A Compact Offset-Fed CP Dielectric Resonator MIMO Antenna for Wireless Applications

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Abstract: Antennas that can operate reliably in various environments and orientations are required in modern wireless communication systems. Circularly polarized antennas are preferred because they minimize the effects of polarization mismatch and signal loss. Due to their compact size, good performance at low frequencies (microwave frequencies), high radiation efficiency, dielectric, and losses. Resonator antennas were used. In this study, the technique of creating a circularly is known as offset feeding technique. polarized dielectric resonator antenna, and the feed is located outside the center to excite two orthogonal modes. The elements of CP-DRA were then mixed to design a miniature 2 port MIMO antenna, which enhanced the communication performance. The antenna was simulated and designed using HFSS, and the necessary S-parameters, such as return loss, axial ratio, radiation patterns, and inter-element isolation, were investigated. The findings indicate constant circular polarization, good matching impedance, and admirable MIMO performance, which implies that the proposed antenna is suitable for wireless communication.

Keywords: Circularly polarized surface, Dielectric. Resonator Antenna MIMO antenna Facilitator Antenna Offset Antenna Facilitator, HFSS

I. INTRODUCTION

As wireless communication devices are used more often, the requirements for higher data rates, higher spectral efficiency, and robust link performance are also becoming increasingly important. In practical propagation environments, the signals are subject to degradation by multipath fading, reflection, polarization mismatch, and so on. This degradation reduces the efficiency of the system. Advanced multiple input multiple output (MIMO) technology uses the ability of the multipath environment to enhance channel capacity and link reliability [1]. Therefore, a suitable antenna structure with steady radiation characteristics is an important basic element in modern communication systems.

Dielectric resonator antennas (DRAs) have garnered a lot of interest due to their appealing characteristics, which include low dielectric loss, high radiation efficiency, and compact construction, and operation at microwave frequency bands [2], [3]. Furthermore, circular polarization (CP) is advantageous over linear polarization in wireless systems because it avoids polarization mismatch and is insensitive to variations in propagation conditions. There are many techniques to realize circular polarization in DRAs, such as offset feeding, vertical strip excitation, and asymmetric resonator structures [4]–[8]. These techniques excite the two orthogonal modes separated in phase by 900, so that an axial ratio (AR) of 3 dB can be maintained below over the desired operating bandwidth [9]–[11].

Performance metrics including isolation, diversity gain, and for a MIMO antenna system to function, the envelope correlation coefficient (ECC) is essential. Compact CP-DRA-based MIMO implementation designs have been proposed in the literature for low ECC and high isolation. These designs utilize different orientations of antennas or geometrical modifications [12], [13]. However, most of these approaches use additional decoupling structures or geometrical modifications to separate antennas, which affect the overall design simplicity [14], [15]. Thus, there is a need for a design that can minimize the overall structure and thereby achieve CP and good MIMO parameters.

In this study, a compact circularly polarized DRA with a two-port MIMO configuration is proposed for C-band applications. Circular polarization is excited using a simple offset-fed technique that avoids a complicated feeding mechanism. The proposed design enhancement involves T-shaped slots in the DRA and to enhance the antenna's surface current dispersion, the ground plane has L-shaped slots.. The result is an impedance bandwidth of 4.67–7.07 GHz with a maximum gain of 5.45 dB and an axial ratio below 3d B within the operating band. The MIMO system shows low ECC and enhanced diversity characteristics.

II. DESIGN METHODOLOGY

A. Single Element Offset-Fed Dielectric Resonator Antenna

As seen in Fig. 1, the suggested antenna makes use of a rectangular dielectric resonator positioned on a substrate with a ground plane. To make the antenna smaller overall, a dielectric material with a high dielectric constant was chosen. The ground plane and dielectric resonator were supported by a FR4 substrate.

To obtain circular polarization, the dielectric resonator is fed at an offset location rather than at the center. This offset feeding generates pairs of orthogonal electric-field components within the resonator. To achieve circular polarization, the feed location must be adjusted such that the two field components maintain nearly identical magnitudes and a phase difference of approximately 90°.

A slight asymmetrical notch was introduced into the dielectric resonator to boost circular polarization. This notch enhances the axial ratio while managing the internal electric-field distribution. The notch size, dielectric resonator, and feed position were carefully optimized using HFSS modeling.

