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# Higher Order Mode Circularly Polarized Two-Layer Rectangular Dielectric Resonator Antenna

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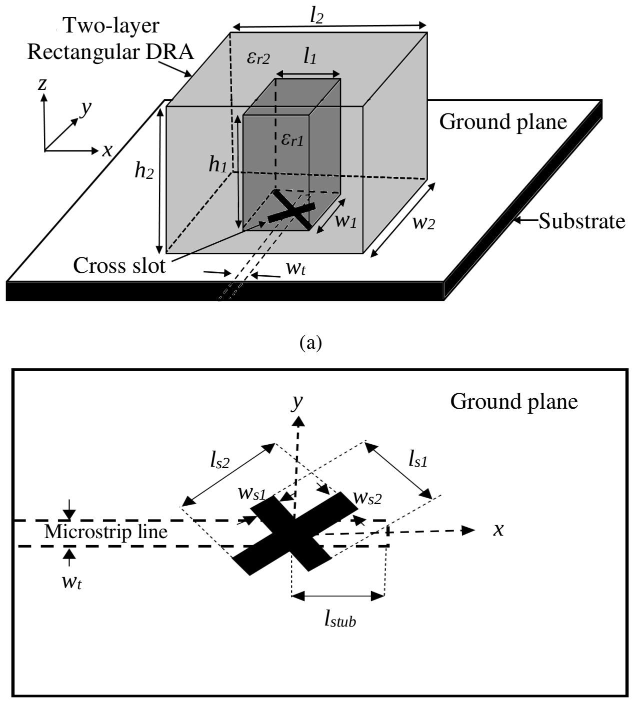
***Abstract*— A two-layer higher order mode circularly polarized (CP) rectangular dielectric resonator antenna (RDRA) is proposed at a frequency range of 10 to 13GHz using a single-feed. The configuration incorporates the DRA and a dielectric coat layer with respective dielectric constants of 10 and 3.5. Utilizing the outer layer offers a number of advantages such as wider impedance and CP bandwidths of ~21%, and 9.5%, respectively, as well as a high gain of ~11dBic. Close agreement has been achieved between experimental and simulated results.**

***Index Terms*—Dielectric resonator antenna, circular polarization, high order mode, 3D printing.**

## I. INTRODUCTION

The last few decades have witnessed a considerable growth in wireless communication systems, with a particular attention being given to high frequency ranges such as the X- and mm-wave bands. Owing to their attractive radiation characteristics such as high radiation efficiencies and wider bandwidths, DRAs are more favorable for high frequency applications [1-5]. In addition, DRA excitation at higher frequencies can be achieved by employing a slot aperture coupling that has been demonstrated experimentally for the first time in [6]. In order to maintain practical antenna dimensions and increase the gain, higher order mode DRAs need to be considered at higher frequencies. The earlier studies on higher order mode DRAs have been mainly focused on linearly polarized radiation [7-9]. On the other hand, circularly polarized DRAs' radiation is less influenced by atmosphere conditions and insensitive to the transmitter and receiver orientations. As a result, singly-fed CP DRAs that operate at lower order modes have been reported in numerous studies with novel approaches such as employing a rotated slot-fed RDRA [10], or proposing a properly engineered DRA geometry with a wide axial ratio (AR) bandwidth of ~9% [11]. Therefore, higher order modes CP DRAs have received increased interest recently. For example, a higher order mode dual-band CP chamfered RDRA has been reported using a single feed point [12]. The dual bands have been achieved by exciting the $TE_{111}$ and $TE_{113}$ resonance modes with respective impedance and axial ratio bandwidths of 11.4% and 1.4% as well as a gain of ~7dBic for the $TE_{113}$ mode. In addition, a quadrature-fed CP RDRA has been proposed in [13] by exciting the $TE_{111}$ and $TE_{113}$ resonance modes with a maximum gain of 6dBic. In a recent study, a cross slot-fed dual band CP DRA that operates in the $TE_{111}$ and $TE_{113}$ higher order mode has been presented with respective impedance and AR bandwidths of 8.4 % and 2.2% and a gain of ~4.3dBic for the $TE_{113}$ mode [14]. Therefore, $TE_{113}$ represents the highest mode order that has been considered for a CP DRA. It is well known that increasing the mode order results in a considerably higher gain [7, 9], which represents a key requirement at higher frequency applications. However, higher order modes are usually associated with a narrower bandwidth, which can be attributed to the fact that the DRA effective dielectric constant increases with the mode order [8]. A well-known technique to improve the bandwidth is the incorporation of a dielectric coat in the configuration, which has been demonstrated for linearly polarised cylindrical and hemispherical lower order mode DRAs [15-18]. However, the impact of the dielectric coat on the performance of higher order modes and/or circularly polarized DRAs has not been considered earlier. In this letter, a CP DRA that operates in the $TE_{11,11}$ higher order mode is proposed, where the aforementioned narrow bandwidth issue has been addressed by coating the DRA with a dielectric layer. The presented results demonstrate that combining




(b)

Fig. 1. Geometry of the configuration (a) Layered rectangular DRA (b) Top view of the feed network.

