A New Wideband Circularly Polarized Dielectric Resonator Antenna

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Abstract. *A wideband and compact circularly polarized (CP) C-shaped dielectric resonator antenna (DRA) is presented and investigated. The proposed C-shaped DR is excited by a simple stripe line connected to a coplanar waveguide (CPW) feeding line. The C-shaped DRA is circularly polarized with 19% axial ratio (AR) bandwidth. It is found that the CP bandwidth can be expanded by using a narrow short circuit strip. The final design achieves CP with 50% AR bandwidth. The proposed circularly polarized DRA (CPDRA) with good radiation characteristics offers an impedance bandwidth of 58% between 3.45 and 6.26 GHz for VSWR ≤ 2. The proposed DRA is fabricated and tested. Very good agreement between simulated and measured results is obtained.*

Keywords

Dielectric Resonator Antenna (DRA), Circularly Polarized (CP), Axial Ratio (AR) bandwidth, Coplanar Waveguide (CPW)-fed.

1. Introduction

Most of satellite communication systems transmit signals using circular polarization (CP) waves. This is due to the advantages of using circularly polarized antennas, the multipath effect could be reduced especially near the receiver. In addition, CP antennas are less sensitive to the transmitter and receiver orientations than linearly polarized antennas [1].

Recently, antennas using high-permittivity dielectric ceramic materials as radiation elements have received lots of attention due to several features like high radiation efficiency, low profile, low temperature coefficient, inherently wide bandwidth and suitable scale in microwave band [2], [3]. Moreover, by choosing a suitable dielectric constant, a reasonable size can be achieved to fabricate an antenna. Furthermore, different radiation patterns are obtained by exciting different modes. Over the last decade, wideband and compact antennas are often required in modern wireless communication systems and thus, different techniques have been presented for wideband DRAs. For wideband DRAs with linearly polarization fields, different dielectric resonator shapes such as P-shaped [4] and also composite structures [5] have been investigated. Although many designs have been developed for DRAs with wide impedance bandwidth and small size, their design to obtain wideband circularly polarized with wide axial ratio (AR) bandwidth can be challenging [1]. It therefore motivates many researchers to develop a wideband circularly polarized DRA (CPDRA) with a compact size [6]. Several designs of circularly polarized (CP) DRAs have been introduced in the literature employing dual and single feed methods [7-9]. Two feed points produce much wider AR bandwidth but it needs a large and complex feeding structure. Single feed mechanisms are preferred due to the smaller antenna size and construction simplicity. Although the single feed is simpler, it provides a narrow axial ratio (AR) bandwidth. For instance, an elliptical DRA in [10], used single slot feed square patch to obtain CP, which results in narrow AR bandwidths, 3.5%. A parasitic patch antenna using rectangular and hemispherical shaped dielectric resonator are introduced in [11], [12] to accomplish a circularly polarized waves with AR bandwidth of 2.7% and 2.4%, respectively. A noticeably higher 3-dB axial-ratio bandwidth of 10.6% has been investigated in [13], for a stair-shaped rectangular DRA. Therefore, it is important to have structure with a single feed mechanism and wide axial ratio bandwidth.

In this paper, a new configuration of wideband circularly polarized DRA with a single feed is presented. By choosing the C-shaped resonator fed by a simple stripe line connected to the CPW feed-line, 19% AR bandwidth is achieved. For further improvement of CP bandwidth, a narrow short grounded strip is introduced and connected to the ground plane in the right hand side of the dielectric resonator. Finally, 50% AR bandwidth is obtained. In the following sections, the design of the proposed CPDRA is described. Parametric studies, simulation and measurement results are presented and discussed.

2. Antenna Configuration and Design

Fig. 1 shows the schematic of the proposed DRA, which consists of a DR, the CPW feed line and a substrate with the dimensions of 30 mm × 35 mm. The C-shaped DRA is fabricated of Rogers-RO3010 with the relative permittivity of $\varepsilon_r = 10.2$ and with a thickness $H = 5.12$ mm, and it is supported by the substrate with a dielectric constant of 4.6, loss tangent, $\tan\delta = 0.019$ and a substrate thickness of 1.6 mm. As shown in Fig. 1, a narrow feed line is fed by a CPW transmission line whose width is W_2. Since both the antenna and the feeding structure are implemented on the same plane, only one layer of substrate with single-sided metallization is used, and the fabrication of the antenna is easy and low cost.

