Dual-band Circularly Polarized Cylindrical Dielectric Resonator Antenna for Millimeter-Wave Applications

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***Abstract*—This paper presents a compact dual-band circularly polarized cylindrical dielectric resonator antenna (CDRA) that operates at 38 and 60 GHz. The proposed design is contained a single wafer of silicon and two annular slots to exciting the DRA. Shorted outer and inner annular slots implemented to generate circular polarization in both bands. The proposed design of CDRA achieves a 3-dB AR bandwidth of 3.34 and 7.53%, with an impedance bandwidth of 9.74 and 24.01% at lower and upper bands, respectively. Also, it has excellent radiation characteristics, which its radiation efficiency and peak gain of 7.6 dBi and 95.22%, respectively. The proposed CDRA with dual-band resonances and gain bandwidth has the excellent potential to be applied for mm-wave wireless communications at the 38/60 GHz bands.**

Keywords - dielectric resonator; circularly polarized; millimetre-wave; dual-band

I. INTRODUCTION

Communication systems nowadays emerge as an industry that delivers consistent, efficient, and essential services to commercial as well as residential users in a timely, efficient way. A majority of communication systems demand antennas that demonstrate characteristics such as broadband, high gain, and circular polarization [1]. Moreover, the antennas need to be compact in size, preserving a low profile while keeping the fabrication cost low. Circularly polarized antennas become more attractive than linearly polarized designs as they demonstrate low multipath interference with flexibility in the receiver direction and overcome the attenuation by fog and rain, especially at millimeter wave ranges [2].

Due to several advantages over other types of antennas, dielectric resonator antennas (DRAs) have found to be potential candidates to be used in wireless applications [3]. They exhibit wide bandwidth, high radiation efficiency, flexibility in feeding, and low losses. Circularly polarized DRAs with different shapes with were proposed by antenna researchers. They have incorporated cross-slots, truncated corners, and dual orthogonal feeding to obtain circular polarization [4]. However, the CP bandwidth of a single antenna element is typically narrow. Therefore, an antenna array that is fed using a sequential arrangement is required to improve the CP bandwidth [5]. Despite the advantages of DRAs over printed antennas, the integration of other system components is not allowed due to their 3-D configuration. In [6], An aperture fed LP SIW-DRA designed to be operated around 60 GHz by integrating a circular piece with two slits on it exhibits CP performance. A two-port SIW-DRA with a hollow patch resonates at 5.2 GHz and 24 GHz covering WLAN and ISM bands [7]. In [8], a DRA with supporting dielectric bars exited around 60 GHz using printed ridge gap waveguide technique is presented. Nevertheless, the surface wave losses reduce the radiation efficiency of antennas.

