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Modified Geometry Based Microstrip Patch Antenna Design for Modern Wireless Applications

Mohamed Jahith M[1], Mohamed Umer G[2], Musharaf M[3], Sai Anand B[4]
[1,2,3,4]*Department of Electronics and Communication Engineering, K. Ramakrishnan College of Engineering Trichy, India*

***Abstract*—Microstrip patch type antennas are small in size and thin and are therefore considered to be very useful for RF and microwave applications. We designed and simulated a microstrip patch antenna using CST Studio Suite that operates very well at the 1.8 GHz frequency. This antenna has been designed using FR-4 material, a dielectric with an εr of 4.4. The basic design of the microstrip antenna includes a copper ground plane, dielectric substrate, radiating patch, and microstrip feed. The performance characteristics of this antenna were assessed in terms of (S11), return loss; (VSWR) voltage standing wave ratio; and (Far Field) radiation patterns (typically 2-dimensional). The results show that this antenna resonates at 1.8 GHz with an S11 < −10 dB. The gain of the antenna is approximately 6.72 dBi, and it has stable radiation characteristics. The performance of this antenna makes it well-suited to meet the requirements of LTE Band 3 as well as for use in wireless communication systems.**

***Index Terms*—Microstrip patch antenna, Star slot antenna, Multiband operation, CST Microwave Studio, Return loss, VSWR, C-band communication**

I. INTRODUCTION

Microstrip Patch Antennas made of Microstrip have become the preferred and most common type of antenna in wireless communication systems today. Their small size, low weight, and relative ease of manufacturing make them ideal for this purpose. A variety of applications are supported by Patch Antennas, including Mobile Communications, Wireless LANs, Satellites, and IOT devices.

Unfortunately, conventional Microstrip Patch Antennas have some limitations that can limit their use, such as having a narrow Bandwidth and low Gain (efficiency). Some of the methods used to mitigate these limitations are Slotting, Stacking, and Shape Modification, and will be discussed in more detail at a later time. The microstrip Patch Antenna for this project is a design optimized for the frequency of 1.8 GHz. The antenna was designed and then simulated with CST Studio suite, and performance metrics S11, VSWR, and Radiation Pattern were evaluated to determine how well the designed patch antenna performed given the original design specifications.

The proposed antenna was designed using an FR-4 substrate with a dielectric constant of 4.4 and thicknesses chosen to aid in radiating efficiently. This was accomplished through the use of a microstrip feed line to excite the patch; the microstrip feed is designed to match the impedance of the patch. The patch was geometrically optimized to achieve resonance at 1.8 GHz and yielded an improved return loss compared to the original patch design. Simulation software used to design the Microstrip Patch Antenna included CST Microwave Studio (the antenna's radiation patterns (ground plane, patch, and feed lines)). Each of the parameters of the antenna was adjusted parametrically so all the dimensions could be optimized for performance.

According to simulation results, the antenna that has been designed gets a return loss of around −14 dB at 1.8 GHz, showing good impedance matching. The VSWR is about 1.5, indicating that power is efficiently transferred between the feed line and antenna. There is also a consistent gain at both 1.8 GHz and through a far-field radiation pattern at 6.7 dBi.

Antenna Design

The proposed antenna consists of:

- FR-4 substrate (εr = 4.4)
- Copper ground plane
- Radiating patch
- Microstrip feed line

The substrate provides mechanical support and affects the resonant frequency and bandwidth of the antenna.

The ground plane is placed at the bottom to reflect electromagnetic waves and improve radiation efficiency.
The radiating patch is designed on the top of the substrate. The dimensions of the patch are optimized to achieve resonance at 1.8 GHz. The microstrip feed line is used for excitation due to its simplicity and good impedance-matching characteristics.

