Design of mmWave Antenna for Next-Generation Technologies

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Abstract: This paper presents a compact rectangular patch antenna designed for 38 GHz mmWave applications. The antenna rests on Rogers RT/duroid 5880(tm) substrate materials (εr = 2.2, thickness = 0.5 mm) where it integrates a rectangular patch antenna with a cutout to enhance impedance and bandwidth performance and combines these elements with a microstrip feedline and a partial ground plane. Simulations indicate a -24.13 dB return loss at 38.2 GHz along with 5.80 dB peak gain and relatively uniform radiation patterns. Analysis of surface current distribution confirms that the patch edges together with feedline achieve efficient radiation of the antenna system. In addition to its suitability for 5G and beyond networks it provides compact size alongside high gain capabilities and efficient performance. Both experimental verification and array integration form parts of the future work.

Keywords— mmWave antenna, rectangular patch, impedance matching, 5G, gain.

2. Introduction

Wireless communication technologies show fast expansion caused by user requirements for elevated data speeds with minimal delay alongside solid signal connection. 5G technology along with future communications has raised essential challenges and prospects through millimeter-wave (mmWave) frequencies because their wide bandwidth makes multi-gigabit data transmission possible [1],[2]. The implementation of mmWave technology faces built-in technical obstacles that cause high propagation losses combined with minimal obstacle penetration while facing more risks of interference. The solution of these challenges needs antenna design techniques which maximize operation efficiency and gain performance while developing beamforming capabilities [3].

MIMO (Multiple Input Multiple Output) systems increase signal strength when multiple antenna elements operate at both transmitter and receiver because they deliver better signal resilience during power or bandwidth restrictions [4]. Strong mutual coupling between densely arranged antenna elements in mmWave frequency systems produces performance deterioration mostly affecting urban and high-mobility environments [5]. Research studies have produced multiple solutions to reduce antenna coupling and enhance isolation performance through the implementation of parasitic elements along with defected ground structures (DGS) and electromagnetic bandgap (EBG) materials [6],[7]. Modern substrate engineering techniques combined with metasurface technology allowed a significant improvement of impedance performance while expanding the bandwidth capability and directing the gain [8]. Despite these developments, mmWave antenna design still faces trade-offs between size, efficiency, and bandwidth. Research into mmWave antenna characteristics especially focusing on patch antennas slot antennas and phased arrays leads to continuous architectural development because these designs enhance integration capabilities and manufacturing efficiency [9] [10]. This paper presents a 5G antenna which functions for mmWave frequency-based wireless systems. The design achieves impedance matching and radiation efficiency enhancement as key features which maximize system performance while maintaining a small physical size. Performance tests along with design procedure analysis and simulation results demonstrate that this antenna satisfies the requirements for present networks.

3. Proposed Antenna Design

The proposed design consists of a compact rectangular patch antenna optimized for 38 GHz mmWave applications. It is fabricated on a Rogers RT/duroid 5880(tm) substrate ($\varepsilon r = 2.2$, thickness = 0.5 mm) with overall dimensions of 12 mm × 10 mm. The structure includes a radiating patch, a microstrip feedline, and a partial ground plane, ensuring balanced radiation performance. The projected antenna's design is illustrated in Figure 1.

The 7 mm × 6 mm radiating patch has a 6 mm × 5 mm rectangular cutout to improve bandwidth and impedance matching by altering the current distribution. To increase radiation efficiency, the patch is raised
0.5 mm above the substrate. There is an efficient power transfer mechanism provided by the 4 mm × 1 mm microstrip feedline yet an 8 mm × 1.6 mm extension ensures stable connections. A precise delivery of antenna signal occurs through the small (1.5 mm x 0.5 mm) lumped port. The bottom layer contains the 4 mm × 10 mm Perfect Electric Conductor (PEC) ground plane extension. A reduced partial ground structure allows the antenna to minimize radiation behind it while improving front-back balance which ultimately results in compact operation. A simulation radiation box with dimensions 20 mm × 18 mm × 10 mm uses air as its content to achieve precise evaluation of far-field characteristics while eliminating boundary disturbances. The evaluation of performance relies on electromagnetic full-wave simulation which measures return loss together with radiation patterns and gain as well as antenna efficiency.