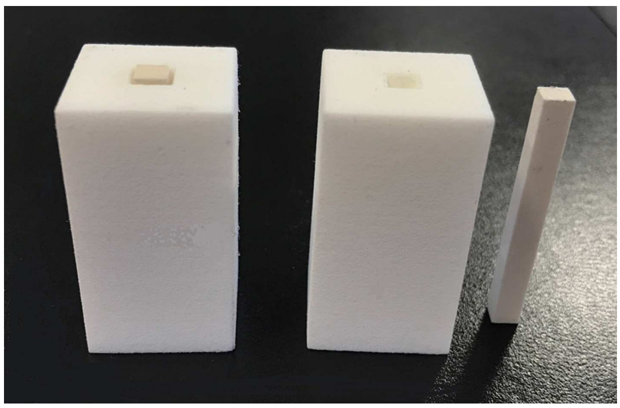


Fig. 2. The outer dielectric coat and the rectangular DRA before and after assembly.

DRA that operates in a higher-order mode, outer dielectric layer and cross slot excitation presents a novel approach for generating wider impedance and CP bandwidths of ~21%, and 9.5%, respectively, together with an enhanced gain of ~11dBic. The simulations have been conducted using CST microwave studio [19]. A prototype of the layered higher order mode DRA has been built and measured with close agreement between experimental and simulated results.

## I. ANTENNA CONFIGURATION

Figure 1 illustrates the proposed layered RDRA configuration and feed network, where a cross slot has been employed to excite the antenna [20, 21]. The DRA has been fabricated using Alumina with a dielectric constant of 10 and a loss tangent of tanδ<0.002. Two configurations have been considered that utilize the same DRA element without, and with, a dielectric coat. The DRA dimensions have been chosen as $l_1$=$w_1$=4 mm and $h_1$=40 mm. Further, the outer layer has been fabricated using a 3D printed Polyimide layer with a dielectric constant of 3.5 and dimensions of $l_2$=$w_2$=20 mm and $h_2$=41 mm. A central rectangular air-gap has been created in the Polyimide dielectric coat to accommodate the DRA as illustrated in Figure 2. Once the coat is fabricated, the DRA has been inserted in the central air-gap and a dielectric powder has been utilized to fill any gaps between the DRA and the coat.

A 50Ω microstrip-feed line has been etched on a Rogers RO4535 substrate with a dielectric constant of 3.48 and a loss tangent of 0.0037. The respective length, width, and thickness of the substrate are 150mm, 100mm, and 0.8mm. Furthermore, in order to excite the CP RDRA two slots have been itched on the copper ground plane. Each slot is tilted by an angle of $45^0$ with respect to the microstrip line that has been printed on the backside of the substrate. Additionally, unequal slot lengths have been chosen in order to excite two near-degenerate orthogonal modes of equal amplitude and $90^0$ phase difference that are needed to generate the CP radiation [20]. The coupling cross slot element lengths have the same width of $w_{s1}$ = $w_{s2}$=1mm and unequal lengths of $l_{s1}$=4.4mm and $l_{s2}$=5mm. In addition, an open stub length of $l_{stub}$=2.5mm has been utilized for optimum matching. Furthermore, a double sided adhesive copper tape has been employed to eliminate the potential air-gaps between the DRA and ground plane [22] . The reflection coefficient has been measured using an E5071C vector network analyzer, whereas the radiation patterns and gain have been measured using an NSI system.

## III. RESULTS

### A. Single Layer Higher Order Mode CP RDRA

A rectangular DRA prototype has been fabricated with dimensions that supports the $TE_{117}$ mode at 11.1GHz. The simulated and measured reflection coefficients are presented in Figure 3, with respective impedance bandwidths of 1.9% and 1.78%. The measured resonance frequency is 11.2GHz, which agrees well with the simulated counterpart. The broadside gain and AR are depicted in Figure 4 with measured and simulated gains of ~7.5dBic at 11.2GHz. The simulated CP operation bandwidth extends from 11.1 to 11.37GHz, which corresponds to a 3dB AR bandwidth of 2.4% that agrees well with a measured AR bandwidth of 2.3% over a frequency range of 11.1 to 11.4GHz.

