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WIDEBAND CIRCULARLY POLARIZED DIELECTRIC RESONATOR ANTENNA WITH A SQUARE SPIRAL MICROSTRIP FEEDLINE

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Abstract—A rectangular dielectric resonator antenna (DRA) with a square spiral microstrip feedline is investigated in this paper. The design utilizes a feeding structure to excite two resonant modes ($TE_{\delta 11}$ and $TE_{1\delta 1}$ modes) of the rectangular DRA that are spatially orthogonal in polarization and in phase. The antenna with the proposed feeding structure has provided a measured circular polarization (CP) over a bandwidth of $\sim 15.5\%$ in conjunction with an impedance-matching bandwidth of $\sim 31.25\%$ at the same frequency range. The gain of the dielectric resonator antenna varies between 6.8 and 7.2 dBi across the bandwidth ($7.5 \sim 8.75$ GHz). Reasonable agreement between the simulated and measured results is obtained.

1. INTRODUCTION

In recent years, the dielectric resonator antenna (DRA) has been widely explored because of a number of advantages such as its small size, low loss and ease of excitation [1–3]. Since it has no metallic loss and does not excite any surface waves, the DRA offers higher radiation efficiency than the microstrip antenna does. Early studies of DRA primarily concentrated on linear polarization (LP). Lately, the circularly polarized (CP) DRA has received tremendous attention [4–6]. Circularly polarized antennas owing to their reduced polarization mismatch and multipath fading win a wide range of applications in the communication systems. Also, a CP antenna is much less sensitive to the transmitter and receiver orientations than a LP antenna. Owing to the above advantages, it is very popular for certain applications such as satellite communications, including global positioning systems.

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In general, circular polarization can be obtained from DRAs using single feeds or multiple feeds. Among them, the single-feed configurations usually have simple structures and require less space on the feed substrate. The feed losses in the single-feed configurations are likely to be less than those in multiple-feed configurations. However, the axial-ratio (AR) bandwidth of a single-feed CP antenna [7] is usually smaller than that of a multiple-feed CP antenna [8].

Numerous designs of circularly polarized cylindrical DRAs have been reported in the literature by using the dual and single feed mechanisms. For instance, a 3-dB axial ratio bandwidth of 3.4% has been obtained when a cylindrical DRA is excited by perturbed annular slot with backing cavity [9]. A circularly polarized cylindrical dielectric resonator antenna using a helical exciter with a 3-dB axial ratio bandwidth of 6.4% has been reported in [10]. The hollow rectangular DRA with an underlaid quadrature coupler offering a 10.54% AR bandwidth has been demonstrated in [11]. An elliptical DRA with a circular polarization bandwidth of 3.5% has been investigated using a single-probe feed [7]. AR bandwidths of 3.91% and 2.2% have been achieved for cylindrical DRA excited by a cross-slot [12], and slot-coupled structure [13], respectively. A conformal square spiral strip exciting the cylindrical DRA with a 4.3% CP bandwidth has been reported in [14]. Since the traveling-wave current distribution changes slowly with frequency, a wider CP bandwidth is expected. Such a feeding method has been reported in [15], where a CP bandwidth of 7% has been achieved using a spiral strip to excite a rectangular DRA.

In this paper, a square spiral microstrip line is used to achieve a left hand circularly polarization (LHCP) radiation. Potential advantages include a simpler structure, a 31.25% impedance-matching bandwidth with $S_{11} < -10\,\text{dB}$ and a 15.5% bandwidth with AR less than 3 dB.

2. CONFIGURATION OF ANTENNA

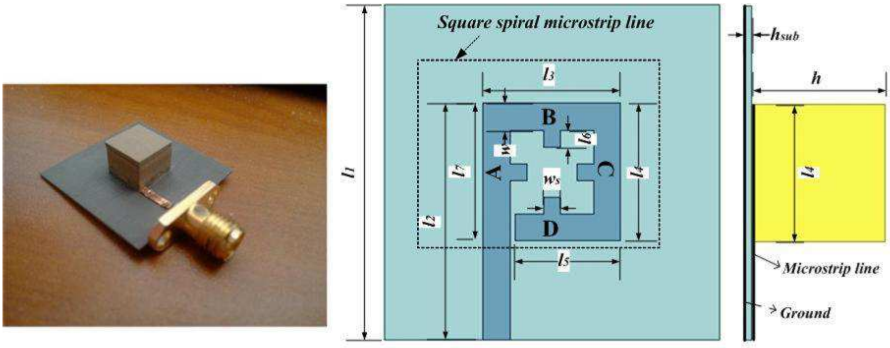
Figure 1 shows side and top views of the proposed antenna. A rectangular dielectric resonator of permittivity $\varepsilon_r = 9.6$, is fed with a square spiral microstrip transmission line. The initial dimensions of the radiating portions of the antenna are calculated using the equations developed with the dielectric waveguide model (DWM) for a DR in the free space. The following equations are obtained for the wave-numbers and the dominate mode of resonant frequency [1]:

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \tag{1}$$

$$k_z \tan(k_z d/2) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_z^2} \tag{2}$$

$$k_x = \frac{\pi}{a}, \quad k_y = \frac{\pi}{b}, \quad k_0 = \frac{2\pi f_0}{c} \tag{3}$$

where k_x, k_y and k_z denote the wave-numbers along x, y and z directions inside the DRA, respectively. The following is the optimized size. The dimensions of the rectangular DRA are 8.2 mm × 8.2 mm × 8 mm, and the resonant frequency of the corresponding dominate mode is approximately 7.8 GHz. The DRA is mounted on a substrate of dimensions 33 mm × 33 mm and thickness $h_{sub} = 0.5$ mm. The substrate has a relative permittivity of $\varepsilon_{rs} = 2.2$. The square spiral 50 Ohm microstrip feedline is place on the top side of the substrate while the ground plane (33 mm × 33 mm) is printed on underneath the substrate. According to the equations in [16], the width of the 50-Ohm microstrip line can be obtained. In order to obtain wideband circularly polarized characteristics, four-feeds or two-feeds with the complicated feed network are usually used. In this paper, a simple single feed structure that adopts phase lag characteristics of microstrip line is designed. The length of the square spiral microstrip feedline under the DRA is approximately selected as one dielectric wavelength ($\lambda_g = l_3 + l_4 + l_5 + l_7$, $\lambda_g = \lambda_0/\sqrt{\varepsilon_{eff}}$) of the dominant mode. Since the large phase lag is provided when current flows through square spiral microstrip line (one dielectric wavelength), the current with equal magnitude and a phase difference that increases 90° orderly from A to D is obtained in Fig. 1. Therefore, a good circularly polarized characteristic can be achieved by the simple feed structure. The square spiral microstrip line consists of four segments with lengths of $l_7 = 8.2$ mm, $l_3 = 8.2$ mm, $l_4 = 8.2$ mm, $l_5 = 6.3$ mm. Each segment has a strip width of $w = 1.6$ mm. All of the four segments have a small



prototype of the CP DRA
(a)

top view
(b)

side view
(c)

Figure 1. The configuration of the DRA, (a) prototype of the DRA, (b) top view, (c) side view.

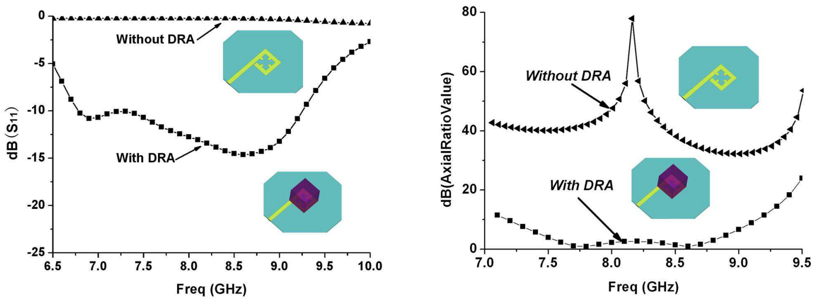
stub, which can improve the phase lag of the square spiral microstrip line, and the small stub has dimensions of $w_s = 1\,\text{mm}$ and $l_6 = 1\,\text{mm}$. The final dimensions of the antenna are summarized in Table 1.

Table 1. Final dimensions of the antenna proposed.

