the band notch characteristics are obtained by using SRSs at WLAN frequency 5.3 GHz and X-band satellite communication system 7.4 GHz. Initially, a rectangular patch has been modified to attain the proper impedance matching in the frequency range from 3.0 to 12.0 GHz. Further, a Split Ring Slot (SRS) is introduced in the antenna geometry to generate WLAN band rejection, and the dimensions of this slot are changed to get the rejection at X-band satellite frequency band. The process of applying the SRS in the geometry of proposed UWB antenna and the optimization of different parameters are discussed in detail in the upcoming sections.

2. ANTENNA CONFIGURATION

2.1. Design of Proposed Monopole Antenna

The proposed rectangular shaped monopole antenna has been premeditated and fabricated on an abundantly existing low cost FR4 glass epoxy substrate having 1.6 mm thickness, 4.4 dielectric constant, 19,000 kg/m^3 mass density with loss tangent of 0.02. The antenna is designed by using a coplanar waveguide (CPW) transmission line with a compact size of $18 \times 18\,\text{mm}^2 = 324\,\text{mm}^2$. The design evolution of proposed monopole antenna without band notch filters is delineated in Fig. 1. Initially, the rectangle-shaped structure (step-1) with length 'L_P' and width 'W_P' has been used to design the metallic resonator (radiating patch) of proposed antenna using CPW feed, and its dimensions are calculated by using following equations [26] and found as 10.5 mm and 13.5 mm, respectively.

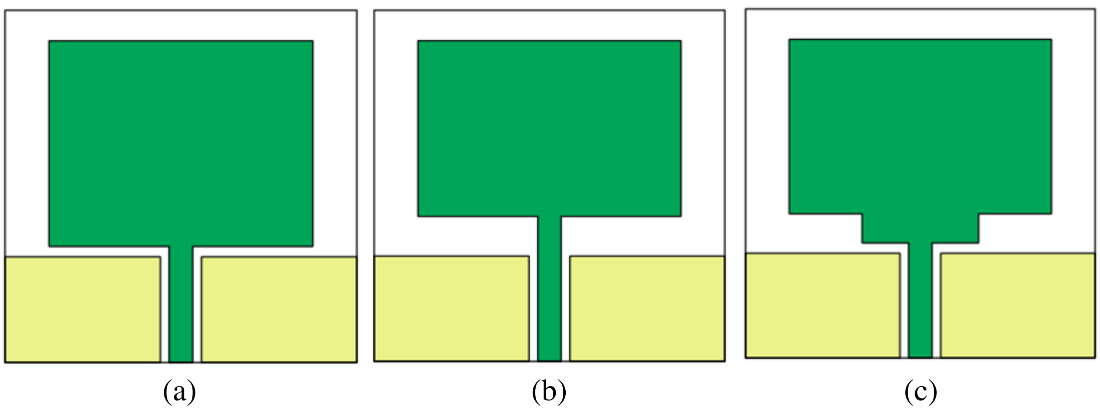

Figure 1. Design evolution of proposed monopole rectangular metallic patch antenna (a) step-1, (b) step-2 and (c) step-3 (reference antenna).

Width (W_P) of rectangle-shaped metallic resonator (radiating patch) is evaluated by using Equation (1)

$$W_P = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

The effective dielectric constant of the substrate is computed by using Equation (2) and found as 2.908.

$$\varepsilon_{reff} = \left[\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\right]\frac{1}{\sqrt{1 + {}^{12h}/_{W_P}}}, \quad 1 < \varepsilon_{reff} < \varepsilon_r \tag{2}$$

Extended incremental length (ΔL) of the proposed antenna is obtained by using Equation (3) as shown below. Now the total length (L_P) of radiating patch is computed with the help of Equation (4) as given below, where $1/\sqrt{\mu_o}\varepsilon_o$ is the speed of light in vacuum.

$$\Delta L = h * 0.412\left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W_P}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W_P}{h} + 0.8\right)}\right] \tag{3}$$

$$L_P = \frac{1}{2f_r\sqrt{\mu_o}\varepsilon_o\sqrt{\varepsilon_r}} - 2\Delta L \tag{4}$$

Voltage standing wave ratio (VSWR) is a vital parameter of a band notch antenna as it is related to reflection coefficient which leads to impedance matching. If there is a larger mismatch between VSWR and reflection coefficient, then there will be very poor impedance matching. So, to attain a good impedance matching VSWR for antenna is considered ≤ 2 [27]. Further, to attain improvement in the VSWR of proposed monopole antenna, the patch is modified by subtracting the rectangle of length 1.5 mm and width 6.15 mm from both the lower edges of rectangular patch (step-2) as shown in Fig. 1(b). Lastly, for achieving the desired UWB frequency range from 3.1 to 10.6 GHz, the final geometry of proposed monopole is delineated in Fig. 1(c) by inculcating a rectangular stub to the lower side of patch which is close to the CPW transmission line (step-3). By using a similar process, the antenna with a circular patch has also been used in this manuscript for better understanding about the UWB antenna. The geometries of designed antenna shown in Fig. 1 (with rectangular shaped metallic patch) and Fig. 2 (with circular shaped metallic patch) are simulated and investigated by using Ansys HFSS 13 simulator, and the acquired results are reported in Fig. 3 and Fig. 4.

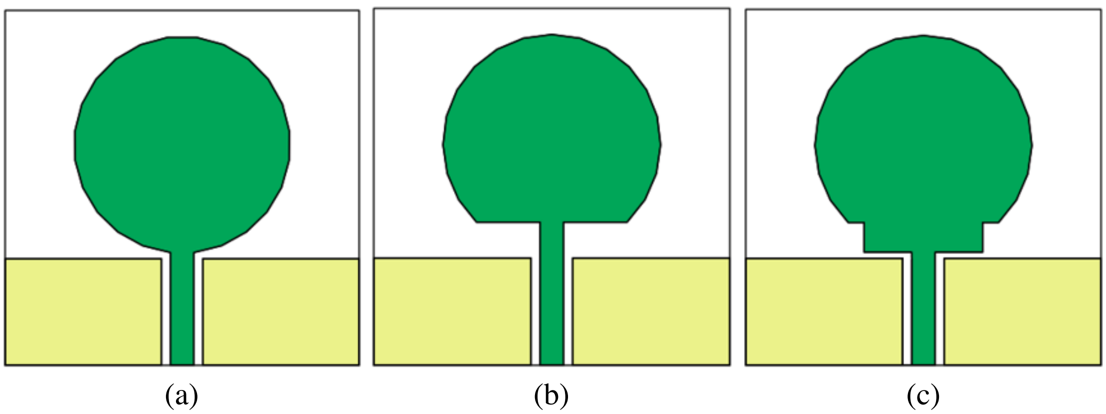

Figure 2. Steps for designing circular shaped metallic patch monopole antenna (a) design-1, (b) design-2 and (c) design-3.

