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Research Article

MIMO Antenna with Notches for UWB System (MANUS)

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In this paper, a trinotch band MIMO antenna is designed for upper and lower WLAN (5.1 GHz, 5.5 GHz) i.e., (802.11a/g/n/ac/ax) and satellite X-band (8.5 GHz). The placement of closely found notches at 5.1 GHz and 5.5 GHz is addressed by taking advantage from the placement of the same notch elements at appropriate distances from each other, to split single resonance into bire-sonances. Similarly, the third notch is produced at 8.5 GHz via a U-shaped slot added in the antenna. 2x1-MIMO antenna with notch bands is expected with better isolation by analysis of co-configurations and cross-configurations.

1. Introduction

In the last decade, the ultra-wide band (UWB) and multiple input multiple output (MIMO) antenna has gained a growing interest because of its high date rate transmission, increased channel capacity, mitigating interference, and improved link quality. Thus, UWB-MIMO antennas for wireless communication and mobile devices are drawn much interest in the last decade. In 2002, the federal communication commission (FCC) allocated a license to the UWB communication from 3.1 GHz to 10.6 GHz with the limited power emission spectrum [1–3]. Fewer techniques like slot antenna, hexagonal wide slot, tapered shaped slot, scarecrow patch, and many more that are used to achieve UWB characteristics [4–6].

However, worldwide interoperability microwave access (WiMax) 3.3–3.7 GHz, wireless local area network (WLAN) 5.1–5.8 GHz, and satellite service band 8.02–8.4 GHz have interference within the UWB system because of high date rate. Notching characteristics is introduced in the UWB to suppress the either single, double, or triple frequency bands. The antennas are highly preferable which have notching capabilities at these bands to mitigate the interference. The dual notched bands for WiMax and WLAN are achieved by meandered radiating patch and U-shape-slot in the feed line and the antenna has stable gain across the UWB [7].

To reduce the in-band interference notching characteristics of the antenna are essential. Different parasitic elements are attached with the substrate to produce notches in the band [8]. The notching characteristics for WiMax, WLAN, and satellite service provider are done by introducing the C-shape slot at the main radiator, complementary-SRR (CSRR) at the ground plane, and inverted U-shape slot at the center of the patch, respectively, using three different antennas [9].

A notch band (2.9–3.2 GHz) is introduced to remove the in-band interference by mouse-ear shaped arm (MESA) to the edge of each four-leaf radiator and two parasitic layer annular disk and baluns to make the antenna an ideal candidate for 2 G, 3 G, 4 G, and 5 G base station applications [10]. A triple rectangular notched band for 5 G, WLAN, and satellite downlink are introduced by using a pair of electromagnetic band gap (EBG) for 5 G and WLAN notching, and a split ring resonator (SRR) is used to notch the satellite downlink [11].

Researchers developed many techniques to notch the band to mitigate the in-band interference like etching slot on the patch [12, 13], EBG structure [14–16], inserting a resonant cell in microstrip line [17], SRR [18, 19], and coupling a parasitic element to the radiators [18, 20]. MIMO technology solves the problem of reliability and multipath fading. UWB faces the challenge of multipath fading and reliability. The UWB-MIMO technologies enhance the challenge of high data rate efficiency and mitigate the multipath fading. It is necessary to ensure low mutual coupling effects for the MIMO antenna system. The UWB-MIMO vivaldi antenna uses the technique of etching a T-shape slot on the ground plane and two SRR.

The authors achieve a notching effect at WLAN and X-band communication satellite and also optimize the mutual coupling effect in the whole working band [21]. MIMO antenna with a gap sleeve and H-slot fed with coplanar wave guide (CPW) with four orthogonal elements and good isolation produced dual notches at WiMax and military radar band with mutual coupling below −25 dB [22]. Four element differential pairs UWB-MIMO antenna is presented with dual notch characteristics at WiMax and WLAN bands [23]. Single notched bands antennas are described for WiMax and WLAN frequency band [24–27].

In [28], the coplanar waveguide rectangular notched UWB-MIMO is presented, where UWB is achieved by truncating the ground side. The notching characteristic is obtained by the electromagnetic gap and decoupling is improved by the parasitic decoupler. The high isolation is achieved in UWB-MIMO by placing crossed X-shaped stubs between two unconnected planes in [29]. The researcher proposed different shapes for notches and MIMO antenna like mushroom structure [30] bent etched self quasi complementary antenna [31].

