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Design and Analysis of 5G Antenna

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ABSTRACT

The design and simulation of a compact microstrip patch antenna intended for 5G sub-6 GHz wireless communication.The antenna is designed on an FR-4 epoxy substrate, which has a dielectric constant of 4.4, a thickness of 1.6 mm, and a loss tangent of 0.002. A rectangular radiating patch with microstrip line feed is used to ensure simple structure and easy integration. The antenna design is simulated using a full-wave electromagnetic solver to evaluate key performance parameters. Simulation results show a return loss (S11) of –41 dB, indicating excellent impedance matching. The voltage standing wave ratio (VSWR) is 1.01, confirming minimal signal reflection. Additionally, the design achieves a gain of 4.00 dBi, demonstrating efficient radiation characteristics. The antenna exhibits a stable radiation pattern and sufficient bandwidth around the operating frequency. These features make it suitable for WiFi, WiMAX applications.

Keywords: Microstrip patch Antenna,

INTRODUCTION:

In the era of rapid technological advancements, wireless communication systems have become integral to modern life, with increasing demands for high-speed data transfer, compact hardware, and efficient spectrum utilization. Among the enabling technologies, antennas play a crucial role as the interface between the electrical and electromagnetic domains. Microstrip patch antennas (MPAs) are particularly attractive due to their low profile, ease of fabrication and suitability for integration into compact devices. These characteristics make MPAs an ideal choice for fifth-generation (5G) wireless communication, especially in sub-6 GHz bands such as the 3.25 GHz range.

The 5G sub-6 GHz spectrum, notably the n78 band (3.3–3.8 GHz), supports high data rates and low latency over wide coverage areas. Designing efficient antennas in this band requires careful optimization of parameters such as return loss, voltage standing wave ratio (VSWR), and gain. The choice of substrate material significantly influences antenna performance. FR-4, with a relative permittivity (εr) of 4.4 and a standard thickness of 1.6 mm, remains a widely used low-cost dielectric despite its moderate loss characteristics [1].

The performance of an MPA depends heavily on patch dimensions, feed structure, and the dielectric properties of the substrate. As demonstrated by Rana et al. [2], careful adjustment of these parameters allows for enhanced bandwidth, gain, and radiation efficiency in S-band applications. This work focuses on the design and simulation of a microstrip patch antenna operating at 3.25 GHz on an FR-4 substrate. The proposed antenna achieves a return loss of –41 dB, VSWR of 1.01, and a gain of 4.00 dBi, making it suitable for sub-6 GHz 5G applications, including WiFi and WiMAX.

Materials & Methods:

Design Approach:

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The antenna is designed to operate at a resonant frequency of 3.25 GHz, falling within the sub-6 GHz band used in 5G and WiMAX communications.The design omits any specification of physical conductor material such as copper, as the focus is entirely on electromagnetic simulation, where ideal conducting surfaces are assumed using Perfect Electric Conductor (PEC) boundaries.

In the development of a rectangular microstrip patch antenna for communication systems, careful selection of key design parameters is essential, specifically the resonant frequency (fc), dielectric constant (εr), and substrate thickness (h). The resonant frequency is primarily governed by the patch's physical dimensions and the substrate's electrical properties. As shown in Equation (1), the resonant frequency is a function of the patch's length and width, and the substrate's permittivity, with $c = 3 \times 10^8 \mathrm{m/s}$ representing the speed of light in free space. The dielectric constant influences how electromagnetic waves propagate through the substrate, while the substrate thickness impacts the bandwidth and overall radiation efficiency of the antenna. Moreover, the substrate wavelength is inversely related to the square root of its dielectric constant, meaning higher permittivity allows for more compact antenna designs, which is particularly advantageous in space-constrained applications.

Design Considerations and Key Equations:

Its physical dimensions and substrate characteristics determine the resonance frequency of the patch antenna. The patch width and length are calculated using the standard transmission line model equations:

- **Patch Width (W):**

$$W = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

- **Effective Dielectric Constant ($\varepsilon_{\text{reff}}$):**

$$\boldsymbol{\varepsilon}_{\text{reff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{h}{W}\right)^{-0.5}$$

- **Length Extension (ΔL):**

$$\boldsymbol{\Delta}L = 0.412h * \frac{(\varepsilon_{\text{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{\text{reff}}-0.258)\left(\frac{W}{h}+0.8\right)}$$

- **Patch Length (L):**

$$L = \frac{c}{2f_{c}\sqrt{\varepsilon_{\text{reff}}}} - 2\Delta L$$

- **Ground Plane Dimensions:**

$$L_g = L + 6h, \quad W_g = W + 6h$$

Table1:Initial dimensions of designed Antenna

Parameter	Dimensions(mm)
Patch Size (W× L)	21 × 27
Ground Plane Size($W_g \times L_g$)	60 × 60

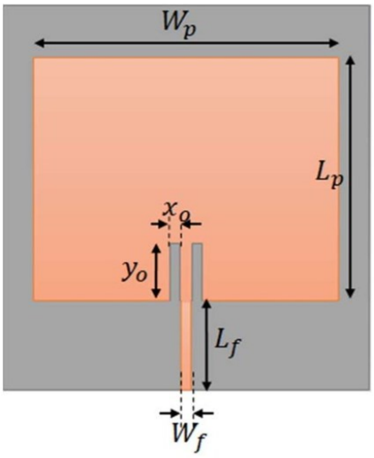

Fig 1: Patch antenna dimensions

Table 2: Final dimensions of designed Antenna

W_p	L_p	W_f	L_f	x_0	y_0
27mm	21mm	2.895mm	19.65mm	1.05mm	6.7mm

RESULTS AND DISCUSSION:

Simulation Results:

The proposed rectangular microstrip patch antenna was designed and evaluated using full-wave electromagnetic simulation software such as

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ANSYS HFSS. The simulation focused on analyzing the antenna's reflection coefficient, impedance matching, gain, bandwidth, and radiation characteristics across the frequency range of 3.0 GHz to 3.5 GHz. The simulation was carried out assuming Perfect Electric Conductor (PEC) surfaces for the patch and ground plane, and an FR-4 substrate with a dielectric constant of εr = 4.4 and thickness h = 1.6 mm.