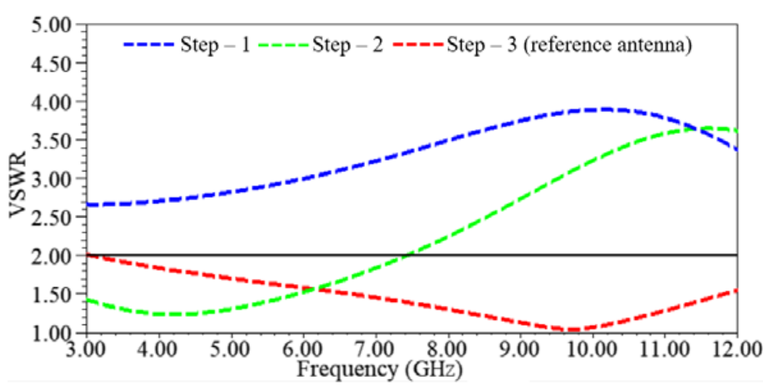

Figure 3. VSWR plots for different designing steps of the proposed UWB antenna (rectangle-shaped metallic patch) to get desired frequency range.

It is observed from Fig. 3 that the rectangle-shaped patch antenna designed in step-1 does not exhibit the value of VSWR below 2 for the entire frequency range (3 to 12 GHz). Further, the antenna structure is modified and named as step-2, as previously discussed to improve the VSWR bandwidth. This antenna structure shows the VSWR bandwidth of 4.59 GHz (7.41–12.0 GHz). So, from this discussion, it can be easily understood that both the structures designed in step-1 and step-2 do not reveal the VSWR ≤ 2 for the complete UWB frequency range. The value of VSWR ≤ 2 can only be obtained with the proper impedance matching of antenna. Therefore, to resolve this problem, the

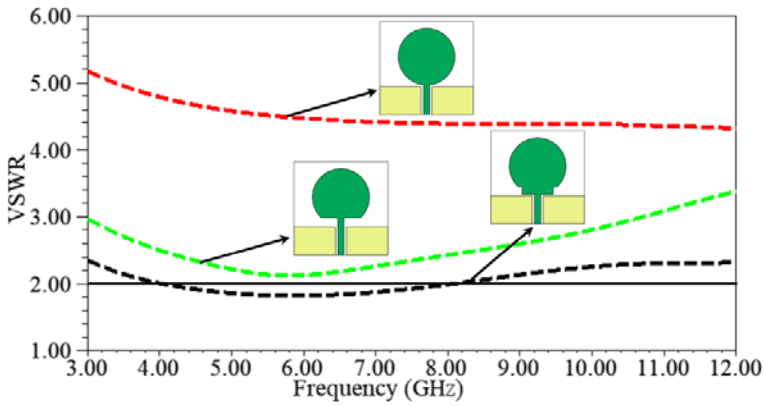

Figure 4. VSWR plots for different designing stages of circular shape metallic patch antenna.

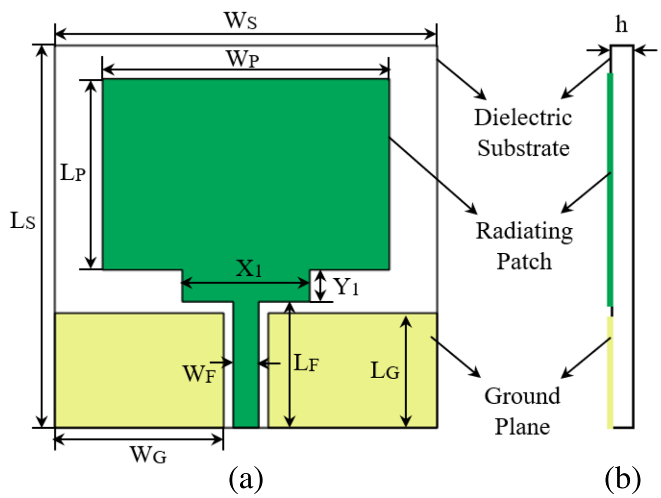

Figure 5. Optimized geometry of proposed UWB monopole antenna without band notch filter; (a) front view and (b) side view.

rectangular stub is attached to the patch in step-3 (final geometry) to obtain the optimum impedance matching characteristics. Final/reference geometry of proposed monopole antenna elucidates the value of VSWR ≤ 2 in the frequency range from 3.0 to 12 GHz with UWB impedance bandwidth of 9.0 GHz. The VSWR of proposed monopole antenna (reference antenna) is less than 1.5 for the anticipated UWB range (3.1–10.6 GHz) and projects the optimum impedance matching of antenna. Similarly, the VSWR plot for a circle-shaped monopole patch antenna is delineated in Fig. 4. It is observed that the antennas in design-1 and 2 do not exhibit the value of VSWR below 2 for the entire frequency range from 3 to 12 GHz. Further, the antenna design-3 is investigated and reveals the VSWR bandwidth of 4.05 GHz (4.05–8.1 GHz). So, from this, it can be simply understood that the structures from design-1 and design-3 do not reveal VSWR ≤ 2 for the complete UWB frequency range. From the aforesaid discussion, it is crystal clear that the rectangular patch shows better performance parameters than circular patch. Therefore, keeping these under consideration a rectangular patch is elected for the proposed antenna, and its structure is limned in Fig. 5 with its dimensions which are delineated in Table 1 for more limpidity.

