Dual-port MIMO dielectric resonator antenna for WLAN applications

Dual Port MIMO Dielectric Resonator Antenna for WLAN Applications

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***Abstract*—A dual port multiple input multiple output (MIMO) dielectric resonator antenna (DRA) for 5 GHz IEEE(802.11a/h/j/n/ac/ax) is discussed in this paper. Two prototypes of single feed DRA and dual feed MIMO DRA are fabricated and measured results are compared with the simulated data. The proposed single feed DRA and dual feed MIMO DRA exhibits wide Impedance Bandwidth (IBW). Antennas has been fabricated on Rogers RT Duroid substrate with Eccostock made DRA placed over the substrate. DRAs are excited by aperture coupled feed to achieve wide bandwidth and high efficiency. The measured IBW of uni-port DRA and dual-port MIMO DRA are 26.6% (4.75-6.21 GHz) and 27.5% (4.7-6.2 GHz) respectively. Maximum gain of the antenna is 7.4 dBi. The results of the antennas are in good agreement with simulated data and they are suitable for WLAN applications. These antennas are also compact with area of substrate 32.8 cm^2.**

***Index Terms*—Dielectric resonator antenna, multiple input multiple output, WLAN.**

I. Introduction

Multiple-Input Multiple-Output (MIMO) technology uses multiple transmitters and receivers to transfer more data at the same time. The advent of MIMO antennas is a boon for human kind, seeking high speed wireless data transmission in various applications. Initially patch antenna based MIMO antennas were proposed in the literature until Ishmiya et. al.[1], [2] proposed DRA based MIMO antenna which have more degree of freedom for designing and low loss due to absence of metal in DRA. DRA based MIMO antenna comprises advantages of both MIMO and DRA technoloy. In the literature, researchers proposed different DRA based MIMO antenna for different applications. Thamae et al. [3] proposed dual-port cylindrical DRA with two orthogonal feeds. Yan et al. [4] proposed dual-port frequency agile MIMO DRA for dynamic spectrum access applications in cognitive radios. Roslan et al. [5] investigated MIMO rectangular DRA (RDRA) for 4G applications. Sharawi et al. [6] proposed eight-element, dual-band, low profile MIMO antenna system using cylindrical DRA for wireless access points. Hussain et al. [7] proposed eight CDRAs based MIMO linear antenna array system for mm-wave. Roslan et al. [8] proposed two F shaped DRAs based MIMO antenna by exciting two orthogonal modes at two ports for 4G applications. Hussain et al. [9] proposed sixteen CDRAs based Four port MIMO linear antenna array system for mm-wave applications at 30 GHz with bandwidth of 6.7%. Nasir et al. [10] presented single rectangular DRA based MIMO antenna fed by two microstrip lines for 4G applications. Sharma et al. [11], [12] proposed two element mushroom shaped DRA and A-shaped DRA excited by a microstrip feed line and conformal patch to achieve wide-band operation. Sharma et al. [13] proposed two element CDRA based hybrid MIMO antenna for WLAN and WiMAX applications. Das et al. [14] presented a compact back-to-back DRA-based four-port MIMO antenna system with bi-directional diversity. Kumari et. al. [15] presented dual ring element MIMO DRA excited by U-shaped printed line feed to achieve wide bandwidth. In present catena of research, main focus is to design a compact MIMO DRA which can work for wide bandwidth and this paper presents a MIMO DRA which is compact in size due to single element and dual feed, for WLAN applications.

In this paper, an aperture coupled fed DRA is presented and fabricated which is extended to dual feed MIMO DRA. The proposed DRA is unique due to its kite shape structure which is a combination of cylindrical DRA and L-shaped DRA, along with conformal copper strips to increase gain up to 7.5 dBi. Prototypes of both the antennas have been fabricated to validate the simulated results. The measured IBW of single feed DRA is 26.6% (4.75-6.21 GHz) and of dual feed MIMO DRA, Impedance Bandwidth (IBW) is 27.5% (4.7-6.2 GHz). Maximum gain has been measured 7.5 dBi (DRA) and 7.4 dBi (MIMO DRA). 10 dB port isolation bandwidth for MIMO DRA has been measured 5-6.2 GHz which is under IBW and covers 5 GHz IEEE(802.11a/h/j/n/ac/ax) band for WLAN. Envelope correction coefficient (ECC), total active reflection coefficient (TARC), diversity gain (DG) and Mean effective gain (MEG) are measured within accepted range for MIMO operation.

