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High Gain Circularly Polarized Cylindrical DRA for mm-wave On-chip Applications

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Abstract

A circularly polarized (CP) cylindrical dielectric resonator antenna (CDRA) at millimeter wave frequency is designed to obtain improved antenna gain. The cylindrical DRA mounted on a Silicon substrate, on-chip-antenna (OCA), which is excited by simple dual conformal microstrip feeding network. Circular polarization is produced by exciting two broadside fundamental orthogonal hybrid modes inside CDRA. The proposed CP CDRA antenna is simulated using ANSYS HFSS software and it demonstrates a peak gain of 1.9 dBiC with a 3 dB axial ratio (AR) bandwidth of 4.7 % at center frequency of 53.525 GHz and impedance bandwidth of 19.3 % at center frequency of 54.9 GHz.

1 Introduction

An on-chip-antenna (OCA) is an integral component of System-on-Chip (SoC) based wireless communication systems built on a silicon substrate and its integration with chip helps realising compact designs. OCAs find their applications in biomedical implants, RFID based SoC, next generation mobile terminal, etc. [1]. Various techniques are explored to design on-chip circular polarized (CP) antennas for millimeter-wave applications. In [2], although good axial ratio (AR) bandwidth and impedance bandwidth achieved but gain was very low at - 4.4 dBiC and the structure is complex with artificial magnetic conductor (AMC). Despite good AR bandwidth in [3], gain and impedance bandwidth are low. Various CP DRA designs have been explored in the mm-wave frequency but not for on-chip mm-wave applications. To the best of the authors' knowledge, this paper presents first DRA design that finds its usage in mm-wave frequency on-chip CP applications.

2 Antenna geometry

The antenna structure consists of cylindrical-shaped dielectric block ($Ca_5Nb_2TiO_{12}$ with ε_r = 48) placed on double substrate layer comprising of Silicon Dioxide (ε_r = 4, H1 = 0.022 mm) and Silicon (ε_r = 11.9, H2 = 0.3 mm), and dimensions are chosen such that it operate at 60 GHz millimeter wave frequency [4]. The structure is excited with conformal copper metal microstrips (a practical thickness of 0.001 mm and the widths (w) of all microstrips same to provide 50 Ω impedance) placed on CDRA sidewalls at right angles to each other as shown in Fig. 1. The design specifications (in mm) of proposed CDRA are as follows: D = 0.672, h = 0.312, H_1 = 0.022, H_2 = 0.3, L_1 = 0.6, L_2 = 0.15, L_3 = 0.336, L_4 = 0.75, L_5 = 0.21, dl = 0.25, w = 0.1.

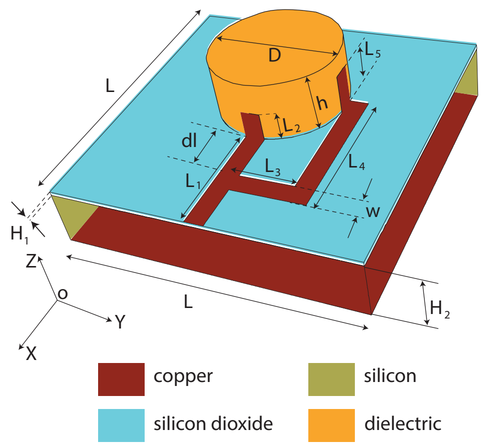

Figure 1. Antenna geometry with its dimensions

The proposed antenna design explained in steps for linear polarization (LP) and circular polarization (CP) generation.

3 Results and discussion

3.1 LP with single conformal microstrip excitation

In the proposed antenna, circular polarization is obtained in steps of realization of linearly polarized broadside fields by exciting $HE_{11\delta}$ (hybrid) modes. Firstly, linear polarization is achieved by placing single conformal microstrip (L_1, L_2 strips alone i.e. without L_3, L_4 and L_5) on DR sidewall from Fig. 1. The resonant frequency of the structure is found to be 60 GHz for the dimensions of CDRA mentioned in previous section and calculated using the below empirical formula [5].

$$fr = \frac{6.321c}{2\pi a\sqrt{(\varepsilon_r+2))}}[0.27+0.36(\frac{x}{2})+0.02(\frac{x}{2})^2] \quad (1)$$

where x= D/2h , D(=2a) is diameter and h is height of CDRA.

