Compact CPW fed Four Port MIMO Antenna for UWB applications with Wi-Fi/ISM/WLAN Band Notch Characteristics

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***Abstract*—**

A compact UWB with WLAN notch-based four-element CPW fed MIMO/diversity antenna is presented in this paper. Multiple elements facilitate the design to transmit and receive the signal from all directions enhancing the channel capacity and diversity performance. The inverted L-shaped stub attached to the ground enhances the impedance bandwidth (10 dB) and provides the UWB response. Plus and cross-shaped decoupling structure is accomplished to diminish the surface current and enhances the isolation between antenna elements and it is more than 20.2 dB from port-1 to port-4 without affecting the impedance bandwidth and radiation pattern. A complimentary split ring resonator (CSRR) in the radiator is utilized to eliminate the Wi-Fi/WLAN band. The |S11| of UWB MIMO antenna varies from 3.26 GHz to 14 GHz which can be utilized in portable, Radar, Satellite, and wireless applications. The simple decoupling structure is used to correlate and isolate the antenna elements, therefore acceptable ECC and CCL parameters are achieved.

***Keywords*—** Diversity Antenna, Multiple input Multiple output (MIMO) Antenna, UWB applications, Band Rejection Antenna

1. Introduction

In subsequent years, with the advancement of technology, the dimensions of wireless communication are also increased, due to which demand of bandwidth and channel capacity of the antenna have also increased [1]. Ultra-wideband (UWB) antenna has drawn more attention due to its strength of affordable price, higher transmission rates, and larger communication capability [2]. Despite all these advantages, UWB communication suffers the problems of reliability and multipath signal fading that degrades the system performance [3]. To address these problems, the MIMO system ensures a practical solution without adding any extra bandwidth and power usage [4]. In the conventional MIMO antenna, the distance between two elements should be kept minimum λ/2 for the acceptable value of isolation. But to achieve the compact MIMO antenna the distance between two antenna elements reduces which decrease the isolation between antenna elements results in low ECC and CCL. Multiple decoupling technologies is used in literature such as MTM, EBG, and DGS, where DGS influences the S-parameter of antenna.

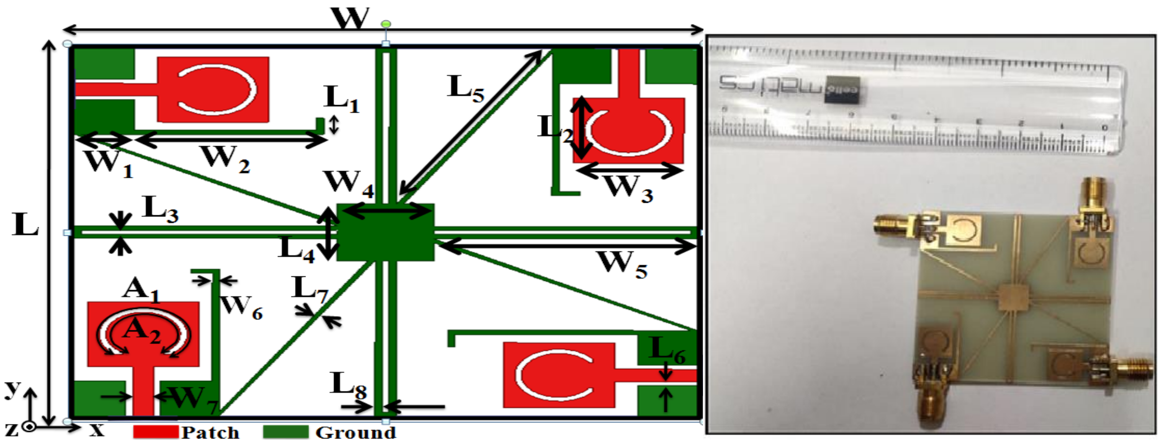
In [5] to obtain insertion loss of -17 dB through the polarization diversity four antenna elements are placed orthogonally, where stub in the ground plane eliminates WLAN band and works as a notch. The design proposed in [6] utilizes similar technology to attain the same value of isolation along with the 4.91 GHz to 6.41 GHz notch band. In [7] compact printed four-port antennas are employed perpendicular and obtained polarization diversity with mutual coupling decreases from -17 dB between antenna elements. In [8], CPW fed four-port MIMO antenna is reported perpendicular to each other so that low mutual coupling without decoupling structure is achieved where the two SRR slot is introduced in the rectangular radiator to minimize the interference in WLAN and Wi-Max band. In [9], a semi electrical shape CPW fed four-port antenna with tapered feed is suggested where isolation is enhanced with semi-elliptical slots in the ground without additional decoupling structure. In [10] micro strip antenna with folded strip notch is presented where the mutual coupling is reduced through the T stub and CSRR slot in the ground. Four rhombic-shaped planar antennae with elliptical CSRR notch placed orthogonally is used in [11] where a cross-shaped decoupling structure is utilised to isolate the antenna elements. A circular slot, the disc-shaped radiator is used with [12] with the defected ground where unconnected ground and distance between the radiators are used to isolate the antenna element. In [13] circular-shaped radiator is used to achieve a four-port antenna where EBG structure is utilized to isolate the four-port antenna elements and radiator ground is unconnected to each other.

