A new Technique to Generate Circular Polarization in Periodically Deformed Rectangular Dielectric Resonator Antenna using PMC Boundary Approximation

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Abstract

In this paper, a new procedure to produce broadside circular polarization (CP) in modified rectangular dielectric resonator antenna (DRA) has been presented. The dielectric resonator is deformed periodically in stair-shaped form along anti-clockwise direction. The concept of perfect magnetic boundary conditions at the interface of air and dielectric resonator has been successfully applied in this work. Final proposed antenna shows input impedance bandwidth and axial ratio bandwidth of 35% (3.34 – 4.76 GHz) and 8.5% (3.70- 4.03 GHz) respectively.

1. Introduction

Dielectric resonators (DRs) are made of ceramic materials which are much efficient at very high frequencies due to the absence of metallic parts which prevents skin effect phenomenon. Moreover, DRs have 3D structure which gives three degree of freedom along three dimensions as compared to planar antennas having lateral dimensions only affecting the resonant frequency. Some other inherent properties of DRs include flexibility in coupling schemes, easy integration with existing technology, low loss, and high power handling capacity etc. [1]. Circular polarization (CP) state of radiated EM wave is one of the important far field parameter which has been widely to overcome the limitations imposed by linearly polarized antennas in modern communication network. CP antenna advantages includes higher probability of successful connection, easier installation, more resistant to atmospheric conditions etc. [2]. To generate CP wave in a dielectric resonator (DR), two feed ways which are single or dual feed have been extensively used in literature. The technique to generate CP wave in a DR using single feed requires exciting spatially separated orthogonal modes with ±π/2 phase difference. In literature, CP is generated by using special microstrip feed networks [3], different slot configuration [4] in conventional DRs. The other technique to generate CP is to modify the shape of conventional DRs such as reported in [5-7]. In this article, a new modified rectangular DRA is presented for realizing circular polarization. This work is motivated from same author's previous work where the concept of PMC approximation has been used for CP generation [8].

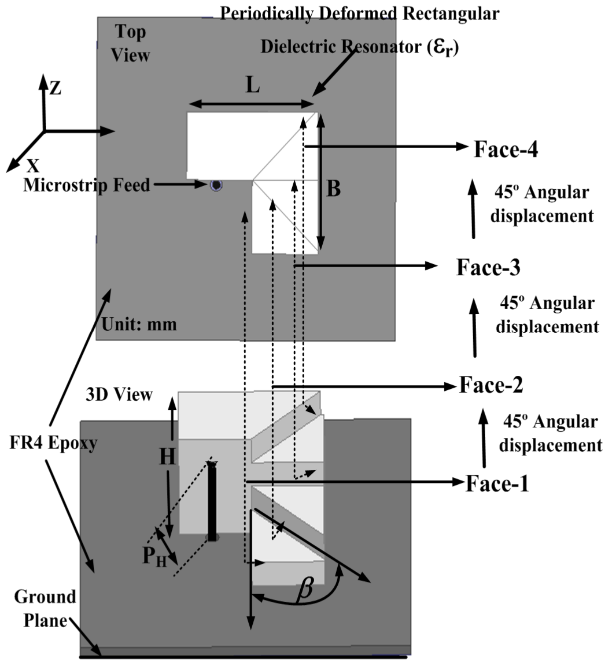

Figure 1. Perspective view of proposed circularly polarized antenna [All dimensions are in mm: L = B = 22, H = 16, P_H = 14, β =45°, ε_r = 9.8]

This Paper is organized as follows: Proposed design configuration with structure details and theoretical background are given in section II. Then, the underlying operating principle with antenna design steps are discussed with proper explanation in section III followed by simulation results. Ansys HFSS software version 14.0 has been used for all the simulations carried out in this work.