Impedance Matching:

Impedance analysis using the Smith Chart showed that the antenna's input impedance is well matched to the standard 50 Ω transmission line. The feed line position and dimensions were carefully tuned during simulation to minimize mismatch and reflection losses.

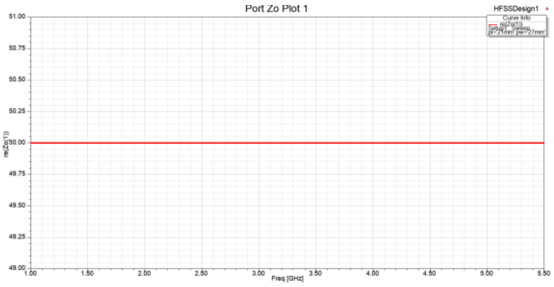

Fig 2 : Port Zo Plot

Return Loss (S11):

The antenna achieved a minimum return loss of –41 dB at the resonant frequency of 3.25 GHz, indicating excellent impedance matching and minimal reflection of incident power. Return loss below –10 dB is considered acceptable for antenna performance, and the achieved value signifies strong coupling between the feed and radiating elements. This suggests that nearly all the input power is radiated, and very little is reflected back to the source. Return loss shown in fig 3.

Bandwidth:

The –10 dB return loss bandwidth of the antenna was approximately 100 MHz, spanning from 3.20 GHz to 3.30 GHz.The achieved bandwidth is a function of both substrate parameters and optimized patch dimensions.

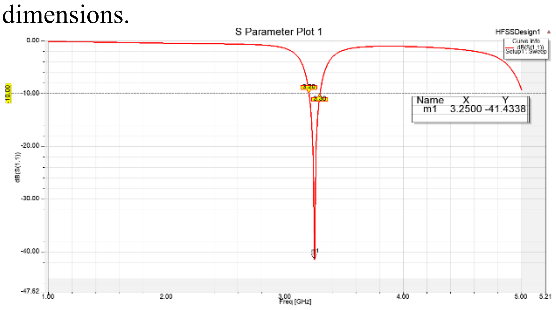

Fig 3: **Return Loss vs Frequency**

Voltage Standing Wave Ratio (VSWR):

At the resonant frequency, the VSWR was calculated to be 1.01, which is almost ideal. A VSWR value below 2 is generally acceptable for practical antennas, while values close to 1 imply near-perfect impedance matching. This ensures maximum power transfer between the antenna amounted and the transmission line.VSWR shown in fig 4.

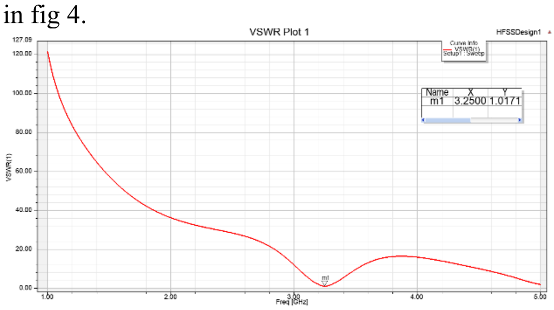

Fig 4: **VSWR Plot**

Gain:

The simulated realized gain of the antenna was found to be 4.00 dBi at 3.25 GHz. This level of gain is considered suitable for applications requiring directional radiation over moderate distances, such as sub-6 GHz 5G networks, WiFi, and WiMAX systems. Gain shown in fig 5.

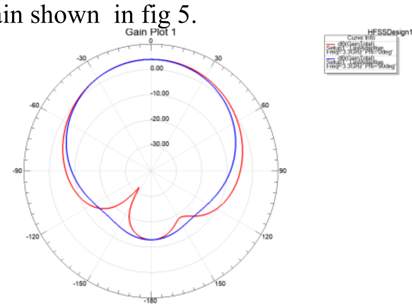

Fig 5: **Gain Plot**

Table 4: Comparison between previous published works

References	**Frequency**	**Material**	**S11**	**VSWR**	**Gain**
[1]	2.45	FR-4	-20.405 dB	1.221	2.592 dB
[2]	3.25	FR-4	-25.12 dB	---	---
[3]	3.2	Pyralux FR 911	-31.38 dB	---	---
[4]	2.4	FR-4	-28 dB	1.08	3.023dB
Proposed work	3.25	FR-4	-41.43 dB	1.01	4.00dB

Conclusion:

A compact rectangular microstrip patch antenna designed for sub-6 GHz 5G applications,

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specifically at a center frequency of 3.25 GHz, was successfully simulated and analyzed. Key antenna parameters were optimized through simulation, resulting in a return loss (S11) of –41 dB, a VSWR of 1.01, and a gain of 4.00 dBi at the target frequency. These values indicate excellent impedance matching, efficient radiation performance, and strong suitability for wireless communication systems such as WiFi, WiMAX, and 5G mid-band networks. The design approach did not include physical fabrication but relied entirely on electromagnetic simulation using ideal boundary conditions, confirming the feasibility of the proposed structure for practical sub-6 GHz wireless applications. **Future work** may focus on physical realization, flexibility analysis, or performance improvement through techniques like slotting, defected ground structures, or machine learning-based optimization.

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