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5G MIMO ANTENNA FOR SMARTBAND

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***Abstract**:* This paper presents the design and implementation of a 5G Multiple Input Multiple Output (MIMO) antenna specifically for smartwatches, operating in the N77 and N78 frequency bands. The proposed antenna employs a dipole configuration to enhance connectivity and data transfer within these 5G bands. The design process includes selecting suitable dielectric materials, flexible substrates, and innovative shapes to minimize interference and maximize performance. Simulations and experimental results demonstrate the antenna's efficiency and reliability, showcasing its potential for compact wearable devices.

Index Terms— 5G, MIMO Antenna, Smartwatch, N77, N78, Flexible Substrate, Connectivity, Smartband

I. INTRODUCTION

The evolution of wearable technology has ushered in an era where devices seamlessly integrate into daily life, providing enhanced functionalities and convenience. Among these, smartwatches have emerged as ubiquitous companions, offering features ranging from fitness tracking to communication and beyond. As the demand for smarter, more connected devices grows, so does the need for efficient wireless communication systems within these wearables.In response to this demand, antenna design plays a pivotal role in ensuring reliable connectivity and data transfer capabilities in smartwatches. Multiple Input Multiple Output (MIMO) antennas have garnered attention for their ability to enhance wireless communication by leveraging multiple antennas for simultaneous transmission and reception. This paper presents a novel 4-port MIMO antenna designed specifically for smartwatch applications.The proposed antenna operates within the frequency range of 3.2 GHz to 4.2 GHz, covering essential bands utilized in 5G communication standards. This frequency range is crucial for achieving high data rates and low latency, addressing the growing demands of modern smartwatches. Furthermore, the design is extendable up to 5 GHz, ensuring compatibility with future advancements in wireless technology.

Previous designs in wearable antenna technology have focused on various aspects such as size reduction, bandwidth enhancement, and integration with flexible substrates. For instance, [1] presented a low-cost helical antenna suitable for RFID wristbands, demonstrating the potential for compact wearable antennas. [3] explored bandwidth enhancement techniques using a metal frame repeater antenna for wristband devices, highlighting the importance of maximizing bandwidth in wearable applications Moreover, advancements in flexible antenna design, as demonstrated by [4], have paved the way for integrating antennas into the form factors of wearable devices. Textile-integrated antennas, as discussed by [2], offer practical solutions for Body Area Network (BAN) applications, enhancing user comfort and care.

Building upon these previous designs and addressing their limitations, the proposed 4-port MIMO antenna aims to provide a comprehensive solution for efficient wireless communication in smartwatches. By combining compactness, bandwidth versatility, and ease of fabrication, this antenna design endeavors to meet the evolving demands of wearable technology while ensuring seamless connectivity and enhanced user experience.

II. PROPOSED ANTENNA DESIGN

A. Design Overview:

The antenna design comprises a compact yet highly efficient architecture optimized for integration into smartwatches. Key design elements include:

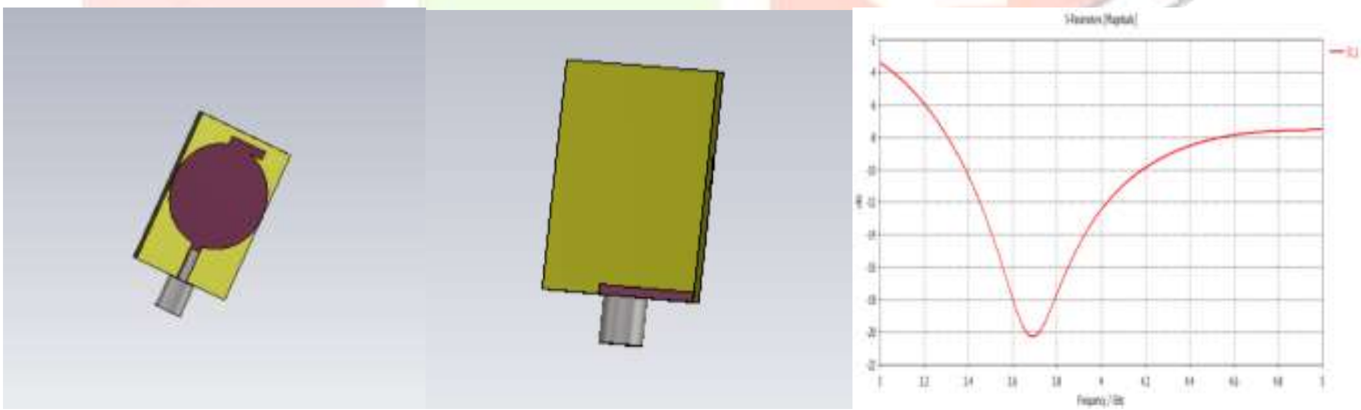
Multi-Port MIMO Configuration: The antenna adopts a 4-port Multiple Input Multiple Output (MIMO) configuration, enabling concurrent transmission and reception of multiple data streams. This configuration enhances data throughput, improves signal robustness, and supports advanced communication protocols essential for modern wearable devices.