Parameter	h_{sub}	l_1	l_2	l_3	l_4	l_5	w	w_s	l_6	l_7
Unit (mm)	0.5	33	20.6	8.2	8.2	6.3	1.6	1	1	8.2

3. SIMULATION RESULT AND DISCUSSION

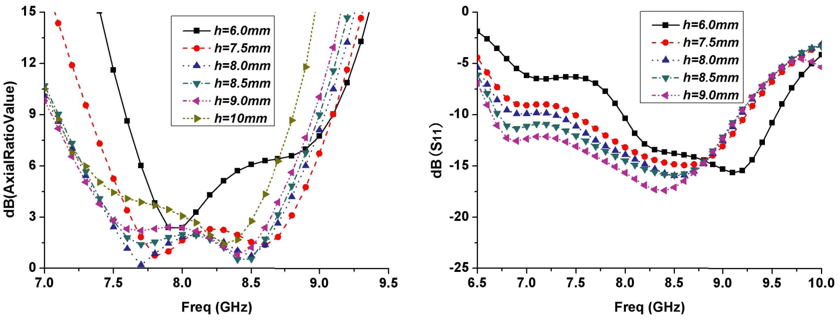
The proposed antenna consists of square spiral microstrip feedline and rectangular dielectric resonator. In order to show the performance of the antenna radiation, the effect of the square spiral microstrip line is studied. The reflection coefficient and AR with the DRA and without the DRA are given in Fig. 2. It can be seen that the DR determines the radiation characteristics of the proposed antenna. Moreover, the square spiral microstrip feedline functions as impedance matching and offers the feed with equal magnitude and 90° in phase difference.



(a) (b)

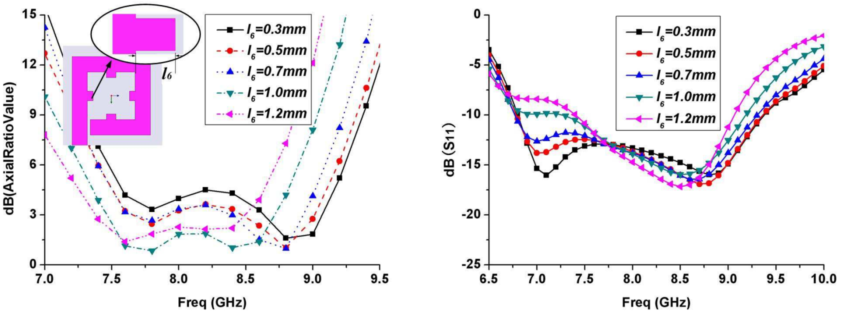
Figure 2. Effect of the antenna with DRA and without DRA, (a) reflection coefficient and (b) AR.

A parametric study of the proposed DRA is carried out using Ansoft High Frequency Structure Simulator (HFSS). Several simulated parameters, including the reflection coefficient, AR, gain, radiation patterns, and different internal electric field distributions are presented in Figs. 3–5. For brevity, only the effects of the DRA height h, stub line length l_6 and the fourth segment spiral line length l_5 on the antenna performance are presented.



(a) (b)

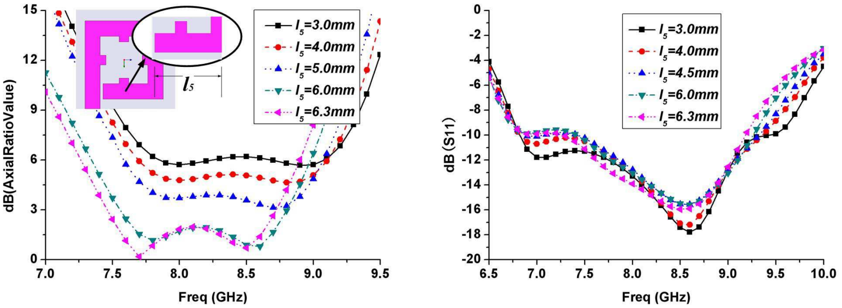
Figure 3. Effect of DRA height h on (a) AR and (b) reflection coefficient.



(a) (b)

Figure 4. Effect of stub length l_6 on (a) AR and (b) reflection coefficient.

The results of varying h are shown in Fig. 3. It can be observed that reflection coefficient changes substantially, but the AR almost has no change, as h increases from 7.0 to 9.0 mm. Fig. 4 shows the results for different stub lengths l_6. The AR is affected significantly as l_6 increases from 0.3 to 1.2 mm. It was found that the stub length l_6 does not affect the reflection coefficient much. Also, the effect of changing the fourth segment microstrip line l_5 is investigated in Fig. 5. The AR changes significantly when the length of l_5 increases from 3.1 to 6.3 mm. The effects on the gain and bandwidth of the antenna are minimal (not shown). It is found that the DRA dimensions generally affect the impedance, and the square spiral microstrip line size mainly