2.2. Effects of the Width of Rectangular Stub

The parametric study of width 'X_1' of rectangular stub has been optimized from 12.0 to 6.0 mm with decreasing step size of 2.0 mm for attaining the proper impedance matching and VSWR ≤ 2 for the

Table 1. Parametric dimensions of proposed UWB monopole antenna.

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
W_S	18	W_F	1.2
L_S	18	L_F	5.934
W_P	13.5	X_1	6.0
L_P	9.0	Y_1	1.5
W_G	7.95	h	1.6
L_G	5.4		

entire UWB frequency range. The comparison of VSWR curves for different variations in 'X_1' parameter is depicted in Fig. 6. It can be anticipated from Fig. 6 that the VSWR is above 2 for the entire frequency range at '$X_1 = 12.0$ mm'. To improve VSWR, the value of 'X_1' is changed from 12 mm to 10.0 mm (decreased step size = 2 mm), and it is noticed that the value of VSWR is less than 2 at the frequency range from 11.35 to 12.0 GHz with corresponding VSWR bandwidth of 0.65 GHz. Further, in the same way, the value of 'X_1' is taken as 8.0 mm, and the designed antenna reveals the VSWR bandwidth of 7.45 GHz in the frequency range of 4.55–12.0 GHz. From above-said discussion, it is limpid that the values of $X_1 = 12.0$, 10.0, and 8.0 mm do not show VSWR ≤ 2 for the complete UWB frequency band (3.1–10.6 GHz) due to the mismatching of impedance. By considering the value of '$X_1 = 6.0$ mm', the designed monopole antenna reveals an optimal impedance matching characteristic (VSWR ≤ 2) in the frequency range from 3.0 to 12.0 GHz and also yields UWB impedance bandwidth of 9.0 GHz. Keeping aforementioned discussion in mind, the optimal value of 'X_1' can be fixed as 6.0 mm.

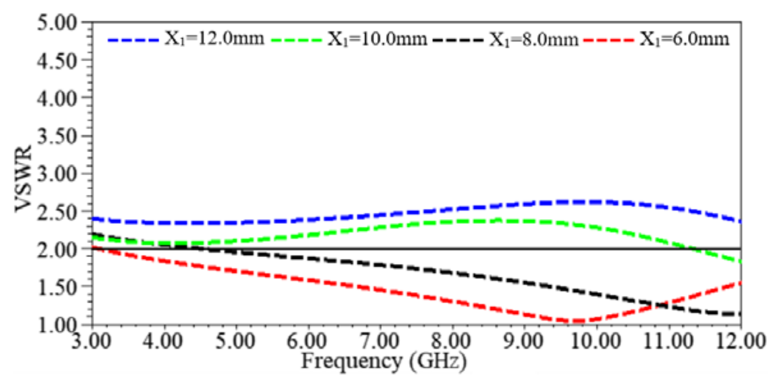

Figure 6. VSWR curves for different variations in 'X_1' parameter to obtain UWB frequency range.

In this section, the monopole antenna has been proposed with wide impedance bandwidth (VSWR ≤ 2) of 9.0 GHz (3.0–12.0 GHz). Further, an SRS has been introduced in the geometry of final proposed monopole antenna (step-3) to obtain a notch at WLAN frequency band. Similarly, the outer and inner radii of this SRS is modified to acquire band-notch characteristics at X-band satellite communication. The effects of SRS on the performance of proposed monopole antenna for attaining the desired band notch will be briefly conferred in the following section.

3. PARAMETRIC STUDY OF PROPOSED UWB MONOPOLE ANTENNA WITH BAND NOTCHED CHARACTERISTICS

In this section, an SRS with outer radius R_1 and inner radius R_2 with split gap width S_1 is employed in the geometry of designed UWB monopole antenna to get the WLAN rejection band centred at 5.3 GHz as shown in Fig. 7(a). Further, split gap width is kept the same as S_1 (renamed as S_1'), and the SRS is modified by changing the outer radius to R_1' and inner radius to R_2' for attaining the rejection at X-band

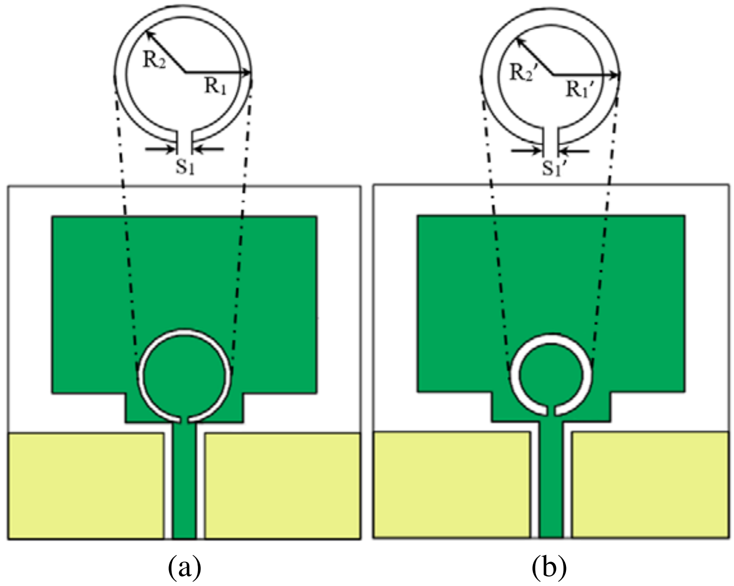

Figure 7. Geometry of the proposed UWB antenna with band rejection characteristics: (a) WLAN and (b) X-band satellite communication.

satellite communication centred at 7.4 GHz as delineated in Fig. 7(b). The selection of a precise position of SRS and its accurate dimensions is a quite cumbersome and time-consuming process. Results of the monopole antenna with band-notch characteristics are compared manually by varying the width split gap and inner and outer radii of the SRS. Finally, the location and dimensions are selected which give the best results. The process of attaining the desired notch band rejection characteristics is discussed in details in the following subsections.

3.1. UWB Antenna with WLAN Band Rejection

After employing the SRS in the geometry of proposed monopole antenna, its parameters are optimized to attain the WLAN band-notch characteristics. The dimensions of SRS and the notched frequency band are adjusted and calculated by using the following equation [28], and the optimized dimensions of SRS are illustrated in Table 2.

$$f_r \approx \frac{c}{\sqrt{\varepsilon_{reff}}\lambda_g} \approx \frac{c}{\sqrt{\varepsilon_{reff}} \cdot 2 \cdot \text{slot\_length}} \tag{5}$$

where $\varepsilon_{reff} = (\varepsilon_r + 1)/2$ is the effective dielectric constant, and c is the speed of light in vacuum.

