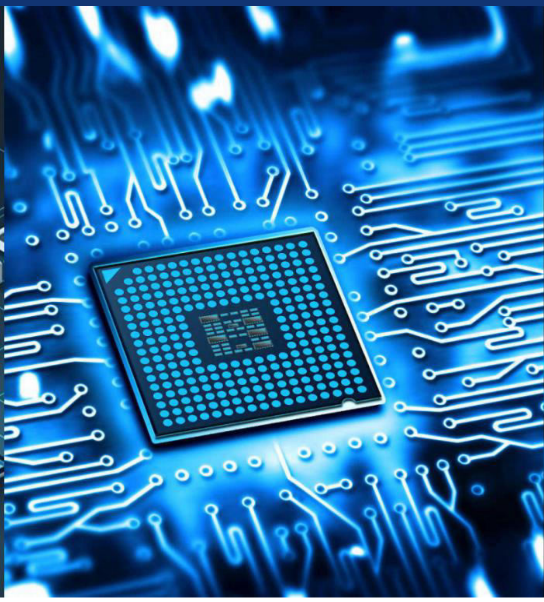
IJIRCCE

ISSN(O): 2320-9801

ISSN(P): 2320-9798



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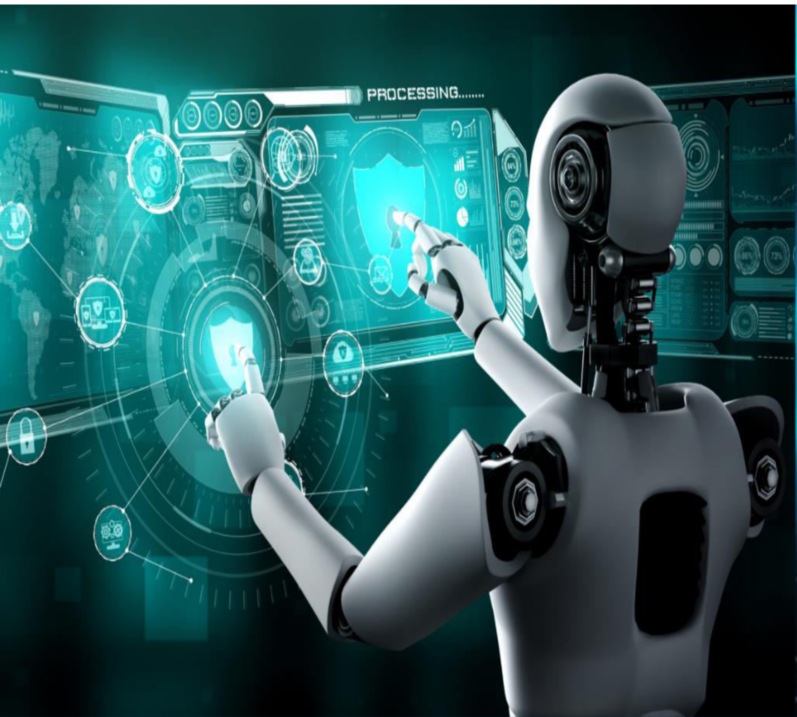

