Mutual Coupling Reduction in C-shaped Dielectric Resonator Antenna array for MIMO Applications

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***Abstract*— A technique to reduce the mutual coupling between two closely spaced dielectric resonator antennas (DRA) is proposed for wireless MIMO applications. The design starts with a miniaturized C-shaped DRA. There is an air gap between the dielectric resonator and finite ground plane. In this proposed antenna, microstrip line feeding is used for easy fabrication. The S-parameter of C-shaped DRA is providing desired frequency of interest at 3.5 GHz and 5.8 GHz, which is suitable for WiMAX applications. An array of two elements C-shaped DRA array has been designed. The approach for reducing the mutual coupling (S_{21} and S_{12}) in C-shaped DRA array has been presented for MIMO applications. The proposed technique simply reduces the mutual coupling by only reducing the dimension of the ground plane with proper arrangement of array elements. After suitable modification of ground plane, the final simulated result yields better than -30 dB of mutual coupling at resonant frequencies. The S-parameter, gain, directivity, radiation pattern results for C-shaped DRA as well as the S-parameter results for mutual coupling of DRA array are presented here.**

Keywords- Dielectric Resonator Antenna, Mutual Coupling, WiMAX, Microstrip Line feed, MIMO.

I. INTRODUCTION

The Dielectric Resonator Antenna offer advantages such as low cost, ease of manufacture, wider bandwidth, and high radiation efficiency. DRAs can be designed with different shapes to accommodate various design requirements. DRAs can also be excited with different feeding methods, such as probes, microstrip lines, slots, and co-planar lines [1]. As compared to the microstrip antenna, the DRA has much wider impedance bandwidth due to their many advantageous features. These include their compact size, light weight, the versatility in their shape and feeding mechanism with simple structure. Among the different shaped DRA, the cylindrical shaped DRA offers greater design flexibility, whereas the ratio of radius to height (r/d) controls the resonant frequency and the Q- factor [2-4]. Fabrication is also simpler than the other shaped DRA. Various modes can be easily excited within the cylindrical DRA, which results in either broadside or omni-directional radiation patterns [5-7]. The performance of a simple cylindrical shaped DRA can be enhanced by using a modified ring shaped or C-shaped DRA [8]. Analytical studies carried out on different types of antenna array have demonstrated that the mutual coupling in array could be reduced by proper arrangement of array elements with finite ground plane. Generally using the ground plane edge resulted in a conceptual 75% volume reduction and lighter antenna weight, as compared to a perpendicular ground plane. It has been discussed that the introduction of air gaps between the dielectric resonator and the ground plane can improve the impedance bandwidth of the antenna significantly [9].

A systematic comparative study on the mutual coupling (S_{21} and S_{12}) between cylindrical DRA and circular microstrip patch antennas has been presented in [10]. An approach for reducing mutual coupling in two closely spaced metamaterial-inspired monopole antennas is recently reported in [11].

This paper demonstrates a simple technique to reduce the mutual coupling between two closely spaced dielectric resonator antennas (DRA) for wireless MIMO applications. Initially, a miniaturized C-shaped single DRA is designed with an air gap between the dielectric resonator and ground for WiMAX applications. In this proposed antenna, microstrip line feeding is used for easy fabrication. The desired frequency of interest is at 3.5 GHz and 5.8 GHz, which is suitable for WiMAX applications. Further, a two elements C-shaped DRA array with finite ground plane is designed. It has been discussed that the mutual coupling reduction in array is possible by proper arrangement of the resonators in combination with an appropriate selection of the ground plane size, which is important for wireless MIMO applications.

II. ANTENNA DESIGN

As discussed in the previous section that a wide bandwidth can be achieved by modifying the basic shape of the DRA and also by introducing an air gap between the dielectric resonator and ground. Thus, the first design step is to modify the shape of a cylindrical DRA. From the analytical studies carried out on cylindrical dielectric resonators it has been demonstrated that the Q-factor could be reduced by removing a central portion of the dielectric material to form a ring [1]. The resonant frequency (f_0) of

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the ring DRA having outer radius ‘a’ and inner radius ‘b’ can be determined using [1]:

$$f_0 = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{\pi}{2h}\right)^2 + \left(\frac{X_0}{a}\right)^2} \qquad (1)$$