2. Antenna Layout and Design Details

The mathematical description of electromagnetic fields inside a DR is very much complex. To solve the field equations and analyzing its behavior, the perfect magnetic conductor (PMC) approximation has been widely used in literature [15]. Under this scenario, dielectric medium having higher permittivity value shares open circuit boundary condition with air. The higher the permittivity ratio at the boundary more accurate will be the behaviors of fields at the interface as per PMC approximation. At this conditions, the tangential magnetic field and normal component of electric field vanishes whereas, tangential component of electric field and normal magnetic field component is present at the air-dielectric interface. In this work, DR with permittivity of 9.8 is used which has 10 times higher permittivity value than air and expected to behave in accordance with PMC boundary conditions at the interface. The perspective view of proposed antenna is displayed in Fig. 1 with design details.

3. Theoretical Background and Results

The process of generation of CP is divided into two parts. Initially, the orthogonal modes have been established in the DR using structure modification technique. Secondly, phase quadrature relationship has been obtained between the orthogonal modes.

(A) Orthogonality Condition in Dielectric Resonator: The process of establishment of orthogonality condition in the DR is examined first. Fig. 2 shows the design evolution of proposed CP antenna through various steps. In the first step as shown in Fig. 2(a), a conventional rectangular DR is used with dimensions L × B × H mm^3. Then, a quarter section of DR is removed form it to form Antenna-1 which is the reference configuration. The inner faces formed are named as Face-0 and Face-1. A co-axial feed is applied at one of the faces (Face-0) and Face-1 is restructured to generate CP. As per PMC boundary conditions, electric fields (E-fields) at air-dielectric interface near Face-1 (called as E_{Face-1}) are tangential to its surface. In the second step, Antenna-2 is formed by removing another section of dielectric material with same center angle 'β' from Antenna-1 from a height of h1 (= 4 mm) where Face-2 is formed and fields at Face-2 are called as E_{Face-2}. Due to PMC approximation, some component of electric fields are tangential to Face-1 and some are tangential to Face-2 as a consequence of DR modification. Due to this, the angular separation between E_{Face-1} and E_{Face-2} becomes 45°. Again, in the third step, Antenna-2 is remodified again by removing a dielectric with same center angle of 45° to form Antenna-3. In this case, Face-3 is formed and corresponding fields tangential to Face-3 are called as $E_{Face-3.}$ Now, the angular separation between E_{Face-1} and E_{Face-3} becomes 90°. At last, Antenna-4 is formed by following the same previous steps and Face-4 is formed with electric fields tangential to Face-4 named as $E_{Face-1.}$ In the final proposed DR, the fields components has been resolved where it can be noticed that the angular separation between E_{Face-1} and E_{Face-3} becomes 90° whereas angular separation between E_{Face-2} and E_{Face-4} becomes 90°. In this way, by using the concept of PMC boundary condition at the air-dielectric interface, the orthogonal components are obtained using structure modification. Simulated input reflection coefficient and broadside axial ratio during different antenna stages is illustrated in Fig. 3. It has been observed that Antenna-4 provides maximum axial ratio bandwidth. The decomposition of E-fields inside Antenna-4 (Final Proposed antenna) is demonstrated in Fig. 4, where the resolved field components at air-dielectric interface can be observed following the PMC approximation.

