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INTEGRATED MICROWAVE AND mm-WAVE MIMO ANTENNA SYSTEM

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Abstract : The complete coverage of the operating frequency bands from microwave bands to enable fifth-generation (5G) Internet of Things (IoT) systems to operate across microwave and millimeter-wave frequency bands, a versatile multiband antenna has been developed. This antenna covers frequencies ranging from microwave (2.5/3.5/5.5/7.5 GHz) to mm-wave (23–31 GHz), and features a 4-port MIMO configuration with pattern diversity for comprehensive 360-degree coverage in 5G IoT applications. The multiband capability is achieved through the integration of well-designed quarter-wavelength stubs. Across critical frequency ranges like 2.3–2.6 GHz, 3.2–3.8 GHz, 5.0–6.1 GHz, and 7.1–8. GHz (with |S11| < –10 dB), the antenna demonstrates strong performance, while also effectively operating within the 23–31 GHz mm-wave band with desired radiation properties. Notably, the antenna exhibits over 95% radiation efficiency and consistent gain characteristics (> 2.5 dBi at microwave bands and 6.5 dBi at mm-wave bands). Additionally, the antenna design extends to a 2 × 2 MIMO setup. This antenna module is well-suited for 5G IoT applications, particularly in indoor environments such as smart homes, offices, and vehicle-to-everything communications.

Index Terms **- Fifth-generation (5G) communication, Internet of Things (IoT) antenna, MIMO antenna, sub-6 GHz and millimeter wave (mm-wave) antenna, vehicular communication.**

I. INTRODUCTION

The demand for efficient wireless communication systems in the 5G and Internet of Things (IoT) era has spurred the development of advanced antenna technologies. Integrated microwave and millimeter-wave Multiple Input Multiple Output (MIMO) antennas have emerged as a promising solution. These antennas combine microwave and millimeter-wave frequencies, enabling high data rates and increased network capacity. Their 360-degree diversity pattern ensures robust and reliable connectivity, crucial for IoT applications dispersed across various environments. This integration enhances coverage and addresses challenges such as signal multipath fading, improving the overall performance of 5G IoT networks.

The convergence of 5G communication and IoT aims to connect people, data, processes, infrastructure, and devices with high data rates and low latency. 5G-enabled IoT, combined with artificial intelligence, will revolutionize sectors like smart cities, healthcare, agriculture, manufacturing, transportation (ITS), and augmented reality.

To ensure seamless connectivity, 5G technology operates across two frequency bands: existing sub-6 GHz bands and new, unused millimeter-wave (mm-wave) spectrum. This broad spectrum supports high traffic growth and meets the demand for high bandwidth networks. Macro cells operating in the sub-3 GHz and sub-6 GHz bands provide wide coverage, while 5G small cells operating in mm-wave bands deliver intense capacity where needed.

II. EXISTING SYSTEM

The progression of IoT necessitates antennas that can efficiently operate across various frequency bands while remaining simple and cost-effective. Traditional methods involving multiple antennas for different frequency bands often result in larger, more complex, and expensive devices. Shared aperture antennas have emerged as a solution, integrating sub-6 GHz and mm-wave bands into a single structure. This integration simplifies device design and enables seamless connectivity across diverse frequency ranges. Previous studies have explored shared aperture designs, including those combining WLAN and Wi-Gig frequencies or addressing specific 5G bands like 2.5/3.5 GHz and 24/26/28 GHz. While numerous designs have achieved multiband functionality, challenges remain, particularly in MIMO configurations due to complex feeding networks and limited space for multiple ports. Recent advancements have tackled these challenges by introducing single-fed triple-band antennas capable of operating at microwave and mm-wave frequencies simultaneously. These antennas offer benefits such as simplified feeding mechanisms and broader frequency coverage. However, current solutions often do not fully cover all critical bands required for 5G IoT applications.

