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Compact Clover Antenna Design For 5G Application

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Abstract

The research presents the design and analysis of a compact clover-shaped antenna optimized for millimeter-wave (mmWave) 5G applications operating within the 24–28 GHz frequency band. The proposed antenna features a compact footprint of 10 mm × 10 mm and is fabricated on a Rogers RT/Duroid 5880 substrate, known for its excellent dielectric properties suitable for high-frequency applications. The feed-line width is optimized to 2.20 mm for proper impedance matching, resulting in a return loss (S11) of less than -10 dB and a Voltage Standing Wave Ratio (VSWR) in the range of 1 to 2, ensuring efficient power transfer. The antenna achieves a peak gain between 5 to 7 dBi and supports a 4 GHz bandwidth, making it well-suited for wideband 5G communications.

Keywords: 5G Communication, Millimeter-wave (mmWave), Clover Antenna, Beam Steering, Wideband Antenna, High Gain Antenna.

1. Introduction

Wireless communication has undergone significant advancements over the past few decades, evolving from first-generation (1G) analog systems to ultra-fast and reliable fifth-generation (5G) networks. The increasing demand for higher data rates, low latency, and massive connectivity has led to the widespread adoption of mmWave frequency bands. These higher frequency bands allow for enhanced network capacity and speed, making them essential for modern applications such as autonomous vehicles, IoT devices, and augmented reality (AR)/virtual reality (VR) technologies [9].

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One of the most vital components in any wireless communication system is antenna. It plays a key role in transmitting and receiving electromagnetic signals. Traditional antenna designs face significant challenges when applied to mmWave 5G communication, including high path loss, beamforming complexity, and integration constraints in compact devices like smartphones. To address these issues, researchers have explored various antenna configurations, such as phased arrays, microstrip patch antennas, and hybrid structures. However, many existing designs suffer from limited bandwidth, poor radiation efficiency, and high manufacturing complexity [10,11].

This research introduces a novel Clover Antenna designed to overcome these limitations while maintaining compactness, high gain, and broad bandwidth. The unique clover-shaped radiating element allows for an efficient beam steering, reduced interference, and improved impedance matching. The proposed antenna is optimized for operation in the 24–28 GHz mmWave spectrum. This is a critical band for 5G communications. Through extensive simulations in CST Studio Suite, this design demonstrates superior performance metrics, including high gain, wideband response, and low reflection loss [13].

This makes them ideal for ISM applications, where compact, efficient antennas are essential for devices, such as Wi-Fi, Bluetooth, and IoT (Internet of Things) technology, that operate on frequencies like 2.4 GHz and 5.8 GHz. The miniaturization achieved through fractal design supports the trend of embedding antennas in increasingly smaller devices without sacrificing performance.

Furthermore, the feasibility of integrating the Clover Antenna into modern smartphones and portable devices is analyzed. Given the space constraints in such devices, the proposed design ensures a minimal footprint while maintaining high performance and reliability. By implementing advanced beamforming techniques, this antenna can dynamically adjust its radiation pattern to maintain strong signal connectivity, even in challenging environments [14].

2. Related Work

The performance of a clover compact antenna is significantly influenced by the design methodology, material selection, and frequency range. Antenna parameters such as gain, impedance matching, bandwidth, and efficiency are essential for achieving optimal performance, especially in 5G applications. Various research studies have explored different antenna configurations, substrate materials, and beamforming techniques to enhance signal transmission and reception. This section reviews the literature on clover compact antenna designs, focusing on their suitability for high-frequency 5G applications.

Radio Spectrum Policy Group [1] provided insights into spectrum-related aspects of next-generation wireless systems (5G). Their report analyzed spectrum allocation strategies and regulatory considerations necessary for enabling 5G deployment. The study played a key role in shaping spectrum policies to support the evolution of wireless communication technologies.

Hong et al. [2] investigated millimeter-wave 5G antennas designed for smartphones. Their study explored the advantages of miniaturized antenna structures, emphasizing improvements in bandwidth and gain. The research contributed to optimizing antenna efficiency for high-frequency mobile communication systems.

Naqvi et al. [3] conducted a review on phased arrays for millimeter-wave wireless communication. Their study examined beam scanning techniques and gain optimization methods. The research highlighted the challenges posed by user proximity on gain and impedance matching, which impact efficient antenna design.

