Multifunctional Reconfigurable Millimeter Wave Dielectric Resonator Antenna

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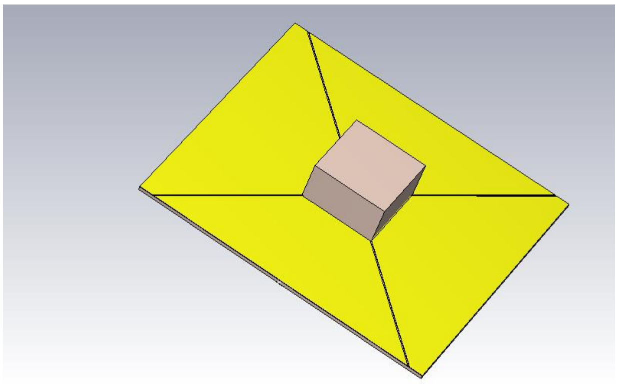
***Abstract*— A millimeter-wave (mmWave) dielectric resonator antenna (DRA) with multifunctional reconfigurability is proposed. The design integrates two PIN diodes into each arm of the feeding cross-slot, allowing electronic control over the effective arm length. This configuration enables the antenna to switch between three polarization states. Linear polarization (LP) is achieved when all diodes are either forward-biased (ON) or reverse-biased (OFF), resulting in dual-bandwidths. In contrast, circular polarization (CP) is realized when the diodes on one arm are ON and those on the other arm are OFF. Switching the biasing states of the four PIN diodes reconfigures the CP sense from left to right hand CP, or visa versa. The CP mode delivers a gain of over 6 dBic with an impedance bandwidth of ~20%.**

Keywords—DRA, circular polarisation, millimeter waves, PIN-diode. Reconfigurable antenna.

I. Introduction

Over the last decade, mmWave frequencies have received considerable interest in wireless communications, military and medical applications. However, the challenges of mmWave signals propagation are inevitable, such as environmental interference and multipath fading. Therefore, dielectric resonator antennas represent an ideal candidate for such frequencies due to the higher radiation efficiency, enhanced directivity when operating in higher-order resonance modes, and other appealing radiation characteristics [1, 2]. Besides, the implementation of reconfigurable antennas can be a critical factor in mitigating these challenges since they enable control over polarization, frequency, radiation pattern, and bandwidth [3]. In conjunction, reconfigurable DRAs have increasingly gained interest among researchers to tune either frequency, bandwidth or polarization [4, 5]. Besides, the development of CP mmWave antennas has gained popularity to achieve a reliable and robust communication system operation due to their resilience to multipath fading and misalignment between receiving and transmitting antennas.

On the other hand, published research on mmWave reconfigurable DRAs remains limited, as many techniques used to achieve reconfigurability at lower frequencies become impractical at mmWave frequencies due to the reduced device dimensions. To the authors' knowledge, a few simulation-based investigations on mmWave reconfigurable DRAs have been reported [6]–[9] In addition, an experimental study has reported a measured prototype of a pattern-reconfigurable 60 GHz DRA [10]. Besides, a prototype of a frequency reconfigurable mmWave DRA has been reported [11].



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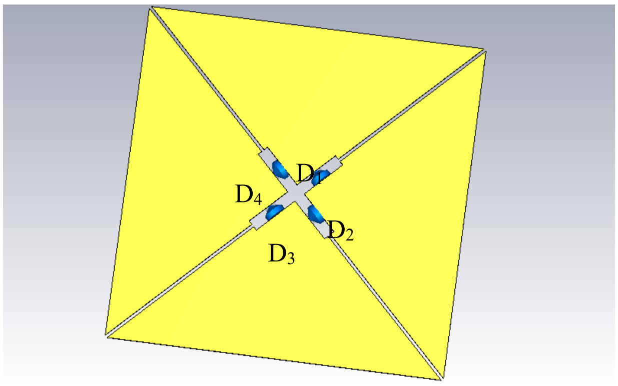

