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Mutual coupling reduction in circularly polarized dielectric resonator MIMO antenna

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Article Info

ABSTRACT

In this article a novel circularly polarized (CP) rectangular dielectric resonator antennas (RDRA's) array has been designed. A unique conformal feeding strip has been used to excite the RDRA's having a distance of λ/2. Various techniques are investigated to reduce mutual coupling (MC). Different formations, comprise of reorientation of the antennas have been employed to suppress MC and to enhance CP bandwidth. By the unique orientation the mutual coupling has been reduced by ~ 14 dB. A broadband circular polarization over a bandwidth of ~ 18.8% in conjunction with an impedance matching bandwidth of ~ 11.3 % has been achieved. The design has been modeled and simulated using computer simulation technology (CST). Two different simulation techniques i.e. finite integration technique (FIT) and Finite element method (FEM) have been used to compute and validate the results respectively. A significant resemblance in results have been observed.

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1. INTRODUCTION

From las few decades' communication engineers are focusing more on DRAs because of there good features such as wide bandwidth, no metallic losses and flexible shapes [1-2]. Recently, a significant progress in wireless activities has boosted the multiple inputs multiple outputs (MIMO) antenna technologies. For wireless application, MIMO antenna systems are used for long-term evolution (LTE) network, wireless local area network (WLAN), and worldwide interoperability for microwave access (WiMAX). MIMO system offers better quality of services in non-line of sight (NLOS) communication since it offers significantly wider bandwidth of up to hundreds of gigabit compared to a single input single-output (SISO) system [3]. Additionally, MIMO antennas have the capability to improve the channel capacity over a limited available bandwidth to attain a high data rate. MIMO is an essential part of existing technologies because of enhancement of different parameters, i.e. gain, data rate, capacity, and efficiency, etc.

The concept of MIMO was initiated using the capacity theorem [4]. In wireless communication system, MIMO has been used in conjunction with pulse amplitude modulation (PAM) signals [5], directional digital transmission and reception using beam-forming signal-processing applications [6-7], digital transmission systems with multi-channel [8-9] and multivariate analysis with memory over the Gaussian channel [10]. In modern wireless application, most of the devices are compact sizes. The handy and small

devices set a bound on the space between antennas in MIMO system. The close vicinity of the radiating antennas in MIMO can cause the degradation of different antenna parameters such as gain and return loss. Such degrading outcome is jointly known as a mutual coupling, which rigorously affects the near and far field characteristics. A low value of mutual coupling need to be maintained between the antennas to ensure an efficient MIMO antenna systems, [11].

MIMO system using microstrip patch antennas have low efficiency such as in [12], where a dual-band patch antenna is used together with capacitive loaded loops. In such design, the antenna efficiency in lower and higher frequency band has about 30% and 70% respectively. This shortcoming of low efficiency in multiple patch antenna systems can be solved by replacing the patch antennas with dielectric resonator antennas (DRAs) for MIMO since DRAs possess very high radiation efficiency [13].

A number of methods has been proposed by different researchers to decrease mutual coupling between DRAs. About 20 dB isolation has been achieved by using artificial magnetic conductor (AMC) ground plane [14]. In [15], a 24 dB reduction in mutual coupling has been obtained using EBG structure between radiating elements. A Split ring resonators in [16] reduces mutual coupling by approximately 28 dB. Paper [17] proposed the use of an arc between two rectangular DRAs, which causes a 5 dB reduction in mutual coupling. On the other hand for exciting, conformal strip is used to excite the DRA as that is easier in use and provide better impedance matching with DRAs [18-19].

Previously, researcher focus a lot on linearly polarized antennas but due to the drawbacks of degradation of quality issue cause by the orientation of transmitter and receiver antennas [20], Now a day's high attention toward circular polarization has been paid, as circularly polarized antenna system is insensitive to the orientation as claimed in the literature [21-25].

