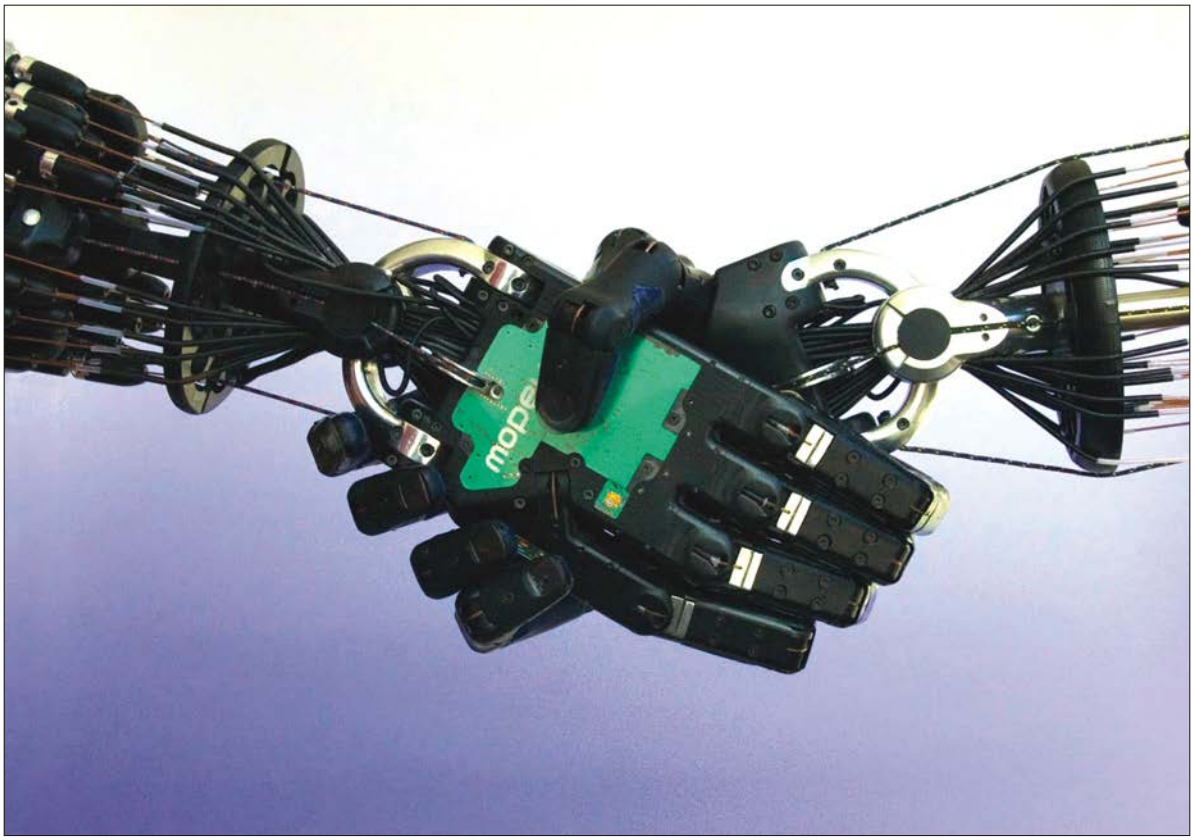

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Research Article
Bandwidth Enhancement of a Circularly Polarized Cylindrical DRA Using Multi-dielectric Layers

[1]M.I. Sulaiman, [1]H. Basarudin, [1]A.F. Ramli and [2]M.N.M. Yasin

[1]British Malaysian Institute, Universiti Kuala Lumpur, Bt. 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia
[2]School of Microelectronic Engineering, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia

Abstract
Compact and highly efficient antennas exhibiting wide operational circularly polarized (CP) bandwidth capability are becoming increasingly popular for current research activity in the wireless communication technology. Dielectric resonator antenna (DRA) remains one of the most attractive candidates for such requirements. In this study, a multilayer DRA configuration using a single point feeding mechanism is proposed for further enhancement of the CP bandwidth. The cylindrical multilayer DRA that is excited using a conformal square spiral conducting metal strip has been studied theoretically and experimentally. Utilizing such antenna configuration has yielded a measured CP and return loss bandwidths of ~5.6 and 15%, respectively. The results represent an additional CP bandwidth increment of ~66% compared to the single layer cylindrical DRA configuration using the same excitation method. Additionally, a good agreement has been attained between the measured and computed results.