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II. Antenna Design and Operating Principle

Antenna design layouts of single feed DRA and dual feed MIMO DRA are shown in Fig. 1. In Fig. 1(a,b) single feed DRA is shown and in Fig. 1(c,d) dual feed MIMO DRA is shown. Fig. 1(e,f,g) shows trimetric and side views to demonstrate six metallic patches etched on the body of DRAs. Roger RT duroid substrate with ϵ_r 2.2 and height 1.6 mm is cut down in octagonal shape and an aperture coupled feed is etched on the substrate. Major steps involved to reach the proposed DRA are shown in Fig. 2. Using Equation (3-5) of [25] for TE_{111} mode, a Rectangular DRA (RDRA) with dimensions $34 \times 34 \times 18mm^3$ resonating at 5 GHz has been designed with simulated IBW from 4.86-5.15 GHz, but very small simulated gain in this frequency range. Low substrate area become essential when aiming for a compact antenna design. So, open ground area has been increased by reducing dimensions of RDRA, such that it became a L-shaped DRA. By optimizing size of DRA, Antenna-1 as shown in Fig. 2 has been obtained. A cylindrical DRA (CDRA) with optimized radius has been merged at the center of Antenna-1 and this antenna is represented as Antenna-2. Height of cylindrical DRA kept same as that of L-shaped DRA. In Antenna-3, four cylindrical air gaps with optimized radii and distance between each other, has been introduced in Antenna-2. In Antenna-4, six metallic patches with optimized width and height have been etched on the surface of DRA of Antenna-3. Simulated IBW and gain of Antenna-1, Antenna-2, Antenna-3 and Antenna-4 are shown in Fig. 2. While moving from Antenna-1 to Antenna-4, optimization of different parameters has been done using simulation software ANSYS HFSS.

Dielectric resonator is placed on a thin Roger's substrate and TE_{111} mode is excited using aperture coupled feed method. Symmetrical shape of DRA is considered so that it has been easily adopted in dual port MIMO DRA, with port symmetry properties (where in S_{ij}, i and j are interchangeable). In Fig. 3, it is observed that IBW of Antenna-4 is the largest among all four antennas. Fig. 4 depicts that gain of Antenna-4 is highest among all four antennas and maximum simulated gain of Antenna-4 is 7.85 dBi. Table-I summarizes the impedance bandwidths and maximum gains of Antenna-1, Antenna-2, Antenna-3 and Antenna-4. It was noted with the merging of CDR in L-shaped Antenna-1, IBW and gain of the Antenna-2 has been increased. Introduction of air gap will again enhance operational frequency and lower the resonance impedance of the Antenna-3. The 3-db bandwidth, is not significantly affected by air gap [26]. Air gap is also used for better impedance matching [17], [18], [20]. Effect of copper strips on simulated IBW and gain of DRA are shown in Fig. 5 and Fig. 6, respectively. From Fig. 5 and Fig. 6 it has been concluded that gain and IBW increase on addition of conformal copper strips.By image theory, effective shape of DRA has been changed in discrete manner as per placement of vertical patches etched on the surface of DRA and connected to ground [26]. So, these vertically copper patches resulted gain enhancement and multiple resonances which yield broadening of IBW. But optimization of length and spacing of copper patches are required, to maintain maximum radiation in desired direction.

