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CIRCULAR POLARIZED DIELECTRIC RESONATOR ANTENNAS USING A SINGLE PROBE FEED

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Abstract—In this paper six novel Dielectric Resonator Antennas (DRAs) providing Circular Polarization (CP) using single probe feeds are proposed. By splitting the fundamental mode of conventional rectangular or cylindrical DRA into two near-degenerate orthogonal resonant modes, CP is obtained. The proposed antennas are numerically investigated using Finite Element Method (FEM). Parametric study on all antennas is carried out. The results show that the impedance bandwidth ($S_{11} < -10\,\mathrm{dB}$) of all reported antennas is in the range of 112–140 MHz. Also, the Axial Ratio bandwidth ($AR < 3\,\mathrm{dB}$) range of presented antennas is 28–33 MHz. The investigation shows radiation patterns of all proposed antennas are remaining broadside throughout the bandwidth.

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1. INTRODUCTION

Dielectric Resonators (DRs) are widely used in microwave circuits including oscillators, filters and cavity resonators [1, 2]. Also, Dielectric Resonator Antennas (DRAs) are attractive as electromagnetic wave radiators due to high radiation efficiency, ease of excitation, simple geometry, compactness and ability to obtain different radiation characteristics using different modes of operation [3–8]. These advantages of DRs make them as practical elements for antenna applications [2] at microwave frequencies.

Early development of mobile and wireless communication systems such as Bluetooth and Wireless Local Area Network (WLAN) working at 2.4 GHz needs broadband antennas. Therefore, different approaches have been proposed to enhance the bandwidth [9–11]. Moreover, the circularly polarized antenna is insensitive to transmitter and receiver orientation, offers less sensitivity to propagation effects and is suitable for satellite communications [8].

Antennas providing CP radiated waves need additional circuitry such as 3 dB quadrature phase couplers or 90° transmission line phase shifters. Cylindrical ring DRA fed by two probes has been reported in literature, where two probes excite a resonator by two equal amplitude phase-quadrature signals using an external 3 dB quadrature coupler [12]. A circular polarized cylindrical DRA excited using a simple microstrip feed line has been reported [13]. In [13] a microstrip line has been designed in order to excite two orthogonal $HE_{11\delta}$ modes. A circular polarized cylindrical DRA excited by dual conformal strips offering Axial Ratio (AR) bandwidth of 20% has been investigated [14]. The DRA which has been presented by [14] need an external feeding system in order to produce the quadrature signals for the dual strips. A simple design for a cylindrical DRA to achieve a dual band CP by a single microstrip line also has been proposed [15]. By choosing adequate shorted section of an annular slot, circular polarization operation of the slot-coupled DRA has been implemented [15]. A rectangular DRA producing CP using a single slot feed and a probe has also been investigated [16, 17]. A circular sector DRA providing CP using a single probe feed has been reported [18]. A design method of circular polarization DRA consisting of a cubical dielectric and an external feeding probe has been reported [19].

In this paper, six novel DRAs which provide CP with a single probe feed are proposed. A single feed circular polarized DRA has less complexity and is desirable in situations where it is difficult to place dual orthogonal feeds [20, 21]. The proposed antennas are divided into two categories. The first category refers to modified rectangular DRAs and the second category presents modified cylindrical DRAs. In the first and second categories the impedance bandwidth of the antennas is in the range of 112–130 MHz and 135–140 MHz respectively. Also, the AR bandwidths of the antennas are in the range of 28–33 MHz & 31–32 MHz in the first and second category respectively.

