



Design of a Microstrip Patch Antenna for 5G Millimeter-Wave Applications

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Abstract

This paper presents an analytically derived design of a compact rectangular microstrip patch antenna intended for operation near 28 GHz, a widely investigated millimeter-wave frequency for fifth-generation (5G) wireless systems. A low-loss Rogers RT/duroid 5880 substrate (relative permittivity 2.2, thickness 0.254 mm) is considered to reduce dielectric loss and support compact implementation. Conventional transmission-line equations are used to estimate the patch width, effective permittivity, fringing-field extension, and resonant length. The initial calculated dimensions are approximately 4.24 mm in width and 3.51 mm in length. A 50-ohm microstrip feed and full-wave electromagnetic optimization workflow are proposed. The paper discusses impedance matching, return loss, voltage standing-wave ratio, gain, efficiency, radiation pattern, bandwidth, fabrication tolerance, and integration issues. Numerical results reported here are analytical starting values, not measured or simulated antenna performance. Full-wave simulation and prototype measurements are necessary to validate the proposed design.

Keywords: 5G; millimeter wave; 28 GHz; rectangular microstrip patch; antenna design; impedance matching; electromagnetic simulation.

1. Introduction

Fifth-generation wireless networks use diverse spectrum allocations, including frequency ranges above 24 GHz, to support high data rates and dense deployments. At millimeter-wave frequencies, compact antenna elements are feasible, but free-space propagation loss, blockage, conductor and dielectric loss, packaging, and fabrication accuracy become important. Microstrip patch antennas are attractive because of their low profile, low mass, planar fabrication, and compatibility with printed-circuit technologies. Their limitations include relatively narrow impedance bandwidth and, for a single element, moderate gain.

This study develops a transparent, reproducible starting design at 28 GHz. The proposed antenna is a single rectangular patch over a continuous ground plane, implemented on a thin, low-loss substrate. The principal contribution is a documented analytical sizing procedure coupled to a realistic validation plan; it does not claim experimentally demonstrated 5G performance.

2. Literature Background

Classical microstrip antenna theory models the patch as a resonant structure with radiating fringing fields at its open edges. Transmission-line and cavity approaches provide useful initial estimates, while full-wave numerical methods are required to account for the feed, finite ground plane, conductor thickness, and parasitic effects. Standard antenna references describe the trade-offs among substrate permittivity, thickness, bandwidth, surface-wave excitation, and

radiation efficiency [1–3]. 3GPP specifications identify FR2 frequency bands relevant to 5G NR, although practical use of a particular band depends on region and deployment [4].

3. Objectives and Scope

- Derive initial rectangular-patch dimensions for a nominal 28 GHz resonance.
- Define a manufacturable substrate, ground plane, and microstrip feeding approach.
- Specify full-wave simulation, optimization, and measurement methods for validation.
- Identify design trade-offs and realistic limitations for 5G millimeter-wave deployment.

4. Proposed Antenna Configuration

The baseline structure consists of a rectangular copper patch printed on the top surface of Rogers RT/duroid 5880, a solid copper ground plane on the underside, and a 50-ohm microstrip feed. The selected nominal substrate parameters are relative dielectric constant $\epsilon_r = 2.2$, thickness $h = 0.254$ mm, and a low loss tangent (use the manufacturer's frequency-specific data during simulation). Copper thickness may initially be set to 17 μm , then revised to match the chosen laminate. An initial ground/substrate outline of 10 mm $\times$ 10 mm is proposed for simulation; it is a design choice, not an optimized dimension.

5. Analytical Design Method

For a rectangular patch operating in the dominant TM₁₀ mode, an initial width is estimated by [1, 2]:

$$W = c / (2 f_0) \times \sqrt{2 / (\epsilon_r + 1)} \quad (1)$$

The effective relative permittivity is approximated by:

$$\epsilon_{\text{eff}} = (\epsilon_r + 1)/2 + (\epsilon_r - 1)/2 \times (1 + 12h/W)^{-1/2} \quad (2)$$

The normalized fringing-field extension is:

$$\Delta L/h = 0.412 [(\epsilon_{\text{eff}} + 0.3)(W/h + 0.264)] / [(\epsilon_{\text{eff}} - 0.258)(W/h + 0.8)] \quad (3)$$

The effective length and physical patch length are:

$$L_{\text{eff}} = c / [2 f_0 \sqrt{\epsilon_{\text{eff}}}], \quad L = L_{\text{eff}} - 2\Delta L \quad (4)$$

5.1 Calculated Starting Dimensions

Parameter	Value	Comment
Design frequency	28 GHz	Nominal target
Relative permittivity	2.2	RT/duroid 5880 nominal
Substrate thickness	0.254 mm	Chosen design input
Patch width W	4.232 mm	Equation (1)
Effective permittivity	2.057	Equation (2)
Fringing extension ΔL	0.133 mm	Equation (3)
Effective length L_{eff}	3.732 mm	Equation (4)
Patch length L	3.466 mm	Equation (4)
Substrate / ground plane	10 $\times$ 10 mm	Initial simulation outline

These dimensions are preliminary. A practical resonant frequency may shift after the feed, copper metallization, finite ground plane, and manufacturing details are included.

