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Design of Micro Strip Patch Antenna

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Abstract: *Compact and highly efficient communication gear is more important than ever in the current era of fast technological innovation. The need for antennas that can fit into small locations without compromising performance has increased dramatically as we move toward more integrated and portable electronic gadgets. This change has forced engineers and researchers to move beyond conventional, large antenna designs in favor of more efficient options that satisfy the demanding requirements of modern wireless networks.*

Microstrip fabrication and cost-effectiveness are in line with the increasing need for wireless communication antennas that are small, light, and effective. A rectangular microstrip patch antenna that operates at 3.61 GHz and is appropriate for wireless communication applications is designed and simulated in this project. MATLAB, a high-performance electromagnetic field simulator, is used to analyze the design, which uses FR4 Proxy as the substrate. Excellent performance for the specified frequency band is confirmed by the simulation results. In addition to achieving effective radiation properties, the suggested design can be expanded for array topologies and upcoming wireless technologies.

Because of its low profile and ease of fabrication, patch antennas have become a feasible alternative.

Keywords: Substrate: FR-4, Patch , Feedline, Frequency : 36.1GHz , Gain: -8 dB, Simulation: MATLAB

I. INTRODUCTION

Generally speaking, an antenna is a component of a system that may send or receive electromagnetic waves. Numerous types of antennas are employed in various applications. Wire, aperture, printed, array, reflector, and lens antennas are a few of them. One of these antennas is a printed antenna made with photolithography. Microstrip antennas are the most widely used type of printed antenna. The traditional microstrip fabrication method is used in its construction. A microstrip antenna features a ground plane on one side and a radiating patch on the other side of a dielectric substrate.

Microstrip patch antennas, microstrip slot/traveling antennas, and printed dipole antennas are the three varieties of microstrip antennas. Microstrip patch antennas of the three types mentioned above can have any shape. The majority of microstrip slot/traveling antennas are circular or rectangular in form. The shapes of printed dipole antennas are rectangular and triangular. Choosing the right substrate material is the most crucial aspect of antenna design.

This work presents an analysis that provides the material needed to construct a microstrip patch antenna based on its intended use. The following goals are included in the design of microstrip patch antennas for wireless applications: Choose among the following four substrate materials: FR-4, RO4003, GML1000, and RT/Duroid 5880. Choose one of the following four shapes: H, E, S, or U. This particular project focuses on the meticulous simulation and design of a rectangular microstrip patch antenna. We can optimize for particular radiation patterns and gain characteristics that are necessary for dependable signal transmission by limiting the scope to a rectangle geometry.

This project acts as a link between the practical implementation of creating hardware for real-world wireless situations and theoretical electromagnetic ideas. Compact and highly efficient communication gear is more important than ever in the current era of fast technological innovation. The need for antennas that can fit into small locations without compromising performance has increased dramatically as we move toward more integrated and portable electronic gadgets. This change has forced engineers and researchers to move beyond conventional, large antenna designs in favor of more efficient options that satisfy the demanding requirements of modern wireless networks.

The Microstrip Patch Antenna has become one of the most promising technologies for meeting these contemporary needs. Its practical advantages, such as its incredibly low profile, which enables it to be installed on flat surfaces or integrated straight into circuit boards, are what fuel its appeal rather than merely a fad. Additionally, these antennas are an excellent option for mass-produced consumer devices because to their MATLAB, a potent high-performance electromagnetic field simulator, was used for this project's analytical phase. The intricate relationships between the physical dimensions of the antenna and the generated electromagnetic waves could be modeled by utilizing MATLAB's computational capabilities. Before any real prototypes are built, the design can be refined in a virtual setting thanks to this simulation system.

The implications of this design go well beyond a single antenna unit in the future. The architecture created here is very adaptable and can be readily expanded or changed for array topologies, which are crucial for beamforming and boosting signal strength in cutting-edge 5G and 6G systems. The next generation of global communication will be defined by increasingly sophisticated wireless technologies, which this project establishes a strong foundation for.

The target operating frequency of 3.61 GHz is essential to this design. For many modern wireless applications, such as satellite communications and new mobile network protocols, this specific frequency is ideal. In a congested wireless band, even a small variation can result in considerable signal loss or interference, hence it is crucial to make sure the antenna resonates perfectly at this frequency.

The design uses FR4 Epoxy as the main substrate material to get the required effects. In the electronics industry, FR4 is well known for its dependable electrical insulation and superior mechanical qualities. By employing this substrate, the antenna retains the dielectric qualities required for effective electromagnetic wave propagation over the patch while gaining structural integrity.

