Analysis of Sectorization Technique in Conventional Dielectric Resonators for Circular Polarization

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Abstract

The analysis presented in this article is based on the investigation of circular polarization (CP) performance in Dielectric Resonator Antennas (DRA) by use of their geometrical dimensions with simple probe feeding technique. The operating principle is based on detuning of degenerate modes and proper optimization of the sector angle (β) which provides an extra context for better optimization of antenna performance as compared to conventional geometries. Sectorization method has been implemented for the first time in DRA technology for circular polarization analysis and corresponding physics is developed. The property of degenerate modes in DRA geometry has been explored for CP generation

1. Introduction

The process of CP generation in DRA either requires flexible feeding arrangements or modifying the 3D geometry itself [1]. There are several arbitrary modifications reported for DRAs which are complex and does not introduce any new design parameter. From literature survey, it has been found that "sectorization" is one such simplest modification technique which has the ability to control the degeneracy property in cylindrical and hemispherical DRAs [2-3]. In this work, we have proposed sectorization technique in CDRAs and HDRAs for analysis of CP which is relatively simple than previously reported work [4-5] and introduces a new design parameter called as sector angle (β). The proposed method is sectorization has various advantages over conventional geometries such as, a new parameter, "β" is obtained that can be tuned for better antenna performance. The second advantage of this approach is its simplicity in fabrication as compared to available modification techniques which are generally complex and arbitrary modified leading to fabrication difficulty. Also, this approach provides compactness, less weight (due to volume reduction) etc. This paper introduces the sectorization in DRAs (cylindrical and hemispherical) that are potentially advantageous for CP applications which offers less fabrication complexity. Table I shows the detuning process and modes details in conventional DRAs for getting CP. For rectangular DRA, no modification is required but for bodies of revolution like cylindrical and hemispherical DRA.

TABLE 1. PROPOSED TECHNIQUES IN CONVENTIONAL DRAS

Shape	Degenerate orthogonal modes	Detuning process
Rectangular	$TE^x_{\delta 11}$ and $TE^y_{1\delta 1}$	Using Unequal Dimension (Available in literature)
Cylindrical (Proposed)	$TM^x_{11\delta}$ and $TM^y_{11\delta}$	Using Sectorization (this work)
Hemispherical (Proposed)	TE^x_{111} and TE^y_{111}	Using Sectorization (this work)

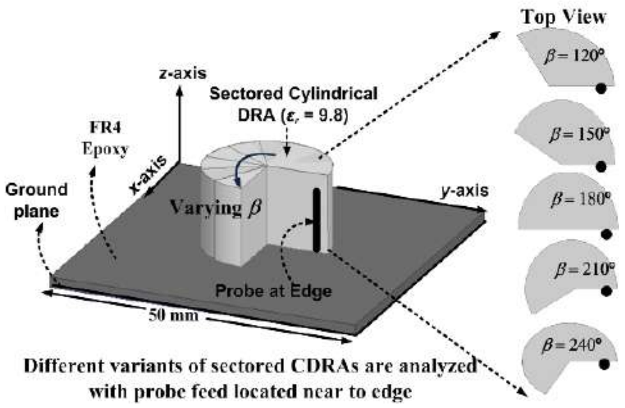


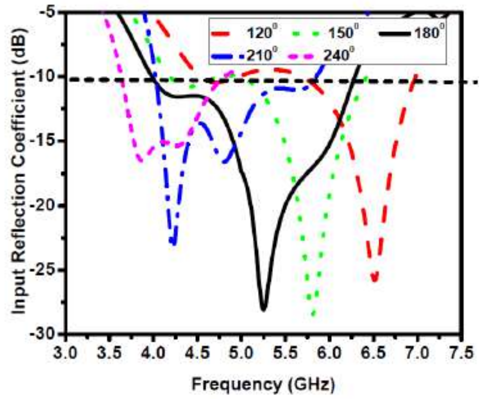
Figure 1. Sectored cylindrical DRA fed with a co-axial probe feed for circular polarization generation with top view of various sector values

