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A Singly Fed Rectangular Dielectric Resonator Antenna With a Wideband Circular Polarization

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***Abstract*—A rectangular dielectric resonator antenna (DRA) that is excited using an outer-fed square spiral strip has been studied theoretically and experimentally. Utilizing such excitation has provided a circular polarization over a broad bandwidth of $\sim 14\%$ in conjunction with an impedance-matching bandwidth of $\sim 11\%$. The structure has been rigorously modeled using a method of moments (MoM) model. A good agreement has been attained between computed and measured results.**

***Index Terms*—Circular polarization, dielectric resonator antennas (DRAs), moment method, spiral antennas.**

I. Introduction

The design of circularly polarized (CP) dielectric resonator antennas (DRAs) has been the focus of numerous research studies using dual and single feeding mechanisms [1]–[9]. The dual-feed excitation approach is known to provide circular polarization over a wide bandwidth [1]–[3]. However, it has several limitations such as the added complexity of incorporating the feeding network in the design, as well as increasing the overall size of the antenna. On the other hand, a single-feed solution is more attractive owing to its simplicity of construction in addition to the smaller overall antenna size.

Several techniques on building a singly fed CP DRA have been reported in the literature. For instance, a CP rectangular DRA using a single-slot feed has been reported [4], where an axial ratio (AR) bandwidth of 1.8% has been achieved. An elliptical DRA with a circular polarization bandwidth of 3.5% has been investigated using a single-probe feeding [5]. A parasitic patch has been used to accomplish a circular polarization for a hemispherical DRA with a bandwidth of 2.4% [6], and for a rectangular DRA with an AR bandwidth of 2.7% [7]. A significantly higher CP bandwidth of 10% has been reported using a single feed, where a coaxial probe has been used to excite a circular sector DRA [8]. Another design has been reported in [9], in which a 10.6% CP bandwidth has been attained for a stair-shaped rectangular DRA that is excited by a narrow slot rotated at an angle of 45° with respect to the DRA side. In all these studies, the antennas have good impedance-matching bandwidth at the same frequency of the achieved circular polarization.

This letter proposes a new method to design a CP DRA using a square spiral-shaped strip for excitation. The achieved results show a measured circular polarization bandwidth of 14%, which is greater than the bandwidths reported in the literature for singly fed DRAs. The designed antenna offers an impedance-matching bandwidth of 11% over the same frequency range. The return losses, AR, and far-field patterns been have been measured and compared to theory, and they show close agreement.

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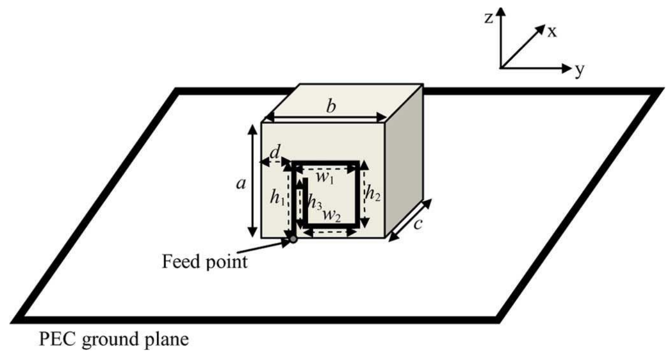

Fig. 1. Rectangular DRA excited by a square spiral strip.

II. Formulation

Fig. 1 illustrates a rectangular DRA that has been excited using a square spiral monopole. The configuration has been modeled using the volume surface integral equation (VSIE)-based [10], [11] moment method model, where the rectangular dielectric has been meshed to 2546 tetrahedrons and the metallic strip to 86 triangular surface patches, giving a total of 5530 unknowns. The surface and volume integrals over the source triangles and tetrahedrons have been computed using symmetric quadrature rules [12], in which the number of points has been varied from seven to one depending on the separation distance between source and field points. Approximate Galerkin method of moments (MoM) has been used, in which the test has been employed at the centroids of the observation triangles and tetrahedrons, and the singularity of the self-term matrix elements has been extracted using the procedure proposed in [13]. The perfectly conducting ground plane has been considered using the image theory. A delta-gap voltage generator model has been employed. An iterative design procedure has been followed to determine the dimensions of the feeding spiral-shaped monopole that are needed to establish a traveling-wave current distribution along the metallic strip, which excites two orthogonal, nearly degenerate modes that produce circular polarization radiation.

