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Mutual Coupling Reduction in Circularly Polarized Dielectric Resonator MIMO Antenna Arrays Using Slot

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Abstract—An effective technique for reducing the mutual coupling between cylindrical dielectric resonator antennas (CDRA's) by using a Slot. This is achieved by separating the two closely spaced CDRA's antennas at the optimum distance (λ/4) and creating a slot between DRA's. Both CRDA's are placed in E-Plane. Using the proposed techniques, a new current path is introduced which in result not only reduces the mutual coupling between the two CDRA's but also produce the circular polarization. The proposed technique reduced the mutual coupling (MC) ~ 12 dB throughout the entire band of interest. Average Gain of ~ 5.9 dBi is attained throughout. Return loss of ~12.16dB Moreover, 3-dB axial ratio bandwidth of 12.5% is achieved. The design is simulated in professional simulating tool i.e. CST, which use FET (finite integration technique) computational technique that is further validated through another computational technique FEM (Finite element method) and significant resemblance in results is examined.

Keywords: Mutual coupling; Slot; circular polarization; DRA; MIMO antenna.

1.0 INTRODUCTION

Over a couple of years, a substantial progress in wireless activities has boosted the multiple inputs multiple outputs (MIMO) antenna technologies. For wireless application, MIMO antenna systems are used for wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX) and long-term evolution (LTE). MIMO framework offers better nature of work in non-line of sight (NLOS) since it offers fundamentally more extensive transfer speed of up to several gigabits contrasted with a single input single-output (SISO) framework [1]. Also, MIMO receiving wires have the ability to enhance the channel limit over a constrained accessible transmission capacity to accomplish a high information rate. MIMO is a basic piece of existing advances on account of the upgrade of various parameters, for example, gain, information rate, limit, and proficiency, and so on.

The idea of MIMO was introduced by using the capacity theorem [3]. In wireless communication system, MIMO has been used in combination with pulse amplitude modulation signals [4], directional digital transmission and reception using beam-forming signal-processing applications [5, 6], digital transmission systems with multi-channel [7, 8] and multivariate analysis with memory over the Gaussian channel [9].

Now a day's in current wireless application, mostly the devices are small in sizes. The compact and handy devices set a bound on the space between antennas in MIMO system. The adjacent locality of the radiating elements in MIMO can be a reason of deprivation of many antenna characteristics like, return loss, Axial ratio and gain and jointly such outcome is known as a MP, which thoroughly disturbs the near and far field parameters. A MC of low value is essential to be sustained between the radiating elements in order to guarantee an efficient MIMO antenna systems, [2].

Microstrip patch antennas have been used in MIMO system but such antennas have very low efficiency such as mentioned in [10], where a dual-band microstrip patch antenna is used along with capacitive loaded loops. In these techniques, the efficiency of the antenna has about 30% and 70% in lower and higher frequency band respectively. Low efficiency issue of microstrip patch antennas can be resolved by substituting the microstrip antennas with DRA for MIMO subsequently DRAs retain high radiation efficiency [11]

A lot of techniques has been used by numerous researchers to reduce MC between radiators. Almost 19.5 dB isolation has been attained by utilizing artificial magnetic conductor (AMC) ground plane [12]. On the other side, in [13] around 23 dB reduction in mutual coupling has been reported by using electromagnetic band gap structure (EBG) structure between radiating elements. Another technique through which MC drop down by approximately 28 dB using split ring resonators (SRR) in [14]. Paper [15] proposed the use of an arc which work as a defected ground structure between two cylindrical DRAs, which causes a 5.8 dB reduction in MC. In order to excite the DRA, conformal metal strip has been as that is easy to handle and additionally, offer better impedance matching with DRAs [16, 17].

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2.0 ANTENNA GEOMETRY AND DESIGN

The dimension of the single CDRA is taken from the literature. [18] i.e. a=10.54 (height) mm and b=14(diameter) and permittivity and εr = 10. The novel feed is made up of five individually cut strips. The Slotted length, distance and width of the feed are c=10.25mm, d=8 mm, e=1mm & f= 6.20 mm respectively.

Slot is a technique through which air play very important role and in result enhanced the isolation between the closely packed radiating elements [19] Figure 1 illustrates a CDRA excited by Novel (III)-shaped conformal metal strip. The metal strip feed is used as it delivers better impedance matching with CDRA's.

Figure 2 demonstrate the return loss of single CDRA i.e.5.9 dB, in parallel no Axial Ratio that is shown in Figure 3. The CDRA is used in a two-element array design as shown in Figure 4 that is placed on an 80 mm x 80 mm PEC ground plane.