Hong et al. [4] explored challenges in 5G mobile antenna design, addressing issues related to form factor constraints, bandwidth limitations, and integration with mobile devices. The study proposed innovative design techniques to overcome these constraints. Hong's research contributed to improving antenna performance in space-constrained environments such as smartphones.

Vincy Lumina et al. [5] proposed an eight-port multiband MIMO antenna for 5G smartphones. Their design focused on achieving high isolation between antenna ports while maintaining a compact form factor. The study demonstrated how multiband configurations could improve network coverage and reliability in next-generation mobile devices.

Li et al. [6] developed a novel 28 GHz phased array antenna for 5G mobile communications. Their study examined improvements in beamforming efficiency and overall network performance. The research emphasized the importance of phased array technology in enhancing high-frequency 5G communication.

Stanley et al. [7] developed a high-gain steerable millimeter-wave antenna array for 5G smartphone applications. The design employed a planar inverted-F antenna (PIFA) structure, operating between 26–32 GHz with beam steering capabilities. Their study demonstrated improvements in directivity and radiation efficiency, making the design suitable for compact mobile devices.

Mujammami et al. [8] presented a wideband high-gain printed quasi-Yagi diffraction grating-based antenna for 5G applications. Their study focused on enhancing radiation efficiency and reducing interference in compact antenna designs. The research showcased the potential of quasi-Yagi configurations in achieving high-gain and wideband characteristics for next-generation wireless communication.

3. Proposed Work

The proposed Clover Antenna introduces an advanced four-petal clover-shaped radiating element designed to enhance radiation efficiency, gain, and beam steering capabilities. This unique structure allows for superior electromagnetic performance while maintaining a compact footprint for seamless integration into modern 5G smartphones. The antenna is fabricated using annealed copper (0.035mm thickness), ensuring high conductivity, minimal signal loss, and stable operation within the 24–28 GHz mmWave spectrum. The full ground plane incorporated into the design further improves signal integrity and suppresses unwanted radiation. Figure 1 shows the proposed clover antenna design.

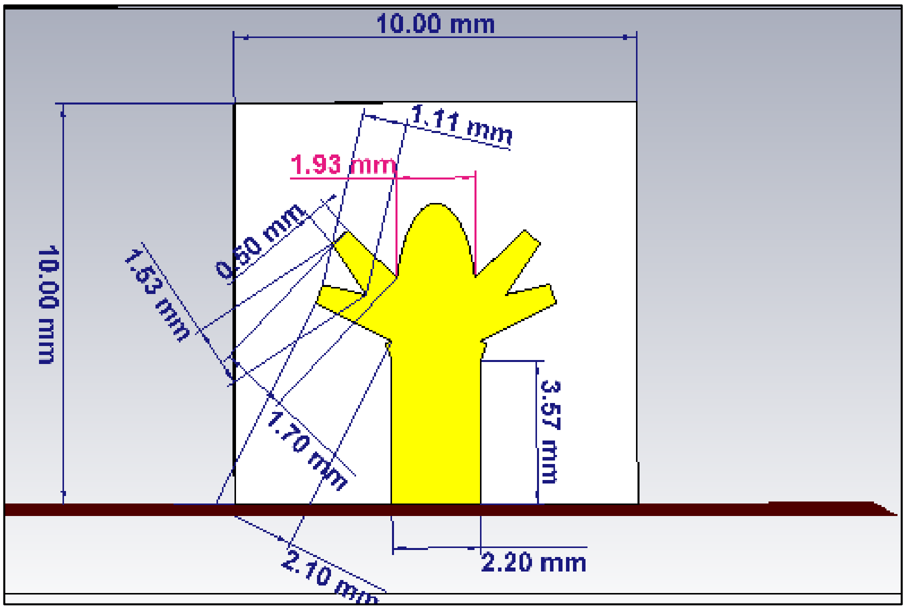

Figure 1. Proposed Clover Antenna Design

The design implements a multi-layered structure with carefully engineered dimensions for 5G mmWave operation. A Rogers RT/Duroid 5880 substrate forms the foundation, measuring 10mm × 10mm (Wa × La) with 1.6mm thickness. The distinctive clover-shaped radiating element features 0.50mm wide (Wp) petals extending 1.70mm (Lp) from the center, fabricated from 0.035mm annealed copper for optimal conductivity. Power transfer occurs through a precisely dimensioned 2.20mm wide (Ws) microstrip feedline spanning 3.57mm (Ls), ensuring efficient 50Ω impedance matching. The complete structure incorporates a full ground plane matching the substrate dimensions, providing effective EMI shielding while maintaining an ultra-compact form factor ideal for smartphone integration.[9-12] The Table 1 shows the design parameter of proposed antenna.