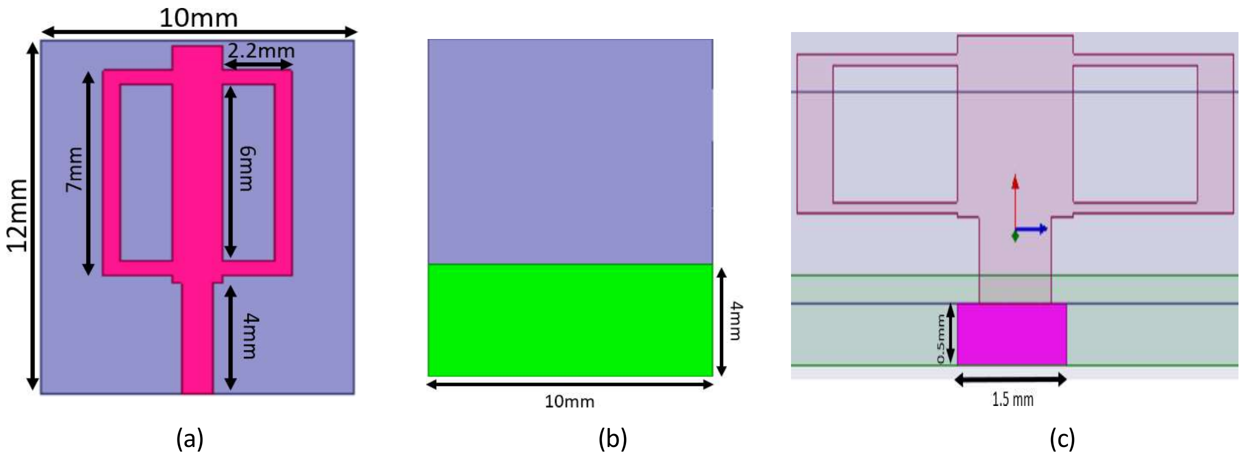

Figure 1. The proposed antenna design (a) radiating plane (b) ground plane (c) excitation port

4. Result and Analysis

4.1 S-parameter Plot:

A systematic evaluation of the antenna operational performance occurs through a performance metric assessment and simulation data validation. The simulated return loss (S11) of the rectangular patch antenna shows results in Figure 2 between 20 GHz to 50 GHz. Numerous resonances in the plot show that this antenna can work across diverse frequency bands. This antenna achieves its main operational frequency at
38.2 GHz where return loss reaches a high level of -24.13 dB which indicates optimized impedance operation. The antenna shows its potential for multi-band or wideband operation because secondary resonances occur at 23.2 GHz (-9.96 dB) and 26.8 GHz (-9.90 dB) and 33.2 GHz (-10.44 dB) and 44.9 GHz (-9.96 dB). The experimental findings demonstrate that the antenna works well as a component for mmWave technology which powers 5G and future wireless systems. This antenna presents promising capabilities for multi-band and broadband communication by resonating strongly at 38.2 GHz together with multiple other frequency points which support current high-frequency network requirements.

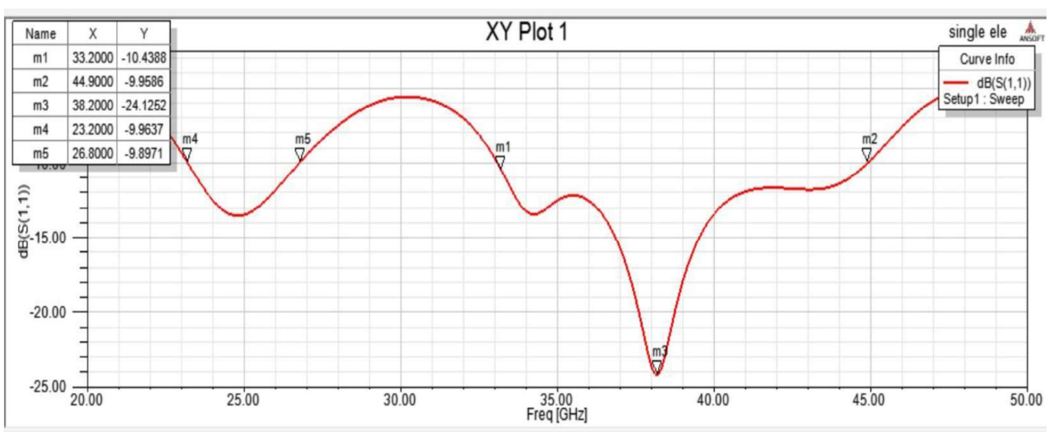

Figure 2. Simulated S-parameter plot of the proposed antenna

4.2 Gain:

The proposed rectangular patch antenna displays its total gain distribution across multiple spatial directions per Figure 3. The antenna reaches its design peak realized gain of 5.80 dB which shows optimal radiation happens at the desired frequency. The antenna generates almost omnidirectional radiation patterns that demonstrate significant gains between different radiated sections. Multiple lobes appear in the pattern because the antenna's physical aspects and the substrate properties affect its complicated radiation characteristics. The measured results confirm that the antenna functions well in millimeter-wave (mmWave) communications systems mainly because of its high gain capability combined with controlled radiation patterns for 5G and upcoming wireless transmission systems.

