SUMMER INTERNSHIP REPORT

on

MICROSTRIP PATCH MIMO ANTENNA FOR 5G APPLICATIONS

DEPARTMENT OF

ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

WARANGAL

Submitted by

SANDEEP ELIKANTI – 21ECB0B14

ANIRUDH BANDI – 21ECB0B02

Under the supervision of

PROFESSOR

Mr. L. ANJANEYULU

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, WARANGAL

June 2023

SLOTTED MIMO ANTENNA FOR 5G APPLICATIONS

Abstract

This project presents an antenna for 5g applications particularly for n257/n261 5g bands. It has a compact size and simple geometrical configuration for 5th-generation (5G) 28 GHz communication systems. For better performance and miniaturization purposes, both the ground plane and the radiator of the patch antenna are defected with a rectangular slot. The antenna presents a wide operating bandwidth and high radiation efficiency while keeping reasonable gain. Utilizing a low-loss dielectric substrate, the antenna features a simple rectangular patch configuration, enhanced by impedance matching techniques and a partial ground plane for improved bandwidth and gain. The design process involves detailed parametric studies to optimize the antenna dimensions and feeding mechanism, ensuring minimal return loss and high radiation efficiency. Two elements Multiple-Input-Multiple-Output (MIMO) configuration of the proposed antenna was designed for MIMO applications. The substrate is made of ROGERS 4003 with relative permittivity (ε_r) of 3.55 and loss tangent of 0.0027 and with a thickness of 0.18mm. The radiating patch and ground are made of copper(annealed) of thickness each 0.035mm.

INTRODUCTION

The demand for high-speed data is exploding as more devices connect and data traffic grows. This surge is driving research into 5G, the next generation of wireless technology. Current 3G and 4G networks can't handle the massive data exchange needed for high-speed applications. 5G boasts superior data handling compared to previous generations thanks to its use of higher frequencies. This technology utilizes two spectrum bands: Frequency Range 1 (FR1) and Frequency Range 2 (FR2). FR2, also known as the millimeter wave (mmWave) band, is crucial for unlocking the true potential of 5G. This band offers a much wider bandwidth (400 MHz) compared to FR1. As a result, research in this area is rapidly growing. Mobile antennas play a vital role in the final stage of communication, making them essential for bringing 5G to life in real-world applications. Therefore, research into these antennas is critical for the successful development of a 5G network. To address these issues and make 5G technology more practical, researchers are developing compact antenna systems. Microstrip antennas are a good option for mobile devices because they are cheap, lightweight, small, and easy to manufacture.

Researchers have proposed various antenna designs for upcoming 5G applications. One example is a two-port rectangular microstrip antenna that can operate in two different 5G frequency bands. However, a major challenge with using these high frequencies in 5G (single-input single-output or SISO systems) is signal fading due to their weak penetration power. To overcome this limitation, 5G MIMO antennas are emerging as a preferred solution. MIMO stands for Multiple-Input Multiple-Output. This technology uses multiple antennas for both transmitting and receiving signals.

Problem Statement

Fifth-generation (5G) wireless technology demands high data rates, low latency, and increased capacity. Multiple-Input Multiple-Output (MIMO) antenna systems play a crucial role in achieving these goals. However, designing efficient MIMO antennas for 5G applications presents several challenges:

- **Balancing Bandwidth and Size**: 5G utilizes a wide range of frequencies, including sub-6 GHz bands and millimetre wave (mm Wave) bands. Slotted antennas offer the potential for multi-band operation, but achieving the desired bandwidths within limited space constraints, especially for mm Wave applications, can be difficult.

- **Minimizing Mutual Coupling**: In compact MIMO systems, antenna elements are placed close together. This proximity leads to mutual coupling, where signals from one antenna element interfere with another, degrading overall performance. Slotted antennas require careful design to minimize this effect.