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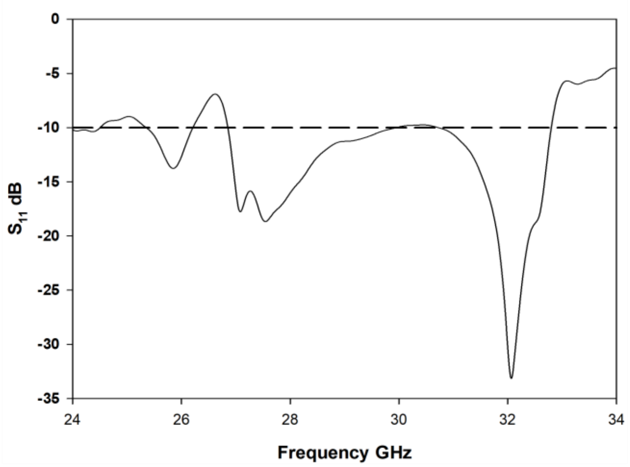
Fig. 1: (a) Reconfigurable DRA above a sectorized ground plane, (b) Feeding cross-slot including four PIN diodes.

TABLE I: BASING STATES OF THE FOUR PIN DIODES

State	*D_1, D_3 Bias*	*D_2, D_4 Bias*	*Polarization*
1	Reverse	Forward	LHCP
2	Forward	Reverse	RHCP
3	Reverse	Forward	LP
4	Forward	Forward	LP



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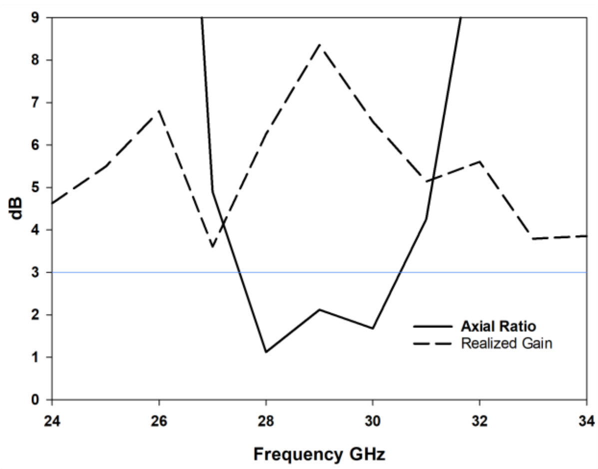

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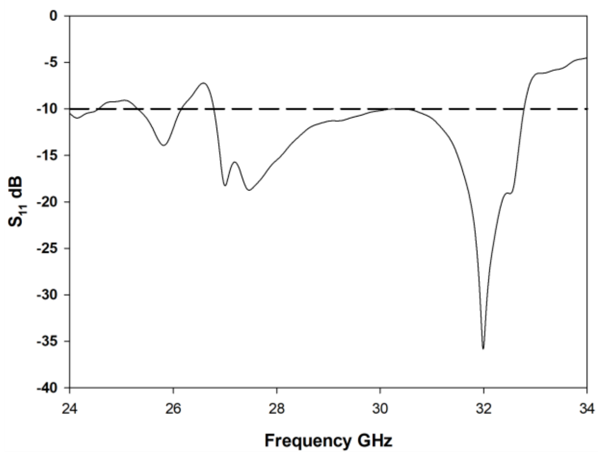
Fig. 2 Performance of the LHCP DRA when PIN diodes D_1 and D_3 are reverse biased while D_2 and D_4 are forward biased: (a) Reflection coefficient, (b) AR & gain.



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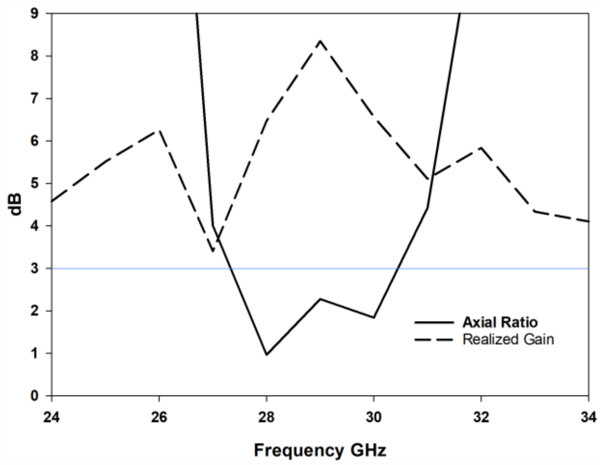

(b)

Fig. 3 Performance of the RHCP DRA when PIN diodes D_2 and D_4 are reverse biased while D_1 and D_3 are forward biased: (a) Reflection coefficient, (b) AR & gain.