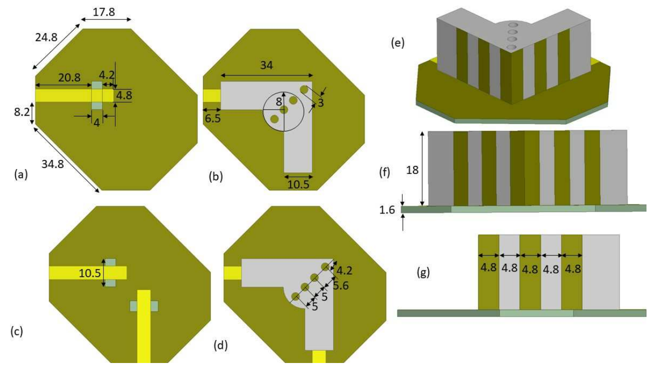

Fig. 1: Geometry of the Antenna

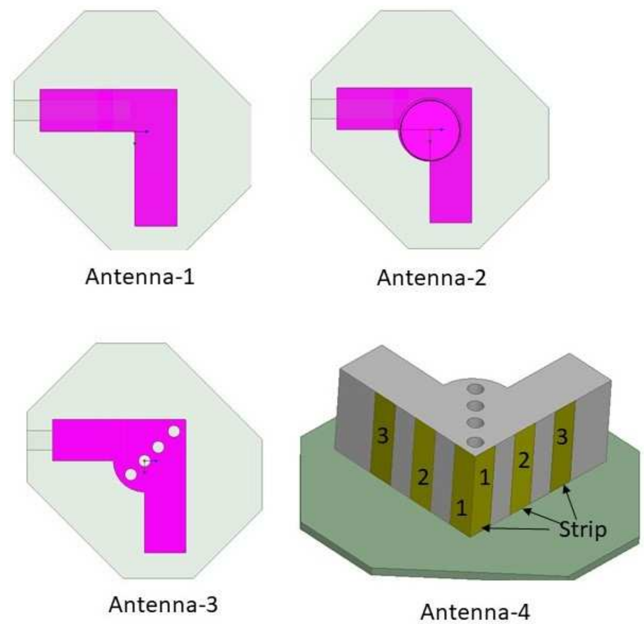

Fig. 2: Steps involved in design of proposed DRA

TABLE I
IBW and maximum gain comparison of Antenna 1-4

Antenna	IBW	Maximum Gain (dBi)
1	5.1-5.7 GHz	4.2
2	5-5.9 GHz	5
3	5.1-6.1 GHz	5.6
4	4.7-6.2 GHz	7.85

III. Results and Discussion

To validate simulated results of both the proposed antennas, two prototypes have been fabricated. Fig. 7 and Fig. 8 show fabricated prototype of proposed DRA and MIMO DRA, respectively. Adhesive has been used to stick dielectric resonators on substrate. Soldering deformity of connectors and adhesive on DRA may be responsible for variation in measured results. Far field results have been measured in anechoic chamber with corrugated horn antenna as reference antenna while keeping other port matched with 50 Ω. Standard measurement

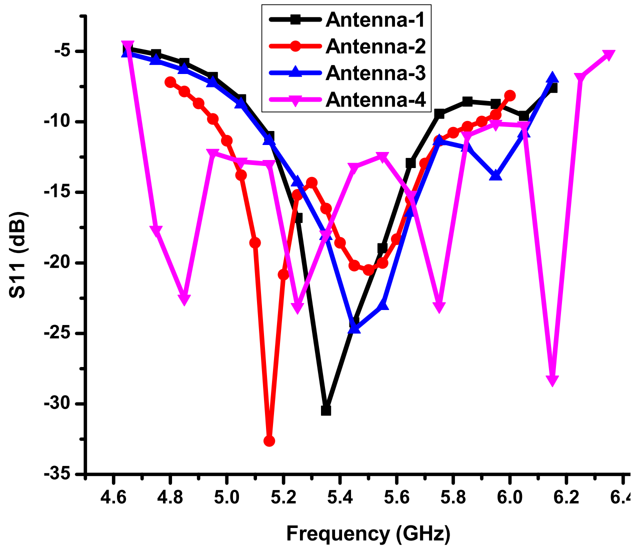

Fig. 3: Simulated S_{11} of Antenna-1,Antenna-2, Antenna-3 and Antenna-4

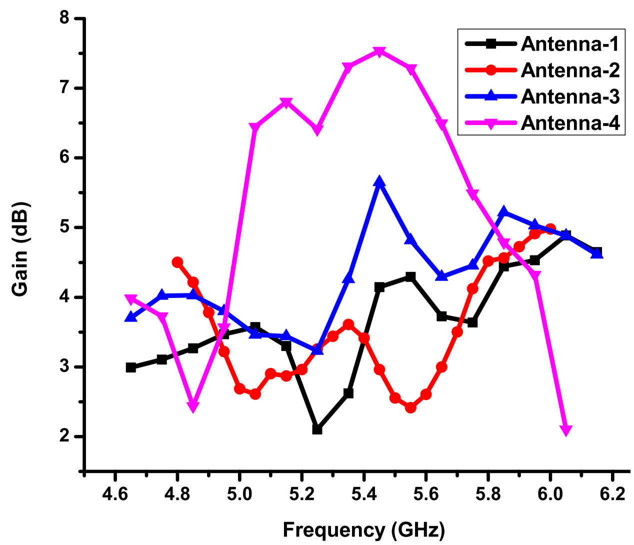

Fig. 4: Simulated Gain of Antenna-1,Antenna-2, Antenna-3 and Antenna-4

procedures [27]–[30] adopted for parameters measurement and eq.(1-7) have been implemented by MATLAB. In this section, different results of fabricated prototypes have been discussed and compared with their simulated counterparts.

