Progress In Electromagnetics Research Letters, Vol. 46, 95–100, 2014

High Gain Circularly Polarized Rectangular Dielectric Resonator Antenna Array with Helical-Like Exciter

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Abstract—A novel (2×2) high gain circularly polarized rectangular dielectric resonator antenna array integrated with helical-like exciter is proposed. The array offers a maximum gain of 12.9 dBi at the operating frequency. The circular polarization is obtained by incorporating helical-like exciter in the array structure. A prototype of the proposed configuration integrated with helical-like exciter has been fabricated and tested, and the idea has been verified. A good agreement has been obtained between the measured and simulated results.

1. INTRODUCTION

The dielectric resonator antenna (DRA) has received increasing attention because of its attractive features such as small size, low cost, versatile and flexible excitation techniques, wider impedance bandwidth, high radiation efficiency, high temperature tolerance [1–5]. DRA can be excited by different feeding mechanisms such as direct microstrip line feed [6, 7], co-axial probe [8], aperture coupled by microstripline or coplanar waveguide [9–11], conformal strip feed [12] and designed with various shapes. Recently, circularly polarized (CP) DRA has attracted extensive attention due to insensitivity to the orientation between the transmitter and receiver. This feature is very useful in various communication systems. There are different mechanisms, by which a circularly polarized DRA can be obtained, such as dual coaxial probe [13], dual conformal strip [14], with parasitic strips [15], rotated sequential feed [16], aperture feed [17], spiral slot [18], and special shaped DRA. The method of producing circular polarized radiation using cylindrical DRA with helical exciter has been reported in [19] recently. In this paper, the helix feed excites two orthogonal $\mathrm{HE}_{11\delta}$ modes in phase quadrature in the DRA, resulting in a circular polarized wave. The maximum measured 7.7 dBi gain was reported in this paper. Very recently, present authors have proposed a high gain circularly polarized cylindrical dielectric resonator antenna array using helical exciter [20]. In the said paper, a maximum gain of 13.8 dBi at the operating frequency was successfully demonstrated. To the very best of our knowledge, no one has ever explored such a high gain circularly polarized rectangular type DRA array integrated with helical-like exciter in the open literature before.

In this paper, an array has been proposed to achieve high gain circularly polarized DRA array integrated with helical-like exciter. The helix feed excites two orthogonal $\mathrm{TE}_{\delta 11}$ modes in phase quadrature in the DRA, resulting in a circularly polarized wave for our proposed antenna array. The maximum measured gain 12.9 dBi has been achieved for the proposed antenna. The proposed antenna is simple and inexpensive to fabricate. The design of the antenna has been performed using Ansys High-Frequency Structure Simulator (HFSS) based on the three-dimensional finite element method (FEM) [21]. The field distributions for the $\mathrm{TE}_{\delta 11}$ mode for a single element DRA are shown in Fig. 2. The proposed DRA antenna array has greater radiation efficiency, very little radiation loss and conductor loss, high temperature tolerance capabilities compared to microstrip patch antenna array. Details of the proposed antenna design and measurement results are presented and discussed in the following sections.

Received 17 April 20144, Accepted 28 May 2014, Scheduled 12 June 2014
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2. ANTENNA DESIGN

The proposed antenna has been designed at a centre frequency of 5.2 GHz, and accordingly the characteristic parameters of FR-4 and DRA have been optimized during the process of simulation. In this design, initially a single rectangular DRA of length 4.7625 mm, width 4.7625 mm, height 20 mm and dielectric constant 20 has been taken for the base element, then a four-element array has been designed to operate at 5.2 GHz. Fig. 1 shows the schematic diagram of the proposed antenna array. FR-4 substrate of thickness of 1.58 mm, loss tangent of 0.02 and dielectric constant of 4.4 has been taken for this design consideration. A power divider using a $\lambda/4$ transformer has been designed on the FR-4 substrate to feed the array. A coaxial line fed technique has been used, and the array is fed by a SMA connector through power divider.