2. Sectorization Analysis in CDRA and HDRA

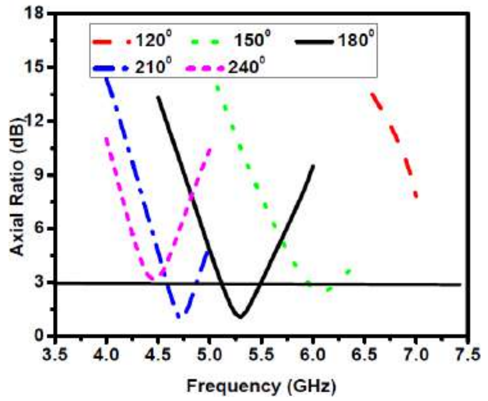
Bodies of revolution includes cylindrical and hemispherical DRA which is analyzed in this section. The manner of getting CP radiation from sectored DRA generally requires the identification, excitation and detuning of degenerate orthogonal modes.

2.1 Sectored Cylindrical DRAs

Various sectored geometries with sector angle 'β' (120°-270°) obtained from cylindrical DRA are shown in Fig. 1 with radius r = 10 mm and height H = 12.5 mm positioned on a 50 × 50 mm^2 FR4 Epoxy grounded substrate (ε_r = 4.4, tan δ = 0.02). This paper proposes sectorization method to detune the excited degenerate $TM_{11\delta}$ mode having degeneracy along azimuthal direction. The sectored cylindrical DRA supports TM^x and TM^y modes. The



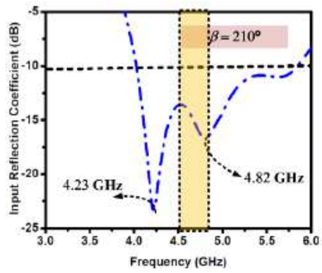
(a)



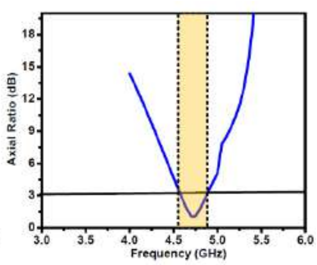
(b)

Figure 2. Simulation results of $S_{|11|}$ and axial ratio at various sectored CDRA geometries.

aspect ratio is fixed at 1.6 and β is varied from 270° to 120° (Fig. 1). Upon varying β at fixed aspect ratios, the corresponding $S_{|11|}$ and axial ratio (AR) plot for different variants of sectored cylindrical DRAs formed are plotted in Fig. 2(a) and Fig.2(b) respectively. From observation, it is revealed that the resonance frequency of degenerate modes for β = 240° and 210° has been slightly separated and one form (β = 210°) is taken for explaining the consequence of this variation on CP, Fig. 3(a) and Fig. 3(b) shows the $S_{|11|}$ and AR for β = 210° only. It has been perceived that wide -10 dB impedance bandwidth of 48.2% (3.9-6.39 GHz) and 3-dB ARBW of 6.3% (4.58-4.88 GHz) has been obtained respectively for β = 210°. It is worth mentioning here that, the purpose of taking this design example is to show the CP generation by sectorization only. However, ARBW can be further enhanced by adjusting other relevant parameters such as feed location, aspect ratio and sector angle. Now, the lower mode resonance frequency is obtained at 4.23 GHz whereas higher mode resonance frequency is obtained at 4.82 GHz. Sectored CDRA supports degenerate orthogonal $TM_{11\delta}^{x}$ and $TM_{11\delta}^{y}$ modes which have same resonance frequency and orthogonal electric field configuration but varies as $\sin(\varphi)$ and $\cos(\varphi)$ with equal magnitude in azimuthal direction. The sectorization technique perturbs the conventional CDRA geometry along azimuthal direction resulting in separation of resonant frequency and quality factor of these modes ($TM_{11\delta}^{x}$ and $TM_{11\delta}^{y}$). In order to validate the change in the field variation along azimuthal direction, Fig. 4 shows the electric field magnitude at lower frequency (4.23 GHz) and higher frequency (4.82 GHz) at different phase angles.



