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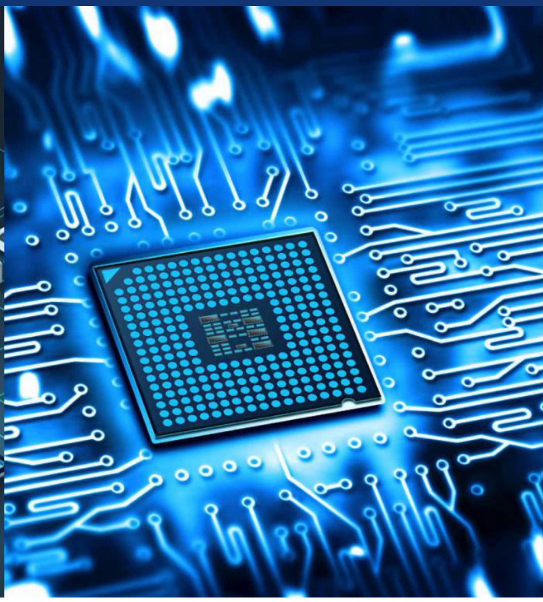


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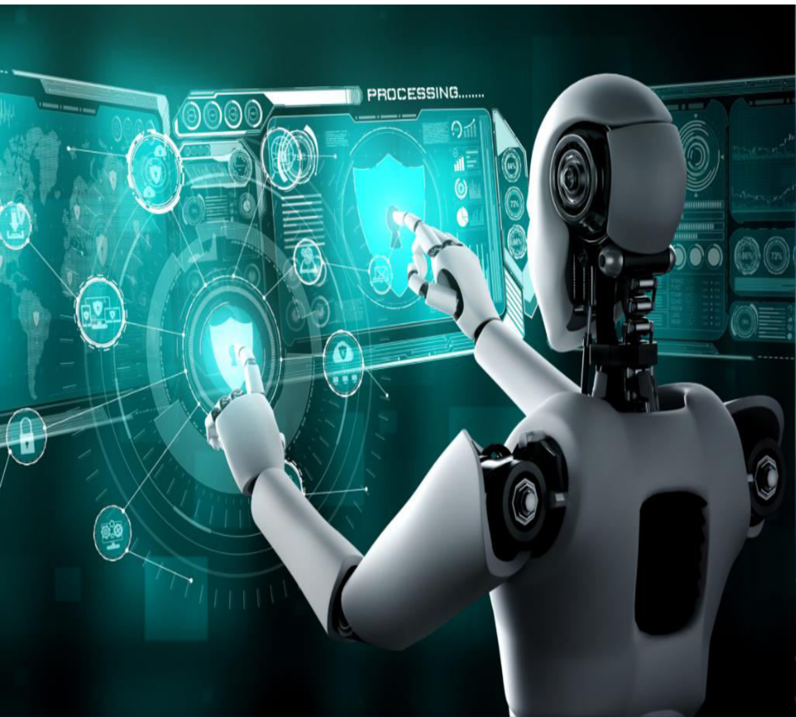

