



Design of a Rectangular Microstrip Patch Antenna for 5G Wireless Communication Systems

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KEYWORDS	ABSTRACT
Rectangular microstrip patch antenna, 5G wireless communication, HFSS, Rogers 4350 substrate, inset-fed transmission line, S-parameters, bandwidth enhancement, antenna gain, radiation pattern, directivity, efficiency.	This project presents a comprehensive framework for the design and simulation of a rectangular microstrip patch antenna for modern 5G wireless communication systems. The study aims to achieve improved antenna performance in terms of gain, Radiation pattern, directivity, S11, bandwidth, and efficiency. The antenna is designed to operate at a central frequency of 3.3 to 3.8 GHz and is developed using High-Frequency Structure Simulator (HFSS). both of which are prominent tools for full-wave electromagnetic modelling. To balance performance and cost effectiveness, the antenna is designed on a substrate material with a low dielectric constant of 3.66 and a low loss tangent of 0.0009. An inset-fed transmission line structure is implemented to ensure stable impedance matching and efficient signal excitation. The designed antenna achieves a maximum bandwidth and peak gain. To further enhance the gain, Radiation pattern, directivity, S11, bandwidth, and efficiency, a substrate material consisting of multiple identical rectangular patch elements is proposed. This Rogers4350 configuration significantly improves both the maximum bandwidth and the overall gain of the antenna system. The antennas discussed in this project are specifically designed for the 3.3 to 3.8 GHz frequency band and are suitable for use in 5G mobile communication.

INTRODUCTION

In advanced wireless communication systems, antennas play a crucial role in enabling reliable

connectivity, and microstrip patch antennas are widely employed due to their suitability for modern communication requirements [1]. With the rapid

deployment of fifth-generation (5G) wireless networks, there is an increasing demand for compact, low-profile, and high-performance antennas capable of operating efficiently in the sub-6 GHz and millimeter-wave frequency bands [2]. Microstrip patch antennas consist of a radiating metallic patch printed on one side of a dielectric substrate with a ground plane on the opposite side, offering advantages such as low fabrication cost, lightweight structure, ease of integration with planar circuits, and compatibility with microwave and RF systems [3]. Due to these advantages, rectangular microstrip patch antennas are extensively studied and preferred over other geometries because of their simple design procedure, predictable radiation characteristics, and ease of parameter optimization [4].

Recent studies have demonstrated that antenna performance parameters such as return loss, bandwidth, gain, and radiation efficiency are significantly influenced by substrate properties, including dielectric constant, thickness, and loss tangent [5]. Low-cost substrates like FR-4 and low-loss materials such as Rogers series are commonly used to achieve a balance between performance and fabrication feasibility in 5G antenna designs [6]. Additionally, proper selection of feeding techniques, including microstrip line feeding, lumped port excitation, and impedance matching networks, is essential for minimizing reflection losses and achieving stable antenna operation [7]. Geometry optimization techniques, such as modifying patch dimensions, feed placement, and structural configuration, have been reported to enhance impedance matching and radiation performance [8].

Simulation-based design approaches using High-Frequency Structure Simulator (HFSS) are widely adopted for accurate electromagnetic analysis and validation of antenna characteristics, including S-parameters, radiation patterns, gain, and electric and magnetic field distributions [9]. Several researchers have also highlighted that array configurations and optimized feeding networks can further improve gain and directivity for 5G applications [10]. Despite significant advancements, designing a compact rectangular microstrip patch antenna that simultaneously offers wide bandwidth, adequate gain, and stable radiation characteristics remains a challenging task for 5G wireless communication systems [11]. Motivated by these research findings, this work focuses on the design and

simulation of a rectangular microstrip patch antenna using HFSS, optimized to achieve improved impedance matching, enhanced gain, and reliable radiation performance suitable for 5G wireless communication applications [12].

