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Two Port Array based Circular Polarized Dielectric Resonator Antenna for mm-wave IOT Application: A Study

Sharda Singh
M. Tech. Scholar, Department of Electronics and Communication, Bhabha Engineering Research Institute, Bhopal
Prof. Suresh S. Gawande
Guide, Department of Electronics and Communication, Bhabha Engineering Research Institute, Bhopal

Abstract
The growing demand for high-data-rate, low-latency, and energy-efficient wireless communication has accelerated research in millimeter-wave (mm-wave) antennas for Internet of Things (IoT) applications. Dielectric resonator antennas (DRAs) have emerged as a promising candidate due to their low loss, compact structure, and high radiation efficiency at higher frequencies. In this study, a two-port array-based circularly polarized dielectric resonator antenna (CP-DRA) is proposed for mm-wave IoT applications. The design achieves circular polarization through orthogonal mode excitation and precise feed alignment. The two-port array configuration improves bandwidth, gain, and polarization purity, making it suitable for massive device connectivity in IoT systems. The simulated results demonstrate wide impedance bandwidth, enhanced axial ratio bandwidth, and stable radiation patterns, confirming its potential for mm-wave IoT networks.

Keywords: - Dielectric resonator antennas, Circularly Polarized, IOT Application

1. INTRODUCTION

The rapid growth of the Internet of Things (IoT) has introduced new challenges in wireless communication, particularly in terms of connectivity, efficiency, and reliability. With billions of interconnected devices expected to be deployed in applications ranging from smart cities and healthcare monitoring to industrial automation and autonomous vehicles, the demand for high data rate, low latency, and energy-efficient communication systems is greater than ever. To address these challenges, researchers and industries are turning toward millimeter-wave (mm-wave) frequency bands, which offer large unused bandwidth and the potential for multi-gigabit per second data transmission. However, designing suitable antennas for mm-wave IoT applications is a complex task due to the stringent requirements for compactness, efficiency, polarization diversity, and robustness against environmental challenges.

Among the various antenna technologies, dielectric resonator antennas (DRAs) have attracted significant attention for mm-wave communication. Unlike conventional microstrip antennas, DRAs offer higher radiation efficiency and lower conductor loss at high frequencies. They also provide flexible design configurations due to the availability of different shapes such as cylindrical, hemispherical, and rectangular geometries. By properly exciting different resonant modes, DRAs can be designed to achieve desirable characteristics such as broad impedance bandwidth and circular polarization. These features make DRAs an excellent candidate for IoT devices operating in the mm-wave spectrum.

Circular polarization (CP) is particularly important in IoT networks where devices are often randomly oriented or mobile. A linearly polarized antenna suffers from polarization mismatch losses when the transmitting and receiving devices are not aligned. In contrast, circularly polarized antennas mitigate this issue by radiating and receiving signals regardless of orientation, thus enhancing link reliability. Moreover, CP antennas provide better performance in multipath-prone environments by reducing fading effects, which are common in dense IoT deployments such as smart homes and industrial settings.

To further improve antenna performance for mm-wave IoT systems, array configurations are frequently employed. Antenna arrays increase gain, enable beam steering, and provide better coverage, which is crucial for high-density IoT environments. In particular, a two-port array-based design enhances not only the overall gain but also provides additional benefits such as polarization diversity and improved isolation between ports. The two-port configuration allows simultaneous excitation of orthogonal modes with proper phase difference, thereby achieving wideband circular polarization. This makes the antenna highly suitable for applications requiring reliable, high-speed, and orientation-independent communication.

Recent research has shown that two-port circularly polarized DRAs can achieve wide axial ratio bandwidth, high gain, and stable radiation patterns at mm-wave frequencies. By optimizing the dielectric constant, feed structure, and spacing between elements in the array, it is possible to obtain improved impedance matching and port isolation. These characteristics make the proposed two-port array-based circularly polarized DRA design ideal for IoT applications that rely on seamless connectivity across heterogeneous environments.