1.1. Contribution of the Research. The novelty of the proposed antenna is to optimize the placement of the elements. The placement of the elements i.e., notches at 5.1 GHz and 5.5 GHz is addressed by taking advantage from the placement of the same notches at appropriate distances from each other which splits the single resonance into the biresonance.In this paper, a triple notch band UWB-MIMO antenna is presented with the mutual coupling of below −22 dB. The paper is divided into three parts: 1. Design of UWB antenna 2. Introduce triple notches for WLAN and satellite network provider 3. Finally, design co & cross UWB-MIMO antenna

1.2. Organization of the Article. The rest of the paper has organized as follows: Section 2 explains the notch antenna design configuration and parametric analysis of the antenna. In Section 3, detailed simulations have been presented in detail with a prototype of UWB-MIMO antenna crosses. Section 4 shows the comprehensive discussion on results i.e., notch band for WLAN, satellite service provider, and MIMO and isolation. Section 5 concludes the research article with some feature directions.

2. Notch Antenna Design

2.1. Antenna Design Configuration. The proposed UWB antenna is a design on FR epoxy substrate with a thickness of 1.6 mm relative permittivity of 4.4, relative permeability of 1, and dielectric loss tangent of 0.02. The proposed UWB-MIMO antenna design has the following steps (Figure 1 and Table 1):

(1) First, a rectangular substrate of length and width is drawn. The rectangular patch of length and width is drawn on the top of the substrate $(l_1 x w_1)$. The tapered microstrip line with an annular sector at the top is used as a feed line which consists of two sections: a rectangular section of length and width $(l_3 x w_3)$ and the tapered annular sector have $(l_4 x w_4)$. The substrate and the feed line are separated by distance w_5 from the right side. The main rectangular patch on the top of the substrate is etched with a rectangular slot of length and width $(l_2 x w_2)$. The top of the annular feed line is attached with the arc of radius (r_1). The arch slot is introduced by taking the difference of circles $(r_3 \text{and} r_2)$. The ground plane for the antenna is embedded with length and width $(l_6 x w_6)$. The multiple slots are introduced in the ground plane of dimension $(l_7 x w_7)$. The slots in the ground plane are separated from each other at a distance (d_2).

(2) For the notches characteristic at the WLAN band and satellite provider band, parasitic strips (PS) are added at the ground side. Multiple rectangular parasitic strips of dimension $(l_8 x w_8)$ are added at the back of the antenna for notching. The parasitic strips are separated by selective distance (d_1).

(3) The co-UWB-MIMO and cross-UWB-MIMO is designed by selecting a separation distance (d_3) for co-UWB MIMO design and separation distance (d_4) for cross-UWB-MIMO to get the optimized results. The antenna design layout and quantitative parameters are shown in Figure 1 and Table 1, respectively.

2.2. Parametric Analysis of Antenna. Once the antenna design is completed for UWB-MIMO and triple band notching of WLAN and satellite provider, different parameters are calculated and implemented. The parameters were analyzed to find the optimum dimension to achieve the required application results. The distance (d_1) in parasitic strips affects the notching band position for the WLAN band as shown in Figure 2. Figure 2 shows that with an increase in distance between the parasitic strips, the notching at the WLAN band moves to a lower frequency band, and the notching band moves to a higher frequency by decreasing the distance between the parasitic strips. The internal