2. ARRAY GEOMETRY AND DESIGN

Figure 1 illustrates the RDRA Configuration and dimension of conformal metallic strip to excite the antenna [18] i.e. a=26.1(height) mm, b=25.4 (breadth) c= 14.3 (width) and permittivity (εr) = 8. The novel feed is made up of five individually cut strips. The optimized feed parameters are h1=11 mm, h2=10.50 mm, d1= 10.5 mm d2=1mm d3= 2.5 mm and l = 8.0 mm respectively. Similarly for parasitic patch the dimension are same as in [26].The boundary condition of Zmin is set to be Et=0 in order to simulate the effect of an infinite ground plane. The Proposed feed has been exited through discrete edge port. Mashed parameters like, lines per wavelength, lower mesh limit and Mesh line ratio limit is 62, 37, and 52 respectively and finally, for the proposed final formation of Antenna array, mesh cells for the RDRA array without parasitic is 5, 10,439.Furthermore , same mashed parameters are kept for RDRA array with parasitic patch. The optimized design has been simulated by using hexahedrons meshing.

The novel design has been simulated in CST by using transient solver, which is based on the finite integration technique (FIT).The conformal metal strip feed has been used as it delivers better impedance matching with RDRA's.
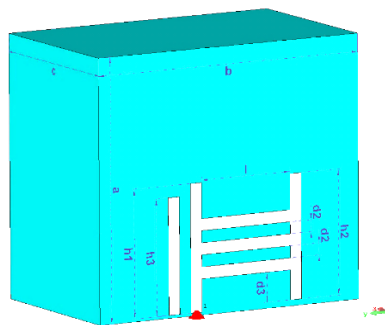

Figure 1. Configuration of the RDRA and conformal Strip

Above mentioned RDRA has been used in two antenna-system. The DRA's are placed back-to-back and the center-to-center spacing between the RDRA is chosen to be 35.62 mm that is equivalent to λ0/2 at 4.2 GHz as demonstrated in Figure 2a.In order to examine the outcome of antenna orientation on antenna MC, two additional topologies have been studied in Figures 2b and 2c with approximately same center-to-center spacing. In the orientation of Figure 2b, one of the DRA is rotated 90° with respect to the other one making orthogonal MIMO array while on the other side the RDRA's of Figure 2c are aligned.

In the last orientation the DRA's are placed face-to-face and the center-to-center spacing between the RDRA is chosen to be similar as above mentioned cases as demonstrated in Figure 2d.

3. RESULTS AND DISCUSSIONS

The basic reason for mutual coupling is either through propagating surface waves or by means of radiation [26], in order to overcome such issues different orientations have been examined that are discussed below in detail.
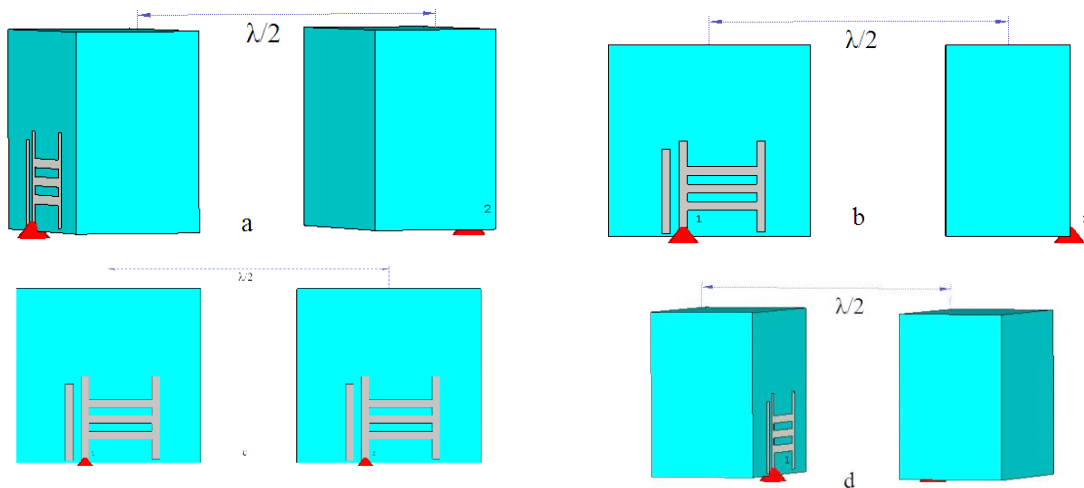