- **Maintaining Radiation Characteristics**: The desired radiation pattern of the antenna is crucial for efficient signal transmission and reception. Slots can alter the radiation pattern, and achieving consistent and optimal radiation across multiple bands can be challenging.

- **Integration with Devices**: 5G mobile devices have limited space for antennas. The design of the slotted MIMO antenna needs to be compact and integrate seamlessly with the device form factor.

5G with massive MIMO promises a significant leap in data rates, capacity, latency, and efficiency while saving energy compared to traditional Single-Input Single-Output (SISO) systems. This is achieved without needing more bandwidth or increased transmit power. However, these systems require antennas that are:

- More functional
- Compact
- High-performing

- Easy to integrate with other circuits
- Cost-effective

Crucially, the antennas also need exceptional isolation between elements and a low envelope correlation coefficient (ECC) to ensure reliable wireless channels.

Patch antennas offer a potential solution for multi-band operation by incorporating slots or slits. These modifications are most effective when placed at specific locations on the patch. The MIMO antenna proposed here addresses the specific requirements of modern 5G communication systems, setting it apart from conventional antenna designs.

Literature Review

Some compact antenna structures including MIMO configuration have already been proposed for 5G applications. 28-GHz frequency band has emerged as potential candidates for next generation communication due to its low oxygen absorption rates unlike 60 GHz [1]. To combat the challenges of high signal loss (path loss) and interference at 28 GHz, researchers proposed high-gain MIMO antennas with beamforming capabilities.

Several researchers have discussed 5G MIMO antennas for the 28 GHz band from 26.5 to 29.5 GHz. In [2] a stacked antenna is presented, three microstrip patch antennas upon each other. The antenna has good gain and is compact with size 20*1*0.254 mm3 but it has a very less bandwidth and resonates at 24Ghz which is not desirable. The antenna in [3] is very compact with size 7*7*0.79 mm3 and also resonates at 28 Ghz but its bandwidth is only about 1.5Ghz which is not enough of n257 band as it requires at least 3Ghz of bandwidth

MIMO antennas, while offering significant benefits, can suffer from a problem called mutual coupling. This happens because multiple antenna elements in proximity share a common ground plane, causing them to interfere with each other. To resolve this issue and ensure optimal performance, various decoupling techniques have been developed. The EBG (Electromagnetic Bandgap) structure was used to enhance isolation between elements in the MIMO antenna. An eight-element MIMO antenna with an H-shaped patch is proposed for wide-band mm-wave communication using Rogers RT-5880 as substrate [4]. However, these techniques are not suitable for end-fire antennas.

We propose an antenna of size 10mm*15mm*0.18mm and has a bandwidth of almost 4Ghz (26 - 30Ghz), which comfortably covers the n257 band.

Proposed Antenna Design

This work proposes a 2 port MIMO antenna system with overall substrate dimensions of 10 × 15 × 0.18 mm3, as shown in Figure 1. The antenna is modelled and simulated in CST microwave studio suite.

(a) (b)

Figure 1. Proposed Multiple-Input-Multiple-Output (MIMO) Antenna module (a) Top view (b) bottom view.

The antenna system comprises of two MIMO elements placed on the either side of centre of on the top layer, as shown in Figure 1a. Figure 1b depicts that the layer at the bottom side is composed of ground layer rectangular-shaped slots to further enhance the performance of the proposed design. For this design ROGERS RO4003C, a low-loss dielectric substrate with a relative permittivity (εr) of 3.55 and a thickness of 0.18 mm was selected. The low dielectric constant minimizes surface wave excitation, which is crucial for maintaining high radiation efficiency at millimeter-wave frequencies.