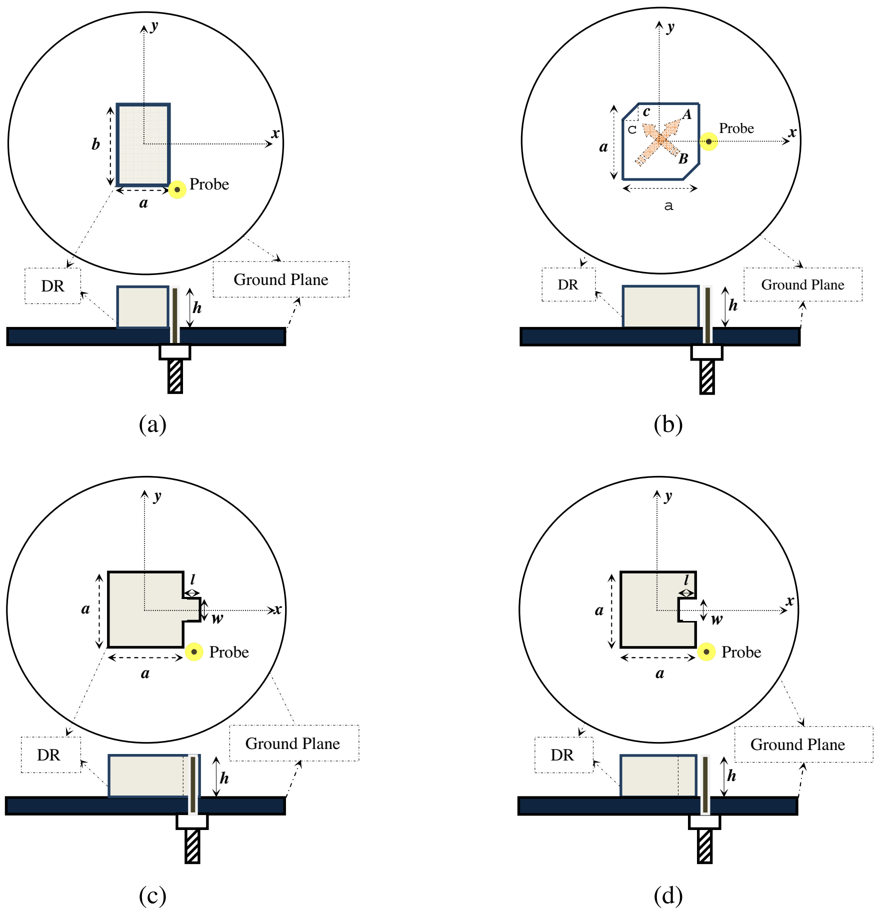


Figure 1. Top and side views of (a) the first, (b) second, (c) third and (d) forth proposed rectangular DRAs.

2. ANTENNAS CONFIGURATIONS

2.1. Rectangular Structures

Figure 1(a) shows the top and side views of the first proposed rectangular DRA. This structure which is called diagonal probe-fed rectangular DRA is excited at the corner of the resonator. Fig. 1(b) illustrates the top and side views of the second recommended structure. As shown in this figure, the resonator is chamfered at its two corners and is excited by a coaxial probe located at $x = a/2$ and $\varphi = 0°$. Also Fig. 1(c) shows the geometry of third proposed rectangular DRA. This antenna is obtained by modifying square DRA by adding a rectangular perturbation segment in one side of the DRA. In the forth structure which is indicated in Fig. 1(d), CP is achieved producing a rectangular notch in one side of DRA. In all these antennas the resonator has a relative dielectric constant of $\varepsilon_r = 38$ (Zirconium Tin Titanate) and is located on the top of a circular ground plane with a diameter $d = 100\,\text{mm}$ which is excited by a single coaxial probe of height h located close to DRA.

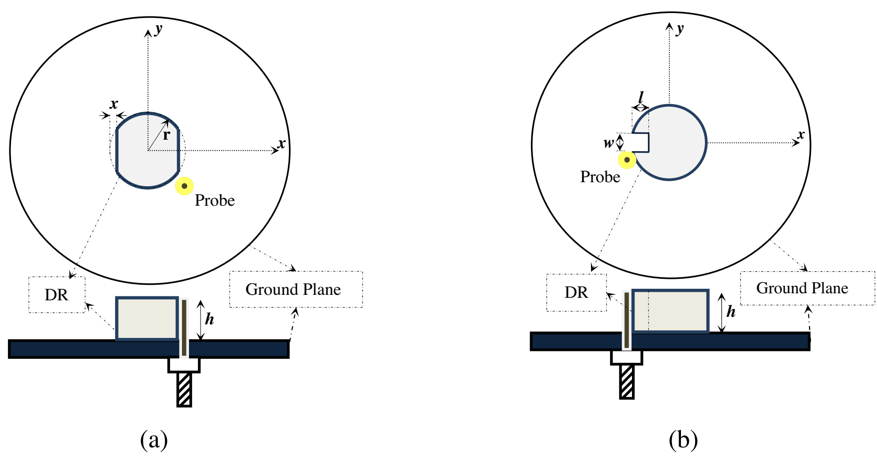
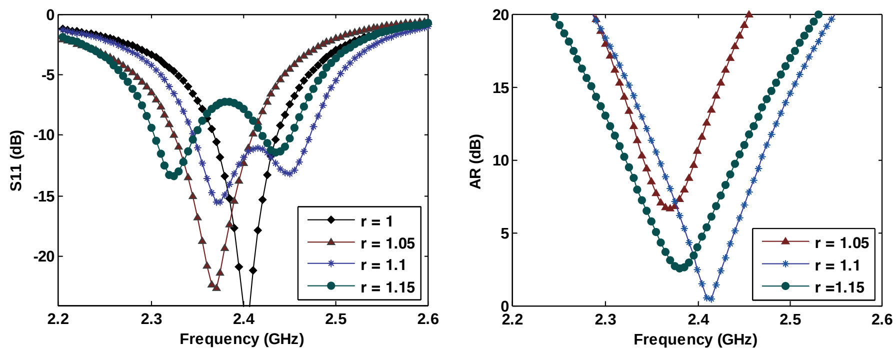