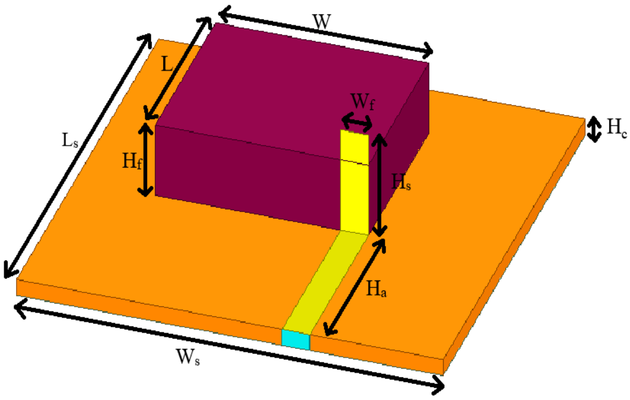

Fig. 1. Geometry of the single offset-fed dielectric resonator antenna. [L_s = 40mm, W_s = 40mm, H_c = 1.6mm, L = 17mm, W = 20mm, H_f = 7mm, W_f = 2.6mm, H_s = 10mm, H_a = 16.5mm]

B. Offset Conformal-Strip Fed DRA

In the first configuration, the dielectric resonator was activated by placing a metallic conformal strip directly on its surface. The strips were deliberately placed at a distance from the middle of the resonator. This offset position is important because it is involved in the generation of two perpendicular electric-field components in the dielectric material.

In the design phase, the position and dimensions of the conformal strip were altered using parametric analyses. Even small changes in the offset distance have a significant effect on both the axial ratio and impedance matching. An appropriate offset location and notch size were used to achieve a steady circular polarization over the relevant frequency band.

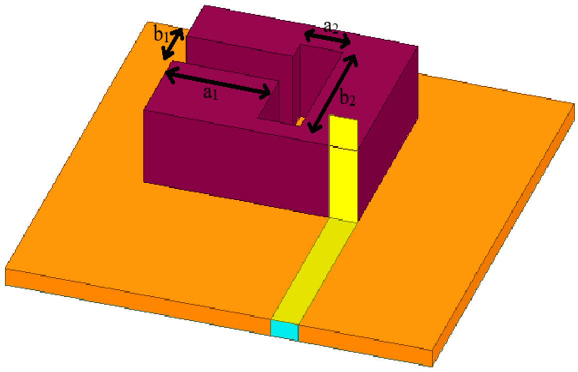

Fig. 2. Geometry of offset conformal-strip fed dielectric resonator antenna. [a_1 = 10mm, a_2 = 4mm, b_1 =4mm, b_2 = 12mm]

C. Offset Micro strip-Slot Fed Dielectric Resonator Antenna

In the second design, an offset micro strip-slot feeding technique was employed. This approach uses a microstrip line to hit the giving resonator with an etched slot on the ground plane. To generate field asymmetry, the slot was offset from the resonator center. To accommodate circular polarization, an asymmetrical notch is inserted into the dielectric resonator, similar to the conformal strip provided by the antennas. Using this feeding technique, the antenna can radiate in the opposite direction of the conformal strip-fed DRA. The slot dimensions of the offset position in the intended impedance matching require the maintenance of an efficient axial ratio.

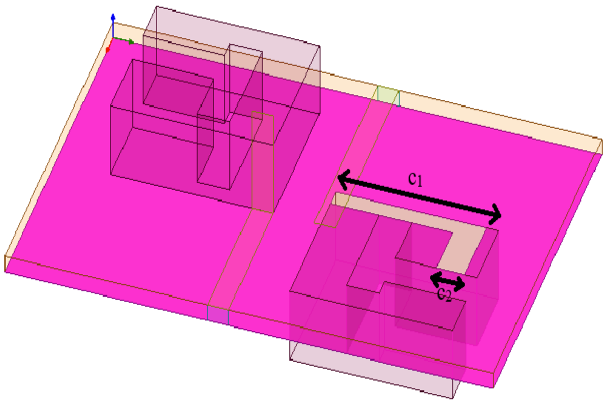

Fig. 3. Geometry of offset microstrip-slot fed dielectric resonator antenna. [C_1=18.5mm, C_2=3.5mm]

The antenna consists of a dielectric resonator constructed on a substrate with a ground plane. The feeding mechanism is designed to energize the resonator. The design aids in attaining the desired operational frequency and radiation characteristics.