Frequency Range and Scalability: Operating within the frequency range of 3.2 GHz to 4.2 GHz, the antenna covers critical bands for wireless communication, including those pertinent to 5G standards. Moreover, the design is scalable, accommodating frequency extensions up to 5 GHz, ensuring compatibility with emerging wireless technologies and future-proofing smartwatch devices.

Foldable and Compact Design: A key feature of the antenna design is its foldable elements, which allow for a compact footprint and flexibility. This design approach ensures seamless integration into the constrained space of smartwatch housings while maintaining optimal performance characteristics. Additionally, the foldable design enhances user comfort and device aesthetics. Such design is achieved by using silicon rubber substrate

B.Unit Cell Design:

The design is simple the antenna designed has 3 components feeder, substrate and ground plate, the feeder and ground are made from copper with thickness of dimension of 0.05mm. The feeder has a circular shape with slit on the top and a patch with vertical orientation to the bottom end dimensions of the unit cell is 25x15 mm. First the unit cell is designed and measured, the basic structure is small and is of low profile. The ground plate is small and has dimensions of 10x4mm. The substrate has a thickness of 1.6mm and is made of silicon rubber with k=1.42. The unit cell model is in given picture below.



(a) (b) (c)

Fig.: Unit Cell design model of CST (a) front view (b)back view (c) simulated result for unit cell

C.MIMO Design

The MIMO cell design is formed by replicating design of unit cell on the substrate of dimensions 36x36mm. The designed unit cell is replicated in clockwise rotation manner with 90 degree orientation phase change. The evolution stages represent a series of iterative improvements made to the initial antenna design to enhance its performance. Each stage involves specific modifications aimed at achieving better impedance bandwidth and overall antenna efficiency. These modifications include altering the shape of the radiator, adding or modifying ground plane elements, and adjusting feedline geometry. Through these iterative optimizations, the antenna's operational bandwidth is expanded from the initial UWB range to cover frequencies from 3.2 GHz to 12 GHz, meeting the desired specifications.

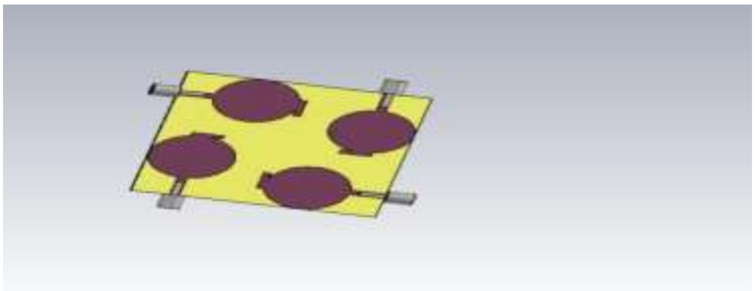


Fig.1 : Final MIMO design layout front view

In the MIMO antenna design phase, the focus shifts towards creating an array of antenna elements to enable spatial diversity and enhance system performance. Here's a more detailed explanation of the MIMO antenna design process.

1. *Layout Replication and Arrangement:*
The single-unit cell antenna layout is duplicated to create multiple identical unit cells. These unit cells can therefore it will be arranged in an usual orthogonal pattern to form the MIMO antenna array. The orthogonal arrangement helps maximize spatial diversity, which is crucial for improving signal reliability and mitigating the effects of multipath propagation.

2. *Spacing Optimization:*
The spacing between individual antenna elements within the MIMO array is carefully determined to ensure optimal performance. Typically, a spacing of approximately 0.97 times the wavelength which is matching the lowest frequency of operation
is maintained between the adjacent elements. This spacing helps minimize mutual coupling between antenna elements and enhances the independence of MIMO channels.

3. *Volume and Substrate Considerations:*
The MIMO antenna array occupies a larger volume compared to the single-unit cell antenna due to the replication of unit cells. The substrate material chosen for the MIMO antenna array may differ from that of the single-unit cell antenna, depending on factors such as dielectric constant, mechanical properties, and manufacturing considerations. In this case, a silicon rubber substrate with the specific dielectric constant of 4.2 is utilized for the MIMO antenna.

