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Bandwidth Enhancement of Circularly Polarized Cylindrical DRA using Parasitic Half Loop

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Abstract: Antennas exhibiting wide operational circularly polarized (CP) bandwidth capability has been the focus of the numerous research activity in the wireless communication technology. Dielectric resonator antenna (DRA) provides one of the most attractive candidates for such requirements. In this paper, a single-point fed cylindrical DRA with a parasitic half loop is proposed for further enhancement of the CP bandwidth. The DRA configuration that is excited by a driven open half loop conducting metal strip with a parasitic loop has been studied theoretically and experimentally. Utilizing such excitation has provided a measured CP and return loss bandwidths of ~8.12%, and 8.23% respectively. These results represent an additional CP bandwidth increment of ~85% compared to those achieved by the cylindrical DRA configuration excited by a driven half loop only. Additionally, a good agreement has been attained between the measured and computed results.
Keywords: Dielectric resonator antenna, DRA, single point excitation, circularly polarized antenna

1.0 INTRODUCTION

Several designs of circularly CP DRAs have been reported in the literature employing dual and single-point feeding mechanisms. Although dual feeding mechanism usually yields a wider CP bandwidth, single feed methods are preferred as they offer a compact antenna size as well as construction simplicity.

One of such design proposed in the literature is a chamfered cylindrical DRA excited by a probe feed, achieving a CP bandwidth of 1.2% [1]. A CP bandwidth of 1.33 % has been obtained when a cylindrical DRA is excited using a corner cut square patch [2]. A microstrip-line-fed cylindrical DRA with two identical metal strips printed on its surface offering a 2.2% AR bandwidth has been demonstrated in [3].AR bandwidths of 3.91% and 2.2% have been achieved for cylindrical DRAs excited by a cross-slot [4], and an annular slot [5], respectively.

Recently, a novel DRA excitation method with the ability to generate a wider CP bandwidth has been proposed by M.I. Sulaiman and S.K. Khamas [6], in which a conformal open half loop conducting metal strip has been applied onto a rectangular DRA. The antenna provides a measured 3-dB CP bandwidth of 7%, which is considerably greater than the bandwidth of ~ 3% reported by B. Li and K.W. Leung [7] using a similar size rectangular DRA. Subsequently, the open half loop excitation method has been applied onto a cylindrical DRA [8] in which a CP bandwidth of 4.14% has been obtained in comparison to the 2.2% CP bandwidth reported by M.T. Lee et al [9].

The possibility of enhancing the CP bandwidth obtained using such cylindrical DRA configuration is investigated next by employing a parasitic open half loop metal strip. Enhancing the CP bandwidth of a loop antenna by adding a parasitic element is a well-known procedure that has been reported in earlier studies. For instance, the addition of a parasitic element inside a circular loop antenna has resulted in the increase of AR bandwidth from 6.5% to 20% [10]. In a later study [11], a pair of parasitic rhombic loops has been placed inside a dual-rhombic loop. The AR bandwidth of this configuration was found to be 46%, which is more than three times wider than those achieved without the parasitic element. Additionally, the combination of two AR bands from a dual rhombic loop antenna with double parasitic loops has contributed to a very significant increase in the AR bandwidth from 3% to 23.7%, as reported in [12]. The effects of adding a pair of parasitic loop inside dual rectangular loop antenna has been investigated in [13], in which the 3dB AR bandwidth has been reported as 46% compared to 18% without the parasitic elements. Furthermore, the incorporation of a parasitic circular loop onto a probe-fed CP circular loop antenna has generated a wide CP bandwidth of 16%, compared to less than 6% for a single loop [14].

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2.0 MATERIALS AND METHODS

Fig. 1 illustrates the geometry of a cylindrical DRA that is excited using concentric (driven and parasitic) open half-loops. The configuration can be divided into two parts; dielectric volume and metal surface. The dielectric volume has a radius of a, a height of h and a dielectric constant of ε_r. For the metal surface, the driven half-loop has a width of w_d, a height h_d and a gap size of g_d located at a gap position of g_p. The parasitic half-loop that is placed inside the driven element has dimensions of w_p and h_p, and the parameters of the gap within this parasitic element follow those within the driven element.