However, a mmWave DRA configuration that offers multifunctional, e.g. bandwidth and polarization, reconfigurability has not been reported earlier. Therefore, such a design is proposed in this study for a rectangular DRA that is fed using a cross slot loaded by 4 PIN diodes. The reconfigurable DRA has been designed and simulated using CST Microwave Studio.

II. ANTENNA CONFIGURATION

An Alumina DRA, ε_r=9.9, has been considered with respective length, width, and height of 5.2, 5.2, and 2.9 mm. As illustrated in Fig. 1(a), the DRA has been placed on a 20 mm ground plane above a Roger RO4350B substrate. The ground plane has been divided into four sectors separated by a gap of 0.1 mm to facilitate the DC biasing. The antenna offers four reconfigurable states with various polarizations and frequencies. Fig. 1(b) demonstrates the feeding cross-slot with physically equal arm lengths. However, on each slot arm, there are two PIN diodes that can reduce the effective arm slot to 1.7 mm when they are forward biased, compared to 3.2 mm when they are reverse biased. This in turn reconfigures the polarization as well as the impedance bandwidth. On one arm of the slots, the diodes have been defined as D_1 and D_3, and on the other arm, D_2 and D_4. Four biasing states have been considered, as illustrated in Table I. It should be noted that such an arrangement simplifies the biasing of the four PIN diodes to be like that of two PIN diodes. Also, circular polarization is achieved in States 1 and 2, albeit with opposite senses with a wide impedance bandwidth, and linear polarization in States 3 and 4 with dual, albeit narrower, bandwidths.

III. RESULTS

The configuration of Fig. 1 has been simulated using the CST time domain solver, considering 4 biasing states. In State 1, the diodes are biased so that the 1st arm length is L_{s1}=3.2 mm, and the 2nd arm length is L_{s2}=1.7 mm, which produces a LHCP radiation. As illustrated in Fig. 2(a), a wide impedance bandwidth of ~20% has been achieved over a frequency range of 26.9-32.8 GHz. Simultaneously, the lowest axial ratio (AR) of 1.1 dB has been achieved at 28 GHz with an AR bandwidth of 10.3% as demonstrated in Fig. 2(b). In addition, a maximum realized gain of 8.5 dBic has been achieved at 29 GHz with a radiation efficiency of 85%. In the 2nd state, the diodes' biasing has been chosen to achieve L_{s1}=1.7 mm and L_{s2}=3.2 mm, which inversely change the polarization sense to RHCP with the identical impedance and

