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Circularly polarized rectangular dielectric resonator antenna excited by an off-set conformal metal strip

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ABSTRACT

A rectangular dielectric resonator antenna (DRA) has been excited by an off-set single conformal metal strip. By using such excitation technique two degenerate resonant modes, TExδ11 and TEy1δ1 of the rectangular DRA have been excited to achieve circular polarization (CP). A CP bandwidth of ~5.2% in conjunction with a wide impedance matching bandwidth of ~54% has been provided by the proposed DRA configuration. The antenna design has been simulated using computer simulation technology (CST). Antenna prototype has been built to verify the impedance matching bandwidth. Far field parameters have been optimized and verified using two simulation techniques in CST i.e. finite integration technique (FIT) and finite element method (FEM). A good agreement between the simulated and measured result has been observed for S11. Similarly a very good resemblance between the far field results from FIT and FEM have been demonstrated.

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1. INTRODUCTION

In recent years, dielectric resonator antennas (DRAs) have been acquiring the focus of researchers due their attractive features such as flexible design, no metallic losses, wider bandwidth and may more [1-27]. The linearly polarized systems are more susceptible to losses, whereas the circularly polarized systems are much more reliable. The circular polarization of DRA can be achieved by using dual feeding technique but at the cost of larger size and complexity of feeding network [12-14]. The single feeding mechanism is much more popular due to simple network and compact size. Many circularly polarized DRAs excited by single feeding technique have been reported in literature. A 3dB axial ration (AR) bandwidth of 2.7% of a rectangular DRA has been achieved by parasitic patch [15]. A CP bandwidth of 6.3% achieved by truncating the opposite corners on the rectangular DRA has been reported in [16]. A cross slot fed rectangular DRA with 3.5% CP bandwidth has been demonstrated in [17]. A circularly polarized two-layer rectangular DRA with 9.5% CP bandwidth, excited by a cross slot microstrip line feed has been reported in [18]. A 7.2% CP bandwidth of a rectangular DRA has been achieved by T-shaped feed [19]. As demonstrated in [20], a spiral strip has been used to achieve 7% CP bandwidth of a rectangular DRA. An 11% axial ratio bandwidth of a singly fed rectangular DRA has been achieved by parasitic patch as reported in [21]. An off-centered microstrip line has been used to excite a cylindrical DRA to achieve 3 dB axial ratio bandwidth of 3.47% [22]. A semi-eccentric annular DRA excited by a coaxial probe has provided CP bandwidth of 5.17% as reported in [23]. As reported in [24] an 18% CP bandwidth of a loop antenna printed on a layered dielectric sphere has been achieved by probe feeding. In all discussed articles the antennas provide good impedance matching bandwidth over same frequency range.

In this article the CP of rectangular DRA has been achieved by an off-set single conformal metal strip. Using this simple and economical excitation technique, a CP bandwidth of 5.2% has been obtained. A wide impedance matching bandwidth of 54% has been offered by the antenna over same frequency range

2. RESEARCH METHOD

A rectangular DRA fed by an off-set single conformal metal strip has been illustrated in Figure 1. The antenna configuration has been modeled using a time-domain integral equation (TDIE) based on FIT [25].

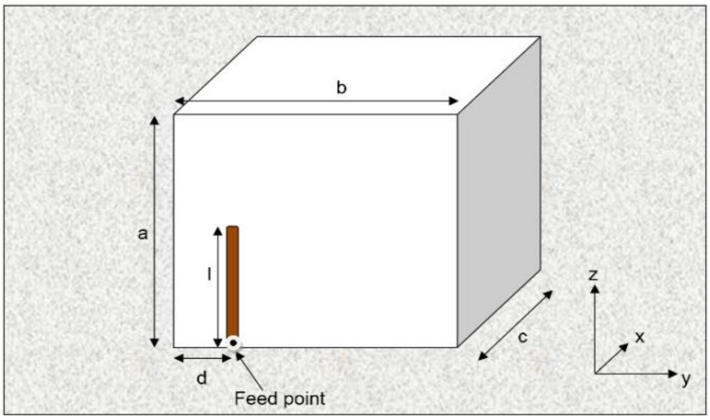

Figure 1. Rectangular DRA fed by an off-set conformal metal strip

The design has been built using the hexahedral meshing in which setting the cells per wavelength = 40, similarly the cells per max model box edge = 20. The fraction of maximum cell near to model = 20 and the number of Cells = 555,519. In boundary conditions Zmin has been set at Electric (Et = 0) to simulate the effect of infinite ground plane. The DRA block has been excited by a single conformal metallic strip and single port has been used to energize the model. The iterative design procedure has been adopted to optimize the feed position to excite two degenerate modes to generate circularly polarized wave [16].

