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# Design and Simulation 0f Rectangular Microstrip Patch Antenna with Gain Enhancement

[1]Dr. K. Padmaleela, [2]Akula Ashwini, [3]Gundu Bhavani, [4]Pathkula Harchitha, [5]Shagam Lakshimi Prasanna
[1]Associate Professor, [2,3,4,5]B.Tech Students,
Department of Electronics and Communication Engineering,
Vignan's Institute of Management and Technology for Women, Kondapur (V), Ghatkesar (M), Medchal District – 501301, Telangana, India.

**Abstract: This paper presents the design and simulation of a rectangular microstrip patch antenna with gain enhancement using an inset feed technique for high-frequency wireless communication applications. Microstrip antennas are widely preferred due to their compact size, low cost, and ease of fabrication; however, they suffer from limitations such as low gain and narrow bandwidth. To overcome these issues, the proposed antenna operates at 26 GHz in the 5G millimetre-wave band and utilizes a low dielectric constant substrate (RT/duroid 5880) along with optimized patch dimensions and inset feeding to achieve improved impedance matching and radiation efficiency. The antenna is modeled and analysed using ANSYS HFSS, where key performance parameters such as return loss (S11), VSWR, gain, and radiation pattern are evaluated. The simulation results demonstrate a significant reduction in return loss below −20 dB, acceptable VSWR, and enhanced gain compared to conventional designs, indicating efficient power transfer and minimal signal reflection. The proposed antenna exhibits stable radiation characteristics and is well-suited for modern applications such as 5G communication, wireless networks, and satellite systems, offering a compact and efficient solution for high-frequency antenna design.**

## 1.1 INTODUCTION

The rapid advancement in wireless communication technologies has created an increasing demand for compact, efficient, and high-performance antennas. Among the various types of antennas, microstrip patch antennas have gained significant attention due to their advantages such as low profile, ease of fabrication, conformability, and compatibility with integrated circuits. A rectangular microstrip patch antenna typically consists of a metallic patch printed on a dielectric substrate with a ground plane on the opposite side. These antennas are widely used in applications such as mobile communication, GPS, satellite systems, and radar. However, their performance is limited by certain drawbacks, including low gain, narrow bandwidth, and surface wave losses.

Gain is one of the most critical parameters in antenna design, as it determines the efficiency and coverage capability of the antenna. For modern applications such as 5G and high-frequency communication systems, higher gain antennas are required to ensure reliable and long-distance signal transmission. To address these limitations, various techniques have been proposed to enhance the gain of microstrip patch antennas. These include modifying the patch geometry, introducing slots, optimizing feed techniques, using low dielectric constant substrates, and incorporating defected ground structures (DGS). Each method aims to improve current distribution, reduce losses, and enhance radiation efficiency. In this project, a rectangular microstrip patch antenna is designed and simulated with the objective of improving gain while maintaining good impedance matching and radiation characteristics. The design process involves selecting appropriate dimensions for the patch, substrate, and ground plane, followed by the application of gain enhancement techniques. The antenna performance is analysed using simulation tools, and the results demonstrate improved gain, reduced return loss, and better overall efficiency.

## 1.2 OBJECTIVE

The objective of this project is to design and simulate a rectangular microstrip patch antenna with improved gain and overall performance. Microstrip patch antennas are widely used in modern wireless communication systems due to their compact size, low profile, and ease of fabrication, but they often suffer from drawbacks such as low gain, limited bandwidth, and higher return loss. This project focuses on addressing these limitations by carefully selecting the substrate material, optimizing the dimensions of the patch and ground plane, and


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employing an appropriate feeding technique such as inset feeding for better impedance matching. Gain enhancement techniques, including slotting and structural modifications, are incorporated to improve radiation efficiency and directivity. The antenna is modeled and analysed using electromagnetic simulation software like HFSS/Ansys, and its performance is evaluated through parameters such as gain, return loss (S11), VSWR, and radiation pattern. The overall aim is to achieve a high-gain, well-matched antenna with stable radiation characteristics suitable for high-frequency and advanced wireless communication applications. In a communication system, the antenna is used to radiate the electrical energy produced by the transmitter into space in the form of electromagnetic waves. Similarly, when electromagnetic waves arrive from space, the antenna captures these waves and converts them back into electrical signals that can be processed by the receiver. Another important objective of an antenna is to direct the radiated energy in a desired direction to improve communication efficiency. By controlling parameters such as gain, directivity, radiation pattern, and bandwidth, antennas help in achieving better signal strength and long-distance communication.