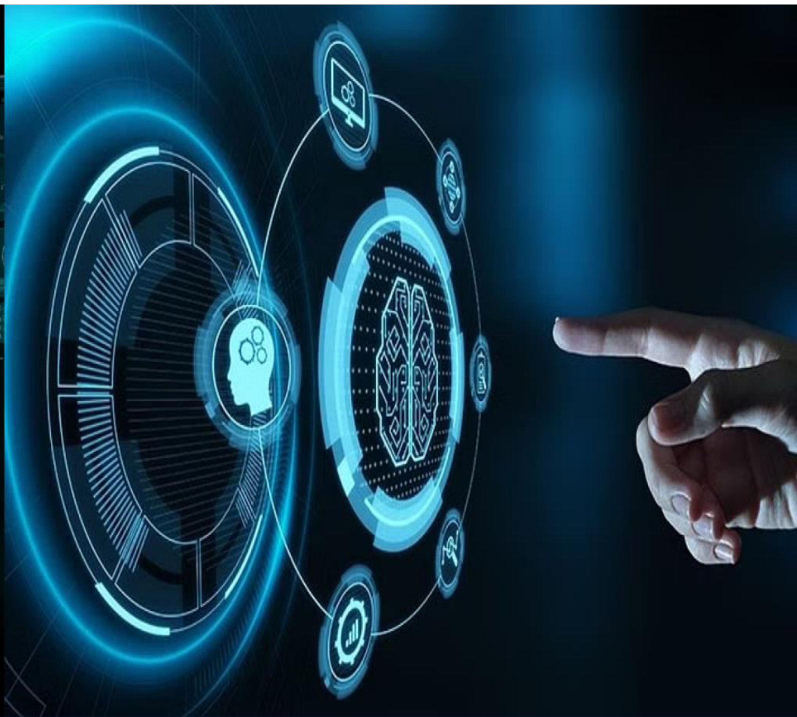

Impact Factor: 8.771

Volume 13, Issue 3, March 2025

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International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Low-Cost 9.4 GHz Microstrip Patch Antenna Design with PLA

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ABSTRACT: The paper presents a low-cost rectangular micros-trip patch antenna with a center frequency of 9.4 GHz, using copper tape as the conductive element and poly-lactic acid (PLA) as the dielectric substrate. This design is intended to create a cost-effective, environmentally friendly, and easily fabricable antenna for radar and communication systems. PLA dielectric substrates are 1.5 mm thick and have a relative permittivity of 2.75 and a loss tangent of 0.017. Antenna simulations in CST Microwave Studio showed an S11 of -17 dB, bandwidth of 503 MHz, and gain of 7.11dBi. It is demonstrated that the antenna operates effectively at the desired frequency, making it suitable for use in radar and wireless communication systems. This study demonstrates that copper tape and PLA, a biodegradable material, can be used to create inexpensive, readily manufactured microstrip patch antennas. Keywords--3D Printing, Poly-lactic Acid, Patch Antenna, Antenna 5G

I. INTRODUCTION

Microstrip patch antennas have revolutionized modern communication systems due to their compact, planar design and ease of integration into various electronic devices. They are widely used in military systems, satellite and mobile communications, and radar applications. However, the demand for cost-effective and sustainable materials has led to research on biodegradable alternatives like **polylactic acid (PLA)**, a thermoplastic polymer derived from renewable resources. PLA offers advantages such as **low cost, biodegradability, and compatibility with 3D printing**, making it a viable option for rapid antenna prototyping.

This study focuses on the design and fabrication of a **9.4 GHz microstrip patch antenna using PLA as the dielectric substrate and copper tape as the radiating element**, operating in the **X-band** for radar applications. The work demonstrates that high-frequency performance can be achieved with an eco-friendly and budget-friendly approach.

Additionally, advancements in **3D-printed antennas** are explored, highlighting fabrication techniques such as **Direct Metal Laser Sintering (DMLS), Stereolithography (SLA), and Fused Deposition Modelling (FDM)**. Researchers have experimented with various materials, balancing dielectric properties and ease of printing. **Simulation tools like HFSS and CST MWS** play a crucial role in optimizing antenna design, while **Vector Network Analyzer (VNA) measurements** ensure performance validation.

Further studies investigate **PLA/Flax composites** for antenna substrates, emphasizing their potential in reducing electronic waste and promoting sustainable electronics. Additive manufacturing also enhances antenna efficiency, enabling **geometric optimizations** that improve gain and bandwidth while reducing production costs. The integration of **electrified conductive filaments** showcases the feasibility of 3D-printed antennas for wireless applications, offering greater design flexibility compared to traditional fabrication methods.

In summary, the use of **PLA-based materials** in antenna design not only supports environmental sustainability but also opens new possibilities for **low-cost, high-performance RF applications**, particularly in wireless communication and radar systems.

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II. LITERATURE SURVEY

1. Introduction to Microstrip Patch Antennas

Microstrip patch antennas (MPAs) are widely used in wireless communication systems due to their **low-profile structure, ease of fabrication, and cost-effectiveness**. They typically consist of three key components: **a radiating patch, a dielectric substrate, and a ground plane**. High-frequency microstrip antennas, particularly at **9.4 GHz**, are essential for applications such as **satellite communications, radar systems, and wireless sensor networks**.

Traditional MPA designs utilize expensive materials like **FR4 and silver-coated substrates**, making them less viable for low-cost implementations. To reduce costs, researchers have explored alternative materials such as **Polylactic Acid (PLA) as a substrate and copper tape as a conductive layer**. PLA, an **eco-friendly thermoplastic**, combined with **copper tape**, a **flexible and low-cost conductor**, presents a promising alternative for economical yet efficient antenna designs.