III. PROPOSED SYSTEM

Our proposed single-fed multiband antenna presents a pioneering solution, functioning across both microwave (2.5/3.5/5.5/7.5 GHz) and mm-wave (24/26/28 GHz) bands. This antenna is specifically crafted to address the diverse connectivity needs of 5G IoT devices and sensors. Moreover, its 4-port MIMO configuration ensures strong connectivity with polarization diversity and minimal interaction between MIMO elements, meeting the rigorous standards of 5G-enabled IoT requirements. Our innovation represents a significant advancement in realizing integrated microwave and mm-wave MIMO antennas, offering unmatched pattern diversity and isolation crucial for future IoT applications.

3.1 Single Element Antenna:

The antenna design features a triangular monopole with five metallic stubs at the front and two stubs at the rear, interconnected via shorting vias. Fabricated on a Rogers-5880 substrate with a dielectric constant (εr) of 2.2 and a loss tangent (tan δ) of 0.0009, this design ensures effective transmission and reception across microwave and mm-wave frequencies. The front metallic stubs, functioning as quarter-wavelength monopoles, resonate at frequencies of 2.5, 3.5, 5.5, 7.5, and 28 GHz. Additionally, the rear stubs, connected to the main radiator through shorting pins, contribute to enhancing bandwidth, particularly at the 2.5- and 3.5-GHz frequency bands.

Fig.1. Single Element Antenna Front and Back side

The antenna design incorporates carefully optimized stub lengths to achieve resonances across both microwave and mm-wave bands. Key dimensions include parameters such as A = 16, L = 21, h = 1.6, gm = 3, ws = 2, gw = 4.1, wp = 13, pw = 5, l1 = 10.5, b1 = 13.7, l2 = 8.2, b2 = 9.2, l3 = 5.9, b3 = 4.8, l4 = 3.5, b4 = 5, l5 = 2, s = 1, w = 1, wo = 3.2, ba = 14.2, bb = 9.2, la = 10.5, and lb = 8.2, all measured in millimeters (mm). These dimensions are meticulously chosen to ensure optimal antenna performance across specified frequency bands, making it a robust solution for 5G IoT applications requiring diverse connectivity and high bandwidth capabilities.

Initially, a stub of width (w) is positioned to the far left of the main radiator to achieve resonance at a lower frequency. This antenna (antenna 1) exhibits two resonances: the primary resonance from the source antenna at 8.5 GHz and an additional resonance at 2.5 GHz. The overall length of the monopole resonating at 2.5 GHz ($L_{2.5GHz}$) is determined as $L_{2.5GHz} = l1 + w1 + wo = \lambda_{2.5GHz}/4$.

Additional stubs are then added near the first one with a spacing of (s = 1 mm) to achieve resonances at 3.5, 5.5, and 7.5 GHz. These antennas, denoted as antenna 2, antenna 3, and antenna 4 respectively, have overall lengths of resonating stubs calculated as follows:

$L_{3.5GHz} = l2 + w2 = \lambda_{3.5GHz}/4$

$L_{5.5GHz} = l3 + w3 = \lambda_{5.5GHz}/4$

$L_{7.5GHz} = l4 + w4 = \lambda_{7.5GHz}/4$

To address limited bandwidth issues typically seen in monopole antennas, especially at lower frequencies like 2.5 (7.2%) and 3.5 GHz (9.5%), two additional stubs are added at the back of the antenna via shorting pins (antenna 6 and antenna 7). These stubs are carefully tuned to resonate at adjacent frequencies (2.4 and 3.7 GHz) to bridge individual resonances for bandwidth improvement, resulting in enhanced bandwidth to 11% at the 2.5 GHz band and 17% at the 3.5 GHz band.

Additionally, to cater to 5G IoT at the mm-wave band (24/26/28 GHz), an additional even stub of length (l5) is added at the right corner of the main rectangular monopole, designated as antenna 5. The length of the mm-wave stub (L_{26GHz}) is determined as $L_{28GHz} = l5 = \lambda_{28GHz}/4$. This antenna provides resonance from 22 to 33.9 GHz in the mm-wave band.