Simulated and measured IBW of DRA is shown in Fig. 9. Measured IBW is 26.6% (4.75-6.21 GHz). Fig.10 displays simulated and measured S_{11} and S_{12} of MIMO DRA. Photographs of measurement setup are also shown in the inset of Fig. 9 and Fig.10. Due to symmetry of structure S_{22} is same as that of S_{11} and not shown in Fig.10. It has been calculated that measured IBW of fabricated MIMO DRA is 27.5% (4.7-6.2 GHz) and 10 dB isolation bandwidth is 5-6.2 GHz. Far field co-pol and x-pol radiation patterns have been measured at different frequencies and found suitable gap between co-pol and x-pol values at broadside direction. Far field co-pol and x-pol radiation pattern measured at 5.1 GHz

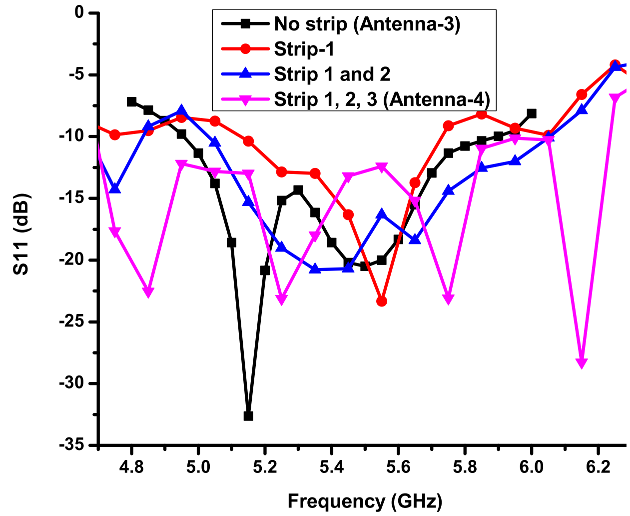

Fig. 5: Parametric analysis of S_{11} vs Frequency for different number of strips on DRA surface

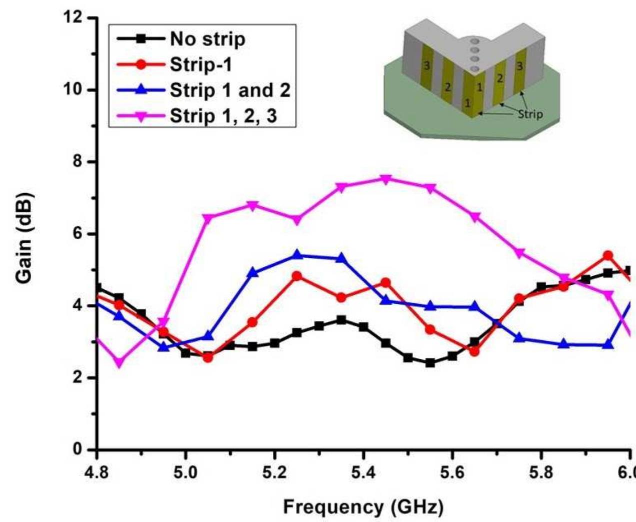

Fig. 6: Parametric analysis of Gain vs Frequency for different number of strips on DRA surface

and 5.7 GHz which covers complete band of 5-6.2 GHz as shown in Fig. 11. Co-pol radiation is at least 10 dB better than x-pol radiation pattern in broadside direction at all frequencies. Fig. 12 shows radiation pattern of MIMO DRA at 5.1 GHz and 5.7 GHz. Simulated and measured gain variation of both

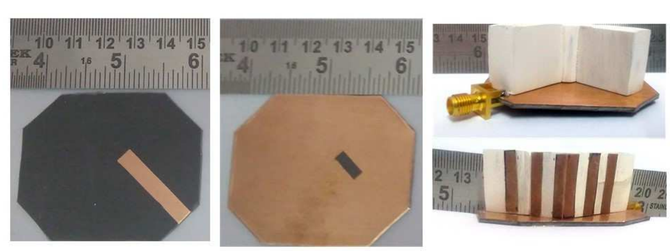

Fig. 7: Photographs of fabricated DRA (Top View, Bottom View and Side Views)