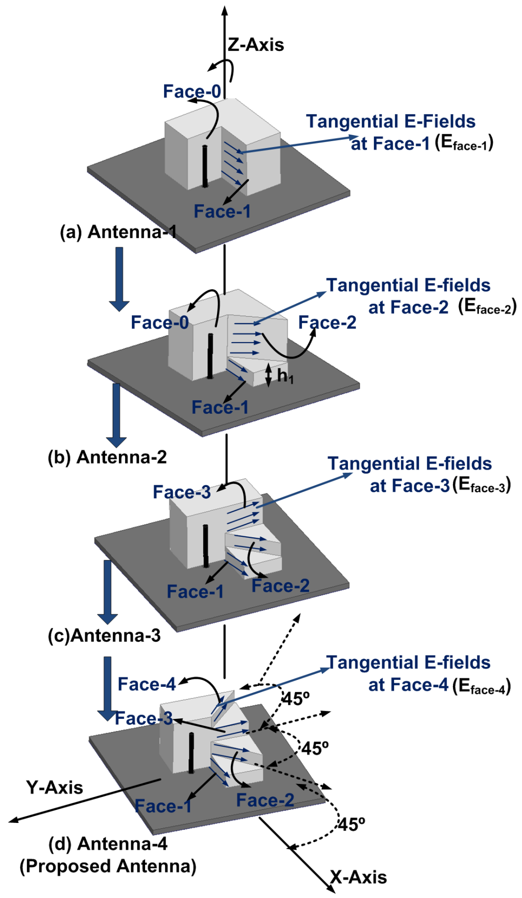

Figure 2. Design Process of proposed antenna (a) Antenna-1 (Face-0 and Face-1 are formed) (b) Antenna-2 (Face-2 is formed) (c) Antenna-3 (Face-3 is formed) (d) Antenna-4 (Face-4 is formed) (Final proposed antenna)

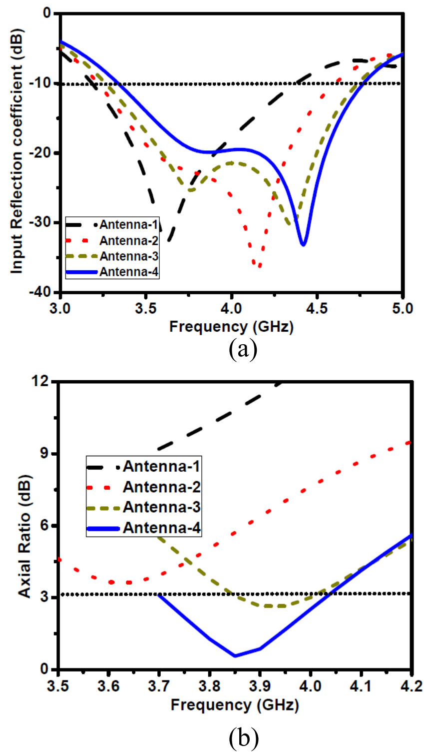

Figure 3. Simulated (a) S_{11} and (b) Axial ratio during different antenna stages.

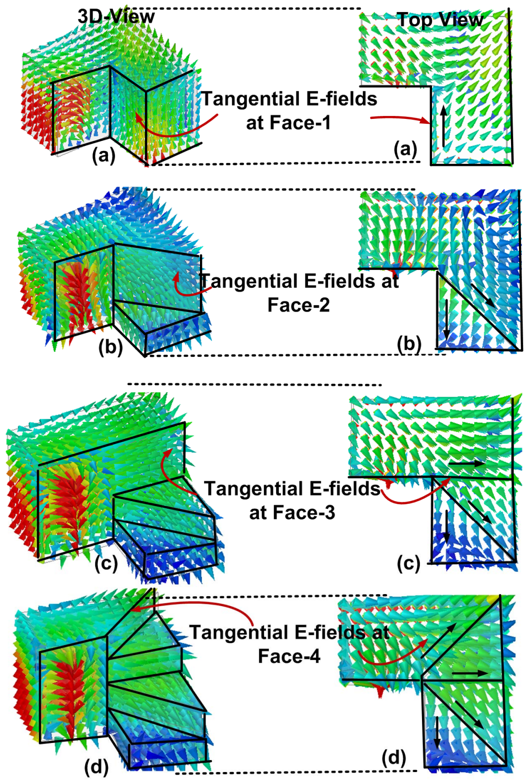

Figure 4. Electrical field distribution (4 GHz) during different stages (a) E_{Face-1} is shown (b) $\angle (E_{Face-1}, E_{Face-2}) = 45^o$ (c) $\angle (E_{Face-2}, E_{Face-3}) = 45^o$ and $\angle (E_{Face-1}, E_{Face-3}) = 90^o$ (d) $\angle (E_{Face-4}, E_{Face-3}) = 45^o$ and $\angle (E_{Face-4}, E_{Face-2}) = 90^o$

