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Article

A Novel Compact Highly Isolated UWB MIMO Antenna with WLAN Notch

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Abstract: This paper presents a compact Multiple Input Multiple Output (MIMO) antenna with WLAN band notch for Ultra-Wideband (UWB) applications. The antenna is designed on 0.8 mm thick low-cost FR-4 substrate having a compact size of 22 mm × 30 mm. The proposed antenna comprises of two monopole patches on the top layer of substrate while having a shared ground on its bottom layer. The mutual coupling between adjacent patches has been reduced by using a novel stub with shared ground structure. The stub consists of complementary rectangular slots that disturb the surface current direction and thus result in reducing mutual coupling between two ports. A slot is etched in the radiating patch for WLAN band notch. The slot is used to suppress frequencies ranging from 5.1 to 5.9 GHz. The results show that the proposed antenna has a very good impedance bandwidth of $|S11| < -10$ dB within the frequency band from 3.1–14 GHz. A low mutual coupling of less than -23 dB is achieved within the entire UWB band. Furthermore, the antenna has a peak gain of 5.8 dB, low ECC < 0.002 and high Diversity Gain (DG > 9.98).

Keywords: Multiple input multiple output (MIMO); ultra-wide band (UWB); defected ground structure; envelope correlation coefficient; diversity gain

1 Introduction

Owing to the requirements of higher data rates, mobile networks require a larger spectrum to fulfill these demands. Therefore, MIMO antenna becomes the center of attention. As the name suggests, multiples antennas are used for transmission and reception to increase data rate and channel capacity [1]. When multiple antennas are placed within a close proximity, it results in increasing mutual coupling among the adjacent antennas and thus causes performance degradation of overall MIMO antenna system. This issue becomes worse when we increase the number of radiators in a MIMO antenna

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design. Designing an efficient antenna with enhanced isolation and improved MIMO performance is the requirement of emerging communication technologies.

Various techniques have been used for isolation enhancement such as Defected Ground Structure (DGS) [2,3], Electromagnetic band gap (EBG) [4–7], Parasitic Element [8–11], complementary split ring resonators [12–14], metallic stubs and shorting pins [15–18], and neutralization line [19,20]. For instance, in [2], S-Shape periodic defected ground structure (PDGS) is used for coupling reduction. The proposed PDGS reduces the mutual coupling by 40 dB in a narrowband. Moreover, isolation can also be improved by making multiple rectangular shape DGS in between patch antennas [3]. In [4], EBG is used in the ground plane for improving isolation between patch antennas. A novel EBG is etched in the ground plane to stop EM waves propagation in a particular band. The results show a reduced mutual coupling of around 10 dB in the operating band. In [5], mutual coupling has been reduced by using uni planar EBG in between two radiators. The use of EBG reduces the mutual coupling by 20 dB in a narrowband of 5.8 GHz. A double layer twin patch EBG (DLDP-EBG) is used in [6] for coupling reduction. It is observed that it helps in reducing mutual coupling at the frequency range of 4–6 GHz by approximately 5 to 30 dB. In [7] EBG and DGS technique are used together for isolation enhancement. The DGS helps in reducing mutual coupling for more than 25 dB in the entire UWB range and EBG reduces the coupling effect by 10 dB in the frequency range of 4–5 GHz. The overall size of this antenna is $26 \times 31\ mm^2$. The use of parasitic structure is also commonly used for coupling reduction. In [8], a circular parasitic element is used in the ground plane. This helps in creating reverse coupling. A $67 \times 67\ mm^2$ size of antenna reduces mutual coupling to −20 dB. Moreover, mutual coupling is also reduced by using fan shape decoupler [9], in [10] a rectangular parasitic element is inserted between radiators for mutual coupling reduction. Moreover in [11] novel design parasitic structure is used to have isolation enhancement. In addition, Complementary Split Ring Resonator (CSSR) also helps in reduction of mutual coupling. In [12] the use of CSRR reduces the mutual coupling by more than 10 dB. In [13,14], folded split ring resonator (FSRR) is used for isolation enhancement. A slotted strip has been used in [15] for coupling reduction. In [16], six metallic pins are connected at the edges of patch antenna. These pins act as reflector and thus suppress the signal coming from adjacent patch. Moreover, [17,18] metallic stub technique has been used for isolation enhancement. In [19,20] neutralization line technique has been proved to be an effective method for coupling reduction. Moreover, Frequency Selective Surface (FSS) is also used for introducing a band stop and gain enhancement in the UWB antenna [21,22]. The FSS is a two-dimensional, thin periodic array that demonstrates its filtering properties to transmit (band pass) and/or reflect (stop band) electromagnetic waves (EMW). Similarly, a compact size planar antenna for wideband 5G communication utilizing low transmission loss and high gain is presented [23,24].