### 1.3 Flow Description

The block diagram illustrates the step-by-step procedure for designing a microstrip patch antenna using ANSYS HFSS. The process begins with defining the antenna specifications such as operating frequency, substrate material, and required dimensions. Based on these inputs, the patch dimensions like length and width are calculated to achieve the desired resonant frequency. Next, the design is implemented in the HFSS environment by creating the substrate, ground plane, and radiating patch. After building the geometry, a suitable feeding technique (such as microstrip line or coaxial feed) is added to excite the antenna. Material properties are then assigned, and boundary conditions are set to simulate real-world radiation behaviour.

Once the model setup is complete, excitation and mesh settings are applied to prepare the structure for simulation. The simulation is then executed to obtain important performance parameters such as S-parameters (return loss), VSWR, gain, and radiation pattern. These results help in understanding how effectively the antenna operates.

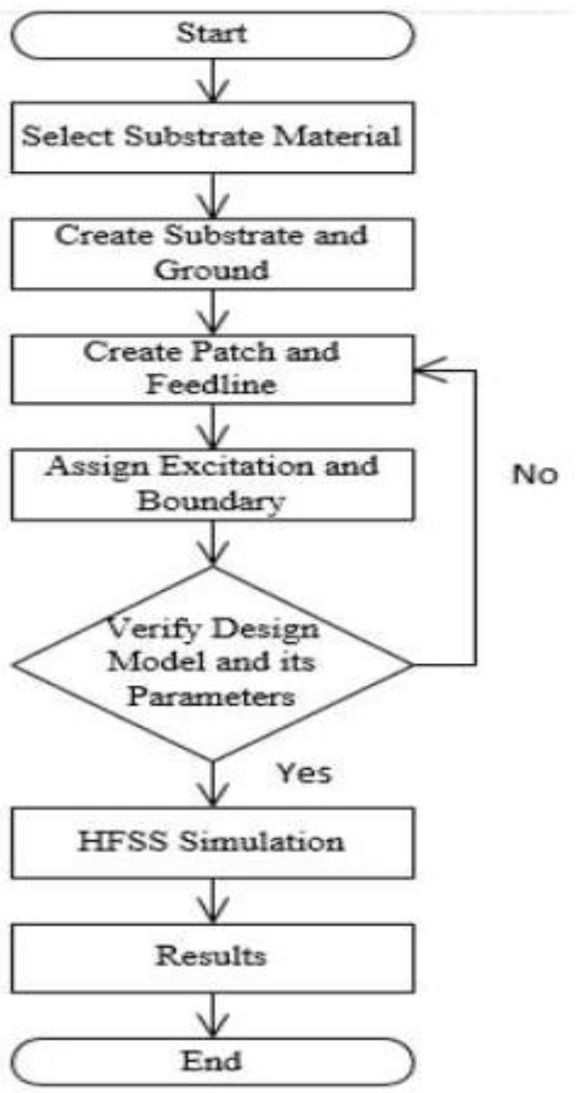


**Fig 1.1: Flow chart**

Finally, if the obtained results do not meet the desired requirements, the design is optimized by adjusting parameters like dimensions, feed position, or substrate properties. This iterative process continues until the antenna achieves optimal performance, completing the design cycle.

## II. LITERATURE SURVEY

The Literature Survey presents a comparative analysis of various microstrip antenna designs based on key performance parameters such as operating frequency, gain, and S-parameters (return loss). From the comparison, it is observed that different antenna structures operate over a wide range of frequencies, from MHz to GHz bands, depending on their intended applications.