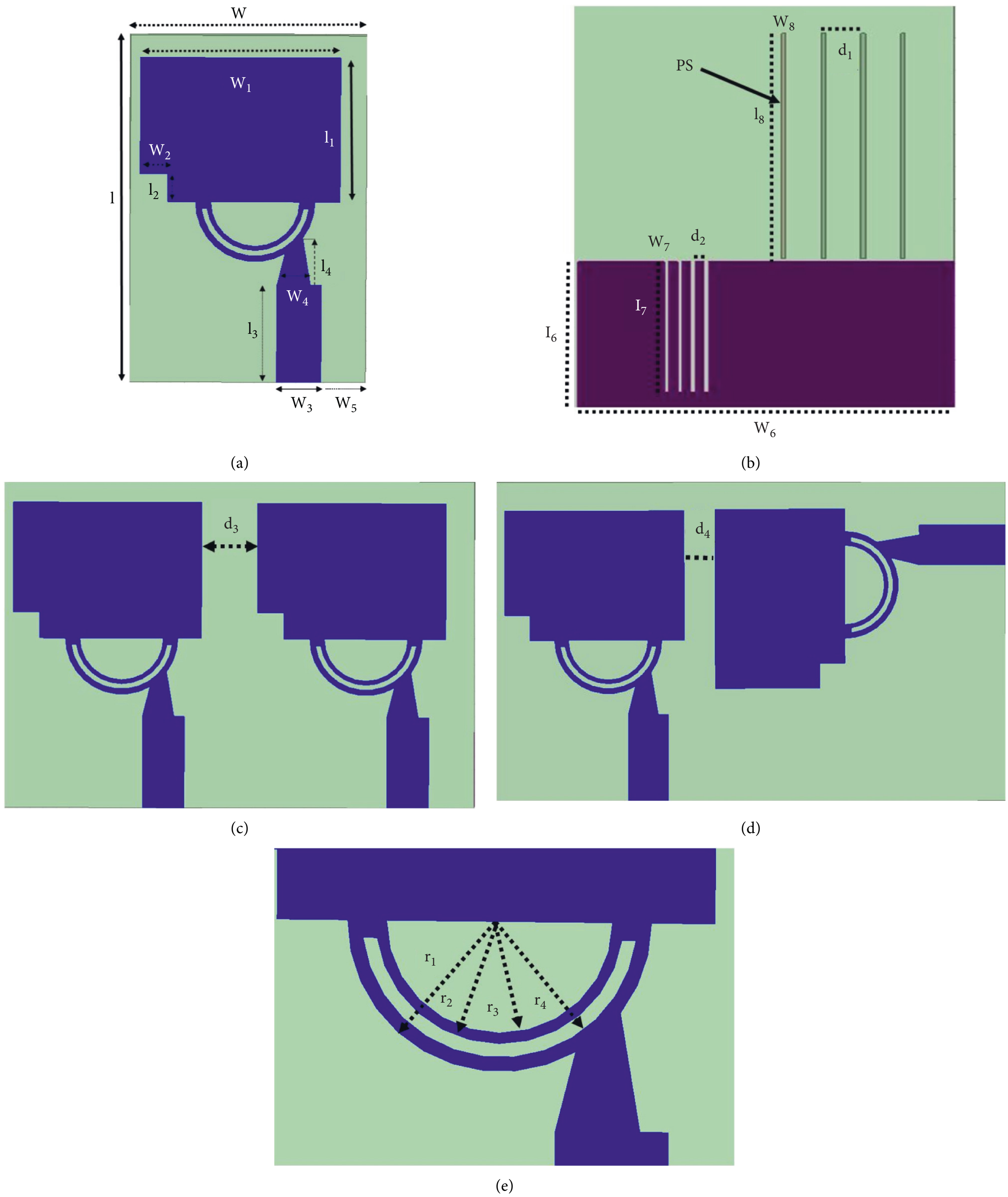


FIGURE 1: (a) Front view, (b) back view, (c) cross-MIMO, (d) co-MIMO, and (e) internal view.

U-shaped slot radius (r_2) introduced the notching characteristic at the satellite provider band as shown in Figure 3. The notching characteristic at the satellite provider shift towards the lower frequency by increasing the radius of the U-shaped slot and the notching shift towards the higher frequency band by the reduction of the U-shaped slots radius.

The UWB antenna matching can also be controlled by the dimension of etched rectangular slot (l_2xw_2). The parasitic strips at the ground of the antenna produce the

Table 1: Optimized dimensions of proposed antenna.