After the simulations were finished, it was evident from the results that the antenna performs exceptionally well over the desired frequency range. The information verified that the design satisfies the requirements for radiation efficiency, bandwidth, and return loss. These results demonstrate that the rectangular patch configuration is highly effective for the planned 3.61 GHz application and verify the original design predictions.

Background and Motivation

Although the microstrip antenna was first proposed in the early 1950s (1953/1955), its practical use was restricted for almost twenty years.

The 1970s Explosion: The development of Printed Circuit Board (PCB) technology and the pressing need for low-profile, conformal antennas in aircraft, satellite, and missile applications marked the beginning of significant development in the 1970s.

Important Contributors: Scholars like Howell and Munson are acknowledged as trailblazers who developed the first designs, like the rectangular patch fed by a microstrip line.

Manufacturing: Since photolithography is frequently used to create them, they are very compatible with monolithic microwave integrated circuits (MMICs).

Particular engineering benefits that satisfy the requirements of contemporary, portable electronic systems are what propel the broad use of MPAs.

Problem Statement

The gap between the intrinsic physical constraints of conventional patch antennas and the intended performance needs of contemporary wireless systems is usually outlined in the design of a microstrip patch antenna (MPA). The majority of design problem statements stem from the following technological shortcomings of standard microstrip patch antennas:

1. Narrow Bandwidth: For high-speed data transmission in 5G or Ultra-Wideband (UWB) applications, conventional patches usually have a very narrow frequency range (generally less than 5%).
2. Low Gain and Efficiency: Standard designs frequently have low radiation efficiency and gain (usually 1–5 dBi) due to conductor and dielectric losses as well as surface wave excitation.
3. Physical Size: Because lower operating frequencies necessitate bigger patch size, they are challenging to incorporate into small, contemporary IoT or mobile devices.
4. Spurious Radiation: Unwanted radiation from feeding methods can occasionally result in low polarization purity and higher amounts of cross-polarization.

Proposed Solution

Specifically created for wireless communication applications like 5G communication, the suggested system presents an enhanced Microstrip Patch Antenna that operates at 3.61 GHz. MATLAB, a 3D electromagnetic analysis program built on the Finite Element Method (FEM), is used to build and simulate the antenna.

The suggested design makes use of FR4 proxy with a low loss tangent and dielectric constant (εr) of 2.2, in contrast to traditional patch antennas that employ standard substrates. This substrate selection guarantees improved impedance matching, increased efficiency, and a wider bandwidth.

To achieve consistent input impedance and efficient radiation performance, the antenna is a rectangular patch with an edge-fed probe arrangement. Transmission line model equations were used to get the ideal patch dimensions (length ≈ 38 mm, width ≈ 29 mm) and ground plane dimensions (length ≈ 118 mm, width ≈ 134 mm).

Important outcomes of the simulation include:

3.61 GHz is the resonant frequency.

With its high gain, low return loss, and small size, the suggested design solves the drawbacks of conventional antennas and may be included into contemporary portable wireless systems.

Scope of the Project

The design, analysis, and implementation of a microstrip patch antenna for wireless communication systems are the main objectives of this research. It entails choosing appropriate materials, dimensions, and feeding methods while researching important factors like return loss, bandwidth, gain, radiation pattern, and efficiency. In order to assess antenna performance and optimize it for uses like Bluetooth, Wi-Fi, and mobile communication, the project also makes use of simulation tools. Performance-enhancing strategies, including altering patch structures or forms, could be investigated. Furthermore, testing and manufacturing can be done to compare simulated and real-world results, which can improve antenna efficiency and better comprehend real-world problems.

Report Organization

To present the project in a methodical way, this report is divided into multiple sections. The microstrip patch antenna and its significance in contemporary wireless communication systems are introduced in the first section. The literature review, which highlights earlier studies and advancements in antenna design, is covered in the following section. The technique section, which describes the design strategy, material selection, dimensions, and simulation tools utilized, comes next. The simulated and real-world findings, along with characteristics like return loss, bandwidth, gain, and radiation pattern, are shown in the results and analysis section. A summary of the results, difficulties encountered, and potential opportunities for future advancements in antenna performance round out the paper.

II. OBJECTIVE

1. Create a small, low-profile antenna that can be mounted on flat surfaces.
2. Get a high gain to improve the efficiency of signal transmission and reception.
3. Acquire a large bandwidth to enhance communication quality and accommodate broader frequency ranges.