D. Two-Element MIMO Antenna Configuration

A small, two-port MIMO antenna system was created by combining two circularly polarized dielectric resonator antennas. Two antenna elements are placed on opposing sides of the substrate, aligned, and dispersed to the different surroundings in order to achieve pattern diversity. This configuration lessens the mutual interactions between the antenna elements by decreasing the overlap between the radiating fields.

The performance of the MIMO antennas was measured using key characteristics, such as the S-parameters, diversity gain, envelope correlation coefficient (ECC), and multiplexing efficiency. Low ECC values indicate that the two antenna elements function independently, and good port isolation confirms the minimum coupling between the antennas.

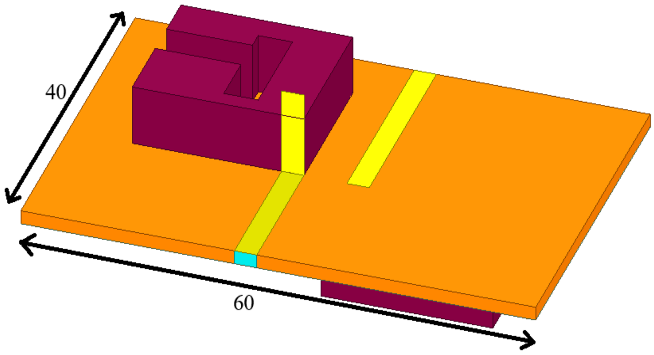

Fig. 4. Geometry of two-element MIMO dielectric resonator antenna configuration.

The dielectric resonance principle is employed in antennas for the effective radiation of electromagnetic waves confined within dielectrics. A circularly polarized wave is produced when two orthogonal modes are stimulated with unequal amplitudes and a 90° phase difference. In the MIMO configuration, multiple antennas can be configured optimally to reduce interference and improve signal patterns.

III. RESULTS AND DISCUSSION

Circular polarization occurs when two perpendicular electric field components have similar amplitudes and a phase difference of 90 °. This criterion is achieved in the proposed antenna by utilizing an offset-fed approach and an asymmetrical design.

When the dielectric resonator is excited from an offset position, two orthogonal modes are generated. These modes rotate with time, resulting in a circularly polarized wave. By adjusting the design, the antenna can produce both right- and left-hand circular polarizations. The proposed antenna was simulated using Ansys HFSS, and its design was developed. Single-element and MIMO systems were explored for several performance parameters in this study.

A. S-Parameters and Impedance Matching

The impedance characteristics of the antenna were investigated using S parameters. The S_{11} reflection coefficient indicates how well the antenna is matched to its input port. The reflection coefficients S_{11} and S_{22} are below −10 dB over the entire band, which implies acceptable impedance matching at both ports. The transmittance coefficient S12/S21 is less than -20 dB, which specifies excellent port isolation without the need for an increased number of decoupling structures. Good agreement between the antennas was observed in the simulated and measured results. design's durability.

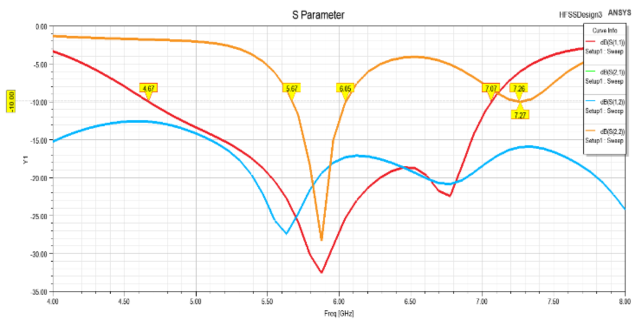

Fig. 5. S-Parameter of proposed two port MIMO antenna configuration

Based on the S-parameter results, the antenna exhibited good impedance matching in the C-band. The S11 levels were less than −10 dB, implying good power transfer and little reflection.

B. Axial Ratio Performance

The axial ratio measures the circular-polarization behavior of the antenna. The simulated axial ratio did not exceed 3 dB within the target frequency range, thereby verifying the stability of the circular polarization. The offset feeding approach coupled with the asymmetrical notch contributes significantly to this performance by activating two modes of perpendicularity with equal strength.

