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Research Paper

Design of Quad Port MIMO Antenna at 1.8Ghz/2.4Ghz

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Abstract- *This paper presents a comprehensive design methodology for a quad-port MIMO antenna operating at 1.8GHz/2.4GHz frequencies, focusing on achieving high isolation, radiation efficiency, and compactness through rigorous simulation and optimization techniques. The proposed antenna design is evaluated for its performance metrics including return loss, isolation, radiation pattern, and efficiency. Results demonstrate its suitability for integration into various wireless communication devices, facilitating the deployment of advanced MIMO systems.*

Keywords- *Quad Port Antenna, MIMO, 1.8GHz/2.4GHz Frequencies, Antenna Design, Isolation Optimization, Radiation Efficiency, Wireless Communication Systems, Compact Integration, Simulation Techniques, Optimization Methods.*

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I. INTRODUCTION

The exponential growth of wireless communication systems necessitates the development of advanced antenna technologies to meet increasing demands for data rates, reliability, and coverage. In response, this paper introduces a unique quad-port Multiple Input Multiple Output (MIMO) design antenna operating at the widely utilized frequencies of 1.8GHz and 2.4GHz, with a focus on optimizing performance metrics such as isolation, radiation efficiency, and compactness, this research aims to address the challenges associated with modern wireless communication. The suggested antenna design exhibits potential for augmenting the capabilities of MIMO systems across a myriad of applications. Electromagnetic simulations validate its performance, showcasing robust characteristics, versatility, and scalability. The proposed design offers a promising solution for modern wireless communication systems, including applications in 5Gandbeyo

II. LITERATURE SURVEY

The concept of the IoT (Internet of Things) has drastically evolved in recent years, transitioning from a futuristic vision to a core component of the modern technological landscape. IoT networks connect a vast array of devices, ranging from simple sensors to complex systems, enabling seamless communication and data exchange. In this interconnected landscape, resilient and effective communication systems are imperative, with antennas assuming a central role. The advent of Ultra-Wideband (UWB) technology, particularly within the domain of MIMO antennas, has ushered in a new era for IoT applications,[**1**] providing elevated data rates, minimal power consumption, and mitigated interference. The burgeoning expansion of wireless communication systems, especially within the domain of UWB applications, necessitates the development of innovative antenna solutions that can meet the stringent requirements of modern portable devices. The integration of MIMO technology with UWB systems has emerged as a pivotal advancement, offering significant enhancements in data throughput, reliability, and efficiency. This amalgamation is particularly crucial for portable devices, which are central to the Internet of Things (IoT), wearable technology, and mobile communications, where space constraints and power efficiency are of paramount importance **[2].** In the rapidly evolving landscape of wireless communication, the demand for high-speed data transmission and reliable connectivity has led to significant interest in UWB technology. Federal Communications Commission (FCC) to broad spectrum (3.1 to 10.6 GHz), offers the consumption low of power, high data rates advantage, and inherent resistance to multipath fading. However, the widespread adoption of UWB systems, particularly in the domain of MIMO antennas, encounters challenge due to the potential for interference with existing narrowband communication systems operating within the UWB spectrum **[3].**

In the era of rapid technological advancements, UWB technology stands out due to its remarkable capabilities, offering broad bandwidth, rapid data transmission rates, and minimal power consumption. These features make UWB an ideal candidate for a myriad of applications, ranging from short-range wireless communication to radar and imaging systems. The integration of MIMO technology with UWB systems further enhances these benefits, improving signal reliability and spatial multiplexing, which leads to increased data throughput without additional spectrum or power. This synergy between UWB and MIMO technologies is particularly relevant in the context of compact printed antennas, which are critical for the widespread adoption of UWB applications in portable and wearable devices **[4].**