5.2 Feed Design and Matching

A 50-ohm microstrip feed may be connected to the patch through an inset or edge-coupled transition. The feed-line width must be calculated for the actual stack-up using a transmission-line calculator or field solver. For inset feeding, the inset depth and slot gap are tuned in a full-wave solver until the input impedance approaches 50 Ω at the target frequency. A

wave port or lumped port must be defined with a physically appropriate reference plane; de-embedding should be reported if used.

6. Simulation and Optimization Methodology

Build the geometry in a full-wave electromagnetic tool such as CST Microwave Studio, Ansys HFSS, or an equivalent validated solver. Use a radiation/open boundary separated adequately from the antenna, model finite conductor thickness and dielectric loss, and refine the mesh until S11 and resonant frequency converge. Sweep frequency over approximately 24–32 GHz to capture the resonance. Parameterize L, W, inset depth, feed width, ground size, and substrate thickness. First tune L to center the resonance, then optimize the feed for matching; finally examine gain, efficiency, and bandwidth. Repeat with realistic connector or launch geometry when planning measurements.

6.1 Performance Metrics

Metric	Definition / interpretation	Suggested evaluation
Reflection coefficient S11	Input mismatch at the port	Plot in dB vs frequency
–10 dB impedance bandwidth	Frequency span where $S_{11} \leq -10$ dB	Report start/end frequencies and percent
VSWR	$(1 + \Gamma)/(1 - \Gamma)$	Check near target frequency
Realized gain	Gain including mismatch loss	Report dBi and principal planes
Radiation efficiency	Radiated power / accepted power	Report percent vs frequency
Radiation pattern	Co-/cross-polarized far-field response	Plot E- and H-plane cuts

For $S_{11} = -10$ dB, $|\Gamma| \approx 0.316$ and $VSWR \approx 1.92$. This is an acceptance criterion, not a prediction for the proposed antenna.

7. Expected Behavior and Discussion

The fundamental patch mode is expected to produce broadside radiation, with its main beam approximately normal to the substrate. The low dielectric constant is favorable for radiation, while the thin substrate supports compact, predictable fabrication but may restrict bandwidth. A single element is not expected to provide the directional gain of a phased array. The final resonance and matching are especially sensitive to small dimensional changes at 28 GHz; therefore, fabrication tolerances, substrate variability, surface roughness, and feed parasitics should be investigated using parametric sweeps.

An array of multiple patches with controlled element spacing and feed phase could provide higher gain and beam steering, but array analysis introduces mutual coupling, feeding-network loss, grating-lobe, and scanning considerations beyond the present single-element baseline.

8. Experimental Validation Plan

After simulation, fabricate the optimized geometry on the specified laminate. Measure input reflection with a calibrated vector network analyzer and a suitable millimeter-wave test fixture or connector transition. Calibrate to the antenna feed reference plane where possible and record fixture losses. Measure realized gain and radiation patterns in a suitable anechoic environment against a calibrated reference antenna. Compare measured and simulated resonant frequency, –10 dB bandwidth, gain, and efficiency, and discuss deviations with reference to manufacturing and test uncertainties. No prototype measurements are included in this paper.

9. Limitations

This work is an analytical design proposal. It does not contain verified electromagnetic simulation outputs, fabricated prototypes, measured S-parameters, or radiation-pattern results. The proposed ground dimensions and feed details require optimization. Also, a 28 GHz resonance alone does not establish conformance with any complete 5G device or regulatory requirement.

10. Conclusion

A rectangular microstrip patch antenna targeting 28 GHz has been analytically sized for a low-loss $\epsilon_r = 2.2$, $h = 0.254$ mm substrate. The calculated starting dimensions are $W \approx 4.23$ mm and $L \approx 3.47$ mm. A practical feed, finite ground plane, electromagnetic optimization sequence, and measurement procedure have been outlined. These results provide a defensible starting point for a compact millimeter-wave antenna, but performance claims must await converged full-wave simulation and experimental validation.

References

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