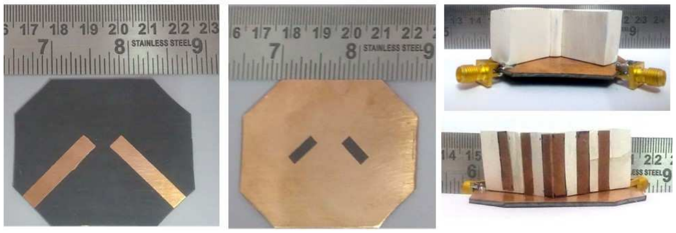

Fig. 8: Photographs of fabricated MIMO DRA (Top View, Bottom View and Side Views)

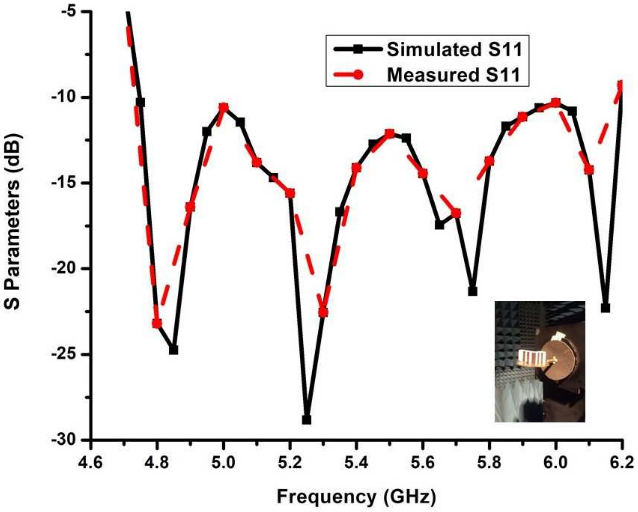

Fig. 9: Simulated and measured S-parameters of proposed DRA

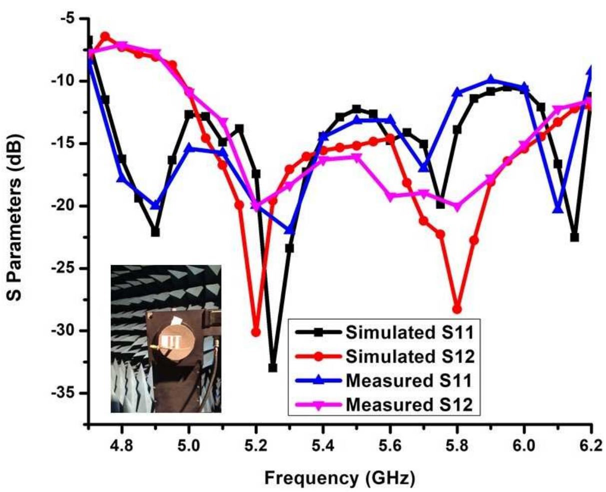

Fig. 10: Simulated and measured S-parameters of proposed MIMO DRA

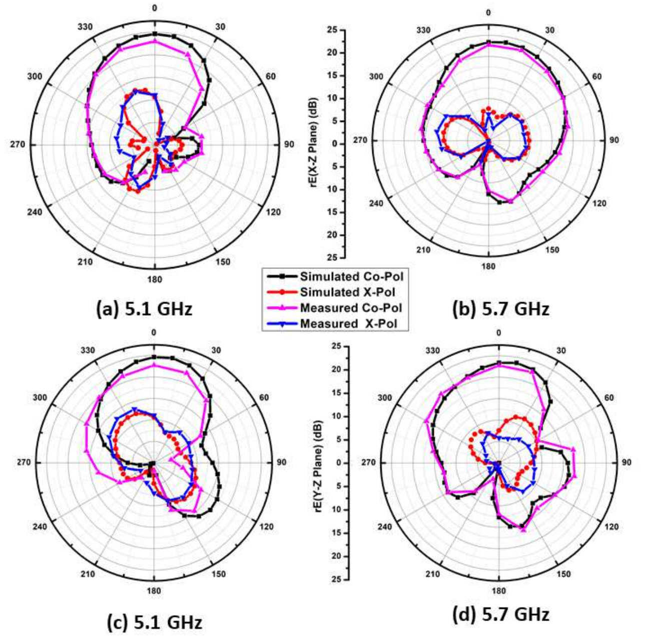

Fig. 11: Simulated and measured radiation pattern of proposed DRA at 5.1 GHz and 5.7 GHz. E-plane (a,b) and H-plane (c,d)