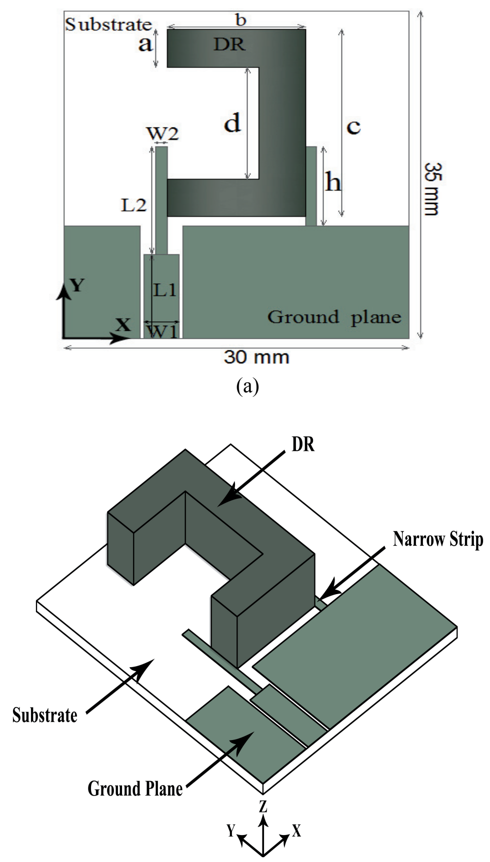


Fig. 1. (a) Top view and (b) 3D view of the proposed CPDRA.

The DR is designed with C-shaped cross, which is characterized by the dimensional parameters *a, b, c,* and *d* as shown in Fig. 1. The width of the feed line is $W_1 = 3$ mm to have an input impedance of 50 ohm.

The dimensions *a, b, c, d* of the proposed DRA are 4 mm, 10 mm, 20 mm and 12 mm, respectively. The feed line is shown by two different widths W_1 and W_2 and different lengths L_1 and L_2, respectively. By changing the width of the feed line, from W_1 to W_2, the optimum matching is achieved. On the other side of the narrow strip probe feed, a narrow strip is connected to the ground plane. By using this grounded strip, the DR is surrounded by conducting narrow strips from both sides and introduces some symmetry that eliminates the probe type of mode that usually causes asymmetric radiation pattern in a form of tilting the main radiation direction of the broadside direction. The optimal dimensions enabling the best impedance matching and AR bandwidth are presented in Tab. 1.

Parameter	W_1	W_2	L_1	L_2	h
Value (mm)	3	1	9	11.5	8.5
Parameter	*a*	*b*	*c*	*d*	
Value (mm)	4	12	20	12	

Tab. 1. Optimized DRA dimensions (in millimeters).

In the next section, the effective parameters are studied and the measured results are also presented and compared in the last section.

3. Parametric Study and Discussion

For a better understanding of the proposed circularly polarized DRA impedance bandwidth with the variation of some parameters, a parametric study is performed to illustrate the effect on the VSWR, which is usually helpful for practical antenna design. The CST Microwave Studio software 2012 [14], based on the finite integration technique, was used for the parametric analysis.

In addition, an important factor of enhancing the bandwidth is the efficient coupling between the DR and the feed. The feed line width and length overlapping with the DR are main parameters to achieve matching over wide bandwidth. First, the effect of feed line and its key parameter L_2 is studied, and the results are illustrated. Fig. 2 shows the effect of L_2 on the matching for the proposed CPDRA. The impedance matching is sensitive to the length (L_1 and L_2) and width of the matching transformer (W_2) (see Fig. 1).

The impedance matching is degraded by increasing the length L_2 in the middle band. On the other hand, by decreasing the value of this parameter, the operating frequency is shifted to higher frequency. Fig. 2 indicates that when the length L_2 is 11.5 mm, the quality of the impedance matching is improved. Furthermore, the VSWR is increased, considerably. Thus, by selecting this value, the VSWR of 2.38 from 3.56 GHz to 5.94 GHz is obtained. Here the CP bandwidth is around 19% from 3.85 GHz to 4.64 GHz.