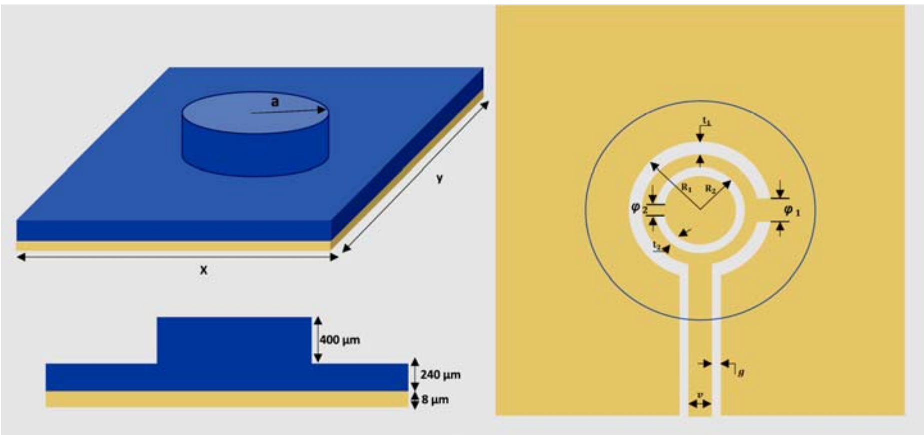


Figure 1. The configuration of the proposed CDRA

Some DRA designs presented by the antenna research community carry the driving electronics using a substrate made of either silicon [9]–[10] or GaAs [11]. A DRA, which is fed by a CPW excites at HE11δ mode demonstrate a gain of 3.2 dBi [12]. Nonetheless, its radiation efficiency is only 51%. A DRA fed by an H Shaped slot to be excited at TE11δ mode is presented in [13]. Though it shows an enhanced radiation efficiency of 59%, the gain of the fabricated antenna was only 0.5 dBi. The DRA above patch (DRAP) presented in [14] was constructed as a GaAs substrate. It demonstrates an impedance bandwidth of 29.2% with a gain of 3.6 dBi. In none of the aforementioned designs, the DRA material was ceramic, silicon, or GaAs; thus hybrid integration was required.