In this paper, a compact 4X4 UWB MIMO antenna is demonstrated where CSRR notch is introduced with band rejection ability. The antenna is accomplished in an orthogonal direction so that the diversity characteristic of the radiator is achieved. The antenna element is interconnected with cross and plus-shaped decoupling structure for its practical applications where 20.2 dB minimum isolation is achieved. The antenna is novel in following terms:

- The four CPW fed antenna placed in orthogonally symmetrical pattern to achieve polarization diversity.
- The interference of Wi-Fi/ISM/WLAN is avoided using CSRR technology in the antenna. The current flowing in the outer and inner part of CSRR is out of phase with each other which cancels the vector field therefore antenna provides band rejection ability.
- The L-shaped stub is inserted in the ground plane that provides the UWB response.
- The four port CPW fed antenna is compact in size, fabricated on single side of low cost FR4 material.
- The isolation is achieved more than 20 dB where the effect of decoupling structure is minimum in operating bandwidth and radiation pattern.

2. Antenna Design

The printed UWB four-element antenna geometry with hardware is illustrated in Fig. 1(a) and Fig. 1(b) respectively. The four-port antenna with the cross-shaped ground is designed on the FR4 (dielectric constant (ε_r) = 4.4) substrate. The optimized dimension of the radiator is 45 (W) x 45 (L) x 1.6 (t) mm^3. The detailed parameters of the antenna are assigned and given in Table-1.



(a) (b)

Figure 1(a) Proposed CPW fed four elements CSRR based antenna (b) Proposed hardware of prototype

Table-1 Optimized detail dimensions of CPW antenna

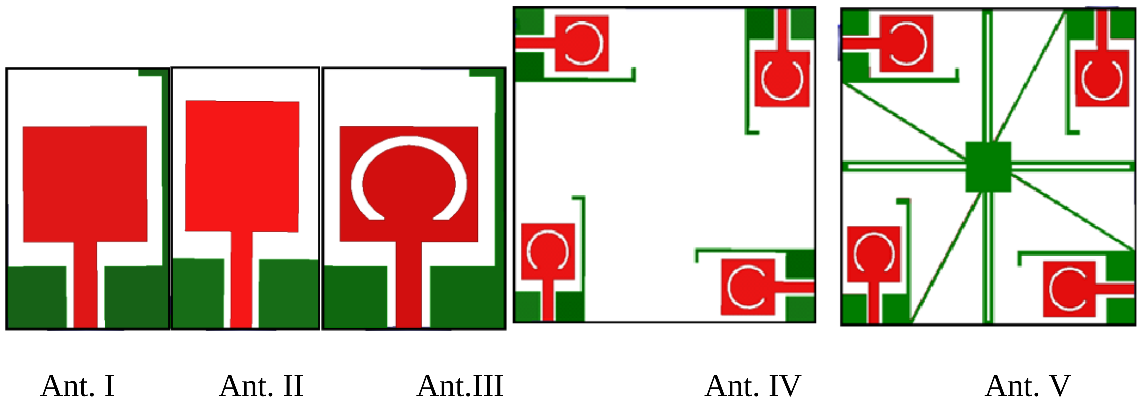
Symbol	**Value(mm)**	**Symbol**	**Value(mm)**
L_1	1.5	W_3	8
L_2	8	W_4	7
L_3	.5	W_5	.5
L_4	7	W_6	.5
L_5	21.38	W_7	1.5