(a)



(b)

Figure 3. Simulation results: (a) $S_{|11|}$ for β = 210°only (b) AR for β =210°only

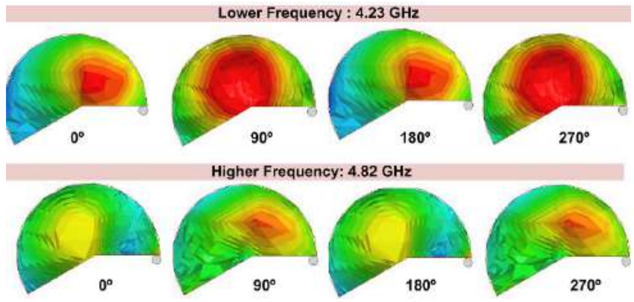


Figure 4. Simulated E-field magnitude distribution at different phase angles for (a) 4.23 GHz and (b) 4.82 GHz (β = 210°) with feed position near to edge.

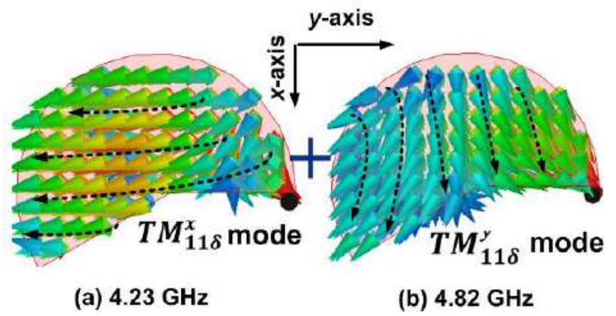


Figure 5. Electric field distribution for β = 210° in sectored CDRA

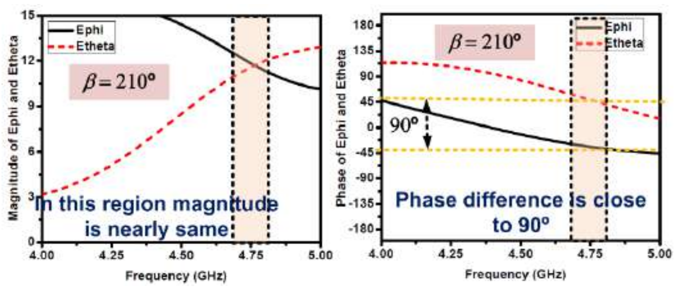


Figure 6. Simulated *E*-field magnitude and phase components of orthogonal electric fields for β = 210°only.

From Fig. 54, it can be verified that there is a difference in electric field magnitude at these two resonant frequencies.

Also, it is to be noted that, electric field concentration is more for $TM^{y}_{11\delta}$ as compared to $TM^{x}_{11\delta}$ mode, therefore it ($TM^{y}_{11\delta}$) is excited at lower frequency. To verify the orthogonality, *E*-field is depicted in Fig. 5, where the direction of *E*-field can be seen in orthogonal arrangement. Fig. 6 shows the detailed description of electric field magnitude and phase variation of individual orthogonal component in the working frequency band for better understanding of CP phenomenon

2.2 Sectored Hemi-spherical DRAs

In this section, various sectored geometries with sector angle 'β' (150°-270°) obtained from hemispherical DRA are shown in Fig. 7 with radius r = 11 mm positioned on a 50 × 50 mm^2 FR4 Epoxy grounded substrate (ε_r = 4.4, tan δ = 0.02).

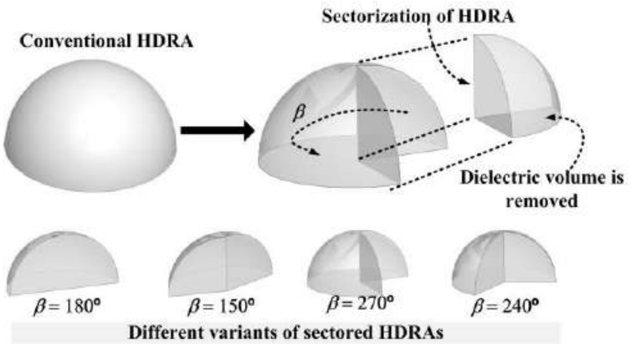
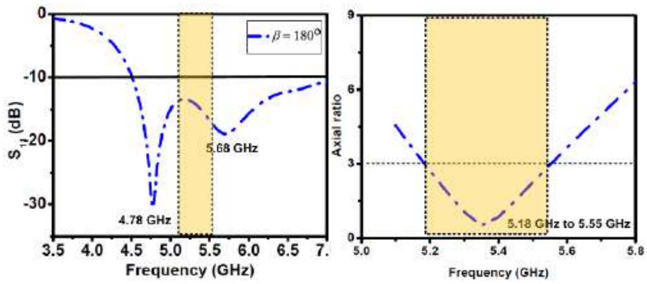


Figure 7 Various configurations of sectored hemispherical DRA.