4. Verify that the antenna functions well in microwave frequency ranges, which are normally between 1 GHz and 6 GHz.
5. To provide targeted signal coverage, design antennas with directional radiation patterns.
6. Preserve low manufacturing costs and mechanical robustness for useful applications.
7. Make it simple to combine with planar fabrication processes and microwave integrated circuits.
8. Provide flexible polarization choices, such as circular and linear polarization.
9. Use design improvements to overcome common constraints like limited power handling and narrow bandwidth.
10.To reduce signal reflection and increase radiation efficiency, achieve impedance matching.
11. Make a variety of applications in satellite, aviation, space systems, and mobile communication possible.
12. Optimize antenna performance and radiation pattern by using various feeding approaches.

III. BACKGROUND OF THE RESEARCH

The need for small, effective, and reasonably priced antennas has grown dramatically due to the quick development of wireless communication technologies like satellite systems, Wi-Fi, and mobile networks. Better solutions are required since traditional antennas are heavy and unsuitable for contemporary portable electronics. Because of its low profile, light weight, ease of production, and compatibility with printed circuit technology, the microstrip patch antenna has gained popularity. It is simple to include into gadgets such as computers, cellphones, and Internet of Things platforms. But it also has drawbacks that need to be addressed, like low gain and a limited bandwidth. In order to improve performance in wireless communication systems, this study focuses on comprehending these issues and creating optimum antenna designs.

Research Work

In order to increase performance, this project's study focuses on the design and analysis of a microstrip patch antenna. It entails choosing appropriate substrate materials and feeding methods in addition to researching various antenna properties like return loss, bandwidth, gain, and radiation pattern. The antenna is designed and analyzed under different conditions using simulation tools such as HFSS or CST. To improve speed and get around constraints like limited bandwidth, methods including slotting, stacking, and changing patch geometry are investigated. In order to compare simulated and real-world outcomes, the research may also involve manufacture and testing. The primary goal of this effort is to provide a dependable and effective antenna for contemporary wireless communication applications.

IV. LITERATURE REVIEW

A number of researchers have made contributions to the development of microstrip patch antenna design, concentrating on enhancing characteristics like efficiency, gain, and bandwidth for wireless applications.
1. Abdulbari et al. proposed a T-shaped rectangular microstrip patch antenna. The T-shaped patch is appropriate for 5G applications because it operates in the 3.6 GHz frequency range. (2021)
2. Balanis C.A. (2010) presented a thorough theoretical framework for microstrip antennas in "Antenna Theory: Analysis and Design," describing the transmission-line and cavity models that serve as the foundation for precise antenna simulations in contemporary tools like HFSS.
3. "Design of Rectangular Microstrip Patch Antenna for Wi-Fi Application: Enhancement of Bandwidth and Gain," Abhishek Javali, IEEE World Conference on Applied Intelligence and Computing (AIC), IEEE 2022.
4. Swarna et al. developed a new slot-loaded microstrip patch antenna with a helipad-like ground modification to address the 5G network's lower frequency range of about 3 GHz.
5. Rana et al. designed and analyzed a microstrip patch antenna for future wireless communication that operates at 3.5GHz. Reduced return loss, a greater gain, a lower VSWR, enhanced directivity, and more effective operation were the objectives the researchers intended to accomplish with this study. Numerous wireless communication applications have led to the development and validation of this antenna. It is used as a reference antenna in communication

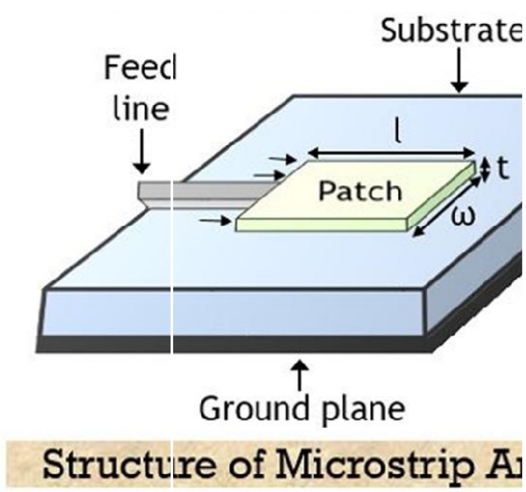
satellites, weather radar, surface ship radar, wireless local area networks (LANs) (802.11) and (802.11)), multimedia applications in satellite radio and mobile TV, optical communications at wavelengths between (1460) and (1530), and other wireless fidelity applications.(2023)

Comparative Insight:
The majority of current research focuses on increasing bandwidth and efficiency through feeding strategies, substrate selection, and shape adjustment. This project stands out, though, because it uses FR4 Proxy to build and simulate a rectangular microstrip patch antenna at 3.61 GHz, attaining high gain (7.5 dBi) and low return loss (8 dB) through HFSS-based optimization.