L_6	.5	A_1	16.3
L_7	.42	A_2	14.4
L_8	.5	W_P	10.5
W_1	4.3	L_P	18
W_2	13.7		

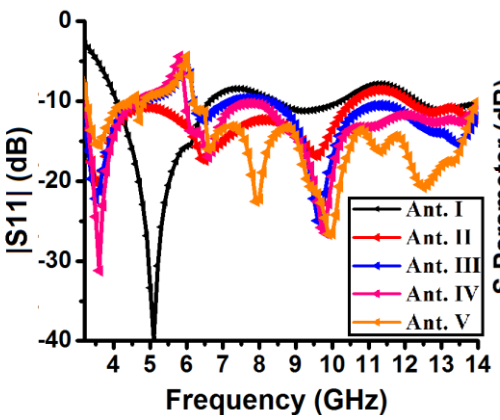
The MIMO antenna consist of four CPW fed antenna placed orthogonally each other to obtain the diversity performance where L-shaped extended ground is used to improve the bandwidth and impedance matching. CSRR technology is incorporated in radiators to mitigate the interference of the WLAN/Wi-Fi band. Isolation between antenna is enhanced by inserting simple cross and plus-shaped decoupling structure in the ground plane with minimal affect in the impedance bandwidth and radiation pattern.

3. MIMO Antenna Design Evolution Steps:

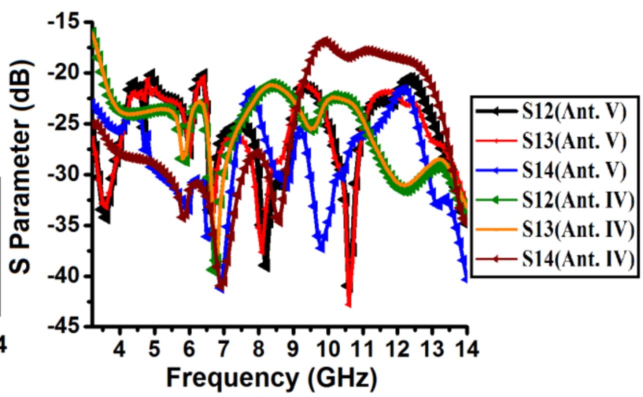
The design steps of CPW fed four-port antenna with CSRR technology accomplished in the radiator is illustrated in fig. 2(a). The evolution step of the MIMO antenna is a bifurcation in five steps with the help of Ant.-I to Ant.-V. The simulated |S11| parameter of different design steps from Ant.-1 to Ant.-V is demonstrated by fig. 2(b) and isolation between different ports of Ant.-IV and Ant-V is represented in fig. 2(c). In the first step, CPW fed single port rectangular-shaped antenna element is considered. The dimensions of the tiny single radiating element Ant.-I is 10.5 x 18 mm^2 that provides the impedance bandwidth from 4.2 GHz to 6.6 GHz.



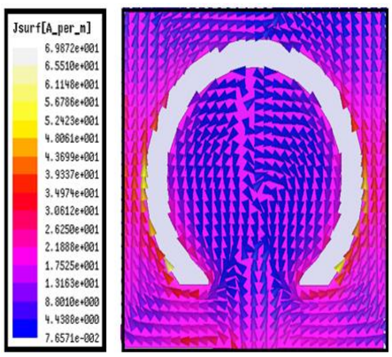
(a)



(b)



(c)



(d)

Figure 2(a) Evolution steps of the proposed prototype (b) |S11| Parameter of evolution steps of Ant.-1 to Ant.-V (c) Isolation of Ant.-IV and Ant.-V (d) Current distribution in the patch at 6 GHz

In the second step, the ground is modified with an inverted L-shaped stub therefore the electric length of the ground plane is increased, which enhances the antenna bandwidth by increasing the surface current path. The single element antenna with an L-shaped stub expends bandwidth from 3.48 GHz to 14.67 GHz (resonance of 3.8 GHz and 10.3 GHz) and responsible for UWB response. In the third step, CSRR is incorporated in the radiator to prevent the interference of the WLAN frequency band in the UWB span. The notch frequency varies from 4.9 GHz to 6 GHz where resonance of notch frequency can be calculated by [12]

$$f_{notch} = \frac{c}{(A_1+A_2)\sqrt{\varepsilon_{eff}}} \quad (1)$$

Where c = light speed, A_1 and A_2 are the length of inner and outer arc of SRR and

$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2}$.