Figure 2. Two-antenna systems composed of RDRA's of Figure 1 with (a) Back-to-Back, (b) perpendicular, (c) aligned, and (d) Face-to-Face Orientations

3.1. Back-to-Back Orientation of RDRA Array

The simulated reflection coefficients (S11<-10 dB) have been presented in Figure 3, the impedance matching bandwidth of 9.06% have been achieved at resonance frequency (f0) of 4.24 GHz. In parallel 3% of 3dB axial ratio bandwidth attained but at different frequency range. Hence the designed geometry is not circularly polarized.
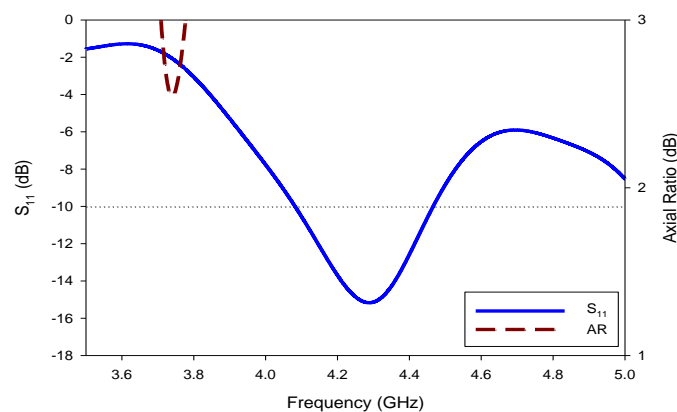

Figure 3. Return loss of back-to-back RDRA array with AR

3.2. Orthogonal Orientation of RDRA Array

As demonstrated in Figure 2b, one RDRA antennas is rotated 90° with respect to the other one, making an orthogonal shape. Additionally, this Configuration helped in achieving the circular polarization. In

Figure 3 the return losses and 3 dB axial Ratio of the perpendicularly placed RDRA's have been presented. The proposed formation offers the return loss S11<-10 dB bandwidth of ~11% and circular polarization bandwidth of 7.38% with a nominal overlap of ~ 1.94%. On the other side, as depicted in Figure 4 Mutual coupling S21 of 4.75 dB has been computed at the minimum of axial ratio i.e. 4.02 GHz. Isolation of perpendicular RDRA array as shown in Figure 5.
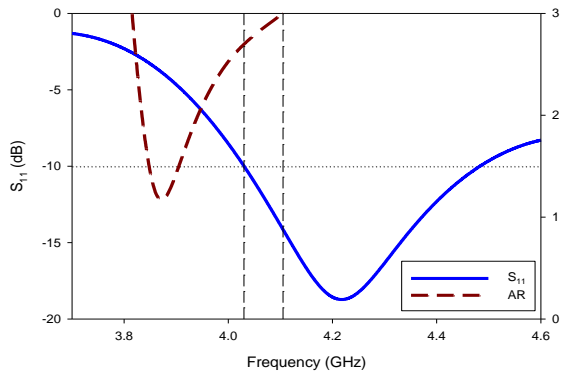
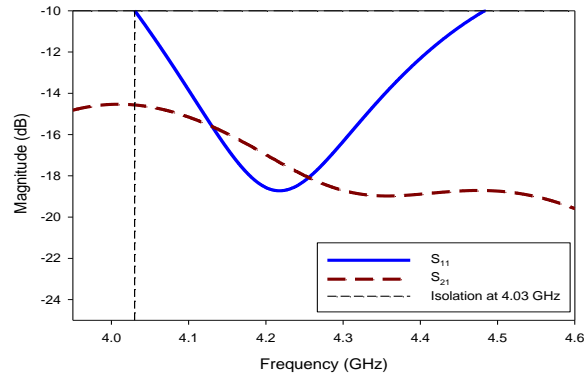

