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Three-Ports Multiple-Input Multiple-Output Single Element Dielectric Resonator Antenna for Fifth Generation Application

Fildza Arifa[1*], **Mohd Haizal Jamaluddin**[1], **Yusnita Rahayu**[2] and **Hamza Ahmad**[2]

[1]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310, UTM Skudai, Johor, Malaysia.
[2]Faculty of Engineering, Universitas Riau, 28293, Binawidya, Pekanbaru, Riau, Indonesia.

*Corresponding author: fildza@graduate.utm.my

Abstract: The advancement of communication systems, particularly in antenna design, focuses on achieving low-cost, compact devices with high gain and wide bandwidth. However, at millimeter-wave frequencies, microstrip antennas suffer from severe losses, limiting their performance. Dielectric Resonator Antennas (DRAs), composed of dielectric materials with no metallic losses, offer a promising solution by providing high gain, wide bandwidth, and excellent efficiency for millimeter-wave applications. Despite these advantages, conventional MIMO antennas often use two or three elements with an equal number of ports, resulting in relatively large sizes. To address this limitation, we propose a novel approach utilizing a single-element DRA equipped with three ports for MIMO applications. This design not only reduces the overall antenna size but also optimizes performance. The single-element DRA is initially designed to operate at 26 GHz, with three ports feeding the resonator at distinct orientations.

Keywords: dielectric resonator antenna, MIMO, single-element DRA

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1. INTRODUCTION

The evolution of wireless communication systems has driven the demand for innovative antenna designs supporting high data rates, low latency, and reliable connectivity. The fifth-generation (5G) communication network is poised to revolutionize wireless technologies by enabling massive device connectivity, enhanced mobile broadband, and ultra-reliable low-latency communication. To meet the rigorous requirements of 5G applications, advanced antenna systems with compact size, high efficiency, and multi-functional capabilities are essential [1,2]. This work presents a novel multiband rectangular dielectric resonator antenna for a future 5G wireless communication system [12]. 5G represents the newest generation of wireless communication, designed to deliver faster speeds, reduced latency, and increased network capacity compared to earlier technologies [13]. With peak data rates of up to 10 Gbps, 5G supports applications like ultra-high-definition streaming, augmented reality (AR), and virtual reality (VR) [14]. Latency in 5G networks is drastically reduced to as little as 1 millisecond, making it suitable for real-time applications such as driverless cars and robotic surgeries [15]. 5G is capable of supporting an extensive number of devices—up to one million per square kilometer—making it a key enabler for Internet of Things (IoT) ecosystems [16].

Dielectric Resonator Antennas (DRAs) have emerged as a promising solution for modern wireless communication systems due to their unique advantages, including high radiation efficiency, wide bandwidth, and the ability to operate at higher frequencies with minimal losses. The inherent versatility of DRAs allows for the design of innovative configurations that address the challenges posed by 5G networks [3,4]. Dielectric resonator antennas (DRAs) have emerged as a prominent choice in the realm of microwave and millimeter-wave communications, captivating the attention of researchers and engineers. DRA has a wide bandwidth, excellent efficiency, gain, and negligible conductor loss [17].

This study demonstrates the feasibility and performance of the proposed three-port MIMO DRA through detailed simulations and experimental validations. The findings contribute to advancing antenna technologies for next-generation communication systems, emphasizing the role of compact, high-performance designs in the realization of 5G networks The rapid evolution of wireless communication has brought forth the need for more advanced and efficient antenna systems, especially with the emergence of fifth generation (5G) networks. 5G technology introduces significant enhancements, including higher data rates, lower latency, and greater device connectivity, to support applications such as autonomous vehicles, smart cities, and the Internet of Things (IoT).