In past different topologies of MIMO systems were investigated. The antennas were placed in mutually optimized positions to achieve the highest isolation. In addition, multiple techniques have been investigated that helps in the reduction of mutual coupling in MIMO antenna. Based on above discussion it can be concluded that reducing mutual coupling in a compact size is a challenging problem in antenna design. In this paper, a new compact microstrip feed MIMO antenna is proposed. The patch slots are included in the radiating surface for filtering of WLAN band. A Complementary stub is protruded in the ground plane of MIMO antenna for achieving high isolation and greater impedance bandwidth. Although, the use of slot in the patch for band suppression is common but is difficult to implement in a compact design.

Most of the proposed models reduce the mutual coupling at the cost of increasing the overall size of MIMO antenna. Similarly, EBG and other techniques reduce the mutual coupling only in a narrowband. However, this research work proposes a compact MIMO antenna design that contributes to reduce the mutual coupling by more than 23 dB in the whole UWB range and suppresses WLAN band. This paper proposes a novel antenna operating in the UWB band while suppressing 5.1–5.9 GHz (WLAN) inference in the UWB spectrum. A novel slotted stub is placed in the ground that helps to design a compact UWB MIMO antenna with high isolation. The simulated and measured results have confirmed that the proposed design is operating in the UWB band with stable radiation pattern, high gain, low envelope correlation, improve Directivity gain and significant isolation. Thus, the proposed antenna has a best trade-off performance and can be a suitable candidate for MIMO systems.

2 Antenna Design

The proposed antenna design is presented in Fig. 1. The overall size of antenna is $22 \times 30\,mm^2$. The antenna is designed using easily available FR-4 substrate ($\in = 4.3$, tangent loss = 0.002) having thickness of 0.8 mm. The antenna is designed with the patch size of $11 \times 9\,mm^2$ (Lp × Wp). The patch is fed through a microstrip line with the dimension of 7 × 1.5 (Lf × Wf). The antenna is composed of two-layer structure. On the top of the substrate, two patch antennas are printed and on bottom layer a shared ground with a complementary EBG is used. The inter element spacing between the patches is kept small i.e., 7 mm to maintain a compact design. The mutual coupling decreases with the increase in separation between patch elements. Increasing the separation will result in reducing the mutual coupling on the other hand it will result in increasing the overall size of MIMO antenna. Thus, reducing the mutual coupling in a compact size antenna is a challenging task for the designers.

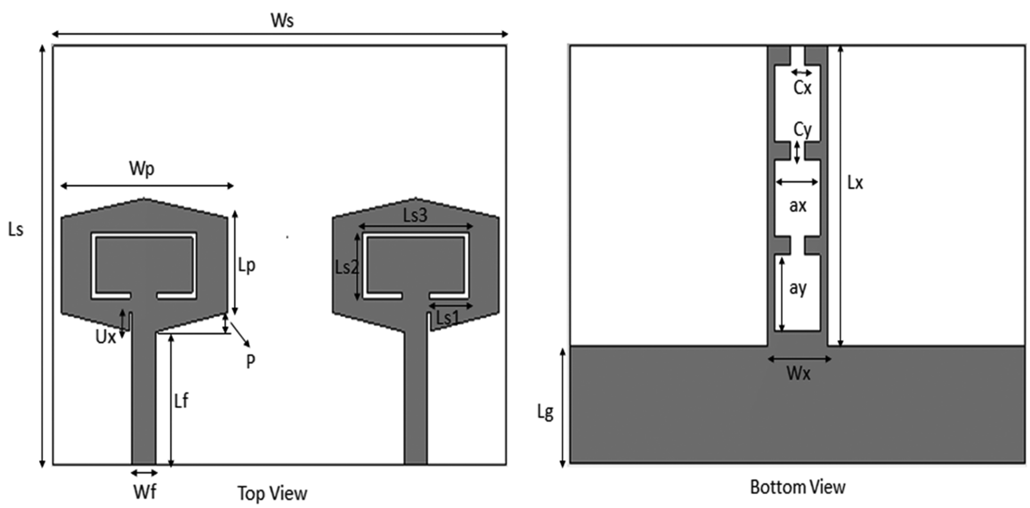


Figure 1: Proposed antenna design

The initial design of MIMO antenna is based on Eq. (1) [7].