The length and width of the strip has been optimized by running many simulations with different parameter sweeps. The results of optimized design from FIT has been validated by fabrication for near field and by FEM for far field results. Prototype of the rectangular DRA as shown in Figure 2.

Figure 2. Prototype of the Rectangular DRA

3. RESULTS AND DISCUSSIONS

The antenna prototype illustrated in Figure 2 has been built using the ECCOSTOCK HiK with permittivity Ɛr = 10. The dimensions of dielectric block; a = 26.1 mm, b = 25.4 mm and c = 14.3 mm have been chosen based from [15]. The conformal metal strip has been cut from adhesive-backed copper tape to stick easily on the DRA surface.

In Figure. 3 the comparison between simulated and measured return losses of the rectangular DRA excited by an off-set conformal metal strip have been presented. As shown the impedance matching i.e. |S11| ≤ 10 dB bandwidth has been achieved over a wide bandwidth of ~ 54%. The feed position has been shifted to excite the degenerate mode pair for CP wave generation. The optimized strip position and parameters are d = 4 mm and l = 11 mm. The width of the metal strip is 1 mm. An aluminum ground plane of 300 x 300 mm2 has been employed. The two degenerate modes i.e. TExδ11 at 2.784 GHz and TEy1δ1 at 3.697 GHz have been excited as shown by the Figure 4.

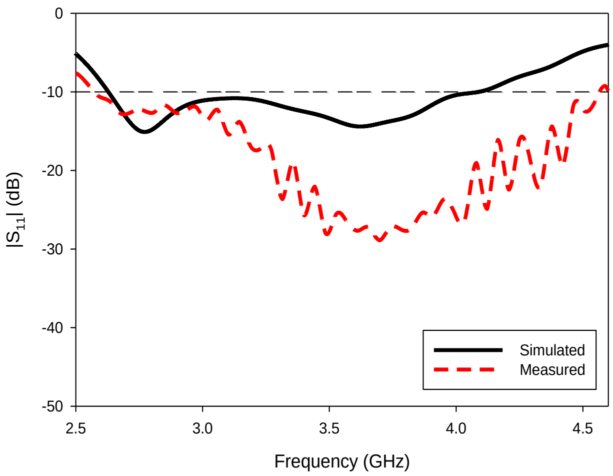

Figure 3. Return losses of the rectangular DRA fed by an off-set conformal metal strip

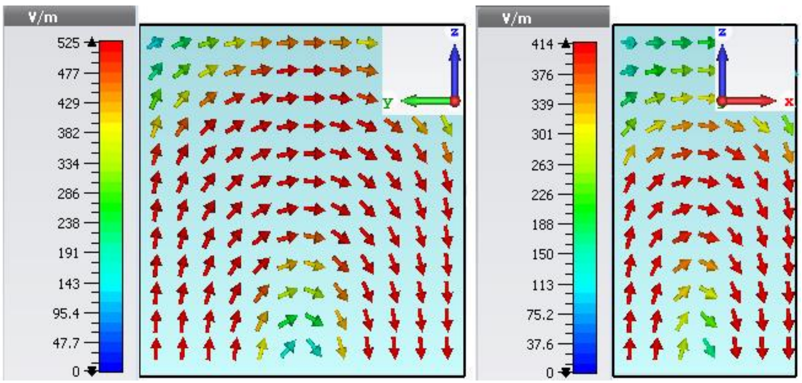

Figure 4. E-field distribution for TExδ11 and TEy1δ1

For comparison, the resonant modes frequencies of the rectangular DRA have also been calculated using dielectric waveguide model (DWM) proposed in [26]. The frequency for TExδ11 mode can be calculated using:

$$k_y = \frac{\pi}{b} \tag{1}$$

$$k_z = \frac{\pi}{a} \tag{2}$$

$$k_x \tan(k_x c/2) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_x^2} \tag{3}$$

Similarly frequency for TEy1δ1 mode can be calculated using:

$$k_x = \frac{\pi}{c} \tag{4}$$

$$k_z = \frac{\pi}{a} \tag{5}$$

$$k_y \tan(k_y b/2) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_y^2} \tag{6}$$