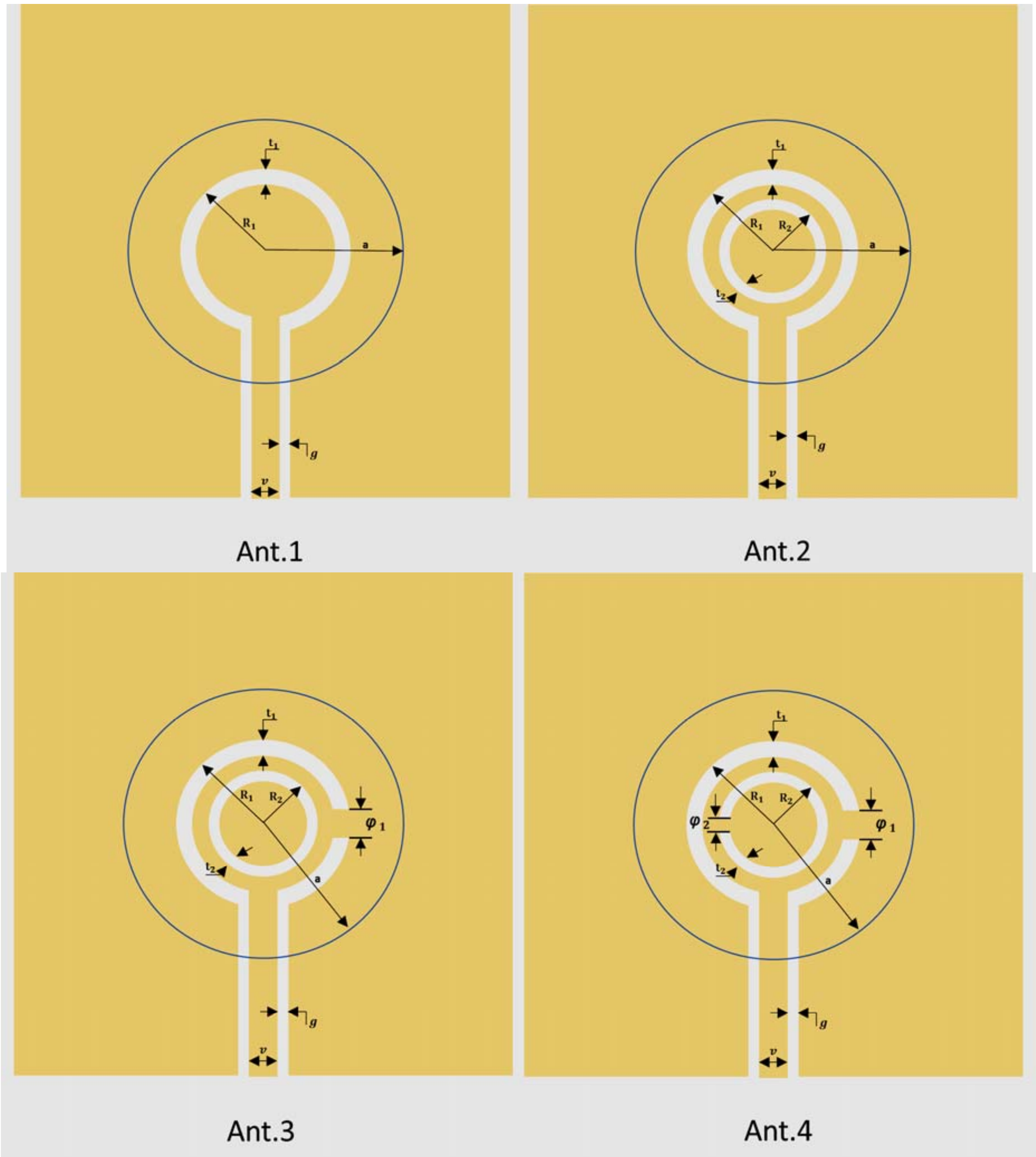


Figure 2. Feeding structures of linear (Ant.1 and Ant.2) and circular polarizations (Ant.3 and Ant4)

In this paper, a circularly polarized CDRA antenna designed using the micromachined technology and fed by CPW method is proposed to resonate at dual bands, which are 38 GHz and 60 GHz. The impact of outer and inner annular slots fed CPW DRA on the radiation characteristics is investigated by simulating the design in the CST software.

TABLE I. DIMENSIONS OF PROPOSED ANTENNA

Antenna parameters	Optimal value (mm)	Antenna parameters	Optimal value (mm)
a	1.3	Φ1	0.14
R1	0.65	Φ2	0.08
R2	0.3	g	0.05
t1	0.25	v	0.07
t2	0.1	x,y	10