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This paper discusses a microstrip patch antenna arranged in a phased array configuration that can conform (bend) to curved surfaces. Such antennas are useful in applications like aircraft or missiles where surfaces are not flat. It operates in the 1545–1555 MHz range and achieves about 7 dB gain, which is good for communication systems. The S-parameter is less than -10 dB, indicating acceptable impedance matching and low reflection.**[1].**

Similarly, the cylindrical circularly polarized microstrip antenna operates. This work focuses on a cylindrical-shaped microstrip antenna that produces circular polarization, meaning it can transmit and receive signals in multiple orientations. This improves reliability in wireless communication. It operates at 2.25 GHz with a gain of around 3 dB, which is moderate. The return loss (< -10 dB) shows the antenna performs efficiently with minimal signal reflection. **[2].**

## III. IMPLEMENTATION

### 3.1 IMPLEMENTATION (ANTENNA MODEL)

The figure shows a complete simulation setup of a rectangular microstrip patch antenna in Ansys HFSS, where each component plays an important role in antenna performance. The radiating patch (red square) is the main element that emits electromagnetic waves when excited by the feed line. The inset feed technique used here helps in achieving better impedance matching, which reduces signal reflection and improves power transfer. The dielectric substrate beneath the patch provides mechanical support and affects parameters like resonant frequency, bandwidth, and efficiency based on its dielectric constant and thickness.

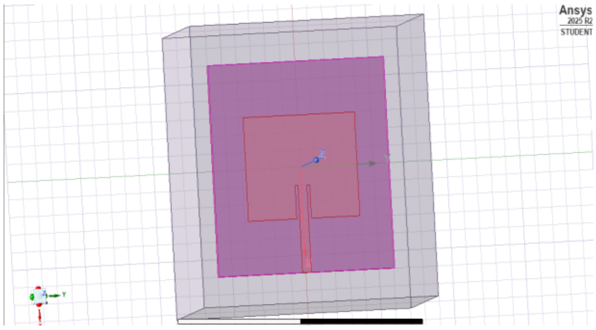


**Fig : Antenna Model**

Below the substrate is the ground plane, which reflects the electromagnetic waves and helps in proper radiation. The feed line is carefully designed to match the input impedance of the antenna, ensuring minimal return loss. The surrounding radiation box (transparent boundary) is essential for simulating open-space conditions and prevents unwanted reflections from the simulation boundaries. The mesh grid visible in the image represents the discretization used by the software to solve electromagnetic fields accurately. Additionally, the antenna is oriented along specific axes (X, Y, Z), which helps in analyzing the radiation pattern in different directions. This entire setup is used to evaluate important parameters such as gain, directivity, VSWR, and S-parameters. By adjusting dimensions like patch length, width, and feed position, the antenna can be optimized to achieve higher gain, better bandwidth, and improved overall performance for applications like 5G and wireless communication systems.

**Insert feeding Technique**

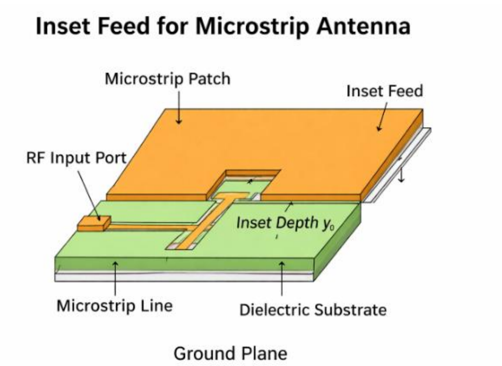


**Fig: Insert Feed**



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## IV. METHODOLOGY

The methodology adopted for the design and simulation of a rectangular microstrip patch antenna with gain enhancement using the inset feed technique involves a systematic and step-by-step approach. Initially, the design specifications are defined based on the target application. In this work, the antenna is designed to operate at a frequency of 26 GHz, which lies in the 5G millimetre-wave band. A suitable substrate material with a low dielectric constant, such as RT/duroid 5880, is selected to minimize surface wave losses and improve radiation efficiency. The substrate thickness, dielectric including high gain and lower turn loss. constant, and other parameters are carefully chosen to meet the desired performance objectives.