$$f_r = \frac{144}{l_g + l_1 + g_p + \dfrac{w}{2\pi\sqrt{1+\in_r}} + \dfrac{w1}{2\pi\sqrt{1+\in_r}}}\ GHz \tag{1}$$

In Eq. (1), f_r is the resonant frequency of the MIMO antenna, l_1 represents the length of the patch, g_p is the distance between the ground and that of the radiator and l_g is the length of the ground. Moreover, W1 and W are the widths of the patch and substrate respectively. By putting values in Eq. (1), the resonant frequency is calculated as 10.5 GHz.

The final design is achieved by the evolution of proposed antenna through different stages as shown is Fig. 2. In Fig. 2, Antenna 1 shows the MIMO antenna with partial ground structure, Antenna 2 consists of stub with complementary slots in it. In Antenna 3 a slot is etched in the patch for creating WLAN band notch [25]. These slots act as resonators and help in suppressing the desirable frequency band. The desired band notch feature can be obtained by adjusting the length and the width of the slot. The length and width of the slot is based on Eq. (2) [25]. The overall length of the slot approximates to $\lambda/2$ of the notched frequency.

$$L_{notch} = \frac{c}{2f_{notch}\sqrt{\varepsilon_{eff}}} \tag{2}$$

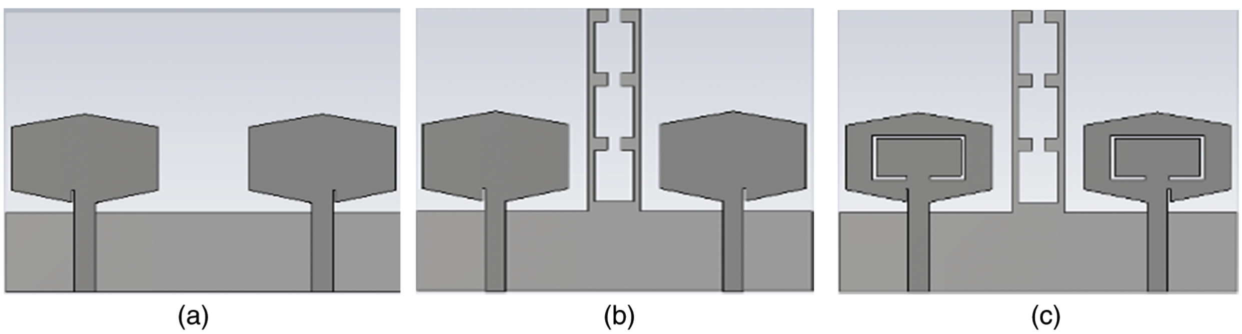


Figure 2: Evolution of MIMO antenna, (a) antenna 1 (without stub) (b) antenna 2 (with stub) (c) antenna 3 (with stub and notch)

Here, L_{notch} represented the length of the slot, f_{notch} is the desired resonant frequency, 'c' is the speed of the light and. $\varepsilon_{eff} = \frac{1+\varepsilon_r}{2}$ is the effective dielectric constant.

The proposed antenna is designed for the UWB application. In Fig. 3a it is evidently clear that Antenna 1 has low impedance bandwidth to cover the UWB band, Antenna 2 operates in the UWB range while Antenna 3 operates in the UWB and suppress the WLAN band. Furthermore, Fig. 3b shows that the Antenna 1 operates with high mutual coupling. Antenna 2 and Antenna 3 results show reduced mutual coupling to within the acceptable range due to DGS technique.