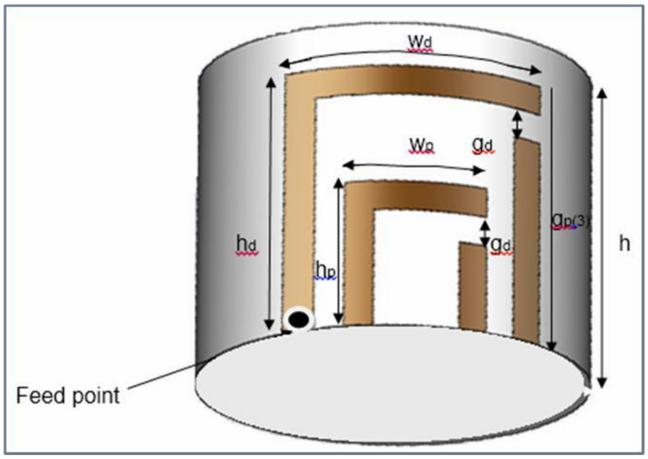

Fig. 1: Configuration of a cylindrical DRA excited by concentric open half loop

The antenna configuration has been modeled using the method of moments in conjunction with the combined RWG and SWG basis functions, where the cylindrical dielectric has been meshed to 2432 tetrahedrons and the metallic strips to 87 triangular patches, giving a total of 4989 unknowns. The optimum dimensions of the feeding metallic strips that are required to establish a travelling-wave current distribution along the half-loops, as well as exciting a DRA mode within the same frequency range, have been determined following an iterative design procedure.

In order to assess the effect of adding a parasitic open half loop onto the cylindrical DRA, the dimensions have been chosen to be as the same as those reported in [8] and [9], that is h = 10.54 mm, a = 7.01 mm and ε_r = 9.2. The dimensions of both half-loops have been optimized after employing these parameters. Throughout the simulations, a gap of size g_d = 1 mm has been placed between the last two metallic strips of each half-loop. Once the optimized parameters for the metal strips have been obtained, a prototype of the design has been built using Alumina ceramic and conducting metal strip. Then, the performance of the DRA has been measured in an anechoic chamber.

3.0 RESULTS AND DISCUSSIONS

A prototype of a multilayer cylindrical DRA that is excited using concentric half-loops is illustrated in Fig. 2. The optimized parameters of the feeding half-loops have been determined using the aforementioned iterative design procedure as h_d = w_d = 9 mm, g_d = 1 mm, h_p = 6 mm, w_p = 5 mm, p_s = l_s = 1 mm, and w_s = 2 mm.

Fig. 2: Prototype of the cylindrical DRA

Reasonable agreement has been obtained between the computed and measured input impedances as demonstrated in Fig. 3. The experimental and theoretical return losses are presented in Fig. 4, where it can be noticed that an $S_{11} \leq$-10 dB bandwidth of 7.69% has been achieved in computations compared to 8.23% in measurements. The minimum S_{11} has been computed at 6.74 GHz compared to 6.92 GHz in the measurements, which represents a difference of 2.77% between the two results. This discrepancy can be attributed to measurements error, as the air gaps between the PEC ground plane and the antenna cannot be fully eliminated since the cylindrical DRA is very lightweight, which has caused some difficultly in positioning it firmly on the ground plane. Additionally, a travelling wave current distribution, which generates CP wave, has been attained along the half-loops as illustrated in Fig. 5.