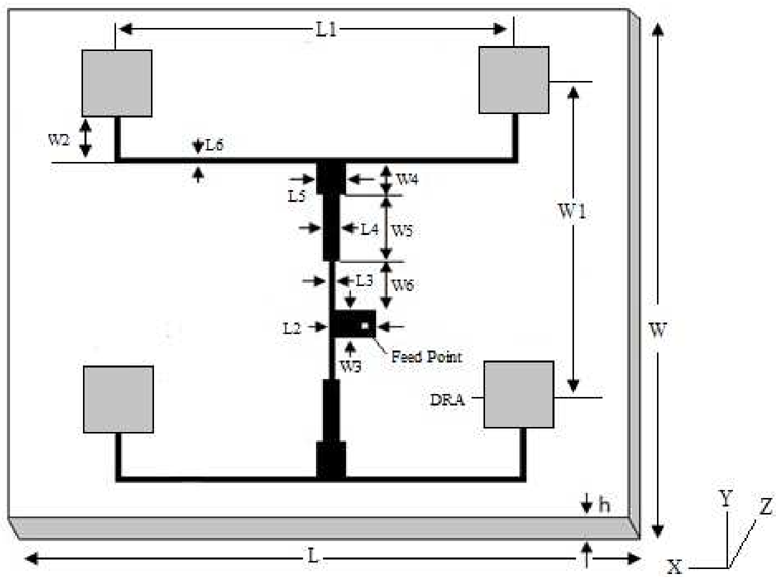
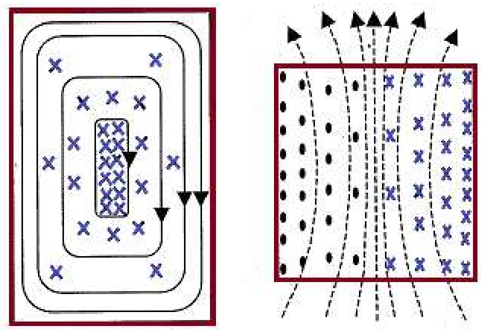


Figure 1. Configuration of proposed antenna.

A width of 1 mm helical-like exciter has been constructed from the adhesive copper tape. The helical exciter of width of 1 mm has been wrapped anti-clock wise on the DRA spirally manually with an angle of 11 degrees. Five turns on the DRA surface has been used. The helical exciter has been connected with the arms of the power divider for the excitation through vertical arms which are also adhesive copper tapes of thickness of 1 mm and height of 2 mm. A photograph of the fabricated antenna is shown in Fig. 3. The optimized design parameters of the antenna are given in Table 1.

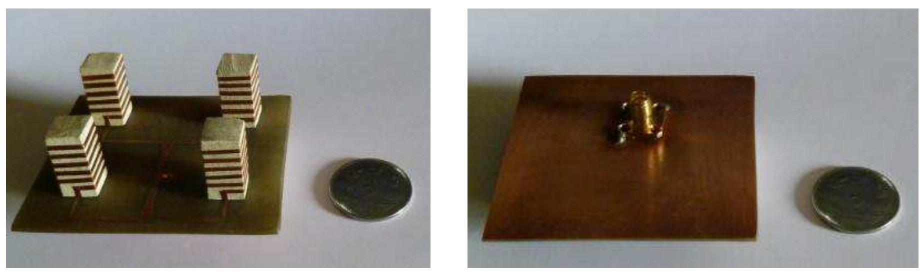
Table 1. Design parameters of optimized antenna (units: mm).

Parameters	Value	Parameters	Value
L	70	W	60
h	1.58	W_1	32
L_1	41	W_2	7.6
$W_3 = W_4 = L_5$	3.05	L_2	6.35
$L_3 = L_6$	0.7	W_6	2.9
L_4	1.61	W_5	8.03



(a) (b)

Figure 2. Field distribution of $\mathrm{TE}_{\delta 11}$ mode inside a single DRA, (a) electric field in the XZ plane at $Y = 0$, (b) magnetic field in the XY plane at $Z = 0$.



(a) (b)

Figure 3. Photograph of fabricated antenna, (a) top view, (b) bottom view.

3. RESULTS

A prototype of the proposed antenna has been fabricated and tested. The simulated resonant frequency of the proposed antenna array is 5.2 GHz with 3.4% impedance bandwidth. The measured return loss is obtained by the Anritsu MS2025B vector network analyzer. The return loss characteristics of the single element and proposed DRA array are studied in Fig. 4. From Fig. 4, it is seen that the -10 dB impedance bandwidth of the simulated single element antenna is 5.4%. The measured result of the proposed array is compared to that of simulated one, and a shift of 95 MHz frequency is observed in the

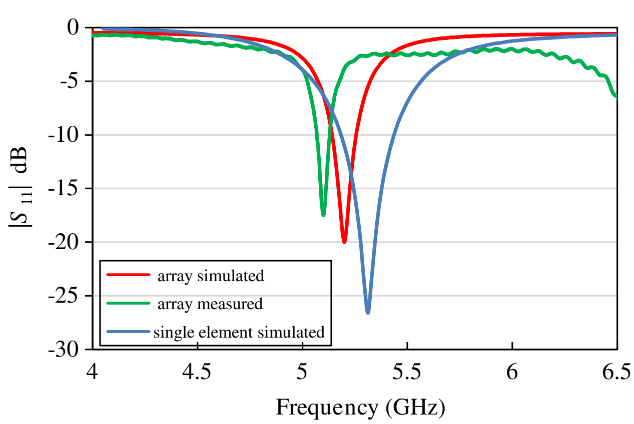


Figure 4. Simulated and measured return loss of proposed antenna.