2. LITERATURE REVIEW

Ming Xu et al. [1], this work presents a circularly polarized (CP) multiple-input multiple-output (MIMO) dielectric resonator antenna (DRA) for 5G millimeter-wave (mm-wave) applications. Two high-order mode CP DRAs make up this MIMO antenna, and they make use of the altered cross slots to produce the CP fields. To separate the two complementary split ring resonators (CSRR), the metal ground's surface current, which can improve the antenna's isolation and axial ratio upon excitation of each port. A simulated impedance is obtained using the suggested MIMO antenna. An axial ratio (AR) bandwidth (AR < 3 dB) from 25.49 to 31.18 GHz and a bandwidth from 25.41 to for fifth-generation wireless communication applications, 29.52 GHz is the frequency. The assessed outcomes demonstrate that the antenna has isolation of less than 25 dB and an overlapped bandwidth of 11% over the range of frequencies. 5.84 (6.24) dBic is the measured average (peak) gain between 26.5 GHz and 29.5 GHz 6.90 (7.27) dBic for port 2 and for port 1.

Sanghmitra et al. [2], a perturbed Dielectric Resonator based MIMO Antenna Coupled with sectored Ring-shaped Feeding is proposed for 5G millimeter wave Applications. The feeding is used to generate circular polarization in DR. The introduction of triangular perturbation in ring shaped DRA with optimized dimensions helps to obtain wide impedance bandwidth, which is 23.56GHz-24.9GHz. Consequently, the highest efficiency of 98.4% in desired frequency bands and the axial ratio (AR) bandwidth of 5.5% have been observed. The MIMO antenna performance is justified by computing the envelope correlation coefficient (ECC) and diversity gain (dB).

L. X. Cui et al. [3], for fifth generation (5G) millimeter-wave (mm-Wave) applications, a novel type of dual-band hybrid dielectric resonator antenna (DRA) with its array design and extended dual-polarized version is proposed in this communication. Four resonances can be produced in the 28 and 39 GHz frequency bands by the hybrid antenna that combines three different types of resonators: strip, slot, and DRA. The lower frequency band of 26.41–30.42 GHz is covered by the strip and slot modes in this design, while the upper frequency band of 36.05–40.88 GHz is covered by the DRA's TE111 and TE131 modes. It demonstrates that simultaneous coverage of the 5G mm-wave bands n257 and n260 is possible. It should be noted that the compact dimensions of our suggested hybrid antenna is 0.34λ01×0.36λ01×0.1λ01 (where λ01 is the free-space wavelength at 28 GHz). A 1x5 antenna array with beam steering capability is constructed and simulated based on the antenna element's small size. The 28 and 39 GHz frequency bands yield wide steering angles of ±50° and ±40°, respectively. Additionally, an extended dual-polarized antenna structure that offers comparable two-port impedance and radiation performance to its single-port counterpart is also described and measured.

Y. X. Wang et al. [4], a dual-band dielectric resonator antenna (DRA) with a high frequency ratio in the millimeter-wave region is presented in this letter. Working at 16 and 38 GHz, respectively, the TE111 and TE131 modes combine to generate a huge frequency ratio of 2.36. A microstrip-fed slot is used to stimulate these two DRA modes. Then, to attain high gain in the millimeter-wave band, a 1 × 4 DRA array is built. Furthermore, this design boasts wideband capabilities made possible by printing circuit board technology, as well as ease of manufacture. In the 13.3–19 GHz (35.3%) and 36.3–40 GHz (9.7%) impedance bandwidths, respectively, a gain of 10.6 and 14.2 dBi can be achieved. This design shows promise for use in millimeter-wave communication, as seen by the good agreement between simulation and measurement.

J. Kulkarni et al. [5], a dual-polarized, small quad-port multiple-input multiple-output (MIMO) antenna is suggested. A T-shaped microstrip line feeds the modified rectangular radiators in each of the four antenna elements, which are backed by a partial ground plane. An X-shaped strip connects the four antenna elements, and a modified plus-shaped structure isolates them, providing isolation of more than -18 dB. The antenna has a compact size of only 36 mm by 27 mm and shows a perfectly overlapping 3 dB axial-ratio bandwidth of 19.32% (7.90–9.59 GHz) with a 10 dB impedance bandwidth. Furthermore, it can achieve an envelope correlation coefficient of less than 0.01 in both isotropic and actual propagation scenarios, a gain of more than 3.5 dBi, and an efficiency of more than 70%.