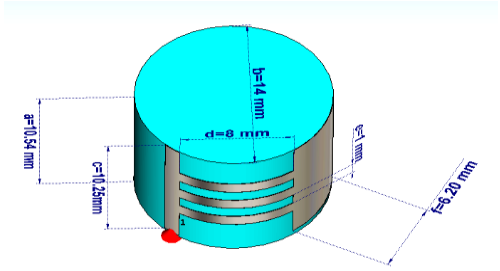

Figure 1: Configuration of the conformal Strip

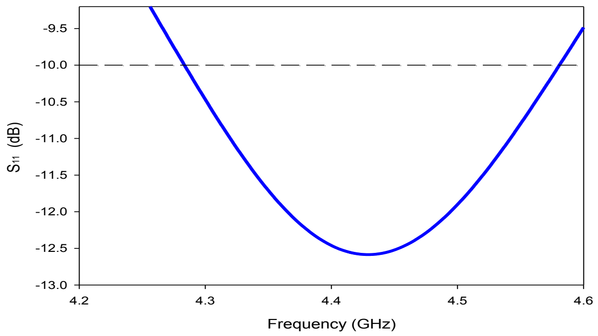

Figure 2: Return loss of Single CDRA

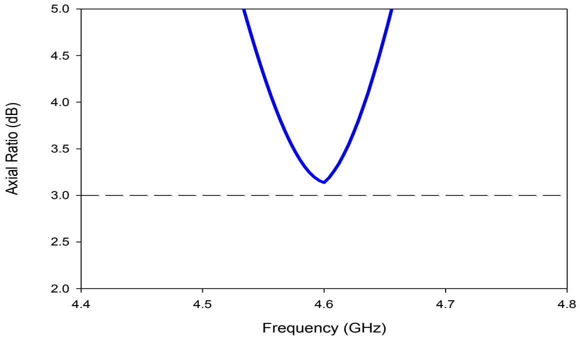

Figure 3: Axial ratio of Single CDRA

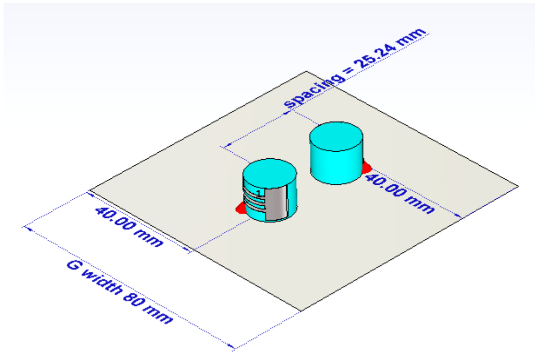

Figure 4: Geometry of Back to Back CDRA array

After numerous simulations, based on parametric analysis using CST tool the dimension of the slot is set to be 19 mm * 2 mm and distance between two CDRA's is kept at $\lambda_0/4$, where λ_0 denotes the wavelength with respect to resonant frequency.

Configuration of the CDRAs based on the Slotted distance is shown in Figure. 4-5 where both the radiating antennas are positioned side by side.

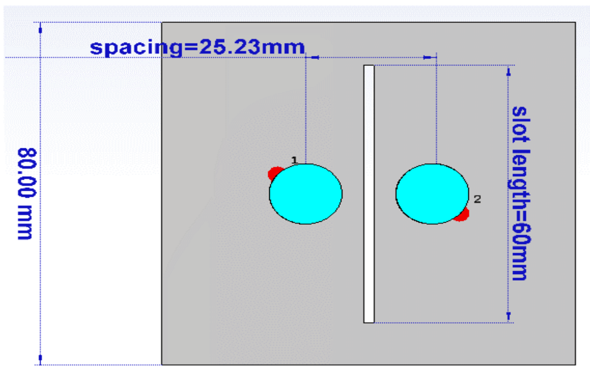

Figure 5: Top view of CDRA array with Slot.

3.0 RESULTS AND DISCUSSIONS

The basic reason for mutual coupling is either through propagating surface waves or by means of radiation, increasing the gap between radiating elements and creating slot cover both these reasons [20]. Because of this configuration resonant frequency shifted to the left, so return-loss S_{11}<-10 dB achieved is = 12.16 dB as shown in Figure. 6 which is further validated through another computational technique called FEM. 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 the results.

A circular polarization over a broad bandwidth of ~12.50% has been attained which is clearly reflected from Figure 7 and also validated trough FEM as well, so because of this configuration not only broad bandwidth of S_{11} is achieved but also Circular polarization as well.