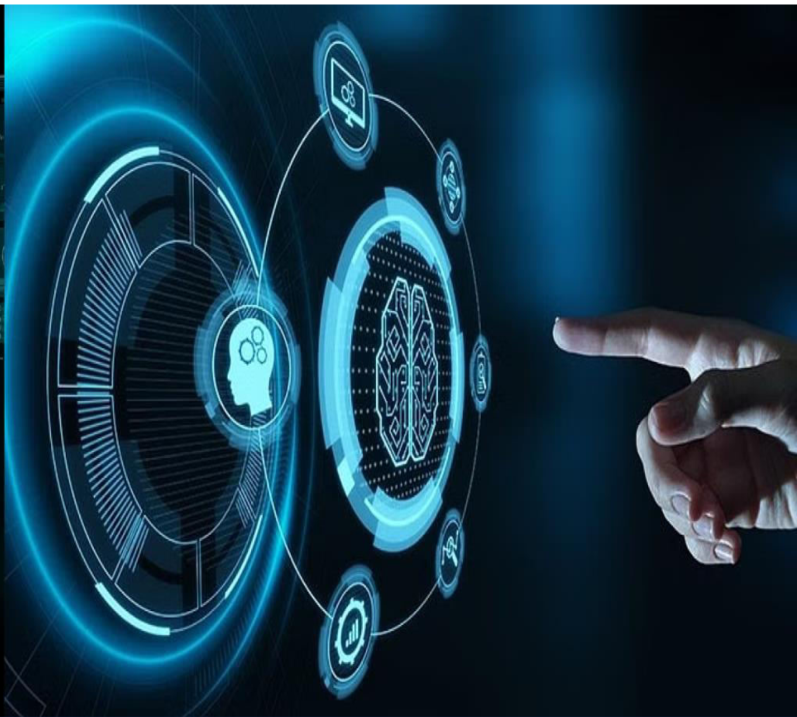

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Low-Cost 9.4 GHz Microstrip Patch Antenna Design with PLA and Copper Tape

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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

important design elements of antennas composed of them. The antenna design incorporSince microstrip patch antennas have a tiny, planar design that is simple to integrate into a variety of electrical devices, they have completely changed modern communication systems [1]. They are used in many different applications, such as military systems, satellite and mobile communications, and radar [2, 3]. But as the need for ecologically friendly solutions rises, there is a growing need for more affordable and sustainable materials in the production of antennas [4]. Even though they function quite well, traditional substrates like FR4 and Rogers RT/duroid are frequently expensive and non-biodegradable [5]. Research on substitute substrates, such as polylactic acid (PLA), a thermoplastic polymer made from renewable resources like cornstarch, has increased due to the growing interest in biodegradable materials [6, 7]. PLA give many benefits that include such as low cost, biodegradability, and compatibility with 3D printing technology, making it a desirable choice for quick antenna design prototyping [8]. Because of its superior electrical conductivity, copper tape could be used in a variety of ways that become radiating elements on the antenna [9]. Another work investigates PLA as an antenna substrate, concentrating on PLA/Flax composites [12]. The study explores the possible implications of these sustainable materials for the development of environmentally friendly electronics and highlights a number of ates short-circuited stubs and U-shaped slots into a rectangular patch to increase impedance matching and bandwidth. The electronics industry's use of PLA/Flax substrates for antennas has proven to be beneficial in reducing electronic waste and lowering its carbon footprint. This indicates that biodegradable materials have the potential to replace conventional PCB materials. Beyond antenna applications, this work creates new opportunities for the use of PLA/Flax composites in other electronic systems where environmental sustainability is a major concern, such implantable devices. In conclusion, the development of PLA/Flax-based antennas not only demonstrates that it is possible to use sustainable materials in radio frequency applications, but it also paves the way for more technological advancements that put the environment first.

II. LITERATURE SURVEY

1.Microstrip patch antennas (MPA) are widely used in wireless communication systems due to their low-profile design, ease of fabrication, and low cost. They typically consist of a radiating patch, a dielectric substrate, and a ground plane. The use of microstrip antennas at high frequencies, such as 9.4 GHz, is often sought for applications in satellite communications, radar, and wireless sensor networks.For cost-effective designs, materials such as Copper Tape and PLA (Polylactic Acid) are considered viable alternatives to more expensive materials like FR4 and silver-coated substrates. PLA is an eco-friendly thermoplastic, and copper tape is a low-cost, flexible conductor, which makes this combination an attractive option for low-cost, yet efficient antenna designs.

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2. Microstrip Patch Antennas at 9.4 GHz At 9.4 GHz, the design of microstrip patch antennas becomes more challenging due to the shorter wavelength, leading to smaller antenna dimensions. At these frequencies,the substrate material properties (dielectric constant, loss tangent, etc.) significantly affect the antenna's performance.

Several studies have focused on designing microstrip antennas for high-frequency operations at 9.4 GHz. Typical design approaches include:

Patch Shape and Configuration: Common designs include rectangular, circular, and elliptical patches. The shape of the patch directly influences the resonant frequency and impedance matching.