Designing of the rectangular patch antenna

A. Ground

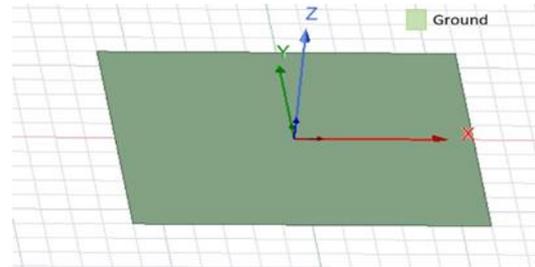


Fig 1(a): Ground

Properties Completed - HFSSDesign1 - Modeler

Name	Value	Unit	Evaluated V.	Description
Command	OverlayRectangle			
Coordinate	Global			
Position	{0, 0, 0}	mm	0mm, 0, 0	
Axis	Z			
XSize	60	mm	60mm	
YSize	60	mm	60mm	

Fig 1(b): specifications

The first step in designing a rectangular patch antenna using HFSS involves creating the ground plane, which serves as the reference conductive surface for the antenna. The ground plane makes sure that the antenna radiates correctly, has the right impedance, and is stable overall. In the HFSS model, a rectangular ground sheet is drawn on the XY-plane, representing the base of the antenna structure. The coordinate system is positioned such that the ground plane lies flat along the horizontal plane, with its thickness considered negligible. The 3D axes (X, Y, Z) help visualize the orientation, where the Z-axis is perpendicular to the ground, indicating the direction of radiation.

B. Substrate

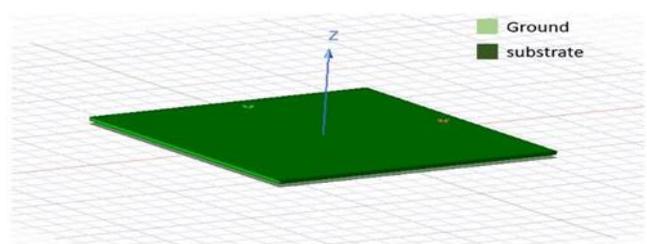


Fig 2(a): Substrate



Fig 2(b): specifications

In this design, the substrate material selected is Rogers RO4350, a high-performance dielectric material widely used in RF and microwave applications due to its low loss characteristics and stable electrical behaviour. This substrate has a dielectric constant (ϵ_r) of 3.66.

The substrate is created using the Create Box command in the HFSS modeler. The property table shown in the second image specifies its exact parameters. The substrate is positioned with its origin at coordinates $(-30, -30, 0)$, establishing the lower-left corner of the rectangular sheet. The X-Size and Y-Size values are each 60 mm, forming a square footprint, while the Z-Size (thickness) is 0.8 mm.

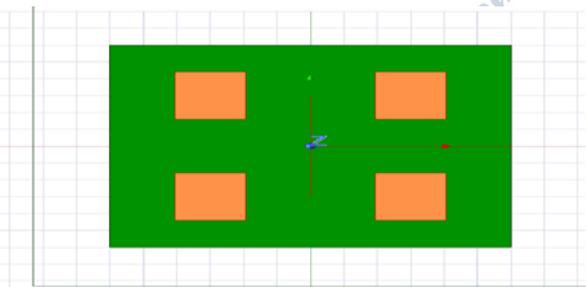


Fig 3(a): Patch

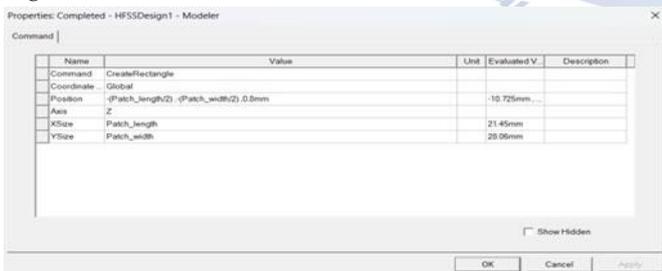


Fig 3(b): specifications

The rectangular patch is designed in HFSS using the global coordinate system with precise control over its geometrical dimensions. Each patch element is configured with a length of 21.45 mm and a width of 28.06 mm, which are optimized to achieve resonance within the desired operating frequency band. The patch is accurately positioned above the substrate to ensure proper alignment with the ground plane and to support efficient radiation characteristic

The figure shows a symmetric 2×2 rectangular microstrip patch configuration on the dielectric substrate, ensuring

structural uniformity. Uniform spacing between the patch elements provides balanced current distribution and stable electromagnetic behavior. This optimized arrangement enhances antenna gain and improves radiation characteristics for 5G wireless communication applications.