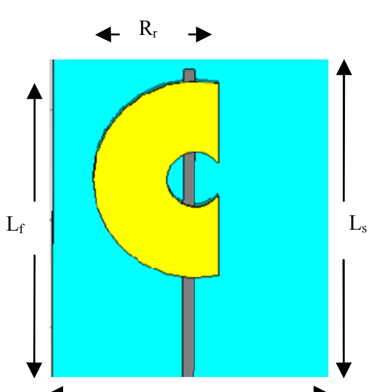
where ‘c’ is speed of light in free space, ‘ε_r’ is dielectric constant of DRA, ‘h’ is height of ring DRA and ‘X_0’ is the solution to

$$\frac{J_1(X_0)}{Y_1(X_0)} = \frac{J_1\left(\frac{b}{a}X_0\right)}{Y_1\left(\frac{b}{a}X_0\right)} \qquad (2)$$

where $J_1(x)$ and $Y_1(x)$ are the first-order Bessel functions of the first and second kind, respectively [1]. If the volume to surface ratio is minimized than the quality factor is reduced. Thus by removing a portion of ring DRA, a C-shaped DRA is designed to get minimum quality factor. The proposed C-shaped DRA is schematically shown in Fig. 1.

The proposed antenna consists of a C-shaped dielectric resonator made up of low cost Teflon material with dielectric constant ε_r = 2.1, outer radius a = 18 mm, inner radius b = 6 mm, height h_r = 5 mm and R_r = 23 mm as shown in Fig.1 (a). The DRA is supported by FR4 substrate having dimension 60 × 50 mm^2 (L_s × W) with height (h_s) = 1.6 mm and dielectric constant (ε_s) = 4.4. On the front side of the substrate, C-shaped dielectric resonator with microstrip line feeding is present and the rear side having the partially printed ground plane as shown in Fig. 1(b). The air gap (g) between the dielectric resonator and ground plane is 5.5 mm. There is an increase in the resonant frequency and a decrease in the Q- factor with an introduction of air gap..

The dimension of the ground plane is 13.5 × 50 mm^2 (W × L_g). As Microstrip line feeding offers the advantage of easy and cost-effective fabrication of DRA, so the proposed DRA is excited by microstrip line feeding shown in Fig. 1, which is dimensioned as L_f = 57.75 mm and W_f = 2 mm. The front view and rear view of fabricated C-shaped DRA is shown in Fig. 1(c) and (d) respectively.



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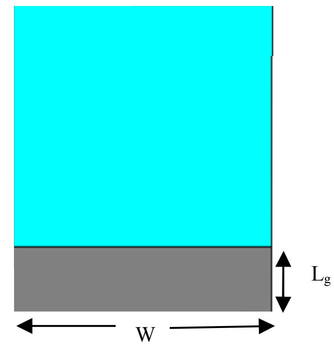

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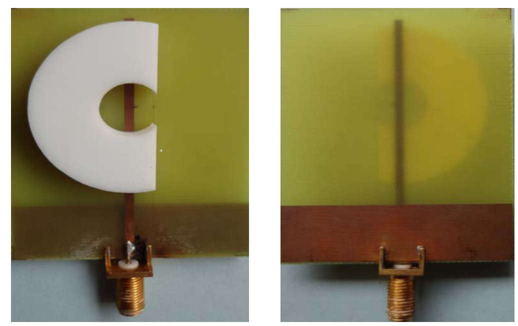
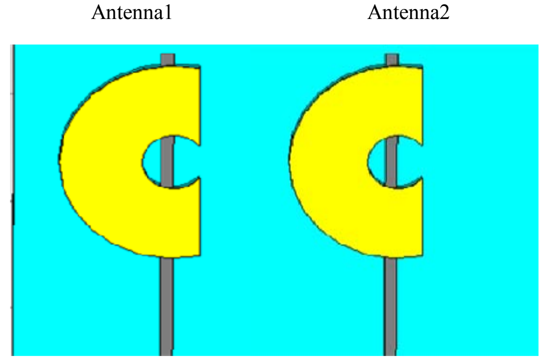

(c) (d)

Fig. 1 C-shaped DRA. (a) Front-view, (b) Rear-view, (c) Front view of fabricated DRA, and (d) Rear view of fabricated DRA