Table 2. Parametric dimensions of split ring slot (SRS).

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
R_1	2.4	R_1'	2.1
R_2	2.1	R_2'	1.6
S_1	0.4	S_1'	0.4

In the proposed UWB monopole antenna, split gap width 'S_1' is varied from 1.0 to 0.4 mm with decreasing step size of 0.2 mm. Initially, the value of 'S_1' is taken as 1.0 mm, and the length (circumference) of slot becomes 14.072 mm. At this value, the antenna exhibits the peak VSWR of 4.35 at 6.3 GHz. Similarly, at '$S_1 = 0.8$ mm' with slot length 14.272 mm, the rejection frequency point gets shifted towards left side with the peak VSWR of 4.65 at 6.1 GHz band. The rejection band again shifts

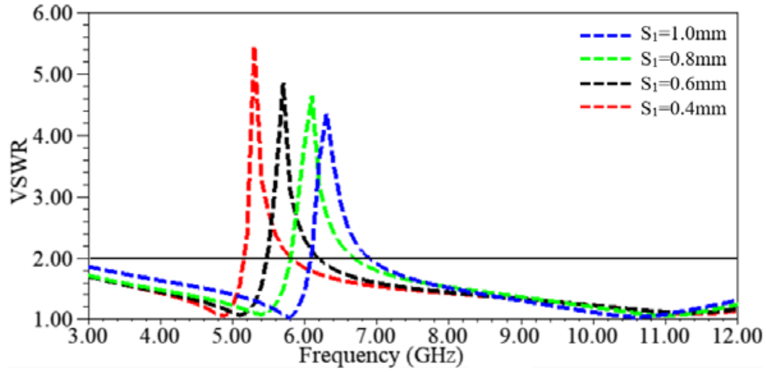

Figure 8. VSWR curves for different variations in 'S_1' parameter to obtain WLAN band notch characteristics.

towards the left side by taking the value of 'S_1' as 0.6 mm with slot length 14.472 mm and exhibits the peak VSWR of 4.84 at 5.7 GHz rejection point. Finally, the desired WLAN rejection frequency has been achieved by taking the value of 'S_1' as 0.4 mm with slot length 14.672 mm. The comparison of VSWR curves with the variations in different values of 'S_1' is illustrated in Fig. 8. It is very much clear from Fig. 8 that at '$S_1 = 0.4$ mm' the proposed monopole antenna displays the peak VSWR of 5.44 at 5.3 GHz band rejection point. From the above-mentioned discussion, it can be revealed that by reducing the gap width of split, the length (circumference) of split ring is increased, and the rejection frequency point gets shifted towards the lower resonance side which also justifies Eq. (5). Lastly, it can be embellished that by fixing the value of 'S_1' as 0.4 mm, the proposed UWB monopole antenna rejects the WLAN frequency band centred at 5.3 GHz (5.15–5.81 GHz). This rejection is mainly due to interference occurred in UWB frequency range.

Further, the proposed antenna has also been investigated by employing a square shaped Split Ring Slot (SRS) with same dimensions as the circular SRS (for WLAN rejection characteristics), for more authenticity of the work, and the comparison of VSWR plots is delineated in Fig. 9. It can be understood from Fig. 9 that the circular SRS properly rejects the WLAN frequency band as compared to the square-shaped SRS.

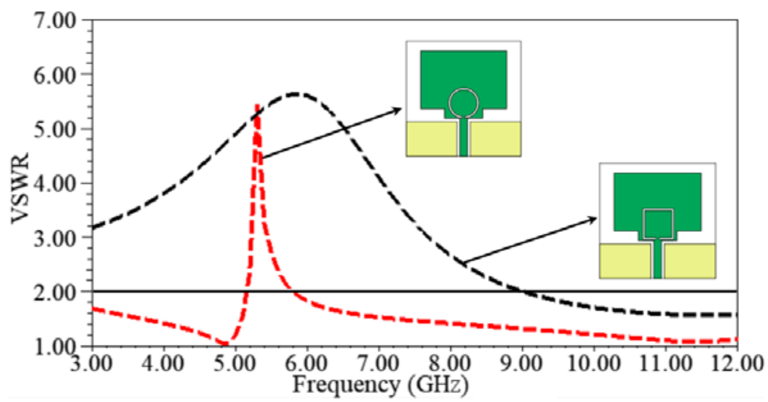

Figure 9. Comparison of VSWR curves for different structures of SRS (circular and square) to obtain WLAN band-notch characteristics.

3.2. UWB Antenna with X-Band Satellite Communication Rejection

The notch band rejection characteristics at an X-band satellite communication system is attained by modifying the inner and outer radii of SRS employed in the geometry of proposed UWB monopole antenna in previous subsection. R_1 and R_2 parameters are changed to R_1' and R_2'. Further, these parameters are varied to get the desired notch frequency band without changing the value of split ring gap ($S_1 = S_1'$). Values of R_1' and R_2' are varied from 2.3 to 2.1 and 2.0 to 1.6 with reducing step size of 0.1 mm and 0.2 mm, respectively as shown in Fig. 10. It can be observed from Fig. 10 that by taking the values of R_1' and R_2' as 2.3 and 2.0 mm, the proposed antenna exhibits the peak VSWR of 4.06 at 6.1 GHz. Further, at $R_1' = 2.2$ mm and $R_2' = 1.8$ mm, the antenna reveals the VSWR of 4.92 at the rejection frequency point of 7.2 GHz. By following the same procedure, the values of R_1' and R_2' are selected as 2.1 and 1.6 mm, and the notch frequency band is centered at 7.4 GHz with the peak VSWR of 5.66. The proposed antenna exhibits the notch bandwidth of 0.55 GHz (ranging from 7.16 to 7.71 GHz). Therefore, from the above-stated parametric study, it can be contemplated that the modification in inner and outer radii of the SRS helps in attaining the X-band satellite communication system rejection band.

