



Design of UWB MIMO Antenna to Reduce the Mutual Coupling Using Defected Ground Structure

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Accepted: 28 January 2021 / Published online: 9 February 2021

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Abstract

A novel compact monopole UWB antenna is described and analyzed using defect in ground plane (DGS). This MIMO design has an area of $60 \times 35 \text{ mm}^2$ with total size of 2100 mm^2 which maintained between the square type patches separation is $0.05 \lambda_0$. The current design achieved tri-band frequencies at 3.5, 4.8 and 9.0 GHz due to introducing arcs at the edges of square type patches. For the impedance bandwidth of the design covers an average peak gain of radiator is 5.04 dBi with a little-bit variations in the current design is ± 1.20 dBi. The measured Impedance Bandwidths of the MIMO design are 1000 MHz (3.0–4.0 GHz), 1300 MHz (4.3–5.6 GHz) and 1100 MHz (8.4–9.5 GHz) covered the frequency range from 2.0 to 10.0 GHz. These frequencies covered the applications of WLAN, bluetooth and ultra-wide band which maintained $\text{VSWR} \leq 2$. The proposed structure resembles a omnidirectional radiation patterns with narrow compact size at the resonant band of frequencies.

Keywords Impedance bandwidth · Peak gain · Ultra wide band antenna (UWB) · Group delay · Envelope correlation coefficient

1 Introduction

The demand for ultra-wideband antenna systems (UWB) requires present emerging wireless applications of communication system requires high data rate and channel capacity. The federal communication commission system (FCC) with unlicensed spectrum which is ranging from 3.1 to 10.6 GHz. In [1], packaging and design of UWB antenna operated from 2.83 to 20.83 GHz produced ECC and DG are less than 0.006 and greater than 9.88 dB. A compact size of $18 \times 34 \text{ mm}^2$ UWB MIMO system operated from 2.93 to 20.0 GHz produced the MIMO parameters within the acceptable limit produced

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dual-band operations have $S_{12} \leq -22$ dB [2]. For dual-band antennas using decoupling method occupied area of 100×150 mm² with edge separation $0.0083\lambda_H$ produced isolation -25 dB [3]. Using compact size designed UWB MIMO [4]. The technique applied for low mutual coupling multilayered structure using EBG structure with edge separation $0.1188\lambda_H$ produced isolation -31 dB [5], a four-element MIMO structure to enhanced isolation with size of 119 mm \times 119 mm using metamaterial type mushroom structure with bandwidth of 2.2% and isolation ≥ -16 dB [6]. A MIMO diversity radiator with a compact size 18 mm \times 36 mm ranging from 2.9 to 20.0 GHz with maintained better MIMO parameters [7]. In [8], CSRR enabled UWB operating 3.0–12.0 GHz with an area 23×29 mm², a compact size of 45.5 mm \times 42 mm radiator have designed a filter based metamaterial using the property of mu-negative [9]. In [10] considered a 4-channel hybrid structure MIMO antenna with an area of 88×88 mm² with 8.2% of bandwidth obtained whose isolation ≤ 0.05 . For radar cross-section areas metamaterial structures are combined with absorbers [11], using parasitic structure and notch band characteristics a UWB-MIMO radiator is designed of size 65×65 mm² whose isolation ≤ -20 dB operating 3.1–17.7 GHz which maintained good MIMO parameters [12]. In [13], designed a biplanar yagi type structure MIMO with 50 mm \times 80 mm with inter element spacing of $0.2008\lambda_H$ produced isolation greater than -17 dB. By using the technique of element rotation a microstrip array with RCS reduction [14], a closely spaced diversity UWB system with greater improvement in isolation have 60 mm \times 40 mm operating 3.1–10.0 GHz whose isolation ≤ 0.04 with in the acceptable region of the MIMO system [15]. A very low compact size of 20 mm \times 35 mm [16] ranging from 3.34 to 3.87 GHz with inter element spacing of $0.1002\lambda_H$ whose isolation maintained ≤ -20 dB. The reduction of mutual coupling using the technique of metamaterial 3-D novel structure with 60 mm \times 60 mm ranging from 2.35 to 2.45 GHz with inter element spacing of $0.1175\lambda_H$ of isolation -18 dB [17]. The elliptical shape MIMO antenna have 16 mm \times 71.5 mm with operating 3.2–14.0 GHz with better MIMO parameters [18] within acceptable limit. For the applications of UWB designed a compact monopole antenna using the technique of DGS ranging 3.2–11.5 GHz ECC and DG are less than 0.015 and greater than 9.4 dB [19]. The designed technique of compact MIMO design with portable devices [20], double sided MIMO designed with peak average gain about 4 dBi and isolation ≤ -20 dB [21]. Finally, a microstrip fed MIMO design have Tee crossed type structure diversity system maintained the ECC ≤ 0.2 within acceptable region of the system [22]. The previous designs interesting to identified that that only focused on the design of compact MIMO antennas but fails to implement the issue of interference between the patches for WLAN and satellite range bands for UWB region applications. Without disturbing the structure of MIMO antenna, this paper adequately address these problems with compact size and considered a defect in ground plane structure (DGS) enhanced the mutual coupling problem. Table 1 indicates the comparison of current work with recently published work. Rest of the MIMO paper explain in Sect. 2 methodology of the current design followed by Sect. 3 describes results includede with their discussion. The concluded version of the current MIMO design discussion in Sect. 4.