### B. Two-layer Higher Order Mode CP RDRA

Incorporating a dielectric coating layer, with a relative permittivity of $\varepsilon_{r2}$, creates a transition region between the DRA and free space,

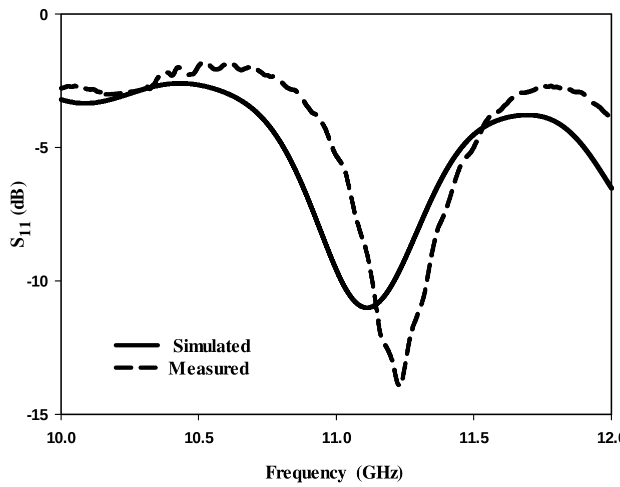



Fig. 3. Reflection coefficient of a single layer RDRA operating in the $TE_{117}$ mode

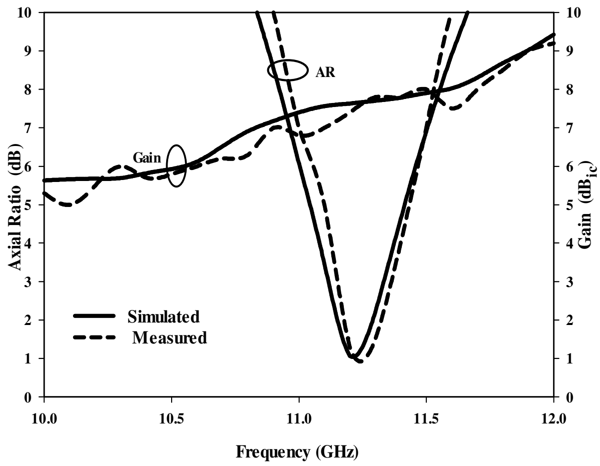
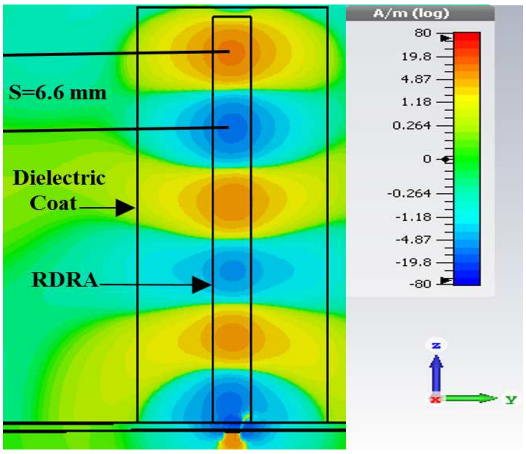


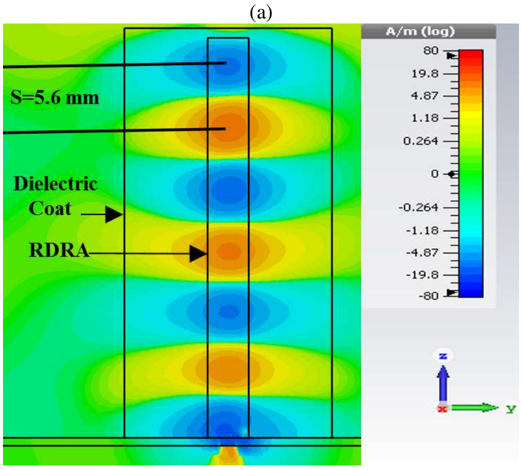

Fig. 4. Gain and the axial ratio of a single layer higher order mode DRA.

which improves the impedance bandwidth considerably [2]. The DRA inner magnetic field distribution can be represented as an array of short magnetic dipoles, in which a maximum gain can be accomplished when the separation distance between the adjacent magnetic dipoles is ~0.4$\lambda_o$, where $\lambda_o$ is the free space wavelength [7]. In addition, when the DRA is surrounded by another dielectric medium, the maximum gain can be achieved when the adjacent magnetic dipoles are separated by a distance of ~0.4$\lambda_g$, where $\lambda_g = \lambda_0 / \sqrt{\varepsilon_{r2}}$ , which results in a lower profile and a more practical configuration. Therefore, a prototype of a two-layer DRA has been fabricated and measured in order to demonstrate the potential of such antenna.