In order further to enhance the AR bandwidth, a grounded narrow strip is used. Hence, the crucial parameter that the CP bandwidth is enhanced is the length of the shorted grounded strip which shown by *h* in Fig. 1. However, this parameter does not have much influence on the operating frequency. Referring to Fig. 3, the sufficient AR is achieved at lower frequencies by decreasing the dimension of *h*. Thus, AR bandwidth for upper operating

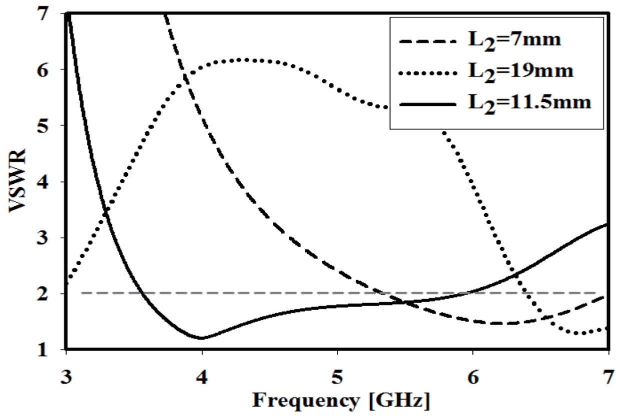


Fig. 2. Simulated VSWR of the CPDRA with different values of L_2.

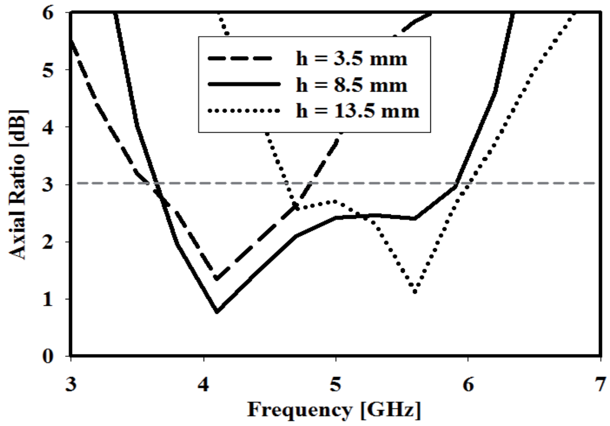


Fig. 3. Simulated AR of the CPDRA with different values of h.

frequencies is degraded. It is clearly seen that, by increasing this dimension, the sufficient axial ratio bandwidth is achieved at higher frequencies only.

As it can be seen clearly in Fig. 4, AR bandwidth is considerably increased after the narrow strip is connected to the ground plane. It is noted that by employing the grounded narrow strip in the right hand side of the dielectric resonator, new current path is generated, and hence orthogonal mode is strengthened. In addition, by using this

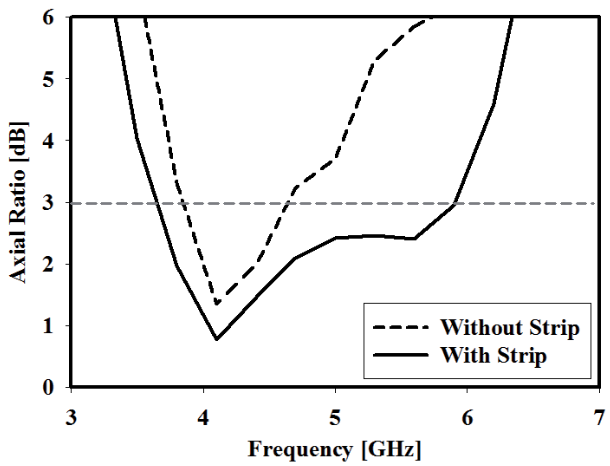


Fig. 4. Comparison between simulated AR of the CPDRA with and without the grounded narrow strip.

strip, orthogonal field inside DR is improved and AR bandwidth is enhanced. The simulated AR bandwidth for the CPDRA is 47% from 3.65 GHz to 5.90 GHz.