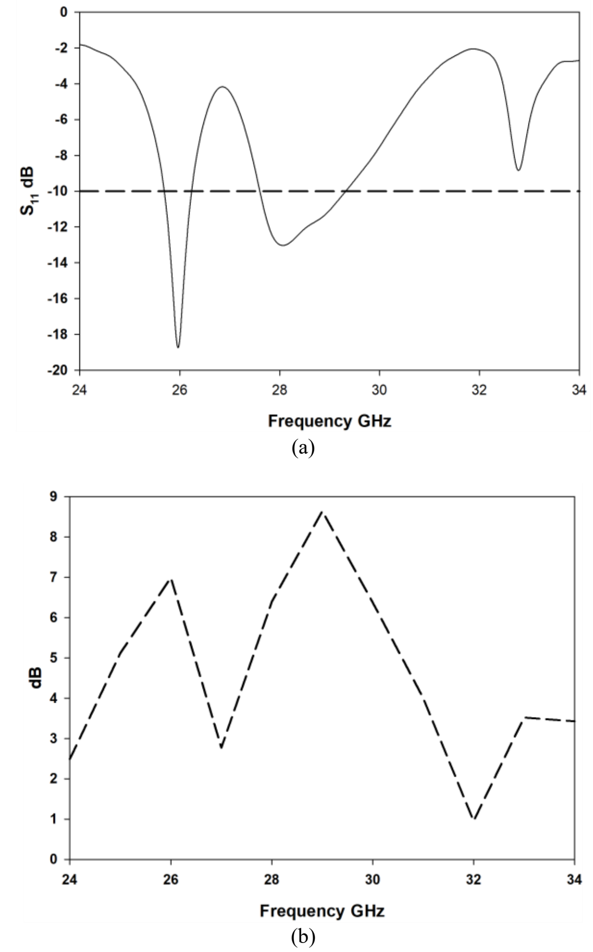

Fig. 4 Performance of the LP DRA when all PIN diodes are reverse biased: (a) Reflection coefficient, (b) Realized gain.

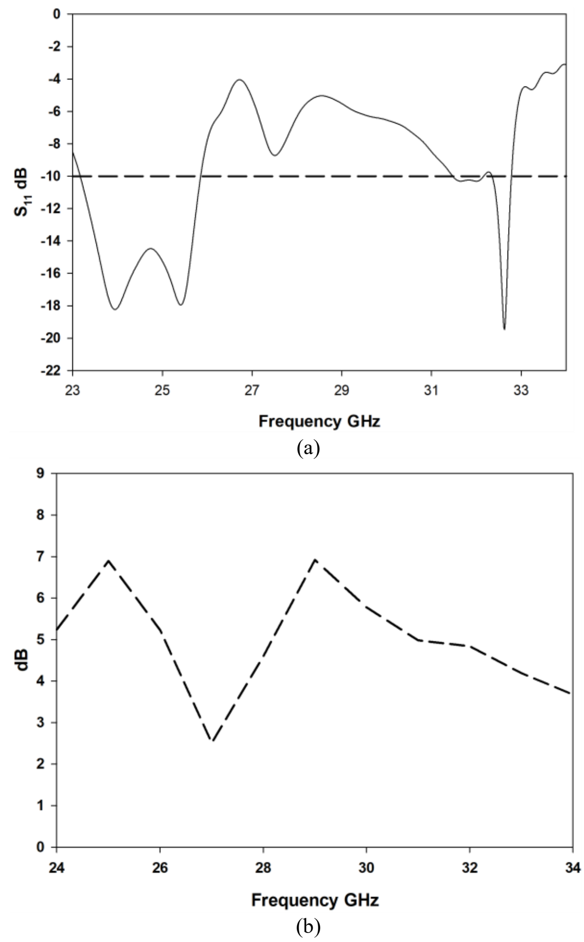

Fig. 5 Performance of the LP DRA when all PIN diodes are forward biased: (a) Reflection coefficient, (b) Realized gain.

AR bandwidth as well as gain as in the RHCP case, as illustrated in Fig. 3.

In the 3rd biasing state, all diodes are OFF with equal cross-slot arms' length of L_{s1}=L_{s2}=1.7 mm, which offer LP radiation. The respective impedance bandwidths of 2.5% and 6% were achieved over 25.7-26.3 GHz and 27.6-29.3 GHz. Operating bands in these states offer a radiation efficiencies of 85% and 90% at the lower and upper frequency bands, respectively, corresponding to respective realized gains of 7 dBi and 9 dBi. In State 4, all the diodes are forward biased, which results in equal length of L_{s1}=L_{s2}=3.2 mm for the two cross-slot arms, resulting in an LP DRA with a dual-band operation. The first band has an impedance bandwidth of 11.4% extending from 23.2-26 GHz. On the other hand, the second bandwidth is 1.3% over a frequency range of 32.36 -32.8 GHz. Operating bands in these states offer a radiation efficiencies of 76% and 74% at the lower and upper frequency bands, respectively, corresponding to respective realized gains of 7 dBi and 5 dBi

