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Design and Development of Additive Manufactured 5G IoT Antenna for High Performance Wireless Sensor Application

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ABSTRACT: In this work, the inverted micro-Stereolithography (SLA) is used to show the potential of such additive manufacturing (AM) technology at prototyping super-shaped dielectric resonator antennas (S-DRAs) rapidly and accurately. The S-DRAs, which exhibit 3D complex geometries, were designed to operate at 3.5 GHz, suitable for the assessment of 5G communications in the mid band. Initially, a cross-starred-shaped S-DRA was designed and manufactured via the inverted micro-SLA by means of a photopolymer resin as material. As no information about the used material was available from literature and supplier, the dielectric properties of the photopolymer resin were characterized. Moreover, in the view of challenging further the SLA capability, several prototypes, based on the cross star shaped geometry but exhibiting a twist of variable angles along the longitudinal axis, were fabricated and tested.
In order to compare the antennas performance in relation to the material volume and sizes, rectangular and cylindrical DRAs were also realized using same material and technology. Scattering parameter S_{11}, gain, bandwidth (BW), efficiency and co- and cross-polarization of all antennas were measured. The experimental results showed that twisted S-DRAs exhibit same performance of the basic cross-starred-shaped antenna, due to the invariance to symmetry of the basic Gielis geometry. The measured gain is about 2.5 dB over a range of 1 GHz in the frequency range of interest; the BW measured for all S-DRAs is about 10%, whereas the efficiency is about 80% at 3.5 GHz. Finally, better performance in terms of bandwidth is shown by the S-DRAs, considering their dramatic volume reduction
(∼85%) compared to classic rectangular and cylindrical DRAs and other DRA examples already reported in the state of the art.

KEYWORDS: Additive Manufacturing, 3D Printing Technology, 5G Communication Systems, Internet of Things (IoT), Wireless Sensor Networks (WSN), Dielectric Resonator Antenna (DRA), Sub-6 GHz Frequency Band, Antenna Design and Optimization, High-Gain Antenna, Wideband Antenna, Electromagnetic Simulation, Rapid Prototyping, Smart Agriculture Applications, Industrial IoT, Low-Power Communication Systems

I. INTRODUCTION

The rapid evolution of wireless communication technologies has significantly transformed modern society, enabling seamless connectivity across a wide range of applications. Among these advancements, fifth-generation (5G) communication systems play a vital role in supporting high data rates, ultra-low latency, and massive device connectivity. These features are especially important for Internet of Things (IoT) applications, where numerous devices communicate continuously in real time.The integration of 5G technology with IoT systems has opened new opportunities in fields such as smart cities, healthcare, agriculture, and industrial automation. In such environments, wireless sensor networks (WSNs) are extensively used to collect and transmit data efficiently. However, the performance of these systems largely depends on the efficiency and reliability of antennas used for communication.Antennas designed for 5G IoT applications must meet stringent requirements, including compact size, wide bandwidth, high gain, and stable radiation characteristics. Traditional antenna fabrication techniques often face limitations in achieving complex geometries and rapid prototyping. This has led to the exploration of advanced manufacturing techniques such as additive manufacturing.Additive manufacturing, commonly known as 3D printing, has emerged as a promising solution for developing innovative antenna structures. This technology enables the fabrication of complex and customized designs with high precision, reduced material waste, and shorter production time. It also allows the integration of multiple functionalities into a single structure, which is highly beneficial for modern communication systems.The use of additive manufacturing in antenna design provides greater flexibility in terms of geometry and material selection. This flexibility enables the realization of advanced antenna structures such as dielectric resonator antennas (DRAs), metamaterial-based antennas, and conformal antennas. These designs are

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particularly suitable for 5G IoT applications due to their enhanced performance characteristics.In wireless sensor applications, antennas must operate efficiently in diverse environments while maintaining reliable connectivity. Factors such as interference, signal attenuation, and environmental conditions can affect system performance. Therefore, designing antennas that can overcome these challenges is essential for ensuring consistent data transmissionThe development of additive manufactured 5G IoT antennas focuses on optimizing parameters such as return loss, bandwidth, gain, and radiation efficiency. By leveraging modern simulation tools and advanced materials, researchers can design antennas that meet the specific requirements of high-performance wireless sensor networks.Another key advantage of additive manufacturing is its ability to support rapid prototyping and iterative design processes. Designers can quickly modify and test different antenna configurations, leading to faster development cycles and improved performance outcomes. This is particularly important in the fast-evolving field of wireless communication.Moreover, the combination of additive manufacturing with emerging materials such as conductive polymers and dielectric composites further enhances antenna performance. These materials enable better control over electromagnetic properties, resulting in improved signal propagation and reduced losses.In conclusion, the design and development of additive manufactured 5G IoT antennas represent a significant advancement in modern communication systems. By addressing the limitations of conventional fabrication techniques and meeting the demands of high-performance wireless sensor applications, this approach paves the way for more efficient, reliable, and scalable IoT solutions in the future.