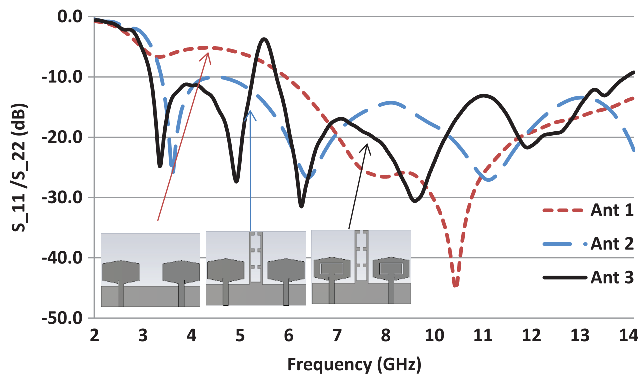
The optimized parameters of proposed MIMO antenna are obtained by complete parametric analysis of design dimensions. These parameters include antenna ground length "Lg" that has been varied from 5.6 to 6.2 mm Moreover, length of the notch "Ls3" is also changed from 6 to 6.6 mm. The final optimized parameters of proposed antenna are presented in Table 1.

Fig. 4 shows the parametric results of 'Lg' parameter. 'Lg' is the length of the ground. By using parametric sweep, the proposed antenna showed optimized impedance bandwidth at Lg = 6.2 mm

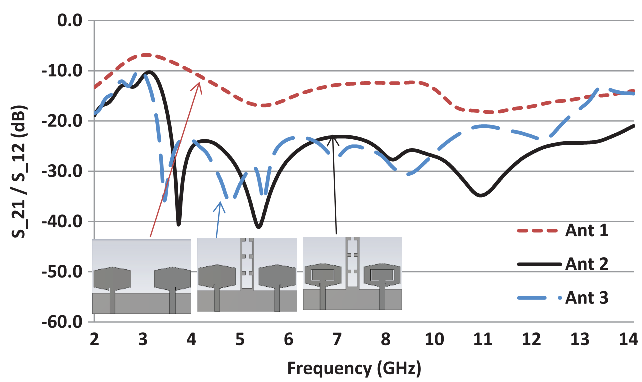
The parametric analysis of slot length LS3 has been studied and the results are shown in Fig. 5. It is obvious that varying the length of the slot has negligible effect on the impedance bandwidth.

The antenna current distribution is obtained by simulating it for three different frequencies i.e., 3.9, 7.4 and 10.5 GHz. Fig. 6 shows the current density of proposed antenna with and without stub.

It can be seen that rectangular stub provided alternate current path and thus enhanced the isolation between two radiating patches.



(a)



(b)

Figure 3: (a) S11/S22 simulated results (b) S12/S21 simulated results

Table 1: Optimized parameter list

Parameters	Values (mm)	Parameters	Values (mm)
Ls	22	Ls1	2.3
Lp	5	Lx	13
Ws	30	Ls3	6.4
Wp	11	LS2	3.5
Lf	7	Wx	4
Wf	1.5	Ax	3
Lg	6.2	Ay	4
P	1	Cy	1