V. BLOCK DIAGRAM & DESCRIPTION OF BLOCK DIAGRAM

The project employs a methodical approach to design and analysis:
1. Learn about the principles of microstrip patch antennas.
2. Choose the appropriate patch dimensions and substrate material.
3. Use CAD tools (such as HFSS or CST) to design the antenna geometry.
4. To examine characteristics like return loss, VSWR, gain, and radiation pattern, simulate the antenna.
5. Construct the prototype antenna.
6. Use measurement tools, such as a network analyzer, to test the prototype.
7. To assess performance, compare measured and simulated results.

Visual Representation:
A block diagram of the Microstrip Patch Antenna:



VII. COMPONENTS REQUIRED

Hardware specifications: A PC or laptop with a minimum of 8 GB of RAM, an i5 processor, and a 500 GB disk.
For testing, use a network analyzer.
Software Requirements: MATLAB. Operating System: Windows 10 or above.
Goal: Verifies the viability of testing and replication.

VIII. WORKING PRINCIPLE

The radiation produced by fringing electric fields between a conductive patch and a ground plane, separated by a dielectric substrate, is the basis for the operation of a microstrip patch antenna. In order to generate the most radiation perpendicular to the substrate, it functions as a resonant cavity and is usually made with a patch length of lamda/2.

Working Principle & Design Components:

1. Structure: Consists of a thin metal patch (radiator) on one side of a dielectric substrate and a ground plane on the other.
2. Radiation Mechanism : When fed, electromagnetic waves form under the patch. Due to the patch being small compared to wavelength, these waves reach the edges, where fringing fields extend into the air, causing radiation.
3. Radiating Slots: The radiation is modeled as two slots separated by the length of the patch, which is generally designed to be slightly less than to allow the fringing field to radiate effectively.

Methodology:

The project follows a systematic design and analysis approach:

1. Learn about the principles of microstrip patch antennas.
2. Choose the appropriate patch dimensions and substrate material.
3. Use CAD tools (such as HFSS or CST) to design the antenna geometry.
4. To examine characteristics like return loss, VSWR, gain, and radiation pattern, simulate the antenna.
5. Construct the prototype antenna.
6. Use measurement tools, such as a network analyzer, to test the prototype.

To assess performance, compare measured and simulated results.

Modules of the Project:

1. Design Module

Make the patch antenna layout according to the substrate material and target frequency.

2. Module for Simulation:

Utilize simulation tools to assess performance metrics such as radiation pattern and return loss.

3. Module for Fabrication:

Use FR4 materials to construct the physical prototype.

4. Module for Testing:

Use instruments to measure antenna performance, then compare the findings of simulations.

Goal: Shows the project's Modularity and distinct functional divisions.

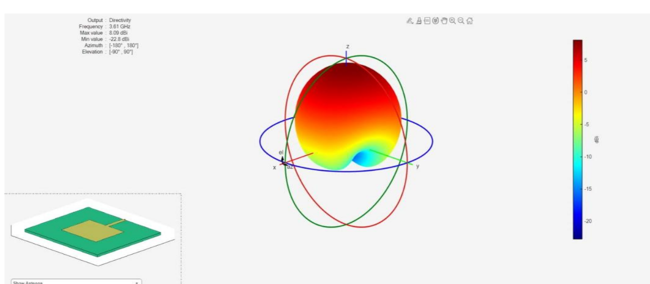
Technologies & Tools:

CAD/Simulation Tools: MATLAB– for antenna design and electromagnetic analysis.

1. Fabrication Tools: FR4 prototyping kit or copper-clad substrate.
2. Testing Instruments: Vector Network Analyzer (VNA) – to measure S-parameters and VSWR.