Sectored HDRA supports degenerate orthogonal TE^{x}_{111} and TE^{y}_{111} modes having mode degeneracy along azimuthal direction. Like CDRA, their resonance frequency can also be slightly separated after sectorization and corresponding $S_{|11|}$ and AR for one of the sector form i.e. β = 180° is presented in Fig. 8. It is revealed that impedance bandwidth of 26% (4.5-7 GHz) and ARBW of 6.9% (5.18-5.6 GHz) has been obtained. It is also confirmed that $TE^{y}_{111}$and TE^{x}_{111} modes are excited at 4.78 GHz 5.68 GHz from the electric field distribution plotted in Fig. 9.



(a) (b)

Figure 8. Simulation results: (a) $S_{|11|}$ (b) AR plot for β = 180° in sectored HDRA

Fig. 8 shows the plot of the magnitude and phase angle of individual electric field component responsible for CP generation in the structure for β = 180°. It has been realized that the magnitude is approximately equal across the operating band with nearly 90° phase difference between them. But, there is amplitude variation in which minimum axial ratio is obtained around 3.6 GHz where both magnitude of both field components is equal as can be perceived from Fig. 10. At a specific frequency range in between the orthogonal frequencies, the responsible modes will have equal magnitude with phase quadrature connection. This phase condition is obtained due to the individual phase shift from both modes in the working range. As conventional HDRA is a symmetrical structure, there is no phase delay between the E_φ and E_θ component. Due to sectorization approach, geometrical symmetry is altered along azimuthal direction in HDRA according to β. This results in different path length for E_φ and E_θ components causing phase difference.

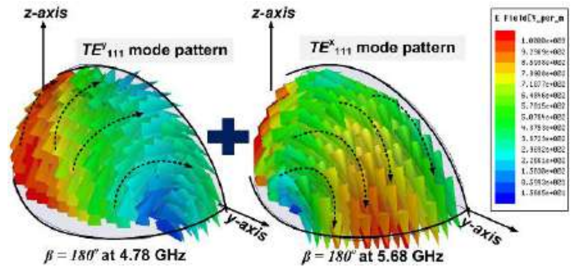


Figure 9. Simulated electric field magnitude and phase difference between orthogonal modes for β = 180° in sectored HDRA

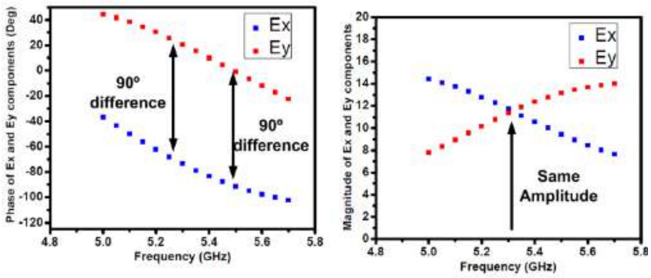


Figure 10. Simulated electric field magnitude and phase difference between orthogonal modes for β = 180° in sectored HDRA

3. Application to Multiple Input Multiple Output (MIMO) Configuration

Sectorization approach can be applied to multiple antenna systems. Since, the sector angle is responsible for altering the orthogonality of modes, it can be used to improve the isolation between two DR elements also. Sectored CDRA or sectored HDRAs are better option for multi-element systems such as multiple input multiple output (MIMO) because these geometries occupies less space and good performance can be obtained by optimizing β values. To support this, we have also performed the isolation study of two-port sectored HDRAs and the corresponding schematic diagram is shown in Fig. 11. The obtained results are seen to be consistent as displayed in Fig. 12. The input reflection coefficient shows 41.3% (4.6 GHz-7 GHz) input impedance bandwidth with the isolation approximately less than -20 dB in the entire working band. Since sectored DRAs are compact in size, almost double number of elements can be added in a given volume of space for increasing the system capacity and range of signal. Fig. 13 shows the electric field distribution inside the two dielectric resonators i.e. DR1 and DR2 at different phase angles at center frequency (5.8 GHz). It can be observed that the net direction of excited field in these resonators are always orthogonal to each and thus maintaining a very good isolation in the MIMO system.