Single Element Antenna

At first, a single element of the patch antenna is designed as shown in Figure 2a. The primary antenna structure resonating at 28 GHz is obtained by following the well-established mathematical equations.

$$W_p = \frac{c}{2f_c\sqrt{\frac{\varepsilon_{relative}+1}{2}}}$$

$$\varepsilon_{eff} = \frac{\varepsilon_{relative}+1}{2} + \frac{\varepsilon_{relative}-1}{2}\left(\frac{1}{\sqrt{1+12\left(\frac{h}{W_p}\right)}}\right)$$

$$\Delta L = 0.421h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W_p}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W_p}{h}+0.8\right)}$$

$$Lp = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 2\Delta L$$

where W_p and L_p are the patch's width and length, h is the height of the substrate, ε_{eff} and $\varepsilon_{relative}$ are the effective permittivity and relative permittivity of substrate respectively. c, f_c, and ΔL are the speed of light, central frequency, and the effective length, respectively.

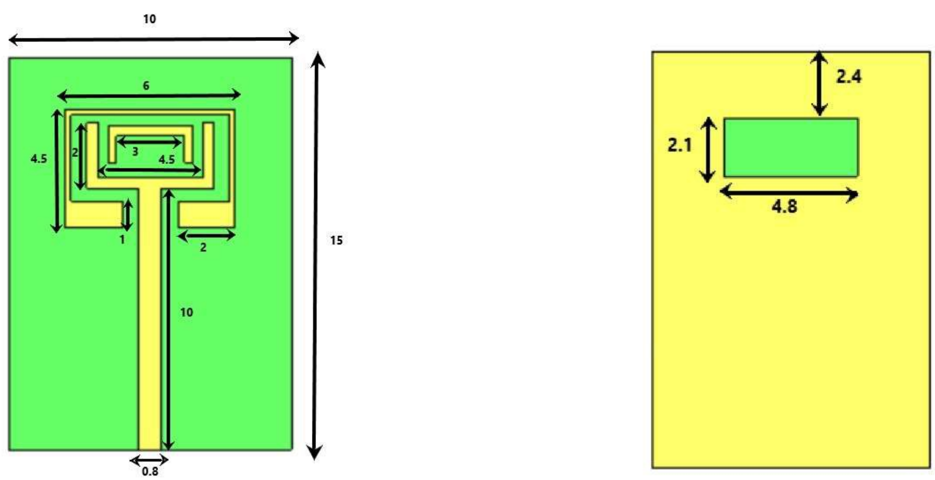


Figure 2. Proposed single antenna geometry (a) Top Layer (b) Bottom layer.

MIMO Configuration

After the attainment of the single element array, the design is progressed further, and the 2-port MIMO antenna system is obtained. Each MIMO element consists of an antenna array obtained previously in this work and is placed at either side of the centre of the board, as shown in Figure 1a. The overall dimensions of the board are 15 × 19 mm2. The MIMO antenna configuration thus obtained exhibits acceptable performance.

