A Study of Circularly polarized MIMO Filtering Dielectric Resonator Antenna for sub-6 GHz

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Abstract

The increasing demand for high-speed and reliable communication in 5G and future wireless networks necessitates the development of efficient antenna systems operating in the sub-6 GHz frequency band. This paper presents a comprehensive study on a Circularly Polarized (CP) Multiple-Input Multiple-Output (MIMO) Filtering Dielectric Resonator Antenna (FDRA) designed for sub-6 GHz applications. The proposed antenna combines the advantages of MIMO technology, circular polarization, dielectric resonator structure, and integrated filtering to achieve high performance in compact dimensions. The incorporation of filtering functionality within the antenna eliminates the need for external bandpass filters, thereby reducing system complexity and insertion loss. Circular polarization enhances the robustness of the communication link by mitigating polarization mismatch and improving signal quality in multipath environments. The dielectric resonator structure ensures high radiation efficiency, miniaturization, and thermal stability. Simulation results show that the antenna achieves a wide impedance bandwidth, high isolation (>20 dB) between MIMO elements, and a broad axial ratio bandwidth (ARBW), all within the sub-6 GHz range. The proposed FDRA design is suitable for compact and integrated wireless systems, making it a strong candidate for next-generation wireless communication devices and base stations operating in the mid-band 5G spectrum.

Keywords: Circularly Polarized (CP), Multiple-Input Multiple-Output (MIMO), Dielectric Resonator

I. INTRODUCTION

The rapid advancement of wireless communication, particularly with the emergence of fifth-generation (5G) and upcoming sixth-generation (6G) technologies, has led to an increased demand for high-performance, compact, and multifunctional antennas. The sub-6 GHz frequency band, a key part of the 5G spectrum, offers a balanced trade-off between coverage and capacity, making it a prime target for reliable wireless communication. To meet the stringent requirements of these systems, antennas must offer wide bandwidth, high gain, stable radiation characteristics, and efficient spectrum utilization.

Multiple-Input Multiple-Output (MIMO) antenna technology plays a crucial role in improving data throughput, reliability, and spectral efficiency in modern communication systems. However, implementing MIMO in compact devices presents challenges such as mutual coupling between antenna elements, complex filtering needs, and space constraints. The integration of filtering capability within the antenna itself has emerged as an effective way to overcome some of these challenges. Filtering antennas can reject unwanted frequencies and reduce the need for external filter circuits, thereby improving efficiency and reducing system complexity [1, 2].

Dielectric Resonator Antennas (DRAs) have gained significant attention in recent years due to their inherent advantages, including high radiation efficiency, low dielectric losses, small size, and suitability for high-frequency applications. DRAs are easily integrable with modern substrates and allow a wide variety of excitation techniques to achieve desired polarizations. Furthermore, their 3D structure and high-Q nature make them highly suitable for incorporating circular polarization and filtering characteristics [3].

Circular polarization (CP) is another vital feature in antenna design, especially for mobile and satellite communication. It helps to eliminate polarization mismatch losses and provides better performance in multipath environments. CP antennas are preferred in dynamic orientations and complex urban environments due to their ability to maintain link quality regardless of the relative orientation between transmitting and receiving antennas [4, 5].

Combining MIMO technology with circular polarization and filtering dielectric resonator structures leads to a highly efficient, compact antenna solution. Such integration not only enhances system performance but also supports simultaneous transmission and reception of signals with minimal interference and distortion. However, designing a circularly polarized MIMO antenna with filtering characteristics using dielectric resonators introduces challenges such as maintaining high isolation between elements, achieving broad axial ratio bandwidth, and preserving impedance matching across the operating band [6].

This study presents a novel Circularly Polarized MIMO Filtering Dielectric Resonator Antenna (FDRA) specifically designed for sub-6 GHz wireless communication applications. The proposed antenna is engineered to deliver wide impedance bandwidth, high isolation, low envelope correlation coefficient (ECC), and excellent axial ratio performance. Filtering is achieved through careful design of the feeding and radiating structures, thereby reducing the need for external RF filtering components [7, 8].

The proposed FDRA design is analyzed through extensive simulation using full-wave electromagnetic software to evaluate key performance parameters such as reflection coefficient (S11), mutual coupling (S21), gain, efficiency, and axial ratio. The simulation results confirm the suitability of the design for compact, high-performance MIMO systems, particularly in 5G mid-band applications. This work contributes to the development of integrated, multifunctional antennas capable of meeting the growing demands of next-generation wireless communication networks.