Key words: Dielectric resonator antenna, CP, bandwidth

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Corresponding Author: M.I. Sulaiman, British Malaysian Institute, Universiti Kuala Lumpur, Bt. 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In the last two decades of the previous millennium, DRA has emerged as a new and popular alternative to conventional antennas such as monopoles and microstrip patches. This trend can mainly be attributed to its compact size and wide operational bandwidth capability. The size of the antenna can be minimized simply by increasing the dielectric constant, ε_r of the material[1] since the dimensions of the DRA are proportional to:

$$\lambda_0/\sqrt{\varepsilon_{r^2}}$$

where, λ_0 is the free-space wavelength. Furthermore, DRA offers wider impedance bandwidth compared to other antenna types such as a microstrip antenna. This is mainly due to the fact that the waves radiate through the entire DRA surface, except for the ground, in contrast with the limited radiation of waves through two narrow edges of the patch in a microstrip antenna[2].

Since the introduction of a dielectric resonator as an antenna (instead of energy storage devices) in early 1980s, researchers have investigated numerous DRA feeding mechanisms and applied various analytical or numerical techniques to calculate the antenna's resonance frequency and operating bandwidth. Much of these works have been summarized in a review paper by Mongia and Bhartia[3].

Initially, investigation of DRAs as wireless communication devices was mainly concentrated on those producing linearly polarized (LP) waves since they are easier to design than CP DRAs. However, with the rapid advancement of satellite communications technology, more attention has been paid to the latter. The CP system is favored over its LP counterpart owing to its insensitivity to the transmitter and receiver orientation. The probability of linking the transmitted CP wave is higher since it radiates in the horizontal, vertical as well as any plane in between. In contrast, LP wave is capable of radiating in one plane only, which is particularly problematic in space-borne applications.

A novel DRA excitation method with the ability to generate a wide CP bandwidth has been proposed by Sulaiman and Khamas[4,5] in which a conformal square spiral 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 Li and Leung[6] using a similar size rectangular DRA. Subsequently, the square spiral excitation method has been applied onto a cylindrical DRA[7] in which a CP bandwidth of 4.2% has been obtained in comparison to the 2.2% CP bandwidth reported by Lee *et al.*[8].

The possibility of enhancing the CP bandwidth obtained by the square-spiral-fed cylindrical DRA is investigated next by employing a multi-dielectric layers. It should be noted that shortly after the measurements of this approach, few studies have been published on the same idea of enhancing the CP bandwidth using a layered DRA configuration. For instance, an increase of 100% in the 3 dB CP bandwidth has been reported by Lee and Lee[9] when a multilayer rectangular DRA fed by cross slot is used instead of single layer structure. Additionally, investigation done by Lu *et al.*[10] demonstrates that the CP bandwidth of the multilayer structure is approximately three times to that of a single layer DRA. In these cases, removing the central portion of the single layer DRA and filling the gap with material of lower permittivity decreases the effective dielectric constant of the overall structure, which causes a reduction the radiation Q factor of the DRA and thus increases the S11 and CP bandwidths.

MATERIALS AND METHODS

In this study, a smaller dielectric cylinder of different permittivity has been embedded within the cylindrical DRA of the same parameters to that used by Sulaiman and Khamas[7]. Figure 1 shows the configuration of the two layer DRA, where a machinable-glass ceramic known as Macor with a relative permittivity of 5.67 has been chosen as the inner layer owing to lower cost and excellent insulation properties, as well as ease of fabrication since it is machinable to any desired shape with standard metal working tools.