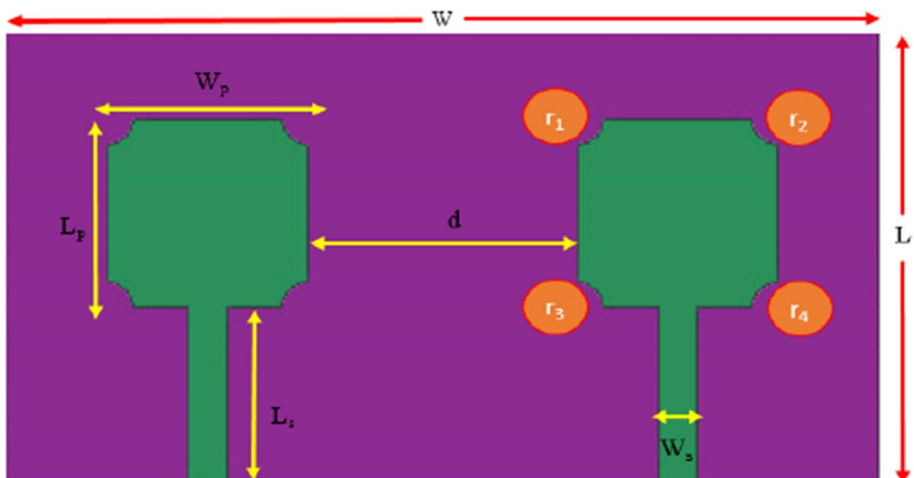
Table 1 UWB MIMO comparison with other MIMO methods

Ref.	Size (mm ²)	S ₁₁ (dB)	S ₁₂ (dB)	f _L – f _H (GHz)
Srivastav et al. [1]	60 × 60	–15	–28.75	2.8–20.82
Gautam [2]	18 × 34	–25	–22	2.9–20
Jiang et al. [5]	60 × 60	–31	–29	2.3–2.8
Zhai et al. [6]	119 × 119	–16	–19	2.39–2.45
Chandel [7]	18 × 36	–40	–29	2.9–20
Khan [8]	23 × 29	–17	–31	3.0–12
Thummaluru [9]	45.5 × 42	–25	–32	3.0–10.0
Kim et al. [10]	88 × 88	–15	–20	2.34–2.54
Jehangir et al. [13]	50 × 80	–17	–21	4.18–6.58
Mao et al. [15]	60 × 40	–20	–24	3.1–10.6
Saurabh et al. [16]	20 × 35	–21	–28	3.34–83.87
Yu et al. [17]	60 × 60	–18	–23	2.35–2.45
Hasan Nazmal et al. [19]	80 × 80	–15	–27	3.2–11.5
Guo et al. [20]	30 × 40	–20	–52	3.1–10.6
Proposed system	60 × 35	–23.73 –27.43 –19.87	–16.53 –18.17 –17.95	3.0–4.0 4.3–5.6 8.4–9.5

2 Design of MIMO Antenna

2.1 Antenna Configuration

The design of proposed MIMO antenna front plane and back plane as illustrated in Figs. 1 and 2. The two radiating patches of similar antenna elements arranged side by side with proper spacing and defect in the ground plane is arranged. A compact area of $0.55\lambda_0 \times 0.95\lambda_0$ (60×35

**Fig. 1** Front view of UWB system

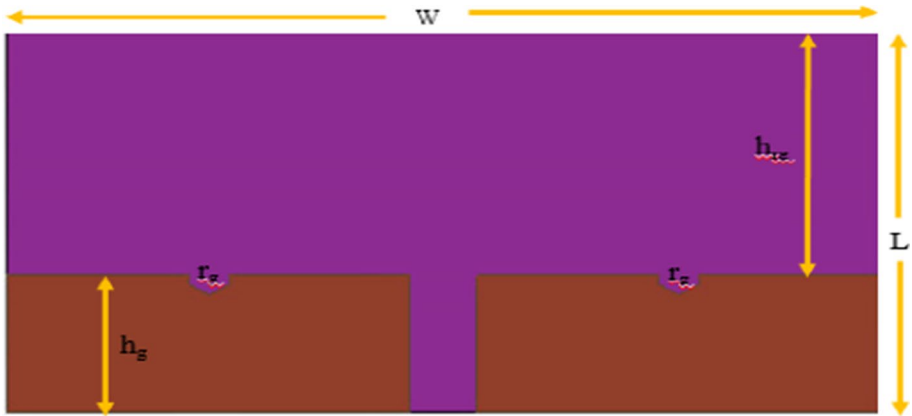


Fig. 2 Back view of UWB system

mm²), the parameter λ_0 indicates the free space wavelength. The current MIMO structure have a rectangular dimension ($L \times W$) considered and perform the operation at the four edges of square patches cut with a radius of r_1, r_2, r_3 and r_4 . A monopole ground plane is considered on back side of the ground plane to improve the impedance bandwidth of the design and reduction of mutual coupling. At the monopole ground plane a half circular arc is removed on both sides of the patch. The proposed UWB system fabricated using the material of FR-4 having loss-tangent of 0.002, permittivity of 4.4 and its thickness is 1.6 mm. Table 2 shows the design parameters of MIMO design system.

Figure 3 shows step by step analysis of the proposed UWB MIMO design. In stage_1 (Antenna # 1) a simple square patch is considered produces an output of UWB range frequency from 3.1 GHz to 10.0 GHz for the entire region maintained $S_{11} \leq -0$ dB. In stage_2 (Antenna # 2) a simple square patch with a small arc cutting from right hand side of the patch produces an output of UWB range frequency from 3.1 GHz to 10.0 GHz for the entire region maintained $S_{11} \leq -10$ dB. In stage_3 (Antenna # 3) a simple square patch with a small arc cutting from right and left hand side of the patch on top corner produces an output of UWB range frequency from 3.1 to 10.0 GHz for the entire region maintained $S_{11} \leq -10$ dB. In stage_4 (Antenna # 4) a simple square patch with a small arc cutting from right, left hand side of the patch on top corners and bottom side of the square patch right corner produces an output of UWB range frequency from 3.1 to 10.0 GHz for the entire region maintained $S_{11} \leq -10$ dB. In stage_5 (Antenna # 5) a simple square patch with a small arc cutting from right, left hand side of the patch on top corners and bottom side of the square patch right, left corners produces an output of UWB range frequency from 3.1 to 10.0 GHz for the entire region maintained $S_{11} \leq -10$ dB. In stage_6 (Antenna # 6) consists of a square patch cutting at the four sides of the corners shifted the same patch with a minimal separation distance become UWB MIMO design. This design produces an output of tri-band frequencies within the UWB frequency