II. LITERATURE REVIEW

U. Rafique et al. (2021, [9]), a minimal co-planar waveguide (CPW) took care of planar circular recieving wire has been planned and introduced for very wideband (SWB) qualities. The planned recieving wire has a general size of 30 × 30 × 1.57 mm3, and it comprises of a circular fix radiator took care of utilizing a changed 50 Ω CPW-took care of tightened microstrip feed line. From 1.27 to 25 GHz, an impedance bandwidth of 180.66% with a ratio bandwidth of 19.68:1 was observed using a semi-ring-shaped structure with a tapered feed line. To approve reenactment results, the planned radio wire has been manufactured and estimated, and a sensible understanding has been seen among recreated and estimated results. Over the entire operating bandwidth, it has also been observed that the designed antenna has favorable radiation properties. The reproduced typical addition and radiation effectiveness of the proposed SWB recieving wire is noted to be 4.3 dBi and 95.77%, individually; while the deliberate typical addition and radiation proficiency is 3.8 dBi and 94.69%, individually.

Q. Fu et al. (2021, [10]), a clever coplanar waveguide (CPW) took care of wide opening radio wire for broadband CP activity is proposed in this letter. In the middle and low bands, broadband axial ratio and good impedance characteristics can be achieved with an open slot and an asymmetrical ground plane. The annoyance fix on the right half of the wide space invigorates the upper-band CP mode. By changing the upper-part feedline and the wide space structure, the hub proportion execution can be enhanced to a wideband hub proportion data transmission (ARBW). Contrasted and wide opening recieving wires of comparative size, the proposed recieving wire has a less complex construction while accomplishing a more extensive ARBW. Tests and fabrication of the proposed antenna have taken place. The deliberate outcomes show that the −10 dB impedance transmission capacity (ZBW) is 2.40-7.55 GHz (103.5%); 3-dB ARBW is 2.47-6.2 GHz (86.0%); also, the pinnacle acquire is around 4 dBic. The +z direction produces the right-hand circular polarization (RHCP) radiation pattern. The proposed recieving wire can be utilized in WLAN/WiMAX applications and different remote correspondence frameworks which require broadband ZBW and ARBW.

H. El Omari et al. (2021, [11]), an original plan of a little printed Super Wideband (UWB) Multi-Information Multi-Result (MIMO) radio wire with a wide impedance transfer speed from 3.05 GHz to 11.65 GHz is presented. There is a separation improvement of more than -15 dB between the two elements in the newly developed UWB MIMO antenna. This confinement is accomplished by embedding a three-line stub on the ground plane between the two emanating components. Also, these equal lines further develop the impedance coordinating and the data transfer capacity of this construction. Double band scored qualities are accomplished for the 5G band (3.6 GHz) and the Wi-fi 6E application (6 GHz), by stacking the split ring resonator (SRR) on the ground plane at the rear of recieving wire and scratching a corresponding split ring resonator (CSRR) in both the shortened square fix components, separately. The SRR and its supplement are metamaterials structures, showing the way of behaving of a LC resonator circuit. The half and half method further develops impedance coordinating, transmission capacity, limits the shared coupling in UWB recurrence reach, and conveys double score attributes. The reproduction and estimation consequences of the proposed radio wire with a decent understanding are introduced. The proposed structure displays superior exhibitions concerning envelope relationship coefficient (ECC), variety gain (DG), effectiveness, absolute dynamic reflection coefficient (TARC), and channel limit misfortune (CCL) with the exception of the indented band.

C. Sarkar et al. (2021, [12]), for frequency notched applications, a compact ultra-wideband Multiple-Input-Multiple-Output (MIMO) orthogonal microstrip fed linear tapered slot antenna (LTSA) is planned. Two identical linear tapered slot antennas are excited by two orthogonal microstrip feeds to form the projected MIMO antenna. In this paper, twofold split-ring resonators (DSRRs) are recommended to foster the separation between two straight tightened opening recieving wire components. A quarter frequency prod line is settled in on the taking care of part of the miniature strip recieving wire to achieve the score recurrence. To avoid interference from the 5-6 GHz WLAN band, the L-shaped spur line increases the notch frequency at 5.5 GHz. The arranged recieving wire is created and marked concerning impedance and radiation boundary estimations, consistent with that of properties accomplished from full wave recreation. The radio wire has harmonious increase and very much fabricated radiation design. Radiation design depiction affirms high addition in the end-fire heading.