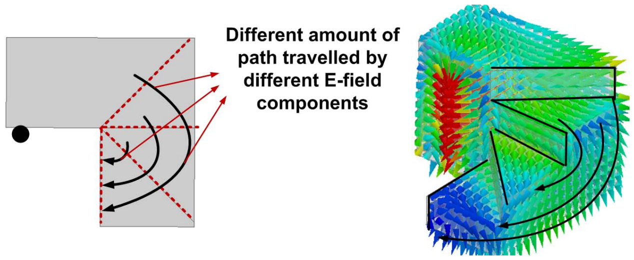

Figure 5. Interpretation of phase difference in the proposed CP antenna.

(B) Phase Difference Condition in DR: In this section, the phase quadrature relationship is discussed between the excited orthogonal modes in the structure. Due to this structure alteration, the E-fields have been resolved into four electric field components (E_{Face-1}, E_{Face-2}, E_{Face-3} and E_{Face-4}) from Antenna-1 to Antenna-4. Since, E-fields have been decomposed inside the same dielectric medium, there exists a path difference between the different field components as shown in Fig. 5. This path difference can be tuned by different '*β'* value. Also phase difference is related to path difference, the required path difference condition of 90° can be obtained by adjusting the spacing between the faces i.e. changing the '*β'* value. Fig. 6 shows four possible antenna designs with different values of '*β*' with their respective electric field distribution. Fig. 7 shows the simulated axial ratio for different values of '*β*' and maximum axial ratio bandwidth is obtained for '*β'* =45°.

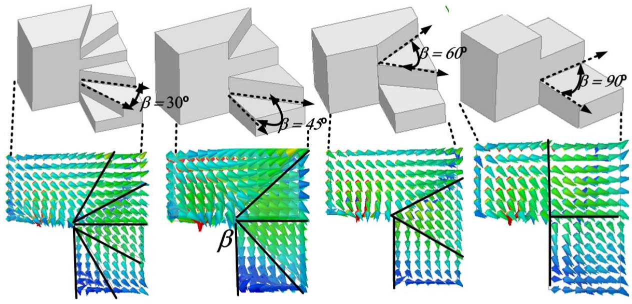

Figure 6. Different antenna configuration obtained using different 'β' values with respective electric field distribution.

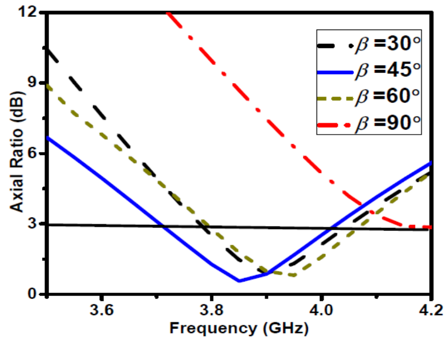

Figure 7. Simulated axial ratio for different antenna configurations with different 'β' values.