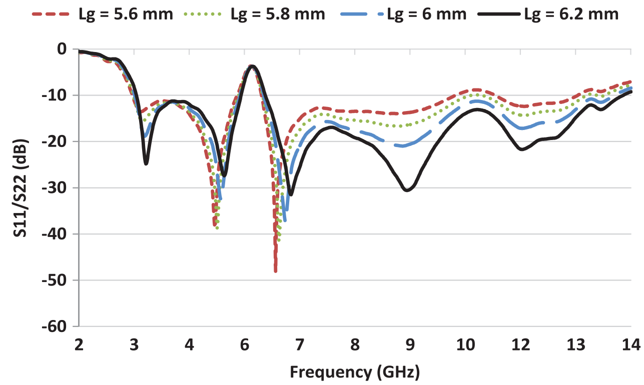


Figure 4: Parametric results of Lg parameter

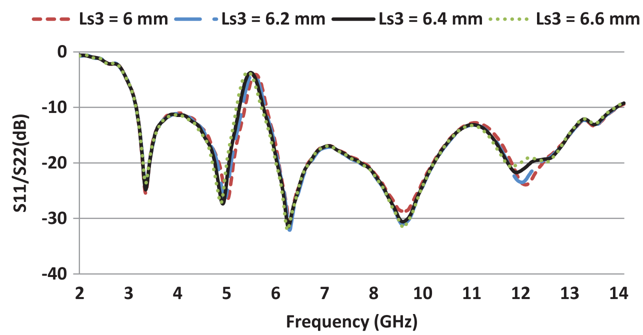


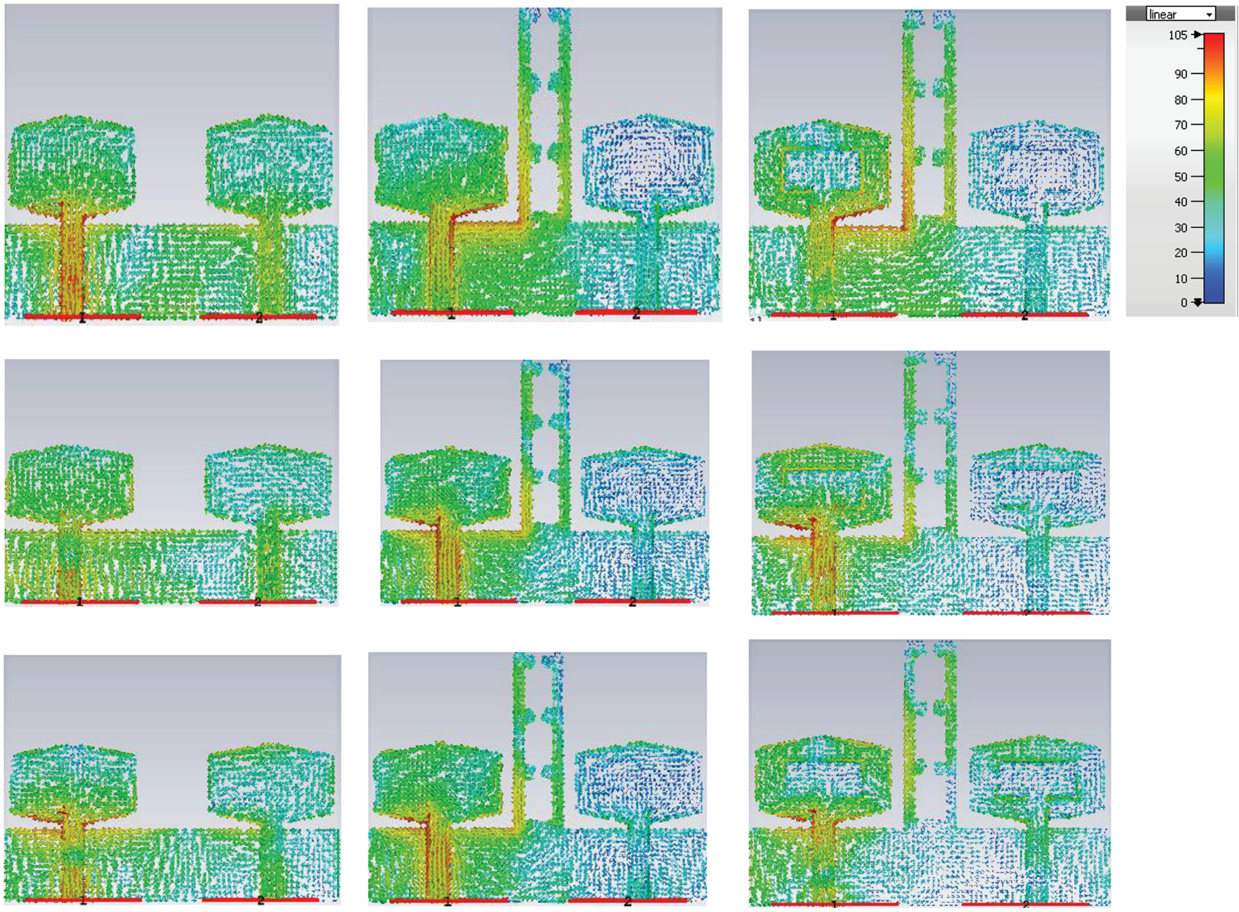
Figure 5: Parametric analysis of slot length L3

3 Results and Discussion

The proposed antenna is optimized after parametric study then the optimized dimensions are used to fabricate the proposed design. Fig. 7 shows the prototype of fabricated antenna.

The reflection coefficient (S11/S22) and transmission coefficient (S12/S21) of fabricated model has been measured using Vector Network Analyzer. It is evidently clear from Fig. 8 that the measurement and simulation results are closely matched. The S11/S22 < -10 dB in the whole UWB range except a notch from 5 to 6 GHz to suppress WLAN band. In addition, the transmission coefficient (S12/S21 < -23 dB) also indicates that antennas have very low mutual coupling between each other despite compact size.