In summary, the proposed single-element receiving antenna design achieves resonances at 2.5, 3.5, 5.5, 7.5, and 24/26/28 GHz, effectively covering both microwave and mm-wave bands to ensure continuous connectivity for 5G IoT applications.

The |S11| of the proposed single-component antenna at microwave and mm-wave bands is plotted. Measurements demonstrate good impedance matching (|S11| < -10 dB) from 2.37-2.65 GHz (11.15%), 3.25-3.85 GHz (16.9%), 5.0-6.1 GHz (19.8%), and 7.15-8.5 GHz (17.2%) at microwave frequency bands. In the mm-wave bands, the antenna resonates from 23-31 GHz (29.6%). This indicates that the antenna covers significant operating frequency bands, including microwave bands for ISM-band (2.4 GHz), WLAN-band (2.5 and 5.5 GHz), 4G LTE band (2.5 GHz), and 5G sub-6-G.

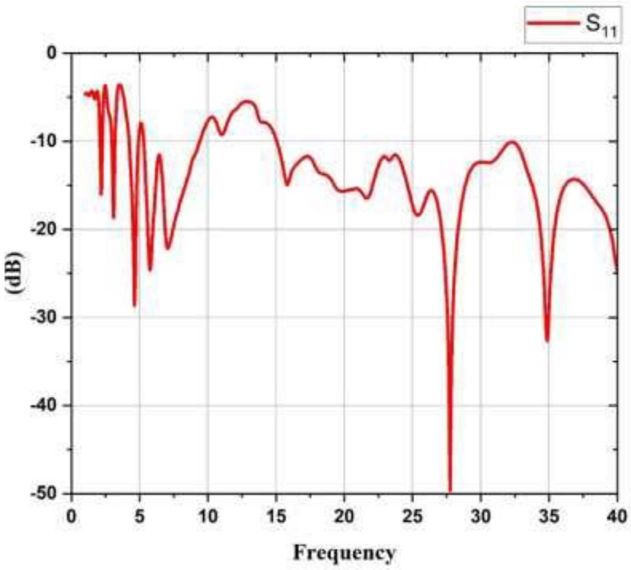

Fig.2. |s11| parameter for Proposed Antenna

3.2 2x2 MIMO Antenna:

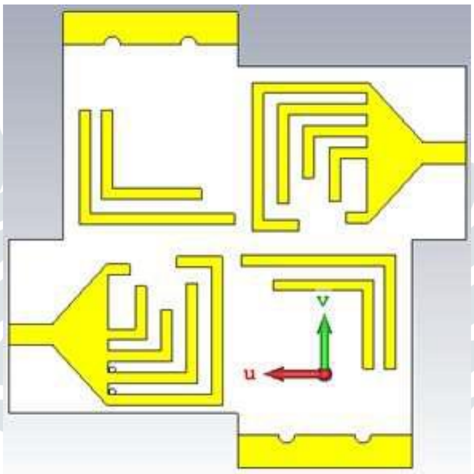

Fig.3. 2x2 MIMO Antenna

The receiving antenna is initially configured in a 2 × 2 MIMO setup by arranging a single-component antenna symmetrically with a distance of d = 16 mm between adjacent antennas. To enhance isolation, the adjacent antenna elements are printed on the backside of the substrate, while the diagonally positioned antennas are on the same plane as the substrate. The mathematical design and physical model of the antenna are depicted in Fig. 11. Simulation and measurement results of the transmission coefficients (|Sij|) demonstrate that the antennas achieve high isolation exceeding 20 dB Additionally, the adjacent antennas exhibit similar simulated isolation values (|S21|, |S32|, |S41|, |S43|) due to their mathematical symmetry. Similarly, the symmetrically positioned antennas (|S31|, |S42|) show identical isolation between them. For brevity, only the measured values of |S11|, |S12|, |S13|, and |S14| are plotted.