D. Feed mechanism and excitation

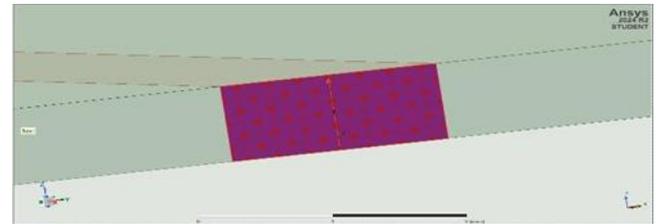


Fig 4: port feeding

The figure illustrates the excitation region applied to the antenna structure in HFSS using a port-based feeding mechanism. The defined port ensures efficient energy transfer from the source to the radiating patch while maintaining proper impedance matching. This excitation setup enables accurate analysis of return loss and radiation characteristics of the proposed antenna design.

E. Feed Network Rectangles:

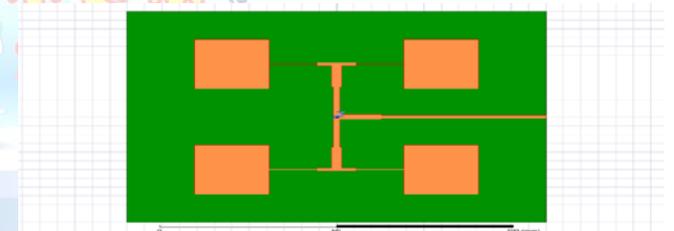


Fig 5: Feeding network

The figure shows the microstrip feed network used to excite the 2×2 rectangular patch antenna configuration. The feed line is designed to distribute power uniformly to all patch elements, ensuring proper impedance matching and balanced excitation. This feeding structure improves radiation efficiency and contributes to enhanced gain and stable antenna performance for 5G applications.

F. Radiation box:

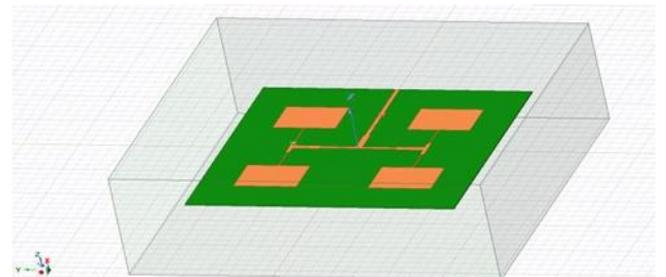


Fig 6(a): Radiation box

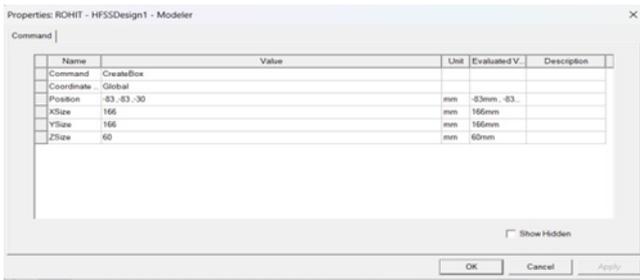


Fig 6(b): specifications

Simulation setup:

Select every surface of the radiation enclosure, right-click, and apply the Radiation Boundary condition. Then choose all four patch elements and set their excitation type to Perfect Electric (E1). After that, select the ground plane and assign it the Perfect Electric (E2) excitation. Finally, select the feeding source and define a Lumped Wave Port excitation for it.

To validate the performance, click on Add Solution setup and set the frequency at 4.05GHz and set the sweep from 2GHz to 5GHz. Save the HFSS design and validate the result. Click on Analyze all to analyze and check the results.

To check the radiation pattern and gain performance, click on radiation and select create far field reports, and then right click on the infinite sphere. Change the values of phi from 0° to 360° and theta values from -180° to 180° . Save the design and check the results section to view the radiation pattern.