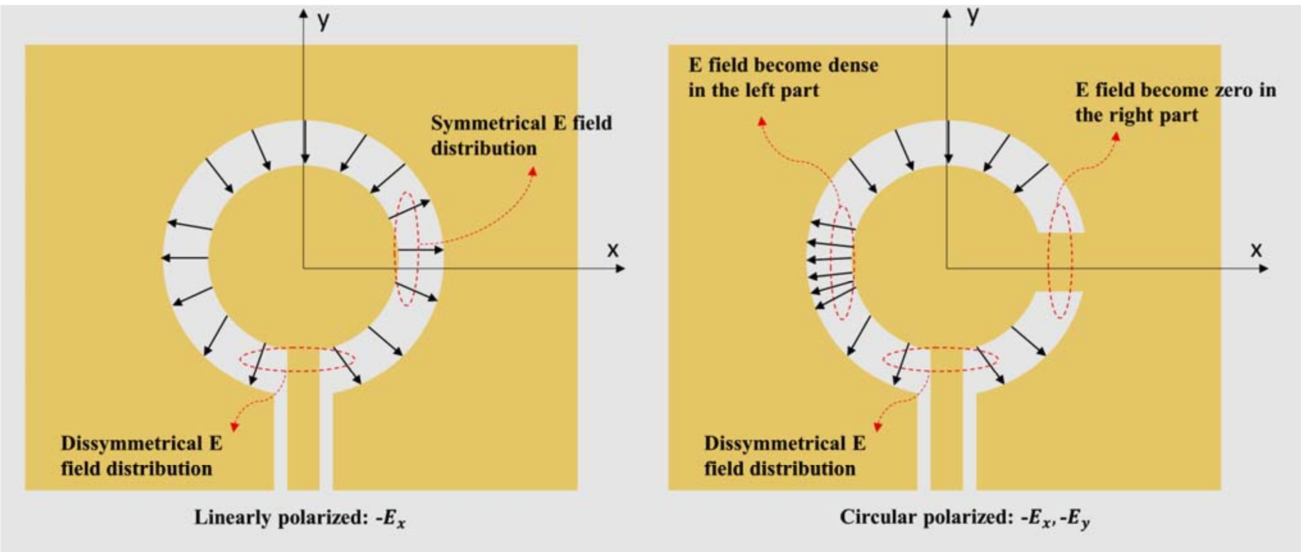
II. GEOMETRY OF PROPOSED ANTENNA

The proposed DRA configuration is shown in Fig. 1. A DRA with a cylindrical shape having a radius of a is designed by etching a silicon wafer of high resistivity 200 Ω.cm, dielectric loss tangent of 0.005, and dielectric constant εr = 11.9 [15]. The height of the DRA is 400 µm and that of the substrate is 240 µm, making the thickness of the wafer 640 µm. Due to the low thickness of the substrate, the DRA excites at all surface wave modes excluding all the fundamental mode of TM0 [16]. The excitation of the DRA is done using annular slots, which has a radius of R1 and width of t1. The feeding CPW line whose slot width is g and the separation between slots is v that placed at the end of the feeding CPW line. Those dimensions were determined to match a characteristic impedance of 50 Ω. The feeding lines are etched on the backside of the silicon wafer, as shown in Fig. 1. Shorting annular slots is introduced to generate circular polarization.

III. SHORTING GAPS METHODS FOR CIRCULAR POLARIZATION

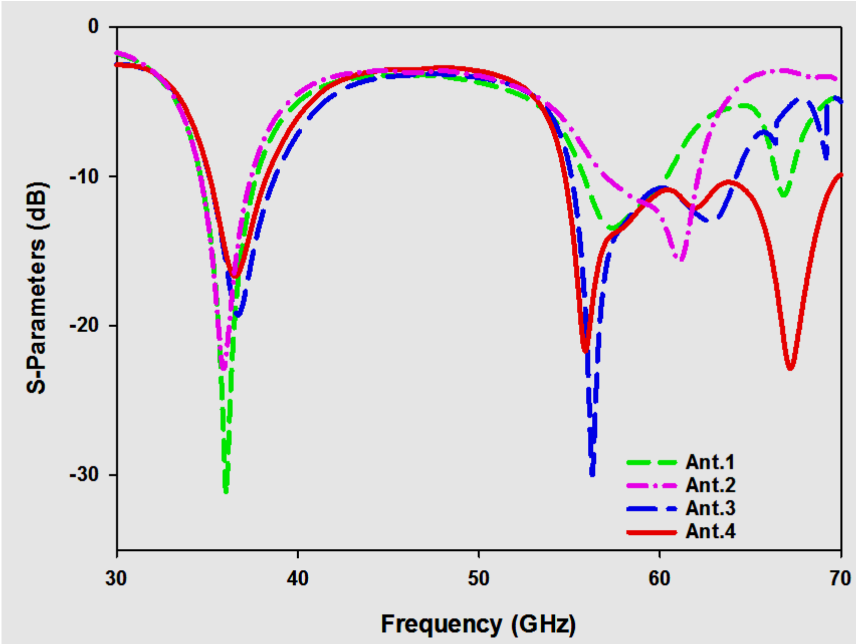
Two basic requirements need to be fulfilled in order to produce circular polarization, i.e. (1) antenna can produce two electric fields orthogonal to each other and (2) the two electric fields are identical in magnitude but have a phase shift of 90◦. A comprehensive study on techniques used to design CP microstrip patch antennas reveals that the slot antennas are used rarely, particularly when exited by a single feed. In this context, a shorting annular slot approach is suggested to produce CP features of a circular-shaped ring slot antenna.

The initial ring slot antenna design demonstrates LP performance. According to the electric field illustrated in Fig. 3(a), the electric field is symmetrical on the horizontal plane along the X-axis. In contrast, due to the presence of the CPW line in the plane along the Y-axis, the vertical electric field is asymmetrical i.e. the circular-shaped slot produces -Ey polarization parallel to Y-axis. For producing horizontal polarization, a shorting pin is introduced connecting the radiating element to the ground plate at the correct position in order to perturb the horizontal electric field. The electric field of the antenna after the perturbation is illustrated in Fig. 3(b).