In the next step, a two elements C-shaped DRA array has been designed with 50 mm center to center distance and 26 mm edge to edge distance with 13.5 × 100 mm^2 (W × L_g) size of ground plane for MIMO applications. Initially, the two resonators are symmetrically mounted on the substrate. Afterward, the resonators are arranged asymmetrically to reduce the mutual coupling in array. Further on, the mutual coupling is more reduced by minimizing the size of the finite ground plane. The final dimension of the ground plane is 13.5 × 48.5 mm^2 (W × L_g). The final design of the C-shaped array is shown in Fig. 2.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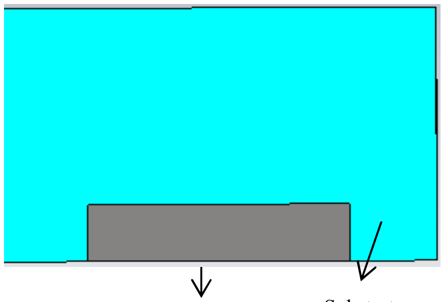


(b)

Fig. 2 Final design of C-shaped DRA array for mutual coupling reduction. (a) Front-view, and (b) Rear view

III. Results and Discussion

A. S-parameter characteristics

The simulation study of S-parameter vs. frequency characteristics for the proposed C shaped DRA has been carried out using CST Microwave Studio software whereas the S-parameter measurement of fabricated DRA were performed using an E8363B network analyzer. The simulated and measured S-parameter vs. frequency curves of the proposed C-shaped antenna has been presented in Fig. 3. From S-parameter results, the resonant frequencies of the proposed C shaped DRA are extracted. The resonant frequencies are found to be 3.5 GHz and 5.8 GHz, which are the desired frequencies for WiMAX applications. From figure, a good agreement between the simulated and measured results was observed.

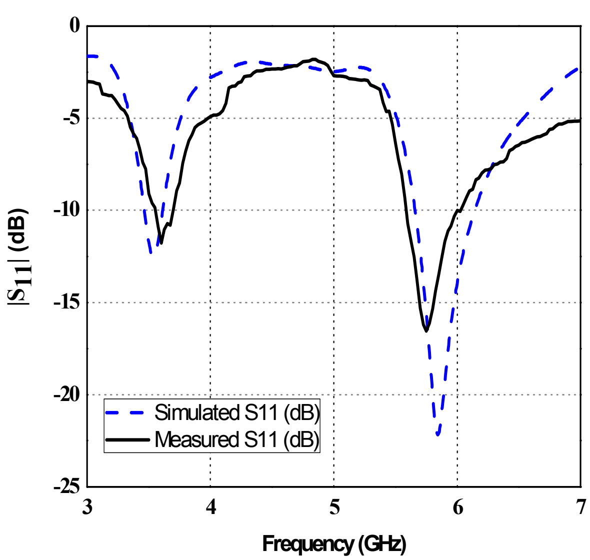
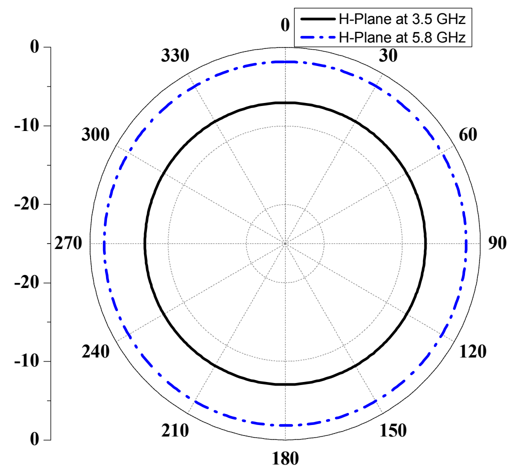


Fig. 3 S-parameter vs frequency of a C-shaped DRA

B. Far field performance

The far field pattern of the proposed C shaped DRA at resonant frequencies 3.5 GHz and 5.8 GHz were obtained. The simulated radiation patterns of the proposed antenna in E-plane & H-planes are shown in Fig. 4. It has been observed from Fig. 4 (a), that the H plane radiation patterns at both 3.5 and 5.8 GHz frequencies are omni-directional. Fig. 4 (b) presents the E plane radiation patterns.