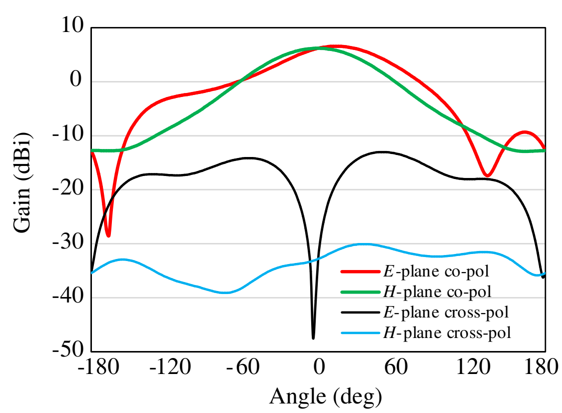


Figure 5. Simulated radiation pattern of the single element antenna.

measurement result. This is due to the error occurred during the process of fabrication. The measured -10 dB impedance bandwidth of the array is 3.1%. The gain and radiation pattern were measured in an anechoic chamber, and the measurement was performed by an Agilent network analyser along with far-field measurement software. The simulated E- and H-plane radiation patterns of the single element antenna are shown in Fig. 5. From Fig. 5, it is observed that the maximum gain for both E- and H-plane radiation patterns is 6.6 dBi, and the cross-polarization level is also very low for the single element antenna. The DRAs are placed for different inter-element spacings, and the effect of radiation pattern and gain are studied. When the inter-element spacing between the DRAs is 0.5λ, the simulated peak gain of 12.6 dBi is observed. The simulated E- and H-plane radiation patterns are shown in Fig. 6 for the said spacing. If the antenna elements are placed more than 1.0λ apart the grating lobes are prominent. Fig. 7 shows the E- and H-plane radiation patterns for the inter-element spacing of 1.0λ. The grating lobes are evident for such a inter-element spacing as seen from Fig. 7. The peak gains of such configurations decrease with increasing inter-element spacing after certain inter-element spacing. The peak gain of 9.1 dBi is found for 1.0λ inter-element spacing. The peak gains for different inter-element spacings are plotted in Fig. 10. The simulated and measured E- and H-plane radiation patterns of the proposed DRA array are shown in Fig. 8 and Fig. 9, respectively. A simulated gain of 13.6 dBi is observed, and measured gain of 12.9 dBi is achieved for the E-plane radiation pattern of the array. For the H-plane radiation pattern, simulated and measured gains were 13.7 dBi and 12.9 dBi, respectively. A

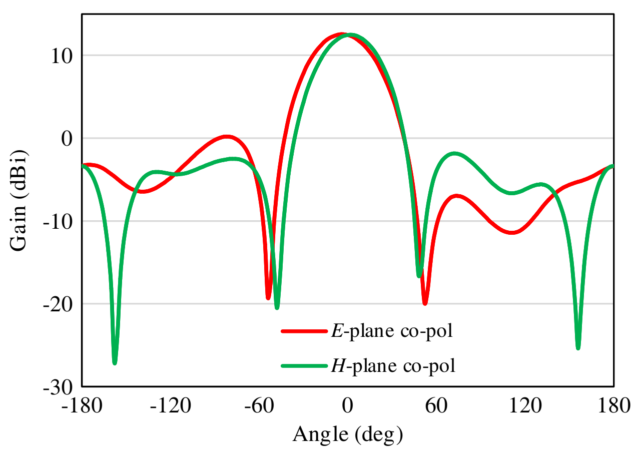


Figure 6. Simulated E-plane and H-plane radiation pattern of antenna array for the inter-element spacing of 28 mm (0.5λ).

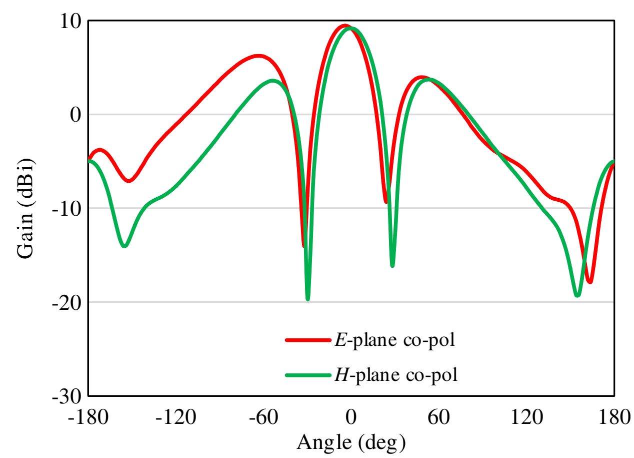


Figure 7. Simulated E-plane and H-plane radiation pattern of antenna array for the antenna spacing 58 mm (1.0λ).