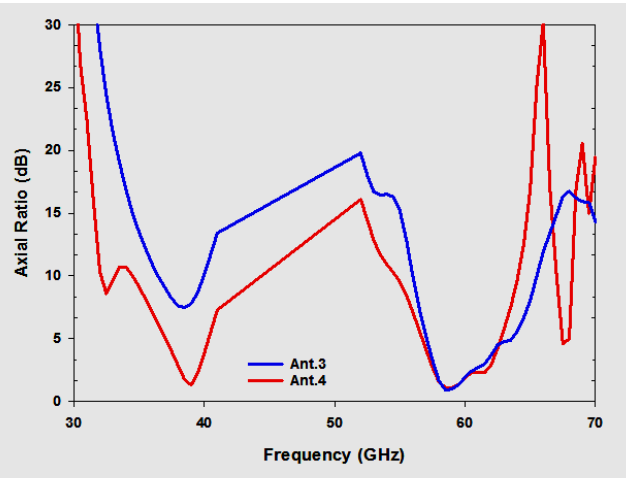


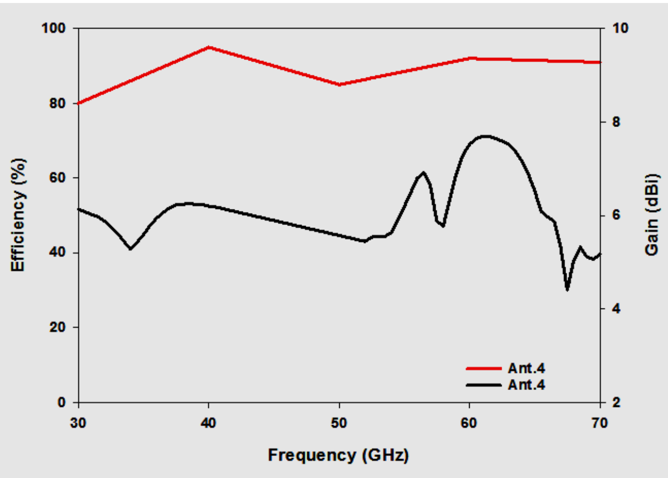
(a) (b)