In Fig. 9, the fabricated antenna is placed in an Anechoic Chamber to measure its performance characteristics. The designed MIMO antenna radiation pattern is also measured at different frequency points i.e., at lower frequency (3.9 GHz), center frequency (6.4 GHz) and higher frequency (9.6 GHz). Fig. 10 shows the simulated and measured results of radiation pattern of proposed design. It can be observed that antenna has omni directional pattern at lower frequency. However, it shows quasi-omnidirectional behavior at higher frequency.



(a) (b) (c)

Figure 6: Current surface distribution at (a) 3.9 GHz, (b) 7.4 GHz (c) 10.5 GHz

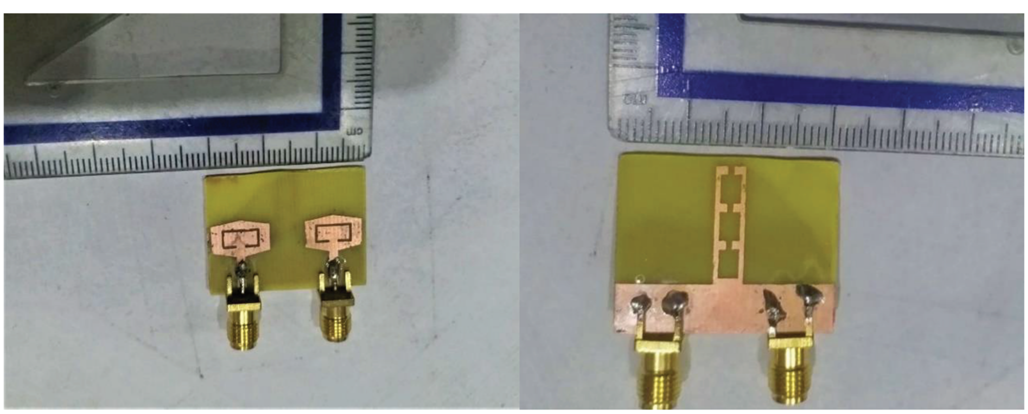
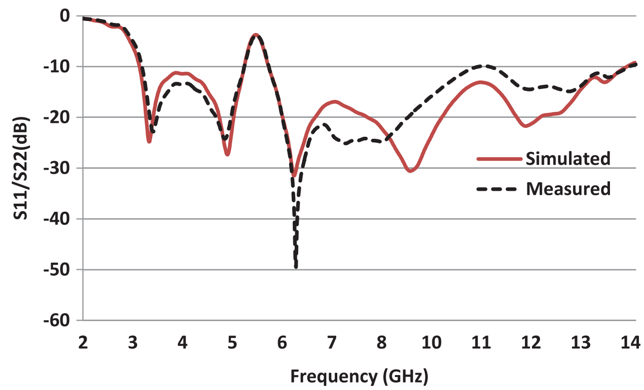
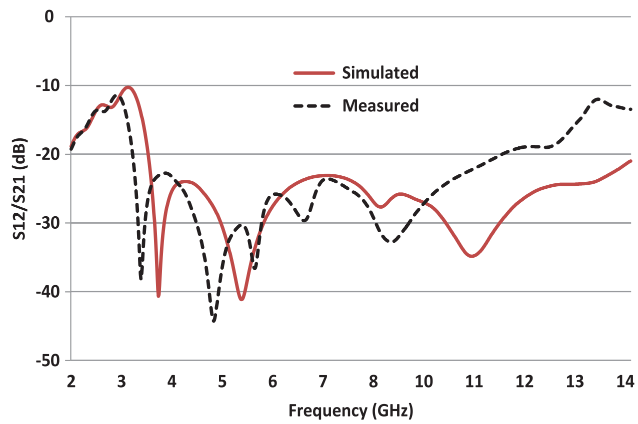


Figure 7: Fabricated design, top view (left) bottom view (right)



(a)



(b)