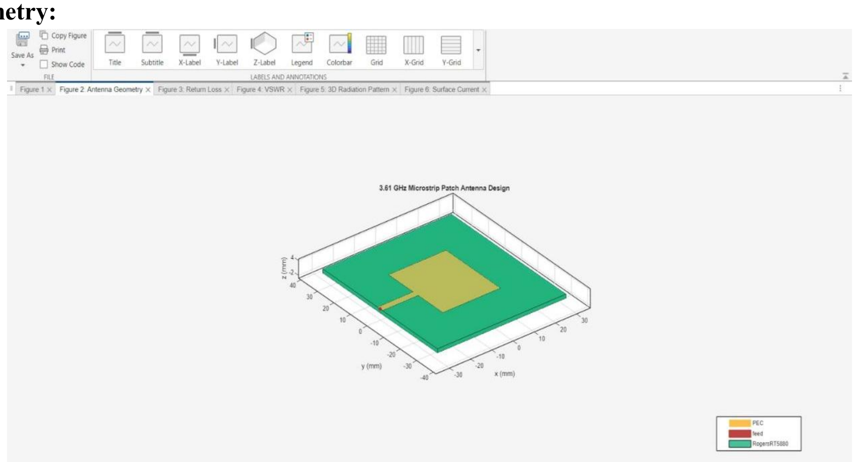
IX. TESTING AND RESULT

1. Radiation pattern:



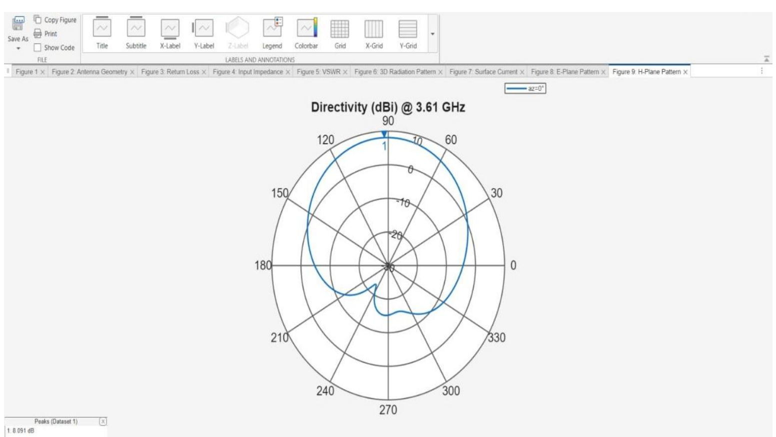
3.61 GHz is the frequency.
Directivity = Maximum value: 8.09 dB
Minimum value: -22.8 dB
Azimuth = -180°, 180° [Complete angular range in the horizontal plane]
Elevation = -90°, 90° [Vertical plane's full angular range]
It displays the directional characteristic of the antenna, with the main lobe displaying maximum emission.
Red: The area with the highest intensity, signifying maximum radiation or directivity (gain).
Yellow or green: Moderate radiation levels with intermediate to medium intensity.
Blue: The lowest intensity, signifying a null region or little radiation.
The color scale goes from -20 dB (blue) to +5 dB (red).

2. Antenna geometry:



It displays components like the patch (yellow), which is a "perfect electric conductor," and the substrate (green), which is a ROGERS RT5880 dielectric support.
The third sort of feed line is the red-colored feed line. It is connected to the excitation patch.
Patch width is approximately 40 mm, and patch length is around 30 mm.
0.787 mm or 1.575 mm is the substrate height.

3. H-Plane:



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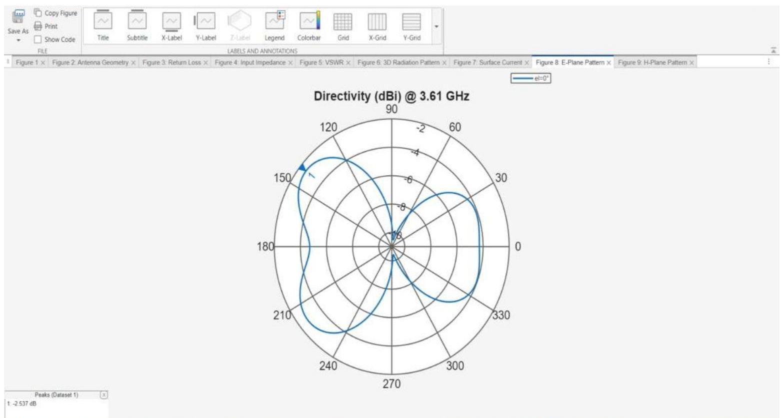
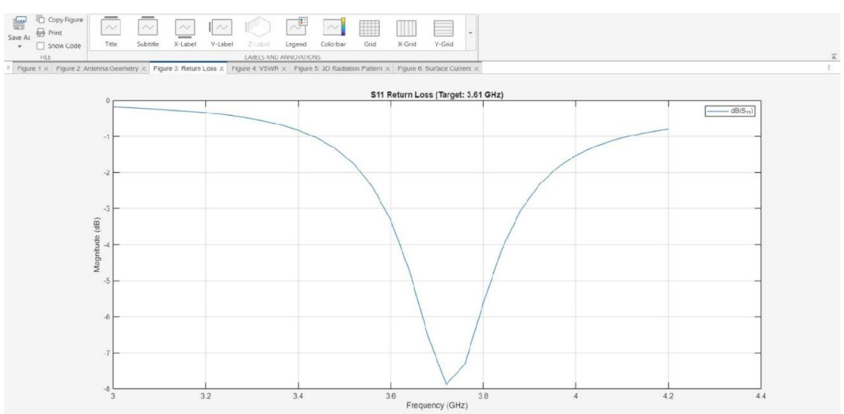
It is a magnetic field-plane. It is perpendicular to the E-plane. The magnetic field vector to the electric field is contained in this plane. Usually, it corresponds to the patch's width. It displays the plane's radiation distribution. perpendicular to the feed. wider beamwidth than the E-plane.
Directivity: around 8 dBi (8.09 dBi)
Wider than the E-plane is the beamwidth. (impacting the coverage area)
Focused energy is ensured by minimizing side lobes in optimum designs.
Analysis of antenna coverage and polarization is aided by it. For wireless systems, it is crucial requiring a particular type of radiation.