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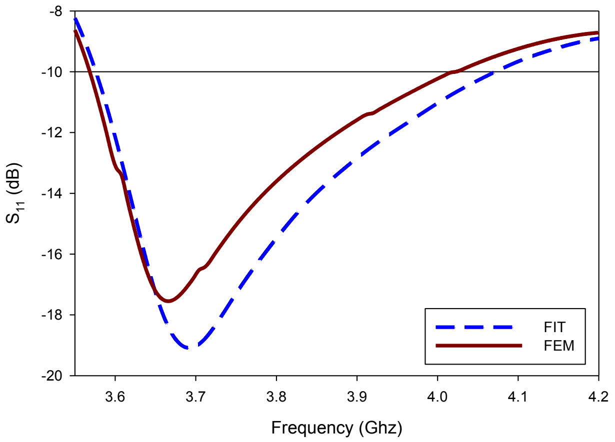

Figure 6: Validation of return loss of Slotted CDRA array

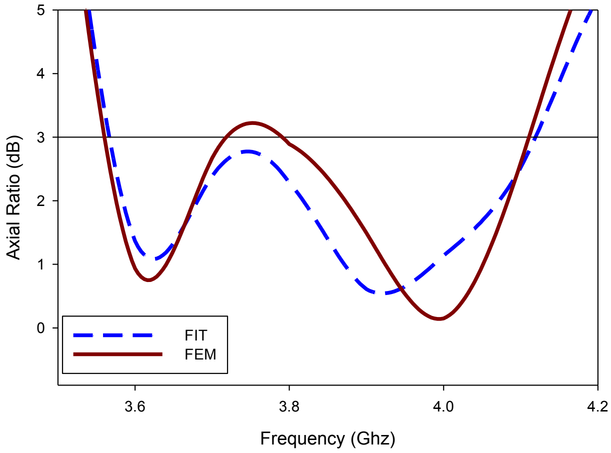

Figure 7: Validation of Axial ratio of Slotted CDRA array

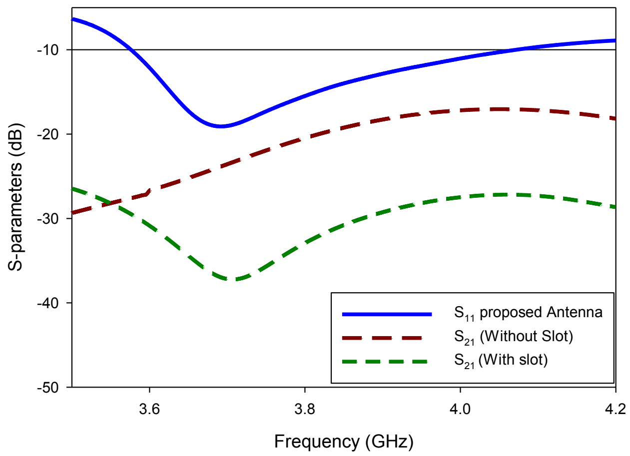

Figure 8: Reduction of MC between Slotted and without Slotted CDRA array

The mutual coupling performance (S_{21}) of Without Slotted design (without Slot) and Slotted design is shown in Figure. 8. It is clear that mutual coupling in Without Slotted antenna is very high within the 3.60-4.07 GHz band. This has been reduced by optimizing the distance of two CDRA. Additionally, due to the reduction in mutual coupling, the CDRA array offers a satisfactory simulated boresight gain of ~5.95 dBi as demonstrated in Figure 9.

As mention in [21], the direction of current flow changes when the Slot design is used, which caused a reduction mutual coupling because of this new current path from active antenna element to passive element has been created, as can be seen in Figure 10 - 11.

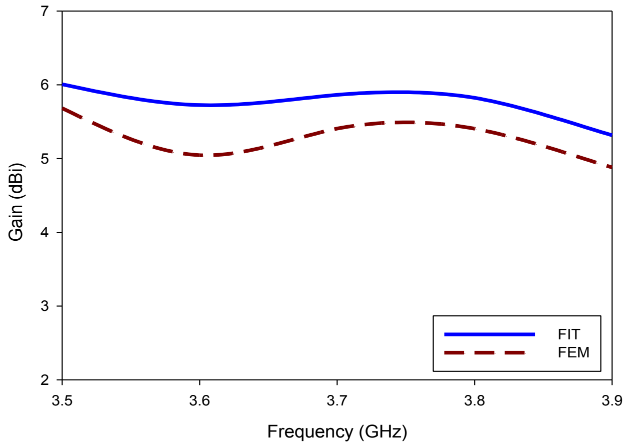

Figure 9: Comparison of Gain

In Figure. 10, current distribution of Without Slotted antenna is co-centric while in Figure. 11, due to the Slotted design and putting slot, the current is anti-clockwise and moving away from slot which clearly shows that the direction of current changes which in result reduces MC. Higher the isolation and lower the envelope correlation coefficient (ECC) are important in MIMO systems [22].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 [22] of the radiating elements.