Figure 8: Simulated and measured results (a) S11/S22 (b) S21/S12

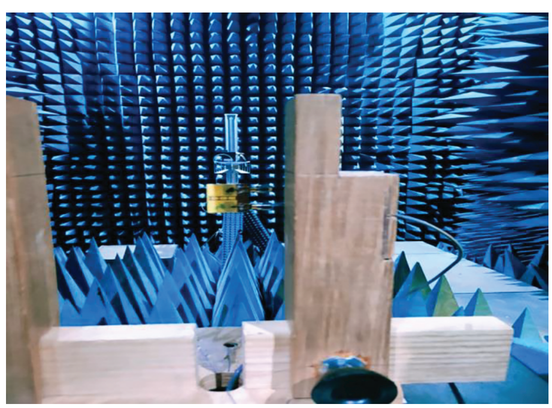


Figure 9: Proposed antenna testing

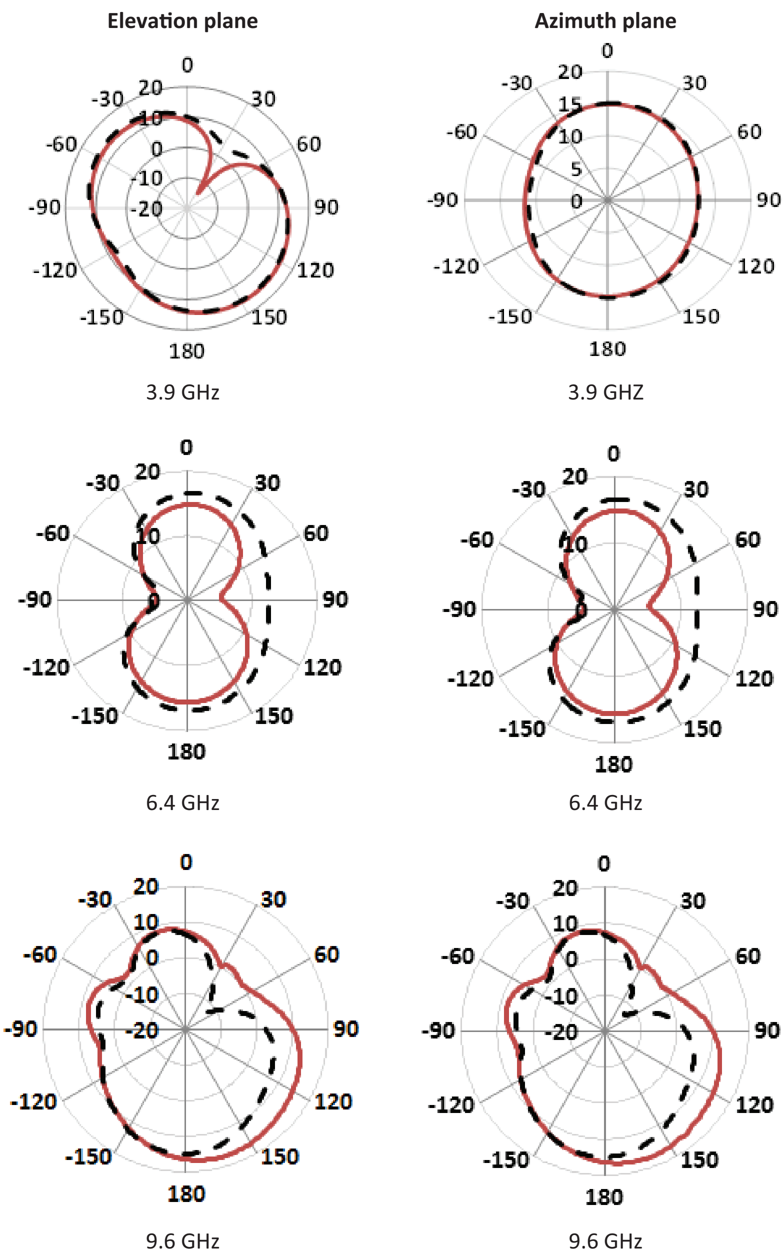


Figure 10: Radiation pattern at (i) 3.9 GHz (ii) 6.4 GHz and (iii) 9.6 GHz

The antenna gain, radiation efficiency and total efficiency results are presented in Fig. 11. This shows that antenna has a peak gain of 5.8 dB and an overall efficiency greater than 80%. In addition, Envelope co-relation co-efficient (ECC) and diversity gain of MIMO antenna was calculated and compared with simulated results. The ECC parameter shows the correlation among the MIMO antenna elements. The lower value of ECC shows that antennas are independent of each other. The ideal value of ECC should be '0'. Fig. 12 shows that ECC of the proposed antenna is less than 0.002. Moreover, the value of Diversity gain is also calculated and is greater than 9.96.