Substrate Material: The choice of substrate material greatly influences antenna characteristics such as bandwidth, efficiency, and radiation pattern. A low-cost option like PLA is being investigated for use in such high-frequency designs, often with trade-offs in terms of dielectric constant and loss.

3. Low-Cost Materials: PLA and Copper Tape PLA (Polylactic Acid):

Advantages: PLA is a biodegradable, low-cost, and easily accessible material for 3D printing applications. It is known for its easy fabrication process and is suitable for creating complex geometries for antennas. Moreover, PLA is a good candidate for prototyping since it can be used in both additive manufacturing and traditional fabrication methods.

Disadvantages: PLA has a relatively high dielectric constant compared to traditional microstrip substrates like FR4, leading to a smaller effective wavelength. It also has a relatively high loss tangent, which could result in poor efficiency in high-frequency applications. However, by carefully tuning the antenna's dimensions and design, the performance can still be optimized.

Copper Tape:

Advantages: Copper tape is an inexpensive, flexible conductor that is widely available. It offers good electrical conductivity, making it a suitable material for the antenna's patch and ground plane. It is easy to work with and can be easily applied to the PLA substrate, making the fabrication process simple.

4. Design Considerations for Low-Cost 9.4 GHz Antennas

The design of a microstrip patch antenna operating at 9.4 GHz with PLA and copper tape involves several key considerations:

Size of the Antenna: The wavelength at 9.4 GHz is approximately 3.19 cm. Since microstrip antennas are typically designed to be a fraction of the wavelength (usually around half), the patch size would be small, roughly 1.6 cm to 2 cm, depending on the specific design approach.

Impedance Matching: The antenna's impedance must be matched to the feeding line (typically 50 Ω). This requires careful tuning of the patch dimensions, feed location, and the properties of the substrate. For PLA, the dielectric constant should be taken into account to ensure proper impedance matching.

Radiation Pattern: The goal is to achieve an omnidirectional or directional radiation pattern depending on the application. The use of PLA may introduce some loss and affect the radiation efficiency, so optimizing the patch geometry and feed configuration becomes critical.

Bandwidth and Efficiency: At higher frequencies like 9.4 GHz, the antenna's bandwidth becomes narrower. Using PLA as a substrate may limit the bandwidth due to the material's higher loss, so advanced techniques like adding a parasitic element or using a thicker substrate might be explored to improve bandwidth.

5. Research and Development in PLA-based Antennas

Recent studies on PLA-based antennas have focused on improving the dielectric properties and reducing losses by incorporating additives or composites. For example:

3D Printing of PLA: 3D printing technology allows for precise control over the antenna's dimensions, which is essential for achieving the desired resonance frequency. PLA's versatility in 3D printing also allows for integration of complex structures, such as metamaterials, to enhance antenna performance.Hybrid PLA Substrates: Combining PLA with other materials, such as glass fibers or conductive polymers, is another research direction to enhance the antenna's performance while maintaining its low cost and ease of fabrication.Copper Tape and PLA Integration: Several papers have discussed using copper tape as the conductor layer for microstrip antennas. This material is well-suited for rapid prototyping and low-cost manufacturing. The tape's ease of application and flexibility allows it to be used on various substrates, including PLA.

6. Examples of Low-Cost 9.4 GHz Antennas Circular Patch Antenna: Some research focuses on designing circular patch antennas at 9.4 GHz using PLA as the substrate and copper tape for the patch and ground plane. These antennas are

optimized for high-gain and wide bandwidth while minimizing cost.Rectangular Patch Antenna: Other designs utilize rectangular patch antennas, where the antenna's dimensions and feeding mechanisms are tuned to achieve a 9.4 GHz resonance. The use of copper tape for the radiating element ensures low manufacturing cost while maintaining reasonable performance.

7. Challenges and Future Directions
Material Losses: The main challenge of using PLA as a substrate for high-frequency applications is its relatively high loss tangent. Research is ongoing to develop hybrid substrates that incorporate PLA with low-loss additives to improve performance at 9.4 GHz.
Precision Fabrication: 3D printing with PLA can have limitations in terms of resolution, which can affect the accuracy of the antenna's dimensions. Advances in 3D printing technology are required to achieve the necessary precision for high-frequency antenna designs.