4. E-Plane :



Electric field plane is referred to as an E-plane. The plane with the electric field vector and the direction of maximum radiation is known as the E-plane. Usually, it is in line with patch length. Directivity (dBi) v/s angle is displayed on the polar graph.
The two primary lobes on the blue curve have a peak directivity of about 8 dB at 0° (broadside direction). -Main lobe: Maximum radiation at 0° perpendicular to the patch surface.
Beamwidth: The angular width (~ 90°) between half-power points.
Null: Minimum radiation areas at +/- 90° from the main lobe.
It verifies the directional performance of the antenna.
Communication systems that need concentrated radiation in the E-plane can benefit from it.

5. Return loss:



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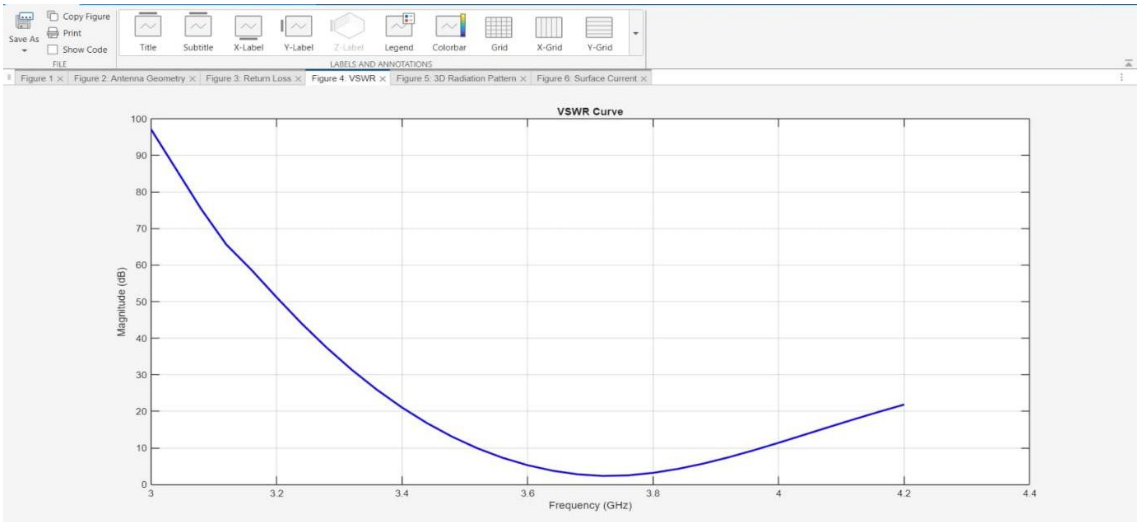
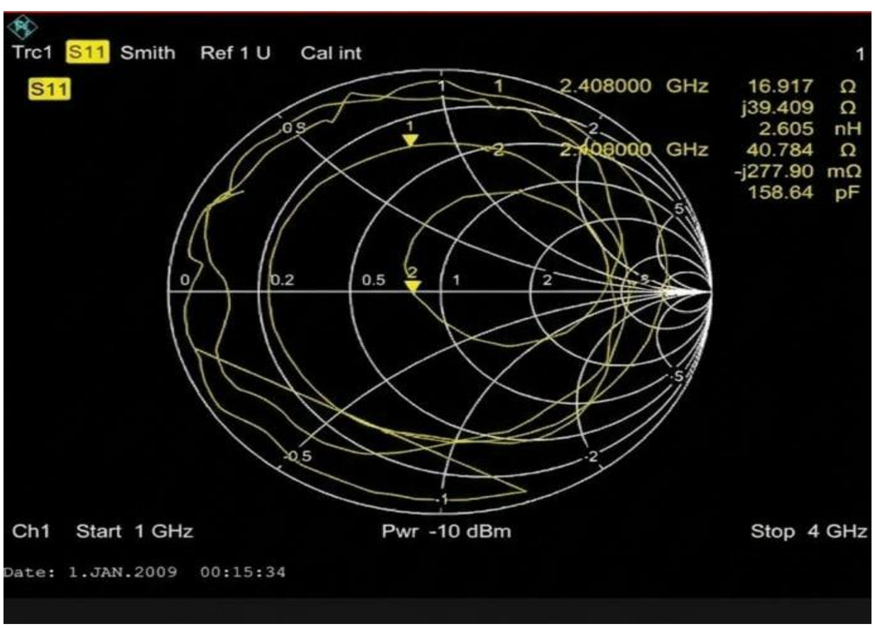
It refers to the quantity of power that is reflected back to the source as a result of an impedance mismatch.
About 7.5 dB at 3.61 GHz.
Better matching and less reflection are indicated by a lower number (more negative).