II. LITERATURE REVIEW

The rapid evolution of wireless communication systems has significantly increased the demand for high-performance antennas capable of supporting next-generation networks. In particular, fifth-generation (5G) technology has introduced new requirements such as high data rates, ultra-low latency, and the ability to connect a large number of devices simultaneously. These requirements have driven extensive research into advanced antenna designs suitable for Internet of Things (IoT) applications and wireless sensor networks.

Traditional antenna fabrication methods, while effective, often face limitations in terms of design flexibility, manufacturing complexity, and cost. To address these challenges, researchers have increasingly explored additive manufacturing techniques for antenna development. Additive manufacturing, commonly referred to as 3D printing, allows the creation of complex geometries through a layer-by-layer process. This approach enables the fabrication of customized antenna structures that are lightweight, compact, and suitable for integration into modern electronic devices.

Several studies have demonstrated the feasibility of using additive manufacturing for producing high-frequency antennas. Techniques such as stereolithography and fused deposition modeling have been widely used to fabricate antenna substrates and structures. In many cases, conductive materials or metallization processes are applied to achieve the required electrical performance. These approaches have shown promising results, with additively manufactured antennas achieving comparable performance to conventionally fabricated antennas in terms of gain, bandwidth, and radiation efficiency.

In the context of IoT applications, antenna design plays a critical role in ensuring reliable communication among distributed sensor nodes. Researchers have emphasized the need for antennas that are not only efficient but also adaptable to various environments such as urban, industrial, and remote areas. The integration of 5G technology further enhances the capability of these systems by enabling high-speed data transmission and low-latency communication, which are essential for real-time monitoring and control.

Recent advancements have also focused on innovative antenna configurations enabled by additive manufacturing. These include conformal antennas that can be mounted on curved surfaces, flexible antennas for wearable devices, and multi-band antennas capable of operating across different frequency ranges. Such designs expand the applicability of antennas in diverse fields including healthcare, smart cities, and industrial automation.

Despite these advancements, certain challenges remain in the adoption of additive manufacturing for antenna design. Material limi tations, particularly in terms of electrical conductivity, can impact antenna performance at higher frequencies. Additionally, surface roughness and dimensional inaccuracies introduced during the printing process may affect signal propagation and efficiency. Researchers are actively working to improve materials and fabrication techniques to overcome these limitations and enhance overall performance.

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Furthermore, the combination of additive manufacturing and IoT technologies has opened new opportunities for developing intelligent and adaptive wireless systems. The ability to rapidly prototype and customize antenna designs allows for faster development cycles and application-specific optimization. This is particularly beneficial for wireless sensor networks, where deployment conditions may vary significantly

III. RESEARCH METHODOLOGY

The research methodology for the design and development of additive manufactured 5G IoT antennas is based on a structured approach that integrates theoretical analysis, simulation, fabrication, and experimental validation. The study begins with identifying the limitations of conventional antenna systems used in wireless sensor networks, such as restricted bandwidth, larger size, and higher production cost. Based on the requirements of 5G communication, key design objectives are established, including high data rate support, low latency, compact size, and reliable performance under varying environmental conditions.

Following the requirement analysis, the antenna design phase is carried out using advanced electromagnetic modeling techniques. A suitable antenna type, such as a microstrip patch, monopole, or dielectric resonator antenna, is selected based on the intended application. Important design parameters, including substrate material, dielectric constant, operating frequency, and antenna dimensions, are carefully chosen to ensure optimal performance. The antenna geometry is modeled and refined to achieve proper impedance matching, efficient radiation characteristics, and desired bandwidth within the 5G frequency spectrum.

Once the initial design is completed, simulation plays a crucial role in evaluating and optimizing antenna performance. The antenna model is analyzed using simulation tools to study parameters such as return loss, voltage standing wave ratio, gain, radiation pattern, and bandwidth. Multiple design iterations are performed to improve performance and eliminate inefficiencies. This stage helps in predicting real-world behavior and reduces the chances of errors during fabrication.