The magnetic field distribution inside the DRA is illustrated in Figure 5, where it can be observed that the separation distance between adjacent short magnetic dipoles, *S*, for the $TE_{11,11}$ mode is 6.6mm at 11.3GHz, which exceeds 0.44λg. Therefore, a higher gain of 11.1dBic has been achieved at this frequency point. Similarly, it can be noted that for the $TE_{11,13}$ mode, the separation distance is 5.6mm, which corresponds to less than ~0.4λg at 12GHz, hence a lower broadside gain of ~7.6dBic has been achieved at this frequency. Figure 6 presents the reflection coefficient of the layered DRA with a close agreement between simulated and measured bandwidths of ~21% and ~18.5%, respectively. This represents a significant bandwidth enhancement compared to that of a single layer DRA. In addition, it is evident from these results that the layered DRA supports a multi-mode operation where the $TE_{11,11}$ and $TE_{11,13}$ modes have been excited at 11.3 and 12GHz, respectively, which also contributes to the bandwidth enhancement.




(a)




(b)

Fig. 5 Magnetic field distribution inside the layered DRA that operates in the (a) $TE_{11,11}$ at 11.3GHz and (b) $TE_{11,13}$ at 12GHz resonance modes.

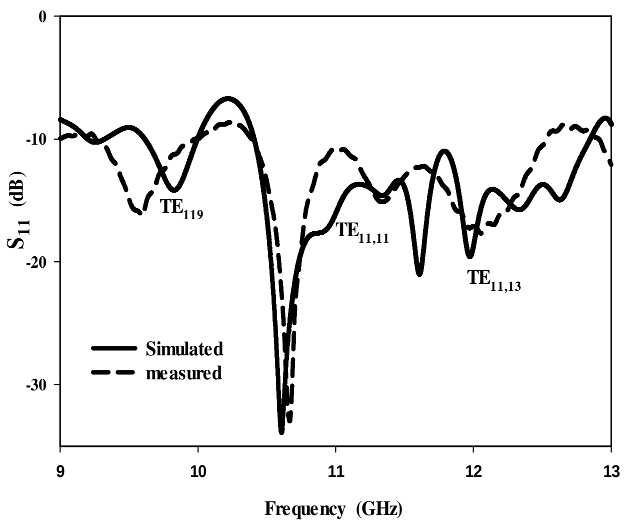
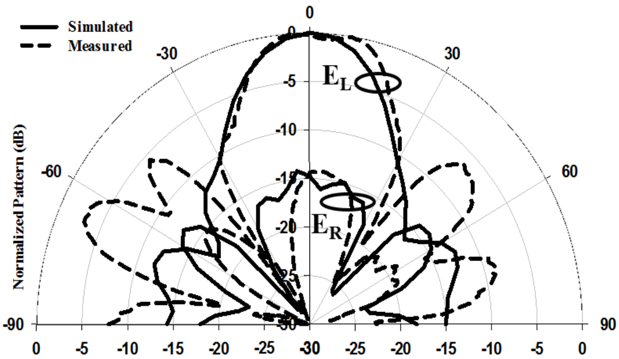
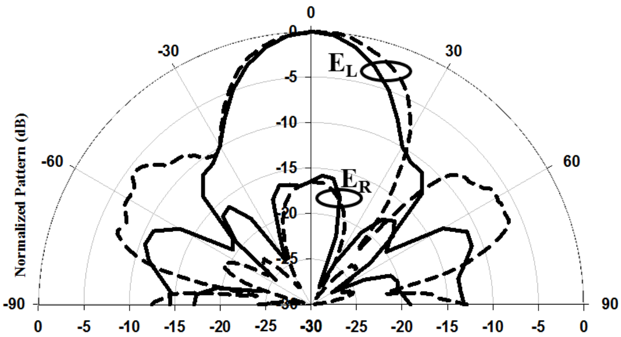



Fig. 6 Reflection coefficient of a layered RDRA operating in multi-higher order modes.