Let the F1 (θ, φ) and F2 (θ, φ) are the field patterns of two CDRA array, then ECC equation is given below:

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

In the same way, the diversity gain (DG) is also dependent upon mutual coupling [23], 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 Fig: 12-13 it is obvious that proposed CDRA array have lower ECC value and higher DG values i.e. ~4.57e-007 and ~9.99 dBi respectively.

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

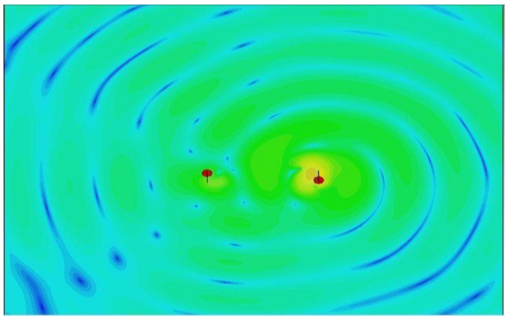

Figure 10: Current flow before introducing slot

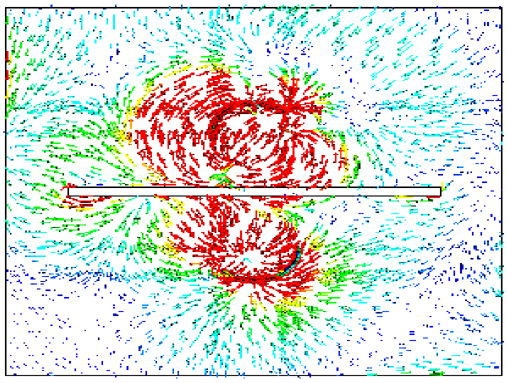

Figure 11: Change in current flow after introducing slot

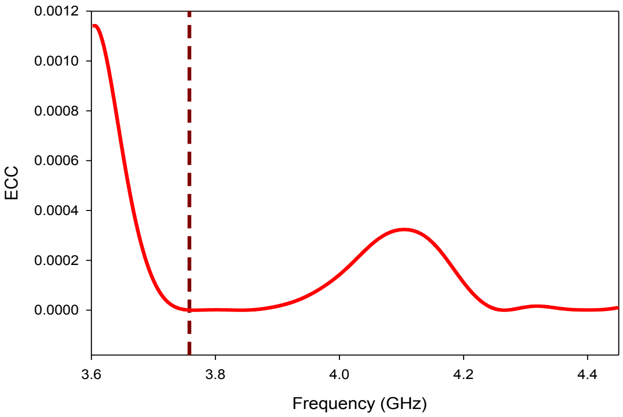

Figure 12: ECC of Slotted distance RDRA array

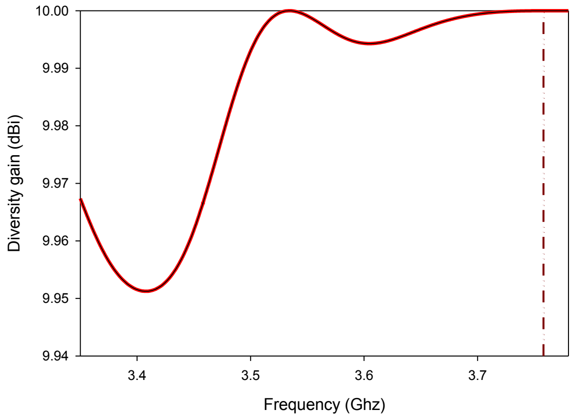

Figure 13: DG of Slotted distance CDRA array

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.

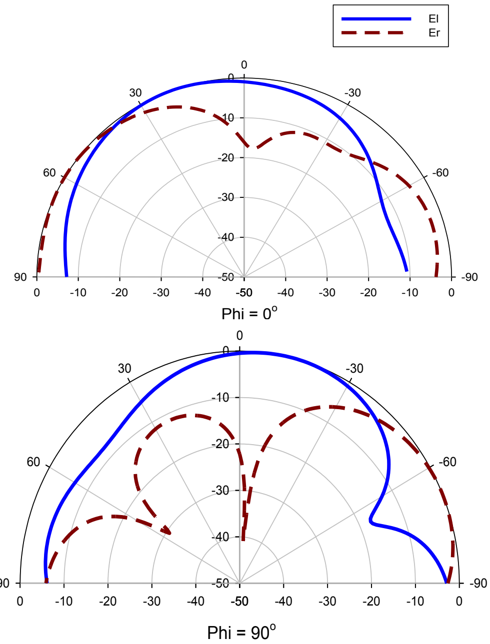

Figure 14: Radiation pattern of Slotted CDRA Array

1. Conclusion

This paper proposed a two-element CDRA array design using Slot technique. With Slotted distance, the mutual coupling has been reduced (< -8.65 dB) over a wideband frequency of 3.65-3.85 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.

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