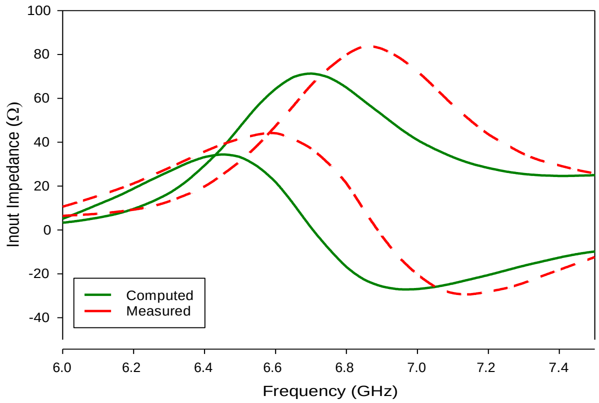

Fig. 3: Input impedance of the cylindrical DRA

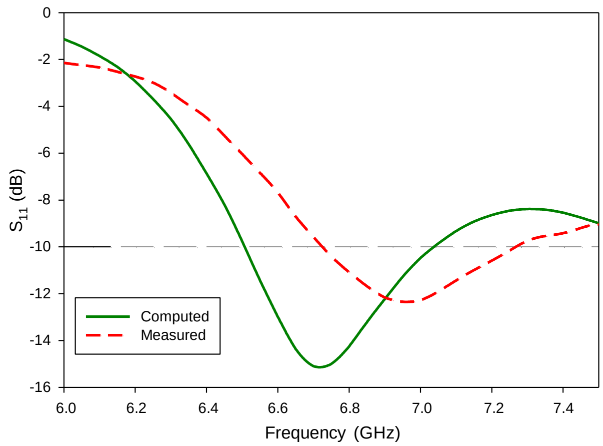

Fig. 4: Return losses of the cylindrical DRA

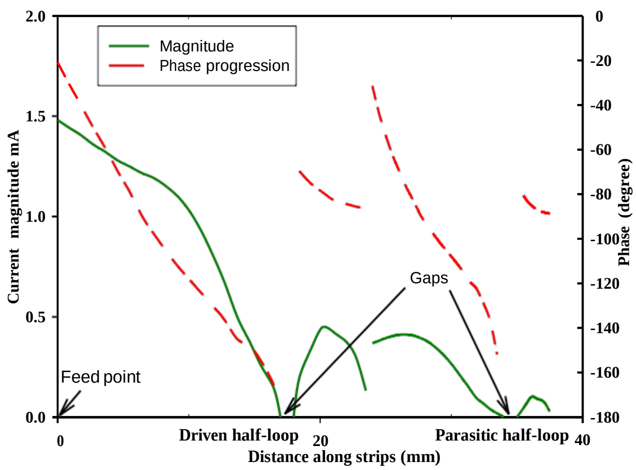

Fig. 5: Return losses of the cylindrical DRA

The bore-sight axial ratio (AR) has been computed and measured as demonstrated in Fig. 6, where it can be noticed that the minimum computed CP is 0.61 dB at 6.75 GHz compared to a corresponding measured value of 1.53 dB at 6.88 GHz. With reference to the figure, the theoretical 3 dB AR bandwidth extends from 6.38 to 7 GHz compared to 6.59 to 7.15 GHz in the measurements. Therefore, CP radiation has been achieved over bandwidths of 9.17% and 8.12% in the analysis and the measurements, respectively, which represents significant increase from the CP bandwidth achieved by the similar cylindrical DRA excited by a driven half-loop only [8]. Additionally, it is several folds higher than the AR bandwidth of ~2% reported in [9]. Furthermore, the overlapping AR and S_{11} bandwidths from computations and measurements are shown in Fig. 7. Based on the results, the theoretical effective AR bandwidth is found to be 8.6% and 8.12% in the computations and measurements, respectively,

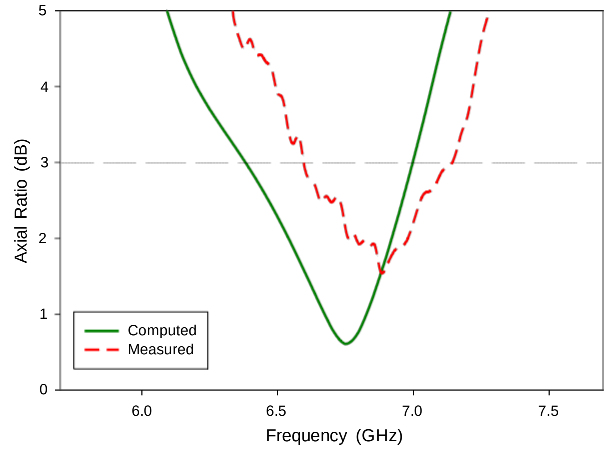

Fig. 6: Axial ratio of the cylindrical DRA

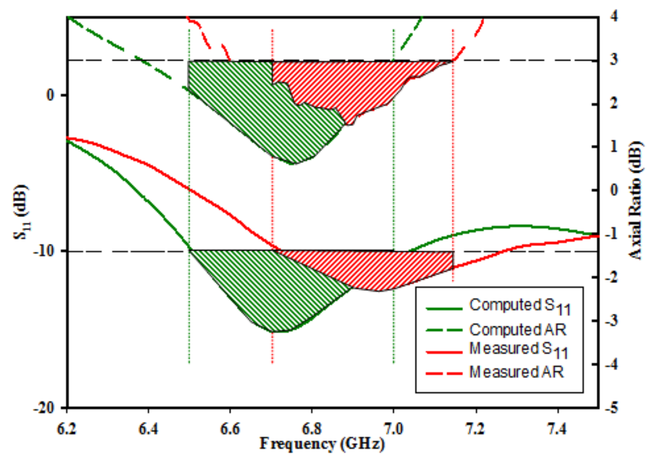

Fig. 7: Regions of overlapping bandwidths for return loss and axial ratio of the cylindrical DRA

The axial ratio beam-width is shown in Fig. 8 and 9, where it can be noticed that the DRA offers circular polarization over measured beam-widths of over 39° in the both planes.