Where kx, ky and kz denote the wavenumbers in the x, y and z directions inside the DRA and k0 represents the free space wavenumber. Additionally, the wavenumbers must satisfy the following:

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \tag{7}$$

$$k_0 = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c} \tag{8}$$

Where λ0 is the free-space wavelength, and c is the speed of light in vacuum. Substitution of (8) in (7) yields the resonance frequency as:

$$f_0 = \frac{c}{2\pi\varepsilon_r}\sqrt{k_x^2 + k_y^2 + k_z^2} \tag{9}$$

The calculated frequency by DWM for TExδ11 mode is found to be 2.712 GHz compared to 2.784 GHz obtained by measurement. Similarly the calculated frequency by DWM for TEy1δ1 mode is 3.708 GHz that is close enough to 3.697 GHz obtained experimentally. Hence a good agreement has been observed between calculated and measured values.

Figure 5 represents the axial ratio of the rectangular DRA in bore-sight direction. As demonstrated the AR bandwidth of ~5.2% has been provided by the antenna. The minimum point of axial ratio i.e. 2.33dB is at 3.09 GHz in FIT and at 3.08 GHz in FEM. The small marginal shift can be attributed to different computational environment of two techniques used. As presented in Figure 6, the minimum AR point lies in between two degenerate modes as explained in [16]. Moreover a wide impedance matching bandwidth has been achieved over same frequency range.

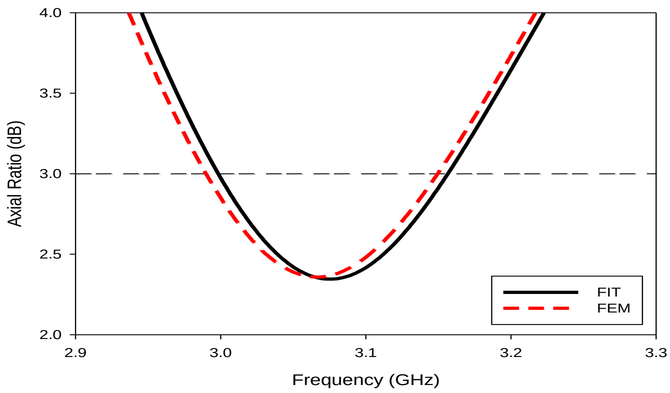

Figure 5. Axial ratio of the rectangular DRA fed by an off-set conformal metal strip

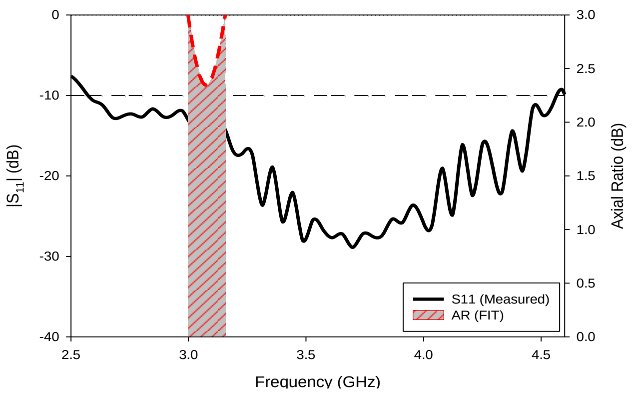

Figure 6. The region of bandwidths overlap of the rectangular DRA fed by an off-set conformal metal strip

In Figure 7, the radiation patterns of the antenna has been demonstrated. At minimum point of AR frequency i.e. 3.08 GHz the left hand field component is greater than right hand field component, hence proving that antenna offers a left-hand circularly polarized wave. The direction of polarization can be reversed by making the strip off-set to right side from center rather than left.