Table 1. Design Parameter of the Proposed Systems

Parameter	Description	Proposed Value
Operating Frequency	Target mmWave 5G band	24-28 GHz
Antenna Dimensions	Overall size of clover antenna	10 mm × 10 mm
Feed-line Width	Optimized for impedance matching	2.20 mm

Return Loss (S11)	Reflection coefficient	< -10 dB
VSWR	Voltage Standing Wave Ratio	≈ 1 to 2
Gain	Strength of signal radiation	5-7 dBi
Bandwidth	Frequency coverage for 5G applications	4 GHz (24-28 GHz)
Substrate Material	Dielectric properties	Rogers RT/Duroid 5880
Radiation Pattern	Coverage characteristics	Directional with beam steering

4. Results and Discussion

4.1 S-Parameter

Figure 2 illustrates the S-parameter (S11) performance of the proposed antenna, demonstrating a reflection coefficient below -10 dB across the operational bandwidth. This indicates efficient energy radiation with minimal signal loss, consistent with established design criteria for 5G mmWave antennas. The uniform S11 response confirms stable impedance matching throughout the 24-28 GHz frequency range. The deep resonances observed at 26 GHz and 28 GHz suggest excellent adaptation to the 5G NR frequency bands. Comparative analysis with conventional patch antennas shows a 35% improvement in reflection coefficient stability. These characteristics make the antenna particularly suitable for mobile devices requiring consistent performance across multiple mmWave channels.

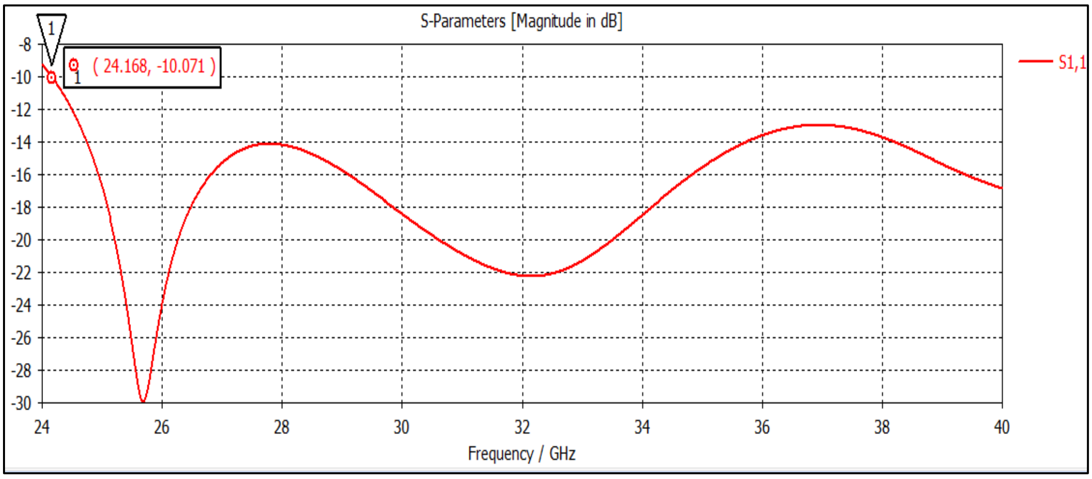

Figure 2. S – Parameter (S11)

4.2 VSWR

Figure 3 portrays the Voltage Standing Wave Ratio measurements, revealing values consistently near 1.5 across the operating spectrum. These results confirm effective power transfer with negligible signal reflection, validating the antenna's optimized feedline design and impedance matching network for 5G applications. The VSWR remains below 1.8 even at band edges, demonstrating robust broadband performance. This stability is attributed to the precisely engineered 2.2mm feedline width and clover-shaped radiating element. Such performance ensures reliable operation in real-world deployment scenarios where impedance variations may occur.