Table 2 Square slot MIMO antenna parameters

Parameters	L_p	W_p	L	W	r_1	r_2	r_3	r_4	h_g	r_g	h_{rg}	L_s	W_s	d
Unit (mm)	25	25	35	60	2	2	2	2	12	1.8	23	6	3	5

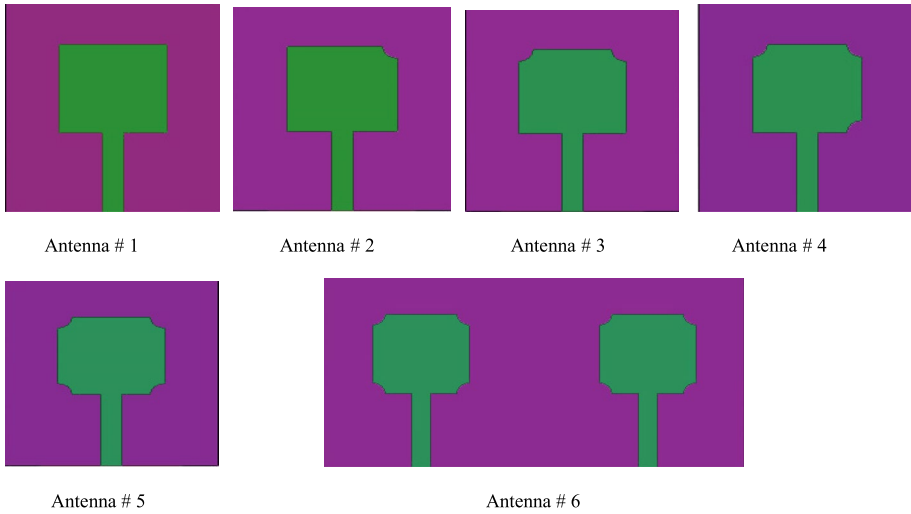


Fig. 3 UWB MIMO analysis step by step stages

from 3.1 to 10.0 GHz for the entire region maintained $S_{11} \leq -10$ dB. Due to this type of novel approach produces a circular polarization for the wireless communication applications. The entire analysis of proposed MIMO design each step by step analysis shown in Fig. 4

2.2 Effect of Ground Plane in MIMO Design

In the current UWB MIMO design system observed that ground plane plays a crucial role for reducing the effect of isolation and improving the antenna parameters. The design system not only improve the isolation but also improve in the parameter of impedance bandwidth. As in the design approach the S-parameters of S_{11} and S_{21} is also same as S_{22} and S_{12} due to identical antennas placed on the substrate. Another observation made in the

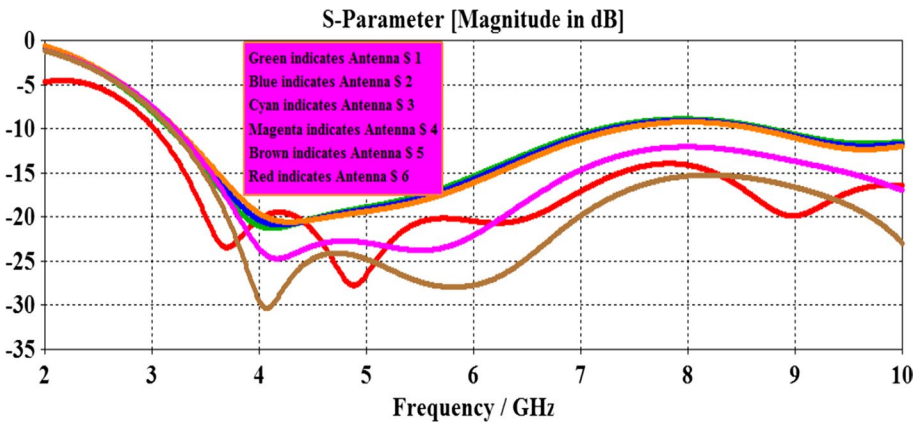


Fig. 4 UWB MIMO system evolution stages

monopole ground design by cutting the half circular arcs at the feeding point of microstrip feeding point minimizes greatly interference among the radiating patches both at bottom plane and top plane of the MIMO design.

2.3 Parametric Analysis of MIMO Design

The effect of various distances explains the parametric analysis of the proposed UWB MIMO system in terms of its reflection (S_{11}) as well as transmission coefficients (S_{12}). The current design provides tri-band frequencies which is at 3.5 GHz, 4.8 GHz and 9.0 GHz due to the strip is located nearer to the feeding point. It is interesting to noticed that there is a change in the distance among the patches mutual coupling parameter varies by parametric variation of distances varied between $d=2$ mm to $d=3.5$ mm. In case_1 consider that $d=2$ mm among the two radiating patches produce the S_{11} & S_{12} are -29 dB and -16 dB. In case_2 consider that $d=2.5$ mm among the two radiating patches produce the S_{11} and S_{12} are -70 dB and -18 dB. In case_3 consider that $d=2.8$ mm among the two radiating patches produce the S_{11} and S_{12} are -50 dB and -20 dB. In case_4 consider that $d=3.1$ mm among the two radiating patches produce the S_{11} and S_{12} are -45 dB and -32 dB. In case_5 consider that $d=3.3$ mm among the two radiating patches produce the S_{11} and S_{12} are -49 dB and -35 dB. Finally, In case_6 consider that $d=3.5$ mm among the two radiating patches produce the S_{11} and S_{12} are -41 dB and -29 dB. The above six cases observed that how mutual coupling parameter influences for various distances in the UWB region. To evaluate the compactness and wideband characteristics of the proposed MIMO design is calculated the Bandwidth Dimension Ration parameter (BDR) using Eq. (1). For the proposed structure BDR is equal to 2100 which represents compactness of the design (Figs. 5, 6).

$$BDR = \frac{\%Band\ width}{\lambda_{length} \times \lambda_{width}} \quad (1)$$

where λ = lower side operating frequency.