The parameters of the outer layer and conformal spiral remain similar to those used by Sulaiman and Khamas[7]. The height, h_2 and radius, a_2 of this inner layer have been varied in proportion to the dimensions of the outer layer. This parameter, P has been used to speed up the optimization process. The CP bandwidth and the corresponding minimum CP frequency point are shown in Fig. 2 as functions of the inner layer aspect ratio. From these results, it can be noticed that as P increases, the resonance frequency for the $TE_{01\delta}$ mode also increases. This can be attributed to the decrease in the effective permittivity of the DRA. Consequently, this leads to a CP bandwidth increment when the dimensions of inner layer increases up to p = 0.9. It should be noted that when p = 1, a single dielectric is achieved with a permittivity of 5.67, which changes the electrical dimensions of the spiral and produces a narrower CP bandwidth. Therefore, the optimum dimensions of the inner dielectric layer have been determined as h_2 = 9.49 and a_2 = 6.31 mm.

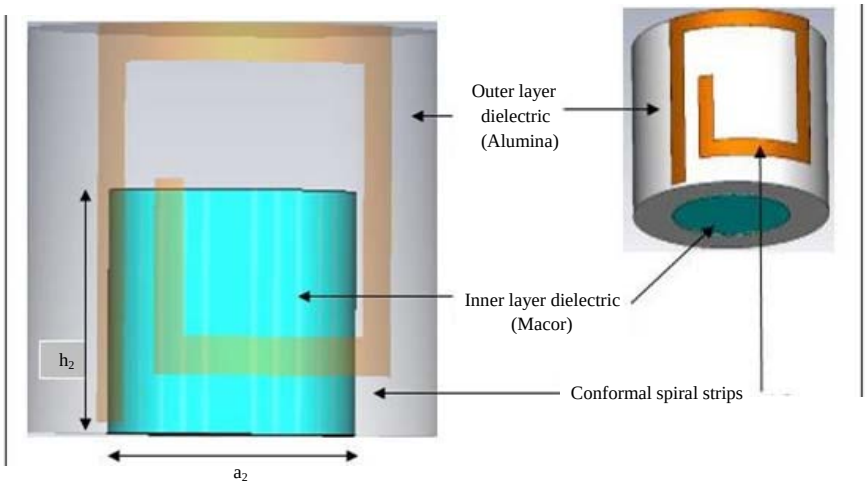

Fig. 1: Configuration of a multilayer cylindrical DRA (Inset: Side-bottom view)

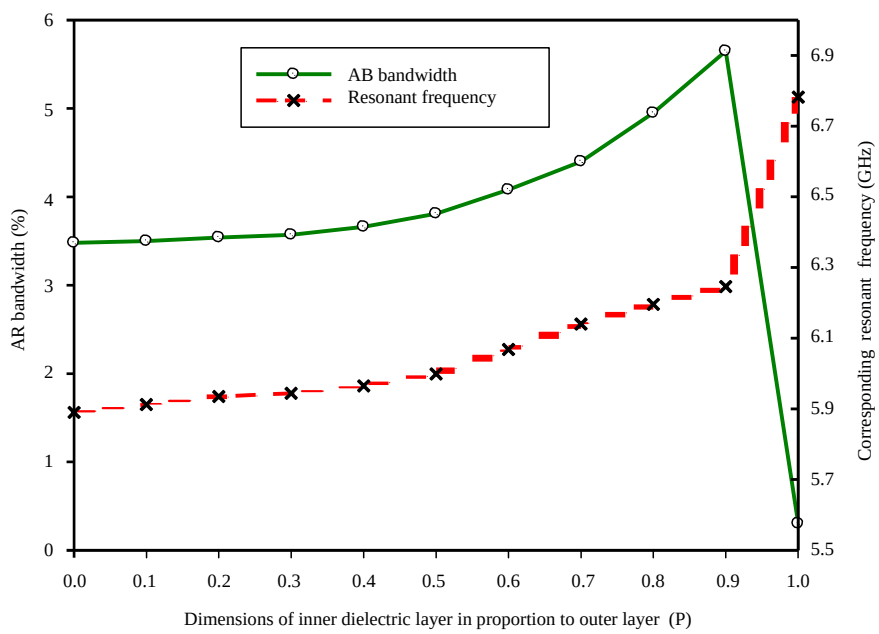

Fig. 2: CP bandwidth and corresponding resonance frequency as a function of the inner layer size

RESULTS AND DISCUSSION

A prototype of the multilayer cylindrical DRA is illustrated in Fig. 3. The parameters of the outer layer dielectric and conformal spiral are similar to those used previously[7] and the inner layer has a parameter of p = 0.9.