8. Conclusion
The design of low-cost 9.4 GHz microstrip patch antennas using PLA and copper tape offers a promising direction for low-cost, quick prototyping of high-frequency antennas. While PLA provides an eco-friendly, easy-to-use substrate, and copper tape offers a flexible and cost-effective conductive material, challenges such as material losses and durability remain. Ongoing research is focusing on optimizing the combination of these materials for enhanced performance and reliability in high-frequency applications.

III. METHODOLOGY

Methodology for Designing a Low-Cost 9.4 GHz Microstrip Patch Antenna Using PLA and Copper Tape
The methodology for designing a low-cost 9.4 GHz microstrip patch antenna using PLA (Polylactic Acid) as the substrate and copper tape for the radiating element and ground plane involves several key stages, from material selection to final design and simulation. Below is a structured approach to the design process:
1.Material Selection Substrate Material:PLA is chosen as the substrate material for its low cost, ease of fabrication (especially with 3D printing), and availability. Its dielectric properties need to be characterized, particularly the dielectric constant (ε_r) and loss tangent ($\tan\delta$). For PLA, ε_r typically ranges from 2.5 to 3.0, with $\tan\delta$ affecting the antenna's efficiency at high frequencies like 9.4 GHz.
Conductor Material: Copper tape is selected as the conductor for the patch and ground plane. Copper is widely used for antenna fabrication due to its excellent conductivity, and copper tape allows for easy application and prototyping.

2.Design Parameters The main parameters to consider when designing a microstrip patch antenna are:
Resonant Frequency: The operating frequency for the antenna is 9.4 GHz. The antenna dimensions need to be calculated to resonate at this frequency.Patch Geometry:
Rectangular Patch: A common design choice for microstrip patch antennas. The dimensions of the patch can be determined using the formula for the resonant frequency of a rectangular patch antenna:
Impedance Matching: The antenna should have an impedance of 50Ω, typically achieved using a microstrip feed. The location of the feed should be carefully selected to match the impedance of the antenna. Techniques such as inverted L-feed, coaxial feed, or microstrip line feed can be used, with the feed point determined by trial and error or optimization techniques.
Ground Plane: The ground plane should be large enough to ensure a stable and symmetric radiation pattern. For a simple rectangular patch, the dimensions of the ground plane are typically chosen to be at least 1.5 times the size of the patch.

3. Design Simulation tools are used to model the antenna's performance before physical fabrication. The following steps are involved in simulation:
Software Selection: Tools like HFSS (High-Frequency Structure Simulator), CST Microwave Studio, or FEKO are commonly used for electromagnetic simulation of microstrip antennas. These tools can predict the performance of the antenna, including its return loss, bandwidth, radiation pattern, and impedance matching.Modeling the Substrate and Patch: In the simulation software, the PLA substrate and copper tape are modeled based on their material properties. The dielectric constant (ε_r) of PLA and the thickness of the substrate are defined, and the copper tape is assigned a conductivity of approximately 5.8×10^7 S/m.

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Optimization: After the initial design, the antenna's dimensions (length, width, and feed position) are optimized to achieve the desired resonant frequency and good impedance matching. The return loss (S11) should be less than -10 dB at the operating frequency (9.4 GHz) for effective power transfer.

4. Fabrication of the Antenna
Substrate Preparation: PLA is either 3D printed or purchased as a sheet. If 3D printing is used, the printer resolution should be high enough to accurately create the dimensions of the patch antenna. A typical PLA sheet thickness ranges from 1 mm to 3 mm, but the exact thickness is determined based on the desired performance and simulation results.

5.Copper Tape Application: Copper tape is applied to form the patch and ground plane. The tape is cut into the desired shapes and affixed to the PLA substrate using adhesive backing. The dimensions of the copper tape correspond to the calculated patch and ground plane dimensions.
Feed Mechanism: The feed is added by cutting a small microstrip line on the PLA surface and connecting it to the copper tape patch. The feed is positioned to ensure proper impedance matching.