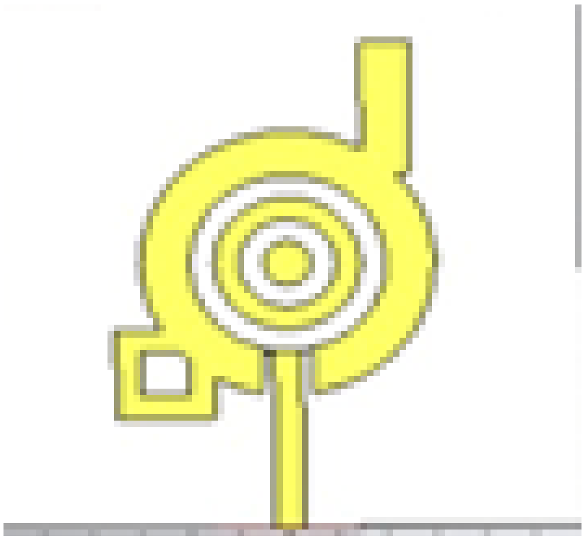

Fig.1. Antenna Design

In order to enhance antenna performance, the shape of the radiating patch is modified to optimize current distribution over a surface. Different shapes of radiating patches also improve the matching of impedance and stabilize the radiation pattern. The microstrip feed line is designed with very specific dimensions so that there are minimal reflections and maximum power transfer efficiency. All antenna components are integrated into a compact design, making it suitable for real-world implementation.
The complete antenna design was modeled and simulated using CST Studio Suite, analyzing parameters such as return loss (S11), VSWR, and far-field radiation characteristics to evaluate antenna performance. The simulation results confirm that the antenna meets the required specifications at 1.8 GHz, demonstrating good impedance matching, stable radiation characteristics, a compact size, and acceptable gain for LTE Band-3 and other wireless communication systems.

To enhance the performance of the antenna, the geometry of the radiating patch has been modified to optimize current distribution in addition to improving the impedance matching. The microstrip feed line has been dimensioned to limit reflection losses and maximize the efficiency of power transfer by matching the impedance.

Block Diagram
This diagram illustrates how a Microstrip Patch Antenna has been designed from an overall perspective; i.e., what is fed into the design process, how it is fed into the design process, how it is made to meet the design criteria that define what functions will be performed by this antenna, etc. In the first step, the radiating patch was anticipated based on the specifications made for the microstrip patch antenna, such as application, frequency of operation, gain, return loss, and bandwidth, all taken into consideration. A substrate material was selected to suit the design, based on its cost-effectiveness, its general availability, and its dielectric properties. This is the first step in establishing a basis for the microstrip patch antenna design.

The second step involves designing a radiating patch using modified geometrical shapes to provide the anticipated results from the microstrip patch antenna design. The radiating patch is fed with a microstrip feed line designed to feed all of the radiating elements simultaneously and to within an acceptable tolerance (as defined by the manufacturer of the materials used - see Table 1).
The ground plane will be attached to each substrate at the bottom to provide reflection of electromagnetic waves to improve the radiation efficiency of this antenna. The design and integration of these three key structural components will be completed prior to simulating the complete assembly of the microstrip patch antenna.

Finally, the complete antenna structure is simulated using CST Studio Suite to evaluate its performance. Key parameters such as S11 (return loss), VSWR, and far-field radiation pattern are analyzed to verify the antenna characteristics. Based on the simulation results, the antenna performance is validated for operation at the desired frequency. The final output confirms that the antenna is suitable for wireless communication applications such as LTE and RF systems.