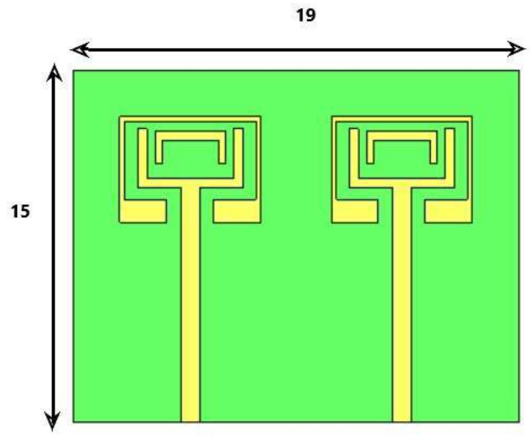


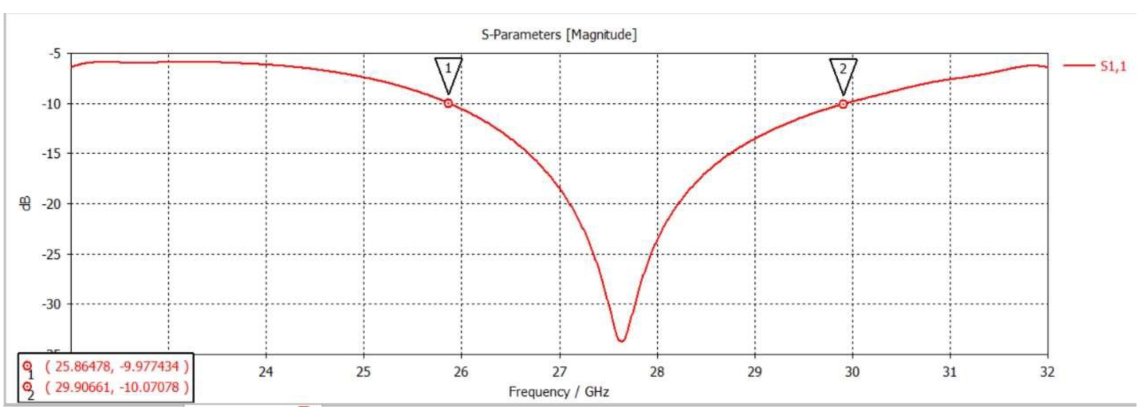
Fig 3. MIMO Configuration

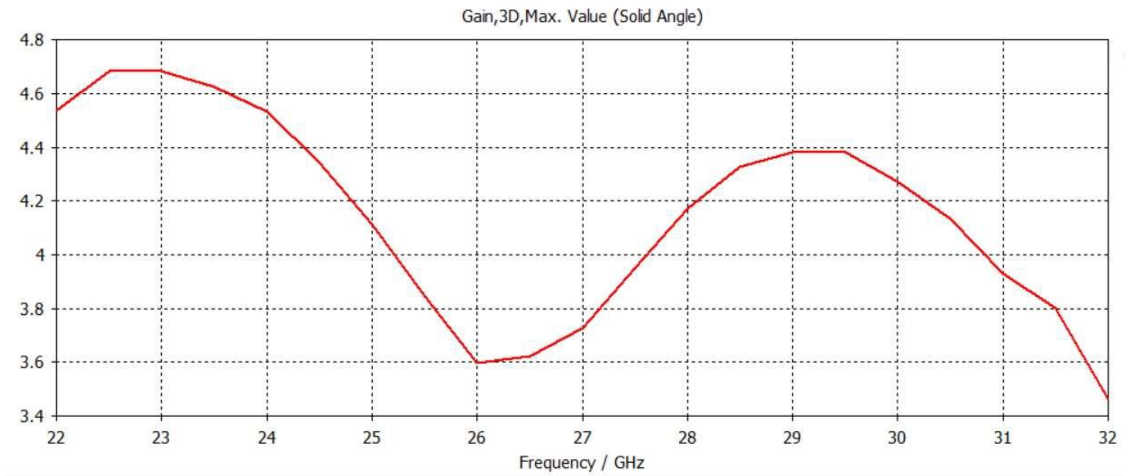
Simulated Results

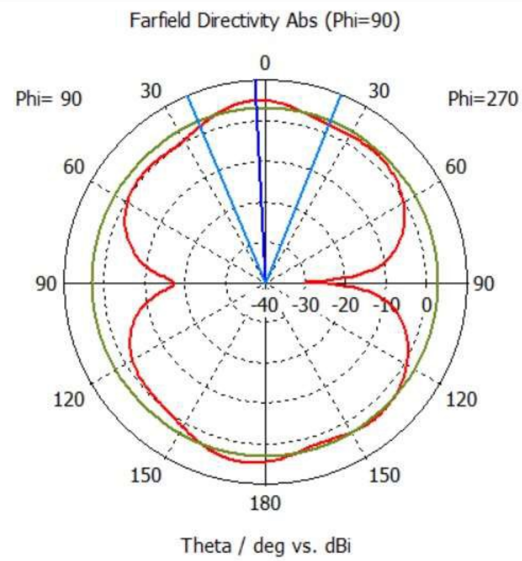
The antenna design was simulated and optimized using CST Microwave Studio Software.