Similarly, as discussed in the previous subsection, a square-shaped SRS is employed in the geometry of proposed antenna with the same dimension as that of circular SRS (for X-band rejection characteristics), and the comparison of VSWR plots is delineated in Fig. 11 in this subsection. It can be anticipated from Fig. 11 that circular SRS properly rejects the X-band frequency from the UWB passband as compared to the square-shaped SRS.

From the overall parametric discussion in Subsections 3.1 and 3.2, it can be lucidly anticipated that WLAN and X-band satellite communication system band rejection characteristics are achieved by optimizing the parameters of the circular shape SRS in two geometries of proposed UWB monopole antenna as compared to the square-shaped SRS. So, the circular shape SRS is taken for the final geometry of proposed UWB antenna, and it is fabricated for authentication of simulated results with measured results, which will be discussed in the following section (Section 4). The grouping of both the results of aforementioned rejected bands are reported in Fig. 12 for better understanding.

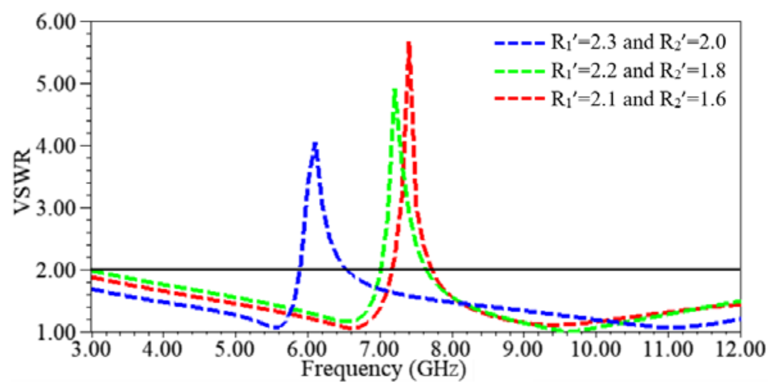

Figure 10. VSWR curves for different variations in 'R_1' and R_2'' parameters to generate X-band notch characteristics.

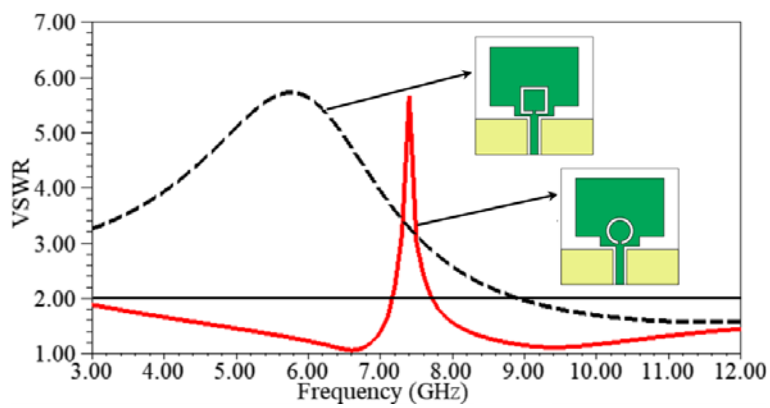

Figure 11. Comparison of VSWR curves for different structures of SRS (circular and square) to obtain X-band notch characteristics.

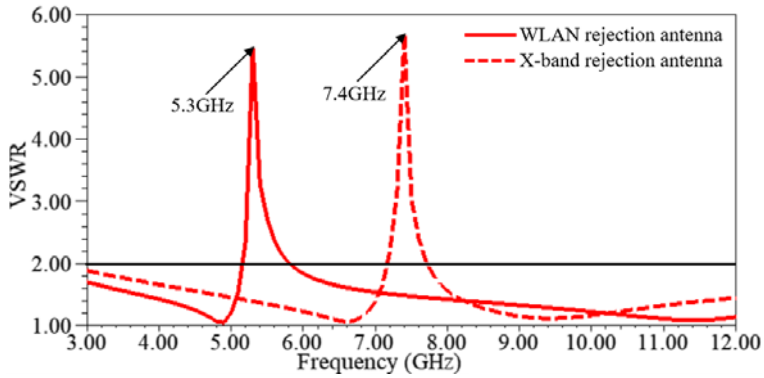

Figure 12. VSWR curves of both the antennas with WLAN and X-band satellite communication system rejection band.

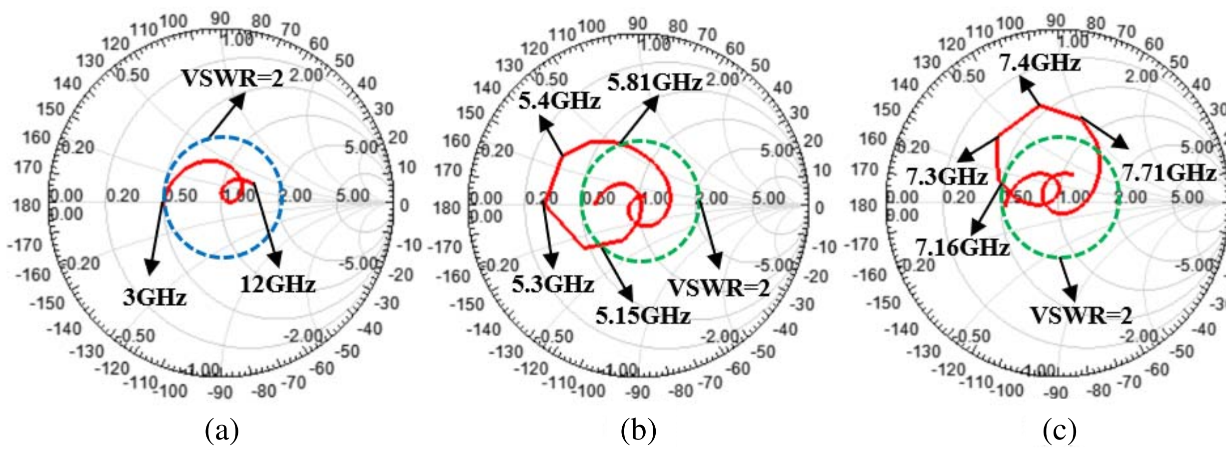

Figure 13. Input impedances on Smith chart (a) without band notch filter, (b) with WLAN and (c) with X-band satellite communication band notch filter.