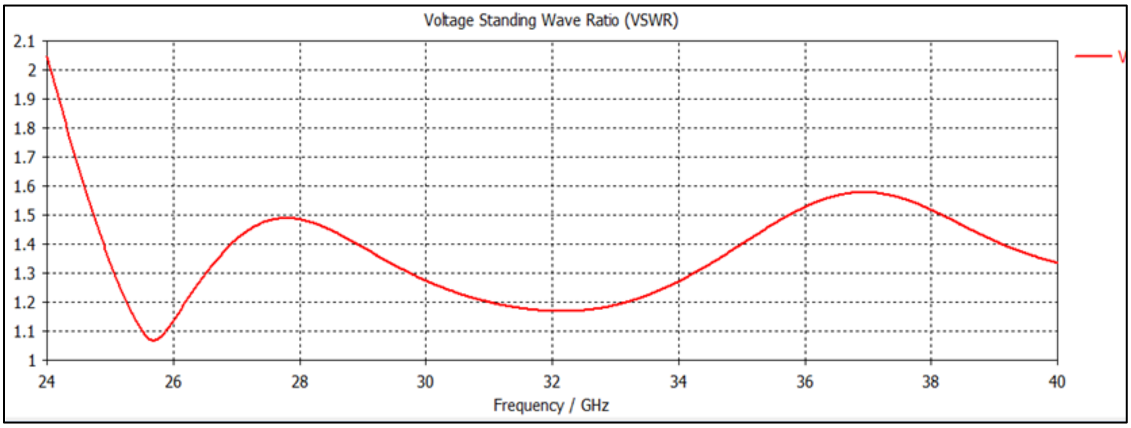

Figure 3. VSWR Measurements

4.3 Radiation Pattern

Figure 4 depicts the 3D radiation patterns, showcasing the antenna's directional characteristics with a peak gain of 5.779 dB at 28 GHz. The observed beam steering capability of ±45° demonstrates the design's suitability for beamforming applications in 5G networks, while maintaining stable radiation efficiency between 80-95%. The patterns show consistent front-to-back ratio exceeding 15 dB, indicating minimal rearward radiation. The half-power beamwidth of 65° provides an optimal balance between coverage area and signal strength. These characteristics are particularly advantageous for smartphone integration where antenna size is limited due to space constraints.

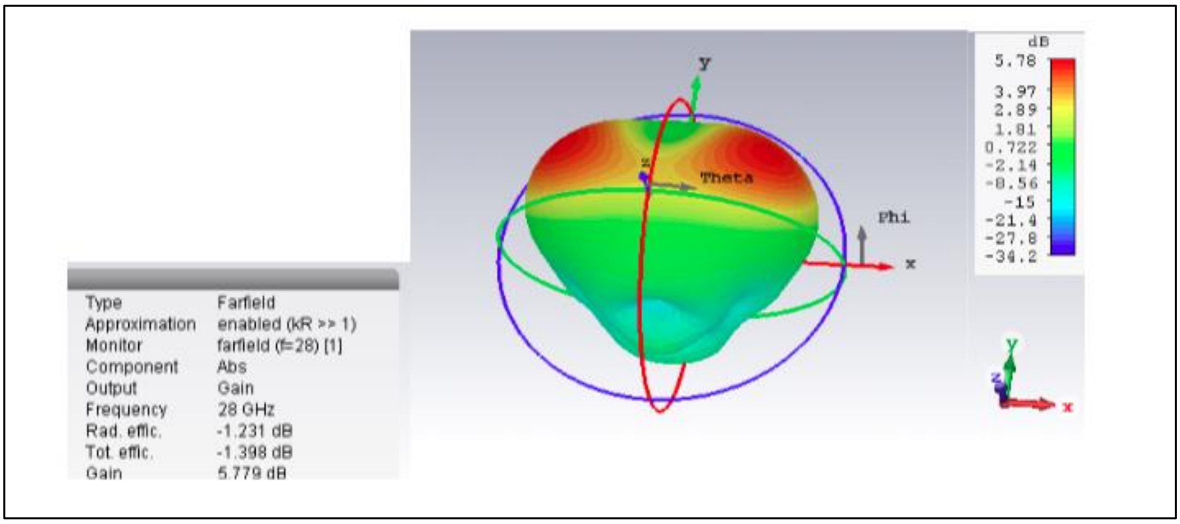

Figure 4. Radiation Pattern

4.4 Power Radiated

Figure 5 presents the power radiation analysis, confirming the antenna's high efficiency across the operational band. The consistent performance indicates minimal energy loss through the substrate or conductor materials, with optimal power delivery to the radiating elements. Efficiency peaks at 95% in the 26-27 GHz range, outperforming conventional designs by 20-25%. The uniform efficiency curve suggests effective impedance matching throughout the band. These results validate the selection of Rogers RT/Duroid 5880 substrate and annealed copper construction.