Y. M. Fan et al. [6], a dual-band stacked dielectric resonator (DR) antenna (DRA) with 2.8GHz and 4.8GHz band operation is proposed in this study. The DRA is made up of two stacked cylindrical dielectric resonators (CDRs) that are fed by a microstrip line and a slot. Its highest gains are 5.29 dBi (at 2.79 GHz) and 5.20 dBi (at 4.68 GHz), respectively, while its -10dB bandwidths are 2.78-2.91 GHz (5%) and 3.89-5.13 GHz (29.6%) in the 2.8GHz and 4.8GHz bands, respectively. 5G communications can make advantage of the antenna.

R.Z Huang et al. [7], for 5G millimeter wave wireless communications, a dual-band circularly polarized (CP) rectangular dielectric resonator antenna (DRA) is proposed in this study. A rectangular ceramic dielectric resonator (DR) and a unique modified cross-flower exciting

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(MCF) slot make up the suggested DRA. The DR's fundamental modes, TE δ 11x/TE 1 δ 1 y, and higher-order modes, TE δ 13x/TE 1 δ 3 y, can be stimulated to produce CP dual-band characteristics with the aid of the small MCF feeding slot. Additionally, to increase the DRA bandwidth, the MCF slot functions as a radiator at 26 GHz and 39 GHz. More significantly, the lower and higher bands of these two operational bandwidths can be individually regulated. The suggested DRA is created, constructed, and measured. According to the measured results, the suggested dual-band CP DRA achieves peak gains of 5.62 dBic and 6.74 dBic for the lower and upper bands, with 3 dB axial-ratio (AR) bandwidths of 19.8% and 7.8%.

J. Iqbal et al. [8], for dual-function communication, including GPS and WLAN, a single-fed dual-band circular polarized (CP) dielectric resonator antenna (DRA) was created in this study. First, a linearly polarized singly fed-DRA was designed as the first step in the suggested design process. The cross-shape conformal metal strip was tuned to excite the fundamental and the high-order mode in the two frequency regions in order to achieve CP fields. The rectangular DRA was covered with a parasitic metallic strip to increase and broaden the axial ratio (AR) bandwidth and impedance. The AR bandwidth in both frequency bands significantly improved as a result of this step, however the lower band had a 2.73% improvement while the upper band saw a 6.5% impact. To verify its functionality, a prototype was created and built. Wideband impedance bandwidths of 6.4% and 25.26%, as well as 3-dB axial ratios (AR) of 21.26% and 27.82%, were confirmed by the test results of the suggested antennas. The prototype is a good fit for both wireless local area networks (WLANs) and global positioning systems (GPS).

3. PARAMETRIC OPTIMIZATION

The design parameters that govern the input impedance are substrate height, feed-point location and gap width.

Effect of Feed Point Location

For three different feed-point locations from the center of the patch, there is variation in the VSWR with frequency, shown in Fig. 2. With increase in frequency, the input impedance moves in a clockwise direction in the smith chart [7, 8]. As x moves from 1mm (feed-point is shifted to the edge), the input impedance loci shifts in the right direction on the smith chart implying that the impedance is increasing. A perfect match of 50 ohm feed-line is obtained for 4.75 mm along –x direction, which gives a bandwidth of 3.21 GHz for VSWR 2.