6.Testing and Measurement After fabrication, the antenna needs to be tested to verify its performance:
Return Loss (S11): A network analyzer is used to measure the return loss (S11) at 9.4 GHz. A return loss less than -10 dB indicates good impedance matching and efficient power transfer.
Radiation Pattern: The radiation pattern of the antenna is measured in an anechoic chamber using a setup where the antenna is rotated while the radiated power is measured. This helps assess the directional characteristics (e.g., omnidirectional or directional pattern) and the gain of the antenna.
Bandwidth: The bandwidth of the antenna is measured by observing the frequency range over which the return loss stays below -10 dB.
Efficiency: The efficiency of the antenna can be determined by measuring the total radiated power compared to the input power.

7.Performance Evaluation Comparison with Simulation Results: The results from the physical tests are compared with the simulation predictions. Deviations in parameters such as return loss, radiation pattern, and bandwidth can be analyzed and optimized in the next design iteration.
Analysis of the Impact of PLA and Copper Tape: The impact of using PLA as a substrate and copper tape as the conductor is evaluated. Factors like material loss, mechanical stability, and overall antenna performance are discussed.

8. Optimization and RefinementBased on the test results, further refinements may be required:Substrate Modification: If the loss is higher than expected, experimenting with thicker PLA or hybrid substrates may improve performance.Feed Adjustment: The feed position or feed type might need to be adjusted to achieve better impedance matching.

9.Final Design and Application Once optimized, the antenna can be used in its intended application. This methodology provides a low-cost, yet effective design for 9.4 GHz microstrip patch antennas, suitable for various wireless communication systems, satellite applications, or sensor networks.
Summary of Methodology:
Material Selection: Choose PLA for the substrate and copper tape for the conductor.
Design: Calculate patch dimensions, feed position, and ground plane size.
Simulation: Use EM simulation software for design validation and optimization.
Fabrication: Manufacture the antenna using 3D printing for PLA and copper tape for the conductive layer.Testing: Measure return loss, radiation pattern, bandwidth, and efficiency.
Optimization: Adjust parameters based on test results for improved performance.

6. Block diagram

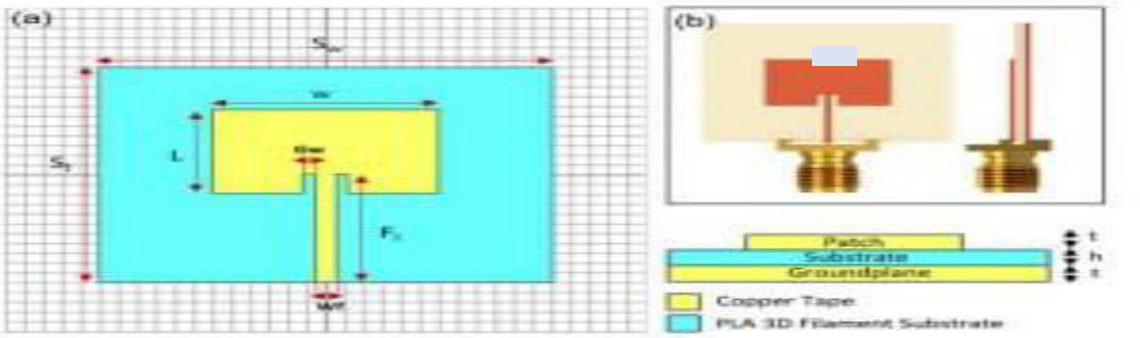

Fig. 1. Microstrip patch antenna (a) 3D simulation view; (b) top and side-view with SMA connector.

IV. RESULTS AND DISCUSSION

The proposed antenna was simulated using CST Microwave Studio to evaluate its performance at 9.4 GHz. The primary metrics analyzed were input reflection coefficient, bandwidth, gain, and radiation pattern. These factors are crucial in determining the antenna's effectiveness for high-frequency applications. A. Input Reflection Coefficient Input reflection coefficient is a measure of how effectively the antenna is matched to the transmission line. It indicates the amount of power that is reflected back due to impedance mismatch. For acceptable antenna performance, the input reflection coefficient should be above 10 dB, meaning less than 10% of the power is reflected. As you can see at Fig. 2 that the simulated input reflection coefficient or S11 for the proposed antenna was 8 dB at 9.6 GHz for unoptimized result (based on calculation) and 17 dB for optimized result (based on parameter sweep on CST Studio that produce the optimized parameters as seen in Table II to get desired frequency at 9.4 GHz, significantly exceeding the minimum requirement for good impedance matching. This input reflection coefficient demonstrates that the antenna is well-matched to the feedline, allowing most of the input power to be radiated by the patch.