Parametric analysis of vertical strip (L_2) is done to get the least value of $|S_{11}|$ and it is obtained at L_2 = 0.15 mm as shown in Fig. 2.

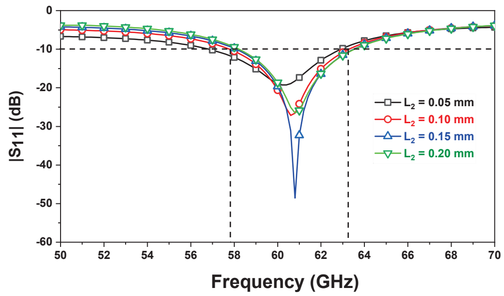

Figure 2. Parametric study of $|S_{11}|$ versus frequency for various values of vertical strip (L_2) for CDRA with single conformal microstrip excitation

3.2 CP with dual vertical strips

In order to achieve circular polarization, another conformal microstrip (L_5) is placed as shown in Fig. 1 (which is connected to L_1 via L_3 and L_4) such that an orthogonal field component can be generated inside CDRA which leads to quadrature phase between them. As shown in Fig. 1, branch L_3 starts from branch L_1 at an offset distance dl from the edge of the CDRA. The effects of L_5 and dl parameters are as shown in below figures.

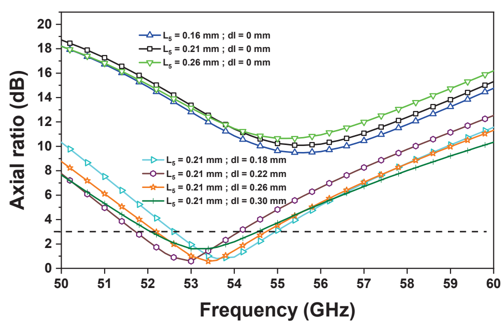

Figure 3. AR versus frequency for various values of vertical strip (L_5) and dl for CDRA with dual conformal microstrip excitation

From Fig. 3, it is noticed that the variation of L_5 alone (dl = 0) is not able to achieve AR below 3 dB, so the parametric analysis of another variable dl is introduced. The axial ratio and return loss plots for different values of dl for fixed L_5 = 0.21 mm, L_2 = 0.15 mm are shown in Figs. 4 and 5, respectively. It is observed that variation of dl significantly impacts CP performance.

From Fig. 4, it is observed that dl = 0.25 mm provides the best CP performance out of various values of dl. From above understandings, to achieve the optimum CP performance dl = 0.25 mm and L_5 = 0.21 mm values are chosen. The 3 dB axial ratio bandwidth is found to be 2.55 GHz (52.25 - 54.8 GHz) and -10 dB impedance bandwidth is

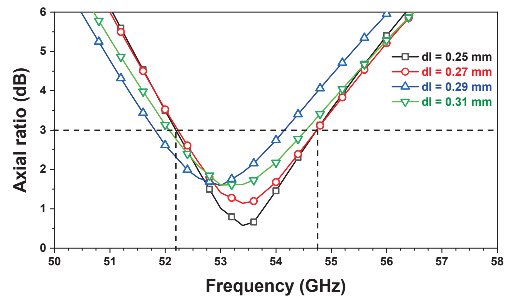

Figure 4. AR versus frequency plots for various values of dl

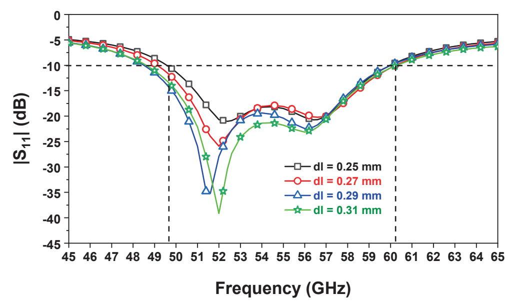

Figure 5. $|S_{11}|$ versus frequency plots for various values of dl

found to be 10.6 GHz (49.6 - 60.2 GHz) as plotted in Figs. 4 and 5, respectively.