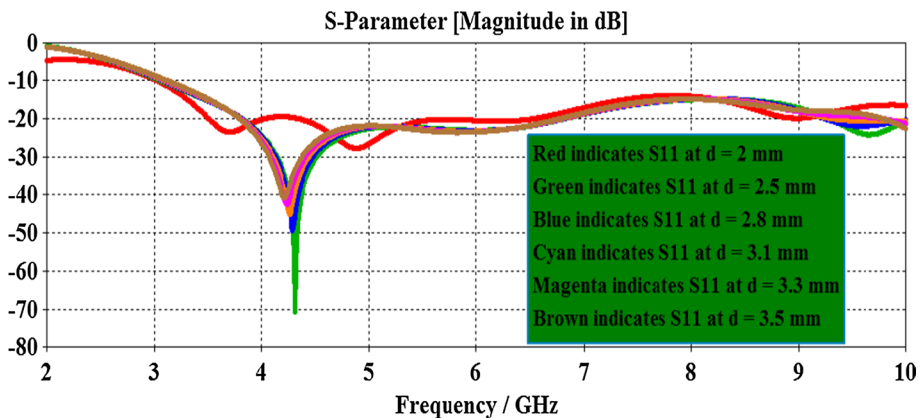


Fig. 5 UWB design for various distances of S_{11}

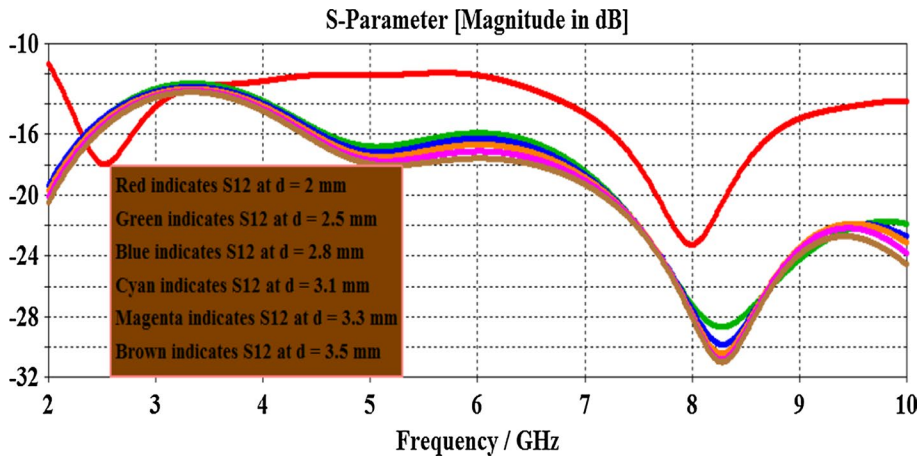


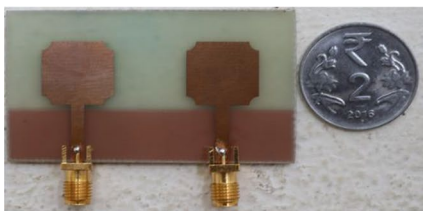
Fig. 6 UWB design for various distances of S_{12}

3 Results Analysis Discussion

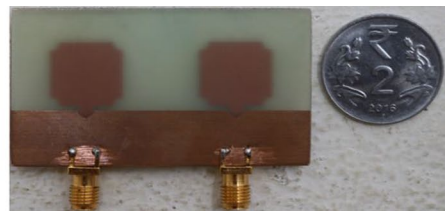
3.1 Performance of Impedance

Figures 7 and 8 indicated that prototype UWB MIMO antenna front and back planes of the current design. Table 2 represents the finalized parameters of the current MIMO design after verified various parametric analysis in terms of among distances produced transmission and reflection coefficients. The comparison of measured as well simulation parameters comparison graph is obtained by measuring the values using Agilent N5234A PNA-L. There is a good agreement between simulated and measured results as function of frequency versus its S-parameters are observed. There is a little-bit variations in measured as well as simulated results due to connector losses and soldering effects of the design. The measured IBW's as well as VSWR < 2 for the proposed structure ranging from 3.0 to 10.0 GHz which consists of 4.0–3.0 GHz, 5.07–4.34 GHz and 9.75–8.20 GHz and for the remaining frequencies VSWR > 2. The comparison graph of measured and simulated VSWR as shown in Fig. 9

Figure 10a–d shows effectiveness of the MIMO structure current distribution on the surface of the antenna at tri-band frequencies. The distribution of currents at various