Figure 2. Top and side views of (a) the first and (b) second proposed cylindrical DRAs.

2.2. Cylindrical Structures

Figures 2(a) and (b) indicate the top and side views of proposed cylindrical DRAs. The first antenna is consists of the cylindrical DR which is chopped normal to its x axis diameter and the second antenna has a rectangular truncation in one side of the resonator. The resonator has a relative dielectric constant of $\varepsilon_r = 38$ (Zirconium Tin Titanate). The DR is placed on the top of circular ground plane with a radius of $d = 100$ mm and fed by single coaxial line. The probe feed is located closed to DR. The probe is excited through connector placed on the back of the ground plane.



(a) (b)

Figure 3. (a) Return loss and (b) axial ratio of the first rectangular antenna for different values of r parameter.

3. ANTENNA ANALYSIS AND PARAMETRIC STUDY

3.1. Rectangular Structures

In the first structure by placing the feed at the corner of DR and choosing the dimension ratio of $r = b/a = 1.1$, two close resonant frequencies are achieved. These two resonant frequencies are the results of splitting of the fundamental mode of rectangular DR (TE_{111}) into two near-degenerate orthogonal resonant modes (TE^x_{111} & TE^y_{111}). Figs. 3(a) and (b) show the return loss and AR of this antenna for different values of r respectively. Dimensions of the antenna are $a = 10$, $b = 15.25$ and $h = 11$ mm along x, y and z directions respectively. In case of $r = 1$ which is the conventional square DRA structure, a single resonate frequency is obtained and the impedance bandwidth is 68 MHz (2.8%). Maximum impedance bandwidth of 130 MHz (5.4%) is obtained at the center frequency of 2.41 GHz for dimension ratio of $r = 1.1$. This impedance bandwidth is almost two times greater than the bandwidth of conventional square DRA. Also, the AR bandwidth of the antenna is 32 MHz (1.3%) for $r = 1.1$.

The return loss and AR of the second antenna for different values of c parameter are indicated in Figs. 4(a) and (b) respectively.