The input impedance has been measured and compared to the MoM computation with close agreement as illustrated in Fig. 4. Additionally, the simulated and measured return losses (S11) agree well with each other as shown in Fig. 5, in which it is evident that S11 ≤-10 dB bandwidths of 15.2 and 14.4% have been achieved in computations and measurements, respectively. The minimum S11 has been computed at 6.25 GHz compared to 6.33 GHz in the measurements, that is, a marginal difference of 1.41% between the MoM model and the experiment. In order to compare the resonance frequency obtained by these results with those predicted by equation proposed by De Smedt[11].

$$k_0 a = \frac{2.327}{\sqrt{\varepsilon_r + 1}}\left[1.0 + 0.2123\left(\frac{a}{h}\right) - \left(\frac{a}{h}\right)^2\right] \quad (1)$$

Extra calculation needs to be implemented by taking into account the presence of inner dielectric layer. From

Fig. 3: A multilayer cylindrical DRA excited by a conformal spiral strip

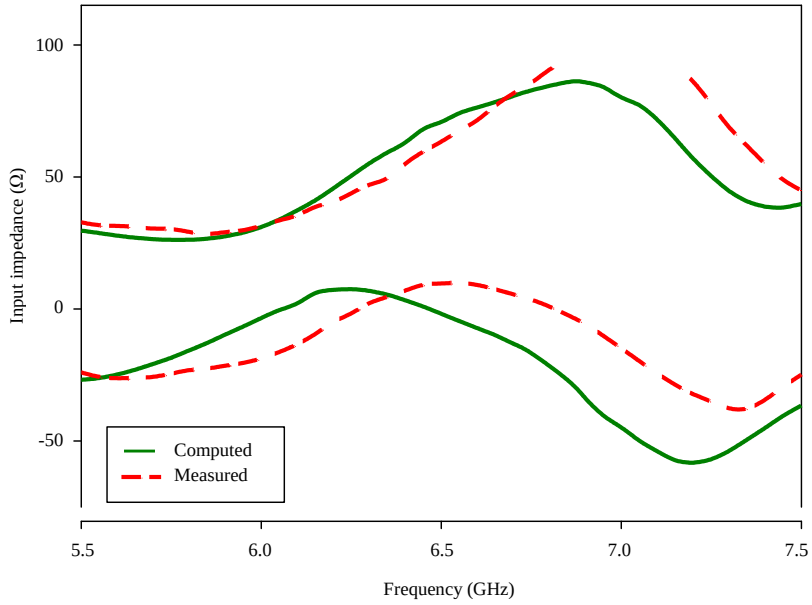

Fig. 4: Input impedance of the multilayer cylindrical DRA

Killips *et al.*[12], when another dielectric layer of parameters ε_{r2}, a_2 and h_2 is added, the effective permittivity of the overall DRA structure becomes:

$$\varepsilon_{eff} = (m)\ \varepsilon_{r2}+(1-m)\ \varepsilon_r \qquad (2)$$

where, m is the volume fraction of the inner layer dielectric which is given by:

$$m = \frac{V_2}{V_{overall}} \qquad (3)$$

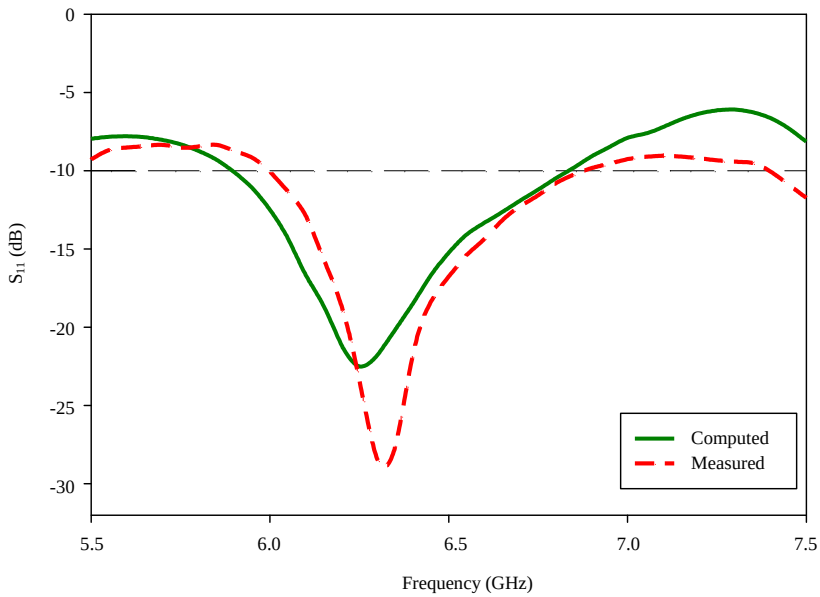

Fig. 5: Return losses of the multilayer cylindrical DRA

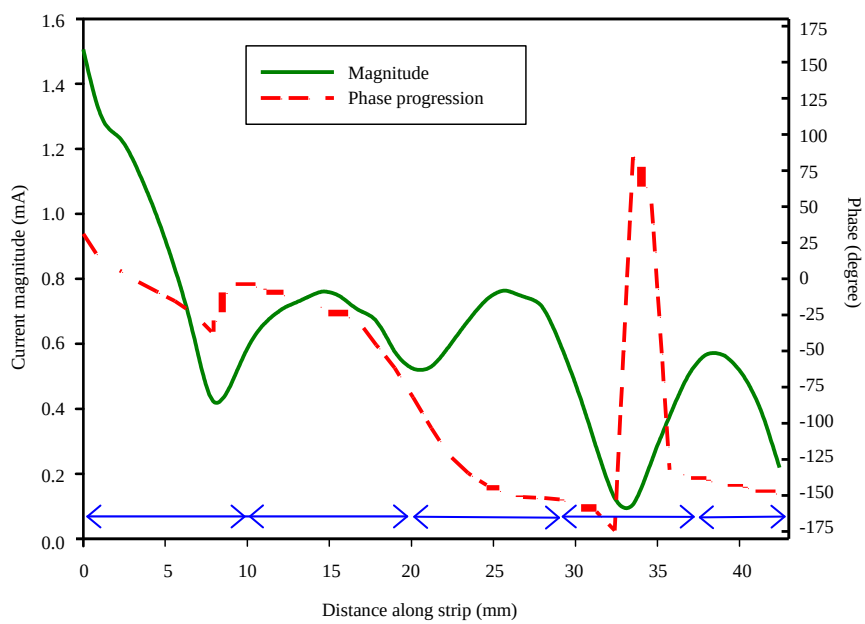

Fig. 6: Current distribution along the spiral strip at 6.25 GHz

Since the cylindrical volume is computed using:

$$V = \pi a^2 h \quad (4)$$

Therefore the effective permittivity of the overall DRA structure can be determined as $\varepsilon_{eff} = 6.62$. Using this value, the predicted resonance frequency for the broadside $TE_{01\delta}$ mode has been calculated using Eq. 1 as 6.55 GHz, which is reasonably close to those obtained by the theory and experiment.

A travelling-wave current distribution has been obtained along the feeding spiral as illustrated in Fig. 6, where it can be observed that smoothly decaying current amplitude has been achieved in conjunction with an approximately linear phase progression. The spiral strip has a perimeter of $1.72\lambda_g$ at 6.25 GHz, which supports the first-mode of radiation.

The axial ratio has been computed and measured at the bore-sight direction as shown in Fig. 7, where it can be seen that the minimum computed CP is 0.67 dB at 6.25 GHz, compared to the corresponding measured value of 1.71 dB