(a) MIMO design front-view



(b) MIMO design back-view

Fig. 7 Prototype of UWB design

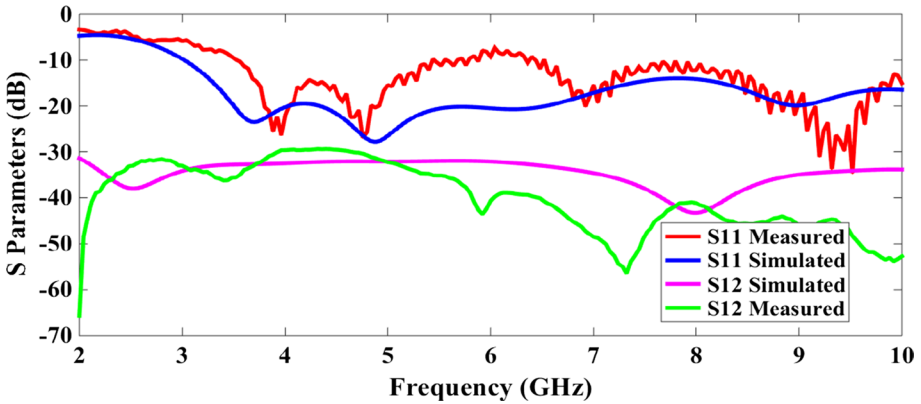


Fig. 8 UWB design comparison of S-parameters

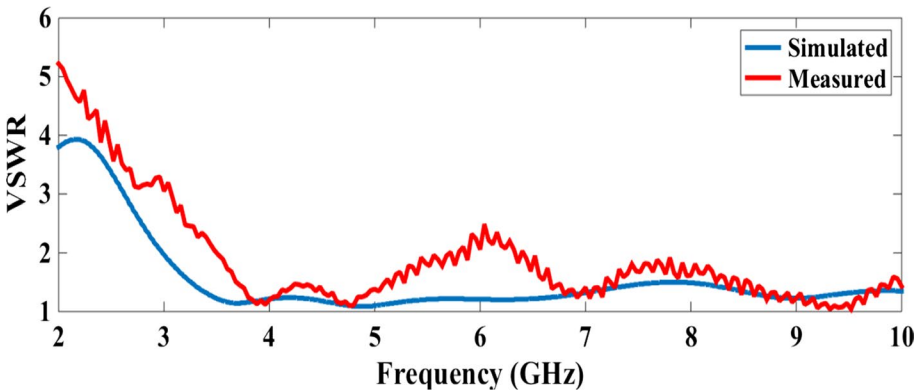


Fig. 9 UWB MIMO design VSWR comparison

frequencies are obtained when one port of the device is terminated with matched load and other port of the device is excited. It can be identified that a monopole ground with small arc consider at the feeding point of the both patches strong maximum amount of current flowing from port 1 of the device to port 2 of the device which resulted high amount mutual coupling among the two ports. With the connected system of monopole ground more amount of current is concentrated at the feeding point of port 1 and resulting improved isolation at the feeding point of port 2. Hence, with the monopole ground plane and small arcs coupling from the device of port 1 to the device of port 2 suppressed. Similarly, this procedure is applied to all the tri-band frequencies considered port 2 excited at 3.5 GHz, port 1 excited at 4.8 GHz and port 2 excited at 9.0 GHz are observed.

The characteristics of tri-band proposed MIMO design are easily identified by using the impedance parameters (Real and Imaginary) which is shown in Fig. 11. From the impedance characteristics noticed that imaginary component is parallel to the resonance of the system and high value of resistive component at the frequencies of 3.5, 4.8 and 9.0 GHz. By consider various values related to C_i , R_i and L_i are calculated the bandwidth as well as resonant frequency of a parallel resonant circuit using the relations of Eqs. (2) and (3)