Fig. 5 compares the VSWR with and without grounded narrow strip. It is found that, by connecting the narrow strip to the ground plane, the related impedance bandwidth is nearly constant in the whole of the frequency band, comparing without using the strip.

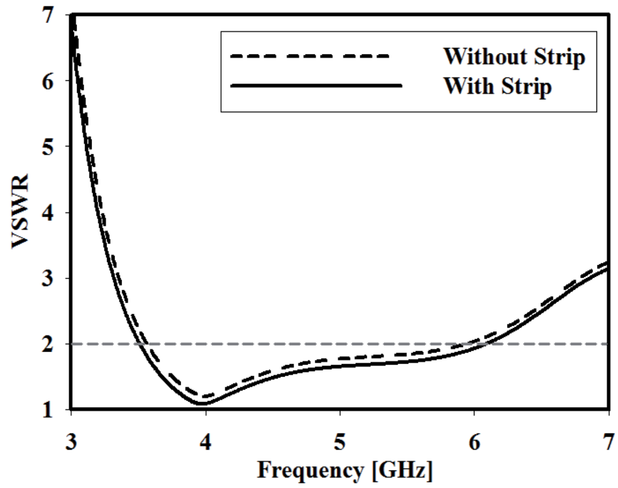
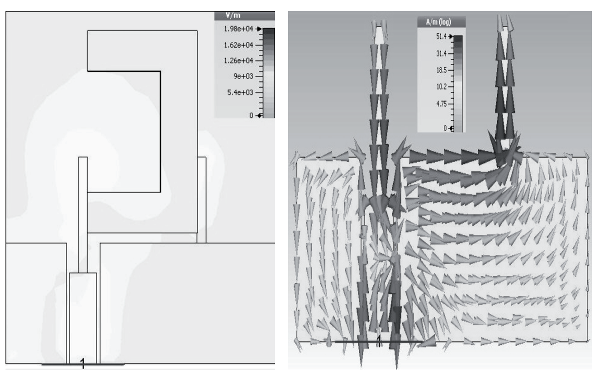


Fig. 5. Comparison between simulated VSWR of the antenna with and without grounded narrow strip.

In addition, the effect of the DRA size on impedance bandwidth and axial ratio is studied. It is found that by changing a (see Fig. 1(a)) the reflection coefficients and AR as a function of frequency are varied. In fact, with an increase of a; that it also means a decrease of d (see Fig. 1(a)); both the impedance and AR passbands shift downward, which is expected because a larger DRA should have a lower resonance frequency.

For more clarification of the behavior of the CP DRA, volume electric field distributions and surface currents are presented in Fig. 6. Because of the simultaneous excitation and coupling of the strip feed and the grounded strip from both sides of the DR, the symmetry of the radiation and field concentration inside the DR can be improved. With the reference to the figure, the new current path that strengthened the orthogonal mode can be obviously seen.



(a) (b)

Fig. 6. (a) Simulated volume electric field distributions and (b) surface current at 4 GHz of the optimized CP DRA.

Tab. 2 shows the simulated impedance and AR bandwidth of the antenna with and without a strip. Also, the expected improvement of the AR bandwidth is clearly seen in this table.

Parameters	Impedance bandwidth	AR bandwidth
CPDRA without strip	3.56 GHz to 5.94 GHz (50%)	3.85 GHz to 4.64 GHz (19%)
CPDRA with strip	3.51 GHz to 6.08 GHz (54%)	3.65 GHz to 5.90 GHz (47%)

Tab. 2. Comparison between the antenna with and without strip.

4. Measurement Results

The photograph of the fabricated CP dielectric resonator antenna is shown in Fig. 7. As final results, the best values of the parameters are as follows: $L_2 = 11.5$ mm and $h = 8.5$ mm. By using these proposed values, a prototype is fabricated and tested.

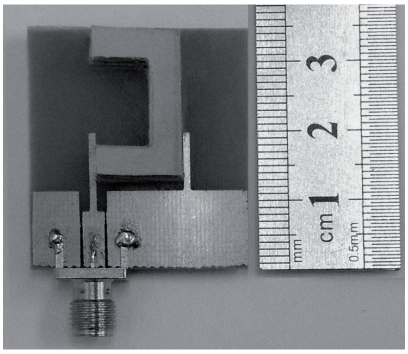


Fig. 7. Photograph of the realized CPDRA.