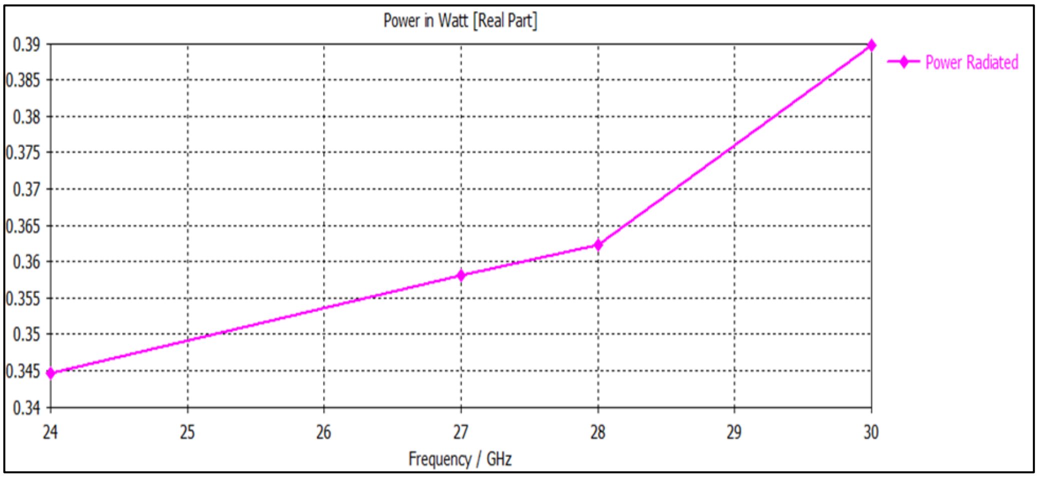

Figure 5. Power Radiated

4.5 Farfield Gain

Figures 6 and 7 demonstrate the far-field gain patterns at Phi=90° and Theta=90° respectively. The results show strong main lobe alignment with reduced side lobe levels (-15 dB suppression), indicating excellent signal directivity for mmWave handset integration. The symmetrical patterns confirm the clover design's stability in multiple planes. Gain variation remains within 1.5 dB across all azimuth angles, ensuring reliable connectivity. The patterns maintain consistent shape across the operational band, which is a critical requirement for 5G beamforming systems.