Parameter	Values in mm	Parameter	Values in mm
L	25	w	17
l_1	10.4	w_1	14.4
l_2	2	w_2	2
l_3	7	w_3	3.2
l_4	3.4	w_4	2.4
l_6	9.1	w_5	3
l_7	8.1	w_6	17
l_8	14	w_7	0.2
d_1	1.8	w_8	0.2
d_2	0.2	r_1	4.2
d_3	4.3	r_2	3.9
d_3	2.5	r_3	3.6

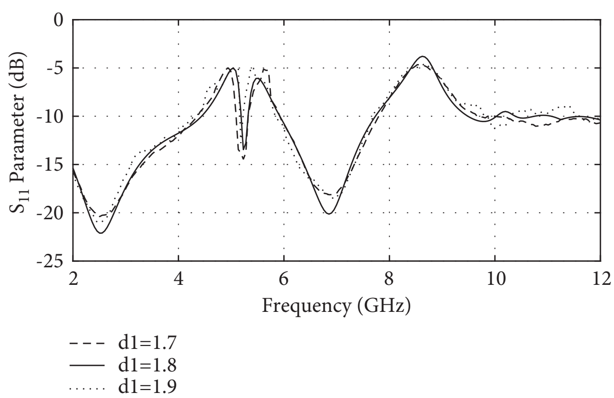


Figure 2: Different values of distance d_1 against s_{11} parameter.

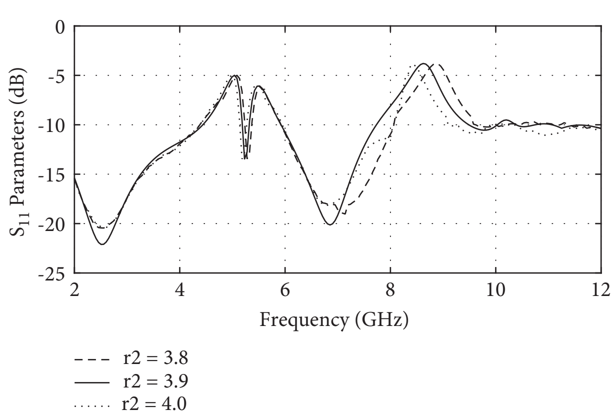


Figure 3: Different values of radius r_2 against s_{11} parameters.

notching characteristics, and the length and width of parasitic strips have a great impact on the notching frequency and bandwidth of notching frequencies. By adjusting the width of parasitic strips of 0.2 mm, the desired results are optimized.

3. Simulation and Measured Results

Assigning the proper dimension to the UWB-MIMO antenna, the antenna is simulated on HFSS. The simulation results such as reflection coefficient, voltage wave standing

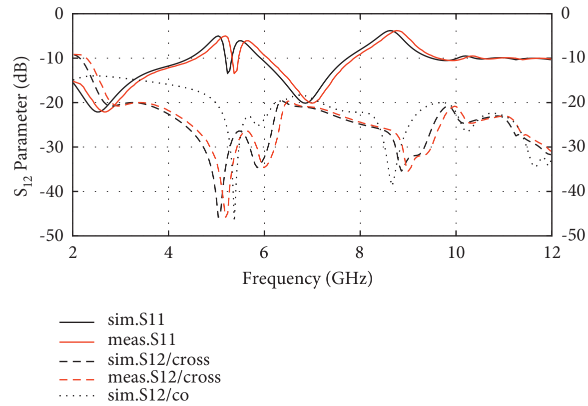


Figure 4: Triple band notches at different frequency against s_{11} parameter and co and cross s_{12} parameters.

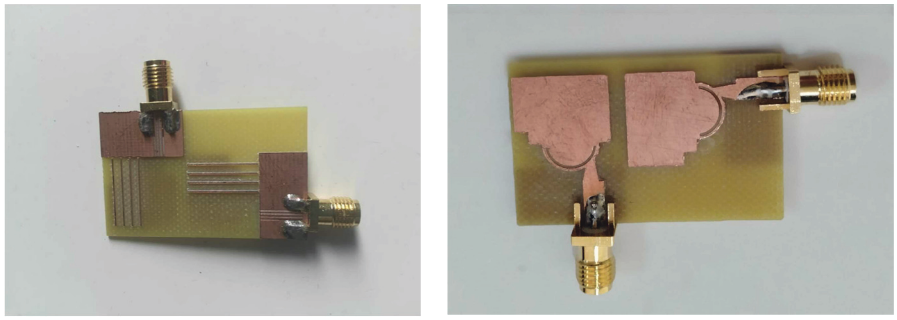
ratio (VSWR), radiation patterns, E-field, H-field and co-UWB-MIMO antenna and Cross UWB-MIMO antenna, and mutual coupling s_{12} parameters results are presented. The simulation shows that the UWB antenna is operational in the 2 GHz–12 GHz band. The interference can be removed from the WLAN and satellite network provider band by introducing the notches at the allocated 5 GHz–6 GHz and 8 GHz–9 GHz bands, respectively.