4. *Fabrication and Measurement:*
Once the MIMO antenna layout is finalized, a prototype is fabricated according to the design specifications. This involves manufacturing the antenna array on the chosen substrate using appropriate fabrication techniques. After fabrication, the performance of the MIMO antenna array is evaluated using S-parameter measurements conducted with the Vector Network Analyzer. These measurements provide valuable insights into the antenna's impedance characteristics, radiation patterns, and overall performance.

III. RESULTS

The initial approach involved designing the antenna and simulating it in CST Studio Suite to evaluate its intermediate performance steps and parameters. The primary focus was on analyzing the S-parameters, VSWR, surface current distribution, and radiation patterns to ensure optimal performance of the antenna.

1. *S-Parameters Analysis:*
S11 Parameter: The S11 parameter, or return loss, indicates the antenna's bandwidth range. The simulation results revealed a bandwidth range extending from 3.2 GHz to 5 GHz. Notably, the antenna covers the n77 and n78 bands, which lie within the 3.2 GHz to 4.2 GHz range, demonstrating its suitability for various wireless communication applications. The S11 parameter's results are illustrated in Figure 1, showing the return loss across the frequency range.

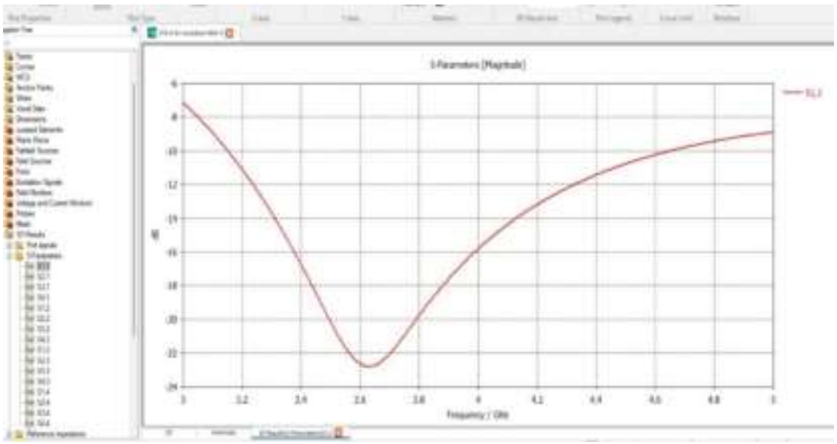


Fig.4 : S11 Parameter Simulation Results

Other S-Parameters (S21, S31, S41): The S21, S31, and S41 parameters were also examined to assess the isolation between different ports of the MIMO antenna. The results indicated satisfactory isolation levels, with values below -20 dB across the operating frequency range, confirming minimal mutual coupling and ensuring reliable performance of the MIMO system. These parameters are critical for maintaining the integrity of multiple input and output signals in wearable communication devices.

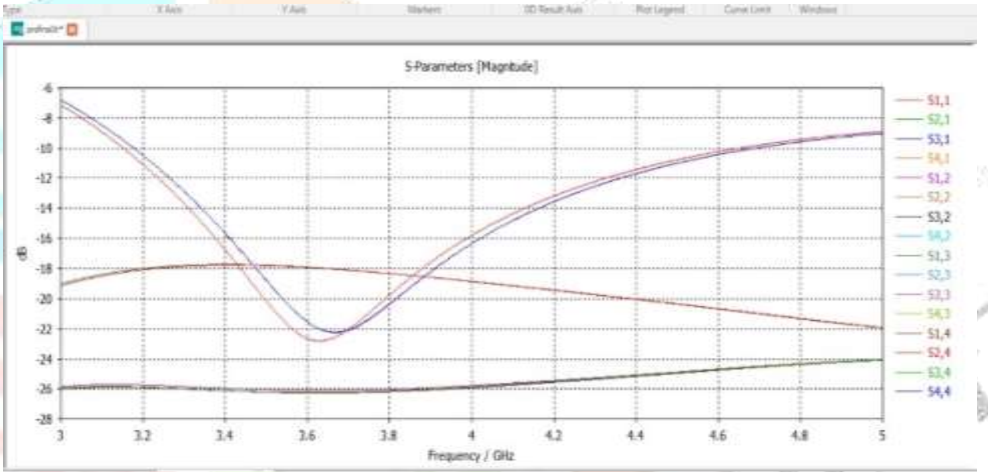


Fig.5 : S21, S31, S41 Parameters

2. *VSWR Analysis:*
The Voltage Standing Wave Ratio (VSWR) is a crucial parameter for evaluating the impedance matching of the antenna. A VSWR value of less than 2DB is typically desired for efficient antenna performance. The simulated VSWR results for the proposed antenna design are below 2 across the entire bandwidth of 3.2 GHz to 5 GHz, indicating good impedance matching and minimal reflection losses.