The average isolation between the diagonally positioned antennas is lower compared to the adjacent antennas, as the distance between them is larger than between the adjacent antennas. It is important to note that the isolation for the mm-wave bands is exceptionally high and is not displayed, given the significant element spacing (16 mm ≈ 1.5 λ o at 27 GHz).

Result:

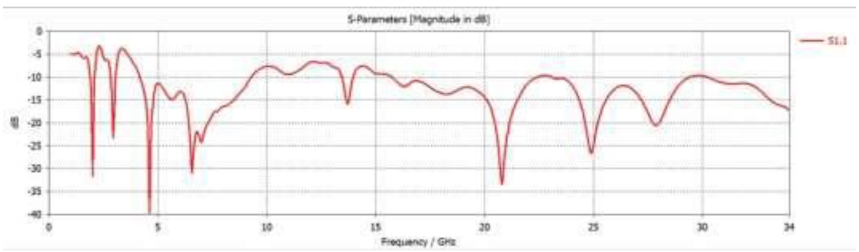

Fig. |s11| of the 2 x 2 MIMO Antenna

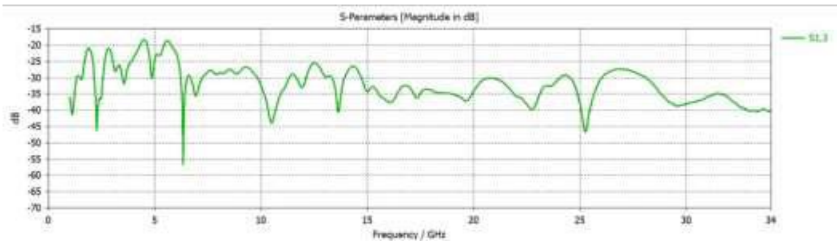

Fig. |s12| of the 2 x 2 MIMO Antenna

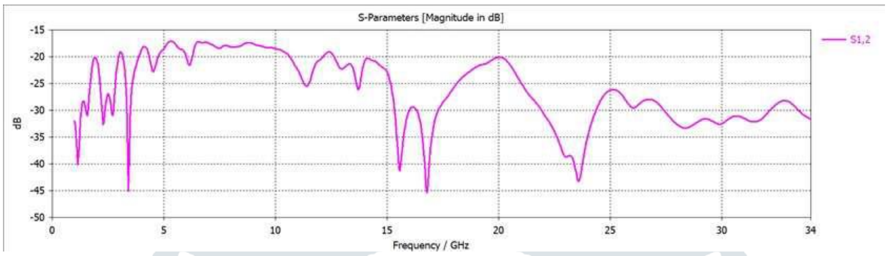

Fig. |s13| of the 2 x 2 MIMO Antenna

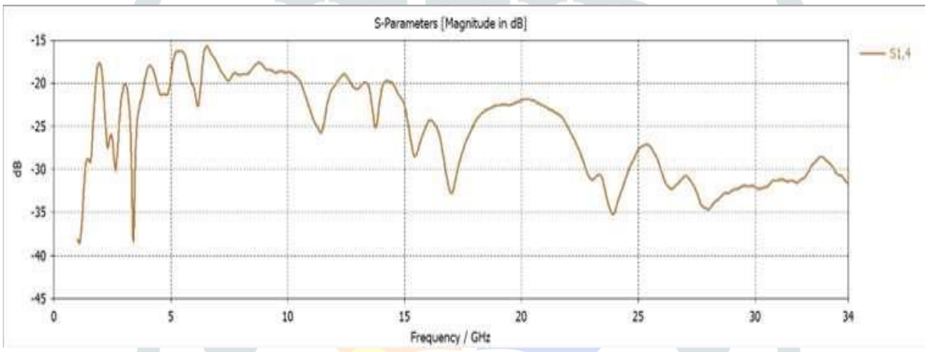

Fig. |s14| of the 2 x 2 MIMO Antenna

IV. APPLICATIONS

5G IoT Connectivity: The advanced multiband 12-port MIMO antenna, characterized by high isolation and pattern diversity across both microwave and mm-wave bands, offers seamless connectivity for modern devices and sensors in 5G IoT applications.