2. Challenges of Microstrip Patch Antennas at 9.4 GHz

Designing microstrip patch antennas at **9.4 GHz** presents several challenges due to **the shorter wavelength**, leading to **smaller antenna dimensions** and **higher sensitivity to material properties**. At such high frequencies, **dielectric constant, loss tangent, and surface roughness** play a significant role in determining the **efficiency and performance** of the antenna.

Several studies have explored the design of **microstrip antennas for high-frequency operations at 9.4 GHz**. Key design considerations include:

- **Patch Geometry**: Rectangular, circular, and elliptical patches are commonly used, with each shape affecting **resonant frequency and impedance matching**.
- **Substrate Properties**: The dielectric constant and loss tangent of the substrate material significantly impact the antenna's bandwidth, radiation efficiency, and overall performance.
- **Feed Mechanism**: Techniques such as **microstrip line feed, coaxial probe feed, and aperture coupling** influence impedance matching and antenna gain.

3. Low-Cost Materials: PLA and Copper Tape

PLA (Polylactic Acid) as a Substrate

PLA is a **biodegradable, cost-effective thermoplastic** widely used in **3D printing**. Its properties make it suitable for **prototyping microstrip antennas**, especially in **low-budget applications**.

Copper Tape as a Conductive Layer

Copper tape is an **affordable and flexible conductor** commonly used for **low-cost antenna fabrication**.

4. Research and Development in PLA-Based Antennas

Ongoing research focuses on **enhancing the performance of PLA-based antennas** through material improvements and fabrication techniques:

- **3D Printing of PLA Antennas:**
  - **Additive manufacturing** allows for precise dimension control, essential for **high-frequency resonance**.
  - **Metamaterial integration** is being explored to improve gain and efficiency.
- **Hybrid PLA Substrates:**
  - Mixing PLA with **glass fibre's or conductive polymers** can improve **dielectric properties** while maintaining **low-cost fabrication**.
- **Copper Tape Integration Techniques:**
  - Studies highlight **improved adhesion methods** for copper tape on PLA to enhance **conductivity and durability**.
  - Investigations into **alternative conductors** (e.g., graphene-based coatings) are ongoing.

5. Examples of Low-Cost 9.4 GHz Antennas

Several prototypes of **low-cost antennas using PLA and copper tape** have been tested, including:

- **Circular Patch Antennas:**

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  - Designed for **high-gain and wide bandwidth applications**.
  - Optimized for **minimal material cost** while maintaining **reasonable performance**.
- **Rectangular Patch Antennas:**
  - Tuning of dimensions and feed location helps achieve **9.4 GHz resonance**.
  - Copper tape is used for the **radiating patch and ground plane**, reducing overall **fabrication costs**.

6. Challenges and Future Research Directions

While PLA and copper tape offer a **low-cost alternative** to traditional materials, several **challenges remain**:

- **Material Losses:**
  - PLA's **high loss tangent** limits efficiency at 9.4 GHz.
  - Research is ongoing into **hybrid PLA composites** that incorporate **low-loss additives**.
- **Precision in Fabrication:**
  - **3D printing limitations** can affect the accuracy of antenna dimensions.
  - **Higher-resolution printing techniques** are being developed to improve **manufacturing precision**.
- **Alternative Conductive Layers:**
  - Copper tape is a simple solution but may not be ideal for long-term stability.
  - Investigations into **graphene-based conductors or conductive inks** are ongoing to enhance durability and performance.

III. METHODOLOGY

Methodology for Designing a Low-Cost 9.4 GHz Microstrip Patch Antenna Using PLA and Copper Tape

The design and development of a low-cost 9.4 GHz microstrip patch antenna using PLA (Polylactic Acid) as the substrate and copper tape as the radiating element and ground plane involve a systematic approach encompassing material selection, design, simulation, fabrication, and testing. The methodology is outlined as follows:

1. Material Selection

Substrate Material:

PLA is chosen as the substrate due to its affordability, ease of fabrication (especially through 3D printing), and accessibility. Its dielectric properties, including the dielectric constant (ε_r) and loss tangent ($\tan \delta$), are crucial for antenna performance. PLA typically exhibits a dielectric constant between 2.5 and 3.0, with the loss tangent influencing efficiency at 9.4 GHz.