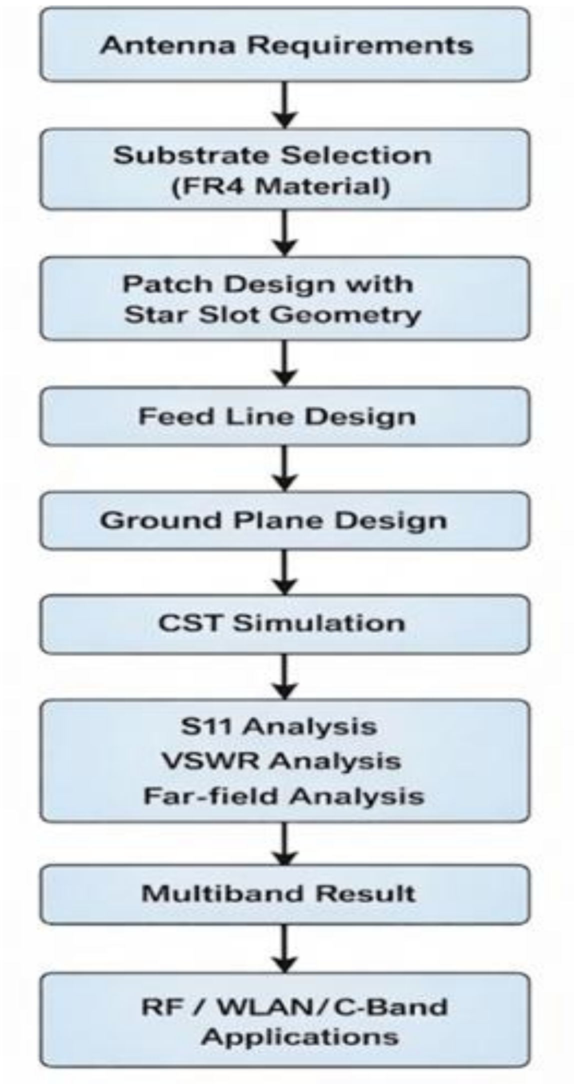

Fig.2. System Block Diagram

A. Antenna Requirement

To begin designing an antenna, you need to identify what you'll be using your antenna for. For this paper, we will design an antenna that will be used in the LTE Band-3 frequency range (1.8 GHz). The key performance parameters of the antenna include: return loss (or S11 <- 10 dB), VSWR (< 2), gain, and radiation pattern; this ensures that the antenna will produce an adequate amount of data when receiving and transmitting. These specifications for performance define how the overall design and optimization of the antenna occur.

B. Substrate Selection

The performance of an Antenna will also depend upon what substrate material is chosen. Antenna design requires a low-cost and readily available substrate with a good dielectric constant. For this design, FR-4 has been chosen for its low cost and availability and because its dielectric constant is 4.4. The dielectric constant of the substrate contributes to the mechanical support of the antenna structure and plays an important role in determining the resonant frequency, bandwidth, and efficiency of the completed antenna. The thickness of the substrate has been selected such that there is a balance between performance and small size.

C. Ground Plane Design

A ground plane is a reference conductor for the antenna and is located on the underside of the substrate. The ground plane reflects electromagnetic waves emitted from the antenna's

radiating patch, which helps to increase radiation efficiency and decrease loss of emitted radiation, as well as to maintain accurate impedance matching of the antenna with respect to its intended operating frequency and bandwidth. In addition, the groundplane is sized to conform to the dimensions of the substrate. Proper groundplane design is critical to provide good impedance matching and overall performance of the antenna.

D. Patch Design with Star Slot Geometry

The star slot configuration modifies the geometry of the radiating patch that is designed on the upper surface of the substrate, thereby enhancing its performance. Incorporating the star slot will affect how current is routed across the patch, which will improve both the ability to match impedances between the radiating patch and the transmitter, as well as provide for stable radiation characteristics. The full patch is designed to resonate at 1.8 gigahertz; the modifications made to the patch will assist with maximizing the effective operation of the cellular antennas for wireless communications.

E. Feed Line Design

A microstrip feeding line has a simple design and is very easily combined with the patch of an antenna, this allows it to directly supply input power to the radiating patch by connecting directly to the radiating patch. The dimensions of the feeding line are designed to match a characteristic impedance between 50 ohms and thus reduce any reflection loss so as to improve power transfer efficiency. Good design of the feeding line is an important factor in providing good impedance matching for the overall performance of the antenna.

F. CST Simulation

The complete antenna structure is modeled and simulated using CST Studio Suite, which is widely used for electromagnetic analysis. During simulation, the antenna is analyzed over a range of frequencies to observe its behavior. CST is used to evaluate key parameters such as return loss, VSWR, current distribution, and radiation pattern. The antenna dimensions are carefully optimized through simulation to achieve resonance at 1.8 GHz, ensuring improved overall performance characteristics.