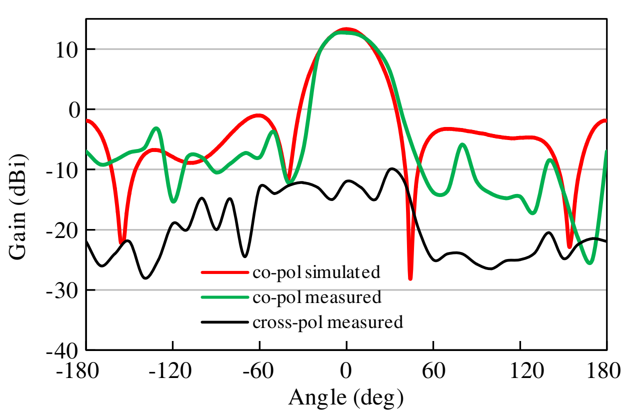


Figure 8. Simulated and measured E-plane radiation pattern of the proposed antenna array.

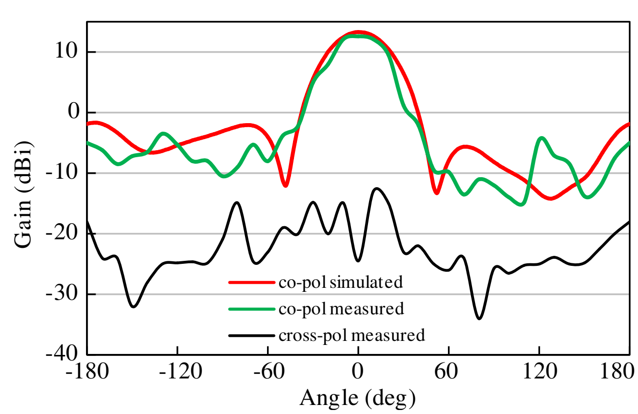


Figure 9. Simulated and measured H-plane radiation pattern of the proposed antenna array.

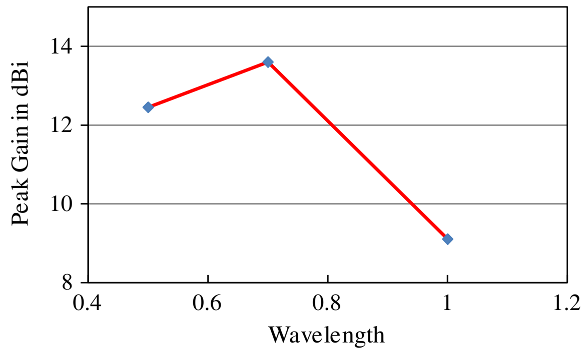


Figure 10. Simulated peak gain for different inter-element spacing.

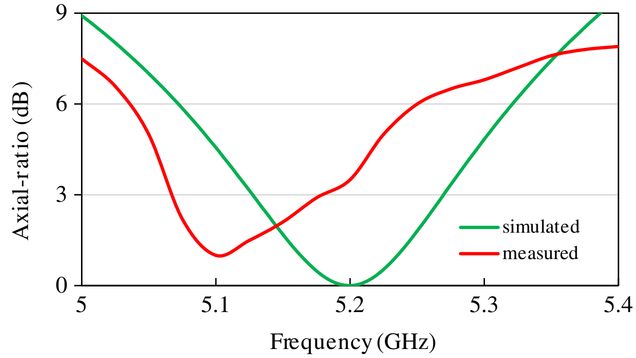


Figure 11. Simulated and measured axial-ratio of proposed antenna array.

good agreement between the simulated and measured radiation patterns for both E-plane and H-plane is observed for the proposed array. The measured levels of cross-polarisation (LHCP) at the broadside direction are also very low for both E- and H-plane radiation patterns. The measured and simulated axial ratios are shown in Fig. 11. The simulated 3 dB axial-ratio bandwidth at 5.2 GHz is 3.3% while the measured axial-ratio bandwidth at the operating frequency is 3.1%. The proposed antenna has 94% radiation efficiency at the operating frequency.

4. CONCLUSION

An array is proposed as a technique of increasing gain of the circularly polarized rectangular DRA with external helical-like exciter. By optimizing the array structure, a circularly polarized radiation pattern and high gain are obtained. A prototype has been fabricated and measured. There is good agreement between the simulated and measured results. The measured 12.9 dBi gain has been found for the proposed antenna.

ACKNOWLEDGMENT

This work was supported by Council of Scientific and Industrial Research (CSIR), Govt. of India.

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