The simulated and measured triple band notches are introduced in the antenna shown in Figure 4. Two notches characteristics are introduced in the WLAN band by placing the parasitic strips at the back of the antenna. In the WLAN band, the notching characteristic are on 5.1 GHz and the second notch is on 5.5 GHz.

The triple notch band MIMO antenna systems satisfy the impedance matching requirement throughout the UWB. The mutual coupling s_{12} simulated and measured results for the co-MIMO and cross-MIMO are less than −15 dB and −20 dB, respectively, throughout the entire band as shown in Figure 5. The measured and simulated s_{12} results for cross-MIMO is in good comparison. The fabricated prototype of UWB-MIMO cross configuration is shown in Figure 5.

The UWB-MIMO antenna for 2 to 12 GHz band is designed on electromagnetic simulator ANSYS HFSS. The simulated results are in good comparison to the requirement. Triple band notches are produced from the UWB-MIMO antenna for WLAN provider at the 5.1 GHz, 5.5 GHz, and 8.5 GHz notch characteristic for the satellite service provider. The co- and cross-MIMO antenna are designed on HFSS, and the mutual coupling effect of the co- and cross-MIMO antenna are optimized.

The notching characteristic for the satellite network provider is introduced by the U-shaped internal slot on 8.8 GHz. The simulated and measured triple notch results are in good comparison. The gain varies from −11 dB to 1 dB and the efficiency of the antenna is more than 85% throughout the entire band. The radiation pattern of UWB-MIMO antenna is observed on *E*-plane at the notching frequencies 5.1 GHz, 5.5 GHz, and 8.8 GHz and also in-band frequency 6.8 GHz. In the *E*-plane, monopole patterns are observed at the notching frequencies. The radiations patterns on the *H*-Plane at notching frequencies and in-band



(a) (b)

Figure 5: Prototype of UWB-MIMO crosses antenna. (a) Front view. (b) Back view and co and cross s_{12} parameters.