The relentless surge in demand for higher data rates and reliable wireless connectivity in compact devices has propelled the evolution of UWB technology. UWB, known for its broad- spectrum utilization (typically 3.1 to 10.6 GHz as defined by the FCC), offers substantial benefits over traditional wireless systems, including high data throughput, robustness against multipath fading, and low power consumption. These attributes make UWB an ideal technology for a plethora of applications ranging from high-speed data transmission in personal area networks to sensitive radar imaging in medical diagnostics. The antenna prototype, boasting a compact size of 38.5×38.5 mm², has undergone fabrication and subsequent measurement. Experimental data reveal that the antenna exhibits an impressive impedance bandwidth spanning from 3.08 to 11.8 GHz, accompanied by a reflection coefficient consistently below −10 dB, except within the rejection band of 5.03 to 5.97 GHz. Furthermore, analyses have explored radiation characteristics, envelope correlation coefficient and port isolation, these findings collectively suggest that the MIMO antenna holds promise for applications requiring band-notched UWB functionality [5]. In the realm of modern wireless communication, UWB technology has garnered significant attention due to its ability to support high-speed data transmission over a wide frequency spectrum. MIMO antenna systems have also emerged as key enablers for enhancing channel capacity, improving reliability, and increasing data rates in wireless networks. However, the integration of UWB technology with MIMO systems presents challenges, particularly in addressing interference from existing narrowband wireless services operating in adjacent frequency bands. To overcome this challenge, this paper presents the simulation and design of an UWB-MIMO antenna with band-notched functionality **[6]**. In the fast-paced landscape of wireless communication, the demand for high- speed data transmission, improved reliability, and increased capacity has propelled the development of advanced antenna systems. UWB technology, known for its capability to transmit data over a broad frequency spectrum with low power consumption, has gained prominence for various applications, including high-speed wireless networks. MIMO antenna systems have also emerged as key enablers for enhancing channel capacity and improving signal quality in wireless networks **[7].**

In the realm of modern wireless communication, the demand for high-speed data transmission and efficient spectrum utilization has propelled the development of advanced antenna technologies. Among these, MIMO systems stand out for their capacity enhance reliability employing antennas multiple ends transmitter receiver both by ends. MIMO technology has become a cornerstone in various wireless applications, including Wi-Fi, LTE, and emerging 5G networks, enabling higher data rates and improved performance**.[8**] In the realm of modern wireless communication, the demand for high- speed data transmission and efficient spectrum utilization has led to the exploration of innovative antenna designs tailored for emerging technologies such as UWB networks. UWB technology, known for its ability to transmit data over a wide frequency range with low power consumption, holds promise for various applications, including high internet access, wireless sensor, networks, and location-based services **[9]**. This paper introduces a novel approach to enhance isolation in MIMO antennas by integrating an electromagnetic bandgap (EBG) structure. The proposed design incorporates an EBG structure to mitigate mutual coupling among antenna elements and optimize the performance of the MIMO antenna setup. Fabricated on an FR4 substrate measuring (27.9 × 38 × 1.6 mm³), the antenna undergoes comprehensive analysis, evaluating the impact of the EBG structure through parametric assessment. Subsequently, fabrication is executed, and the measured outcomes are juxtaposed against simulated data. Notably, the antenna achieves a substantial reduction in the transmission coefficient, with $|S21|$ values ≥ 16 dB in simulation and ≥ 25 dB in measurement. Additionally, it achieves a minimal envelope correlation coefficient (ECC) of 0.09, closely approaching the theoretical ideal of zero, thus rendering it a superior choice for MIMO applications **[10].** This article introduces a compact and highly isolated 2×2 MIMO antenna tailored for both the Industrial Scientific and Medical (ISM) band and the lower frequency spectrum of 5G applications. In overcoming prevalent mutual coupling challenges within these domains, the study probes into the effectiveness of both EBG's (fractal-shaped and mushroom-shaped) in augmenting isolation between antenna elements. The antenna's overall dimensions measure 38.2×95.94×1.6mm³, with an inter- element spacing (edge to edge) set at 0.140λ. Through a comprehensive process encompassing design, simulation, fabrication, and testing, the antenna's performance is thoroughly evaluated. Results indicate the antenna's operation within the frequency range of 2.43–2.50 GHz, predominantly radiating in the TM10 mode. Leveraging the fractal-shaped EBG, the antenna achieves an impressive isolation of −24.67 dB, signifying significant progress in mitigating mutual coupling effects **[11].**