Conductor Material:

Copper tape is selected as the conductor for both the patch and ground plane due to its high conductivity. The ease of application and prototyping advantages make it an ideal choice for this design.

2. Design Parameters

The key parameters involved in designing the microstrip patch antenna include:

- **Resonant Frequency:** The antenna is designed to operate at 9.4 GHz, requiring precise dimension calculations to ensure resonance.
- **Patch Geometry:** A rectangular patch is chosen for its simplicity and well-documented design parameters. The patch dimensions are determined using standard resonant frequency equations.
- **Impedance Matching:** The antenna must achieve a 50Ω impedance, typically through a microstrip feed. Feed placement is optimized using techniques like coaxial feed or microstrip line feed.
- **Ground Plane:** A sufficiently large ground plane ensures a stable and symmetric radiation pattern, generally about 1.5 times the patch size.

3. Design and Simulation

Simulation tools are utilized to model the antenna's performance before fabrication:

- **Software Selection:** HFSS, CST Microwave Studio, or FEKO are employed for electromagnetic simulations, evaluating parameters such as return loss, bandwidth, and impedance matching.

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- **Modelling the Substrate and Patch:** The PLA substrate and copper tape are accurately modelled with their respective material properties. The dielectric constant and substrate thickness are carefully defined.
- **Optimization:** The patch dimensions and feed position are refined to achieve a return loss (S11) of less than -10 dB at 9.4 GHz for optimal power transfer.

4. Fabrication

Substrate Preparation:

PLA is either 3D printed or obtained as a sheet. If 3D printed, high resolution ensures precise antenna dimensions. The substrate thickness is selected based on simulation results, typically ranging from 1 mm to 3 mm.

Copper Tape Application:

Copper tape is cut and applied to form the patch and ground plane. The dimensions align with the calculated patch and ground plane specifications.

Feed Mechanism:

A microstrip line is incorporated on the PLA surface, connecting it to the copper tape patch. Feed positioning is adjusted for proper impedance matching.

5. Testing and Measurement

Post-fabrication, the antenna undergoes rigorous testing:

- **Return Loss (S11):** Measured using a network analyzer to ensure a return loss below -10 dB at 9.4 GHz.
- **Radiation Pattern:** Evaluated in an anechoic chamber to determine the directional properties and gain.
- **Bandwidth:** Measured by observing the frequency range over which return loss remains below -10 dB.
- **Efficiency:** Determined by comparing total radiated power to input power.

6. Performance Evaluation

The measured results are compared with simulation predictions to analyze deviations. Factors such as return loss, radiation pattern, and bandwidth are assessed, and the impact of using PLA and copper tape is evaluated.

7. Optimization and Refinement

If discrepancies arise, adjustments are made:

- **Substrate Modification:** Variations in PLA thickness or hybrid substrates are explored to minimize loss.
- **Feed Adjustment:** The feed type or position is altered for better impedance matching.

8. Final Design and Application

Once optimized, the antenna is ready for application in wireless communication, satellite systems, and sensor networks.

Summary of Methodology:

1. **Material Selection:** PLA for substrate, copper tape for conductor.
2. **Design:** Calculate patch dimensions, feed position, and ground plane size.
3. **Simulation:** Validate and optimize using EM simulation software.
4. **Fabrication:** Manufacture using 3D printing for PLA and copper tape for conductors.
5. **Testing:** Measure return loss, radiation pattern, bandwidth, and efficiency.
6. **Optimization:** Adjust design based on test results.

This structured methodology ensures a cost-effective yet efficient design for a 9.4 GHz microstrip patch antenna, making it suitable for a variety of wireless communication applications.