The directivity as well as gain versus frequency plots of the C-shaped DRA at 3.5 GHz and 5.8 GHz are shown in Fig. 5 (a) and (b) respectively. The simulated directivity at 3.5 GHz is 3.95 dBi and at 5.8 GHz is 5.74 dBi, whereas the simulated gain is 3.27dBi and 5.6 dBi at 3.5 and 5.8 GHz respectively.



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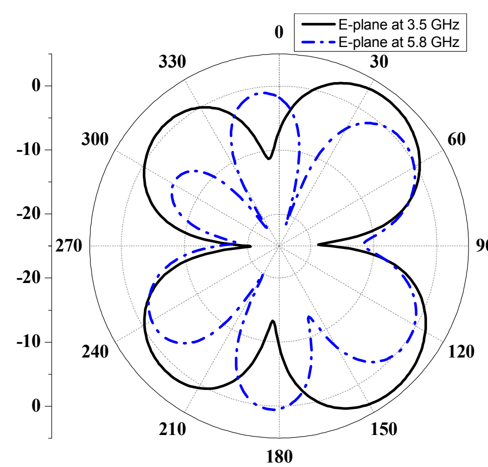
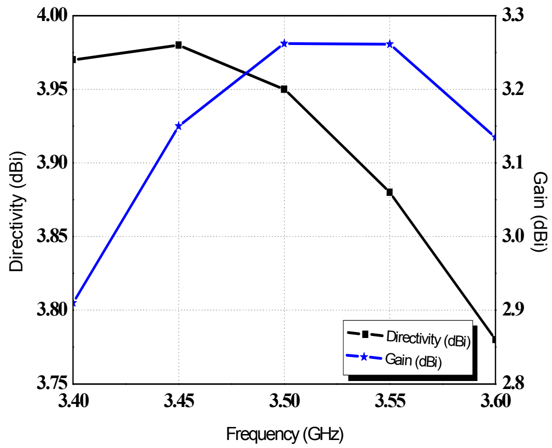


(b)

Fig. 4 Radiation patterns of a C-shaped DRA. (a) H-plane at 3.5 and 5.8 GHz, and (b) E-plane at 3.5 and 5.8 GHz



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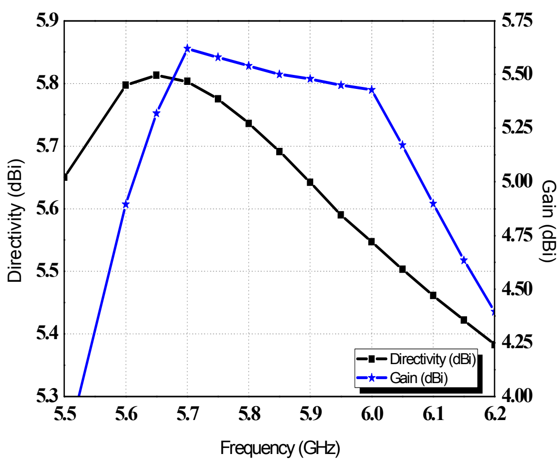


(b)

Fig. 5 Gain and directivity plots of C-shaped DRA. (a) Directivity and Gain at 3.5 GHz, and (b) Directivity and Gain at 5.8 GHz

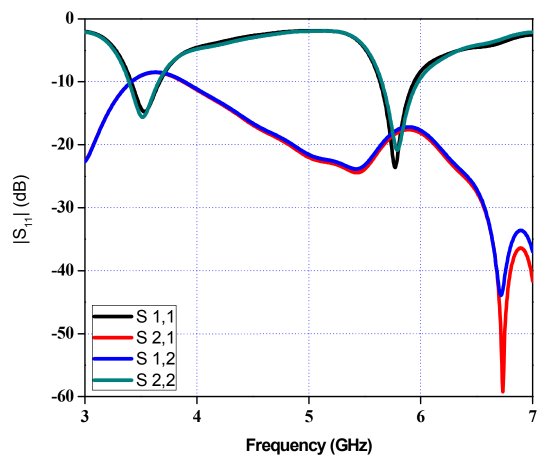
C. Mutual Coupling between two dielectric resonators in a DRA array

A simple approach is proposed for reducing the mutual coupling in two closely spaced C-shaped dielectric resonator antenna arrays. The simulated S-parameter results are presented here.