The antenna is then modelled and simulated using ANSYS HFSS. The design process includes creating the substrate, ground plane, and patch, followed by the incorporation of the inset slot and feedline. A radiation box is defined to simulate free-space conditions, and appropriate boundary conditions and excitation ports are assigned. After modelling, the antenna is simulated to evaluate key performance parameters such as return loss (S11), Voltage Standing Wave Ratio (VSWR), gain, and radiation pattern. Based on the simulation results, the design is optimized by adjusting parameters such as inset depth, patch dimensions, and feedline width. This iterative optimization process ensures that the antenna achieves a return loss below -20 dB and improved gain.

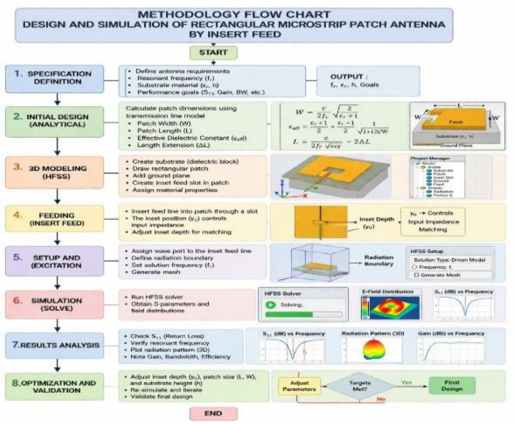


Fig : Methodology

Finally, the optimized antenna design is validated by analyzing its performance characteristics and comparing them with conventional designs. The results demonstrate that the use of the inset feed technique significantly enhances impedance matching and gain, making the proposed antenna suitable for high-frequency 5G communication applications.

## V.RESULT

### GAIN PLOT:

Gain is an important parameter of a microstrip patch antenna. It shows how effectively the antenna radiates power in a particular direction compared to an isotropic antenna.

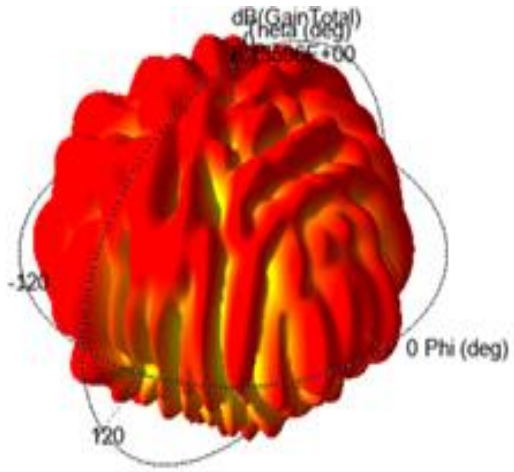


Fig : Gain

The gain of a Microstrip Patch Antenna is an important parameter that describes how effectively the antenna converts input power into radiated electromagnetic energy in a particular direction. Gain represents the ability of the antenna to focus radiated power compared with an isotropic radiator, which is an ideal antenna that radiates equally in all directions. Gain is a fundamental parameter that describes how efficiently an antenna converts the input electrical power into radiated electromagnetic energy in a particular direction. It indicates the ability of the antenna to focus energy in a specific direction compared to an ideal isotropic radiator, which radiates power equally in all directions.

### DIRECTIVITY PLOT:

Directivity is a fundamental parameter of an antenna that describes how well the antenna concentrates



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radiated power in a particular direction. It compares the radiation intensity in a given direction with the radiation intensity of an ideal isotropic antenna, which radiates equally in all directions.