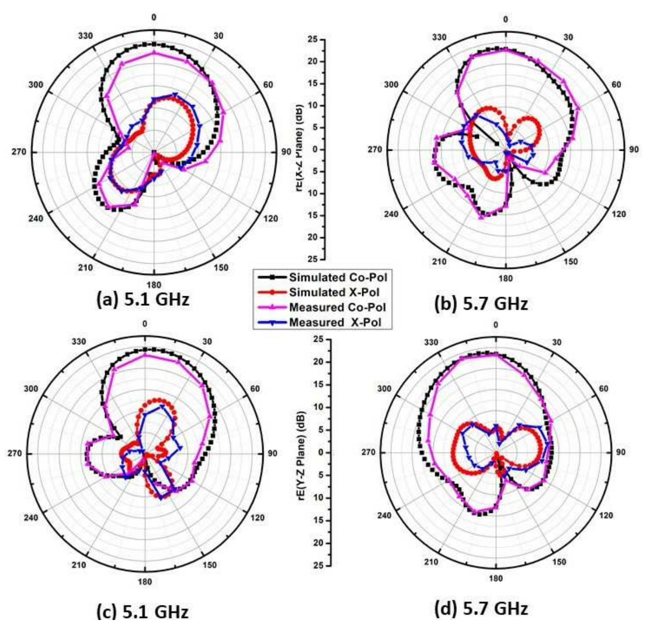

Fig. 12: Simulated and measured radiation pattern of proposed MIMO DRA at 5.1 GHz and 5.7 GHz. E-plane (a,b) and H-plane (c,d)

the antennas with respect to frequency is shown in Fig. 13. It is observed that maximum gain of single feed DRA is 7.5 dBi and of MIMO DRA is 7.4 dBi. Maximum simulated radiation efficiency of DRA is 0.93 as shown in Fig. 14.

MIMO performance metrics have also been studied to justify the performance of the proposed dual feed MIMO DRA. ECC is one of the main performance metrics of MIMO system which describes isolation and correlation of communication channel with each other [31]. ECC expressed in eq. (1) for two port MIMO system [31], [32].

$$ECC = \frac{\left| \iint_{4\pi} \left[\overrightarrow{F_1}(\theta,\phi) * \overrightarrow{F_2}(\theta,\phi) \right] d\Omega \right|^2}{\iint_{4\pi} \left| \overrightarrow{F_1}(\theta,\phi) \right|^2 d\Omega \iint_{4\pi} \left| \overrightarrow{F_2}(\theta,\phi) \right|^2 d\Omega} \tag{1}$$