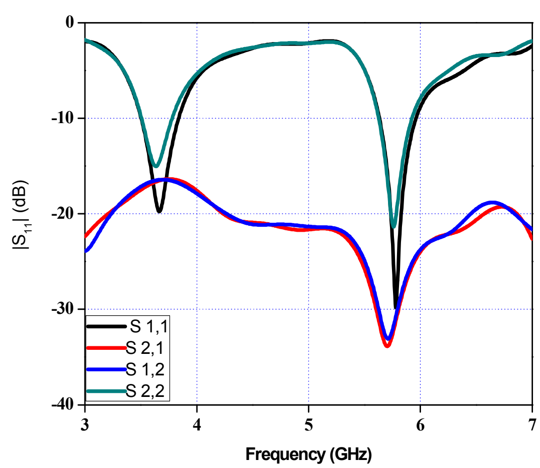
The S-parameter of C-shaped DRA is providing desired frequency of interest at 3.5 GHz and 5.8 GHz. An array of two elements C-shaped DRA array for MIMO applications are arranged in such a manner to provide minimum mutual coupling. The simulated results offer -15 dB of S-parameters (S_{11} and S_{22}) at resonant frequency 3.5 GHz and better than -20 dB S_{11} and S_{22} at 5.8 GHz, which is shown in Fig. 6 (a). Initially, when the resonators are placed symmetrically over the substrate, the array exhibits less than -10 dB of mutual coupling, S_{12} and S_{21} over the complete impedance bandwidth at 3.5 GHz resonant frequency. The peak value of mutual coupling is -8.5 dB at 3.5 GHz and -18 dB at 5.8 GHz. The simulated S-parameter versus frequency plot for symmetrically arranged C-shaped DRA array has been shown in Fig. 6 (a).

An upgrading of mutual coupling reduction can be seen from the $|S_{11}|$ plot shown in Fig. 6 (b), where the resonators of the C shaped array are arranged asymmetrically for reducing the mutual coupling,

A further improvement of mutual coupling reduction is also possible by sinking the size of the ground plane of the array. The reduction in the size of the original ground plane dimension, resulting in a less mutual coupling, as shown in Fig. 6 (c). As a result, for asymmetrically arranged dielectric resonators with reduce sized finite ground plane, minimum mutual coupling is observed. From the final S-parameter results in Fig. 6(c), we observed better than -30 dB of mutual coupling at desired resonant frequencies.



(a)



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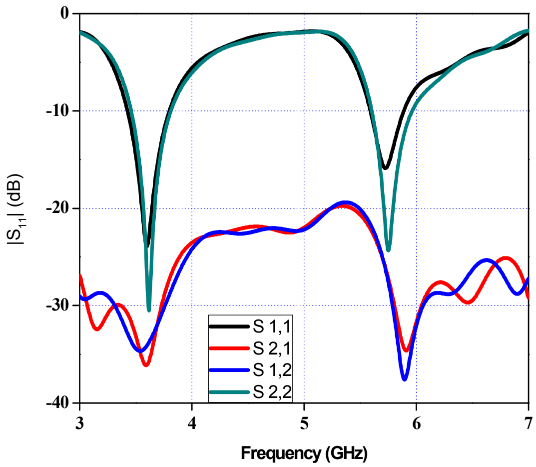

(c)

Fig. 6 S-parameters of C-shaped DRA array. (a) Symmetrically arranged dielectric resonators with actual finite ground plane, (b) Asymmetrically arranged dielectric resonators with actual finite ground plane, and (c) Asymmetrically arranged dielectric resonators with reduce sized finite ground plane

IV. CONCLUSION

An approach for reducing mutual coupling (S_{21} and S_{12}) in DRA array for MIMO applications has been presented. The C shaped DRA array is designed with a finite vertical ground plane for WiMAX applications. In this design, the resonant frequencies of 3.5 GHz and 5.8 GHz are obtained. The Resonators of the C-shaped array are asymmetrically arranged to reduce the mutual coupling as well as the dimension of the ground plane is also decreased to achieve better results. The proposed technique provides nearly -30 dB of mutual coupling at resonant frequencies which is significantly better than the results obtained for the original array. The comparative studies of resulted mutual couplings indicate that the proposed mutual coupling reduction technique provides a good result which is suitable for MIMO applications.

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