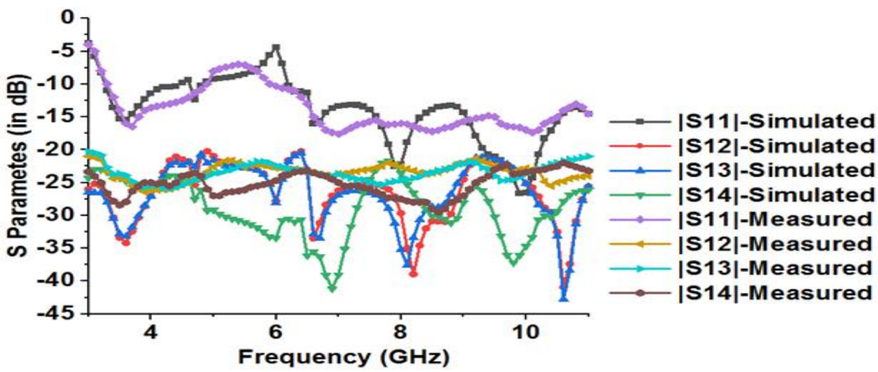
The unwanted band can be manipulated with the help of equation (1) which depends on the length of the circular slot and dielectric constant of the material. The position of the SRR varied to acquire the best outcome. To demonstrate the mechanism of notch characteristics through the SRR technology surface current at the notch frequency 6 GHz is revealed in Fig. 2(d), which illustrates that the current is mainly compound near the slotted radiator. Simultaneously the current flowing in the outer circle and inner circle are out of phase with each other. Due to this, the vector field is canceled and the antenna provides a restriction to radiate at WLAN frequency. Similarly, the same effect can be observed when other ports are excited except the port-1 and remaining ports are ended with the 50-ohm load.

In the fourth step, the design of CPW fed four-port antenna is accomplished by assembling the single antenna element orthogonally in an anti-clockwise direction to achieve polarization diversity. The arrangement of the radiators is supported to maximize the isolation between the ports due to polarization diversity. The isolation between port1-2 and port 1-3 is less than 20 dB. The combination of cross and plus shaped decoupling structure is used to unite all antenna grounds ensuring practical applications. The decoupling structure enhances isolation of MIMO antenna for more than 20 dB from all ports. The antenna is accomplished with easy decoupling structure where the effect of decoupling structure in the MIMO antenna bandwidth and radiation pattern is minimum. Therefore, proposed antenna can be applicable where the antenna device cannot be fixed. The impedance bandwidth of the UWB antenna is achieved from 3.2 GHz to 14 GHz. In the fifth step, the antenna ground is inter connected with a simple crossed and plus shaped decoupling structure to further diminish the surface current that enhances the isolation greater than 20.2 dB between all the ports.

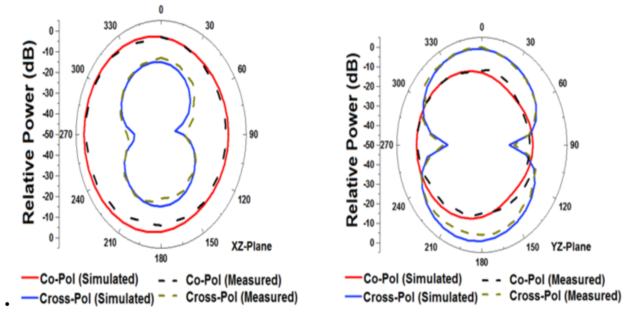
4. Result and Discussion of Four-Port Antenna

To justify the simulation proposed prototype of the MIMO antenna is fabricated based on the optimized mentioned dimension of the antenna. The proposed CPW fed four-port diversity antenna with WLAN rejection band is simulated in HFSS 13 and measured using Anritsu (MS2038C) VNA. The scattering parameter is compared in Fig. 3(a). The response shows a 10 dB impedance BW varies from 3.26 GHz to 14 GHz whereas the notch band varies from 4.8 GHz to 6.2 GHz. The isolation between slotted radiators (S_{21} > 20.2 dB, S_{31} > 20.48 dB and S_{41} > 21.73 dB) is more than 20.2 dB throughout the UWB. The result confirms the good harmony between them. A slight mismatch in the graph occurs due to fabrication error, parasitic effect in soldering, and losses in the SMA connector.