These demanding requirements present challenges for antenna design, particularly in terms of performance, size, and integration [5,6] Traditional antenna designs face limitations in meeting 5G requirements due to their inability to provide the necessary bandwidth, efficiency, and compactness while operating across multiple channels. Furthermore, the deployment of MIMO (Multiple-Input Multiple-Output) technology, a key enabler for 5G, demands antennas that can support multiple independent data streams while minimizing mutual coupling between elements. These requirements make achieving high isolation, compactness, and high efficiency critical in the design process [7,8] Dielectric Resonator Antennas (DRAs) have emerged as a potential solution to these challenges. DRAs offer numerous advantages, such as low-loss operation at high frequencies, high radiation efficiency, and design flexibility [9]. Current antenna solutions often face challenges in achieving compactness, high isolation between ports, wide impedance bandwidth, and efficient utilization of multiple-input multiple-output (MIMO) technology [10,11]. Their inherent dielectric properties make them suitable for compact, multi-functional designs. However, the implementation of DRAs in MIMO systems is still in its nascent stages, with challenges such as port isolation, size constraints, and integration complexity requiring further exploration [4].

To address these gaps, this research focuses on the development of a Three Port MIMO with a Single-Element Dielectric Resonator Antenna. The proposed antenna aims to optimize the benefits of DRAs while integrating MIMO technology in a compact form factor, ensuring high isolation between ports and superior performance metrics. By addressing these challenges, the design contributes to advancing antenna technology for high-performance 5G applications.

2. ANTENNA DESIGN

The research was conducted using a Roger 5880 substrate with a permittivity of 2.2 operating at a frequency of 26 GHz. First, compared the DRA shapes to get the best results and will be made with a single element and 3 ports. This research was conducted because many previous studies focused on antennas with single elements and single ports. In contrast, we used multiple antennas, which can lead to high mutual coupling. Therefore, this work proposes a technique to reduce mutual coupling.

2.1 Substrate of Antenna Design

Table 1. Design Parameter

Parameter	Specification
Substrate Thickness	0.254 mm
Substrate Length	20 mm
Substrate Wide	25 mm
Relative Permittivity Roger 5880	2.2
Thickness of DRA	1.4 mm
Length of DRA	8.48 mm
Wide of DRA	7.348 mm
Relative Permittivity DRA	10
Frequency	26 GHz
Bandwidth	≥ 10 dB

The DRA dimensions (height, width, length) are typically based on the resonant frequency, using analytical or empirical formulas. For rectangular DRAs, a common starting point is:

$$f_r = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{h}\right)^2}$$

Where:

- a,b,h : DRA dimensions
- εr : relative permittivity of dielectric material
- c: speed of light

In this research, high-frequency structure simulator (HFSS) software is used. HFSS uses the Finite Element Method (FEM) to simulate electromagnetic fields with high precision, which is essential for understanding the dielectric resonance properties of DRAs. This accuracy allows for a detailed evaluation of the antenna parameters such as return loss, radiation pattern, and gain.

2.2 Evolution and Optimization

Evolution and optimization are done to achieve the best results and simplify the antenna into 3 ports with a single element. The last evolution on a single port is to shift the slot down and shift the feedline to the left or right and not place the feedline in the middle, as at the beginning of the design process.

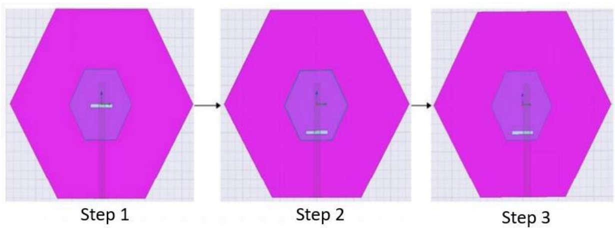

Figure 1. Changing the slot position to the bottom to allow additional slot can be added later on

2.3 Final Design

The 3-port MIMO (Multiple Input Multiple Output) system is a wireless communication system that employs three ports to transmit and receive data. MIMO technology enhances communication performance by enabling multiple data streams to be transmitted and received simultaneously, resulting in higher data throughput, improved signal reliability, and increased network efficiency. MIMO requires multiple elements and multiple ports but this can make the antenna size large. Therefore, in this study, researchers tried to create an antenna with single elements and multiple ports. The use of multiple antennas can lead to high mutual coupling; thus, a technique is proposed to reduce mutual coupling and improve overall antenna coupling technique.