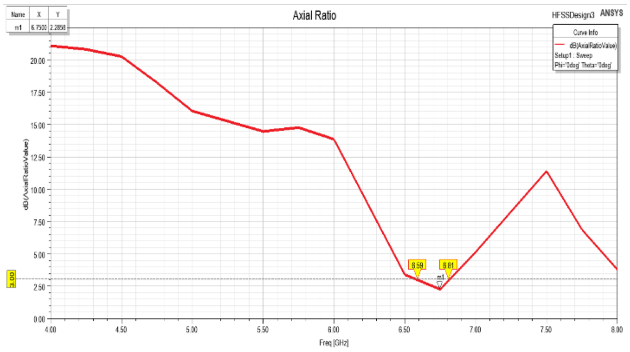

Fig. 6. Axial Ration of the suggested two-port MIMO antenna setup

The axial ratio is less than 3 dB at the operating frequency, and circular polarization is achieved. Signal transmission is unaffected by changes in the polarization orientation.

C. Gain Characteristics

The antenna gain performance was analyzed to understand its radiation strength. The modelling results indicate that the antenna has a constant gain over the operational band.

The gain variation is smooth, indicating that the radiation behavior is constant across the single-element and MIMO systems.

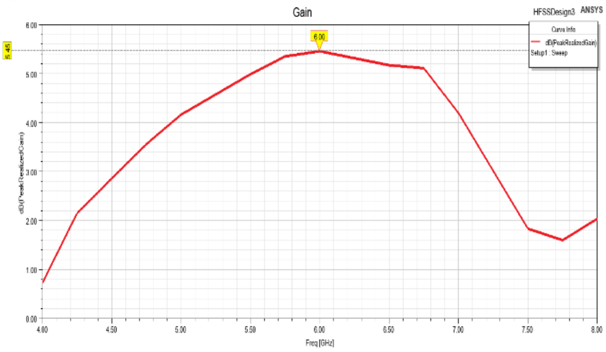

Fig. 7. Plot of gain versus frequency

The gain of the antenna was decent, which is a good indication of radiation efficiency. This indicates that the antenna can be used for communication.

D. Radiation Pattern Analysis

The directional characteristics of both the dielectric resonator antennas were evaluated using their radiation patterns. The results revealed that both designs produced stable radiation with circular polarization in the major radiation direction. The radiation behavior was consistent throughout the operating frequency range.

Although the feeding techniques differ, both antenna elements provide satisfactory radiation performance. The conformal-strip-fed DRA and microstrip-slot-fed DRA radiate in different directions, which helps achieve a variety of patterns in the MIMO arrangement. This opposing radiation reduces the field overlap between the antenna elements and enhances isolation.

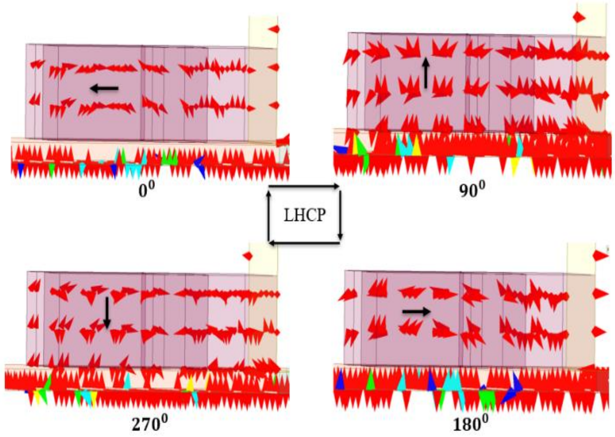

Fig. 8. Radiation pattern of conformal-strip fed CP-DRA

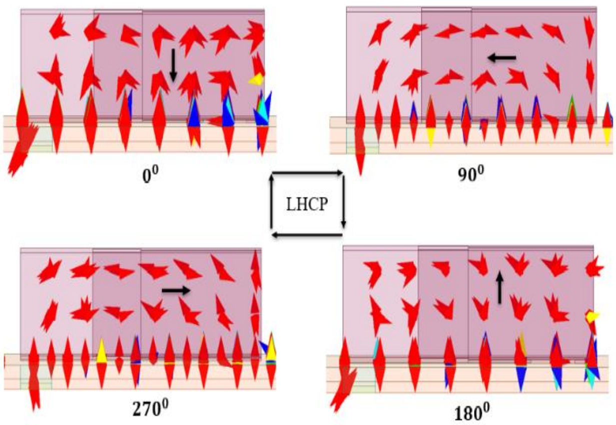

Fig. 9. Radiation pattern of microstrip-slot fed CP-DRA

E. Envelope correlation Coefficient (ECC)

The ECC is used to check the independent radiation of the MIMO antenna elements. A low ECC value indicates that the antenna components can function independently and provide good diversity.