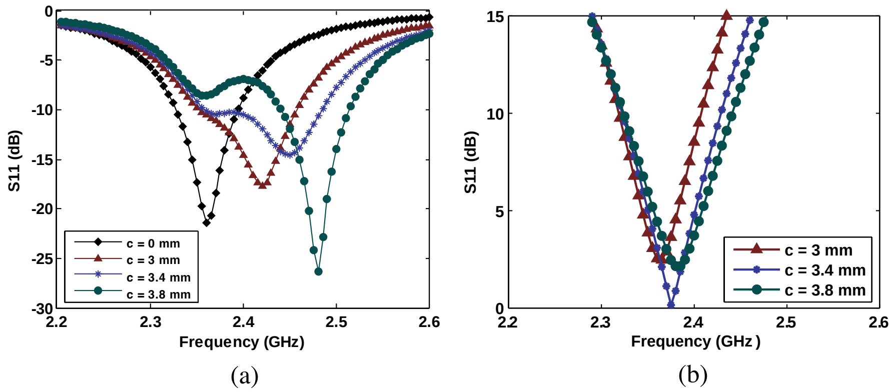
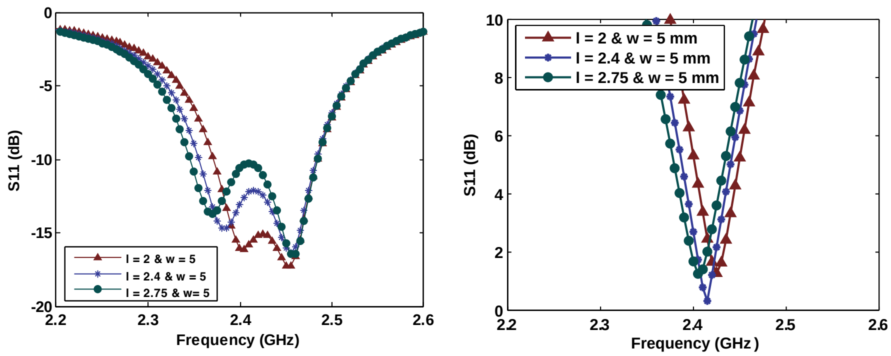


Figure 4. (a) Return loss and (b) axial ratio of the second rectangular antenna for different values of c parameter.

Dimensions of the antenna are $a = 10$ and $h = 11\,\text{mm}$. For comparing the results of the chamfered rectangular DRA with a conventional one, an investigation is done while $c = 0$. The results show that for $c = 0$ AR is at least 35 dB, which shows the conventional square DRA, is radiating a linearly polarized wave. While $c = 0$ the fundamental mode of square DR (TE_{111}) is excited and single resonant frequency is obtained. The impedance bandwidth of the ordinary square DRA is 65 MHz (2.7%) at the center frequency of 2.36 GHz.

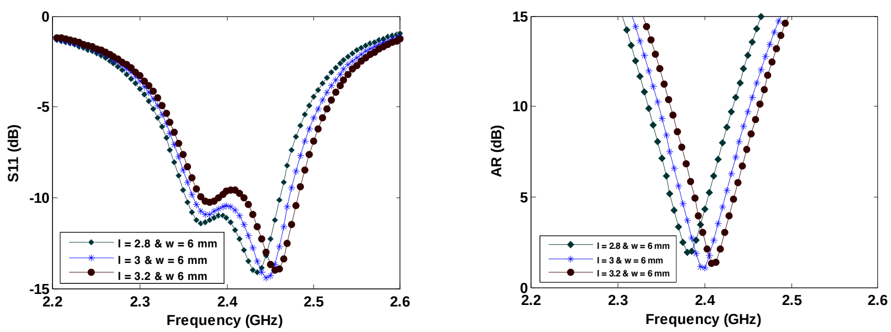
By cutting two corners of DR (increasing c parameter), TE_{111} mode splits into two near degenerate orthogonal modes. The first resonant frequency in return loss diagram is referred to the A arrow direction component of the TE_{111} mode (TE^{A}_{111}). By increasing the c parameter, the resonant frequency of TE^{A}_{111} mode is almost constant according to the constant effective length of the DR along the A arrow. Although, by increasing the c parameter the resonant frequency of the other component of TE_{111} mode (TE^{B}_{111}) is increased because of the effective length reduction along B arrow. The maximum impedance and AR bandwidths of 125 MHz (5.1%) and 30 MHz (1.2%) for this antenna is achieved with $c = 3.4\,\text{mm}$ respectively.

In the third and forth structures by using mutually orthogonal nearly degenerate modes, circular polarization is achieved. Figs. 5(a) & (b) indicate the return loss and axial ratio of the third proposed antenna for different values of perturbation segment surface ($\Delta s = l \times w$). Dimensions of this antenna are $a = 14$ and $h = 11\,\text{mm}$. The first resonant frequency is belongs to TE^{x}_{111} mode because of its longer effective length along x direction and the second one is associated to TE^{y}_{111} mode. By increasing the length of perturbation



(a) (b)

Figure 5. (a) Return loss and (b) axial ratio of the third rectangular antenna for different dimensions of perturbation segment.