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9. Block diagram

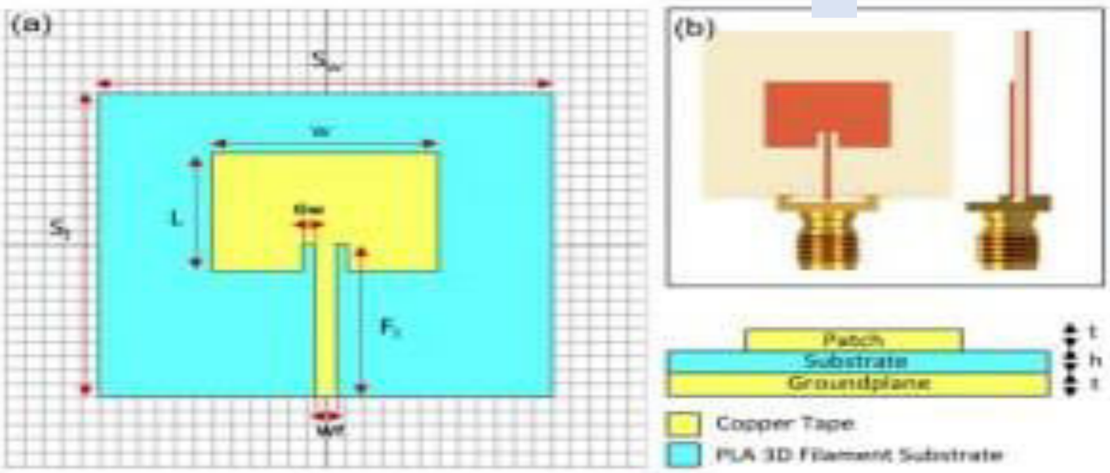

Fig. 1. Microstrip patch antenna (a) 3D simulation view; (b) top and side-view with SMA connector.

IV. RESULTS AND DISCUSSION

The proposed antenna was simulated using ANSYS HFSS to analyze its performance at 9.4 GHz, focusing on key metrics such as input reflection coefficient, bandwidth, gain, and radiation pattern. The input reflection coefficient (**S11**) indicates impedance matching, with an optimal value above 10 dB to minimize power reflection. Initially, the unoptimized design exhibited an **S11 of 8 dB at 9.6 GHz**, but after parameter optimization in CST Studio, it improved to **17 dB at 9.4 GHz**, ensuring efficient power radiation. The bandwidth, measured as the frequency range where **S11 remains below -10 dB**, was also evaluated to determine the antenna's operational stability across frequencies.

The gain and radiation pattern were analyzed to assess the antenna's directional characteristics and efficiency. The gain, representing the antenna's ability to direct energy, was found to be sufficient for high-frequency applications. The radiation pattern was measured in an anechoic chamber, confirming a stable and predictable distribution of radiated energy, crucial for consistent performance. Overall, the simulation results validated that the proposed **9.4 GHz microstrip patch antenna**, designed using **PLA as the substrate and copper tape as the radiating element**, meets the necessary performance criteria, making it a viable solution for wireless communication and high-frequency applications.

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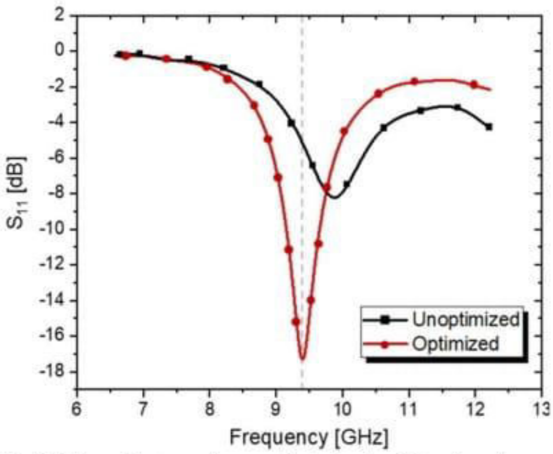

Fig.2. S11 graph between the unoptimized and optimized results.

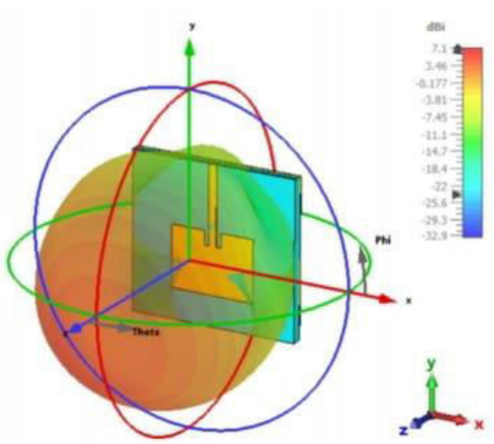

Fig.3. Gain simulated result of the rectangular antenna.