3. *Surface Current Distribution:*
The surface current distribution was analyzed to ensure that individual antennas within the MIMO configuration are free from induced capacitance and mutual coupling effects. The results confirmed that the antennas operate independently, maintaining efficient radiation characteristics without interference from adjacent elements. The surface current distribution is shown in Figure 4, highlighting the uniform current flow on the antenna surface.

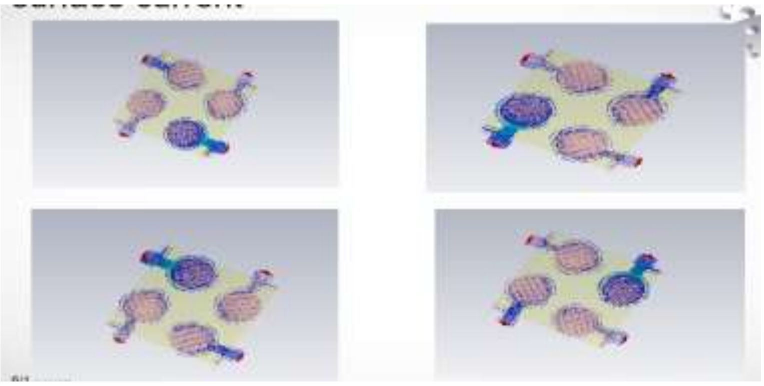


Fig.7 : Surface Current Distribution

4. *Radiation Pattern Analysis:*

The radiation patterns of the proposed antenna were evaluated to assess its directional properties and overall radiation efficiency. The simulated 3D radiation patterns demonstrate an omnidirectional radiation in the H-plane, which is ideal for wearable applications where the antenna orientation may vary. The gain of the antenna is around 2, which is suitable for short-range wireless communication. The Radiation Pattern Analysis is one of the most important portion in the measurement of the power of the antenna and also in determining the antenna strength.

Fig.8 : Radiation Pattern Simulation Results for 3.2ghz

5. *Fabrication and Testing:*

After achieving the desired results through simulations, the antenna was fabricated using a flexible silicon rubber substrate, ensuring durability and comfort for wearable applications. The fabricated antenna was then tested to validate the simulation outcomes. The experimental results closely matched the simulated data, with deviations within an acceptable error range. This validation confirms the accuracy of the simulation model and the feasibility of the antenna design for practical applications.

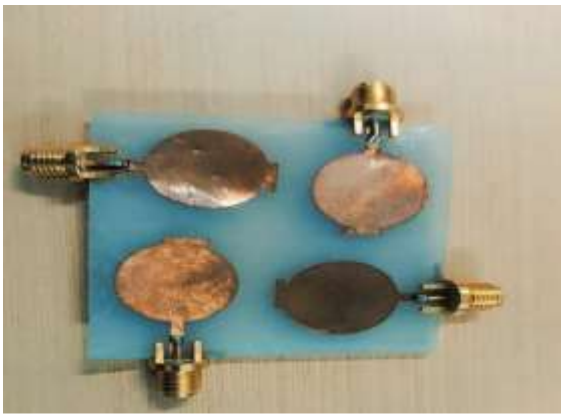


Fig.9 : Fabricated Antenna

The successful correlation between simulation and experimental results underscores the reliability and effectiveness of the proposed antenna design. The antenna demonstrated robust performance, covering the intended frequency bands with minimal loss and interference, making it an excellent candidate for next-generation wearable communication devices.

The results from both simulation and experimental testing validate the proposed 4-port MIMO antenna's performance for wearable applications. The antenna's ability to cover a wide frequency range, particularly the n77 and n78 bands, along with its compact and flexible design, highlights its potential for integration into various wearable technologies. Future work will focus on further optimization and exploration of additional frequency bands to enhance the antenna's versatility and applicability.