(a) (b)

Figure 6. (a) Return loss and (b) axial ratio of the forth rectangular antenna for different dimensions of perturbation segment.

segment, the effective length of the antenna along x direction increases and the resonant frequency of the TE^x_{111} mode decreases. On the other hand, the effective length of the DR through the y axis is effectively insensitive to x parameter variations which conclude a constant resonant frequency for the TE^y_{111} mode. The maximum impedance and axial ratio bandwidths are 130 MHz (5.3%) and 33 MHz (1.3%) respectively, which is obtained while ($\Delta s = l \times w = 2.4 \times 5 = 12\,\text{mm}^2$).

Also, Figs. 6(a) & (b) illustrate the return loss and axial ratio of the last rectangular structure for different values of the perturbation segment surface ($\Delta s = l \times w$). Dimensions of this antenna are $a = 15.25$ mm and $h = 11$ mm. In this structure the first resonant frequency is belongs to TE^y_{111} mode, because of the longer effective length along y direction. By rectangular truncating of DR along the x axis, the effective length of the DR reduces along x direction. Hence, the second resonant frequency in S_{11} diagram pertains to TE^x_{111} mode. The maximum impedance and axial ratio bandwidths are 112 MHz (4.6%) and 28 MHz (1.1%), at the center frequency of 2.41 GHz, respectively. These bandwidths are achieved with ($\Delta s = l \times w = 3 \times 6 = 18\,\text{mm}^2$).

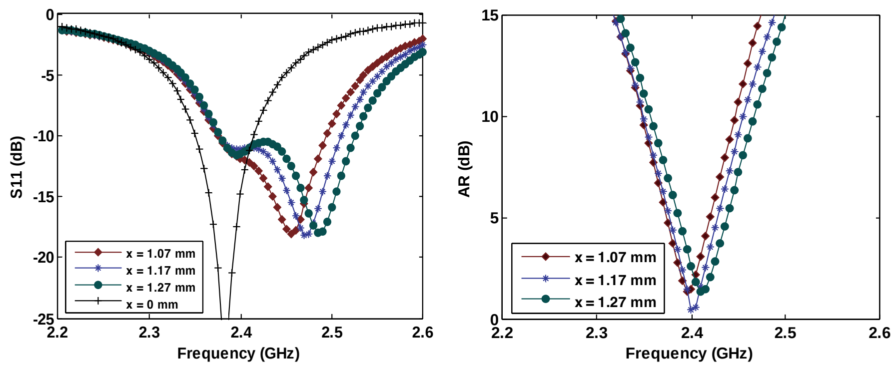
In all proposed structures the fundamental mode of rectangular DR splits into two near degenerate orthogonal modes. Hence, the reported antennas are radiating circular polarized waves. This is almost theoretically similar to microstrip antennas which have been designed for circular polarization [22–25].

Table 1. Performance of reported rectangular dielectric resonator antennas.

Antenna Type	Center Frequency (f_c-GHz)	S_{11}-BW (MHz)	AR-BW (MHz)	Minimum AR (dB)
#1 antenna	2.41	130 (5.4%)	32 (1.3%)	0
#2 antenna	2.42	125 (5.1 %)	30 (1.2 %)	0
#3 antenna	2.42	130 (5.3 %)	33 (1.3 %)	0.3
#4 antenna	2.41	112 (4.6 %)	28 (1.1 %)	0.9