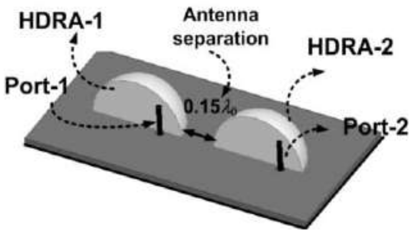


Figure 11. Picture showing a two-port sectored HDRA for MIMO applications using simple probe feeding

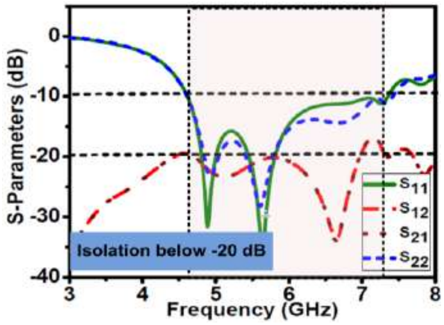


Figure 12. Simulated S-Parameters of a 2-port sectored HDRA used as MIMO design

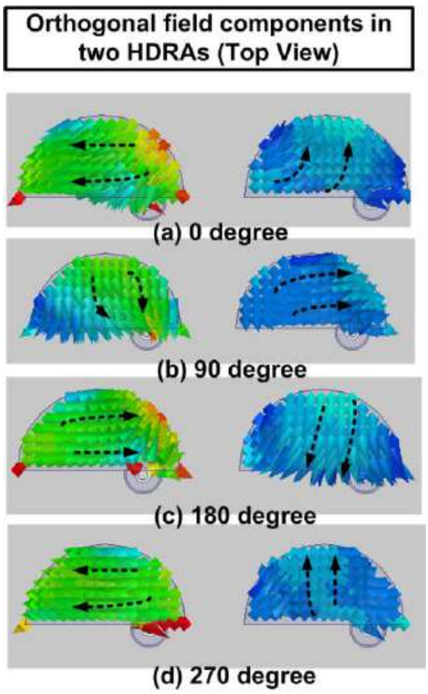


Figure 13. E-field distribution in the MIMO design at center frequency (5.8 GHz) for different phase angle.

4. Conclusion

Sectorization concept has been implemented in DRA for CP analysis in this work. This approach uses the DRA geometry as a design parameter for controlling CP parameter. Degenerate modes are detuned by proposed sectorization technique. The responsible modes are $TM^{x}_{11\delta}$ and $TM^{y}_{11\delta}$ in cylindrical DRA whereas TE^{x}_{111} and TE^{y}_{111} in hemispherical DRAs. An approach to design MIMO systems using proposed method is also briefed.

5. References

1. R. Chaudhary, R. Kumar and R. Chowdhury, "Circularly polarized dielectric resonator antenna", *Artech House*, Norwood, MA, USA, 2021, ISBN: 9781630818180

2. R Chowdhury and R. K. Chaudhary, "Investigation on different forms of circular sectored dielectric resonator antenna for improvement in circular polarization performance", *IEEE Transactions on Antennas and Propagation*, **66**, 10, July 2018, pp. 5596-5601, doi:10.1109/TAP.2018.2854418.

3. R. Chowdhury and R. K. Chaudhary, "Investigation of new sectored hemispherical dielectric resonator antennas operating at TM_{101} and TE_{111} mode for circular polarization", *Progress in Electromagnetics Research (PIER)*, **167**, July 2020, pp. 95-109, doi: 10.2528/PIER20041601.

4. M. T. K. Tam and R. D. Murch, "Compact circular sector and annular sector dielectric resonator antennas", *IEEE Transactions on Antennas and propagate*, **47**, 5, May 1999, pp. 837 - 842, 1999, doi: 10.1109/8.774138.

5. D. Guha and Y. M. M. Antar, "New half-hemispherical dielectric resonator antenna for broadband monopole-type radiation", *IEEE Transaction on Antennas and Propagation*, **54**, 12, December 2006, pp. 3621-3628, doi: 10.1109/TAP.2006.886547.