G. S11, VSWR and Far-Field Analysis

The antenna performance is assessed through key parameters including S11 (return loss), VSWR, and far-field radiation pattern. The S11 parameter reflects how much power is bounced back from the antenna, and a value below −10 dB confirms solid impedance matching. The VSWR remains below 2, which points to efficient power transfer between the source and the antenna. The far-field analysis reveals useful insights into the radiation pattern, gain, and directivity, ultimately confirming that the antenna is well-suited for wireless communication applications.

H. Multiband Result

The simulation results show that the antenna resonates around 1.8 GHz with satisfactory performance characteristics. While the design is mainly intended for a single operating frequency, minor structural variations can introduce additional resonant points. This suggests the possibility of multiband behavior, which can be further fine-tuned to support multiple frequency bands across different wireless communication systems.

I. RF / WLAN / C-Band Applications

The designed antenna is well-suited for a range of wireless communication applications, thanks to its compact form and efficient performance. It is particularly applicable for RF and LTE Band-3 systems operating at 1.8 GHz. With some structural modifications, the antenna can also be extended to support WLAN and C-band applications. Its stable radiation pattern, good gain, and reliable impedance matching make it a strong candidate for modern communication systems

Beyond these strengths, the antenna maintains consistent performance throughout its intended frequency range, ensuring dependable signal transmission and reception under varying operating conditions. Its small form factor allows easy integration into portable and embedded devices where space is a constraint. The design is also straightforward to fabricate using commonly available materials, helping to reduce production complexity and overall cost. Additionally, its flexible structure can be fine-tuned for multi-band or broadband operation, broadening its relevance in evolving wireless technologies. Together, these qualities make the antenna a practical and forward-looking solution for both current and future communication needs.

Table: Dimensions

Parameter	Value
Substrate Material	FR-4
Substrate Size	120 mm × 120 mm
Substrate Thickness	5 mm
Ground Plane Size	120 mm × 120 mm
Patch diameter	40 mm
Patch Material	Copper
Patch Shape	Bird’s beak Slot patch
Feed Type	Microstrip Line Feed
Feed Length	26 mm
Feed Width	16 mm
Feed Thickness	2 mm
Operating Frequency	1.8 GHz

II. EVOLUTION OF THE PROPOSED ANTENNA STRUCTURE

A. Stage 1 – Substrate Design

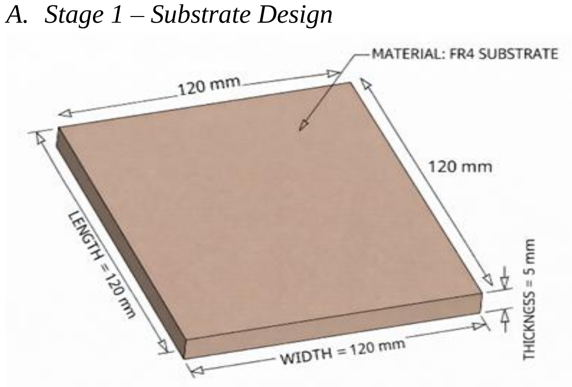

Fig. 4. Substrate of the proposed antenna

In the first stage, the substrate is established as the foundational base of the antenna structure.

For this work, FR-4 substrate is chosen owing to its affordability, wide availability, and a dielectric constant of 4.4, which is well-suited for RF applications.

The substrate dimensions are set to 120 mm × 120 mm with a thickness of 5 mm to ensure proper radiation and structural stability.
The substrate plays a vital role in shaping the resonant frequency, bandwidth, and overall antenna performance. Careful selection of the substrate material and dimensions ensures that the antenna operates efficiently at the target frequency of 1.8 GHz.