The simulated AR result of the antenna, compared to the measured one, is shown in Fig. 8. Such an excellent agreement between simulated and measured results shows the high tolerance of this CP antenna in terms of dimensions and materials. The measured AR bandwidth is about 50% from 3.59 GHz to 5.98 GHz, supporting many wireless applications, such as WLAN, WiMax, and WiFi. A comparison between the measured and the simulated VSWR is shown in Fig. 9, where it can be seen that the measured VSWR of ≤ 2 has been achieved over a bandwidth of 58%, from 3.59 GHz to 5.98 GHz. It is noteworthy represented that impedance bandwidth covers the whole 3-dB axial ratio bandwidth.

Fig. 10 illustrates simulated and measured gain values versus frequency. It is noted that the measured gain values of the antenna varied between 2.4 to 3.6 dB over the covering frequency range. In addition, efficiency of the proposed antenna is greater than 81 % over the whole frequency bandwidth. The measured radiation patterns of the fabricated antenna, right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) gains, at the two selected frequencies, 4 and 5.2 GHz, for *xz*-plane and *yz*-plane, are shown in Fig. 11, respectively. It is evident from these results that the RHCP field component is stronger than the LHCP counterpart by more than about 30 dB in the broadside direction at all the covered frequencies.

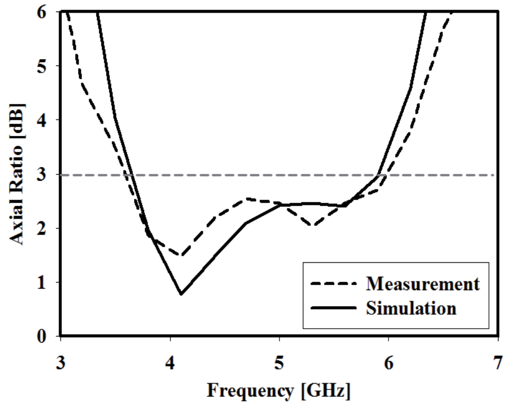


Fig. 8. Measured and simulated AR of the CPDRA.

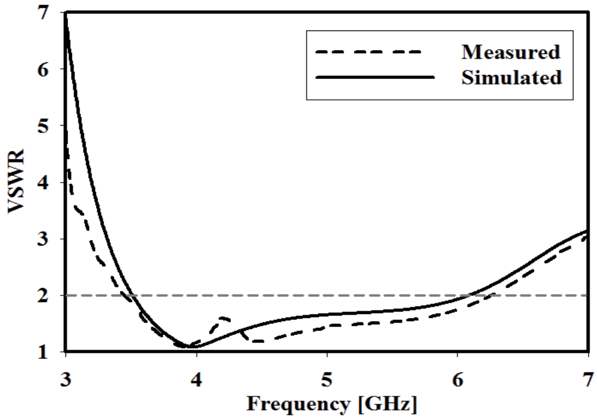


Fig. 9. Measured and simulated VSWR of the CPDRA.