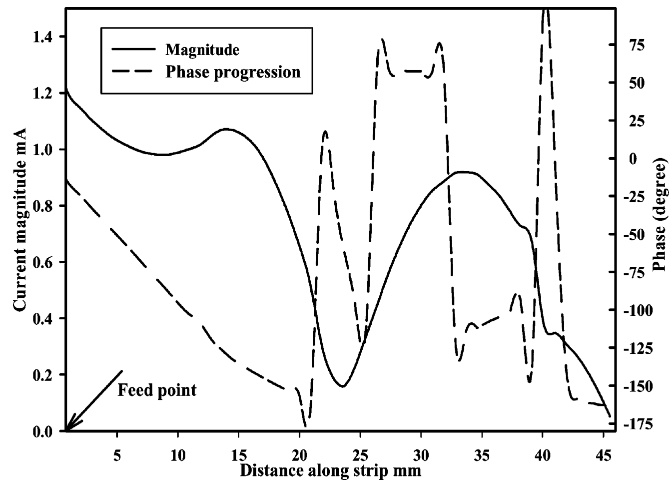

Fig. 2. Current distribution along the spiral strip at 4.1 GHz.

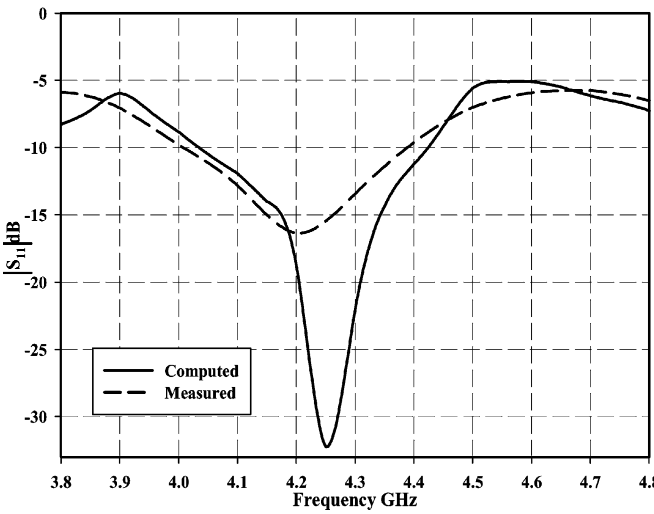

Fig. 3. Return losses of a rectangular DRA fed by a square spiral strip.

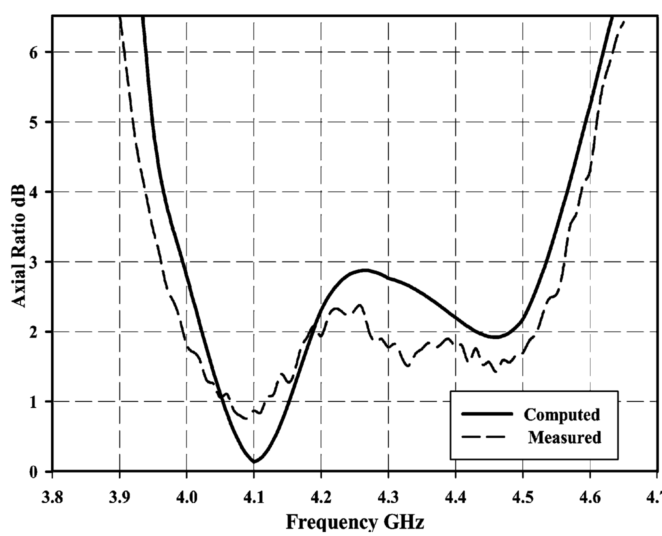

Fig. 4. Axial ratio of a rectangular DRA fed using a square spiral strip.

III. Results

A rectangular DRA prototype has been built using alumina with a relative permittivity of $\varepsilon_r = 9.3$. The dimensions of the DRA are the same as those given in [7]: $a = 25.4$ mm, $b = 26.1$ mm, and $c = 14.3$ mm. The square spiral shape has been constructed using five individually cut strips of an adhesive-backed copper tape that has been stuck easily on the DRA surface. The strips have been attached to each other using silver paint. The optimized parameters of the individual strips are found to be $h_1 = 10.25$ mm, $h_2 = 10$ mm, $h_3 = 8$ mm, $w_1 = 8$ mm, $w_2 = 7$ mm, and $d = 8$ mm. The strip width is 1 mm. A square aluminum ground plane with a side length of 400 mm has been employed, and an HP8720D vector network analyzer has been used in the measurements. Feeding has been implemented by soldering the end of the spiral strip to an SMA connector that is connected to the network analyzer using a 50-Ω coaxial cable. The possible air gap between the DRA and the ground plane has been eliminated by employing the procedure described in [14], in which the DRA is attached to a double-sided adhesive conducting tape that is placed above the ground plane.