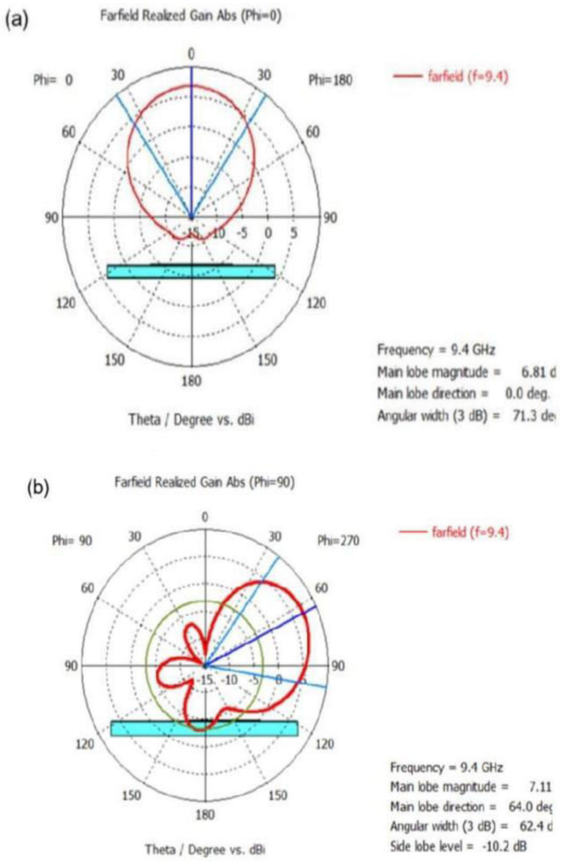

Fig.4. (a) E-Plane (Phi = 0); (b) H-Plane (Phi = 90)

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REFERENCES

[1].M. Sohel Rana,S.Hossain, S.Biswas Rana, and M.Mostafizur Rahman,"Microstrip patch antennas for various applications: a review," IJEECS, vol. 29, no. 3, p. 1511, 2023, doi: 10.11591/ijeecs.v29.i3.pp1511-1519.

[2].M.Niazy, F.Masood, B.Niazi, M.Rokhan, and R. Ahmad, "Analysis of 3x4 Microstrip Patch Antenna Array for 94GHz Radar Applications," International Journal of Research in Engineering and Science (IJRES) ISSN, vol. 9, pp. 43–50, 2021.

[3]. A.Maheshwari and Andreea Danielescu, "Creating environmentally conscious products and environments with smart materials,"Elsevier eBooks, pp. 103–126, Jan. 2024, doi: https://doi.org/10.1016/b978-0- 443-13462-3.00001-7.

[4]. R. Singh, B. S.Dhaliwal, and Shyam Sundar Pattnaik, 3D Printing of Sensors, Actuators, and Antennas for Low-Cost Product Manufacturing. Informa, 2022. doi: https://doi.org/10.1201/9781003194224.

[5]. 2022 IEEE Microwaves, Antennas, and Propagation Conference (MAPCON): IEEE, 2022.

[6]. Emine Avşar Aydın, Mustafa Berkan Biçer, Mehmet Erman Mert, Ceyla Özgür, and Başak Doğru Mert, "3D-Printed Antenna Design Using Graphene Filament and Copper Tape for High-Tech Air Components," SAE Int. J. Aerosp., vol. 16, no. 2, pp. 131–140, 2022, doi: 10.4271/01-16-02-0008.

[7]. A.Inanc and A. B.Sahin, "Low - Cost Perimeter Intrusion Radar System Development," in 2020 7th International Conference on Electrical and Electronics Engineering (ICEEE), 2020. [Online]. Available: http://dx.doi.org/10.1109/iceee49618.2020.9102575

[8]. C.Henning, A. Schmid, S. Hecht, C. Rückmar, K. Harre and R. Bauer"Usability of Bio-based Polymers for PCB," 2019 42nd International Spring Seminar on Electronics Technology (ISSE), Wroclaw, Poland, 2019, pp. 1-7, doi: 10.1109/ISSE.2019.8810257.

[9]. T.Fougeroux, A. Douyère, N. M. Murad, J. Sibille, S. Oree, and J.-L Dubard, "Performance enhancement of low-cost microstrip patch antennas through 3D-printed conductive geometric forms," AEU - International Journal of Electronics and Communications, vol. 177, p. 155211, Apr. 2024, doi: https://doi.org/10.1016/j.aeue.2024.155211

[10]. M.Pozar, Microwave Engineering: Theory and Techniques: John Wiley & Sons, 2021.
APCON): IEEE, 2022.

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