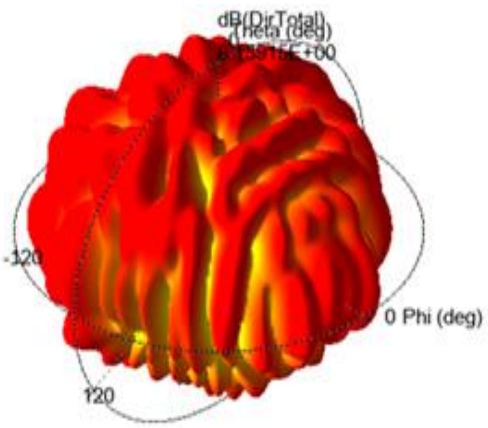


**Fig : Directivity**

In the 3-D directivity plot, the shape represents how electromagnetic energy is distributed in space. The large red lobe indicates the main radiation direction, where the antenna radiates maximum power. Smaller lobes around it represent side lobes, which indicate radiation in other directions with lower intensity. For a microstrip patch antenna, the radiation pattern is generally directional, meaning most of the energy is radiated in one preferred direction perpendicular to the patch surface. Higher directivity means the antenna focuses more energy in the main lobe and less in other directions. A directivity plot (or radiation pattern) shows how an antenna radiates power in different directions. It represents the variation of radiation intensity with respect to angle around the antenna. In the directivity plot, the distance from the center represents the strength of the radiated signal. The direction where the signal strength is maximum is called the main lobe, and smaller radiation regions are called side lobes.

**VSWR PLOT:**

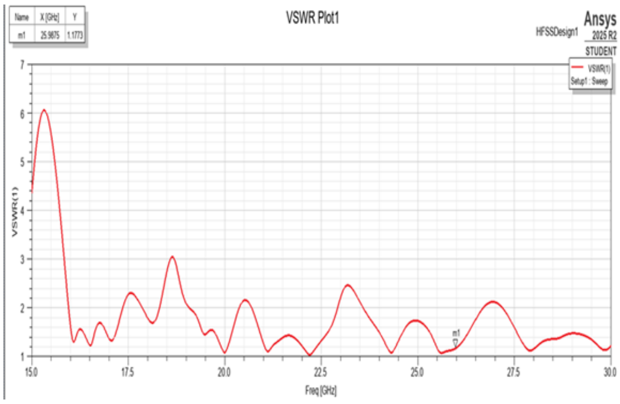


**Fig : VSWR Plot**

Voltage Standing Wave Ratio (VSWR) is an important parameter used to measure the impedance matching between the transmission line and the microstrip patch antenna. It indicates how efficiently the radio frequency (RF) power is transmitted from the feed line the antenna.

When the impedance of the antenna is not equal to the characteristic impedance of the transmission line (usually 50 Ω), a portion of the signal is reflected back toward the source. This reflection creates standing waves along the transmission line. VSWR is the ratio between the maximum voltage (Vmax) and minimum voltage (Vmin) of these standing waves In a microstrip patch antenna, VSWR is used to evaluate how well the antenna is matched with the feed line. Proper impedance matching ensures that maximum power is radiated by the antenna and minimum power is reflected back. Therefore, during antenna design and simulation, VSWR is analyzed over the operating frequency range to ensure that the antenna operates efficiently within the desired bandwidth. Tage (Vmin) of these standing waves. A VSWR plot shows how well an antenna is matched with the transmission line over a range of frequencies. It represents the variation of VSWR with frequency.

VSWR (Voltage Standing Wave Ratio) is the ratio of the maximum voltage to the minimum voltage in a standing wave formed on a transmission line due to impedance mismatch between the antenna and the feed line.

**$S_{11}$ PARAMETER PLOT:**



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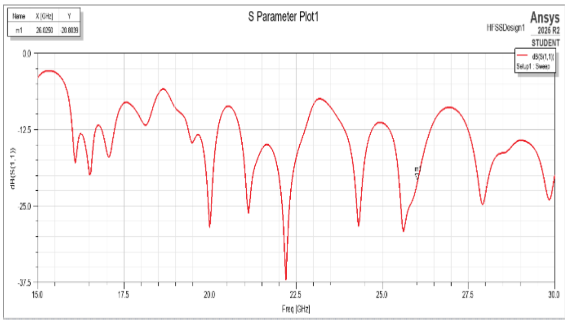


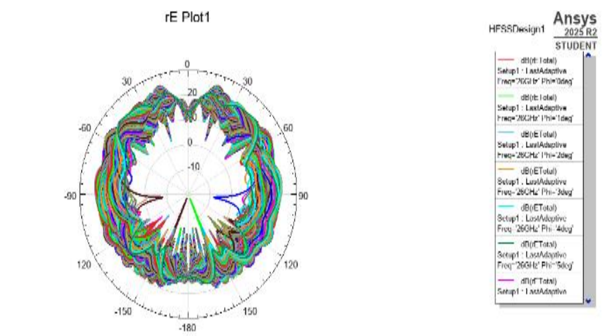

**Fig : S11 Parameter**

The given graph is an **S-**parameter plot (S11) of a microstrip patch antenna obtained using ANSYS HFSS. It shows the relationship between frequency (15 GHz to 30 GHz) and return loss in dB. The S11 parameter indicates how much of the input signal is reflected back from the antenna. Lower (more negative) values of S11 represent better impedance matching and efficient radiation of energy.