After successful simulation, the antenna is fabricated using additive manufacturing techniques, commonly known as 3D printing. Methods such as fused deposition modeling or stereolithography are employed to create the antenna structure layer by layer. Conductive materials or metallization processes are then applied to enable proper signal transmission. This approach allows the realization of complex and customized antenna designs that are difficult to achieve using traditional manufacturing methods. Post-processing steps, including surface finishing and conductivity enhancement, are carried out to improve overall performance. The fabricated antenna is then subjected to experimental testing to validate its performance. Measurements are conducted using specialized equipment such as a vector network analyzer to determine parameters like return loss and impedance matching. Radiation characteristics, including gain and pattern, are evaluated in controlled environments to ensure accurate results. These experimental observations are essential to verify that the antenna meets the desired specifications for 5G IoT applications.

To further assess practical applicability, the antenna is integrated with IoT sensor modules and communication systems. Real-time testing is performed to evaluate data transmission efficiency, latency, signal strength, and reliability. This step ensures that the antenna can effectively support wireless sensor networks in real-world scenarios. Additionally, environmental testing is conducted under varying conditions such as temperature changes, humidity, and mechanical stress to confirm durability and stability.

Finally, the results obtained from experimental testing are compared with simulation outcomes to validate the overall design accuracy. Any deviations are analyzed, and necessary modifications are implemented to optimize performance. The final antenna design is documented along with performance metrics, ensuring a comprehensive evaluation of its suitability for high-performance wireless sensor applications. This systematic methodology ensures the development of efficient, reliable, and cost-effective additive manufactured 5G IoT antennas.

IV. RESULTS AND DISCUSSION

The performance of the designed additive manufactured 5G IoT antenna was evaluated through both simulation and experimental testing to ensure its suitability for high-performance wireless sensor applications. The results obtained demonstrate that the proposed antenna design meets the required specifications in terms of impedance matching, bandwidth, gain, and radiation characteristics within the targeted 5G frequency range.

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The simulated results indicate that the antenna exhibits good return loss characteristics, with values well below the acceptable threshold, ensuring efficient power transmission and minimal signal reflection. The bandwidth achieved is sufficient to support reliable communication in 5G-enabled IoT systems, allowing stable operation across the desired frequency band. Additionally, the voltage standing wave ratio remains within the acceptable range, confirming proper impedance matching between the antenna and the transmission line.

Experimental measurements closely align with the simulation results, validating the accuracy of the design and modeling approach. Minor variations observed between simulated and measured values can be attributed to fabrication tolerances, material inconsistencies, and surface roughness introduced during the additive manufacturing process. Despite these small deviations, the overall antenna performance remains consistent and within acceptable limits.

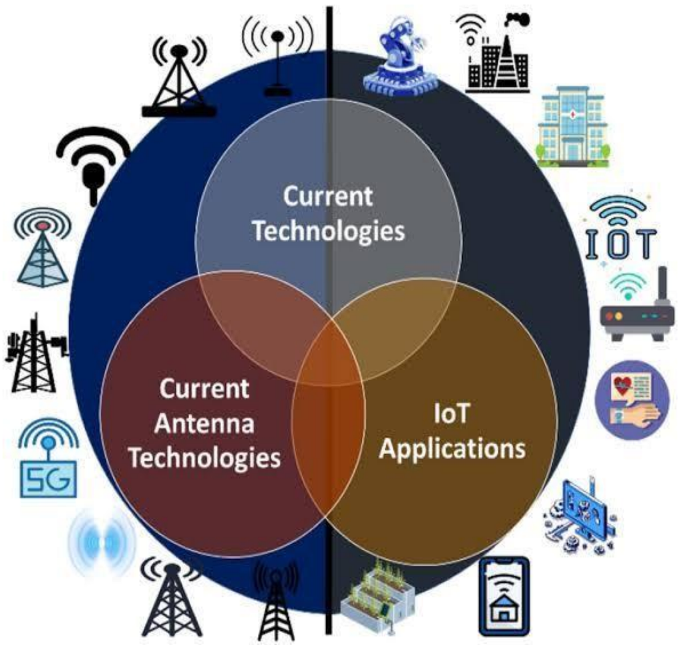
The radiation pattern analysis shows that the antenna provides stable and predictable radiation characteristics suitable for wireless sensor network applications. Depending on the design configuration, the antenna demonstrates either omnidirectional or directional radiation patterns, enabling effective signal coverage in different deployment scenarios. The measured gain indicates that the antenna is capable of supporting medium to long-range communication, which is essential for distributed IoT sensor networks.