3.3. Input Impedance Representation of Proposed UWB Antenna on Smith Chart

The input impedance representation of proposed UWB antenna without notch band filter with wider VSWR bandwidth range from 3.0 to 12 GHz is delineated in Fig. 13(a). Likewise, the input impedances of proposed antenna with WLAN and X-band rejection characteristics are illustrated in Figs. 13(b) and (c), respectively. The VSWR = 2 circle is drawn on the Smith chart, and it is anticipated from Fig. 13(b) that Smith curve comes out from VSWR = 2 circle at 5.15 GHz and reenters at 5.81 GHz. So, it can be clearly visualized from the Smith chart that the curve is outside from the VSWR = 2 circle at the frequency range from 5.15 to 5.81 GHz and exhibits WLAN band rejection characteristics in the proposed UWB antenna. By discerning carefully, the Smith curve is reported in Fig. 13(c). It is noticed that it comes out from VSWR = 2 circle at 7.16 GHz and reenters at 7.71 GHz and contemplated that the curve remains outside from VSWR circle for the frequency range (7.16 to 7.71 GHz) and rejects the X-band satellite communication system from the desired UWB frequency range.

3.4. Surface Current Distribution and Peak Gain of Proposed UWB Antenna

The surface current distribution plots of proposed UWB antenna with WLAN (5.3 GHz) and X-band (7.4 GHz) satellite communication system notch characteristics as well as other frequency points are illustrated in Fig. 14. It can be observed that the current is concentrated and the maximum energy stored near the band notch element (SRS), and further, it cannot be radiated into the air. Fig. 14(b) shows that the current dominates across the SRS which helps in achieving the rejection at WLAN

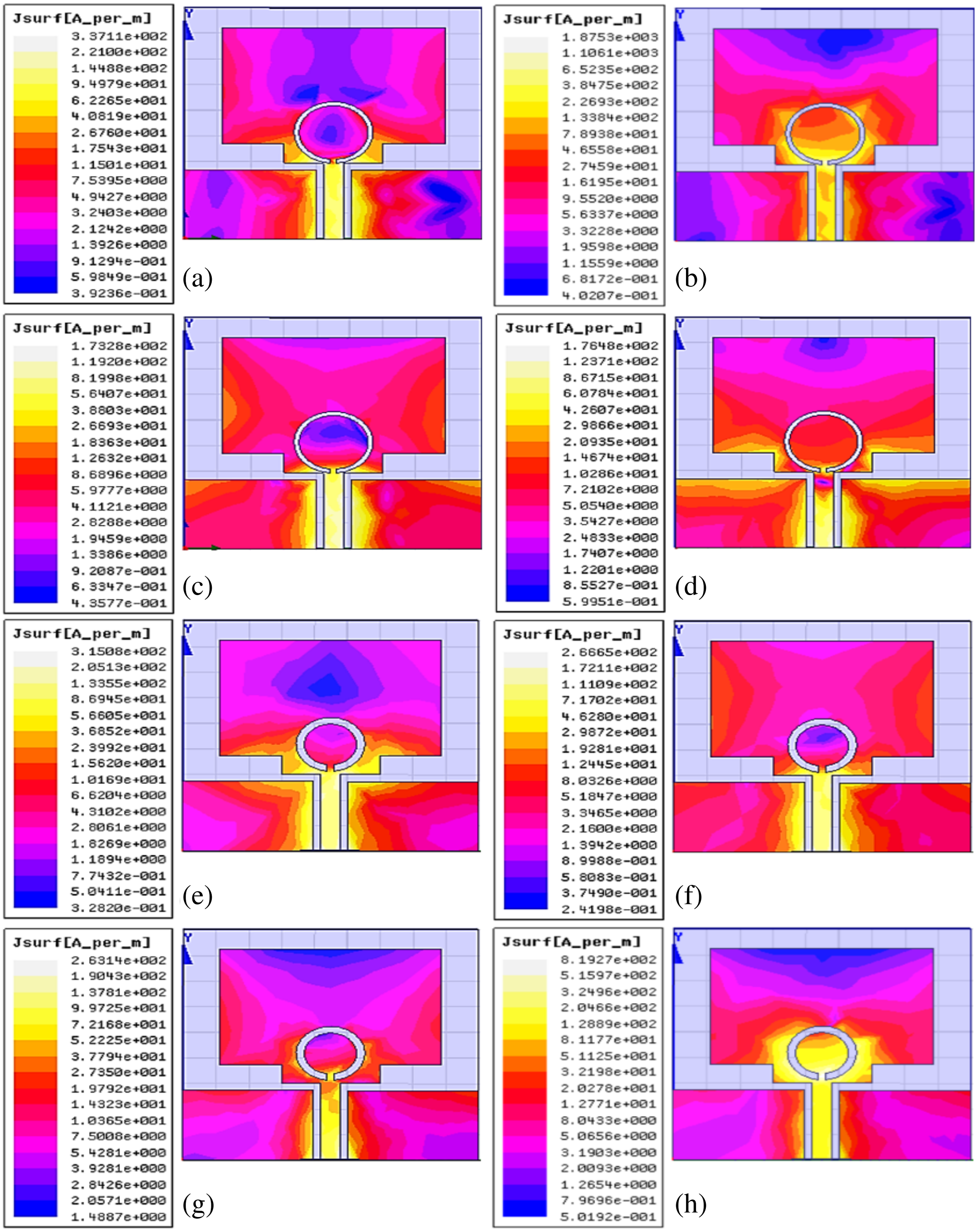

Figure 14. Surface current distribution plots of the proposed UWB antenna at (a) 4.5, (b) 5.3 and (c) 6.5 and (d) 8.5 GHz frequency for WLAN band notch filter and (e) 3.5, (f) 5.5, (g) 6.5 and (h) 7.4 GHz for X-band notch filter.

frequency band. Similarly, Fig. 14(h) reveals that the current also dominates across the notch element and supports in attaining the rejection in X-band satellite communication system. The peak realized gains of proposed antenna with and without band-notch characteristics are delineated in Fig. 15. It is observed that the antenna without band-notch filter exhibits almost constant positive value of gain throughout the entire frequency range 3 to 12 GHz. Similarly, the antenna with WLAN notch filter