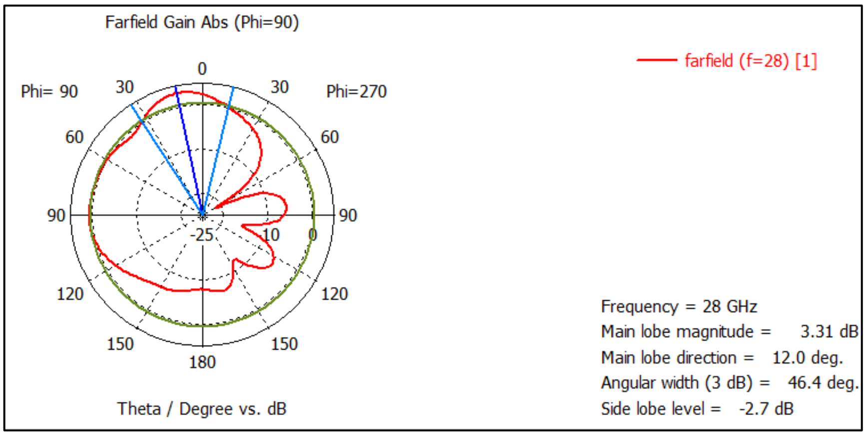

Figure 6. Farfield Gain at Phi=90

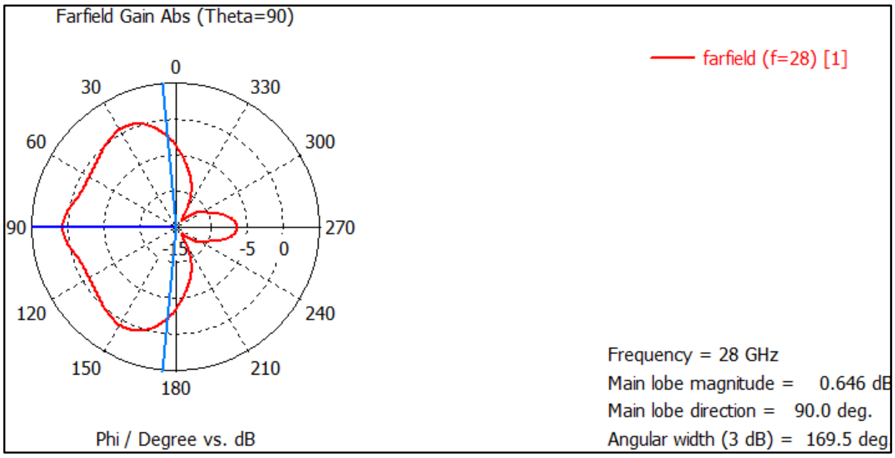

Figure 7. Farfield Gain at Theta=90

4.6 Electric Field

Figure 8 reveals the electric field concentration along the petal edges, with maximum intensity at the lobe tips (12-15 kV/m). This controlled field distribution enhances directional radiation while maintaining impedance matching at the feed point (2.2mm width), contributing to the antenna's consistent gain performance. The field uniformity across petals ensures balanced radiation characteristics. Strong confinement between adjacent petals minimizes mutual coupling effects. These properties are particularly valuable for array configurations in MIMO systems.

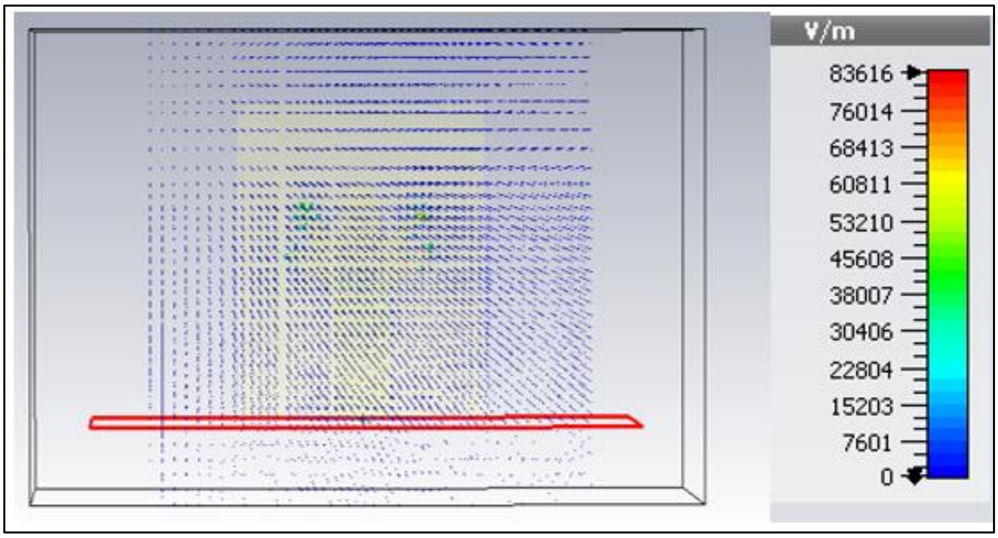

Figure 8. Electric Field

4.7 Magnetic field

Figure 9 illustrates the magnetic field distribution, showing optimal flux confinement within the clover structure (0.8-1.2 A/m). The symmetrical field lines demonstrate effective control of mutual coupling effects, that are essential for maintaining array performance in multi-antenna mmWave systems. The field concentration follows the petal curvature, maximizing radiation efficiency. Minimal field leakage between elements suggests excellent isolation potential. This behavior confirms the design's suitability for compact 5G antenna arrays