Figure 4. Return loss of perpendicular RDRA array with AR

Figure 5. Isolation of perpendicular RDRA array

3.3. Aligned Orientation of RDRA Array

In this layout both RDRA's antennas are aligned as presented in Figure 2c, using such Configuration the CP bandwidth has been enhanced as well as isolation compared to the previous cases. Both the impedance matching bandwidth and 3 dB axial ratio of the aligned geometry has been demonstrated in Figure 6. The return loss improves around 6% to that of orthogonal geometry i.e.17.6% additionally, circular polarization bandwidth improves to 11.2% with an overlap of ~ 7 %.Similarly the mutual coupling S21 has been suppressed to 8 dB, at the minimum of axial ratio as shown in Figure 7.
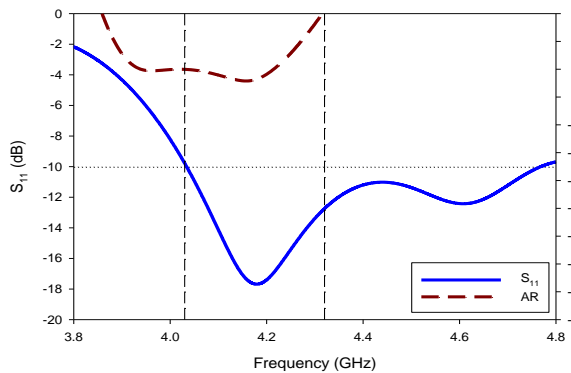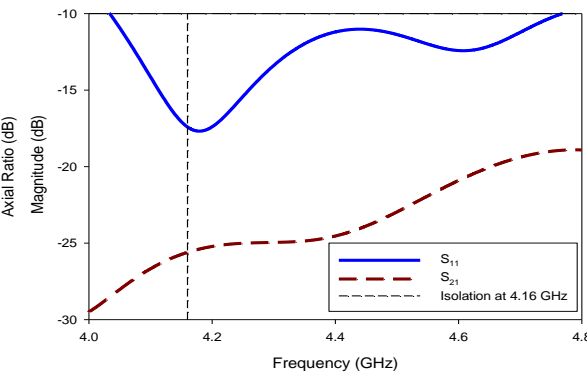

Figure 6. Return loss of aligned RDRA array with AR

Figure 7. Isolation of aligned RDRA array

3.4. Face-to-Face Orientation of RDRA Array

The proposed array has been designed by placing the RDRA's in face-to-face conFigureuration as shown in Figure 2d. By using such conFigureuration a wideband circular polarization along with good impedance matching bandwidth has been achieved over same frequency range. Along with this mutual coupling has been suppressed considerably.

The Figure 8 represents the return losses and the AR bandwidth of the proposed geometry. A broadband of 3 dB axial Ratio bandwidth of ~18.3% has been achieved. The minimum point of axial ratio has been computed at 4.47 GHz. An impedance matching bandwidth of ~ 11% has been offered by the proposed design at resonant frequency of 4.24 GHz. The in conjunction overlapped bandwidth of ~11 % has been provided by the proposed geometry. The isolation between the antennas has been demonstrated in

Figure 9. This conFigureuration offers the maximum mutual coupling suppression i.e. ~14 dB. All this parameters of the final designed has been optimized by using FIT in CST. The results of FIT have been validated using FEM i.e. another computational technique abatable in CST. A minor deviation in the bandwidth and resonant frequency obtained can be attributed to the different computational techniques. In overall, there is a reasonable trend resemblance between them.
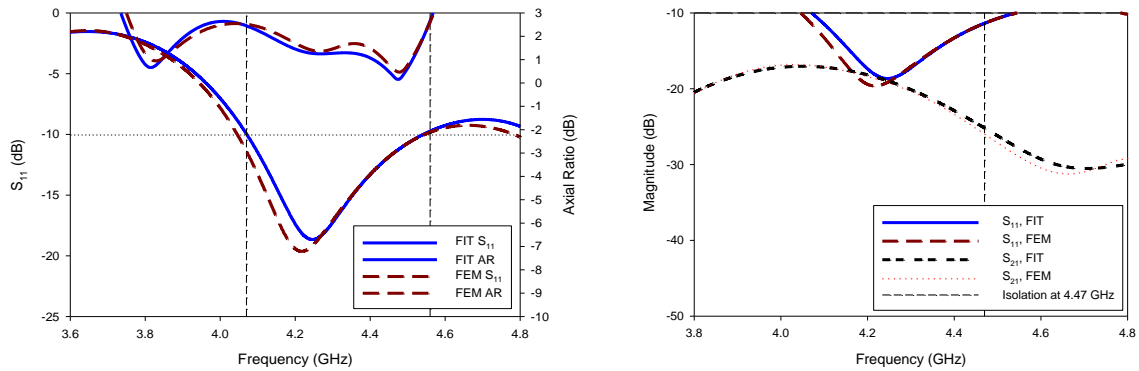