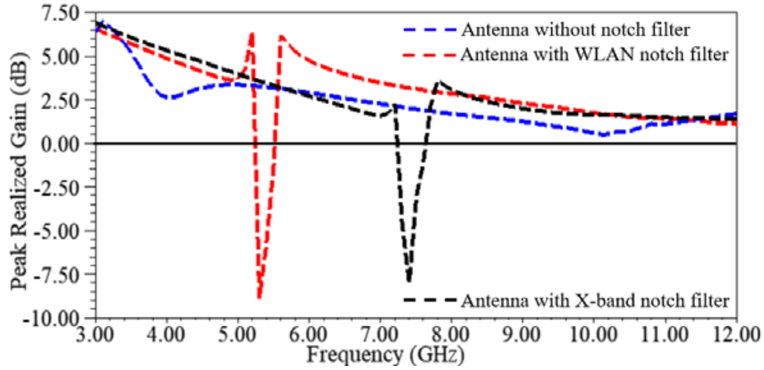

Figure 15. Gains of proposed UWB antenna with and without notch band filter.

shows the value of gain −8.84 dB at 5.3 GHz, and the antenna with X-band notch filter expounds the gain value of −7.96 dB at 7.4 GHz frequency band. These negative values of gain at rejected frequency bands show that the designed antenna does not radiate at 5.3 and 7.4 GHz frequency bands. Lastly, it is also envisaged that the surface current is consistently dispersed over the structure of antenna at the remaining frequency points in the frequency range 3 to 12 GHz.

4. PROTOTYPE AND RESULTS

The fabricated prototypes of proposed UWB antenna with or without notch-band filter are illustrated in Fig. 16. These antennas are tested with the help of Anritsu Vector Network Analyzer (VNA) ranging from 1 to 14 GHz to authenticate the measured results with the simulated ones. Simulated and measured VSWRs of antennas (reference antenna and the antennas with band-notch characteristics) are compared and depicted in Fig. 17. It can be perceived from Fig. 17 that they are in reasonable agreement with each other. The little variations between these results have been noted, and the reasons for these variations may be attributed to fabrication tolerance, environmental conditions, SMA connector losses, and soldering bumps. The measured VSWR plot of proposed reference antenna exhibits VSWR ≤ 2 for the entire frequency range 3.0 to 12 GHz. The WLAN band rejection antenna reveals the VSWR of 4.97 at 5.3 GHz, and X-band satellite communication system rejection displays the VSWR of 4.66 at 7.4 GHz. The reasonable agreement between experimental and simulated results makes the proposed antenna a suitable candidate for UWB applications with band-notch characteristics.

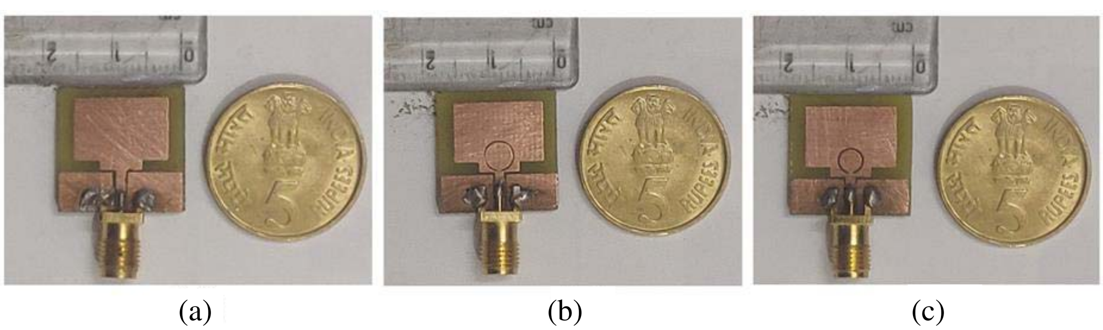

Figure 16. Fabricated prototypes: (a) reference antenna, (b) antenna with WLAN rejection filter and (c) antenna with X-band satellite communication rejection filter.

The simulated and measured radiation patterns in E- and H-planes for both the antennas with WLAN and X-band satellite communication system rejection characteristics at distinct frequency points are illustrated in Figs. 18(a) to (c) and Figs. 18(d) to (e), respectively. It can be embellished from these

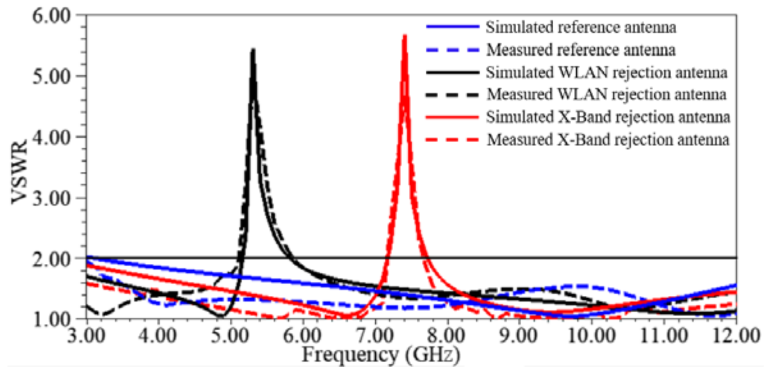

Figure 17. Simulated and measured VSWR curves of proposed UWB antenna with or without band rejection characteristics.