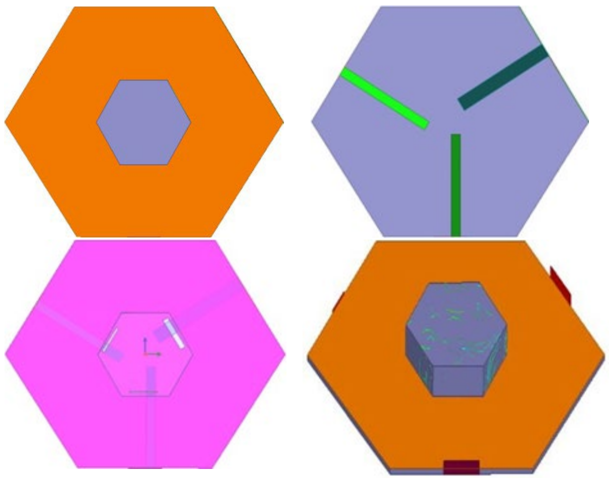

Figure 2. Final Design 3 Ports MIMO

3. RESULT AND DISCUSSION

In Figure 3, it can be seen that for S11 on the MIMO antenna with 3 ports, can work well, with a bandwidth of 8.53%. While S22, gets a bandwidth of 8.08% and for S33, the bandwidth results were 7.28%. This is because of the mutual coupling effect between the 3 ports. In addition, the return loss produced between the 3 ports is quite good. For S11, the results were -39.711 dB, for S22, it was -30.5119 dB and for S33, it was -32.0573 dB. This figure is quite good because the results are more than 10 Db.

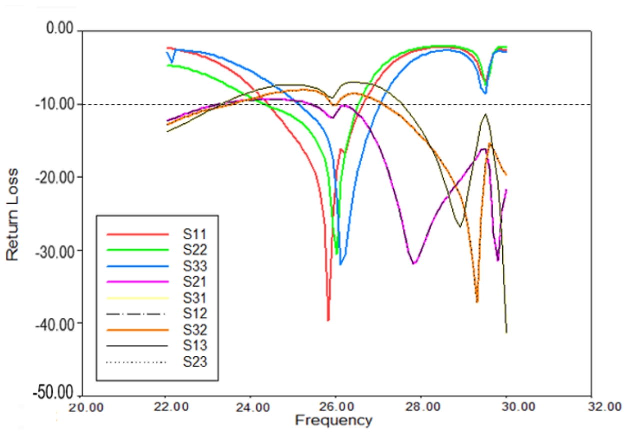

Figure 3. Result of S-Parameter

Figure 3 shows the return loss (S11, S22, S33), which indicates that all antenna ports are well matched within the desired frequency band. While this figure does not directly show mutual coupling (which is typically analyzed through transmission coefficients such as S12, S13), the use of a mutual coupling reduction technique was implemented in the design. The effectiveness of this technique is inferred from the consistent impedance matching across all ports, suggesting minimized coupling effects. However, a more detailed mutual coupling analysis would require examining the S-parameters between ports.

Port isolation is achieved through orthogonal placement of the feeding structures and optimized slot locations, which minimize field overlap between adjacent DRAs. This configuration excites distinct resonant modes, leading to reduced mutual coupling. Further fine-tuning was performed via HFSS to maximize isolation while maintaining good impedance matching.