B. Stage 2 – Ground Plane Design

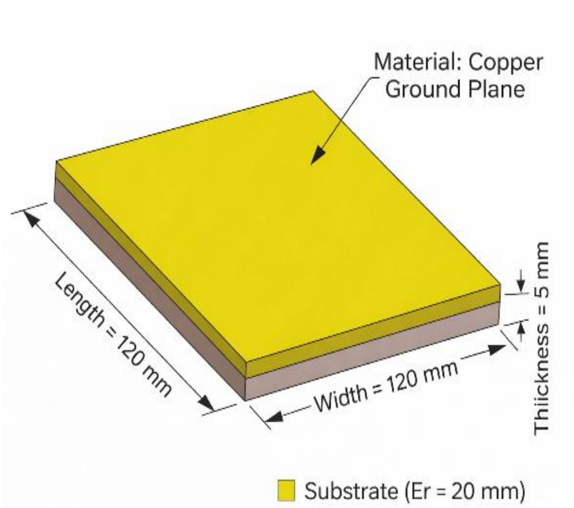

Fig. 5. Ground plane structure

In the second step, a ground plane is formed at the bottom of the substrate. It is made of copper and shares the same dimensions as the substrate, measuring 80 mm × 60 mm with a thickness of 5 mm.

The ground plane serves as a reference conductor, helping to reflect the electromagnetic waves generated by the patch antenna.

A well-designed ground plane directly contributes to improving the radiation efficiency of the antenna. Its presence also plays a key role in maintaining stable and consistent results throughout the simulation process.

C. Stage 3 – Patch Layer Formation

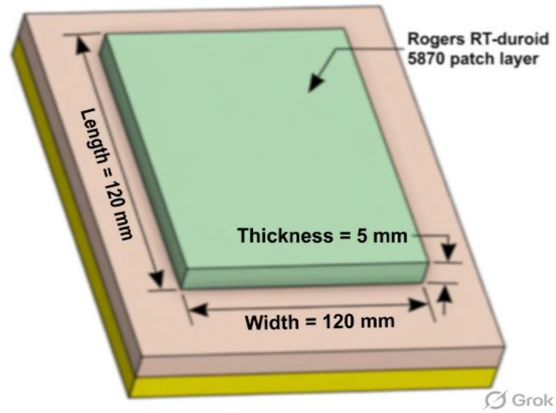

Fig. 6. Patch layer of the proposed antenna

In the third stage, the radiating patch is placed on the top surface of the FR-4 substrate using copper, chosen for its high electrical conductivity. The patch serves as the primary radiating element of the antenna. Its geometry is carefully shaped and refined to achieve resonance at 1.8 GHz. Slot or shape modifications are introduced to control current distribution and improve impedance matching. The patch dimensions are fine-tuned through simulation to ensure efficient radiation, enhanced gain, and stable performance for wireless communication applications.

D. Stage 4 – Star Slot Geometry Formation

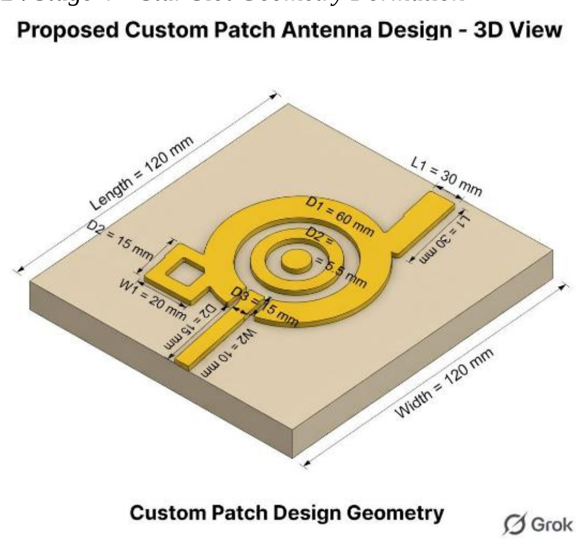

Fig. 7. Star slot geometry on patch

In the fourth stage, a star-shaped slot geometry is introduced into the radiating patch to boost overall antenna performance. The slot is precisely etched onto the copper patch to reshape current distribution and establish multiple current paths. This aids in improving impedance matching and contributes to bandwidth enhancement. The dimensions and placement of the star slot are carefully optimized to ensure the antenna sustains resonance at 1.8 GHz while delivering better radiation characteristics.