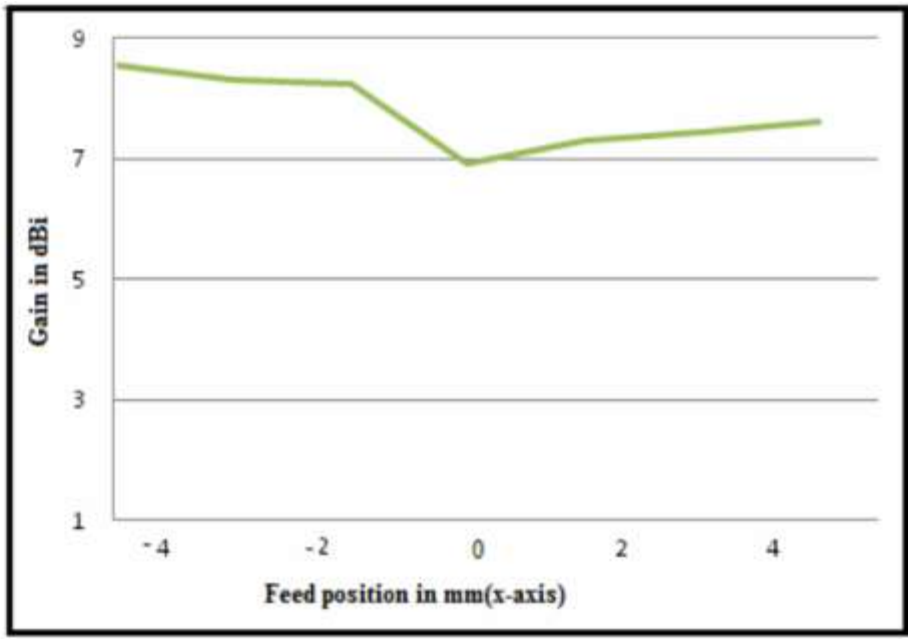

Fig. 1: Gain variations of microstrip antenna

Effect of Gap Width

Gap width governs the interaction between the coupled patch and the main patch. Increase in the gap width decreases the size of the impedance loci, because the interaction between the resonators decreases. Also the impedance loci shift toward the left side of the smith chart is shown in Fig. 3(a) and (b). Further increase in the gap width decreases the size of the impedance loci and the loop disappears for larger gap width. In this case, the gap width is varied from 0.0073 to 0.033. The optimized value of 0.0073 gives good bandwidth thereby increasing the interaction between the co-patch and the main patch [9].

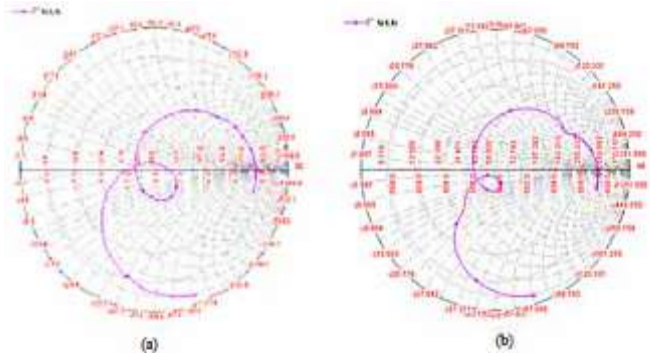

Fig. 2: (a) Smith chart for optimized gap width (b) Smith chart for increased gap width

Effect of Slot

Cutting slots in the radiating patch reduces the resonant frequency. Slot is considered as capacitive reactance on the patch. For a given slot length, resonance frequency decreases with increase in slot width. The increase in slot width increases the impedance linearly. For maximum slot length (15mm), the resonant frequency variations are minimum and maximum for minimum slot length (5mm). Slot loaded microstrip antenna is analyzed using equivalent circuit concept, in which the capacitive reactance of the slot on the patch counteract the inductive reactance of the probe. Fig. 4 shows the variation of bandwidth for various slot lengths [10, 11].

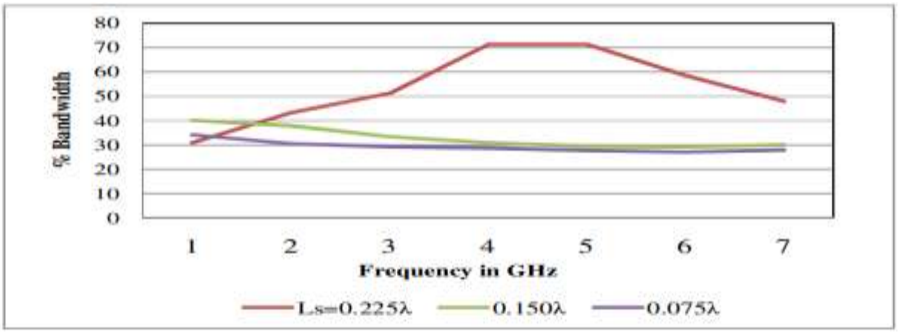

Fig. 3: Bandwidth variations for various slot lengths

Effect of Height, h

With increase in height h, from 0.083 to 0.093 the fringe fields from the edges increase, which increases the extension length and hence the effective length, thereby decreasing the resonance frequency. The bandwidth of the antenna increases from 1.575 GHz to 3.21 GHz, for the optimized height 0.093. The increase in the probe inductance of the feed moves the input impedance in clockwise, thereby introducing inductive shift [12].