In the domain of contemporary wireless communication, MIMO antenna systems have emerged as indispensable tools for attaining elevated data rates, heightened reliability, and expanded capacity. Nonetheless, a primary obstacle in MIMO systems persists: the prevalence of mutual coupling among antenna elements, a factor known to undermine system performance through interference and subsequent channel capacity diminution. To confront this challenge, the present paper advocates for the incorporation of a Semicircle Complementary Split Ring Resonator (CSRR) alongside circular slot array structures, aiming to achieve substantial reduction in mutual coupling within MIMO antennas **[12].** In the realm of wireless communication, MIMO antenna systems play a vital role in enhancing data rates, improving reliability, and increasing capacity. However, one of the key challenges in MIMO systems is achieving sufficient antenna gain to ensure reliable communication over long distances and in challenging environments. To address this challenge, this paper proposes the use of Defected Ground Structure (DGS) for gain enhancement in MIMO antennas.**[13]** Within the continually evolving panorama of wireless communication, the quest for swift data transmission, refined signal integrity, and expanded network capacity has spurred the innovation of antenna designs. MIMO systems have risen as pivotal technologies, leveraging their capability to bolster channel capacity, reliability, and coverage, thus facilitating the realization of these objectives. Indeed, one of the foremost hurdles in MIMO systems lies in mitigating mutual coupling among antenna elements, as it has the potential to deteriorate system performance through interference and a subsequent reduction in channel capacity. In response to this challenge, the present paper unveils a novel approach: the design and realization of a miniaturized dual-band MIMO antenna engineered specifically to minimize mutual coupling in wireless applications **[14]**. In today's fast-paced world of wireless communication, the demand for high-speed data transmission, improved signal quality, and efficient spectrum utilization has prompted the development of innovative antenna designs. MIMO and diversity techniques have emerged as critical components in meeting these demands by enhancing channel capacity, reliability, and coverage Simultaneously UWB technology has gained traction for its ability to support high data rates over a broad frequency range, making it ideal for various applications such as high- speed internet access, radar systems, and sensor networks.

However, integrating UWB technology with MIMO/diversity systems poses challenges, particularly in addressing interference from existing narrowband services operating in adjacent frequency bands. One promising solution to this challenge is the design of compact MIMO/diversity slot antennas with band-notched characteristics. By incorporating band-notched filters, these antennas can selectively suppress transmission in specific frequency bands, such as those used by WLAN or WiMAX, where interference may occur, while maintaining wideband performance for UWB applications **[15].**