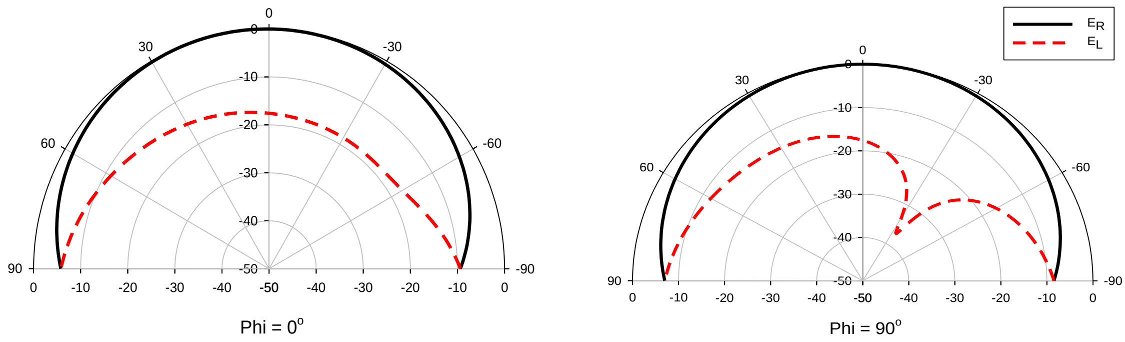

Figure 7. Radiation patterns of the rectangular DRA fed by an off-set conformal metal strip

The beamwidth offered by the antenna has been presented in Figure 8. The antenna offers a circular polarization with useful beamwidth of 81o in the ϕ = 0o plane and 70o in the ϕ = 90o plane. The beamwidths provided by the antenna are comparable to those reported in [27].

The gain of the rectangular DRA has been demonstrated in Figure 9. The antenna provide a useful gain of ~5.3 dBi throughout the whole CP bandwidth. The gain of the antenna has been demonstrated in both FIT and FEM. A good agreement between the results from FIT and FEM has been observed.

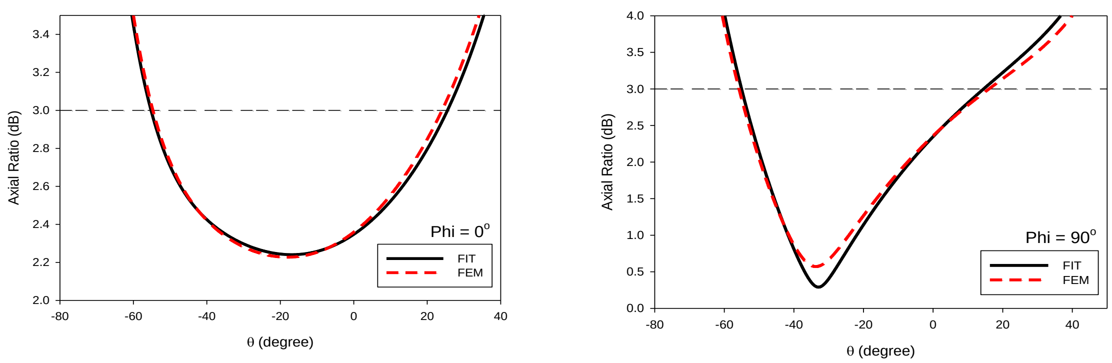

Figure 8. AR beamwidth of the rectangular DRA fed by an off-set conformal metal strip

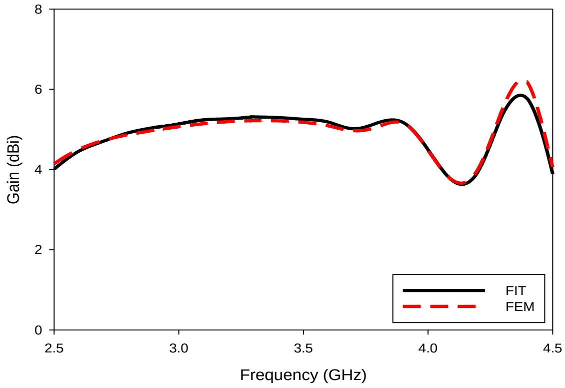

Figure 9. Gain of the rectangular DRA fed by an off-set conformal metal strip

4. CONCLUSION

A rectangular DRA has been excited by an off-set single conformal metal strip. A circular polarization over bandwidth of ~5.2% has been achieved along with a wide impedance matching bandwidth of ~54% over same frequency range. The two degenerate mode pair i.e. TExδ11 at 2.784 GHz and TEy1δ1 at 3.697 GHz has been excited by an off-set metal strip to achieve CP which is a good contribution in designing circularly polarized rectangular DRAs as compared to those reported in early research studies. The antenna offers a CP beamwidth of 81o in the ϕ = 0o plane and 70o in the ϕ = 90o plane. A useful gain of ~5.3 dBi has been provided by the antenna along the whole CP bandwidth. A good resemblance between the simulated and measured S11 has been observed. A similar trend in far field results from FIT and FEM have also been observed.

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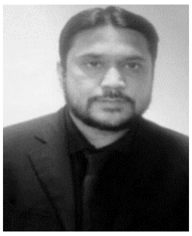

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