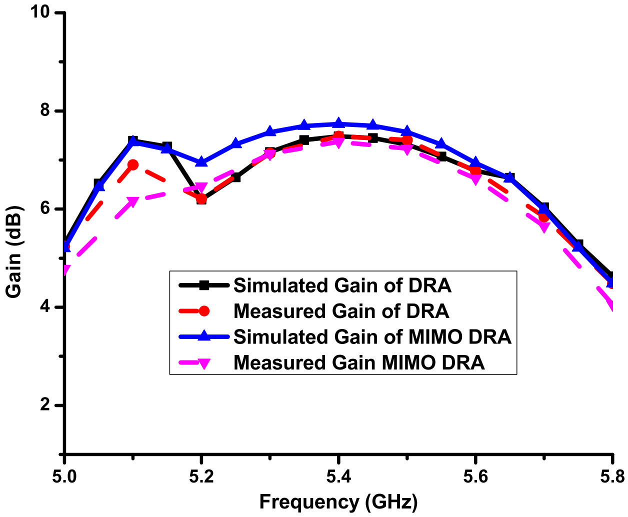

Fig. 13: Simulated and measured gain of proposed DRA and MIMO DRA

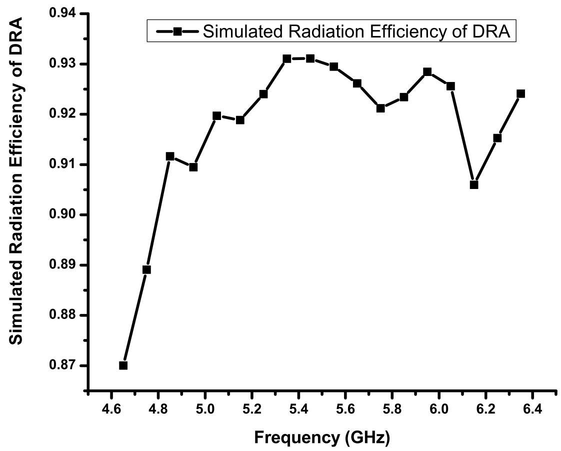

Fig. 14: Simulated radiation efficiency of proposed DRA

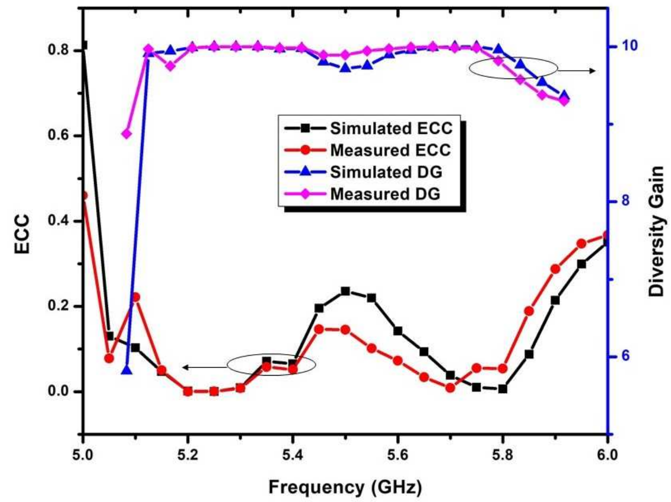

Fig. 15: Simulated and Measured ECC and DG of proposed MIMO DRA

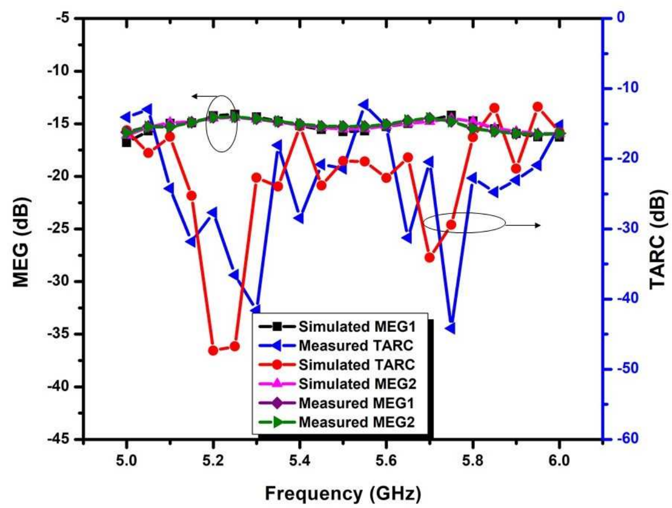

Fig. 16: Simulated and Measured MEG1, MEG2 and TARC of MIMO Antenna

where $\overrightarrow{F_i}(\theta, \phi)$ is three dimensional field radiation pattern of MIMO antenna when port-i is excited. Ω is solid angle.

The DG identifies the amount of improvement that can be seen in MIMO in comparison to SISO (single input single output) system and this can be calculated using eq. (2) from [32], [33]. Fig. 15 depicts simulated and measured ECC and DG of proposed MIMO DRA. Simulated and measured ECC is below 0.3 through out the operating band and DG is more than 9.9 in the same band which signifies higher pattern diversity.

$$DG = 10\sqrt{\left(1 - ECC^2\right)} \tag{2}$$

Mean effective gain measures amount of the power received by the MIMO antenna in comparison to a standard antenna in the standard environment. MEG can be calculated using eq. (3) [31]–[34]. Here N is the number of MIMO elements or ports. MEG for both the ports can be calculated using eq. (4) and eq. (5), whereas eq. (6) is the condition of good diverse performance of MIMO antenna [34].

$$MEG_i = 0.5\Big[1 - \sum_{j=1}^{N} |S_{ij}|^2\Big] \tag{3}$$

$$MEG_1 = 0.5\Big[1 - |S_{11}|^2 - |S_{12}|^2\Big] \tag{4}$$

$$MEG_2 = 0.5\Big[1 - |S_{21}|^2 - |S_{22}|^2\Big] \tag{5}$$

$$|\ MEG_1 - MEG_2\ | < 3 \text{ dB} \tag{6}$$

TARC is a new MIMO performance metric which defines bandwidth and radiation performances under diverse condi-