In this study, the ECC was estimated using the S-parameter formula, which is commonly used for practical antenna analysis. It is expressed as:

$$\rho_e = \frac{|S_{ii}^{*}S_{ij} + S_{ji}^{*}S_{jj}|^2}{\left(1-\left(|S_{ii}|^2+|S_{ji}|^2\right)\right)\left(1-\left(|S_{jj}|^2+|S_{ij}|^2\right)\right)}$$

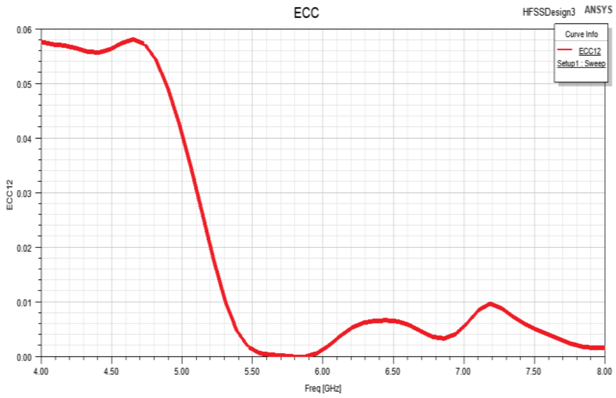

Fig. 10. Envelope Correlation Coefficient (ECC) versus Frequency

The above Fig. 10. Shows how the ECC varies with frequency. According to the graph, the ECC value remained below 0.12 for the entire working band. This low ECC indicates that the two antenna elements have minimal correlation and provide strong pattern and polarization diversity, which is required for MIMO communication systems.

F. Diversity Gain (DG)

The increase in signal reliability attained by employing many antenna elements is referred to as diversity gain. It shows how successfully the MIMO system removes the fading effects and is strongly related to the ECC.

The DG is obtained using the relation given below:

$$DG = 10\sqrt{1-(\rho_e)^2}$$

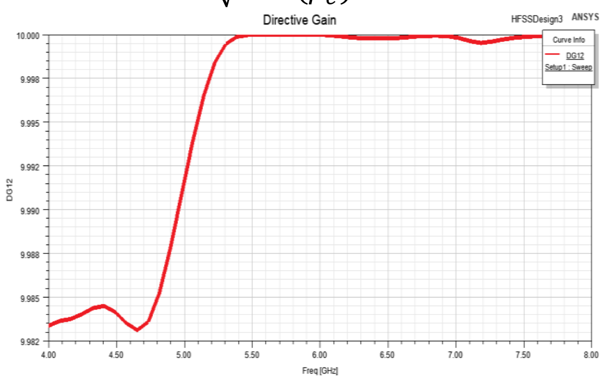

Fig. 11. Plot of DG versus Frequency

The above Fig. 11. shows the diversity gain plot. The DG maintains a near 10 dB throughout the operational frequency range. This shows good diversity performance and proves that the proposed antenna design can successfully combat multipath fading in wireless communication situations.

The MIMO performance was measured using the ECC and diversity gain. The ECC values are very small, suggesting a very weak correlation between the antenna elements. The diversity gain is approximately 10 dB, which proves the good diversity performance.

G. Channel Capacity Loss

This is the gain of the signal reliability obtained by employing several antenna elements. It is directly related to ECC and is used to determine how well the system that uses MIMO reduces the effects of fading.