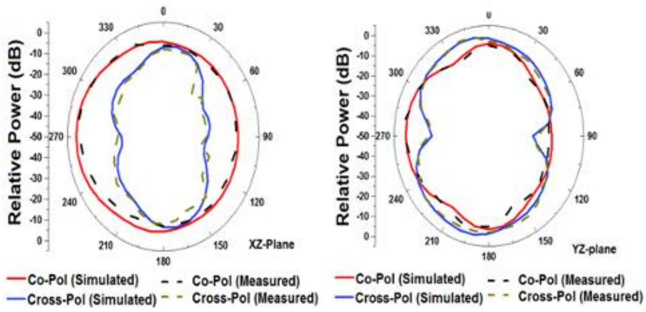
To illustrate the radiation characteristic, normalized far-field design at the three orthogonal coordinate planes xz and yz are measured in the anechoic chamber. The graph is plotted for the frequency 3.6 GHz and 6.6 GHz as depicted in Fig. 3(b) and Fig. 3(c), which reveals that the radiation pattern is approximately stable and Omni directional in operating bandwidth.


S Parametes (in dB)
Frequency (GHz)
|S11|-Simulated
|S12|-Simulated
|S13|-Simulated
|S14|-Simulated
|S11|-Measured
|S12|-Measured
|S13|-Measured
|S14|-Measured

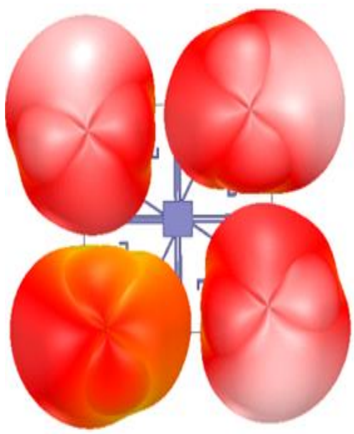
(a)

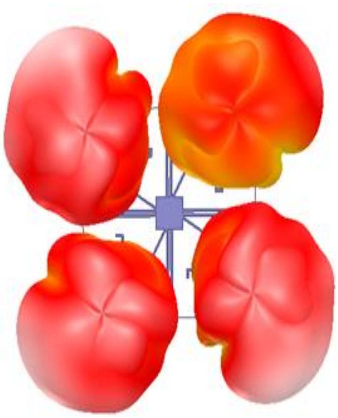

Relative Power (dB)
XZ-Plane
YZ-Plane
Co-Pol (Simulated)
Co-Pol (Measured)
Cross-Pol (Simulated)
Cross-Pol (Measured)

(b)

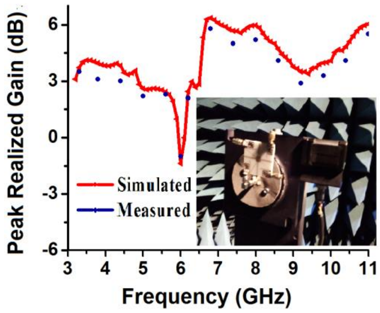

Relative Power (dB)
XZ-Plane
YZ-plane
Co-Pol (Simulated)
Co-Pol (Measured)
Cross-Pol (Simulated)
Cross-Pol (Measured)

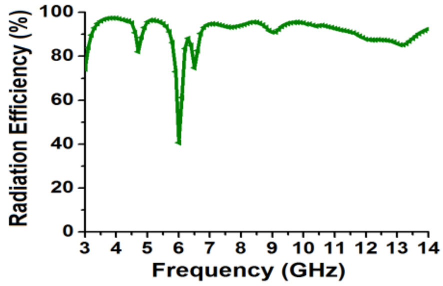
(c)





(d) (e)





(f) **(g)**

The 3D Radiation pattern of the four-port MIMO antenna is depicted in Fig. 3(d) at 3.6 GHz and in Fig. 3(e) at 6.6 GHz. The realized gain varies from 4 dB to 6.3 dB as shown by Fig. 3(f). The realized radiation efficiency of the MIMO antenna is greater than 90% in the lower operating band and greater than 85% in the upper-frequency band and drops down at the notch band as demonstrated by Fig. 3(g).