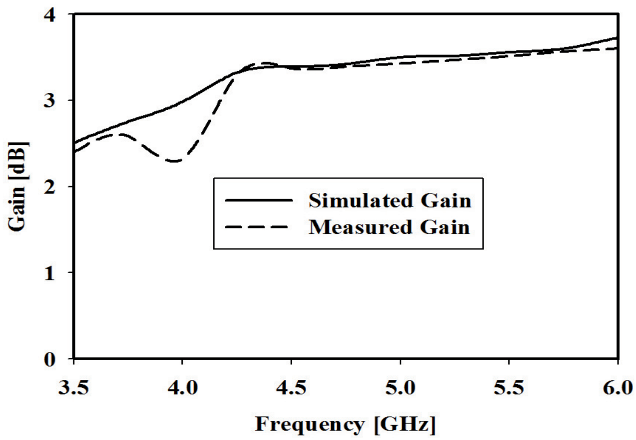
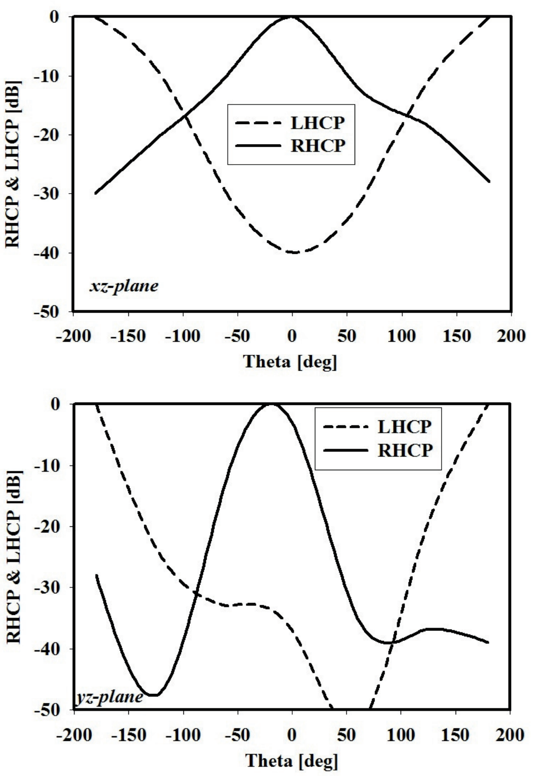


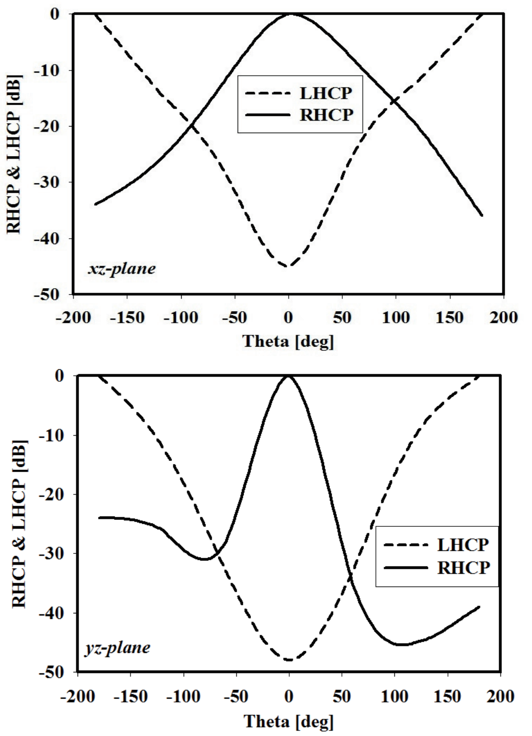
Fig. 10. Measured and simulated gain of the proposed CPDRA.

5. Conclusion

A wideband right-handed circularly polarized C-shaped dielectric resonator antenna was studied. The proposed antenna indicated excellent performance and was quite easy to design and fabricate. This new configuration of CP DRA offers a wider AR bandwidth compared to



(a)



(b)

Fig. 11. Radiation patterns (RHCP and LHCP) of the realized antenna at: (a) 4 GHz and (b) 5.2 GHz for xz-plane and yz-plane.

other CP DRAs which was presented in the literature. Among the advantages of the proposed antenna were its compact size and its low profile. It was shown that by employing a conducting strip to the ground, a 50% wide CP bandwidth was obtained, which was from 3.59 to 5.98 GHz. Furthermore, the measured impedance bandwidth of 58 % between 3.45 and 6.26 GHz for VSWR ≤ 2 was presented. In addition, the high purity of the RHCP field, compared to the LHCP, greater than 30 dB was also observed. It is noted that the measured gains value of the proposed CPDRA are always greater than 2.4 dB. Moreover, the antenna efficiency greater than 81 % was obtained. As a result, the CPDRA is attractive and can be practically used for various wireless communication systems.

Acknowledgements

The authors would like to thank the Ministry of Higher Education (MOHE) for supporting the research work, Research Management Centre (RMC), and Wireless Communication Center (WCC) Universiti Teknologi Malaysia (UTM) for the support of the research under Research University Grant (00G36 and 01H00).

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