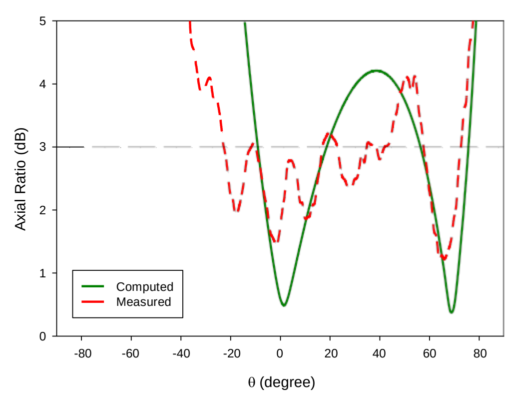

Fig. 8: AR beam-width of the cylindrical DRA at $\phi = 0^\circ$

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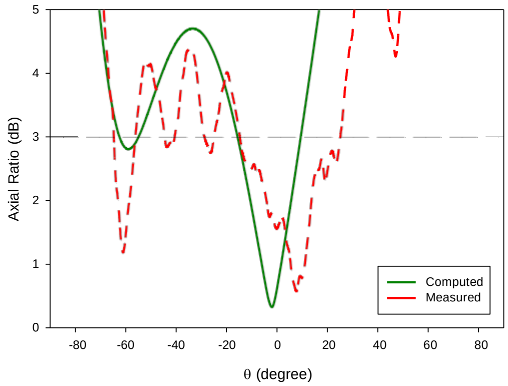

Fig. 9: AR beam-width of the cylindrical DRA at $\phi = 90^\circ$

Furthermore, the stability of the radiation pattern has been studied as shown in Fig. 10, where it is evident that the patterns are stable across the whole CP bandwidth, and an isolation of more than 21 dB has been achieved between the co-, and cross-, polarization components at the minimum AR frequency point. As the right hand CP field component is much stronger than the left hand CP field, the DRA radiates right-hand CP wave.

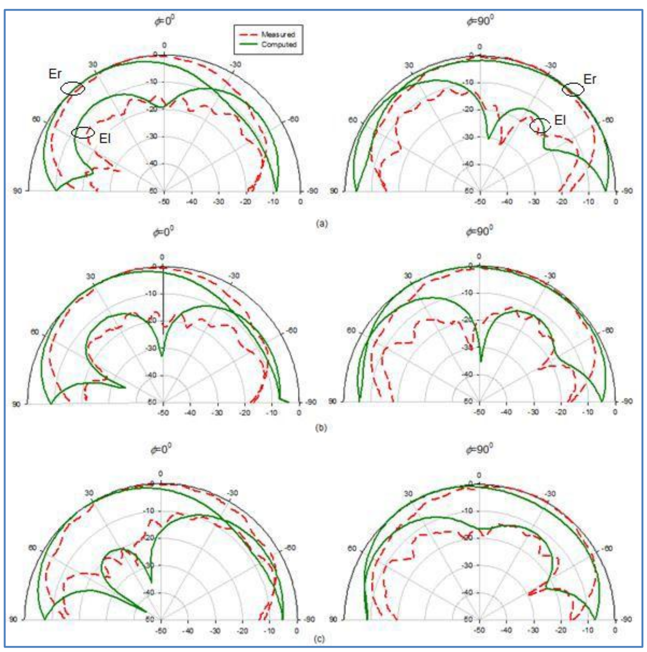

Fig. 10: Radiation patterns of the multilayer cylindrical DRA at (a) beginning, (b) centre, and (c) end of the CP bandwidth.

5.0 CONCLUSION

The CP bandwidth of the cylindrical DRA have been increased substantially through the incorporation of an inner parasitic half-loop within the driven half-loop. With appropriate dimensions and placement of the parasitic element, the parasitic half-loop creates another minimum AR point at frequency close to that created by the driven half-loop. Thus, merging the two AR minimal points results in a wider circular polarization bandwidth. In this cylindrical DRA configuration, the inclusion of concentric parasitic elements has approximately doubled the CP bandwidths compared to those obtained using the driven half-loops only. This is very desirable, since the parasitic half-loop has been included in the structure without increasing the antenna size or complexity. Throughout the research, reasonable agreement has been obtained between computations and measurements with some discrepancies that can be attributed to experimental tolerances, as well as fabrication and measurement errors.

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