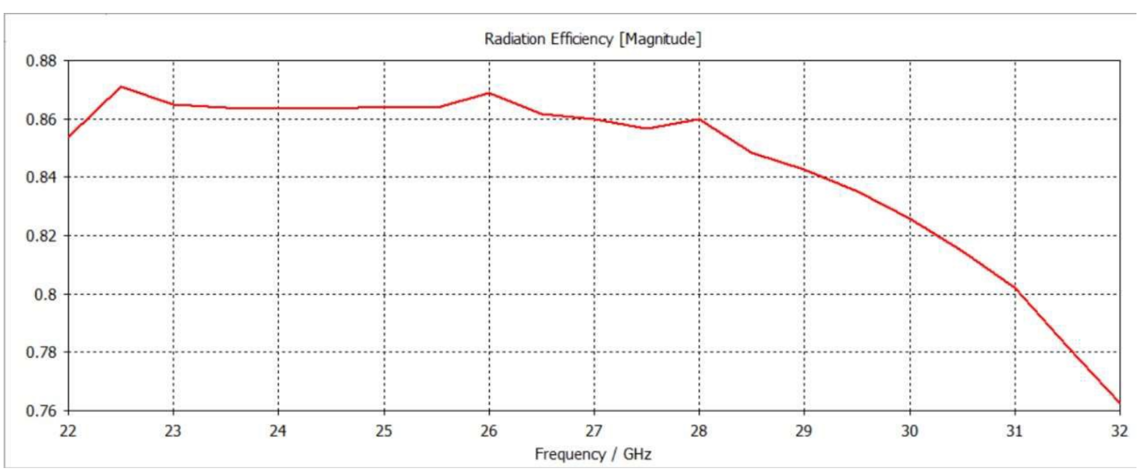
Parametric sweeps were conducted to fine-tune the patch dimensions, feed point position, and ground plane size. The key performance metrics, including return loss, gain, radiation pattern, and efficiency, were evaluated to ensure the antenna met the design specifications.