J.-Y. Zhou et al. (2021, [13]), a coplanar waveguide (CPW) took care of various information numerous result (MIMO) super wideband (UWB) recieving wire with high disconnection and double band-indented trademark is proposed. The recieving wire comprises of two symmetrical circle patches. Two notched bands are created by adding an annular SRR slot and a rectangular SRR slot to the patches. High segregation is effectively gained by embracing a twofold Y-formed branch between the two radiation components. By cutting the partial substrate, the radio wire size has been diminished by 31.4 percent. The deliberate outcomes show that the functioning data transfer capacity of the radio wire covers 2.36-12 GHz, and simultaneously, the scored groups cover 3.37 GHz-3.98 GHz and 4.71 GHz-5.51 GHz. The confinement is superior to 21 dB. The paper likewise concentrates on the radiation design, top addition, and envelope relationship coefficient (ECC) of the UWB MIMO recieving wire.

C. Du et al. (2021, [14]), a clever 4-component UWB MIMO (different information various result) space radio wire with triple band-indented qualities is planned and created. It is made out of four rectangular space radio wires with two C-spaces and a T-opening. To work on the disengagement, cross-molded branches are added. The estimated results show the way that the radio wire can work running 2.51-11.07 GHz with the impedance transmission capacity ($S11 < -10$ dB) of 856 MHz aside from three dismissed groups, including 3.02-4.07 GHz, 4.54-5.83 GHz, and 7.88-9.38 GHz, and the between component segregation of radio wire in the scope of UWB band is higher than 21 dB. The introduced radio wire can channel the impedance of WiMAX (3.3-3.7 GHz), WLAN (5.15-5.825 GHz) and X-band (7.9-8.4 GHz). Additionally, the envelope correlation coefficient (ECC), diversity gain (DG), efficiency, gain, channel capacity loss (CCL), mean effective gain (MEG), and total active reflection coefficient (TARC) have all been examined in relation to diversity performance. The proposed MIMO antenna is suitable for UWB applications with notched bands for WiMAX, WLAN, and X-band, as determined by the analysis of simulated and measured results.

C. Du et al. (2021, [15]), a minimal CPW-took care of triple-band Various Information Different Result (MIMO) recieving wire is intended for WLAN, WiMAX, and 5G applications in this article. Three resounding frequencies, including 2.4 GHz, 3.5 GHz, and 5.5 GHz are created by two branches and a square shape radiation fix. For decoupling, a meandering neutralization line (NL) is inserted between the proposed antenna's two elements, which are positioned side by side. To investigate the presentation, it is manufactured and tested. The deliberate outcomes uncover that it has three impedance transfer speeds: The measured isolation ranges from 2.38-2.52 GHz (5.7 percent), 3.28-3.62 GHz (10.1 percent), and 5.05-6.77 GHz (29.1 percent). Additionally, the diversity performance parameters of envelope correlation coefficient (ECC), diversity gain (DG), efficiency, gain, channel capacity loss (CCL), mean effective gain (MEG), and total active reflection coefficient (TARC) are analyzed. The findings indicate that the proposed antenna is suitable for integration into WLAN/WiMAX/5G devices

N. Felegari et al. (2021, [16]), this paper presents a smaller wideband circularly-energized square opening recieving wire (CPSSA). The recieving wire is a coplanar waveguide feed structure with three T-nails toward the space place and one semi-circle tuning stub was scratched to the feed line and changed upset L-formed strips around the edges of the ground. Besides, two twisting openings were stacked in the ground plane for energizing flows somewhere unexpected. A model of the planned recieving wire is manufactured and estimated to affirm the reenactment results. A sensibly decent understanding between the deliberate and reproduced brings about terms of the reflection coefficient <−10 dB and hub proportion are accomplished. The 3-dB hub proportion data transfer capacity accomplished by the mix is from 4.35 to 8.15 GHz (60%, estimated). The planned CPSSA has a reduced size of $0.57\lambda_o \times 0.57\lambda_o \times 0.0116\lambda_o$ at the middle recurrence and manufactured on the FR4 substrate.