IV. CONCLUSION

The multifunctional reconfigurability of a cross-slot-fed mmWave rectangular DRA has been demonstrated using four PIN diodes. The DC biasing has been simplified by focusing on four states only that offer polarization and bandwidth reconfigurability over a frequency range of 23-33 GHz. The CP radiation has been achieved with a wide impedance bandwidth of ~20% for both LHCP and RHCP. On the other hand, the linear polarization states offer dual-bandwidth operations albeit at different frequency ranges. This is expected since the cross-slot arm lengths are different in the LP radiation scenarios. In all cases satisfactory gain and bandwidths have been achieved with high radiation efficiencies.

V. ACKNOWLEDGEMENT

This work is partly supported by the Engineering and Physical Research Council (EPSRC) under grant EP/X041395/1

REFERENCES

[1] Y. -M. Pan, K. W. Leung and K. -M. Luk, "Design of the millimeter-wave rectangular dielectric resonator antenna using a higher-order mode," IEEE Trans. on Antennas and Propagat., vol. 59, no. 8, pp. 2780-2788, Aug. 2011.

[2] A. A. Abdulmajid, S. Khamas, and S. Zhang, "Wide bandwidth high gain circularly polarized millimetre-wave rectangular dielectric resonator antenna," Prog. In Electromag. Res., vol. 89, pp. 171-177, 2020.

[3] R. W. Asfour, S. K. Khamas and E. A. Ball, "Multifunctional reconfigurable millimeter-wave array antenna," IEEE Access, vol. 13, pp. 4267-4280, Jan. 2025.

[4] J. Ren and T. Yuan, "A frequency-reconfigurable dielectric resonator antenna with a water layer," IEEE Antennas and Wireless Propagat. Lett., vol. 22, no. 6, pp. 1456-1460, June 2023.

[5] Z. Chen, Z. Song, H. Liu, X. Liu, J. Yu and X. Chen, "A compact phase-controlled pattern-reconfigurable dielectric resonator antenna for passive wide-angle beam scanning," IEEE Trans. on Antennas and Propag., vol. 69, no. 5, pp. 2981-2986, May 2021.

[6] M. J. Al-Hasan, T. A. Denidni and A. R. Sebak, "Millimeter-wave fss-based dielectric resonator antenna with reconfigurable radiation pattern," 2014 IEEE Antennas and Propag. Soc. Int. Symp. *(APSURSI)*, Memphis, TN, USA, pp. 1441-1442, July 2014.

[7] J. Li, T. A. Denidni and Q. Zeng, "High gain reconfigurable millimeter-wave dielectric resonator antenna," 2015 IEEE Int. Symp. on Antennas and Propag. & USNC/URSI National *Radio Science Meeting*, Vancouver, BC, Canada, pp. 444-445, July 2015.

[8] J. Li, T. A. Denidni and Q. Zeng, "High gain reconfigurable millimeter-wave dielectric resonator antenna," 2015 IEEE Int. Symp. on Antennas and Propagat. & USNC/URSI National Radio Science Meeting, Vancouver, BC, Canada, pp. 444-445, July 2015.

[9] J. K. Rai, P. Ranjan and R. Chowdhury, "Wideband frequency reconfigurable dielectric resonator antenna with defected ground plane for 5G millimeter wave application," 2024 IEEE Int. Conf. on Interdisciplinary Approaches in Tech. and Management for Social Innovation (IATMSI), Gwalior, pp. 1-4, March 2024.

[10] I. Ben Mabrouk, M. Al-Hasan, M. Nedil, T. A. Denidni and A. -R. Sebak, "A novel design of radiation pattern-reconfigurable antenna system for millimeter-wave 5G applications," IEEE Trans. on Antennas and Propag., vol. 68, no. 4, pp. 2585-2592, April 2020.

[11] A. Soltan, R. Asfour, and S.K. Khamas. “Frequency-reconfigurable millimeter-wave rectangular dielectric resonator antenna”. Sensors, 24(12):3906. June 2024.