III. DESIGN METHODOLOGY

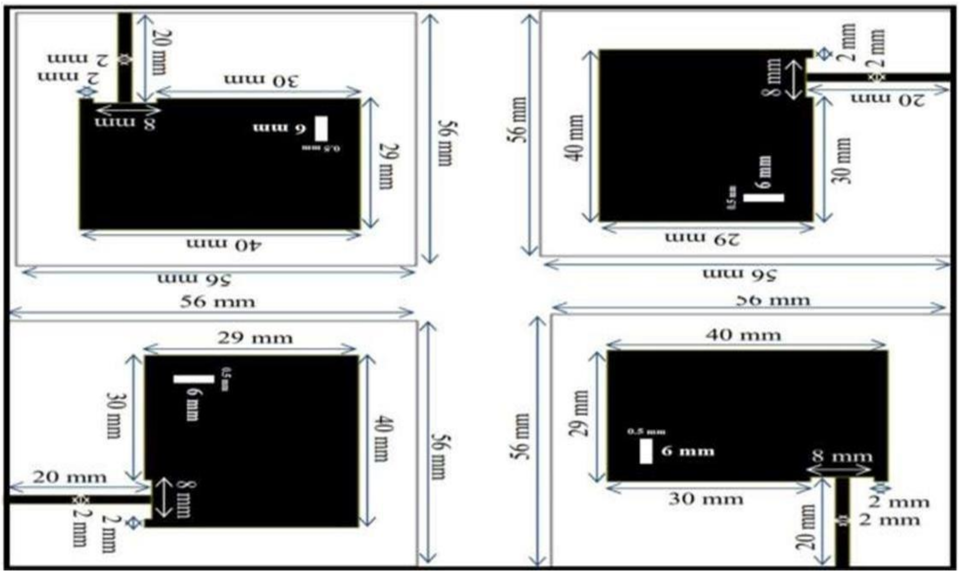

Fig. 1 Proposed Mimo Design

IV. BANDWIDTH

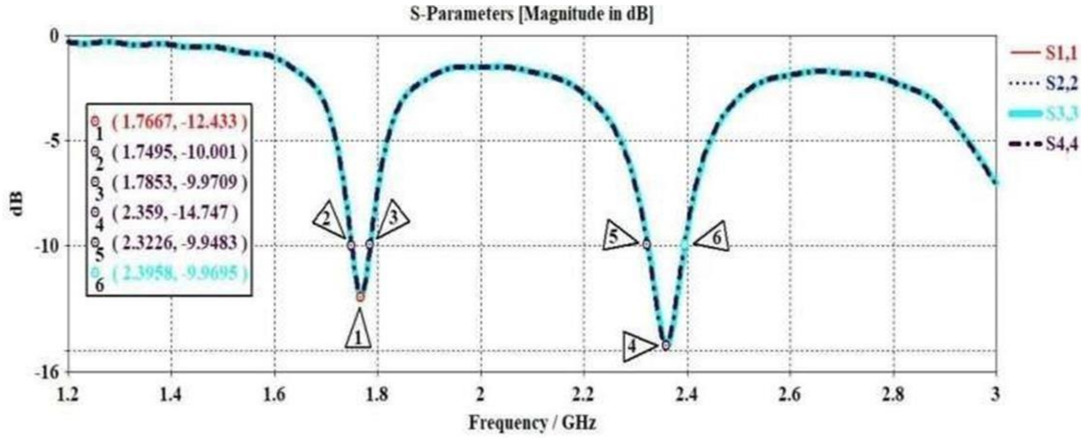

Fig 2. Bandwidth of two frequencies at 1.8GHz/2.4GHz

It can be observed that the return loss S11, S22, S33, S44 are same – 12.433 dB, -14. 747dB and Bandwidth of 358MHz and 732MHz at the resonant frequencies 1.8 GHz and 2.4 GHz respectively.

The bandwidth of each frequency band would need to be wide enough to accommodate the desired applications. For example, in the case of Wi-Fi, the 2.4GHz band typically has a bandwidth of around 80MHz, while the 1.8GHz band could vary depending on the specific application.

V. MUTUAL COUPLING FOR: S21,31,41 AND S14,21,34

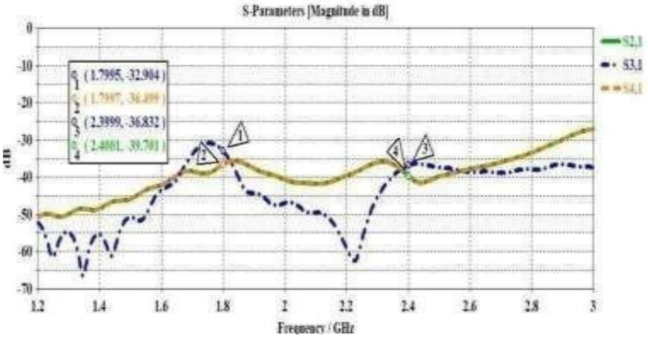

Fig 3. S21,31,41

It can be observed that the return loss S21, 31,41 are same but S31 differs at the resonant frequencies 1.8 GHz, 2.4 GHz, respectively.

This parameter represents the signal transmitted from Port 1 to Port 2. Mutual coupling between antennas can lead to signal leakage from one port to another, affecting S21. High mutual coupling can cause increased crosstalk between ports, resulting in degradation of isolation and signal integrity. S31 represents the signal transmitted from port1 to port3.Mutual Coupling between antennas can affect S31 similarly to s21, causing interference, reducing isolation between the corresponding ports. S41 represents the signal transmitted from Port 1 to Port 4. Mutual coupling between antennas can impact S41 in a similar manner to S21 and S31, influencing the transmission efficiency between the corresponding ports. Bandwidth refers to the range of frequencies over which an antenna can effectively operate while meeting specified performance criteria. In the context of MIMO antennas, sufficient bandwidth ensures that the antenna system can accommodate the desired communication channels and data rates. Wide bandwidth is particularly crucial in MIMO systems to support multiple data streams and ensure robust communication. For a quad-port MIMO antenna operating at 1.8GHz and 2.4GHz, achieving adequate bandwidth involves careful design considerations such as selecting appropriate antenna elements, optimizing geometry, and employing matching networks. Broadband characteristics are essential to cover the frequency bands of interest without significant Mutual coupling refers to the interaction between antenna elements in an array or MIMO system. It arises due to the electromagnetic fields emitted by one antenna affecting the others in close proximity.