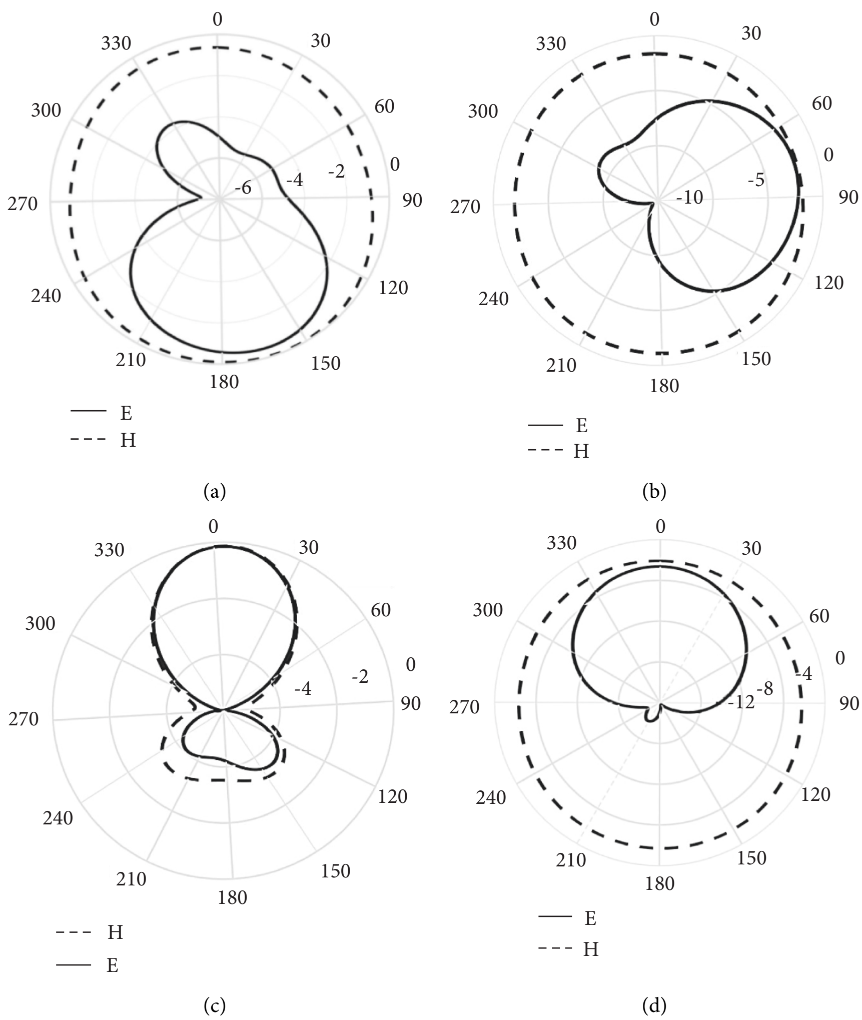


Figure 6: E-H plane for notch and in-band frequencies at (a) 5.1 GHz, (b) 5.5 GHz, (c) 6.8 GHz, and (d) 8.5 GHz.

frequency are in omni directional to perceive or accept the signal from all paths. The radiation patterns at *E-H* planes are shown in Figure 6.

4. Results and Discussion

4.1. Notched Band for WLAN. To minimize the interference in the WLAN band, notches are developed. Two notches at the frequency 5.1 GHz and 5.5 GHz are introduced in the WLAN service provider. These band rejections notches are achieved by introducing parasitic strips at the back side of the antenna. The length and width of the parasitic strips play a vital rule to produce notches at the ultrawide band. The length of parasitic strips and frequency is inversely related. Increasing the length of parasitic strips, it will decrease or lower the notch frequency band and vice versa.

Table 2: Comparison of proposed design with existing techniques.

Reference	Antenna size (mm)	No. of notch bands	Notch bands (GHz)	Notching technique
[13]	19 × 24	3	3.3–3.7, 5.1–5.8, 7.2–7.7	Quarter-wavelength slots
[15]	54 × 47	3	2.2–2.4, 3.2–3.4, 5.5–5.8	Slot on patch and SRR on the feed line
[16]	50 × 52	3	3.3–3.8, 5.1–5.8, 7.1–7.9	EBGs
[18]	40 × 30	4	3.2–3.8, 5.1–5.4,5.7–5.9, 7.5–8.6	SRR
[19]	24 × 24	3	3.3–4, 5.1–5.8, 7.1–7.9	EBGs
[20]	30 × 22	3	3.2–3.7, 5.1–5.3, 5.7–5.9	Parasitic strip
[32]	50 × 50	1	5.1–5.8	SRR on the feed line
[33]	50 × 50	2	5.1–6, 7.8–8.4	Stepped slots
Proposed	17 × 25	3	4.7–5.1, 5.4–5.8, 7.9–9.1	Parasitic strip

The length L for the parasitic strip is calculated from the notch formula at desire notch frequency L is the length of parasitic strips f is notch frequency and E-eff is the effective permittivity. The width of parasitic strips influences the width of notch band frequencies. The width of the parasitic band and frequency is inversely related. When the width of the parasitic strips are decreasing, the width of the notch frequencies band are sharp as compared to the wide width of metallic strips. The notches at the frequency band 5.1 GHz and 5.5 GHz are achieved by adding the parasitic strips of length 14 mm and width 0.2 mm at the back of the antenna.

4.2. Notch Band for Satellite Service Provider. The allocated license for a satellite service provider by the federal communications commission (FCC) is from 8.02 to 8.5 GHz. This band causes interference at the UWB communication due to high traffic. To introduce a notch at the satellite service provider, U-shaped slot is added in the antenna design. It is observed that changing the width of the slot can control the center frequency for the notch. It is shown in Figure 3 that the increase in the width of the slot will create a notch resonance at a lower frequency. Similarly, the decrease in width of the slot created a notch at a higher frequency as shown in Figure 3.