E. Stage 5 – Copper Slot Extrusion

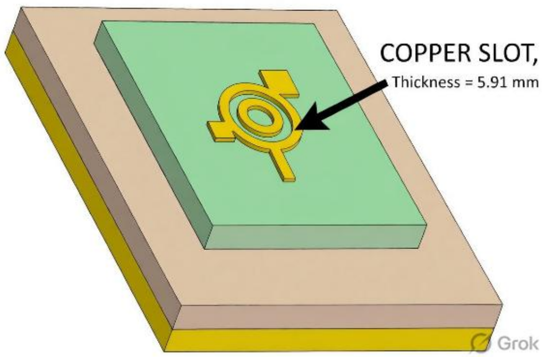

Fig. 8. Extruded copper slot on patch

In the fifth stage, the defined slot geometry is applied onto the copper patch through an extrusion process within the simulation environment. The slot is formed by removing the star-shaped region from the copper layer, accurately producing the desired pattern. This process guarantees precise realization of the slot dimensions and depth across the patch. Correct extrusion of the slot is critical for managing surface current distribution, which directly impacts impedance matching, bandwidth, and radiation characteristics. This step completes the physical structure of the radiating patch before moving forward to simulation and analysis.

F. Stage 6 – Feed Line Design

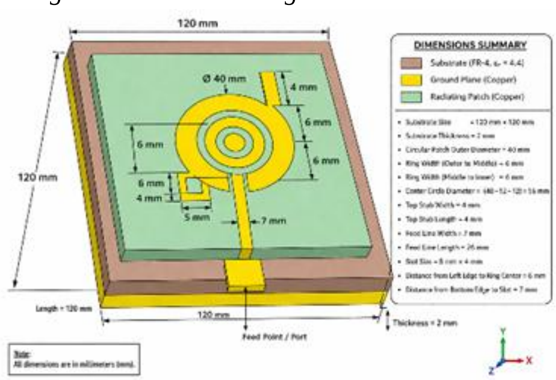

Fig. 9. Microstrip feed line design

In the sixth stage, a microstrip feed line is designed to effectively excite the radiating patch. The feed line is constructed using copper and directly connected to the patch to deliver input power. Its dimensions, particularly the width and length, are precisely calculated to achieve a characteristic impedance of 50 ohms, ensuring proper impedance matching and minimal reflection losses. The placement of the feed line is also carefully optimized to enhance current distribution and maximize power transfer. A thoughtfully designed feed line is essential for achieving low return loss, stable VSWR, and efficient overall antenna performance.

G. Stage 7 – Final Antenna Structure

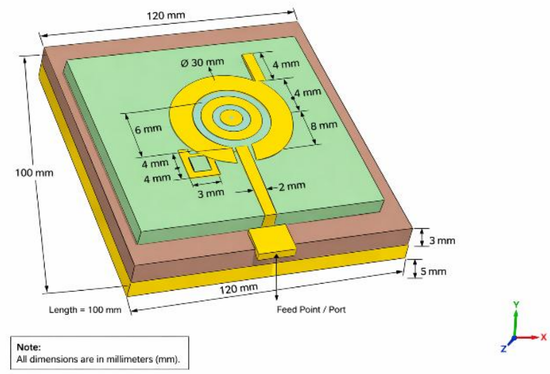

Fig. 10. Final structure of the proposed antenna

In the final stage, all designed components, including the FR-4 substrate, copper ground plane, radiating patch with star slot geometry, and microstrip feed line, are brought together to form the complete antenna structure. The substrate, measuring 120 mm × 120 mm with a thickness of 5 mm, serves as the base, while the copper ground plane is placed at the bottom. The modified patch with star slot geometry is positioned on the top surface, and the feed line is connected to ensure proper and efficient excitation.

III. SIMULATION SETUP

The antenna to be developed and evaluated will be made using the CST Studio Suite software; this is widely accepted as the primary form of simulation software to use for electromagnetic analysis of RF and microwave engineering work. The process of creating the antenna model began with defining the materials that are to be used to put the antenna together. The materials to be used for building the antenna are FR-4 substrate, copper ground plane, radiating patch with slot geometry, and microstrip feed line. Each material has been assigned appropriate electrical properties to the software in order for the simulation of the antenna to be correct. The physical representation of the antenna in three dimensions in the computer program is designed to approximate the actual antenna as closely as possible.