Figure 4 (a) S-parameter of MIMO antenna prototype, normalized radiation pattern in xz and yz plane (b) at 3.6 GHz and (c) at 6.6 GHz, 3D Radiation pattern and diversity performance (d) at 3.6 GHz and (e) at 6.6 GHz (f) Realized Gain (dB) (g) Simulated radiation efficiency (%)

5. MIMO Antenna Parameters

A very useful parameter of the MIMO antenna performance is the envelope correlation coefficient (ECC), which represents correlation among antenna elements. If the correlation is low, then diversity gain and channel capacity would be high. The range of the ECC is 0 to 1 however, for practical applications the recommended value is below 0.5 [14]. ECC value between the ports 1-2, 1-3 and 1-4 is depicted in Fig. 4(a), which reveals that the presented notch-based four-element antenna value is less than 0.01. The ECC of the MIMO antenna can be calculated with the antenna S parameter with the help of the following equation

$$ECC = \frac{|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \quad (2)$$

The total active reflection coefficient (TARC) parameter is utilized to describe the properties of the multi-port antenna. TARC describes the bandwidth of the MIMO antenna, which demonstrates the actual value of the bandwidth of the multiport antenna elements. The range of TARC varies from zero to one [15] if all the incident power is radiated in free space then it has zero value. On the contrary, if incident power is coupled to other port of antenna or it is reflected back then TARC has one value.

The TARC value between port-1 to port-2 for the prototype is discussed in Fig. 4(b) at 0 to 180-phase angle where the minimum variation of the S-parameter is achieved. TARC can be expressed in the form of scattering parameter given by the following equation:

$$TARC = \sqrt{|S_{11} + S_{12}e^{j\theta}|^2} + \left|S_{22} + S_{21}e^{j\theta}\right|^2 / \sqrt{2} \quad (3)$$

The performance of diversity is also examined in terms of diversity gain. ECC parameter can be utilized to find out the value of DG using the following equation.

$$DG = 10\sqrt{1 - |ECC|^2} \quad (4)$$

DG value between the antenna element 1-2,1-3 and 1-4 is represented in Fig. 4(c), which shows that the proposed antenna diversity gain is close to 10. The critical attribute of the multiple antenna system to define the capacity is related to the channel matrix, which corresponds to the radiation characteristic of the radiator as well as on the multipath environment [15]. Thus, the capacity of the MIMO antenna is characterized by an important parameter known as channel capacity loss (CCL), which represents the losses in the diversity channel. Practically it is computed using the measured S parameters in a fading channel with high SNR values given by

$$CCL = -log_2 det(\psi^R) \quad (5)$$

Where ψ^R = correlation matrix of the 4x4 MIMO system in the multipath environment. The ideal value of CCL must be lower than 0.4bps/Hz for the complete required band. Thus from the experimental results illustrated in Fig. 4(d) taken between antenna elements 1-2, 1-3 and 1-

4 it is proved that the better impedance matching and isolation between the elements provides low capacity loss, which shows the good performance of diversity antenna.