Finally, a comparison is evaluated with the previously reported UWB notch band antenna and the proposed antenna in Table 2. Table 2: presents that reference [13, 15, 16, 19, 20] presented a triple notch band with different techniques and maximum antenna size. The study in [18] achieve a quarter notch bands by using the SRR technique. The study in [32, 34] presents a WLAN rejection band by using EBGs and SRR techniques and maximum antenna size. The studies in [33] have dual notch bands for WLAN and satellite provider by using the stepped slots technique, the size of the antenna is comparable with other designs. The proposed design achieved a triple notch band for WLAN and satellite provider by using parasitic strips on the ground side. The triple notch bands are achieved with a compact size of antenna comparable with other designs.

4.3. MIMO and Isolation. The UWB-MIMO technologies have a wide impact in communication systems. The UWB and MIMO abridged the multipath fading and sharp the link quality and channel capacity. In MIMO system, a low mutual coupling is required between the antennas. The performance of the MIMO system can optimize by selecting the distance between the antennas and partial ground and slots on the ground reducing the mutual coupling and improving the isolation.

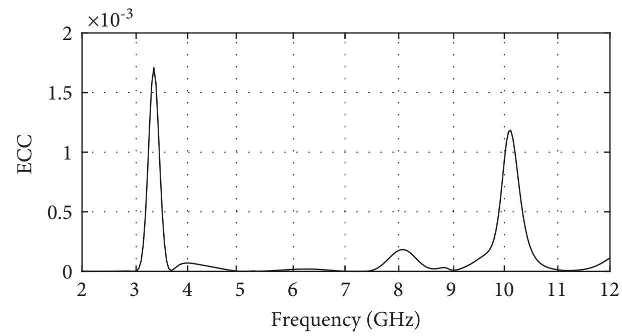


Figure 7: ECC of MIMO antenna.

There is no external element used for the decoupling of the proposed antenna system. The elements are isolated by selecting the optimized distance between the elements in co and cross MIMO design. The isolation characteristics show the suitability of the proposed antenna for MIMO application.

The mutual couplings between the antennas are abridged without any using any decoupling structure. The isolation appearing in s_{12} are still better than −15 dB. The parallel and orthogonal MIMO antenna are implemented and optimizing results are obtained by selecting optimized distance and partial ground and slots on the ground. The isolation results show that the antennas are applicable for MIMO applications.

4.4. ECC. The ECC has been calculated and from the simulation results, and the ECC value should be less than 0.4 which shows that the coupling between the elements is very rare. The proposed design has an ECC of 0.002 which shows the reliable communication which is shown in Figure 7.

4.5. Comparison with Existing Techniques. The comparison in Table 3 of UWB-MIMO antennas shows that the proposed design shows higher isolation with the other design without using any additional decoupling structure. In [25], a narrow slot is used in the ground plane to reduce the mutual coupling between the orthogonal place of MIMO antennas.

Table 3: Comparison of the proposed design with other designs.

Reference	Design layout	Isolation improvement	Minimum isolation (dB)
[25]	Orthogonal	Slot	15
[26]	Side by side	Reflector and slot	15
[27]	Orthogonal	Protruding ground stubs	15
Proposed	Co and cross	Nil	22

In [26], a ground, slots, and Y shaped slot between the side by side or co MIMO antenna are implemented to improve the isolation to make the design applicable for MIMO. In [27], a long protruding strip is attached to the partial ground to enhance the isolation of the orthogonal design. In the proposed design, the side by side and orthogonal layout are presented for the MIMO application. The high isolation is achieved by the selection of optimized distance between co and cross design and partial ground and slots. The mutual coupling are below −15 dB and −20 dB, respectively, which make these design applicable for MIMO application.

5. Conclusions

This paper concludes with a final design of a tri notch band MIMO antenna for upper and lower WLAN (5.1 GHz and 5.5 GHz) i.e, along with (802.11a/g/n/ac/ax) and satellite *X* band (8.5 GHz), respectively. Placement of closely found notches with narrow band width and steep slopes is a challenging task. It is achieved via the addition of parasitic slots. It is observed that the distance between parasitic slots is used to control the closely found notches. Furthermore, the addition of a u-shaped slot in the antenna creates a third notch band to mitigate the satellite *X* band. The antenna is further tested for co- and cross-polarization for the better isolation. The simulated results are found in good agreement with the measured results which makes it a good choice for certain applications.

Data Availability

The data used to support the study are included in this paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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