Figure 8. Return loss of face-to-face RDRA array with AR

Figure 9. Isolation of face-to-faceRDRA array

Additionally, due to the reduction in mutual coupling the proposed orientation array offers a satisfactory simulated boresight gain of ~5.95 dBi as demonstrated in Figure 10.
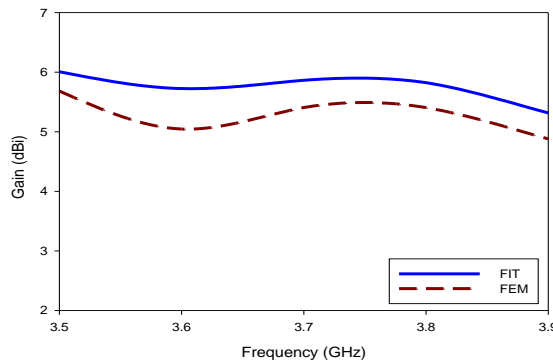

Figure 10. Gain of proposed orientation

In Figure 10 the current distribution of proposed antenna geometry is shown that is co-centric while Figure 11 demonstrate the current distribution of Figure 2a, the current direction is anti-clockwise which clearly shows that the direction of current changes which in result reduces MC basically, The spacing and geometry between the DRA's of the proposed design act in this way which prevent current inducing directly from the aggressor antenna to the victim antenna which in result change the current flow on the ground and that is the main reason of decrease the mutual coupling [19].

Higher the isolation and lower the envelope correlation coefficient (ECC) are important in MIMO systems [27].The ECC is in linked to the mutual coupling, and it is directly proportional to the mutual coupling between arrays. The ECC can be achieved using the far-field characteristics [28] of the radiating elements. Let the F1 (θ, φ) and F2 (θ, φ) are the field patterns of proposed RDRA array, then ECC is given below:

$$\left| \rho_e(i, j, N) \right| = \frac{\left| \sum_{n=1}^{N} S_{i,n}^* S_{n,j} \right|}{\sqrt{\left| \prod_{k(=i,j)} \left[1 - \sum_{n=1}^{N} S_{i,n}^* S_{n,k} \right] \right|}}$$

(1)

In the same way, the diversity gain (DG) is also dependent upon mutual coupling [28], which is acquired in terms of maximum theoretical DG (10 dB) and ρ by using equation given below. DG and correlation is inversely proportional to each other. From Figures 12-13 it is obvious that proposed RDRA array have lower ECC value and higher DG values i.e. ~4.57e-007 and ~ 9.99 dBi respectively.

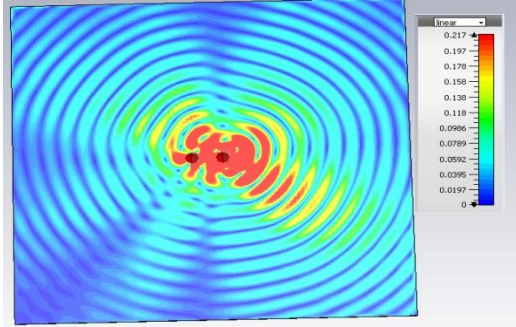$$G_{DG} = 10 \times \sqrt{1 - |\rho|^2}.$$

(2)