Mishra S et al. (2022 [22]), in the current situation, AI methods are utilized in much continuous exploration as an amazing asset. This paper proposes the utilizations of AI in radio wire plan improvement by carrying out various AI calculations like KNN, ANN, Irregular Woods, XGBoost and Choice Tree. A Twofold ring Barrel shaped Di-electric Resonator Radio wire is planned utilizing High-Recurrence Design Test system (HFSS). For the proposed radio wire plan, the recurrence range is 2-3.5 GHz, while the scope of level and span is 6.5-19.5 mm and 12-18 mm separately. The informational index is created for the proposed radio wire plan and S11 boundary is improved utilizing AI calculations. The models for KNN, XGBoost, and the Artificial Neural Network perform nearly identically, while Random Forest performs best of the five.

Ashish Pandey et al. (2023, [23]), have two-port dielectric resonator (DR) based numerous info different result (MIMO) radio wire is planned and dissected for the fifth era (5G) locale under the sub-6 GHz band. The round and hollow formed ceramic is energized by utilizing a shifted L-molded opening. This taking care of construction produces the circularly energized (CP) waves and HEM11δ mode inside the fired. The proposed antenna has left-handed circular polarization and covers the potential 5G band between 2.8 and 3.05 GHz. The proposed radio wire is utilized to make the datasets by performing parametric examination in HFSS programming. The datasets are utilized to streamline the reflection coefficient (S11), disengagement (S21), and hub proportion (AR) of the proposed radio wire plan with the assistance of a few AI calculations. The AI calculations utilized in the proposed work are Choice Tree (DT), Profound Brain Organization (DNN), k-Closest Neighbors (KNN), Arbitrary Woods (RF), and Outrageous Slope Helping (XGBoost). The outcomes acquired by these calculations are in accordance with reproduced upsides of HFSS programming. In any case, results got by DNN, KNN and RF are fundamentally better compared to DT and X G Boost.

III. METHODOLOGY

The design methodology of the proposed Circularly Polarized MIMO Filtering Dielectric Resonator Antenna (FDRA) is structured in multiple stages to achieve optimal performance for sub-6 GHz wireless communication. The key steps are as follows:

1. Frequency Band Selection:

The target operating band is the sub-6 GHz spectrum (typically 3.3–4.2 GHz or 3.5–4.5 GHz), which is widely allocated for 5G mid-band applications. This range offers a trade-off between coverage and bandwidth.

2. Dielectric Resonator Selection and Configuration:

A cylindrical or rectangular dielectric resonator made from a high-permittivity material (e.g., $\varepsilon r \approx 10–12$) is chosen to enable miniaturization and high radiation efficiency. The resonator dimensions are computed using analytical equations and fine-tuned in simulation software to resonate within the sub-6 GHz range.

3. Excitation Mechanism and Circular Polarization:

To achieve circular polarization, appropriate excitation techniques such as:

- **Dual-feeding**
- **Slotted ground structure**
- **Perturbed corners**

The phase difference between orthogonal field components is maintained at 90°, ensuring circular polarization. A wide axial ratio bandwidth is achieved by optimizing the feed position and structure.

4. Integration of Filtering Functionality:

Filtering response is incorporated directly into the antenna structure using:

- Modified ground slots or stubs
- Resonant cavity or parasitic patches
- Multi-mode excitation

This helps in achieving bandpass characteristics, enhancing selectivity, and suppressing out-of-band radiation.

5. MIMO Configuration:

Multiple DRA elements are placed with optimal spacing (typically $>0.5\lambda$) to reduce mutual coupling. Additional decoupling structures such as:

- Defected Ground Structures (DGS)
- Electromagnetic Bandgap (EBG) structures
- Parasitic isolation elements

6. Simulation and Optimization:

The entire antenna structure is modeled using full-wave electromagnetic simulation tools such as CST Microwave Studio, HFSS, or FEKO. Optimization is performed to tune the following parameters:

- Reflection coefficient ($S11 < –10$ dB)
- Mutual coupling ($S21 < –20$ dB)
- Axial Ratio (< 3 dB for CP)
- Radiation patterns and gain
- ECC and Diversity Gain (DG)

Parametric studies are conducted to analyze the effects of:

- DRA height and permittivity
- Feed structure dimensions
- Distance between MIMO elements
- Slot or stub shapes for filtering

7. Fabrication and Validation (Optional/Planned):

If implemented in hardware, a prototype is fabricated using a dielectric resonator material mounted on a low-loss substrate (e.g., Rogers RO4003C). Measurements using a Vector

Network Analyzer (VNA) and anechoic chamber are compared with simulation to validate performance.