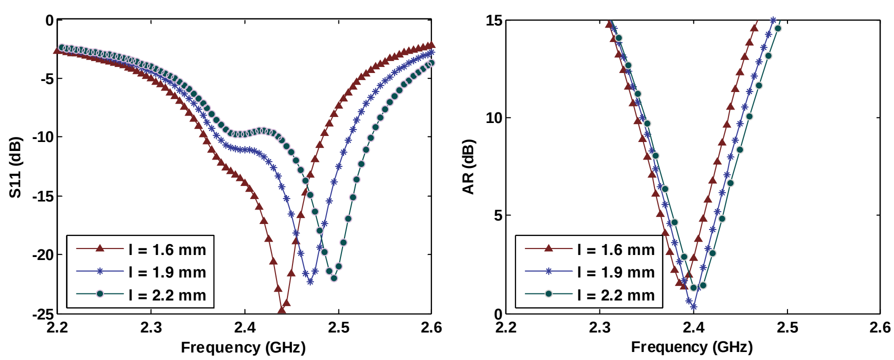
3.2. Cylindrical Structures

By chamfering the conventional cylindrical DRA along x direction and placing the probe feed at suitable positions, two close resonant frequencies are achieved. These two resonant frequencies are the results of splitting the fundamental mode of cylindrical DR (TM_{110} [26]) into two near-degenerate orthogonal resonant modes (TM^x_{110} and TM^y_{110}). Fig. 7(a) shows the return loss of this antenna for different values of x parameter. Dimensions of this antenna are $r = 8.35$ & $h = 11$ mm. In case of $x = 0$ mm which is the conventional cylindrical DRA structure, single resonate frequency is obtained and the impedance bandwidth is 65 MHz (2.6%). By increasing x, two resonant frequencies can be seen and impedance bandwidth will be improved. Maximum impedance bandwidth of 135 MHz (5.5%) at the center frequency of 2.44 GHz can be obtained while $x = 1.17$ mm. This impedance bandwidth is almost two times greater than the bandwidth of conventional cylindrical DRA. The axial ratio of the reported antenna for different values of x is depicted in Fig. 7(b). The maximum axial ratio bandwidth achievement is 31 MHz (1.2%) with a minimum value of 0.4 dB over this bandwidth. Maximum axial ratio bandwidth is obtained at $x = 1.17$ mm.



(a) (b)

Figure 7. (a) Return loss and (b) axial ratio of the first cylindrical proposed antenna for different values of "x" parameter.



(a) (b)

Figure 8. (a) Return loss and (b) axial ratio of the second cylindrical antenna for different values of rectangular notch depth.

In the second cylindrical structure, by modifying the conventional cylindrical resonator the fundamental mode of the DR (TM_{110}) splits into two near-degenerate orthogonal resonant modes

(TM^x_{110} and TM^y_{110}). Cylindrical DR is modified by cutting a rectangular notch on the x axis diameter. If we choose the dimensions of the rectangular notch properly two excited modes will have the same magnitude and 90° phase difference which provides CP. Moreover these two close resonant frequencies yield wide impedance bandwidth. Dimensions of this antenna are $r = 8.4$ & $h = 11$ mm. Maximum achievable impedance bandwidth is 140 MHz (5.7%) at the center frequency of 2.44 GHz. This bandwidth was obtained by choosing $l = 1.9$ mm and $w = 7$ mm. Maximum achievable AR bandwidth is 32 MHz (1.3%). For achieving the maximum AR bandwidth l and w are chosen 1.9 mm and 7 mm respectively. Figs. 8(a) and (b) show the return loss and axial ratio of the second antenna for different values of rectangular notch depth (l). More detailed results are presented in Table 2.

Table 2. Performance of reported cylindrical dielectric resonator antennas.

Antenna Type	Center Frequency (f_c-GHz)	S_{11}-BW (MHz)	AR-BW (MHz)	Minimum AR (dB)
#1 antenna	2.44	135 (5.5%)	31 (1.2%)	0.4
#2 antenna	2.44	150 (5.7%)	32 (1.3%)	0.3

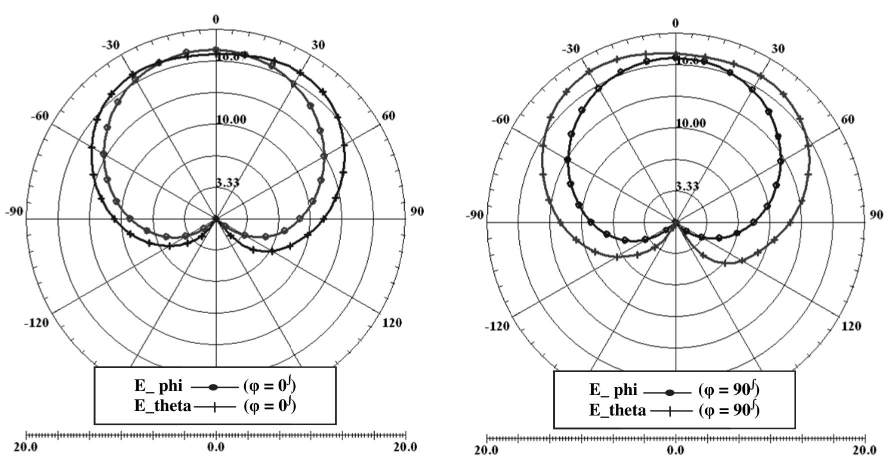


Figure 9. (a) E-plane ($\phi = 0°$) and (b) H-plane ($\phi = 90°$) radiation patterns of the first rectangular dielectric resonator antenna at 2.41 GHz.