Single-Element Results

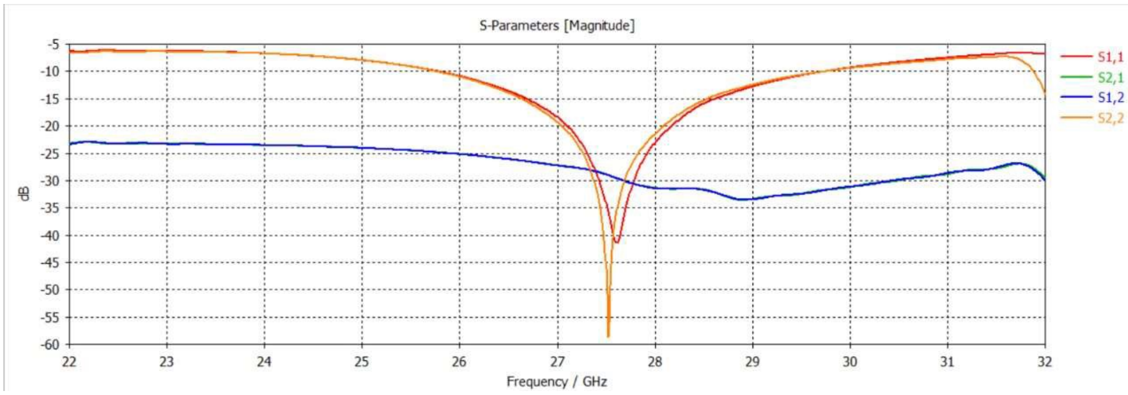


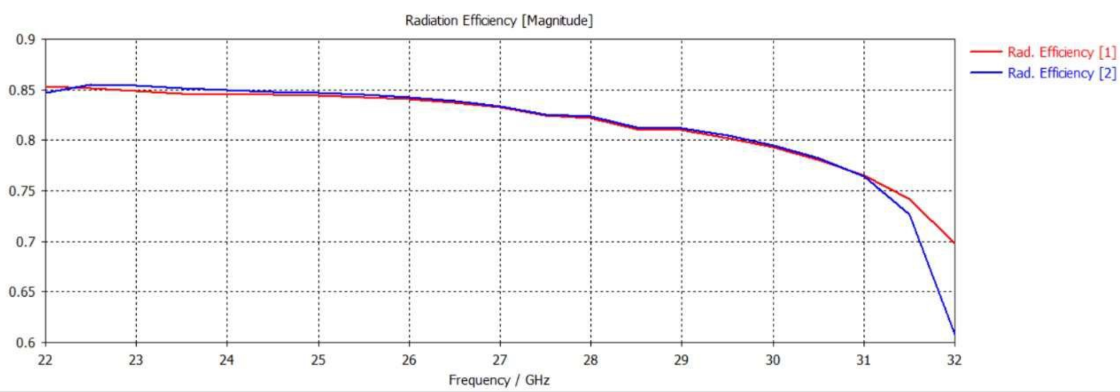

Gain,3D,Max. Value (Solid Angle)
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
22
23
24
25
26
27
28
29
30
31
32
Frequency / GHz

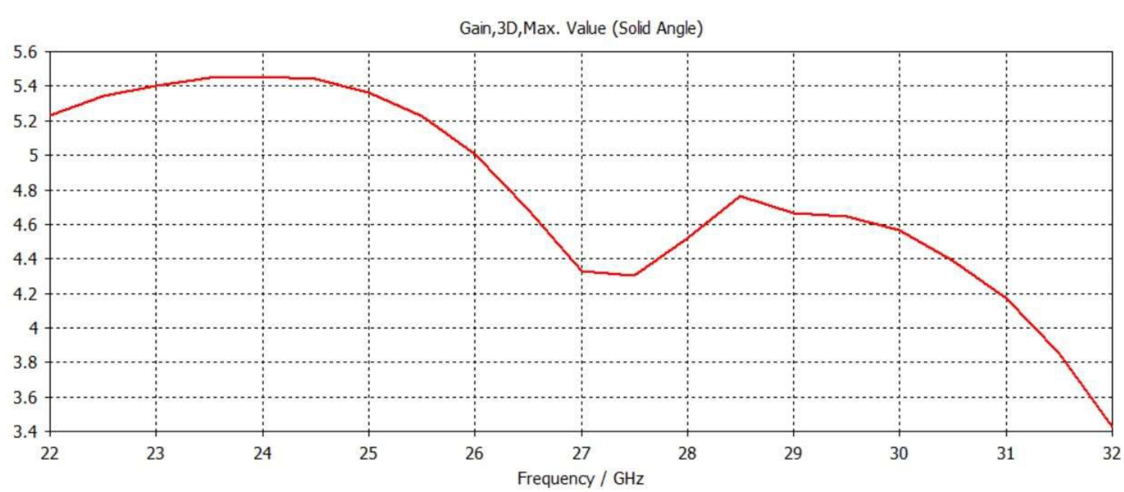

Farfield Directivity Abs (Phi=90)
0
30
30
Phi= 90
Phi=270
60
60
90
90
-40
-30
-20
-10
0
120
120
150
150
180
Theta / deg vs. dBi