2*2 RECTANGULAR MICRO STRIP PATCH ANTENNA USING HFSS

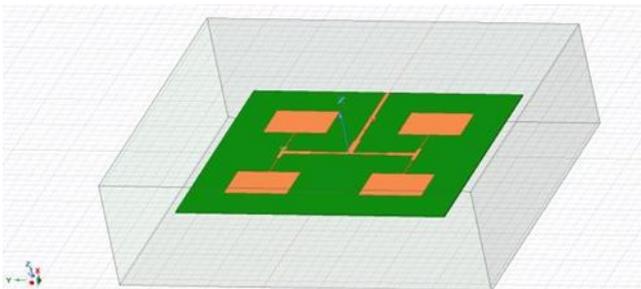


Fig 7: 2*2 rectangular micro strip patch antenna

The figure8 shows a 2*2 rectangular microstrip patch antenna array designed on a substrate of material Rogers 4350, and the four patches are radiating patches. Coaxial feed excites the structure, and the power is distributed to all four patches equally using feed lines. This design improves the gain and

radiation characteristics.

The above model is a periodic meta-material pattern on a dielectric substrate within a radiation boundary. The metallic pattern elements are arranged to create a resonant response upon interaction with the structure by electromagnetic waves. "The air box simulates the free-space to accurately compute the return loss, S-parameters and the radiation characteristics.

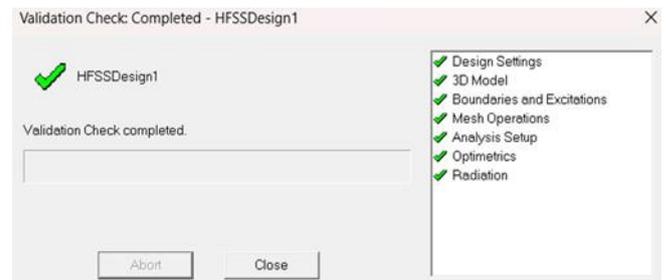
A 3D box was defined in HFSS around the antenna structure for radiation to simulate the antenna in free space. The outer boundaries of the box were given a Radiation Boundary, which makes the outgoing fields be absorbed as if they were traveling in free space. This guaranteed accurate far-field and antenna gain, directivity results and also S-parameter. The radiation box size has been kept at a distance of about one-quarter wavelength away from the antenna in every direction in order to reduce the interactions with the boundaries and maintain the accuracy of the simulation.

The figure12 shows a 2*2 circular patch antenna array with the lumped port excitation. To assign the port excitation, select the source right click on it, and assign lumped wave port excitation. It ensures proper field generation and impedance matching for radiation.

STIMULATION RESULTS:

To simulate the results in HFSS, go to HFSS and then click Analysis setup and add solution setup, set the operating frequency to 3.4GHz. Then add Frequency sweep and set the sweep range 2-5GHz. After setting up the solution setup and frequency sweep, click HFSS and then Analyze all to start the stimulation. Once the analysis is complete, open the results section to view S11/Return loss, Radiation pattern, Gain, and 3D Far-field plots.

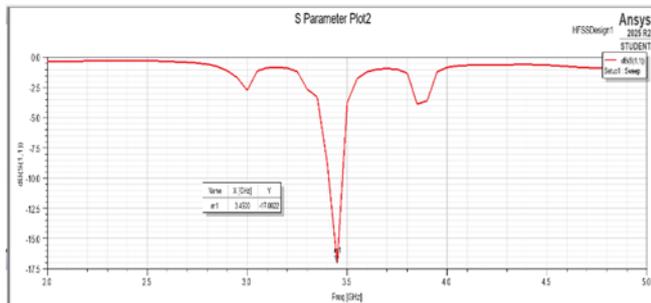
1. validation check



The figure shows the successful validation check of the proposed antenna design in HFSS. All essential components, including geometry, boundaries, excitations, mesh operations, and radiation setup, are

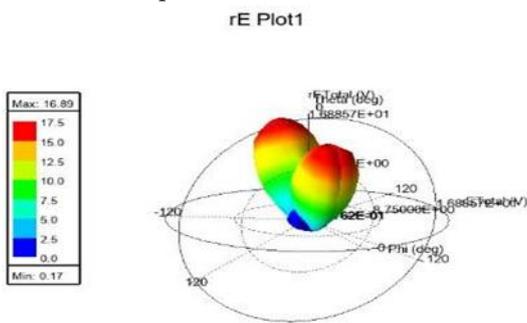
verified without errors. This confirms that the model is correctly configured and ready for accurate electromagnetic simulation.