Figure 3. Electric field distributions of annular slot (a) LP



(a) Impedance bandwidth





(b) AR bandwidth

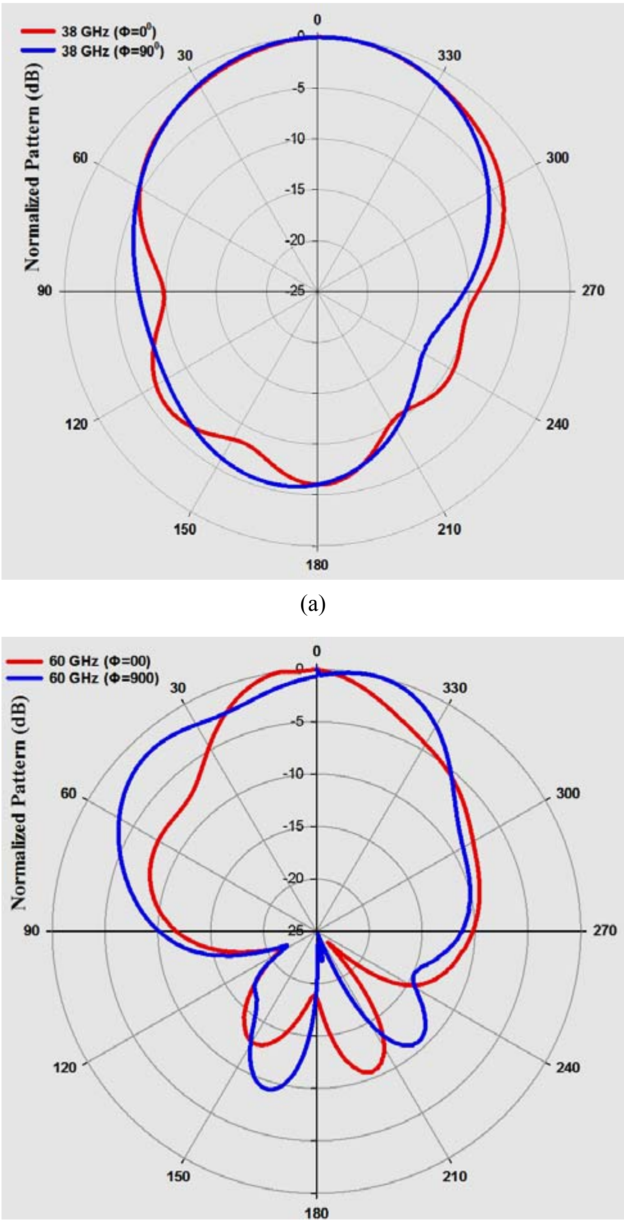
(c) Gain and efficiency

Figure 4. Simulated results (a) Impedance bandwidth (b) AR bandwidth (c) Gain and efficiency.

Due to the stub, no electric field exists in one side of the horizontal plane, while that is denser on the other side. Consequently, the electric field becomes asymmetrical on the horizontal plane as well. Accordingly, the antenna produces another polarization i.e. -Ex parallel to the X-axis. The polarizations, -Ey and -Ex are orthogonal, whereas equivalent magnitudes and a phase shift of 90◦ can be obtained by fine-tuning the size of the slot and the location of the shorting stub. The mathematical derivation for the phase shift is shown in Fig. 3(b), where ∠ Ey + ∠ Ex = 90◦. The antenna illustrated in Fig. 1(b), produces left-hand CP features. However, when the shorting stubs is placed on the left side, the antenna produces right-hand CP characteristics.

IV. RESULTS AND DISCUSSION

To investigate the effect of the inner annular slot and stabs that have used to generate the circular polarization, it proposes four configurations as shown in Fig. 2. The impedance bandwidth slightly improves with adding inner annular slot (Ant.2) from 8.01% to 8.67% at the second band (upper band), but it is reduced in the first band (lower band) from 8.57% to 7.7%. By adding the one shoring stab (Ant.3), the impedance bandwidth significantly improves from 8.67% to 19.2% and it also increases further in case of adding the second stab (Ant.4) to achieve 9.74/24.01% for both bands (38/60 GHz) as shown in Fig. 4(a). The axial ratio (AR) bandwidth of Ant.3 has just a matching in the higher band (6.5%) as demonstrated in Fig. 4(b) but Ant.4 that we proposed covers the lower and upper bands that cooperating at both 38 and 60 GHz, which correspond to 3.34% and 7.53%, respectively.



(a)

(b)

Figure 5. Radiation pattern of proposed design (a) 38 GHz (b) 60 GHz

Fig.4 (c) shows the efficiency and gain over the operating frequency which is fulfill the requirements of mm-wave applications. The radiation patterns of E-plane and H-plane have a broadside direction at 38 GHz and 60 GHz as exhibited in Fig.5.

TABLE II. A COMPARISON BETWEEN DIFFERENT LP/CP ANTENNA

References		Operating bands (GHz)	Impedance bandwidth (%)	Axial ratio bandwidth (%)
[6]		60	9.33	1.35
[17]		60	3.33	1.64
[18]		30	8.26	2.97
[19]		20/30	15.12/10.3	4.1/2.5
[20]		38/60	2/3.3	-
This work	LP	38/60	7.7/8.67	-
	CP	38/60	9.74/24.01	3.34/7.53

V. CONCLUSION

The proposed design demonstrates a wide axial ratio and impedance bandwidths that operates at 38 and 60 GHz. The efficiency and gain are 93.1/95.22 % and 6.1/7.6 dBi at 38 GHz and 60 GHz, respectively. Using both stabs at outer and inner annular slots play an important role to achieve a dual circular polarization band. The performance of CDRA make it a good candidate for mm-wave applications since it covers two bands simultaneously, which is usually make a good price difference compare a single band configuration. A pin diode could be used to switch polarization from linear to circular polarization in future work.

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