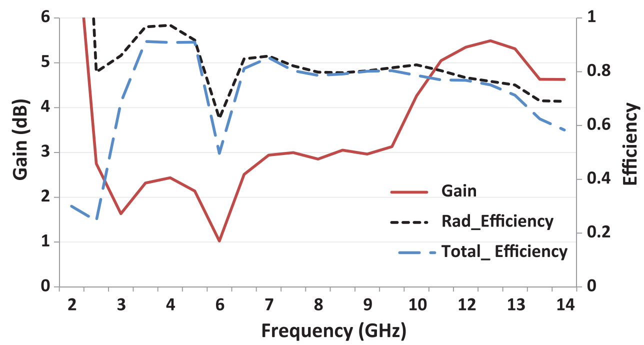


Figure 11: Simulated results of gain, radiation efficiency and total efficiency

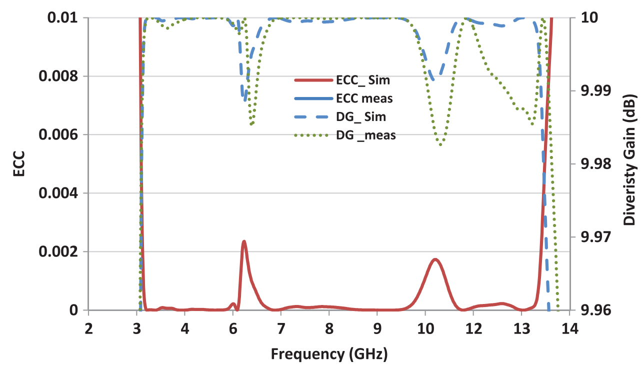


Figure 12: Simulated/measured results of ECC and diversity gain

In Table 2, the performance comparison of proposed antenna with that of previous research work is presented. This table compares the performance in terms of overall size, impedance bandwidth, mutual coupling, gain, ECC and Diversity gain. It can be concluded that the proposed antenna performance fulfills the requirement of UWB systems with significant rejection of narrowband systems using a compact size.

Table 2: Performance comparison with the state of the art

Reference	Dimension mm^2	Bandwidth (GHz)	No. of notches	Isolation level (dB)	Gain (dB)	Diversity gain (dB)	ECC
[26]	38 × 18	3.1–11	–	−18	0.9–4	–	<0.01
[27]	30.75 × 37.8	2.7–11.22	3	−20	0.07–3.40	–	<0.035
[28]	33 × 48	2–13.7	–	−20	1.1–4.3	<9.99	<0.15
[29]	19 × 30	3.1–10.6	2	−18	1.1–2.91	< 9.99	<0.13
[30]	18 × 35	2.1–12	2	−20	1.1–6	–	<0.035
[31]	40 × 28	3.01–13.5	–	−17	–	–	<0.01
[32]	30 × 26	2.85–12.95	–	−20	2.06	–	–

(Continued)

Table 2: Continued

Reference	Dimension mm^2	Bandwidth (GHz)	No. of notches	Isolation level (dB)	Gain (dB)	Diversity gain (dB)	ECC
[33]	23.5 × 83	2.4–2.52, 3.66–4, 4.62–5.52	–	−30	–	<9.96	<0.5
[34]	23 × 40	2–11	3	−17	5.2	–	<0.5
[35]	20 × 34	2.6–11.2	1	−20	4	–	–
Proposed	**22 × 30**	**3.1–14**	**1**	**−23**	**1.1–5.8**	**<9.99**	**<0.01**

4 Conclusion

A compact ($22\,mm^2 \times 30\,mm^2$) MIMO antenna with WLAN band notch is presented in this research paper. The antenna operates in the frequency band ranging from 3.1–14 GHz covering the whole UWB range. The antenna has low mutual coupling (<−23 dB) in the whole UWB band. A ground stub of complementary rectangular shape is used in the proposed antenna. The antenna shows peak gain of 5.8 dB and a radiation efficiency of more than 80%. Moreover, slot is used in the patch for WLAN band (5.1–5.9) GHz suppression. In addition, other MIMO parameters are also obtained i.e., low ECC < 0.002 and high Diversity gain > 9.98. All above performance parameters make the proposed MIMO antenna a suitable candidate for UWB applications.

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