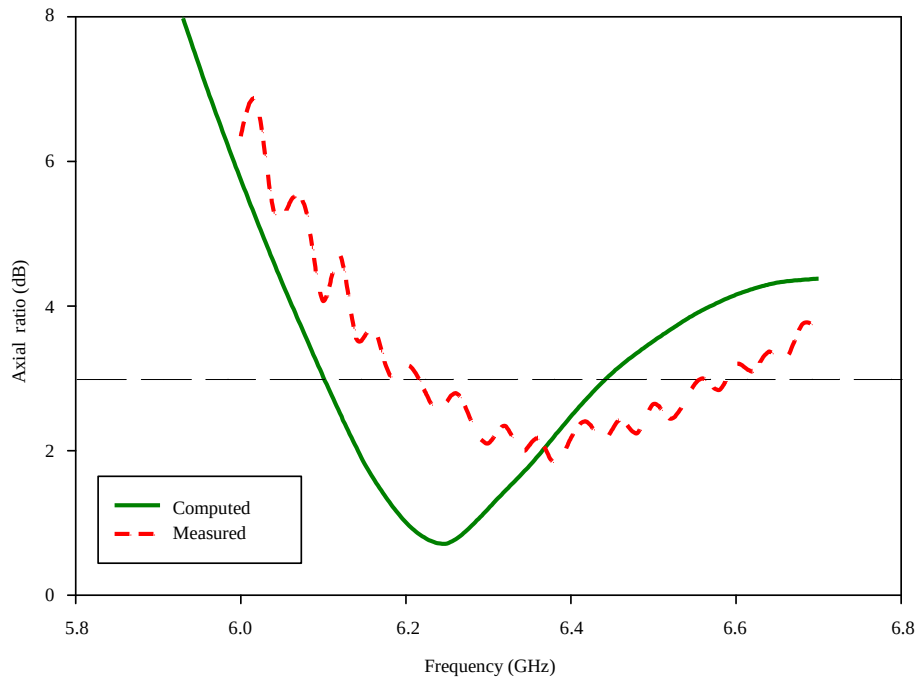

Fig. 7: Axial ratio of the multilayer cylindrical DRA fed by a spiral metal

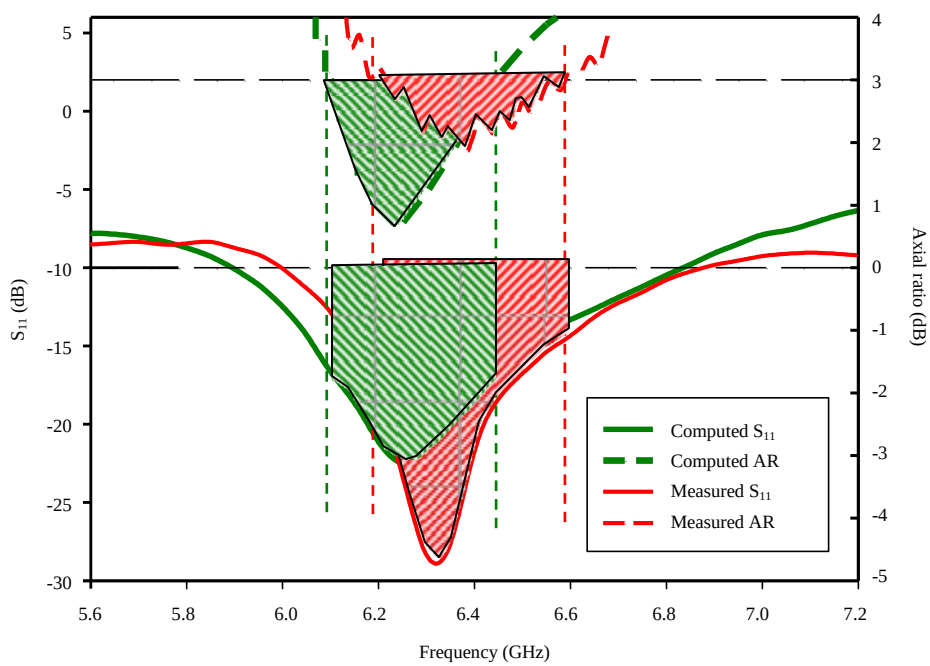

Fig. 8: Region of overlapping bandwidths for return loss and CP

at 6.36 GHz. The measured and computed minimum CP frequency points are close to each other with a slight difference of 1.5%. From these results it can be observed that the achieved 3 dB CP bandwidths are 5.63 and 5.9% in the analysis and measurements, respectively. This represents an increase of over 66% in both computations and measurements for the CP bandwidth compared with those achieved using a single layer cylindrical DRA[7]. It should also be noted that this CP bandwidth is substantially wider than what has been reported in the literature for cylindrical DRAs. Furthermore, with reference to Fig. 8, it can be seen that a sufficient impedance matching bandwidth has been obtained