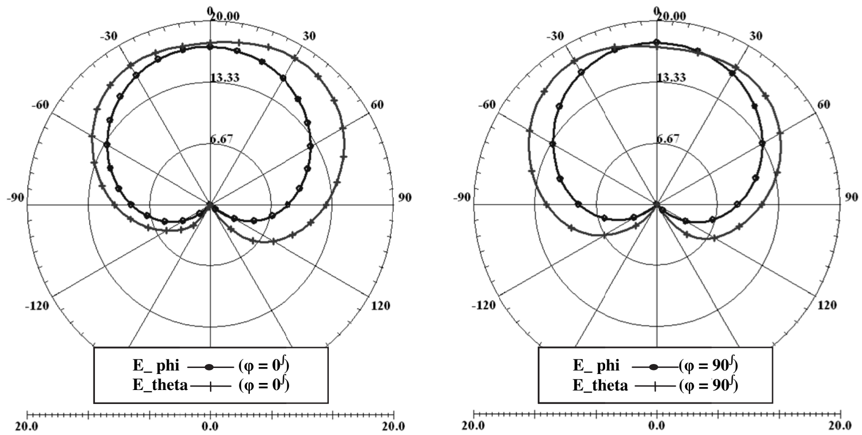


Figure 10. (a) E-plane ($\phi = 0°$) and (b) H-plane ($\phi = 90°$) radiation patterns of the first cylindrical dielectric resonator antenna at 2.40 GHz frequency.

4. RADIATION PATTERN

The radiation patterns in two orthogonal planes ($\varphi = 0°$ & $\varphi = 90°$) of the antenna which is illustrated in Fig. 1(a) are depicted on Fig. 9. Similar to the conventional rectangular DRA the antenna is having broadside ($\theta = 0°$ direction) radiation patterns. It can be seen that by incorporating a suitable dimension ratio ($r = b/a$) and feed position, good circular polarization radiation is achieved. Also, the radiation patterns of the first cylindrical structure are presented in Fig. 10. All reported antennas have approximately the same broadside radiation patterns.

5. CONCLUSION

Six dielectric resonator antennas for circular polarization, using single probe feeds, are presented. In all structures two near-degenerate orthogonal resonant modes are excited which are the results of splitting the fundamental mode of rectangular or circular DR. The obtained impedance bandwidth is approximately two times more than the bandwidth of conventional rectangular or cylindrical DR. The results show that radiation patterns of all antennas are remained broadside. Also, a comparison between all reported structures is provided. The advantages of the proposed antennas compared to other DRA designs include small size, easy design, and simple fabrication.

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REFERENCES

1. Kajfez, D. and P. Guillon (eds.), *Dielectric Resonators*, Artech House, Norwood, MA, 1986.
2. Mongia, R. K. and P. Bhartia, "Dielectric resonator antennas: A review and general design relations for resonant frequency and bandwidth," *Int. J. Microwave Millimeter-Wave Computer.-Aided Eng.*, Vol. 4, No. 3, 230–247, 1994.
3. Mongia, R. K. and A. Ittipiboon, "Theoretical and experimental investigations on rectangular dielectric resonator antennas," *IEEE Trans.*, Vol. 45, No. 9, 1348–1356, 1997.
4. Fayad, H. and P. Record, "Multi-feed dielectric resonator antenna with reconfigurable radiation pattern," *Progress In Electromagnetics Research*, PIER 76, 341–356, 2007.
5. Rezaei, M., M. Hakkak, and K. Forooraghi, "Design of wideband dielectric resonator antenna with a two-segment structure," *Progress In Electromagnetics Research*, PIER 66, 111–124, 2006.
6. Rao, Q., T. A. Denidni, A. R. Sebak, and R. H. Johnston, "On improving impedance matching of a CPW fed low permittivity dielectric resonator antenna," *Progress In Electromagnetics Research*, PIER 53, 21–29, 2005.
7. Kumar, A. V. P., V. Hamsakutty, J. Yohannan, and K. T. Mathew, "Microstripline fed cylindrical dielectric resonator antenna with a coplanar parasitic strip," *Progress In Electromagnetics Research*, PIER 60, 143–152, 2006.
8. Qian, Z. H., K. W. Leung, and R. S. Chen, "Analysis of circularly polarized dielectric resonator antenna excited by a spiral slot," *Progress In Electromagnetics Research*, PIER 47, 111–121, 2004.
9. Rezaei, M., M. Hakkak, and K. Forooraghi, "Effect of magnetic layer on the microstrip-excited rectangular dielectric resonator antennas bandwidth," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 7, 915–927, 2007.
10. Betzios, P. V., I. S. Karanasiou, and N. K. Uzunoglu, "Analysis of a dielectric resonator antenna by applying a combined semi-analytical method and simulation," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 14, 1983–1994, 2007.