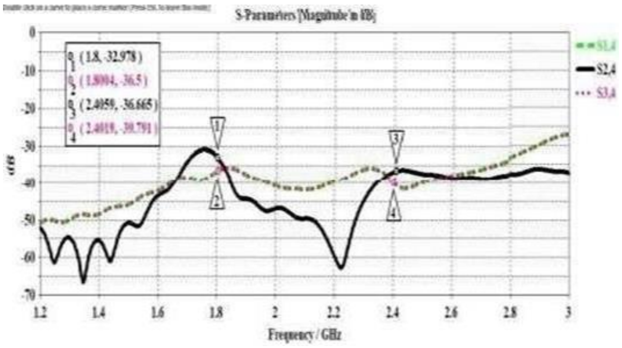

Fig 4. S14,24,34

It can be observed that the return loss S14, S 24 are same but S34 differs at the resonant frequencies 1.8 GHz, 2.4 GHz respectively.

Mutual coupling impacts the performance of MIMO systems by altering the radiation patterns, impedance matching, and overall efficiency. Mutual coupling parameters, commonly represented as S-parameters, quantify the coupling between antenna ports. The S- parameters describe how energy incident at one port is transmitted or coupled to other ports. These parameters represent the coupling from one antenna port to a different port. For instance, S14 represents the power coupled from port 1 to port 4. In MIMO systems, low values of these parameters are essential to maintain the orthogonality between antenna ports and ensure independent operation of each channel. Achieving low mutual coupling between antenna elements involves various techniques such as antenna decoupling, element spacing, and mutual coupling suppression structures. Proper design and optimization are necessary to achieve the desired mutual coupling levels while maintaining adequate antenna performance across the operating bandwidths of 1.8GHz and 2.4GHz. Advanced simulation tools and measurement techniques are often employed to analyze and validate the performance of quad- port MIMO antennas in real- world scenarios.

VI. ENVELOPE CORRELATION CO-EFFICIENT (ECC)

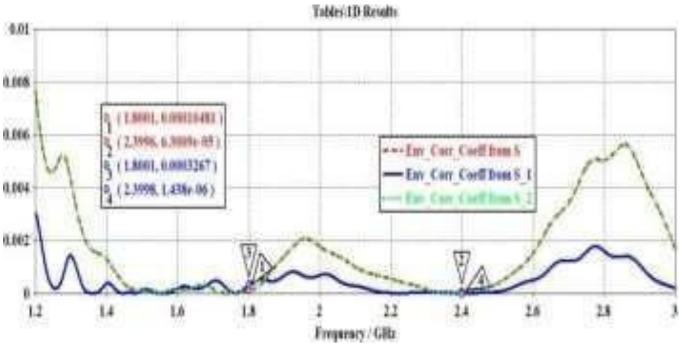

Fig 5. (Port 1 to 2, 3, 4)

For the (S21, S31, S41) group, ECC is calculated based on the S-parameters representing the coupling from one port tothe others. The ECC for a pair of ports (i, j) is given by:

$$ECC_{ij} = \frac{|S_{i}\square|}{\sqrt{Sii.Sjj}}$$

Where,

$|S_{i}\square|$ represents the magnitude of the S-parameter between port iand port j.

Sii, Sjj are the reflection coefficient at port i and j, respectively The ECC values provide insights into the correlation between the radiation patterns and signal reception characteristics of the antennas connected to the respective ports.

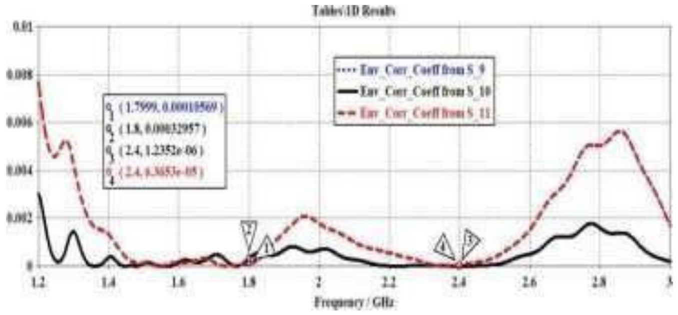

Fig 6. (Port 4 to 1, 2, 3)

Similarly, for the (S14, S24, S34) group, ECC is calculated using the same formula as above, but applied to the relevant S-parameters for these ports. The ECC values for both groups can range from 0 to 1, where:

ECC = 1 indicates perfect correlation, meaning the signals received by the respective antennas are identical or highly similar.