**rE plot:**

The rE plot represents the radiation efficiency of an antenna as a function of direction in a polar format. Radiation efficiency indicates how effectively the antenna converts the input electrical power into radiated electromagnetic power.

Radiation efficiency is defined as the ratio of radiated power to the total input power supplied to the The rE plot is displayed in polar coordinates showing radiation efficiency in different angular directions (0° to 360°).



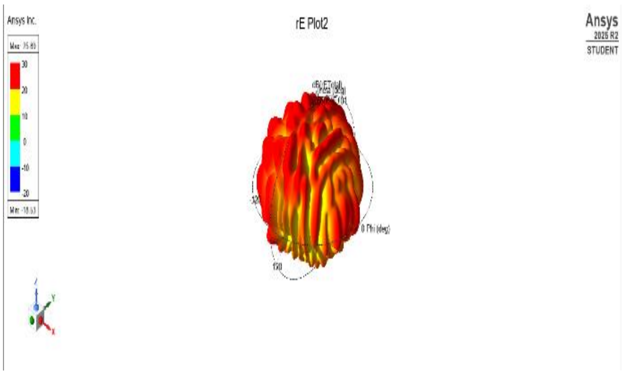




**Fig : rE plot**

The distance from the center of the plot represents the magnitude of radiation efficiency. The circular pattern indicates how efficiently the antenna radiates energy in various directions. Multiple colored curves usually represent different frequencies or simulation sweeps. If the plot forms a nearly circular pattern, the antenna radiates efficiently in most directions. Irregular shapes indicate variations in radiation efficiency due to antenna geometry or frequency changes antenna.

## VI.CONCLUSION

The project presents the design and simulation of a rectangular microstrip patch antenna with gain enhancement using the inset feed technique. The antenna is designed to operate at a frequency of 26 GHz, which is suitable for modern 5G millimeter-wave communication systems. By employing a low dielectric constant substrate and optimizing the antenna dimensions, effective radiation characteristics are achieved. The use of the inset feed technique plays a crucial role in improving impedance matching, resulting in a significant reduction in return loss and efficient power transfer.

The simulation results demonstrate that the proposed antenna achieves a return loss below -20 dB, acceptable VSWR, and enhanced gain compared to conventional microstrip patch antennas. The radiation pattern is stable and suitable for wireless communication applications. Overall, the project



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successfully meets its objectives by improving antenna performance in terms of gain and impedance matching. The proposed design is compact, cost-effective, and suitable for integration into modern wireless systems, making it a promising solution for high-frequency communication applications such as 5G.

## FUTURE SCOPE

The future scope of the design and simulation of a rectangular microstrip patch antenna with gain enhancement is broad and highly relevant to modern communication systems. With the continuous evolution of wireless technologies, this antenna can be further improved to support higher frequency bands such as milli-meter-wave and 5G applications, where high gain and efficiency are essential. Advanced techniques like the use of metamaterials, electromagnetic band gap (EBG) structures, and artificial magnetic conductors (AMC) can be explored to significantly enhance gain and bandwidth. Additionally, the antenna design can be extended to array configurations, where multiple patch elements are combined to achieve much higher gain and directivity for applications like radar and satellite communication. Future work can also focus on reconfigurable and smart antennas that can dynamically adjust frequency, radiation pattern, or polarization using switches or tunable materials. Miniaturization techniques can be applied to make the antenna more compact for integration into portable and IoT devices. Moreover, optimization using machine learning algorithms and advanced simulation tools can be implemented to achieve better performance with reduced design time. Integration with modern systems such as wearable devices, autonomous vehicles, and wireless sensor networks also presents significant opportunities. Overall, the future scope lies in improving efficiency, adaptability, and integration of microstrip patch antennas to meet the growing demands of next-generation communication technologies.

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