The gain and radiation efficiency plots of CP CDRA are as shown in Fig. 6. The gain within the AR bandwidth varies from 1.5 dBiC to 1.9 dBiC and radiation efficiency is in the range of 99 %.

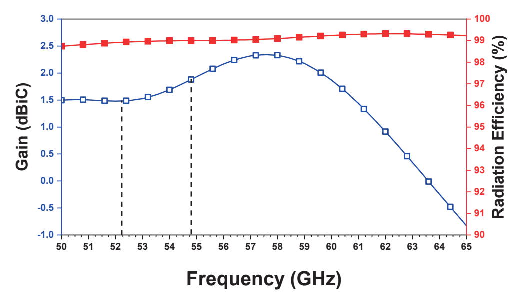

Figure 6. Gain and radiation efficiency of CP CDRA versus frequency at dl = 0.25 mm and L_5 = 0.21 mm

The radiation pattern of the antenna at the peak gain of frequency (54.8 GHz) in AR bandwidth is plotted as shown in Fig. 7. Also the radiation patterns of both LHCP and RHCP for both the E-plane and the H-plane at 54.8 GHz are illustrated in Figs. 8(a) and 8(b). The cross polarisation difference (XPD) between LHCP and RHCP in both the E-plane and the H-plane is determined to be less than 14 dB in the broadside direction.

Table 1. Comparison of proposed antenna with other on-chip CP antenna

Ref.	Structural details	-10 dB impedance bandwidth (ARBW)		3-dB axial ratio bandwidth (BW)		Gain (dBiC)
		BW in GHz	BW in %	ARBW in GHz	BW in %	
[2]	0.18 μm six metal-layer CMOS	34-105	102.15	10	16	- 4.4
[3]	90nm nine metal layer CMOS	59-64	8.13	3	4.9	< 1.1
This work	Microstrip fed CDRA on Si substrate	49.6-60.2	19.3	2.55	4.7	1.9

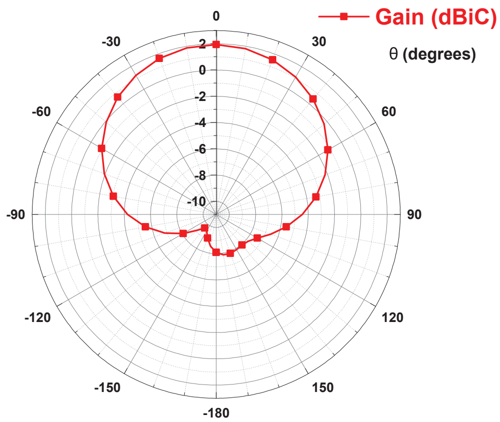

Figure 7. Radiation pattern of CP CDRA at 54.8 GHz with dl = 0.25 mm and L_5 = 0.21 mm

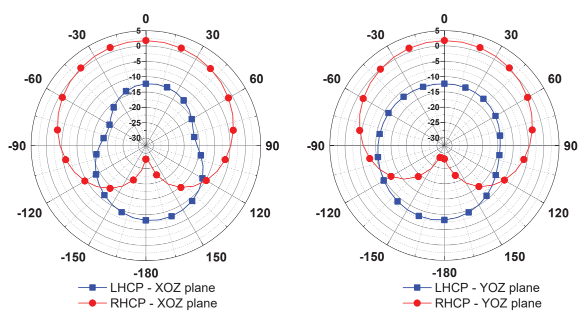

Figure 8. Radiation patterns at 54.8 GHz (a) $\phi = 0^0$ plane and (b) $\phi = 90^0$ plane

4 Conclusion

The designed circularly polarised CDRA has 3 dB AR bandwidth of 2.55 GHz at center frequency of 53.525 GHz, impedance bandwidth of 10.6 GHz at center frequency of 53.525 GHz with an improved gain of 1.9 dBiC at 54.8 GHz. The proposed antenna can find its applications in on-chip millimeter-wave frequency with enhanced gain.

References

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