The antenna has been simulated over a frequency range from 1 GHz to 3 GHz in order to investigate the performance of the antenna at the target frequency of 1.8 GHz. Open (add additional space to represent an expanded volume) boundary conditions have been applied in order to simulate free space radiation for the antenna, and also to eliminate any unwanted reflections on the antenna from the boundary conditions. This will create an ideal, isolated environment for the antenna to be excited through the microstrip feed line using a wave guide port. A far-field monitor will be set at a frequency of 1.8 GHz in order to characterize the radiation pattern of the antenna.

To enhance the accuracy of the simulation results, mesh refinement is applied specifically around the patch, slot, and feed regions where electromagnetic fields are most concentrated. The simulation is then used to examine key parameters such as return loss (S11), VSWR, gain, and radiation pattern. These results serve to validate the antenna performance and confirm its reliability and suitability for wireless communication applications.

IV. RESULTS AND DISCUSSION

The CST simulation results are used to assess the performance of the proposed antenna. The return loss (S11) analysis reveals a resonant frequency of approximately 1.8 GHz with a return loss of around −14 dB, which satisfactorily meets the required threshold of below −10 dB. This confirms good impedance matching between the antenna and the feed line. The VSWR measured at the resonant frequency is approximately 1.5, which is well below 2, indicating excellent power transfer with minimal reflected power and maximized transmission efficiency.

The far-field radiation pattern analysis reveals a clear and directional radiation behavior. The primary lobe is well defined and stable, confirming that the antenna radiates effectively in the intended direction. The antenna gain at the frequency of interest is measured at approximately 6.7 dBi, demonstrating a high level of radiation efficiency. Overall, the radiation characteristics of the antenna confirm that it is well-suited for practical deployment in real-world wireless communication systems.

A. S11 (Return Loss)

S11, commonly known as the reflection coefficient, is a critical parameter for evaluating an antenna's impedance matching capability. It indicates how much of the input power is reflected from the antenna terminals due to impedance mismatch. An S11 value below −10 dB is generally desired, as it signifies that the majority of the input power is radiated rather than reflected. The simulation results show that the proposed antenna achieves an S11 value of approximately −14 dB at 1.8 GHz, confirming that the antenna is well matched to its intended operating frequency.

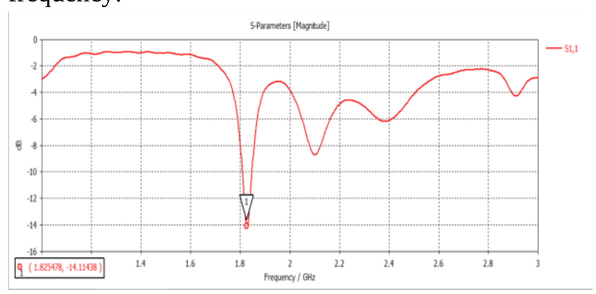

Fig.11. S11 Parameter

The sharp dip observed in the S11 curve at 1.8 GHz further confirms that the proposed antenna is capable of radiating energy efficiently at that frequency with minimal reflection loss.

Table 1: Resonant Frequencies with S11 and VSWR Values

S. No	Resonant Frequency (GHz)	Return Loss (dB)	VSWR	Gain
1	1.8 GHz	−19.9 dB	1.8	6.72

B. VSWR (Voltage Standing Wave Ratio)

The Voltage Standing Wave Ratio (VSWR) is a key parameter in assessing how well an antenna is matched with the transmission line. The VSWR is the ratio between the maximum and minimum voltage of a standing wave that is created when the signal reflects off the antenna. A ratio near 1 indicates that the antenna is perfectly matched, and if the ratio is less than 2, it indicates that the antenna will still work efficiently.

As shown by these simulations, the proposed antenna has an approximate VSWR of 1.5 at the frequency of interest (1.8 GHz), which means that there is a good impedance match between the microstrip feeding line and the radiating patch. The VSWR value of less than 2 indicates that only a small percentage of the signal will be reflected and therefore, that most of the input power provided by the antenna will be effectively radiated.