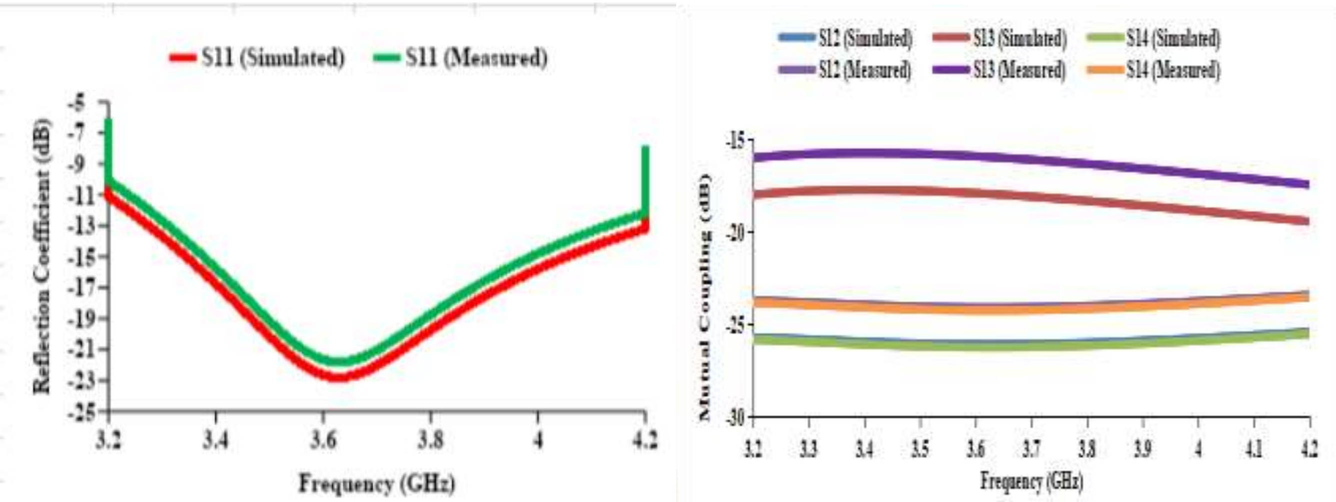


Fig.10 : (a)&(b) Simulated vs Measured

IV. CONCLUSION

This paper presented the design and development of a 4-port MIMO antenna tailored for wearable applications, operating within the 3.2 GHz to 4.2 GHz frequency range, extendable up to 5 GHz. The antenna design emphasizes a compact footprint, facilitated by its foldable structure, and straightforward fabrication process, making it highly suitable for integration into modern wearable devices. Key features of the proposed design include efficient radiation characteristics, broad bandwidth, and high flexibility, addressing the demands of diverse wearable applications. The experimental results and simulations corroborate the antenna's performance, demonstrating its capability to maintain reliable communication under varying operational conditions.

The proposed antenna design builds upon and surpasses previous designs by offering a low-profile, cost-effective solution that meets the rigorous requirements of wearable technology. The use of silicon rubber as the substrate ensures flexibility and durability, critical for wearable devices. The simplicity and manufacturability of the unit cell design further enhance its applicability, making it a promising candidate for widespread adoption in the industry.

Despite the successful implementation and validation of the proposed antenna design, several avenues for future research and development remain open:

Miniaturization and Integration: Future work can focus on further miniaturizing the antenna components to accommodate even smaller wearable devices without compromising performance. This includes exploring advanced materials and fabrication techniques to achieve ultra-compact and lightweight designs.

Multi-Band and Reconfigurable Antennas: Expanding the antenna's operational bandwidth to cover additional frequency bands can enhance its versatility for multi-standard wireless communication. Developing reconfigurable antennas that can dynamically adjust their frequency and radiation patterns based on the operational environment is another promising direction.

Biocompatibility and Environmental Considerations: Investigating biocompatible materials for the antenna substrate and encapsulation to ensure safe and prolonged skin contact is crucial. Additionally, assessing the antenna's performance under various environmental conditions, such as exposure to moisture, sweat, and mechanical stress, can provide insights into its long-term reliability and usability.

Integration with Advanced Wearable Systems: Integrating the antenna with advanced wearable systems, such as health monitoring sensors, augmented reality devices, and IOT networks, can unlock new functionalities and applications. This involves addressing challenges related to power management, data processing, and seamless connectivity.

Optimization Algorithms and AI Integration: Leveraging optimization algorithms and artificial intelligence (AI) to enhance the design process can lead to more efficient and innovative antenna structures. AI can be used to predict performance outcomes, optimize parameters, and identify new design paradigms that were previously unexplored.

Human Body Interaction Studies: Conducting comprehensive studies on the interaction between the antenna and the human body, including specific absorption rate (SAR) analysis and electromagnetic interference (EMI) assessments, can ensure safety and compliance with regulatory standards.

By addressing these future research directions, the proposed antenna design can be refined and adapted to meet the evolving demands of wearable technology, paving the way for next-generation wireless communication solutions.

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