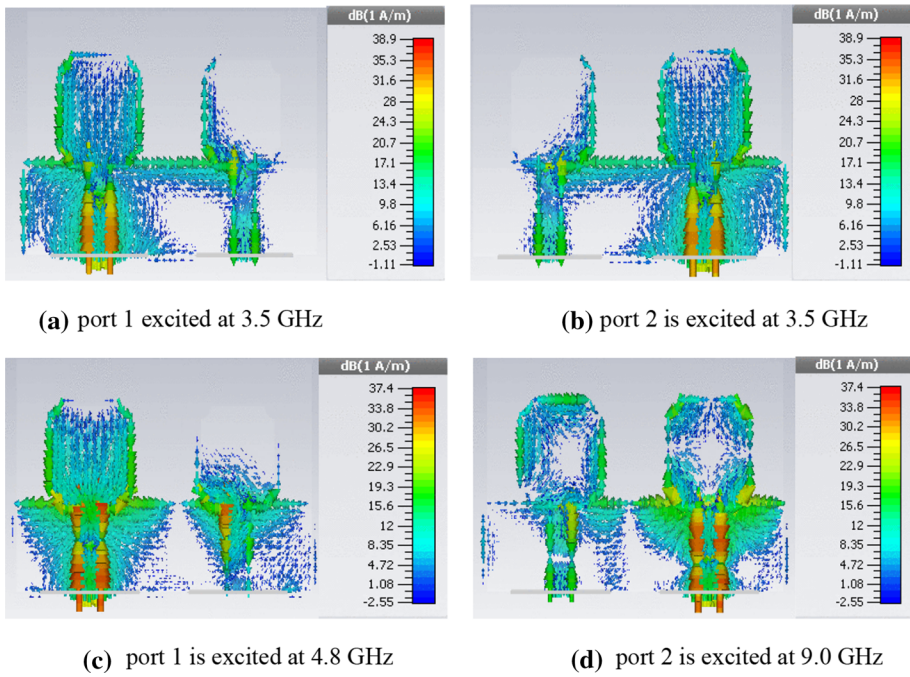


Fig. 10 Distribution of surface currents at 3.5, 4.8 and 9.0 GHz

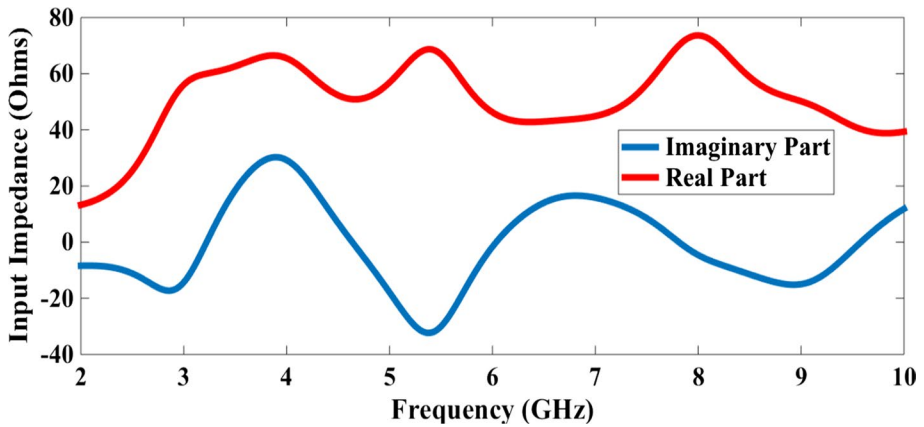


Fig. 11 Impedance versus frequency

$$\omega_0 = \frac{1}{\sqrt{L_i C_i}}; \quad i = 1, 2, 3 \tag{2}$$

$$BW = \frac{1}{R_i C_i}; \quad i = 1, 2, 3. \tag{3}$$

3.2 Time–Domain Analysis of MIMO Design

The parameter which is used to calculate the analysis of face–face and side-by-side (X-axis and Y-axis) orientations with two similar radiating patches is known as group delay. The minimum acceptable value of the current MIMO design obtained at tri-band resonant frequencies. In this process placing one port of the antenna device is excited while other port of the device terminated with 50Ω of characteristic impedance load and vice-versa.

Figure 12 describes that the group delay parameter is almost constant for various orientations and also observed that at tri-band resonant frequencies it varies combination of positive and negative group delay. Another important parameter in time domain analysis is its Pulse Fidelity Factor (PFF) which is calculated from the design in different orientations of face-face and side-side for transmitting as well as receiving antennas. To evaluate the parameter PFF, the correlation factor is evaluated among the input signal for transmitting antenna and output signal for the receiving antenna. The expression for correlated signal is evaluated using Eq. (4) which indicate input signal with $S_1(t)$ and output signal with $S_2(t)$.

$$\rho = \max \left\{ \frac{\int s_1(t) s_2(t - \tau) dt}{\sqrt{s_1^2(t)} \sqrt{s_2^2(t)}} \right\} \quad (4)$$

From the current MIMO design observed that PPC (Pulse Preserving Capability) is good in the orientations of face-face and side-by-side at the input–output system have the correlations factor are 0.7923 and 0.7523.

3.3 Radiation Performance

The radiation patterns of tri-band frequencies are measured by exciting the port of the device and terminated by load impedance of 50Ω with other port and vice-versa. The tri-band

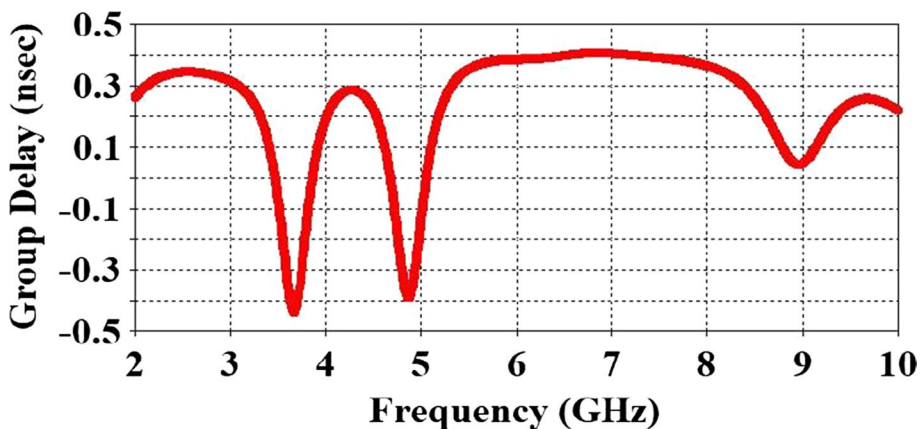


Fig. 12 Group delay versus frequency

resonant frequencies of the current UWB MIMO design illustrated in Fig. 13. The results drawn from the comparison of measured and simulated results observed that stable radiation patterns at the resonant frequencies of 3.5 GHz, 4.8 GHz and 9.0 GHz. In order measure the radiation pattern in yz-plane port # 1 of the connector is excited while the other port #2 device terminated with a load of 50 Ω. Similarly to measure the radiation pattern in xz-plane port # 1 of the device system is terminated with load of 50 Ω while the other port # 2 of the device is excited of the device. Due to the arrangement of identical structure in the substrate, the realized gain of the UWB MIMO system observed that measured and simulated results are almost identical. Figure 14 illustrated the peak gain of the UWB MIMO system comparison (Measured and Simulated) which produce a maximum peak gain of 5.04 dBi. In order to justify the performance of the designed antenna using the parameter of efficiency which is shown in Fig. 15. The comparison of UWB MIMO system efficiency (Simulated and Measured) over the tri-band resonant frequencies greater than 78%. When the horizontal components of the system increases there is an increase in the frequency of the cross-polarized magnitude is proportionally increases. There is a reduction in mutual coupling identified that placing the antenna elements maintaining a proper placement of λ/2 of the MIMO antenna configuration.