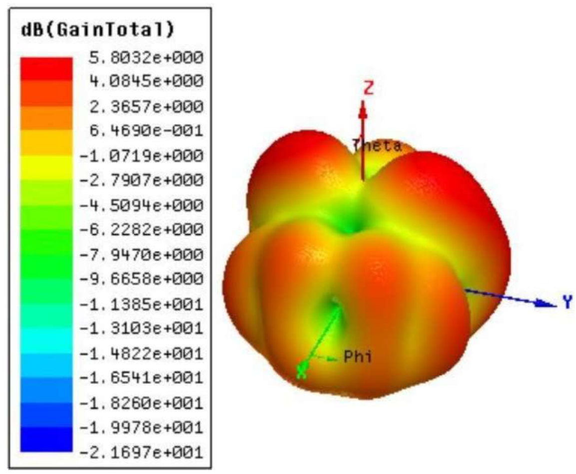

Figure 3. Gain plot of designed antenna

4.3 Radiation Pattern:

The Figure 4 presents the 2D radiation pattern of the antenna design at 38.2 GHz to show its total gain measurement in dB. The examination of the E-plane patterns operates at Phi = 0° and H-plane patterns operate at Phi = 90° to perform radiation analysis. The antenna gain measurement through the E-plane shows as red ink while H-plane gain measurement appears as purple ink when displayed on the graph. The antenna distributes radiation according to its unique pattern to achieve average directivity and reaches its maximum gain value at 7 dB yet forms side lobes and null regions during operation. The radiation pattern shows asymmetric behavior which emerges due to combined effects of substrate influences and edge diffraction processes. MMWave operating conditions can successfully use this antenna because its performance was validated through test results.

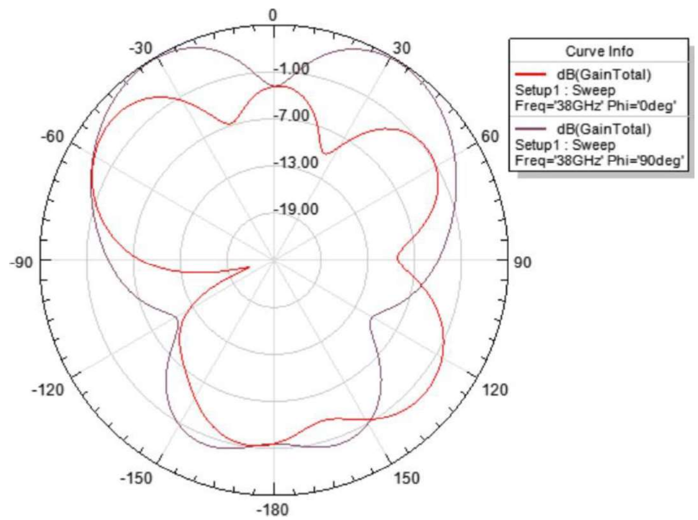

Figure 4*:* Radiation pattern of the proposed antenna at 38.2 GHz

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4.4 Current density:

The distribution of surface current density for the proposed rectangular patch antenna is studied because it affects radiation performance assessment. Figure 5 displays the Jsurf distribution at 38.2 GHz where current concentrations reach their peak values at 2.5579e+002 A/m while concentrated at the edges of the patch and feedline. These points are fundamental for electromagnetic radiation performance as they support impedance match operations. The current density diminishes systematically from the edges to the center of the patch area until it reaches a value of 1.1378e+000 A/m which indicates minimal radiation occurs at this location. The antenna maintains balance in its radiation characteristics because currents spread symmetrically across its patch edges which matches both simulation results from the far-field and enables operational efficiency.

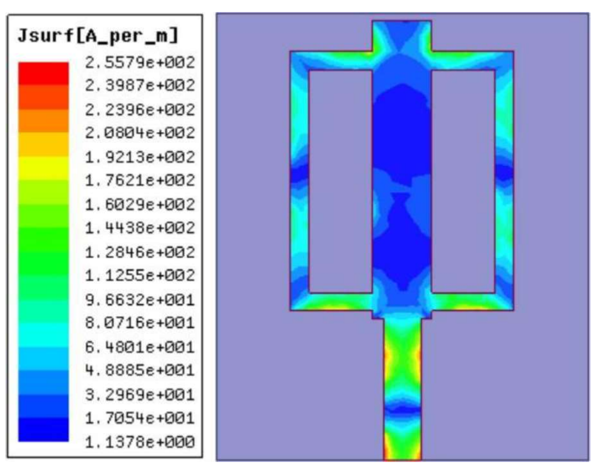

Figure 5. Current density of designed antenna at 38.2 Ghz

5. Conclusion

A research study demonstrates an optimized compact rectangular patch antenna design for 38 GHz mmWave operations. The antenna production uses Rogers RT/duroid 5880(tm) substrate to construct a rectangular patch antenna with a bandwidth enhancement cutout and microstrip feedline and partial ground plane design for improved radiation effectiveness. The simulated results display -24.13 dB of minimum return loss at 38.2 GHz and further resonances at 23.2 GHz, 26.8 GHz, 33.2 GHz, and 44.9 GHz thus indicating multi-band capabilities. The antenna reaches its peak realized gain of 5.80 dB while maintaining almost constant radiation patterns in all directions. The analysis of surface currents demonstrates efficient radiative behavior by concentrating the currents near the edges of the patch as well as at the feedline. The antenna provides an ideal solution for 5G mmWave applications because it maintains stable performance and offers high gain while requiring a small footprint. Further research will include experimental testing and integrating antenna arrays in their system design.

6. Reference

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