The diversity gain is obtained using the following expression:

$$C(\text{Loss}) = -\log_2 \det\left(\psi^R\right)$$

$$\psi^R = \begin{bmatrix} \rho 11 & \rho 12 \\ \rho 21 & \rho 22 \end{bmatrix}, \rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right)$$

and

$$\rho_{ij} = -\left(S_{ii}^* S_{ij} + S_{ji}^* S_{ij}\right), \text{ for i, j} = 1 \text{ or } 2$$

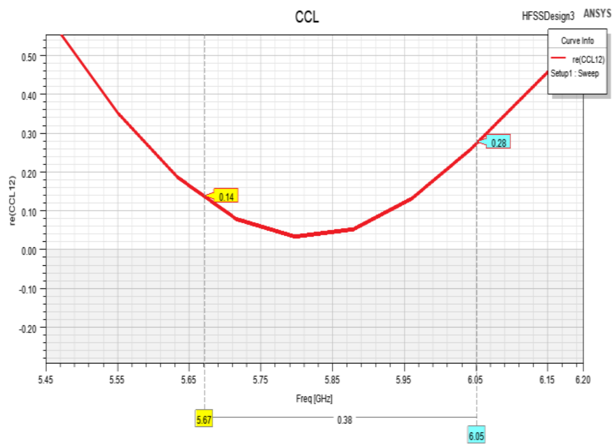

Fig. 12. Channel Capacity Loss versus Frequency

A plot of the diversity gain is shown in Fig. 14. The DG is nearly constant in the operating frequency range (10 dB). This indicates that the diversity performance is excellent and that the proposed antenna system is effective against multipath fading in wireless communication environments.

H. Mean Effective Gain (MEG) Analysis

The MEG is used to evaluate the performance of antenna elements in a multipath environment. The MEG data help determine how successfully each antenna element receives power when signals enter from different directions.

The obtained results indicate that both antenna elements have comparable MEG values in the operating frequency spectrum. The slight deviation in the MEG values indicates equal power capture and excellent MIMO functioning. This indicates that the two antenna components contribute equally to the entire system.

MEG_1 – MEG of Port 1

MEG-1 shows the average power received by antenna element 1 under scattering conditions. This number is primarily used to assess the capacity of each antenna element in MIMO systems in terms of reception [1], [10].

$$MEG_i = 0.5\eta_{irad} = 0.5(1 - \sum_{j=1}^{k} |s_{ij}|^2)$$

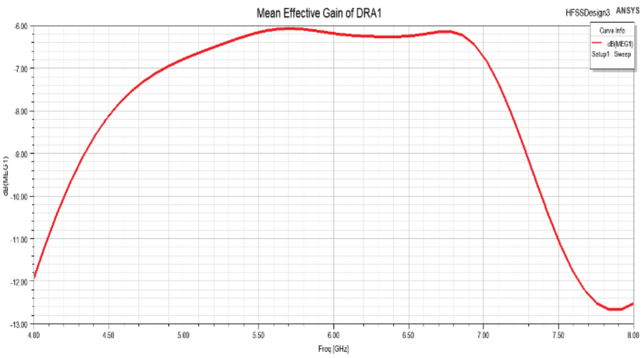

Fig. 13. Plot of MEG_1 for the proposed two-port MIMO antenna system

MEG_2 – Mean Effective Gain of Port 2

The mean power of antenna element 2 under multipath propagation conditions, such as MEG 1. It assists in the analysis of the port behavior of a MIMO antenna system [1],[12].

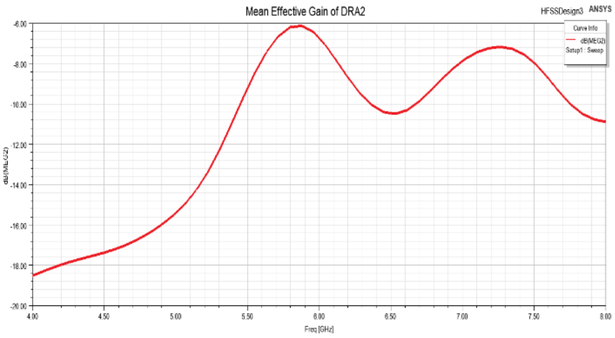

Fig. 14. MEG2 of suggested two port MIMO antenna system

MEG_{12} – MEG Ratio

The power balance of the two parts of the antenna was measured using MEG 12. A balanced MEG between ports in MIMO systems guarantees steady signal reception and high diversity in performance [10], [12].