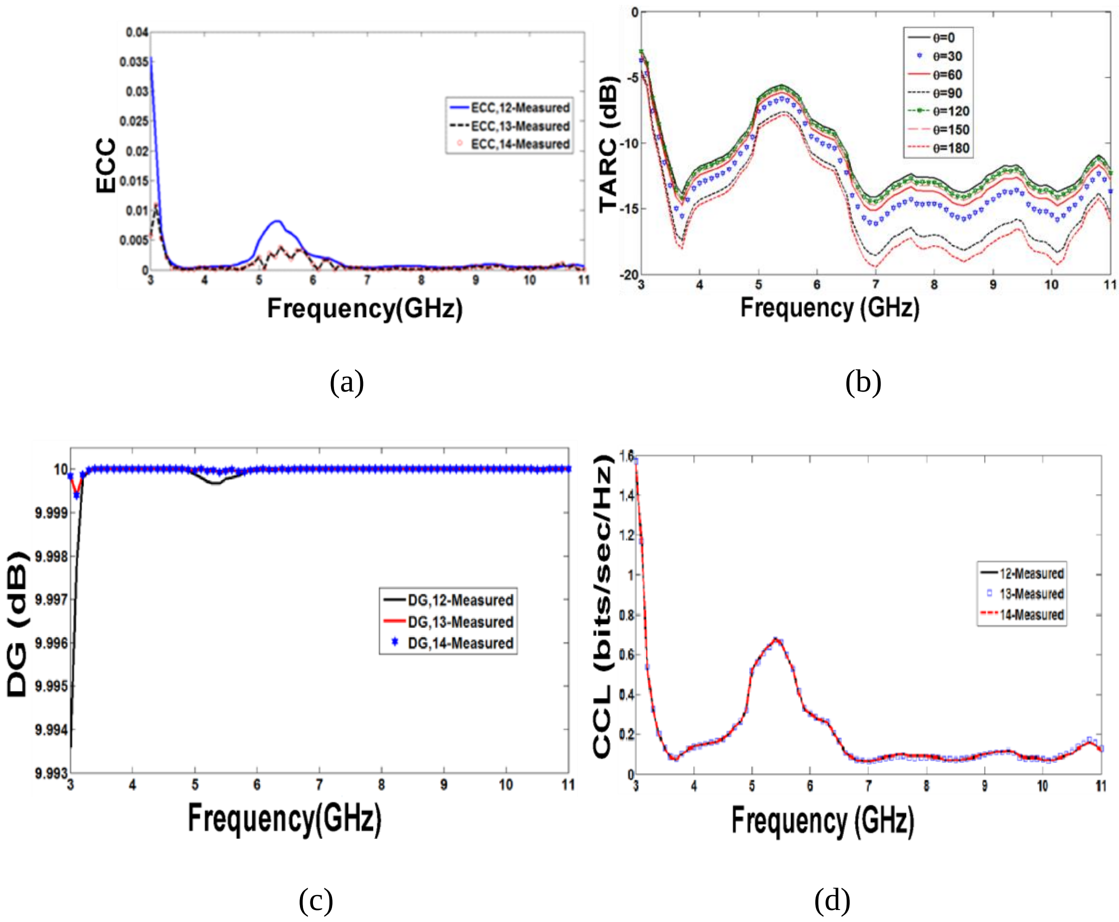


Figure 4 Parameters of measured prototype (a) ECC (b) TARC (c) DG (d) CCL

6. Comparison with the Previous Work

The comparative analysis of relative MIMO antenna with proposed CSRR loaded diversity antenna including the band rejection ability is discussed in Table 2. The comparison between the existing MIMO antenna [5-11, 13] with the presented antenna shows that the proposed design has a compact size, huge impedance bandwidth, high gain, and large isolation value with the connected ground for the entire frequency range. Also in comparison, all the MIMO parameters have the desirable and acceptable values of CCL, TARC, and ECC.

TABLE-2 Comparative analysis of proposed paper with recently published papers

Ref.	Size (mm)	Band (GHz)	Isolation (dB)	Maximum Gain(dB)	ECC	CCL	Common Ground Plane
[5]	50X25	2-12	-17	5.8	.45	-	No
[6]	50X50	2-12	-17	3.3	.15(Uniform) .45(Indoor & outdoor)	-	No
[7]	50X50	2.2-10.4	-14	7.5	0.3	-	Yes
[8]	63X63	.97-35	-17	5	0.01	-	Yes
[9]	72X72	2.8-13.3	-18	6	.06	-	Yes
[10]	36X45	3.03-10.74	-20	8.48	.2	-	No
[11]	60X60	3-16.2	-17.5	8.4	.3	<0.4	No
[13]	45X45	3.1-11	-16	-	.015	-	Yes
This work	45X45	3.26-14	-20	6.35	.02	<0.4	Yes

7. Conclusion

The development of the CPW fed compact MIMO/diversity antenna using CSRR technology having WLAN notch characteristic is presented in this paper. The designed structure provides the 10 dB BW of 3.26 GHz to 14 GHz and prevents interference from the WLAN/Wi-Fi band. The isolation is achieved using polarization diversity and further enhanced by simple cross and plus shape metallic strips without changing in impedance bandwidth and radiation pattern. Cross-shaped metallic strips are also used to make the common ground plane for the same voltage reference level. The proposed antenna has a low profile, easy to fabricate and design. The ECC, TARC, DG, and CCL are evaluated, which are within the acceptable limit to validate the diversity performance.

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