(a)




(b)

Fig. 7 Radiation patterns of a layered DRA excited in the $TE_{11,11}$ mode at 11.3GHz a) $\phi$=0 b) $\phi$=90.

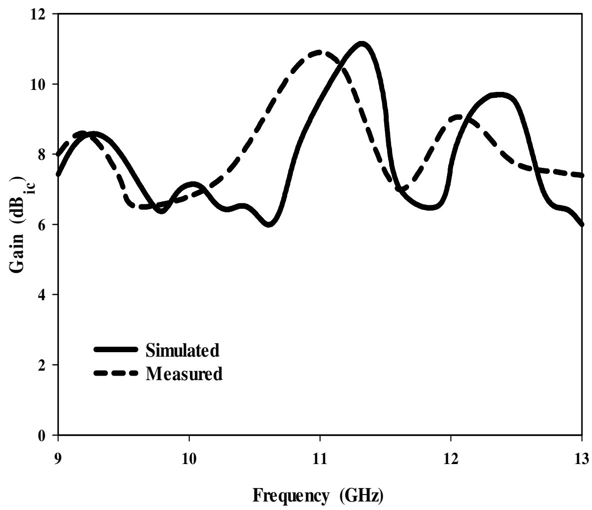



Fig. 8 Gain for a higher order mode layered RDRA.

Figure 7 illustrates a reasonable agreement between the measured and simulated radiation patterns of the layered DRA at 11.3GHz, where it can be noticed that a left hand CP radiation has been achieved since $E_L$ is greater than $E_R$ by 15dB. The measured and simulated gains are presented in Figure 8 with close agreement. However, a slight drop in the measured gain to ~10.6dBic can be observed compared to a maximum simulated gain of 11.1dBic, which may be attributed to experimental errors as well as the existence of un-eliminated air-gaps spots between the DRA and the dielectric coat. In addition, the permittivity of the dielectric coat could have been slightly altered during the 3D printing process,

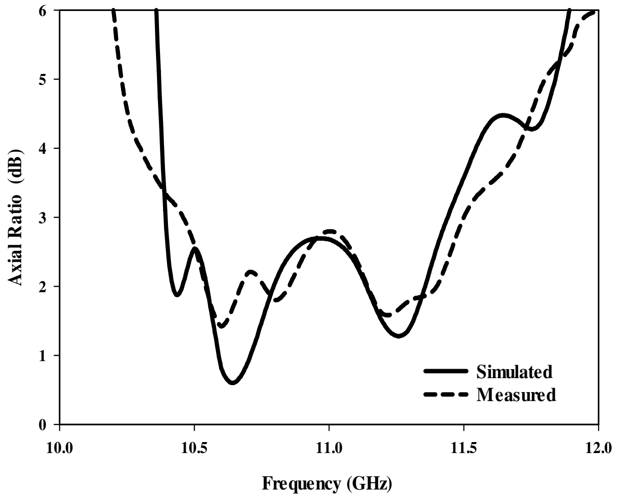



Fig. 9 Axial ratio of a higher order mode layered RDRA.

which may contributes to this discrepancy. The simulated and measured axial ratio of the layered DRA are depicted in Figure 9, where it can be observed that a CP radiation has been achieved over a frequency range of 10.4 to 11.44GHz, which corresponds to a 3dB AR bandwidth of 9.5% compared to a measured counterpart of 9.1%. It is worth mentioning that the length of the slots have been altered slightly to $l_{s1}$=4 mm and $l_{s2}$=5.6 mm in order to achieve a wider CP bandwidth.

## V. CONCLUSIONS

A singly fed higher order mode CP RDRA have been considered theoretically and experimentally, where a dielectric coat has been incorporated in the configuration. As expected, the inclusion of a dielectric coat increases the impedance bandwidth considerably. This is combined with a significant enhancement in the far field characteristics such as AR bandwidth and gain. For example, a two-layer RDRA operating in the $TE_{11,11}$ mode offers respective impedance and 3dB AR bandwidths of ~21% and 9.5%. Additionally, the $TE_{11,11}$ mode provided a higher gain of 11.1dBic compared to 7.5dBic for the single layer DRA operating in the $TE_{117}$ mode, which also offers narrower impedance and AR bandwidths. Furthermore, the presence of the second dielectric layer improves the mechanical robustness of the configuration since a long and thin ceramic DRA can be fragile. In addition, a close agreement has been achieved between the measured and simulated results. Although the DRA has been designed at the X frequency band, the demonstrated high gain and wide bandwidths represent appealing radiation characteristics for applications in the mm-wave and terahertz higher frequency bands.

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