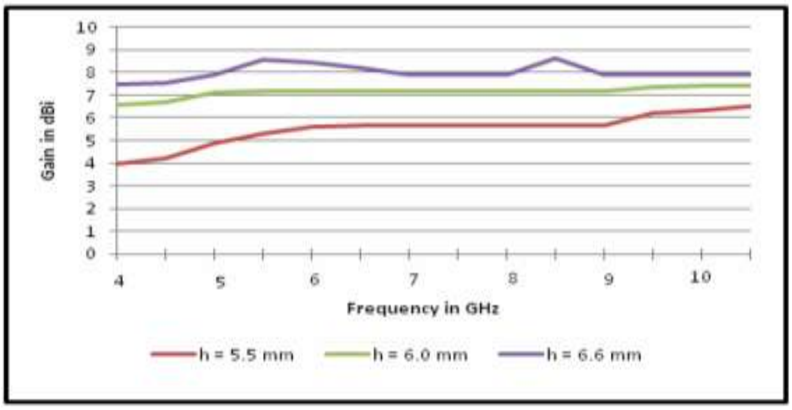

Fig. 4: Gain variations of microstrip antenna

Effect of Width, W

Patch width affects the bandwidth to a larger extent [13]. A larger patch width increases the bandwidth, radiated power and the radiation efficiency. Patch width is chosen greater than the patch length, with good excitation. It is observed that the patch width various from 0.45Ʒ<W

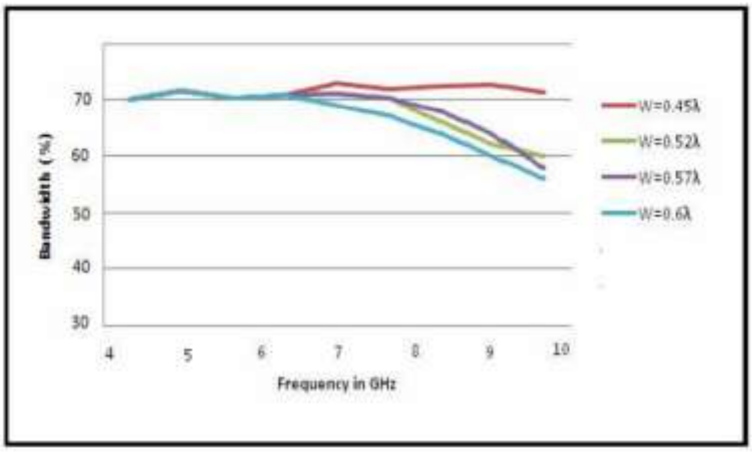

Fig. 5: Bandwidth variations of microstrip antenna

4. CONCLUSION

This study has presented the concept and design approach of a two-port array-based circularly polarized dielectric resonator antenna (CP-DRA) for millimeter-wave IoT applications. With the exponential growth of IoT devices requiring seamless connectivity, the proposed antenna addresses key challenges such as polarization mismatch, high path loss at mm-wave frequencies, and the need for compact, energy-efficient designs. By employing a dielectric resonator structure, the antenna achieves low conductor loss, high radiation efficiency, and compact size, which are essential for integration into portable and embedded IoT systems.

The use of a two-port array configuration significantly enhances the antenna's performance by providing high gain, improved impedance bandwidth, and stable circular polarization. The dual-port excitation ensures wide axial ratio bandwidth with strong isolation, allowing the antenna to maintain robust polarization purity and reliable operation under varying device orientations. These features make it highly suitable for dense IoT environments where devices are randomly positioned and exposed to multipath propagation effects.

Furthermore, the simulated characteristics of the proposed design demonstrate wide impedance bandwidth, enhanced axial ratio bandwidth, high isolation between ports, and stable radiation patterns at mm-wave frequencies. Such results confirm that the two-port array-based CP-DRA can play a pivotal role in next-generation IoT systems, 5G and beyond networks, smart city infrastructures, vehicular communication, and wearable technologies.

In conclusion, the two-port array-based circularly polarized DRA offers an efficient, reliable, and scalable solution for mm-wave IoT communication, meeting the growing demand for high data rate, low latency, and robust wireless connectivity. Future work will focus on fabrication, experimental validation, beamforming integration, and large-scale array extension, enabling its adoption in real-world IoT scenarios.

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