Figure 10. Current flow of face-to-face RDR Array
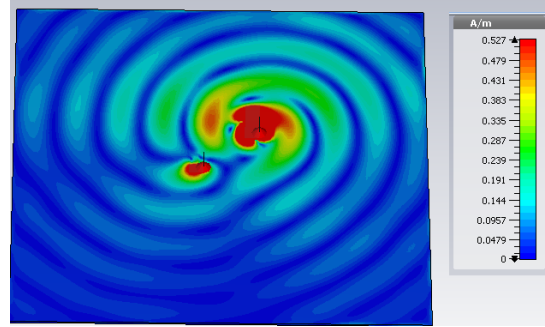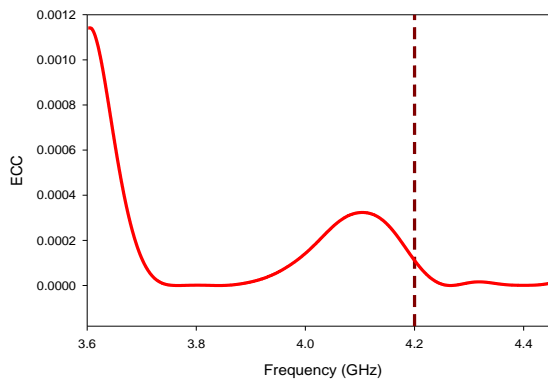

Figure 11. Current flow of back-to-back RDR Array

Figure 12. ECC of Proposed RDRA array
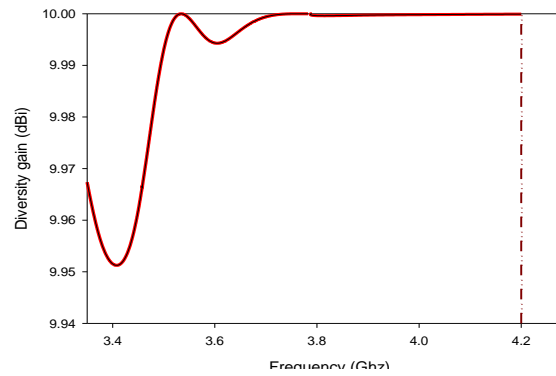

Figure 13. DG of proposed RDRA array

The radiation patterns simulated using FIT at 0° and 90° are shown in Figure 14. From these result, it is evident that the MIMO design generates a left hand circular polarized (LHCP) wave since the left-hand field component is stronger than the right-hand component.
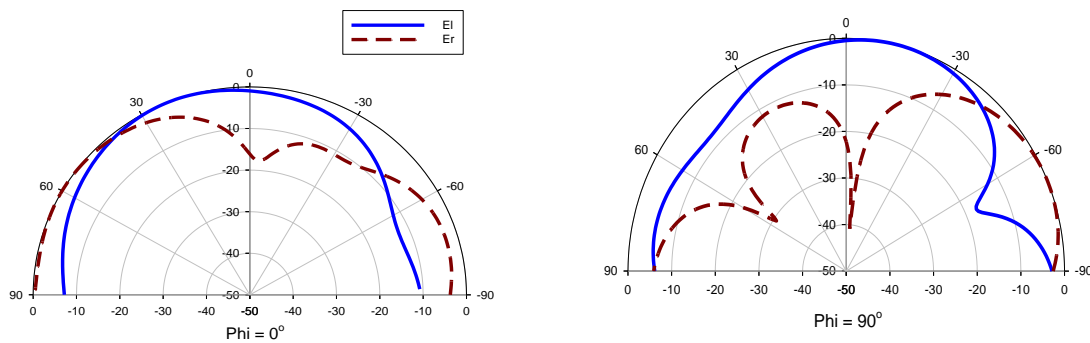

Figure 14. Radiation pattern of Slotted CDRA Array

4. CONCLUSION

This paper proposed a two-element RDRA array with different formation to suppress MC and to enhance CP bandwidth. By the face-to-face orientation the mutual coupling has been reduce over a wideband frequency of 4.06-4.54 GHz. Additionally, an overlapping bandwidths of ~ 7% has been achieved in which a return loss (S_{11} <-10dB) is obtained in conjunction with a 3-dB axial ratio Two different simulation techniques i.e. finite integration technique (FIT) and Finite element method (FEM) have been used to compute and validate the results respectively. A significant resemblance in results have been observed.

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