The current distribution in Fig. 2 consists of outbound and reflected traveling waves along the spiral arm, decaying as they radiate. Close to the feed point, the wave outbound from the feed has not yet decayed much, while that reflected from the end of the arm has decayed twice, radiating significantly in both directions, thus causing least interference. The net result is close to a decaying traveling wave therefore, as can be observed in the relatively linear phase progression and smoother amplitude decay. It is the predominant traveling wave close to the feed that is responsible for the good AR [15]. A comparison between the measured and the computed return losses is shown in Fig. 3, where it can be seen that an $|S_{11}| \leq 10$ dB, that is, a voltage standing wave ratio (VSWR) of ≤ 2, has been achieved over a bandwidth of 11%. The minimum S_{11} has been measured at 4.2 GHz compared to 4.25 GHz in the computations; that is, a marginal difference of 1.1% has been achieved between the two sets of results. Furthermore, the results agree well with a resonance frequency of 4.19 GHz for the TE^y_{112} mode in which the DRA is excited.

The AR has been computed and measured at the boresight direction, $\theta = 0$. The variation of AR as a function of frequency is shown in Fig. 4, where it can be seen that the minimum computed value is 0.17 dB at 4.1 GHz, which is close to the corresponding measured value of 0.8 dB at the same frequency. From these results, it can be observed that the theoretical 3-dB AR bandwidth extends from 4–4.53 GHz compared to 3.96–4.56 GHz in the measurements. These figures show that a circular polarization has been achieved over bandwidths of 12.5% and 14% in the analysis and the measurements, respectively, which is noticeably higher than what has been achieved in earlier studies for a singly fed CP DRA. Employing a finite ground plane and experimental tolerance have produced a slight discrepancy between the predicted and the measured bandwidths. The achieved AR bandwidth is sensitive to the strip length, as changing the latter may generate a standing wave current distribution that deteriorates the circular polarization. It should be noted that the effective AR bandwidth is the same as the impedance-matching bandwidth of 11%. However, the VSWR is ≤ 2.5 for a further 3% of the bandwidth. Therefore,

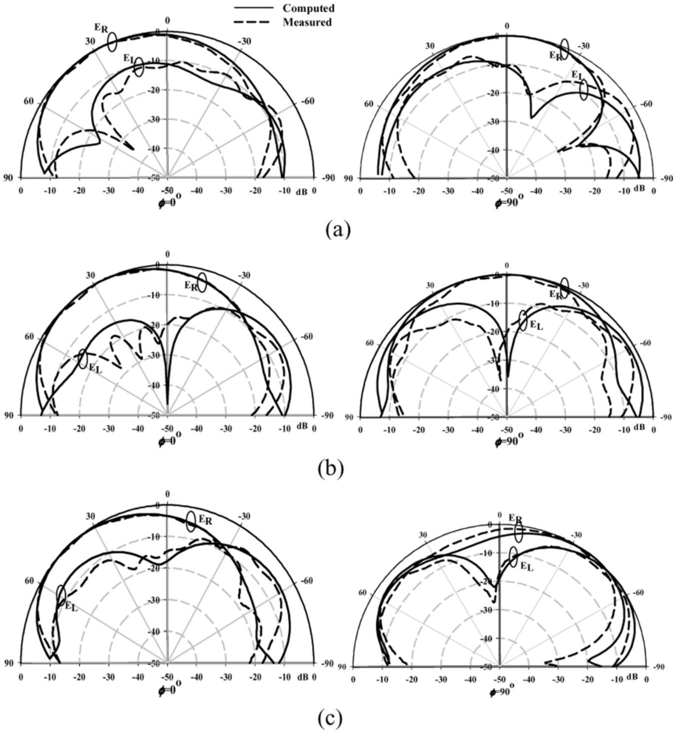

Fig. 5. Radiation pattern of the rectangular DRA at (a) 4, (b) 4.1, and (c) 4.45 GHz.