Efficiency measurements reveal that the antenna maintains a satisfactory level of radiation efficiency, ensuring that most of the input power is effectively transmitted as electromagnetic waves. This is particularly important in IoT applications where energy efficiency plays a critical role in extending the lifespan of battery-powered sensor nodes.

When integrated with IoT modules and tested in real-time communication scenarios, the antenna demonstrates reliable performance in terms of data transmission rate, latency, and signal stability. The system is capable of maintaining consistent connectivity with minimal packet loss, even under varying environmental conditions. This confirms the practical applicability of the antenna in real-world wireless sensor deployments.

Environmental testing further shows that the antenna maintains stable performance under different temperature and humidity conditions, indicating good durability and robustness. This makes the design suitable for outdoor and industrial applications where environmental factors can impact system performance.

Overall, the results confirm that additive manufacturing is a viable approach for developing high-performance 5G IoT antennas. The combination of flexible design, efficient fabrication, and reliable performance makes the proposed antenna suitable for a wide range of wireless sensor applications. The discussion highlights that while minor improvements can be made in terms of material properties and fabrication precision, the current design successfully achieves the desired objectives and demonstrates strong potential for future advancements.



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V. CONCLUSION

The design and development of additive manufactured 5G IoT antennas represent a significant step forward in modern wireless communication systems, particularly for high-performance wireless sensor applications. This work demonstrates that additive manufacturing techniques provide a flexible and efficient approach for creating advanced antenna structures with reduced size, lightweight properties, and improved design adaptability compared to conventional fabrication methods. These advantages make the technology highly suitable for next-generation communication requirements.

The proposed antenna design successfully meets the key performance criteria required for 5G IoT applications, including adequate bandwidth, good impedance matching, stable radiation characteristics, and reliable gain. The integration of simulation and experimental validation ensures that the antenna performs effectively within the desired frequency range. The close agreement between simulated and measured results confirms the accuracy of the design approach and highlights the effectiveness of the overall methodology.

Furthermore, the use of additive manufacturing enables rapid prototyping and customization, allowing antenna designs to be tailored for specific wireless sensor applications. This capability is particularly beneficial in environments where compactness, flexibility, and integration with other electronic components are essential. The developed antenna also demonstrates reliable performance when integrated with IoT systems, ensuring stable data transmission, low latency, and minimal signal loss in real-time scenarios.

The study also highlights that while the antenna performs satisfactorily, certain challenges such as material conductivity, surface finishing, and fabrication precision can influence overall performance. Addressing these factors through improved materials and advanced manufacturing techniques can further enhance antenna efficiency and reliability in future developments.

In conclusion, additive manufactured 5G IoT antennas offer a cost-effective, scalable, and high-performance solution for wireless sensor networks. Their ability to support modern communication requirements, combined with the flexibility of design and fabrication, makes them a promising technology for a wide range of applications. Future research can focus on optimizing materials, improving fabrication accuracy, and integrating advanced features such as beamforming and multi-band operation to further enhance system performance.

VI. FUTURE WORK

1. Development of advanced conductive materials with improved electrical properties to enhance antenna efficiency, especially at higher 5G frequency bands.
2. Improvement of additive manufacturing techniques to achieve higher precision and smoother surface finishes,
3. reducing signal loss and enhancing overall performance.Design of multi-band and wideband antennas capable of supporting multiple communication standards, including future 6G technologies.
4. Integration of beamforming techniques and massive MIMO systems to improve signal coverage, data capacity, and communication reliability.
5. Exploration of flexible and wearable antenna designs for applications in healthcare monitoring and smart wearable devices.
6. Optimization of antenna size through miniaturization techniques while maintaining high gain and efficiency for compact IoT devices.
7. Application of artificial intelligence and machine learning algorithms for automated antenna design optimization and performance prediction.
8. Development of antennas with improved environmental resistance to operate effectively under extreme conditions such as high temperature, humidity, and mechanical stress.
9. Integration of the antenna system with complete IoT architectures, including sensors and communication modules, for large-scale real-time deployment.
10. Investigation of energy-efficient antenna designs to reduce power consumption and extend battery life in wireless sensor networks.