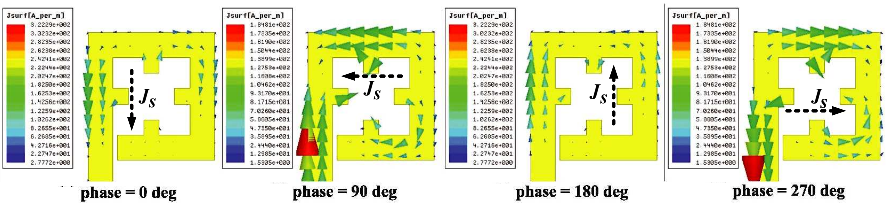
(a) (b)

Figure 5. Effect of the forth segment microstrip line length l_5 on (a) AR and (b) reflection coefficient.

affects the AR. Therefore, to design the antenna, the square spiral microstrip line dimensions l_5 and stub length l_6 should be optimized first to obtain the best AR.

The configuration of one single-feed CP DRA consists of a rectangular DR fed by a square spiral microstrip line, as shown in Fig. 1. This DR configuration is analogous to the single-feed CP rectangular microstrip patch antenna, where two spatially orthogonal modes are excited.

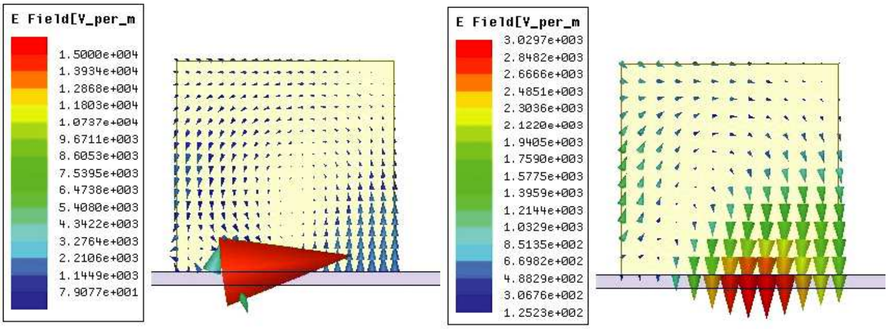
To obtain the circular polarization radiation two orthogonal fields with quadrature phase difference are needed. Different 2D traveling current distributions for various input signal phase angles have been achieved along the spiral microstrip line in different phases at 8.5 GHz as demonstrated in Figs. 6(a)–(d). The current along the microstrip line is almost one cycle. The surface currents of the minimum AR frequency within the operating bandwidth from two orthogonal line currents due to the guidance of the square spiral microstrip line



(a) (b) (c) (d)

Figure 6. Current distributions along the microstrip line at 8.5 GHz.

and the two orthogonal line currents will generate two orthogonal radiations. Additionally, as there will be large phase lag when current flows through square spiral microstrip line, there will be LHCP in far field. Also, Fig. 7 illustrates the electric near-field distributions inside the dielectric resonator, in the x-z plane and y-z plane. The arrows represent the directions of the E-field, while the size and color represent field strength. Two pure modes ($TE_{\delta 11}$ mode and $TE_{1\delta 1}$ mode) that are almost equal in magnitude but differ in phase and space by 90° (i.e., time and space quadrature) are excited by square spiral microstrip line in x-z plane and y-z plane, respectively. Therefore, a circular polarization radiation characteristics can be obtained. Fig. 8 shows the measured and simulated reflection coefficients. The measured and simulated 10-dB impedance bandwidths are 32.5% and 31.25%, respectively.



(a) *xoz* (phase = 0 deg) (b) *yoz* (phase = 90 deg)

Figure 7. Electric near-field distributions at the central frequency, (a) x-z plane, (b) y-z plane.

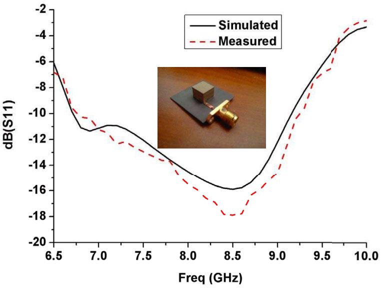


Figure 8. Reflection coefficients of the DRA shown in Fig. 2.

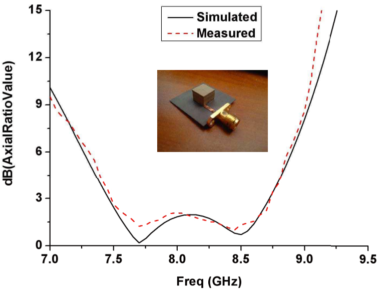


Figure 9. Axial ratios of the DRA.