3.4 The Diversity Characteristics

The behavior of the MIMO performance is evaluated using ECC and DG. ECC evaluated from the isolation among the adjacent antenna elements. This parameter is calculated by using far-field analysis and S-parameter analysis using the Eqs. (5) and (6). ECC parameter results the channel isolation in MIMO wireless communication system. Figure 16 resemblance the comparison of ECC for far-filed analysis and S-parameter analysis with in the acceptable value ≤0.5 for diversity/ MIMO criterion.

$$ECC = \frac{\left| \iint_{4\pi} [E_1(\theta, \phi) * E_2(\theta, \phi)] d\Omega \right|^2}{\iint_{4\pi} |E_1(\theta, \phi)|^2 d\Omega \iint_{4\pi} |E_2(\theta, \phi)|^2 d\Omega} \tag{5}$$

Here $E_i(\theta, \phi)$ represents complex 3-D radiated field pattern

$$ECC = \left| \frac{\iint_{4\pi} |S_{11}^* S_{21} + S_{21}^* S_{22}|}{\left[(1 - (|S_{11}|^2 + |S_{21}|^2))(1 - (|S_{22}|^2 + |S_{12}|^2)) \right]^{1/2}} \right| \tag{6}$$

The DG of the UWB MIMO system can be evaluated using the relation is Eq. (7)

$$DG = \sqrt{1 - |\rho_c|^2} \tag{7}$$

The above relation represents the combination of correlation coefficient and its diversity gain. For the UWB MIMO system at tri-band frequencies MIMO parameters of DG and ECC produces are 9.9994, 9.9996 and 9.9999 and 0.0035, 0.00031and 0.000985 respectively for 3.5 GHZ, 4.8 GHz and 9.0 GHz which is approximately equal to the within the acceptable limit (Fig. 17).