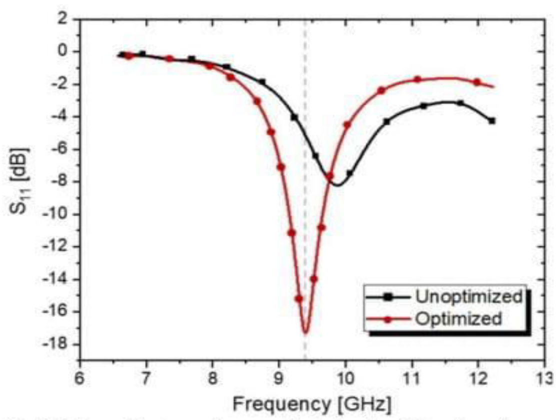

Fig.2. S11 graph between the unoptimized and optimized results.

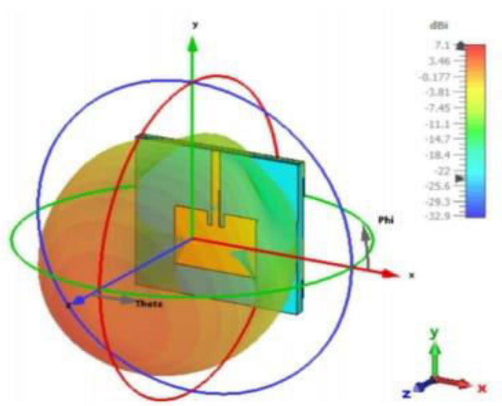

Fig.3. Gain simulated result of the rectangular antenna.

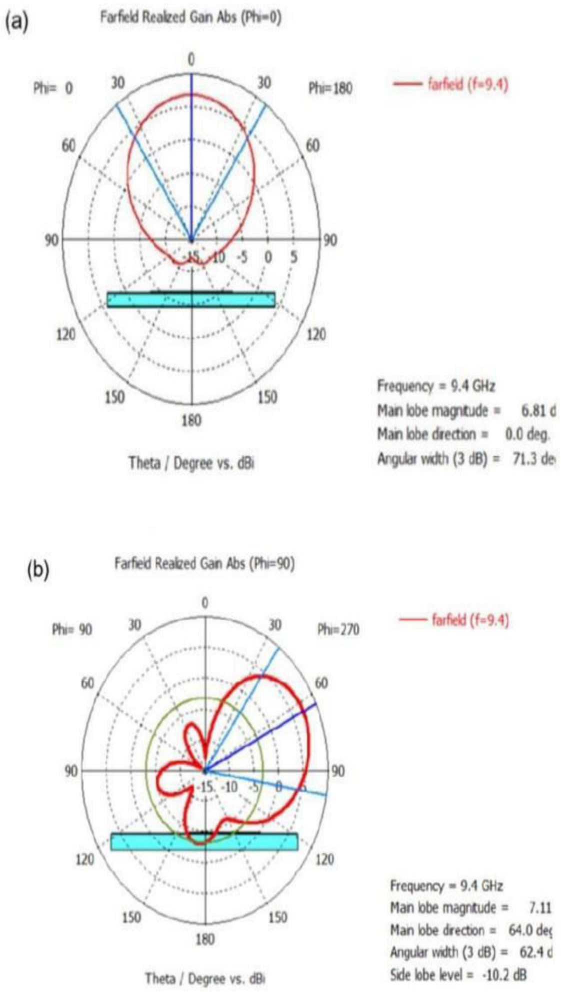

Fig.4. (a) E-Plane (Phi = 0); (b) H-Plane (Phi = 90)

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