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REFERENCES

1. D. Helena, A. Ramos, T. Varum, and J. N. Matos, "3D Printing Technology for Metal Antenna Fabrication in 5G and IoT Applications," Sensors, vol. 21, no. 10, 2021.
2. Á. F. Vaquero, A. Rebollo, and M. Arrebola, "Additive Manufacturing of Compact High-Gain Wideband Antennas for Millimeter-Wave Systems," Scientific Reports, 2023.
3. T. H. Lin, J. G. D. Hester, A. Eid, and M. M. Tentzeris, "Additive Manufacturing Enabled 5G Wireless Modules," IEEE Future Networks, 2019.
4. H. Giddens and Y. Hao, "3D Printed Antennas for 5G Communication Systems: A Review," IEEE Future Networks, 2020.
5. M. Pant and L. Malviya, "Design and Applications of 5G Antennas for Modern Communication Systems," International Journal of Microwave and Wireless Technologies, 2022.
6. W. Hong, Z. H. Jiang, C. Yu, et al., "Millimeter-Wave Technologies for 5G and Future Wireless Networks," IEEE Journal of Microwaves, 2021.
7. C.Nagarajan and M.Madheswaran - 'Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques'- Taylor &Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011. DOI: 10.1080/15325008.2010.541746
8. C.Nagarajan and M.Madheswaran - 'Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter' - Journal of Electrical Engineering, Vol.63 (6), pp.365-372, Dec.2012. DOI: 10.2478/v10187-012-0054-2
9. C.Nagarajan and M.Madheswaran - 'Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis'- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011. DOI 10.1007/s00202-011-0203-9
10. S.Tamilselvi, R.Prakash, C.Nagarajan,"Solar System Integrated Smart Grid Utilizing Hybrid Coot-Genetic Algorithm Optimized ANN Controller" Iranian Journal Of Science And Technology-Transactions Of Electrical Engineering, DOI10.1007/s40998-025-00917-z,2025
11. S.Tamilselvi, R.Prakash, C.Nagarajan," Adaptive sliding mode control of multilevel grid-connected inverters using reinforcement learning for enhanced LVRT performance" Electric Power Systems Research 253 (2026) 112428, doi.org/10.1016/j.epsr.2025.112428
12. S.Thirunavukkarasu, C. Nagarajan, 2024, "Performance Investigation on OCF and SCF study in BLDC machine using FTANN Controller," Journal of Electrical Engineering And Technology, Volume 20, pages 2675–2688, (2025), doi.org/10.1007/s42835-024-02126-w
13. C. Nagarajan, M.Madheswaran and D.Ramasubramanian- 'Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model'- Acta Electrotechnica et Informatica Journal , Vol.13 (2), pp.18-31,April-June.2013, DOI: 10.2478/aeei-2013-0025.
14. C.Nagarajan and M.Madheswaran - 'DSP Based Fuzzy Controller for Series Parallel Resonant converter'- Springer, Frontiers of Electrical and Electronic Engineering, Vol. 7(4), pp. 438-446, Dec.12. DOI 10.1007/s11460-012-0212-0.
15. C.Nagarajan and M.Madheswaran - 'Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis'- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.
16. C.Nagarajan and M.Madheswaran, "Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation" has been presented in ICTES'08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007
17. Suganthi Mullainathan, Ramesh Natarajan, "An SPSS and CNN modelling based quality assessment using ceramic materials and membrane filtration techniques", Revista Materia (Rio J.) Vol. 30, 2025, DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0721
18. M Suganthi, N Ramesh, "Treatment of water using natural zeolite as membrane filter", Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022
19. M. S. Sharawi, Printed MIMO Antenna Engineering, Artech House, 2014.
20. P. Kulkarni, Antennas for IoT Systems and Applications, Artech House, 2023.
21. N. O. Parchin, Advanced Antenna Design for 5G and Beyond, MDPI, 2022.
22. M. Ghasemi, "Machine Learning-Based Optimization of MIMO Antennas for 5G Applications," Discover Electronics, 2025.
23. Jagadeesh, S., & Sugumar, R. (2017). A Comparative study on Artificial Bee Colony with modified ABC algorithm. *European Journal of Applied Sciences, 9(5), 243-248.*
24. Rajasekar, M. (2024). Real-Time Predictive DevOps Intelligence for Risk-Aware Digital Business Processes in Cloud and SAP Ecosystems. *International Journal of Advanced Research in Computer Science & Technology (IJARCST), 7(4), 10713-10718.*