6. VSWR Curve :



Voltage standing wave ratio is known as VSWR. Frequency versus magnitude.
VSWR's exact value is approximately 1.2 (good matching).
Good impedance matching is indicated by an ideal value of less than two.
Gain: around 7.5 dBi.

7. Smith:



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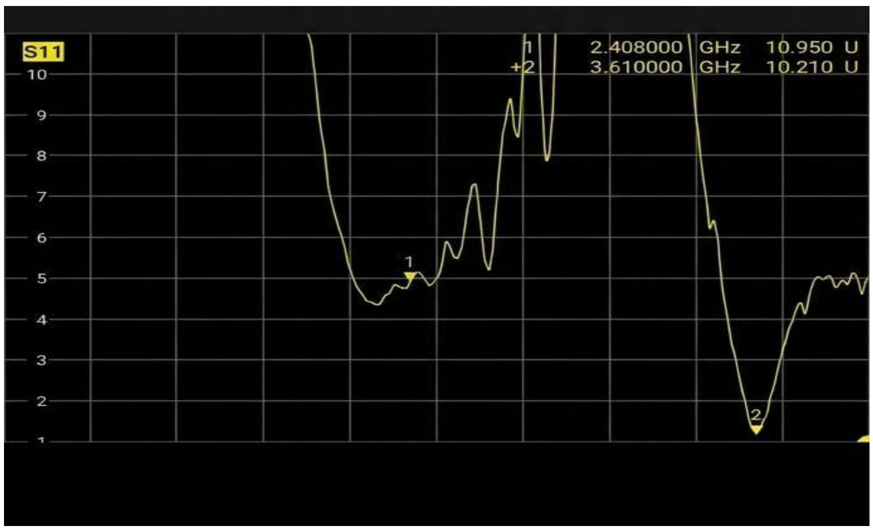
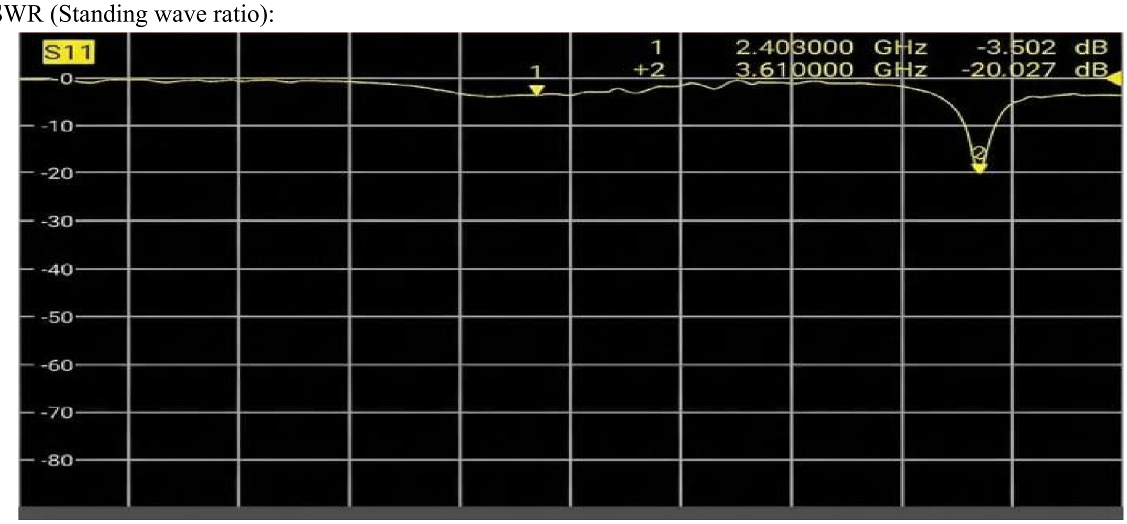
The Smith Chart shows the reflection coefficient, or S11. S11 is indicated by the yellow line. Two marker points are located where:
Marker 1: 2.408 GHz with a capacitive impedance of 16.917 + j39.409 \Omega
Equivalent values are 158.64 PF for capacitance and 2.605 nH for inductance.
Constant resistance or reactance is represented by a circle.
Improved impedance matching is indicated by the trace advancing toward the center; the objective is to get S11 near the chart center (50 \Omega).