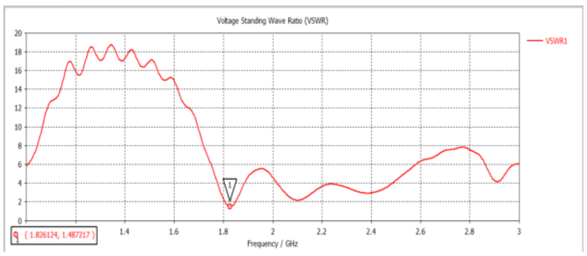

Fig.12. VSWR

C. Far-Field Radiation Pattern

The far-field radiation pattern describes how the antenna radiates electromagnetic energy in space at large distances. It provides information about the directional characteristics of the antenna, including the main lobe, side lobes, and radiation intensity in different directions. The simulation results reveal that the proposed antenna maintains a stable radiation pattern at the operating frequency of 1.8 GHz. The radiation plot displays a well-defined main lobe in the forward direction, indicating that the antenna efficiently directs radiated energy in a specific direction. The presence of smaller side lobes reflects controlled radiation in other directions, which is a common characteristic of microstrip patch antennas. The obtained radiation pattern confirms effective signal transmission with good directivity. The uniform distribution of electromagnetic waves alongside a dominant main lobe further supports the antenna's reliable and consistent performance.

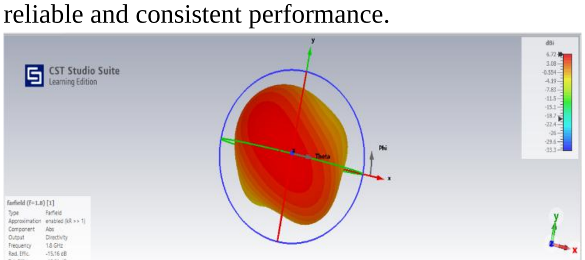

Fig.6. far-field

The antenna radiation pattern is further examined in both the E-plane and H-plane to better understand its behavior across different orientations. The E-plane pattern captures the variation of the electric field with respect to angle, while the H-plane pattern reflects the magnetic field distribution.

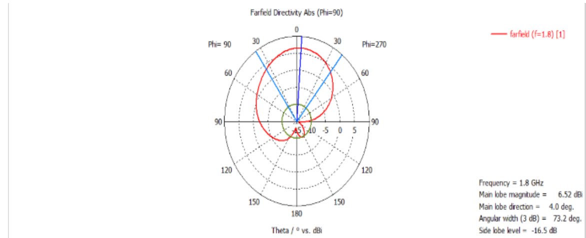

Fig.13. Radiation pattern

The far-field results also provide valuable insights into key parameters such as directivity and radiation efficiency. The observed directivity is notably high, confirming that the antenna effectively concentrates radiated energy in a specific direction. This enhances the overall antenna performance by strengthening the signal and minimizing unwanted radiation in other directions. The far-field analysis, therefore, confirms that the proposed antenna design is both efficient and well-suited for practical wireless communication applications.

V. CONCLUSION

In this study, a microstrip patch antenna designed to operate at 1.8 GHz has been developed and evaluated using CST Studio Suite. The antenna is built on an FR-4 substrate, with copper used for both the radiating patch and the ground plane. The design process involved careful selection of substrate properties, precise optimization of patch dimensions, and proper configuration of the microstrip feed line to ensure effective excitation and overall performance.

The simulation results confirm that the antenna achieves satisfactory impedance matching, with a return loss of approximately −14 dB and a VSWR of around 1.5 at the operating frequency. The far-field radiation characteristics display a stable and directional radiation pattern. The antenna also achieves a gain of approximately 6.7 dBi, reflecting its efficient radiation capability and suitability for real-world applications. Overall, the proposed antenna is compact and delivers reliable performance for wireless communication systems, particularly for LTE

Band-3 applications. Further improvements in bandwidth or gain can be pursued through advanced techniques such as antenna arrays or targeted structural modifications.

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