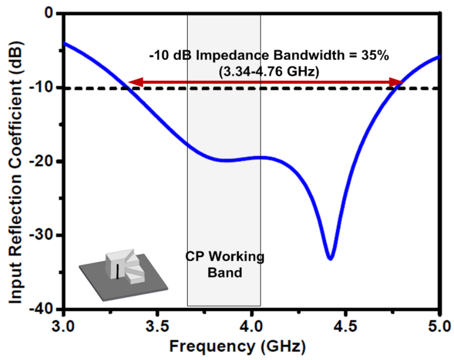

Figure 8. Simulated input reflection coefficient of final proposed CP antenna

(c) Simulation Results and Discussion: Fig. 8 shows the -10 dB input impedance bandwidth plot of 35% (3.34 – 4.76 GHz) centered at 4.05 GHz. In Fig. 9, broadside axial ratio and gain of proposed CP antenna is plotted which shows 8.5% (3.70- 4.03 GHz) of axial ratio bandwidth and 5 dB of average gain in the proposed structure. In Fig. 10, simulated radiation patterns are shown at 3.8 GHz and 3.9 GHz respectively. From the normalized radiation pattern, the difference between the left handed circularly polarized (LHCP) and right handed circularly polarized (RHCP) fields are -23 dB and -24 dB in xz plane whereas in yz plane, -22 dB and -25 dB of difference is observed. Thus, proposed antenna shows LHCP behavior as it is more dominant then RHCP fields in broadside direction. To illustrate the circular polarization orientation, electric field variation is displayed in Fig. 11 as a function of phase angle at 4 GHz. The E-fields are rotating anticlockwise which also confirms LHCP state of polarization.

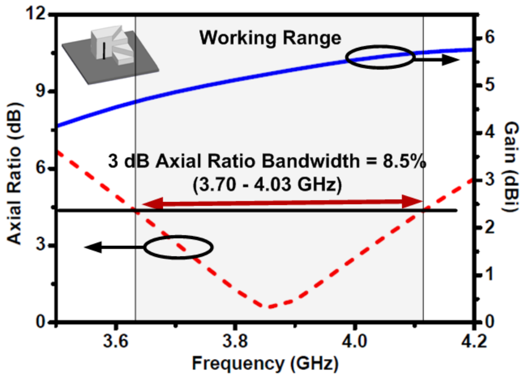

Figure 9. Simulated axial ratio with simulated gain of proposed circularly polarized antenna.

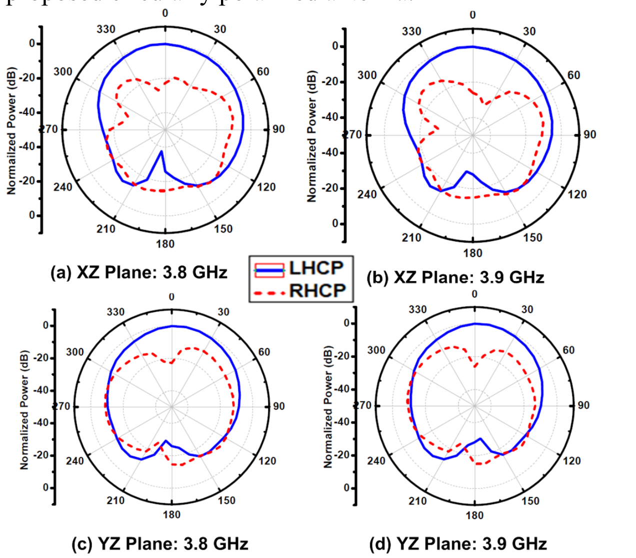

Figure 10. Simulated radiation pattern of proposed CP antenna.

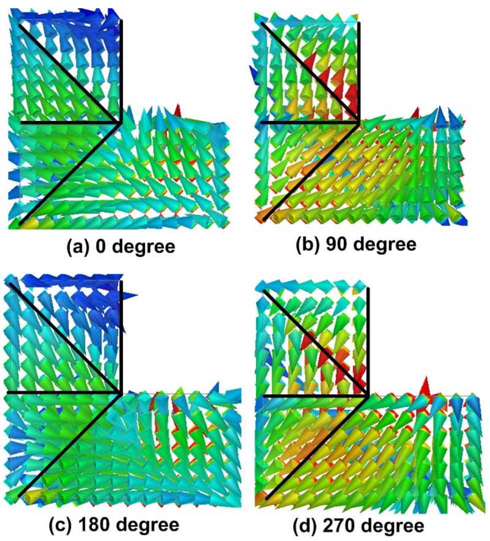

Figure 11. Electric field distribution in the final proposed antenna at 4 GHz during different phase angles.

4. Conclusion

A new concept for obtaining circular polarization has been proposed using modified rectangular DR in periodic fashion along azimuthal path. The idea of resolving the E-fields in space at the interface of air and dielectric by assuming PMC boundary conditions is successfully applied in this work. Simulated results shows 35% and 8.5% of input impedance and axial ratio bandwidth respectively.

5. References

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