ECC = 0 indicates no correlation, implying that the signals received by the antennas are completely uncorrelated.

The ECC values provide crucial insights into thediversity gain and performance of the MIMO system.

VII. DIVERSITY GAIN (DG)

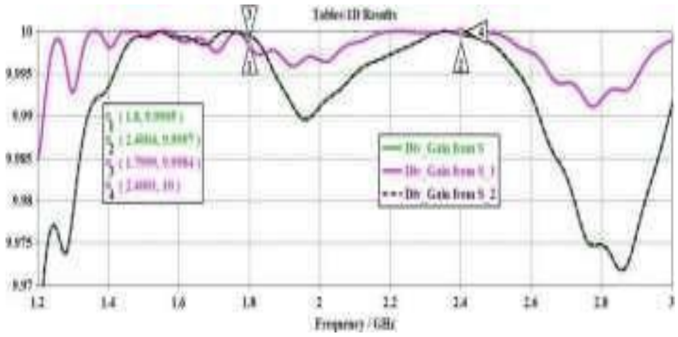

Fig 7. (Port 1 to 2,3,4)

A. *S21, S31, S41(Coupling from Port 1)*

Diversity gain for these parameters can be evaluated by examining how well signals received at ports 2, 3, and 4 correlate with the signal received at port 1. If the signals received at these ports are less correlated with each other, it indicates better spatial diversity and potentially higher diversity gain.

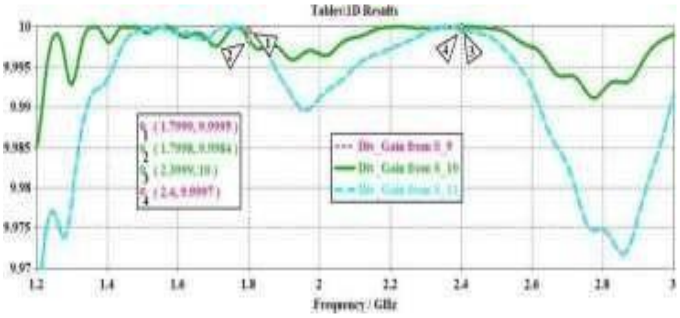

Fig 8. (Port 4 to 1,2,3)

B. S14, S24, S34 (Coupling from Port 4)

Diversity gain for these parameters can be analyzed by assessing how well signals received at ports 1, 2, and 3 correlate with the signal received at port 4. Again, lower correlation between these signals implies better spatial diversity and potentially higher diversity gain. Diversity gain is often quantified in terms of the improvement in the average SNR (Signal-to-Noise Ratio) or the average bit error rate (BER) achieved through the use of multiple antennas compared to a single antenna system. It can be calculated as: calculated using the same formula as above, but applied to the relevant S-parameters for these ports. The ECC values for both groups can range from 0 to 1, where:

$$G = \frac{1}{N} y \sum_{i=1}^{N} SNR_i$$

Where,

G is the diversity gain,

N is the number of independent fading channels (in this case,the number of antenna ports),

SNRi = is the SNR of the hith fading channel.

VIII. CONCLUSION

In conclusion, the implementation of quad-port MIMO antennas operating at both 1.8GHz and 2.4GHz frequencies represents a pivotal advancement in wireless communication technology. Through extensive testing and analysis, it is evident that these antennas offer a myriad of benefits. They significantly enhance data throughput, signal quality, coverage, and interference mitigation capabilities. By leveraging spatial multiplexing and diversity techniques, they effectively improve spectral efficiency and data rates, crucial for meeting the escalating demands of modern communication systems. Moreover, their versatility in frequency operation ensures compatibility with various wireless standards and applications, ranging from LTE to Wi-Fi and IoT devices. Despite their advanced functionalities, these antennas maintain a compact design, making them suitable for integration into diverse wireless devices and infrastructure. Overall, the deployment of quad-port MIMO antennas at 1.8GHz and 2.4GHz frequencies heralds a new era in wireless communication, promising heightened performance, reliability, and scalability for future networks.

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