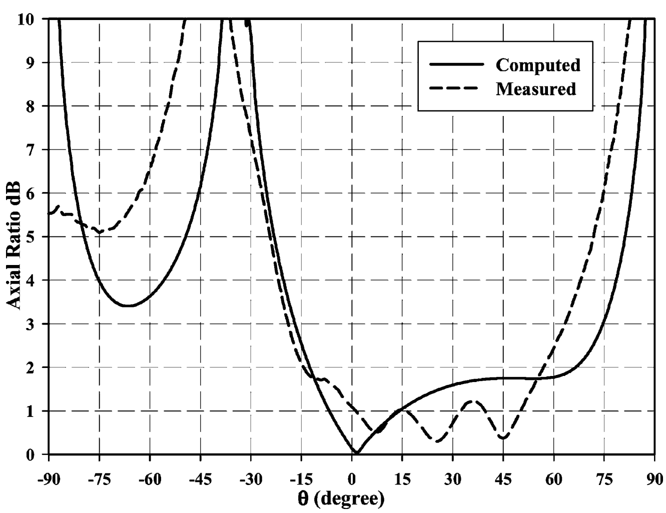

Fig. 6. Axial ratio beamwidth of the rectangular DRA at $\phi = 0°$.

when a matching criterion of $\mathrm{VSWR} \leq 2.5$ is employed, then all of the 14% AR bandwidth can be utilized. The foregoing matching criterion has been adopted in earlier studies [16], [17] and considered to be acceptable.

A comparison between the calculated and the measured radiation patterns is shown in Fig. 5 with reasonable agreement and stability across a bandwidth of 11%. It is evident from these results that this is a right-hand CP DRA, and the right-hand field component is stronger than the left-hand counterpart by more than 30 dB in the boresight direction at 4.1 GHz. Furthermore, a left-hand CP DRA can be attained by changing the square spiral arm winding from clockwise to counterclockwise direction. The variation of the axial ratio with the elevation angle is

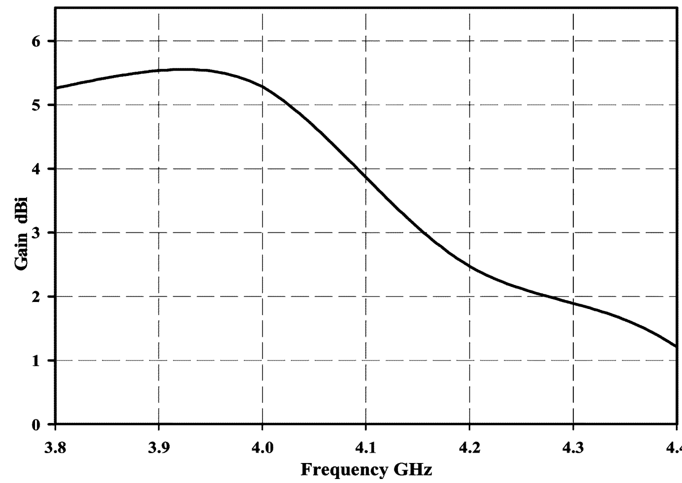

Fig. 7. Computed gain of a rectangular DRA fed using a square spiral strip.

demonstrated in Fig. 6, which shows that the DRA offers circular polarization over a useful beamwidth of 80° in the $\phi = 0°$ plane. In the $\phi = 90°$ plane, the AR beamwidth is 36°. These AR beamwidths are comparable to those reported in [8]. The achieved AR asymmetry in the principle plane is expected as a result of the asymmetrical location of the feeding spiral in that plane. The antenna presents a satisfactory boresight gain as demonstrated in Fig. 7, where it can be seen that a gain of 4 dBi has been achieved at the optimum AR frequency.

IV. Conclusion

A circularly polarized dielectric resonator antenna has been designed using a spiral-shaped monopole for excitation. The antenna provides a measured 3-dB AR bandwidth of $\sim 14\%$, which is considerably greater than what has been reported in earlier studies for a singly fed CP DRA. This has been achieved in conjunction with an 11% impedance-matching bandwidth, $(\mathrm{VSWR} \leq 2)$, over the same frequency range. The far-field pattern confirms that the circular polarization has been attained over a beamwidth of 80°. Furthermore, the antenna is very simple to feed and construct using adhesive conducting strips. A good agreement has been attained between experimental and theoretical results.

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