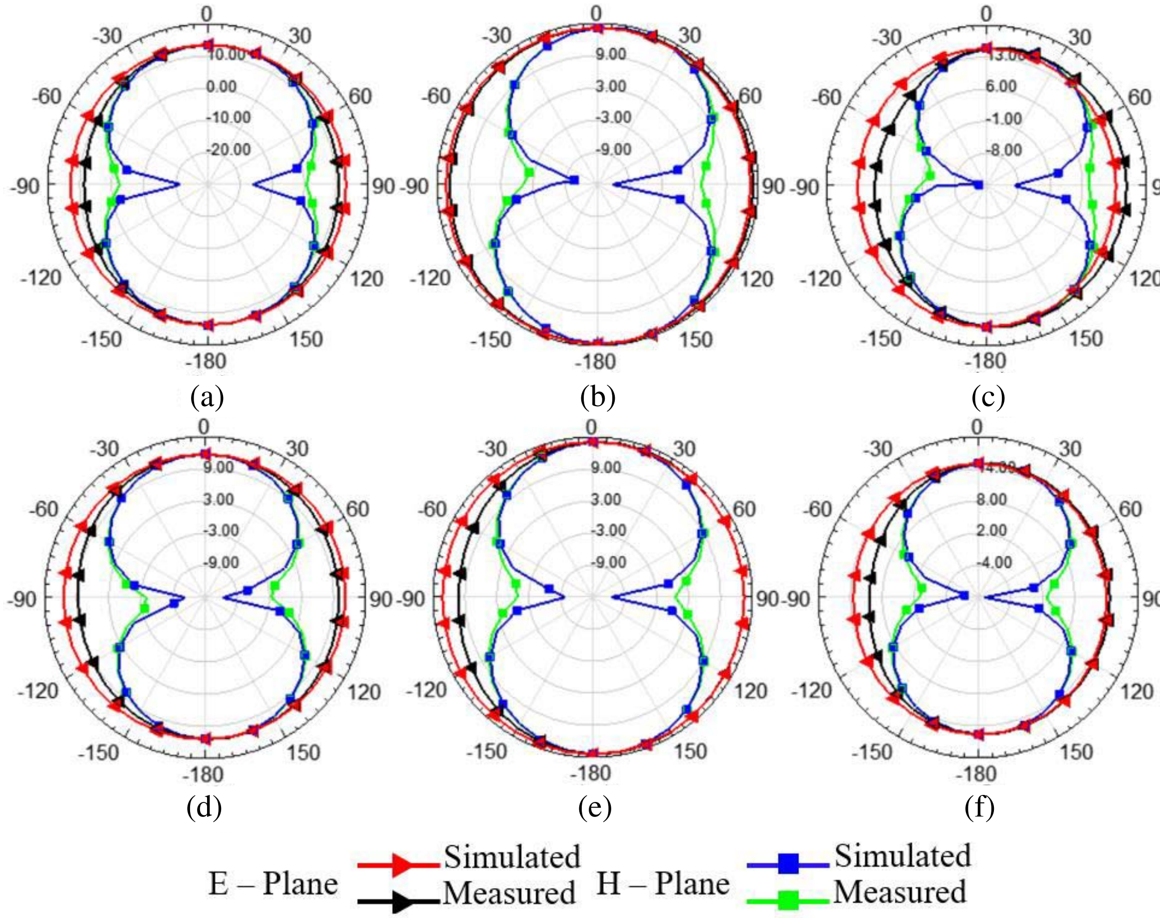

Figure 18. 2D radiation pattern of proposed UWB antenna at (a) 4.5, (b) 6.5 and (c) 8.5 GHz frequency for WLAN band notch filter and (d) 3.5, (e) 5.5 and (f) 6.5 GHz for X-band notch filter.

patterns that the proposed band-notch UWB antennas exhibit perfectly omnidirectional pattern in E-plane (phi $= 0°$) and dipole like pattern in H-plane (phi $= 90°$) at all the resonance points. From this discussion, it can be anticipated that the proposed antenna reports a wider VSWR bandwidth in the desired frequency range due to the stable radiation pattern in both the planes.

The comparisons of the proposed antennas with existing band-notch antennas are tabulated in Table 3. From the table, it can be projected that the proposed UWB antenna with band-notch

Table 3. Comparison of proposed antenna with several existing band notch antennas.

Reference	Size of antenna (mm^2)	VSWR bandwidth range (GHz)	Rejected frequency band (GHz)	Peak gain of rejected frequency band (dB)
[16]	50×40	3.3–12.0	WiMAX 3.5	−0.5
[17]	25×25	3.02–11.34	WLAN 5.5	−3.0
[18]	66×66	1.6–9.2	WiMAX 3.85	Not specified
[19]	39×45	2.9–14.0	WLAN 5.5	−0.6
[21]	16×25	3.1–12.5	WLAN 5.5	−6.0
[29]	35×35	3.1–10.6	WLAN 5.2	Not specified
[30]	34×34	3.1–10.6	WLAN 5.5	−5.0
[31]	35×20	3.1–12.0	WLAN 5.6	−25.0
[32]	37×33	2.3–12.3	WiMAX 3.5	Not specified
[33]	18×35	2.8–10.6	WLAN 5.2	−3.0
[34]	25×30	2.3–13.0	WLAN 5.5	−1.85
[35]	25×25	3.1–10.6	WLAN 5.2	−10.0
[36]	30×36	3.1–10.6	WiMAX 3.5	−3.35
Proposed	18×18	3.0–12.0	WLAN 5.3	−8.84
	18×18	3.0–12.0	X-band 7.4	−7.96

characteristic exhibits wider VSWR bandwidth except References [19, 21, 32, 34]. Though the VSWR bandwidths of the antennas designed in [19, 21, 32, 34] are more than proposed antennas, sizes of these antennas are quite large in comparison to proposed antennas, and the gain of the antenna designed in [32] is not specified. If we consider the antennas designed in [31, 35], they depict more negative gain at WLAN band-notch frequency than the proposed antennas, but the sizes of these antenna are almost double in comparison to the proposed antennas. From the above-mentioned discussion, it is very much clear that proposed antennas are compact in size and undoubtedly reject the WLAN and X-band satellite communication signals from UWB frequency range.

5. CONCLUSION

Compact printed CPW-fed monopole antennas with band rejection at WLAN and X-band satellite communication using a Split Ring Slot (SRS) have been proposed in this manuscript. The rectangular shape radiating patch has been selected and modified to obtain the UWB frequency bandwidth (VSWR ≤ 2) from 3.0 to 12.0 GHz. SRS has been embodied in the geometry of UWB antenna to obtain the WLAN band rejection at 5.3 GHz, and the dimensions of this slot have been modified to obtain X-band satellite communication system rejection band at 7.4 GHz. The antennas with band-notch filter and without band notch filter are fabricated and tested for the authentication of simulated results with measured results, and they are found in reasonable agreement with each other.

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