2. scattering parameter(S11)



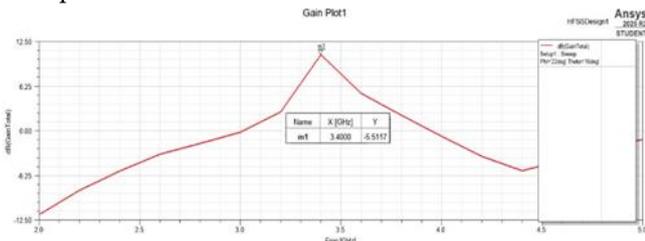
The S_{11} analysis confirms that the designed antenna resonates strongly at 3.45 GHz with a return loss of approximately -17 dB, demonstrating good impedance matching and minimal power reflection at the feed point. Hence, the antenna is suitable for wireless applications operating near this frequency.

3. Radiation pattern



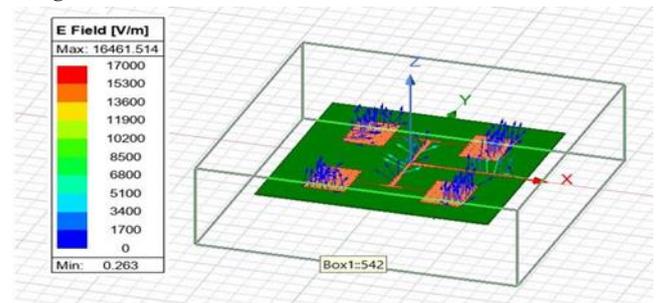
The calculated 3D radiation pattern of the antenna design is presented in Fig. 5A. The electric field on the radiating surface is that of a strong radiated E-field in the main-lobe region at the peak with an intensity of almost 16.8 db. The energy is evenly distributed and no significant side lobe appear; this indicates the antenna energy is directional and the backward radiation is minimum. This demonstrates that the suggested design effectively forward radiates.

Gain parameter



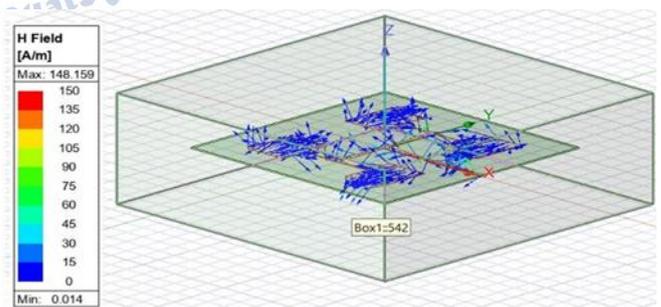
shows the simulated gain fluctuation versus frequency. The gain is gradually rising and the maximum value nearly 10.61 dB at the resonant frequency. After that, a small gain drop can be seen, which is attributed to the misalignment of the impedances. The obtained maximum gain shows that the antenna produces enough radiation power at the desired frequency band and thus can be used for wireless communications.

Magnetic field



The H-Field vector plot is depicting the magnetic field around the radiating element of the designed rectangular microstrip patch antenna. The colour bar represents the range of variation of the magnitude from 0 to about 150 A/m, with the most intense field at the edges of the radiating patch. The direction of magnetic field flow produced by the surface currents is shown by the vector arrows. The field pattern ensures that the antenna works well at resonance and that it is well modelled electromagnetically inside the HFSS radiation boundary.

Electric Field



The above shows the designed antenna's E-field obtained from the HFSS simulation. The left colour bar provides the intensity of the field in V/m from 0.263 V/m (min) to 16461.514 V/m (max). Greater field intensities are in red/yellow and the weaker ones are in blue/green.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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