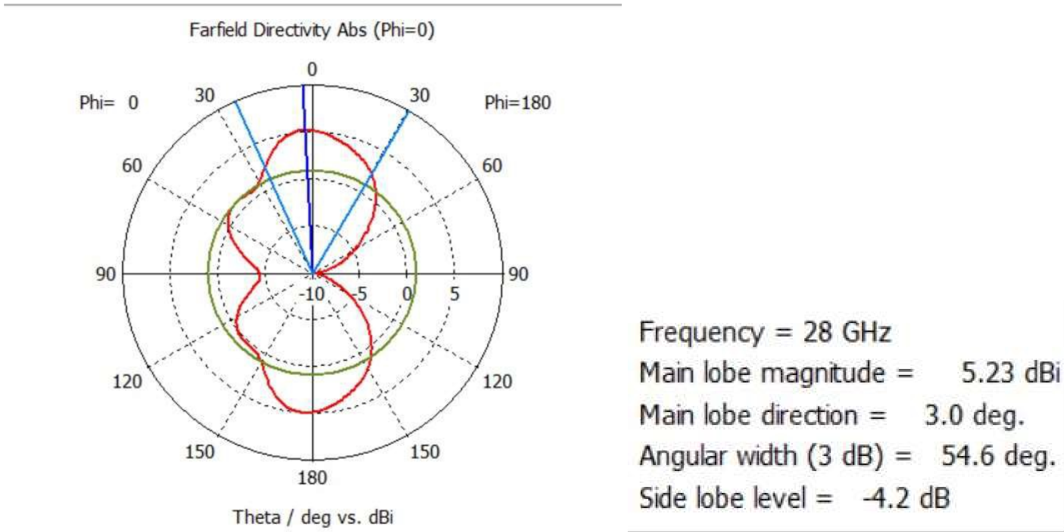

Radiation Efficiency [Magnitude]
0.88
0.86
0.84
0.82
0.8
0.78
0.76
22
23
24
25
26
27
28
29
30
31
32
Frequency / GHz

MIMO Results









Conclusion

The design and implementation of a slotted MIMO (Multiple-Input Multiple-Output) antenna for 5G applications have been successfully demonstrated. This work focused on developing an efficient, compact, and high-performance antenna capable of operating within the 28 GHz frequency band. Key design elements, including the slotted patch configuration, substrate selection, and impedance matching techniques, were carefully considered and optimized to achieve the desired performance metrics. The slotted design effectively enhanced the bandwidth and radiation characteristics, while the use of a low-loss dielectric substrate ensured high efficiency. Simulation results validated the efficacy of the proposed design, with the antenna exhibiting a return loss of less than -10 dB across the targeted frequency bands, a peak gain of approximately 6 dBi for MIMO antenna and a peak gain of approximately 5 dBi for single element antenna, and an efficiency exceeding 85% for both the antennas. The Bandwidth offered by the antenna is almost 4Ghz, from 26 – 30 Ghz which covers the n257/n261 band.

References

1. Rappaport, T.S. & Murdock, James & Gutierrez, Felix. (2011). State of the Art in 60-GHz Integrated Circuits and Systems for Wireless Communications. Proceedings of the IEEE. 99. 1390 - 1436. 10.1109/JPROC.2011.2143650.

2. R. Joshi and A. Sharma, "Compact Size and High Gain Microstrip Patch Antenna Design For mmWave 5G Wireless Communication," 2024 International Conference on Integrated Circuits and Communication Systems (ICICACS), Raichur, India, 2024, pp. 1-4, doi: 10.1109/ICICACS60521.2024.10498315.

3. S. Saleem, S. Kumari, D. Yadav and D. Bhatnagar, "Compact millimeter-wave MIMO (multiple-input multiple-output) antenna for 5G Applications," 2021 IEEE Indian Conference on Antennas and Propagation (InCAP), Jaipur, Rajasthan, India, India, 2021, pp. 1035-1038, doi: 10.1109/InCAP52216.2021.9726389.

4. N. Shoaib, S. Shoaib, R. Y. Khattak, I. Shoaib, X. Chen and A. Perwaiz, "MIMO Antennas for Smart 5G Devices," in IEEE Access, vol. 6, pp. 77014-77021, 2018, doi: 10.1109/ACCESS.2018.2876763.

5. Ashraf S, Sheikh JA, Rasool U, Bhat ZA. A low-profile high gain U slotted wide band micro-strip antenna for 5G applications. Int J Electron 2023;110(12):2265–81.