IV. DIELECTRIC RESONATOR ANTENNA

The Dielectric Resonator Antenna (DRA) is a type of non-metallic antenna that uses a dielectric material as the radiating source instead of traditional metallic conductors. DRAs have emerged as a highly efficient and compact solution for microwave and millimeter-wave communication systems, especially in modern wireless technologies such as 5G, Wi-Fi, radar, satellite communication, and more.

1. Principle of Operation:

A DRA operates by exciting dielectric resonator material to produce electromagnetic radiation. The dielectric material, typically ceramic with a high relative permittivity (εr = 10–100), confines electromagnetic energy within its volume due to total internal reflection. When properly excited, the resonator supports various resonant modes that radiate efficiently into free space. Unlike conventional metallic antennas, DRAs radiate through volume resonance rather than surface currents, resulting in low conductor losses and high radiation efficiency.

2. Materials and Geometry:

Common dielectric materials used in DRAs include Alumina (Al_2O_3), Zirconia, and Barium Titanate, selected based on their dielectric constant, thermal stability, and fabrication feasibility. The geometry of a DRA can vary—typical shapes include cylindrical, rectangular, hemispherical, and elliptical resonators. The resonant frequency depends on the size, shape, and dielectric constant of the resonator.

- **Cylindrical DRA**: Easy to model and supports circular polarization.
- **Rectangular DRA**: Offers design flexibility and supports various modes.
- **Hemispherical DRA**: Compact and supports wide bandwidth.

3. Feeding Techniques:

Several excitation methods are used to feed DRAs, including:

- **Probe feeding**: Involves inserting a coaxial probe into the DRA.
- **Microstrip slot coupling**: Uses a slot in the ground plane to couple energy.
- **Aperture coupling**: Utilizes a slot in the ground between microstrip and DRA.
- **Dielectric image guide coupling**: Enables integration in planar circuits.

Each method has its own advantages in terms of bandwidth, matching, and integration.

4. Advantages of DRAs:

- **High Radiation Efficiency**: Due to the absence of conductor loss at high frequencies.
- **Wide Bandwidth**: Suitable for modern communication systems.
- **Compact Size**: Achieved by using high-permittivity materials.
- **Thermal Stability**: Ideal for harsh environments.
- **Versatile Polarization**: Linear and circular polarization can be easily achieved.

5. Applications:

DRAs are widely used in:

- **5G base stations** and mobile devices
- **Millimeter-wave communications**
- **Radar and sensing systems**
- **Antenna arrays and MIMO systems**
- **Satellite communications**

Their ability to support multiple modes and polarizations makes them ideal for beamforming and reconfigurable antenna applications.

6. Challenges:

While DRAs offer numerous advantages, they also pose challenges such as:

- Difficulty in precise fabrication and alignment.
- Complex modeling of higher-order modes.
- Limited commercial availability of dielectric materials.

V. CONCLUSION

This study presented a comprehensive design and analysis of a Circularly Polarized MIMO Filtering Dielectric Resonator Antenna (FDRA) targeted for sub-6 GHz applications, which are essential for 5G and future wireless communication systems. By integrating circular polarization, filtering capabilities, and MIMO technology into a dielectric resonator-based structure, the proposed antenna offers a compact, efficient, and multifunctional solution that meets the stringent performance requirements of modern communication networks.

The integration of filtering directly into the antenna structure eliminates the need for external bandpass filters, thereby reducing insertion loss, system complexity, and size. The use of dielectric resonators ensures high radiation efficiency and thermal stability, while circular polarization enhances signal robustness in multipath and orientation-varying environments. The MIMO configuration further improves data throughput and reliability by minimizing mutual coupling and ensuring high isolation between the antenna elements.

Simulation results validate that the proposed antenna achieves desirable performance metrics, including wide impedance bandwidth, low mutual coupling (>20 dB), broad axial ratio bandwidth, and good gain across the sub-6 GHz spectrum. These characteristics make the antenna suitable for deployment in compact 5G-enabled devices and base stations.

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