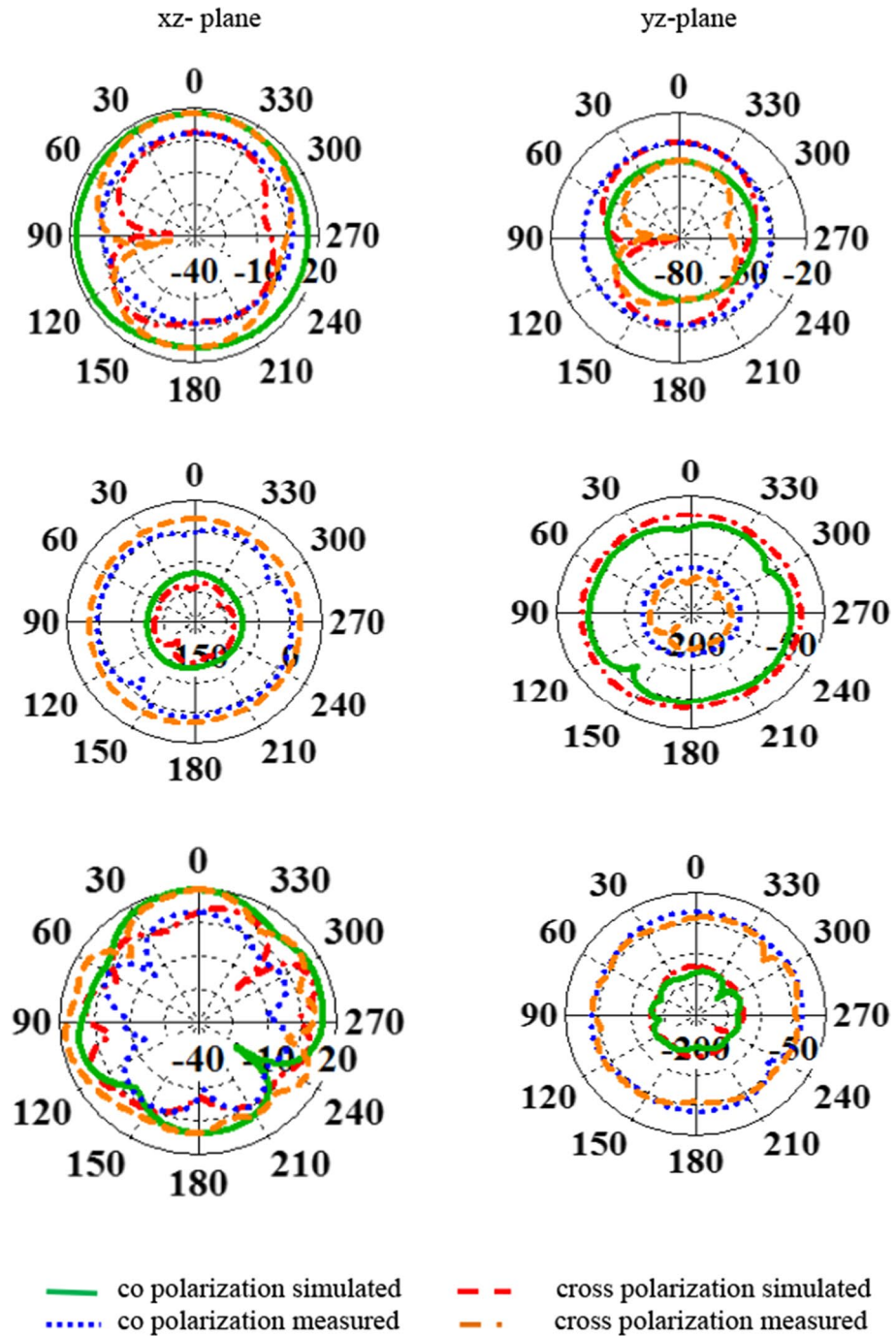


Fig. 13 Tri-band frequencies radiation patterns at 3.5, 4.8 and 9.0 GHz

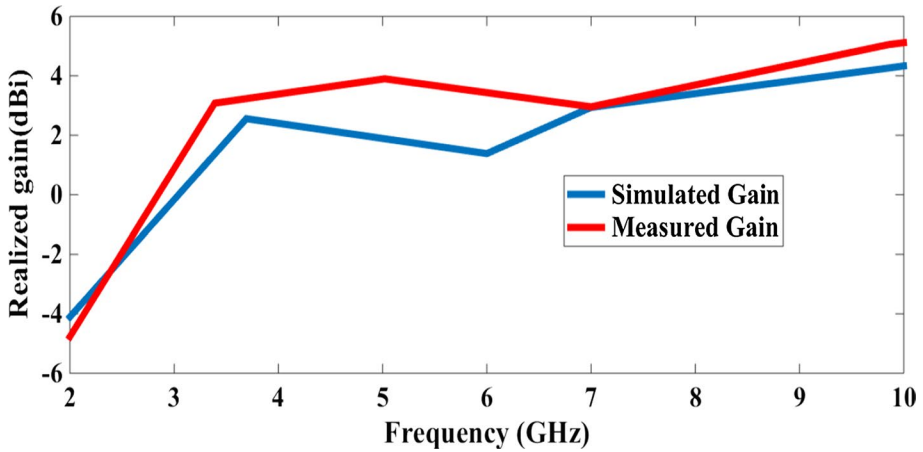


Fig. 14 Realized gain of the proposed structure

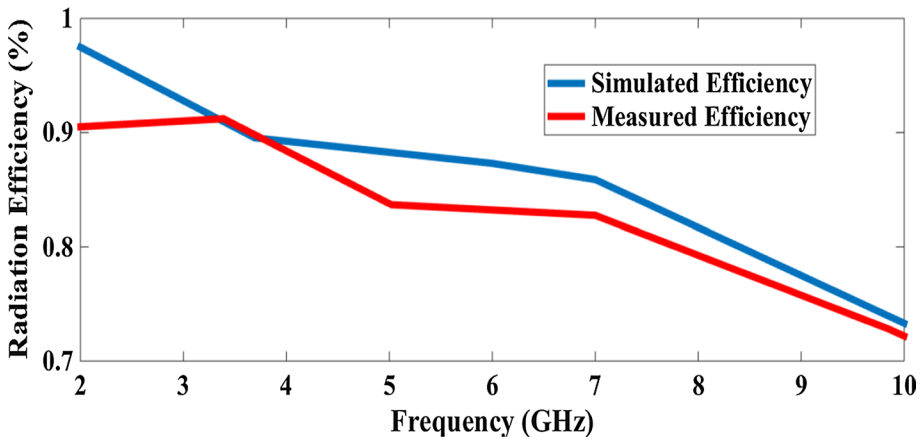


Fig. 15 Radiation efficiency versus frequency

4 Conclusion

In this research article proposed a compact MIMO/ diversity UWB antenna is proposed. This MIMO structure produce tri-band operations among the frequency operated between the UWB regions. The designed structure have compact size of $60 \times 35 \times 1.6 \text{ mm}^3$. The mutual coupling is enhanced by etching the monopole ground plane and a small half circular arcs are cut at the microstrip feeding have been observed. The impedance bandwidth is evaluated for the current MIMO design ranging from 3.0 to 10.0 GHz. The tri-band resonant frequencies produced stable pattern of radiations. In addition to antenna parameters additionally evaluated the real and imaginary parts of the design, group delay and impedance characteristics are observed. The MIMO parameter of ECC is evaluated using far-field and S-parameter analysis. In order to obtain the high channel capacity of the design structure should maintain the $ECC \leq 0.25$. Thus the current design structure of MIMO used for applications UWB.

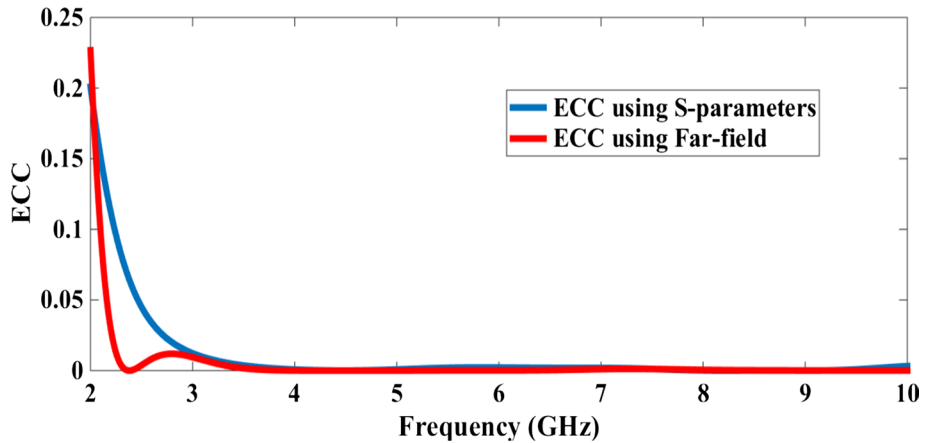


Fig. 16 Radiation patterns at 3.5 GHz, 4.8 GHz and 9.0 GHz

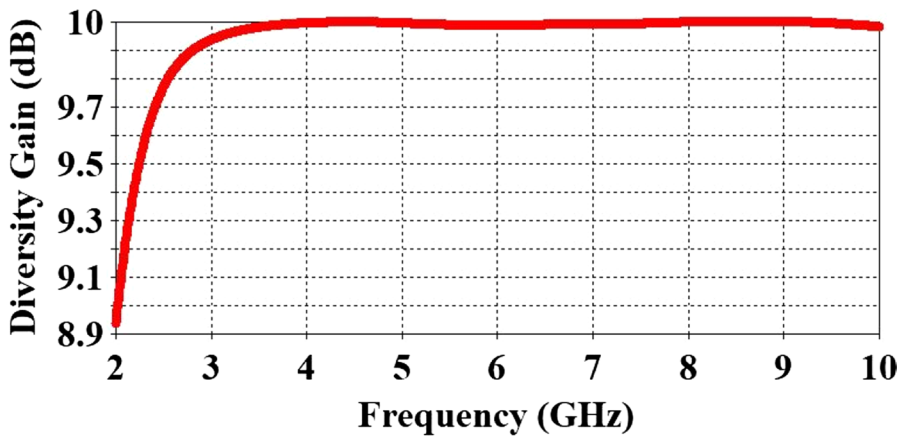


Fig. 17 UWB MIMO radiator diversity gain

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