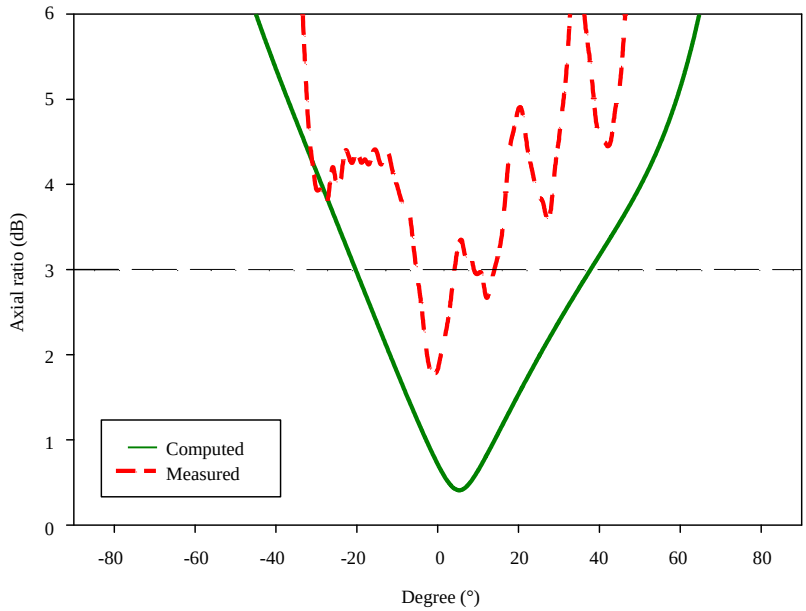

Fig. 9: Axial ratio beam-width of the multilayer cylindrical DRA at $\phi = 0°$

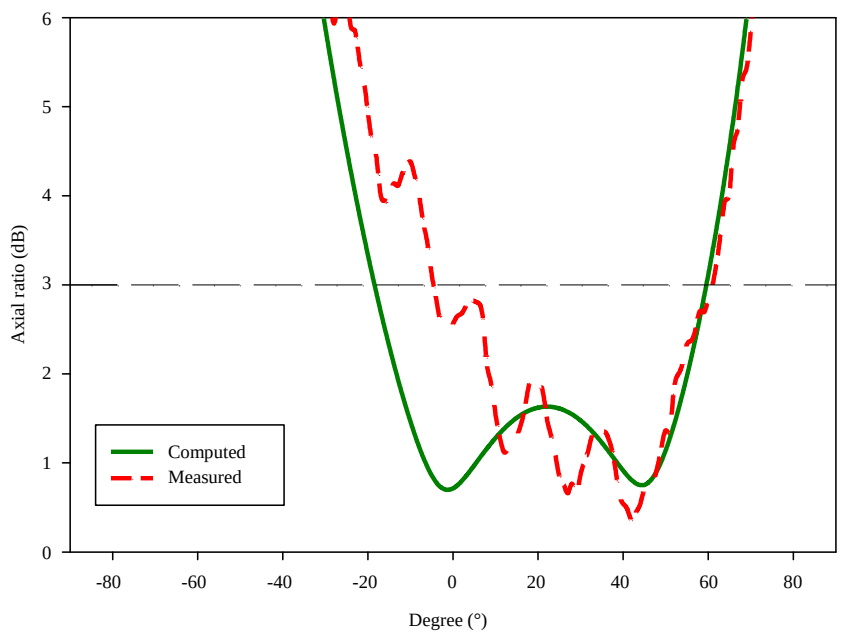

Fig. 10: Axial ratio beam-width of the multilayer cylindrical DRA at $\phi = 90°$

throughout the achieved circular polarization bandwidth. Figure 9 and 10 present the axial ratio beam-width. With reference to the computational result, the DRA offers circular polarization over useful computed beam-widths of 58 and 78°C in the $\phi = 0°$ and $\phi = 90°$ planes, respectively.