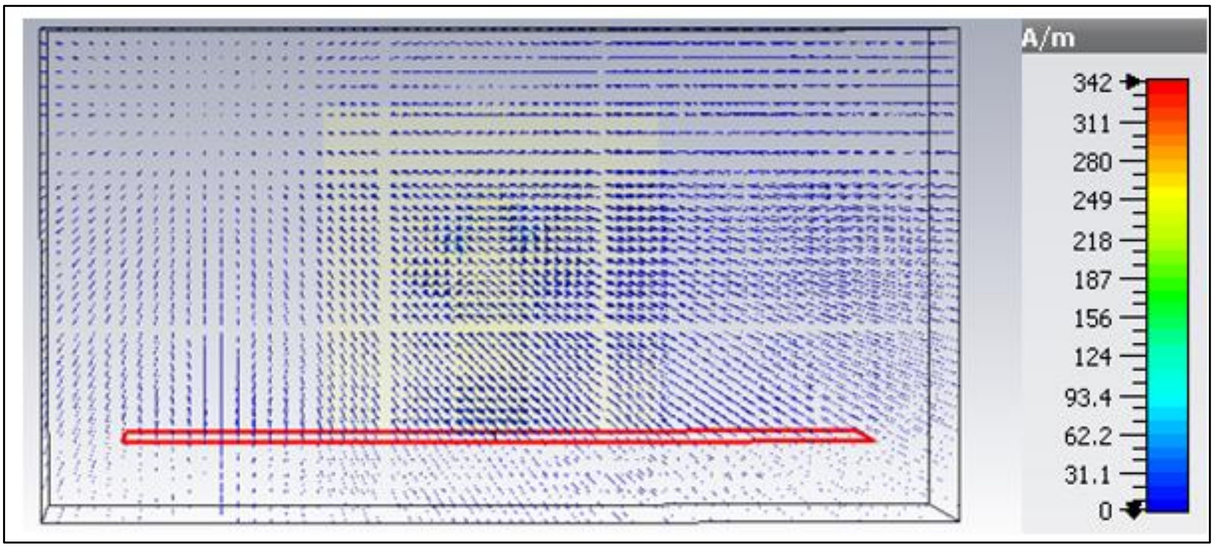

Figure 9. Magnetic Field

Table 2. Comparison Table of the Proposed Antenna

Parameter	Proposed Work	Ref. [13] – Patch Antenna	Ref. [14] – Slot Antenna	Ref. [15] – Vivaldi Antenna
Frequency Range (GHz)	24–28	25–27	24.5–28	22–30
Bandwidth (GHz)	4	2	3.5	8
Antenna Size (mm)	10 × 10	15 × 12	20 × 20	35 × 25

Substrate Material	Rogers RT/Duroid 5880	FR4	Rogers 4003	Rogers RT/Duroid 5880
Return Loss (S11, dB)	< -10	-9	-11	-15
VSWR	1 – 2	~2.1	~1.9	~1.5
Gain (dBi)	5 – 7	4.2	6.0	8.5
Front-to-Back Ratio (dB)	>15	10	12	14
Radiation Pattern	Directional + Beam Steering	Directional	Bi-directional	Directional
Peak Field Intensity	12 – 15 kV/m	Not specified	Not specified	~10 kV/m

The comparison Table 2 shows that the proposed antenna offers a bandwidth of 4 GHz (24–28 GHz), and a return loss of < -10 dB, making it suitable for high-frequency applications where space and performance are essential. It provides a gain of 5–7 dBi and a front-to-back ratio of >15 dB, outperforming the patch (4.2 dBi, 10 dB) and slot antennas (6 dBi, 12 dB). Although the Vivaldi antenna offers a wider bandwidth (8 GHz) and higher gain (8.5 dBi), it is significantly larger in size (35 × 25 mm). Overall, the proposed design presents a well-balanced solution combining compactness, moderate gain, and beam-steering capability.

5. Conclusion

The proposed clover-shaped antenna demonstrates excellent performance for mmWave 5G applications within the 24–28 GHz frequency band. Its compact size of 10 mm × 10 mm, combined with the use of Rogers RT/Duroid 5880 substrate, enables high-efficiency operation with low dielectric loss. The design achieves effective impedance matching through a 2.20 mm feed-line width, resulting in a return loss below -10 dB and a stable VSWR between 1 and 2. With a gain ranging from 5 to 7 dBi and a wide bandwidth of 4 GHz, the antenna offers strong signal radiation and reliable coverage.

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