8. S11:



The yellow curve for S11 (return loss) shows S11 (dB) v/s frequency. Two markers are pointed.
Pointer 1: 2.408 GHz, 3.602 dB return loss.
Pointer 2: return loss = -20.027 dB at 3.610 GHz.
Only 1% of the power is reflected here.

9. SWR (Standing wave ratio):



S11 is represented by the yellow curve [u = linear unit].
Marker 1: 2.408 GHz – S11 = 10.950 U (about 19.6 dB on a linear scale)
Marker 2: 3.610 GHz with S11 = 10.210 U (about 20 dB linear scale)
Resonance with return loss at about 20dB is shown by the abrupt decrease at 3.6 GHz. This translates to >99% power transfer, which is quite good for antenna efficiency.

Future Scope:
MPA has a highly bright future in cutting-edge wireless communication technologies including 5G, 6G, and Internet of Things applications. For ultra-fast wireless communication in 6G and IoT devices, MPAs are developing toward high-frequency bands like THz, utilizing materials like graphene for better performance.
Wearable technology, satellite communication, aerospace (such as aircraft, missiles, and spacecraft), and next-generation short-range wireless communication all use MPA.
It is anticipated that MPAs would be the cornerstone of smart antenna arrays, enabling more accurate communication signal targeting, enhancing network coverage, and decreasing interference.

Technical Developments:
To maximize gain, bandwidth, and directivity for a variety of wireless applications, research focuses on different patch shapes, substrate materials, and feeding processes. Innovations in materials and production methods enhance antenna resilience and decrease losses. MPA has a highly bright future in cutting-edge wireless communication technologies including 5G, 6G, and Internet of Things applications.
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For ultra-fast wireless communication in 6G and IoT devices, MPAs are developing toward high-frequency bands like THz, utilizing materials like graphene for better performance.
MPA is used in wearable technology, satellite communication, aerospace (including spacecraft, airplanes, and missiles), and next-generation short-range wireless communication.

X. ADVANTAGES & LIMITATIONS

• ADVANTAGES
Microstrip patch antennas (MPAs) are a primary choice for 5G communication in the 3.6 GHz frequency range—part of the sub-6 GHz "mid-band" spectrum—due to their physical flexibility and efficient performance at microwave frequencies.
The primary advantages for 5G applications at this frequency include:
1. Small and Low-Profile Design:
Device Integration: They are perfect for the constrained internal space of 5G smartphones and Internet of Things devices because of their flat, "paper-thin" structure, which enables them to be printed directly onto printed circuit boards (PCBs).
Lightweight: MPAs contribute very little weight as compared to conventional large antennas, which is important for portable consumer electronics.

2. Excellent 3.6 GHz Performance:
Targeted Resonance: MPAs can be carefully tuned to 3.6 GHz, which offers effective impedance matching (usually 50) and consistent return loss (generally below -10 dB).
Directional Radiation: The beamforming and MIMO (Multiple Input Multiple Output) technologies used in 5G to boost data throughput and reliability depend on their ability to concentrate energy in particular directions at this frequency.
3. Economical Production:
Mass Production: Compared to intricate mechanical antennas, they are far less expensive to create in large quantities since they can be made using conventional photolithography and PCB manufacturing procedures.
Simple Materials: For designs in the 3.5–3.6 GHz range, common, reasonably priced substrates like FR4 can frequently be utilized.
4. Adaptability and Expandability:
Multi-band Support: To enable the antenna to function over several 5G frequencies at once (such as 2.4 GHz, 3.6 GHz, and 5 GHz), engineers can alter the patch shape (for example, by adding slots or fractal curves).
MIMO Compatibility: Due to its compact size, many antenna elements can be easily packed into an array to meet 5G's high-speed data requirements.

XI. CONCLUSION

The project effectively illustrates how to design, simulate, fabricate, and test a microstrip patch antenna. The antenna's practical use in contemporary wireless communication is demonstrated by the fact that it satisfies the required frequency and performance characteristics. The initiative lays the groundwork for future studies and advancements in small antenna systems.
Microstrip patch antennas have revolutionized the field of antenna design .
offering a unique combination of compact size, low cost , and ease of integration Their versatility and configurability make them an ideal choice for a wide range of application from wireless communication to satellite communication , wearables, and IoT devices. While they face challenges like Narrow bandwidth and low gain, on going research and advancements in design techniques continue to enhance their performance. As wireless technology evolves , MPAs will remain a key component in enabling seamless, efficient connectivity.

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