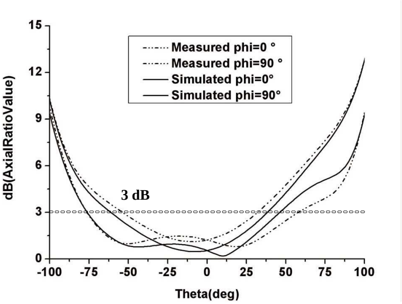


Figure 10. Axial ratio beamwidth of the rectangular DRA.

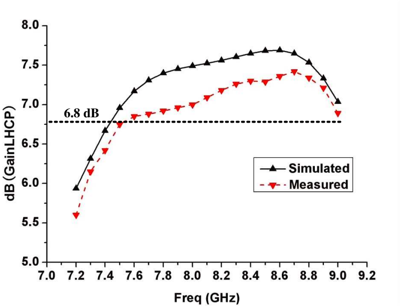
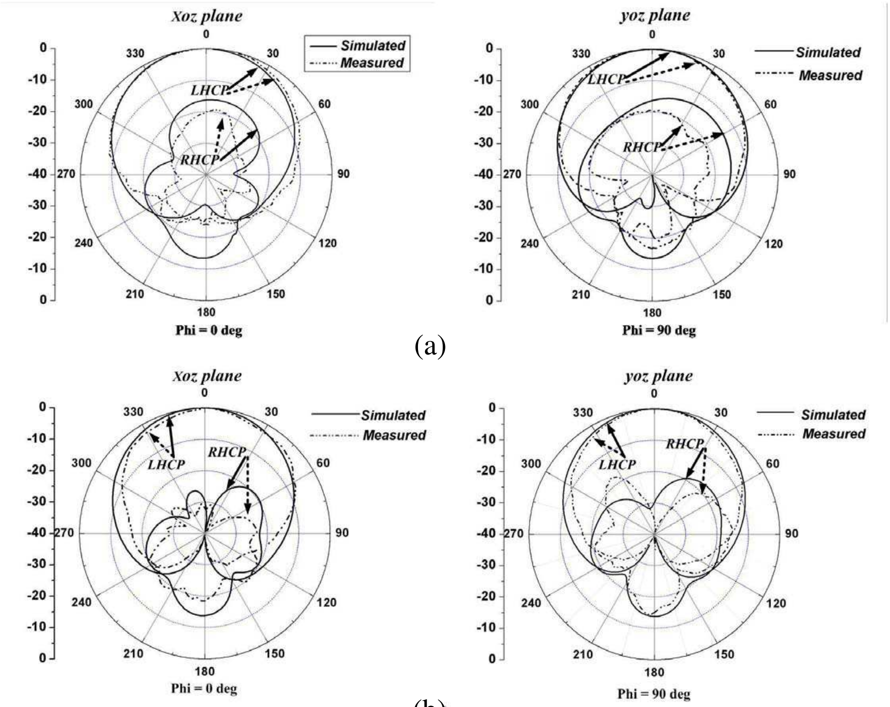


Figure 11. Measured and simulated gains for the proposed DRA.



(a)

(b)

Figure 12. Radiation patterns of the DRA, (a) 7.6 GHz. (b) 8.5 GHz.

Figure 9 shows the AR. The measured and simulated 3-dB AR bandwidths are 15.3% and 15.8%, respectively. It should be mentioned that the entire measured AR passband falls within the impedance passband, which is highly desirable. Furthermore, the antenna provides a reasonable wide beam in the two principle planes taken at the minimum AR frequency as shown in Fig. 10. Fig. 11 shows the measured gain varies between 6.8 dBi and 7.5 dBi across the passband ($7.5 \sim 8.75$ GHz) and is maximum (7.3 dBi) at around 8.7 GHz. The stability of the radiation pattern has been evaluated, and it has been noticed that the patterns are stable across the whole CP bandwidth as illustrated in Fig. 12. Further investigations have proved that the antenna provides a CP radiation over beamwidths of 80° in both phi $= 0°$ and phi $= 90°$ principle planes, respectively, at the minimum S_{11} frequency. Reasonable agreement between the simulated and measured results is obtained.

4. CONCLUSIONS

Techniques for producing circular polarization utilizing a single-feed rectangular DRA are described. The proposed excitation has provided a measured circular polarization over a bandwidth of 15.5% in conjunction with an impedance-matching bandwidth of $\sim 31.25\%$ at the same frequency range. It has stable radiation patterns across the whole CP bandwidth. It is valuable to design a wideband CP antenna with good AR.

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