11. Coulibaly, Y., T. A. Denidni, and L. Talbi, "Design of a broadband hybrid dielectric resonator antenna for X-band applications," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 12, 1629–1642, 2006.
12. Mongia, R. K., A. Ittipiboon, M. Cuhaci, and D. Roscoe, "Circularly polarized dielectric resonator antenna," *Electron. Lett.*, Vol. 30, No. 17, 1361–1362, 1994.
13. Drossos, G., Z. Wu, and L. E. Davis, "Circular polarized cylindrical dielectric resonator antenna," *Electron. Lett.*, Vol. 32, No. 4, 281–283, 1996.
14. Leung, K. W., W. C. Wong, K. M. Luk, and E. K. N. Yung, "Circular-polarised dielectric resonator antenna excited by dual conformal strips," *Electron. Lett.*, Vol. 36, No. 6, 484–486, 2000.
15. Ling, C. W. and C.-Y. Huang, "Dual-band circularly polarized dielectric resonator antenna," *IEEE Antennas and Propagation Society International Symposium*, Vol. 3, 496–499, 2003.
16. Oliver, M. B., Y. M. M. Antar, R. K. Mongia, and A. Ittipiboon, "Circular polarized rectangular dielectric resonator antenna," *Electronic Letters*, Vol. 31, No. 6, 418–419, Mar. 1995.
17. Oliver, M. B., R. K. Mongia, and Y. M. M. Antar, "A new broadband circular polarized dielectric resonator antenna," *Anenna and Propagation Society International Symposium*, Vol. 1, 738–741, Jun. 1995.
18. Tam, M. T. K. and R. D. Murch, "Circular polarized circular sector dielectric resonator antenna," *IEEE Trans. Antennas Propagation*, Vol. 48, No. 1, 126–128, Jan. 2000.
19. Inoue, T., N. Inagaki, N. Kikuma, and K. Sakakibara, "Design of circularly polarized dielectric resonator antenna using modal polarization current model method," *AP International Society Symposium*, Vol. 3, 504–507, Jun. 2003.
20. Esselle, K. P., "Circularly polarized higher-order rectangular dielectric resonator antenna," *Electronics Letters*, Vol. 32, No. 3, 150–151, 1996.
21. Malekabadi, S. A., M. H. Neshati, and J. Rashed-Mohassel, "Modified rectangular dielectric resonator antenna for circular polarization," *International Workshop on Antenna Technology*, 538–541, March 2008.
22. Sharma, P. C. and K. C. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas," *IEEE Trans.*, Vol. 31, No. 6, 949–955, 1983.

23. Yang, S.-L. S., K.-F. Lee, A. A. Kishk, and K. M. Luk, "Design and study of wideband single feed circularly polarized microstrip antennas," *Progress In Electromagnetics Research*, PIER 80, 45–61, 2008.
24. Zhang, M. T., Y. B. Chen, Y. C. Jiao, and F. S. Zhang, "Dual circularly polarized antenna of compact structure for RFID application," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 14, 1895–1902, 2006.
25. Bao, X. L. and M. J. Ammann, "Comparison of several novel annular-ring microstrip patch antennas for circular polarization," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 11, 1427–1438, 2006.
26. Long, S. A., M. W. McAllister, and L. C. Shen, "The resonant cylindrical dielectric cavity antenna," *IEEE Trans.*, Vol. 31, 406–412, 1983.