For good MIMO performance:

$$-3\text{ dB} \le 10\log_{10}(MEG_{12}) \le 3\text{ dB}$$

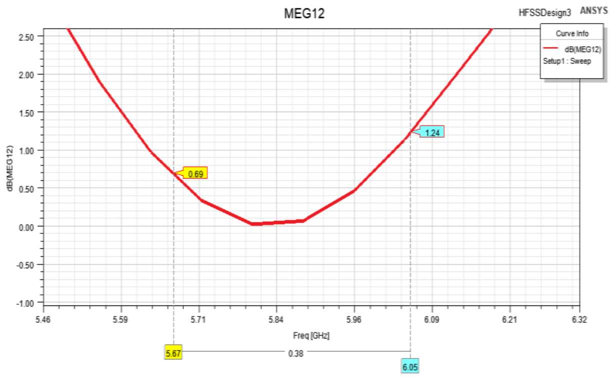

Fig. 15. MEG_{12} of the proposed two affordable antenna port MIMO.

IV. COMPARATIVE ANALYSIS

Table 1: Comparison of existing and proposed CP DR antenna in MIMO configuration

Ref.	Bandwidth (GHz)	Gain (dB)	Circular Polarization	ECC	MEG	CCL (bits/ Hz)
1	0.82-7.82	~4-5	No	<0.5	NA	NA
2	~1	~5	Yes	NA	NA	NA
4	~0.8	4.83	Yes	<0.01	NA	<0.1
5	~1.5	~5	Yes	NA	NA	NA
6	~1.2	~5	Yes	NA	NA	NA
7	5.1-5.6	~5	No	NA	NA	NA
12	2.5-2.55	6.1	Yes	<0.01	NA	<0.5
13	4.85-5.05	~5	No	<0.05	NA	NA
15	~27.5-28.5	~6-7	No	<0.01	NA	NA
proposed	**4.67-7.07**	**5.45**	**Yes**	**<0.01**	**~-6dB**	**<0.28**

It is clear that the number of current published works lack to report the complete MIMO performance parameters such as MEG and CCL. The proposed antenna design is able to provide all the parameters in a single design in additionit also increased bandwidth, gain and diversity performance.

The comparison between the existing antenna and the antenna proposed in this study clearly demonstrates the gain achieved by structuring the new antenna in this way. The simple rectangular cut in the DRA of the existing antenna was replaced with a T-shaped cut in the new antenna, along with an L-shaped slot in the ground plane. This alters the current distribution and performance of the initial design, leading to increased bandwidth, gain, and reflection coefficient while retaining low levels of mutual coupling, similar to the initial design. Notably, the return loss increased from approximately -22 dB in the initial design to -32.5 dB in the proposed antenna, which shows a 2.6 GHz increase in bandwidth from 1.89 GHz to 2.6 GHz. The gain increased from 4.31 dB to 5.45 dB while remaining at a low far-field level. The MIMO results show that the ECC is less than 0.01, compared to less than 0.1 in the initial design, indicating excellent isolation in the structural change. The axial ratio was 2.28 dB, whereas the MEG was relatively even at approximately-6 dB, thus providing good circular polarization. The channel capacity loss in the proposed antenna is only 0.28 bits/s/Hz, and thus the transmission is high. Overall, these results clearly show that the proposed design provides better performance than the existing design, mainly because of the introduction of the T-shaped- and L-shaped modifications.

Most significant change between the current design and the proposed is T-shape cut in the DRA and L-shape defect in the ground plane which are responsible for improving the current distribution, better impedance matching, increase bandwidth and the greatly improved performance of MIMO antenna.

V. CONCLUSION

This paper introduces a novel circularly polarized dielectric resonator MIMO antenna. Circular polarization is realized by exciting the dielectric resonator through a simple offset feed, and therefore eliminating the need for a feed network. The antenna can operate effectively over a bandwidth of 4.67 7.07GHz, while maintaining a stable gain of 5.45d B and a low axial ratio of 3d B, and therefore demonstrating that the antenna can realize circular polarization. In comparison to previous designs, by adding T-shaped slots in the DRA and an L-shaped slot in the ground plane, the current is distributed uniformly across the DRA's surface, improving return loss, increasing gain, and extending the antenna's bandwidth. The MIMO performance is further improved with both low ECC and high Diversity gain, and therefore demonstrates reliable wireless systems.

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