A comparison between the calculated and measured radiation patterns at the optimum CP frequency is shown in Fig. 11 with reasonable agreement. It is evident from these results that this is a right-hand CP DRA, in which the RHCP field is stronger than the LHCP field by more than 18 dB in the bore-sight direction. Again, as in the case with the previous design, a left-hand CP DRA can be attained by changing the square spiral arm winding from clockwise to counter clockwise direction. Finally, the antenna gain of the multilayer cylindrical DRA has been measured at bore-sight. The results are shown in Fig. 12, where it can be seen that the antenna offers a satisfactory gain of over 3 dBi across the whole frequency range of the achieved circular polarization. The gain is lower

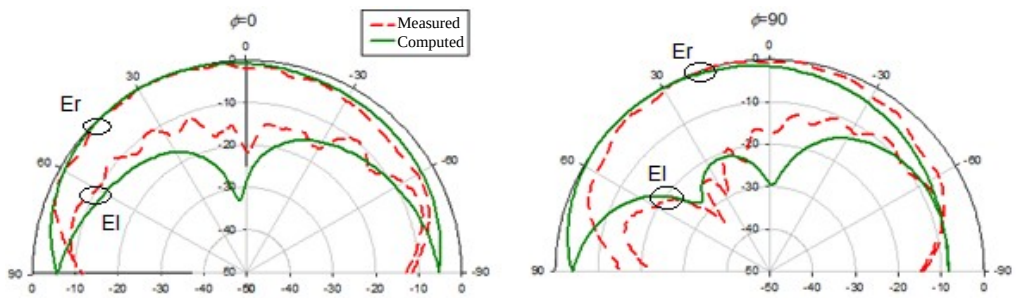

Fig. 11: Radiation patterns of the multilayer cylindrical DRA at the optimum AR frequency point

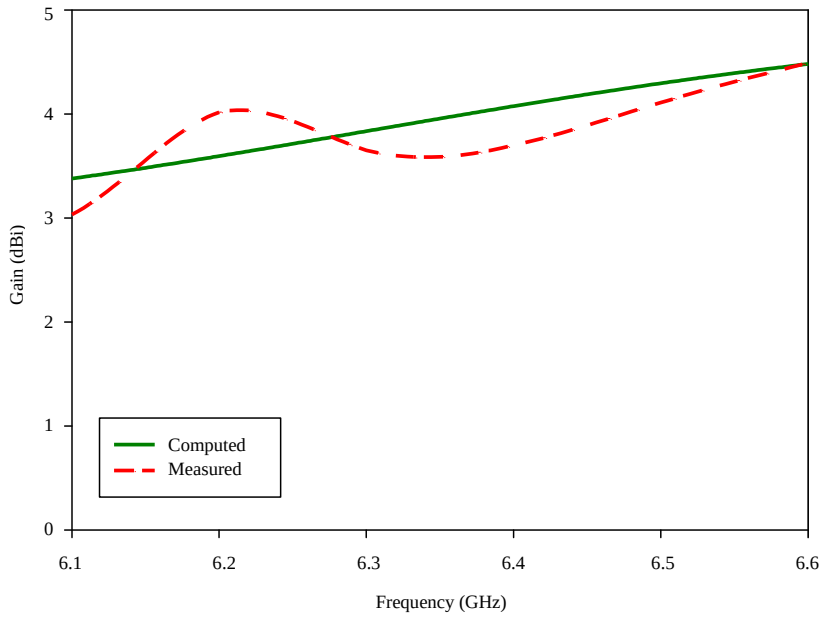

Fig. 12: Gain of the multilayer cylindrical DRA fed by conformal spiral strips

than that achieved by the single layer design due to the slight shift of approximately 5° in the main beam from the bore-sight direction at the CP frequency band as can be seen in Fig. 11.

CONCLUSION

A relatively new approach has been introduced for further CP bandwidth enhancement, which is based on employing a multilayer DRA. The results represent an additional CP bandwidth increment of ~66% on top of the enhancement achieved using the spiral excitation. Therefore, respective CP and S11 bandwidths of ~5.6 and 15% have been achieved by using the multilayer cylindrical DRA. Throughout the research, a good agreement has been obtained between experimental and theoretical results.

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