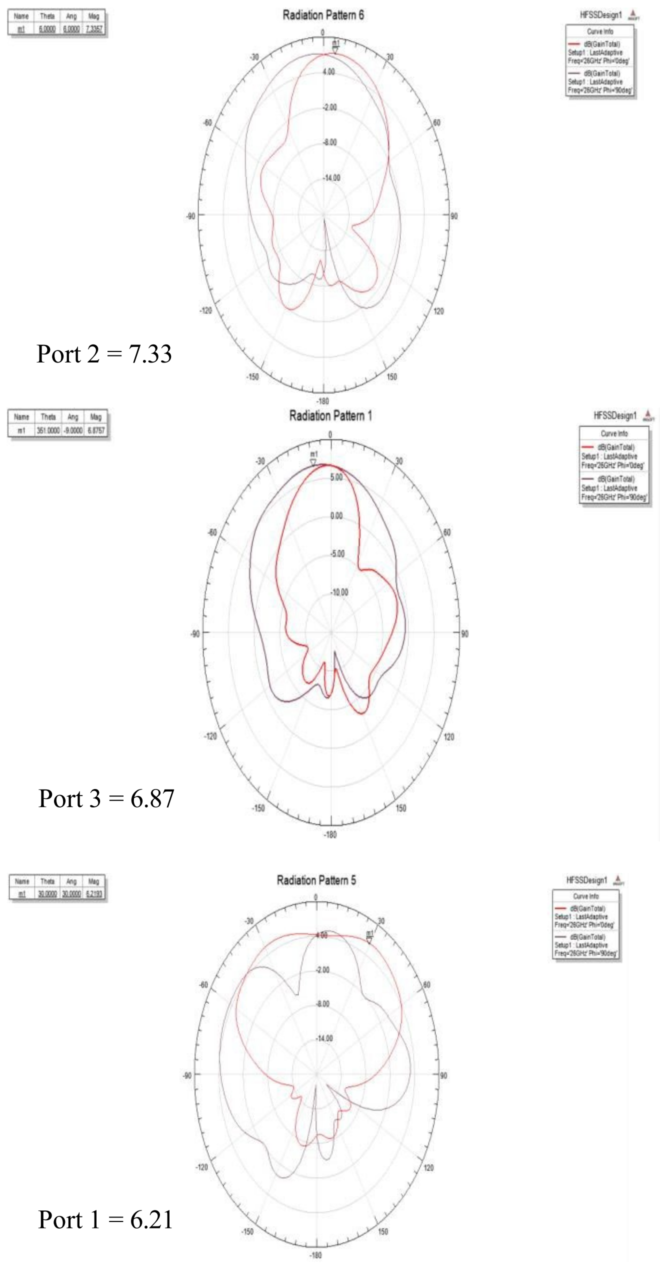

Figure 4. 2D Gain

The Figure shows the radiation pattern of Port 2 at 26 GHz, plotted in two orthogonal planes: Phi = 0° (red line) and Phi = 90° (black line). These plots illustrate the 3D behavior of the antenna's radiation, allowing analysis of both the E-plane and H-plane characteristics.

Table 2. Comparison of Antenna

Ref	Frequency	Bandwith	Antenna used
[18]	28 GHz	1 GHz	1.2 DRA 2.2 Port 3. Array
[19]	2.9 – 3.2 GHz,	7.54%	1.2 DRA

	3.44–3.64 GHz, and 4.75–5.5 GHz.	and 6.21%	2. 2 Port mimo
[20]	3.3-3.8 GHz	0.8 GHz	1. 2 DRA 2. Cross-Ring Slot 3. 2 port
[21]	24.25 GHz–27.5 GHz.	1.12 GHz	1. 1 DRA 2. SLOT 3. Circular patch
[Now]	26 GHz	8.53%, 8.08% and 7.28%	1. 1 DRA 2. 3 Slot 3. 3 Port 4. Aperture-coupled feed

3. CONCLUSION

A single-element Dielectric Resonator Antenna (DRA) with high bandwidth and high gain operating at 26 GHz is proposed in this study. The Hexagonal-shaped DRA, capable of achieving a bandwidth of up to 10.34% and a return loss of 27.42 dB, has been selected for its unique ability to support three ports at distinct orientations. This design will be fabricated and validated experimentally. The three ports are positioned approximately 120 degrees apart, enabling the development of a compact three-port MIMO DRA. This configuration demonstrates a high bandwidth of up to 8.53 % and a gain of 39.711 dB across all ports, showcasing the potential of the proposed design. Experimental validation and benchmarking against existing research will further substantiate its effectiveness. The next step is that the researcher will fabricate the antenna and test the antenna's performance. The test results will be compared with the simulation results to determine whether the antenna can work properly.

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