Indoor Wireless Networks: The antenna's versatile multiband capabilities, including resonance in key frequency bands and polarization diversity, make it an excellent choice for indoor wireless networks, ensuring reliable connectivity for various devices and applications within buildings.

Smart City Infrastructure: Utilizing its 2 × 4 and 3 × 4 MIMO configurations, the antenna is well-suited for smart city deployments, providing enhanced spectral and pattern diversity to support efficient data transmission for diverse IoT devices like smart meters and environmental sensors across urban landscapes.

V2X Communications: With its 360° space coverage and excellent isolation, the proposed MIMO antenna is ideal for V2X (Vehicle-to-Everything) communications, facilitating reliable and efficient data exchange in urban environments and on roads.

V. CONCLUSION

In conclusion, combining microwave and mm-wave antennas into a unified design to meet the diverse frequency demands of a multistandard IoT system poses a significant challenge, mainly due to the considerable frequency difference. In response, we have developed an advanced multiband 12-port MIMO antenna capable of operating across microwave bands (2.5/3.5/5.5/7.5 GHz) and mm-wave bands, ensuring outstanding isolation and pattern diversity crucial for 5G IoT applications.

Positioned at the front are five stubs, with two located at the back. These rear stubs are intricately connected to the central radiator using metallic pins, enhancing bandwidth performance, particularly at the 2.5- and 3.5-GHz bands. To achieve multiband functionality, we have incorporated five inverted L-shaped resonating stubs onto the monopole's front side. Additionally, two stubs have been strategically inserted at the antenna's backside via metallic pins, further enhancing bandwidth performance, specifically targeting the 2.4- and 3.5-GHz bands.

Extensive simulation and measurement analysis confirm the antenna's exceptional performance across crucial frequency bands: 2.5 GHz (2.37–2.65 GHz), 3.5 GHz (3.25–3.85 GHz), 5.5 GHz (5.0–6.1 GHz), and 7.5 GHz (7.15–8.5 GHz). Impressively, the antenna also demonstrates resonance within the 5G mm-wave spectrum (23–31 GHz), exhibiting radiation characteristics conducive to advanced wireless communication applications. This innovative design represents a significant advancement in the field, offering a versatile solution capable of meeting the stringent requirements of modern multistandard IoT systems.

Expanding upon the single-element antenna design, we have translated it into a 2 × 2 MIMO configuration to leverage spatial diversity and enhance signal robustness. By deploying two sets of the original antenna design, we effectively create a 2 × 2 MIMO system, enabling improved spectral efficiency and mitigating the effects of multipath fading.Expanding upon this foundation, we have advanced the MIMO system to a 2 × 4 configuration by incorporating four sets of the single-element antenna design, effectively doubling the number of transmitting and receiving elements. This 2 × 4 MIMO system significantly improves spectral efficiency and spatial diversity, enhancing signal reliability and throughput.

Continuing our innovation, we propose a 3 × 4 MIMO system by integrating three sets of the original antenna design, resulting in a total of twelve transmitting and receiving elements. This configuration offers even greater spectral efficiency and pattern diversity, facilitating enhanced data rates and improved system performance in challenging wireless environments. By progressively scaling up the MIMO system from 2 × 2 to 2 × 4 and eventually to the proposed 3 × 4 configuration, we ensure comprehensive spectral and pattern diversity, thereby optimizing the performance of the antenna system for demanding 5G IoT applications.

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