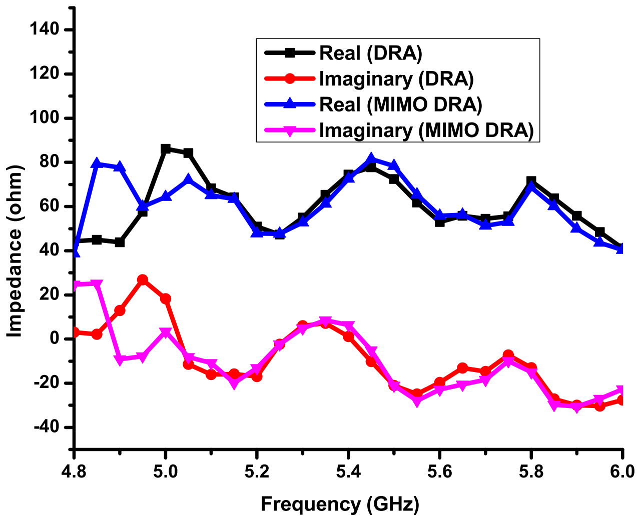

Fig. 17: Simulated input impedance of proposed DRA and MIMO DRA

tions. For dual port MIMO system it can be calculated using eq. (7) given in [32], [33].

$$TARC = \sqrt{\frac{\left(S_{11} + S_{12}e^{j\theta}\right)^2 + \left(S_{21} + S_{22}e^{j\theta}\right)^2}{2}} \quad (7)$$

where θ is input feeding phase.

Desirable value of TARC for MIMO system is less than 0 dB. Fig.16 depicts simulated and measured values of mean effective gain of both ports and total active reflection coefficient of proposed MIMO DRA. It has been concluded from Fig. 16 that MEG1 and MEG2 have almost same values in entire operating band and difference between MEGs is less than 3 dB whereas TARC value over entire operating band has been less than -10 dB which is good for MIMO operation. Fig. 17 depicts simulated input impedance of both the antennas. Surface current distribution of MIMO DRA, when port-1 excited, is shown in Fig. 18. Table-II displays comparison between recent single element MIMO DRAs and proposed single element MIMO DRA. In comparison to recent MIMO DRAs with single DR element, proposed MIMO DRA exhibits wider IBW and higher gain.

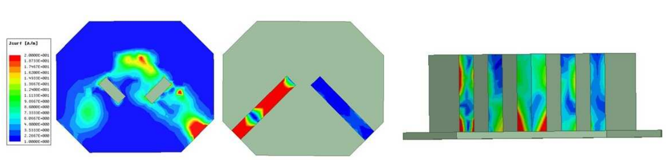

Fig. 18: Current distribution when port-1 is excited

IV. Conclusions

In this paper, an aperture coupled fed DRA is proposed followed by dual feed MIMO DRA. Aperture coupled feed is used to achieve wide bandwidth. Both the antennas have been fabricated to validate simulated results. Proposed DRA exhibits 26.6% (4.75-6.21 GHz) IBW whereas proposed dual feed MIMO DRA exhibits 27.5% (4.7-6.2 GHz) IBW. Maximum gain of the proposed DRA is 7.5 dBi and proposed MIMO DRA is 7.4 dBi. Both the antennas are suitable for 5 GHz IEEE(802.11a/h/j/n/ac/ax) WLAN applications. Advantages of proposed antennas are wide bandwidth, high gain and compact substrate size of area 32.8 cm^2.

TABLE II
Comparison with recent single element MIMO DRA

Ref.	IBW	Gain	Excitation	Isolation between ports	No. of Ports
[16]	(698–716 MHz, 728–746 MHz) LTE bands	3.96 and 3.19	Aperture coupled and probe coupled	-40	2
[17]	3.4–3.7 GHz and 5.15–5.35 GHz	5.7 and 6.61	Probe	-13, -16	2
[18]	1.43–1.50 GHz and 2.50–2.69 GHz	3 and 6.48	Microstrip feed and probe	-23	2
[19]	1.41–1.49 GHz and 2.2–2.85 GHz	4.83 and 4.92	Probe	-6	2
[20]	3.42–3.80 GHz, 4.97–5.50 GHz	5.2 , 6.38	Aperture coupled	-20	2
[21]	5.18-5.83 GHz	5.94	Microstrip feed	-30	2
[22]	3.78-4.07 GHz	5.1	Multiple feed line	-16	2
[23]	1.0 GHz to 1.62 GHz	-	Slot coupled	-	8
This Work	4.7-6.2 GHz	7.5	Aperture coupled	-15	2

Acknowledgement

Binod K. Kanaujia acknowledges DBT & COE project funds for providing infrastructure support and DST-PURSE, Govt. of India & UPE II ID:340, JNU for providing support throughout this work. Authors would like to acknowledge the Principal, G.B. Pant Engineering College Delhi, India, for providing antenna measurement facility at G.B.P.C.E. Delhi.

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