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Design and implementation of a 1×4 microstrip antenna for 5G applications

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***Abstract*—The rapid development of wireless communication has led to increasing demands for high-speed, low-latency, and high-capacity networks. One of the main challenges in implementing 5G technology is designing antennas that can operate efficiently at higher frequencies while maintaining a wide bandwidth and stable performance. Conventional microstrip antennas often face limitations in bandwidth and gain, making them less ideal for meeting 5G performance requirements. To address this issue, a 1×4 microstrip antenna array was designed and realized using a combination of the Proximity Coupled feeding technique and Defected Ground Structure (DGS) with a U-Slot configuration. The antenna was designed to operate at a center frequency of 2.6 GHz, targeting the 5G mid-band. The design process involved electromagnetic simulation using CST Studio Suite, followed by fabrication and measurement using a microwave analyzer to evaluate real-world performance. Measurement results show that the antenna achieves a bandwidth of 170 MHz, a gain of 7.5 dBi, and a return loss of -25.76 dB, with a directional radiation pattern suitable for 5G. Compared to five related studies, this antenna demonstrates superior performance by combining two optimization techniques and achieving balanced results in both simulation and physical realization. The proposed design outperforms previous works in terms of gain, bandwidth, and impedance matching, making it a strong candidate for further development as a high-performance antenna for 5G communication networks.**

***Keywords*—Bandwidth; Defected Ground Structure; Gain; Microstrip antenna; Proximity coupled; 5G**

I. INTRODUCTION

THE rapid development of wireless communication technology continues in line with the increasing demand for faster and more reliable data services. One of the latest innovations in communication technology is the fifth-generation (5G) network, which promises low latency, high data transfer speeds, and greater capacity compared to previous generations. [1], [2], [3]. To support 5G applications, hardware capable of meeting the appropriate specifications is required. In wireless communication systems, the antenna plays an important role as one of the main components [4], [5], [6].

Microstrip antennas are a popular choice for 5G applications due to their advantages in minimal size, low production cost, and high integration capability with other devices. However, the design and manufacture of microstrip antennas for 5G applications require special attention to one parameter factor, namely bandwidth, so that the resulting latency is low [7], [8], [9].

In references [10], [11] [12], [13], [14], [15] a rectangular patch microstrip antenna was designed with an operating frequency of 2.6 GHz. The design was carried out using Ansoft HFSS software with simulation material using an FR4-Epoxy substrate. The performance of the 1x4 linear array antenna operating at 2.6 GHz is significantly enhanced by the integration of proximity coupled feeding and U-slot Defected Ground Structure (DGS). Proximity coupling improves impedance bandwidth by minimizing spurious radiation and decoupling the feed network from the patch, while the U-slot DGS effectively manipulates return current paths on the ground plane to induce additional resonances and reduce mutual coupling between array elements. Together, these techniques enable the array to achieve a wide impedance bandwidth exceeding 100 MHz and a return loss of ≤ -10 dB, consistently meeting IMT-2020 standards for 5G mid-band applications. This design configuration successfully optimizes gain and radiation efficiency, providing a compact, high-performance solution for sub-6 GHz 5G wireless systems.

The application of Defected Ground Structure (DGS) in the research of [16], [17], [18], [19], [20], [21], [22] is another supporting technique to widen the bandwidth of a microstrip antenna. the application of Defected Ground Structure (DGS) is proven to be a highly effective, low-profile technique for enhancing microstrip antenna performance by strategically modifying current distribution on the ground plane through specific geometric patterns. Integrating DGS induces additional resonances that significantly widen the antenna's bandwidth and optimize impedance matching, thereby ensuring that return loss is effectively suppressed across a broader frequency range. The primary advantage of this method lies in its ability to achieve superior performance for 5G communications without increasing the complexity of the feeding structure, making it an efficient design solution for compact wireless devices.

In both studies, [23], [24] demonstrates that proximity-coupled feeding acts as a crucial technique for overcoming the inherently narrow bandwidth limitations of microstrip patch antennas, especially when applied to complex structures like Franklin antenna arrays. By utilizing electromagnetic coupling rather than direct conductive contact between the feed line and the radiating elements, this method effectively suppresses spurious radiations and introduces additional resonant modes, which significantly expands the impedance bandwidth.

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Furthermore, the research confirms that this feeding mechanism, when optimized through advanced computational models such as Artificial Neural Networks (ANN), ensures a stable radiation pattern and high gain across the wide frequency bands required for 5G mmWave and mid-band communications.

In this study, the author will design and develop a 1×4 microstrip antenna for 5G applications at a frequency of 2.6 GHz using the proximity coupled feeding technique and the Defected Ground Structure method. This antenna is expected to provide optimal performance in terms of bandwidth to support the reliability and speed of communication in 5G networks.

II. METHODS

This study focuses on the design of a rectangular patch microstrip antenna array operating at 2.6 GHz for 5G applications. The methodology consists of theoretical analysis, dimensional calculations, optimization techniques, simulation using CST Studio Suite, and fabrication followed by performance measurement. The antenna is designed to achieve a bandwidth greater than 100 MHz, in accordance with the minimum requirements specified by the ITU IMT-2020 (International Mobile Telecommunications-2020) standard for 5G mid-band operation [25], [26], [27].

TABLE I
ANTENA MICROSTRIP SPECIFICATION

Specification	Characteristics
Frequency	2,6 GHz
Bandwidth	≥ 100 MHz
Radiation Pattern	Directional

A. Antena Design Parameters

The antenna was designed using FR4 substrate with a dielectric constant (εr)of 4.4 and a thickness (h) of 1.6 mm. The design parameters include patch width (W), patch length (L), effective dielectric constant ($\varepsilon_{r_{eff}}$), feedline impedance, and ground plane dimensions. The wavelength is calculated using [28]:

$$\lambda_0 = \frac{c}{f}$$

C is the speed of light (3×10^8 m/s) and f is the operating frequency (2.6 GHz).

Patch width is calculated as[28]:

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

Effective dielectric constant[28]:

$$\varepsilon_{r_{eff}} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left[(1 + \frac{12.h}{W})^{-\frac{1}{2}}\right]$$

Patch length is adjusted using the fringing effect[28]:

$$\Delta L = 0{,}412.h.\frac{(\varepsilon_{r_{eff}} + 0{,}3)(^W/_h + 0{,}264)}{(\varepsilon_{r_{eff}} - 0{,}258)(^W/_h + 0{,}813)}$$

Calculation of Patch Length[28]:

$$= \frac{C}{2f\sqrt{\varepsilon_{r_{eff}}}} - 2\Delta L$$

Calculation of Ground Plane Width [28]:

$$Wg = 6h + W$$

Calculation of Ground Plane Length [28]:

$$Lg = 6h + L$$

Calculation of Microstrip Line Length (Lf) [28]:

$$Lf = \frac{1}{4}\lambda g$$

Element Spacing[28]:

$$\lambda = \lambda_g = \frac{c}{f\sqrt{\varepsilon_r}}$$

B. Feeding Network

The feeding structure utilizes a quarter-wave transformer with three impedance levels: 50Ω, 70.7Ω, and 100Ω. The width of the feedlines is calculated based on the required impedance using transmission line equations. This ensures impedance matching across the cascaded array elements [29].

C. Optimization Technique

Two enhancement techniques are applied [28]:

1. Proximity Coupled Feeding: Improves impedance bandwidth by loosely coupling the feedline through the substrate layer without direct contact.
2. U-Slot DGS: Introduced on the ground plane to manipulate current paths and increase bandwidth. Among several DGS variants tested, the U-slot configuration provided the widest bandwidth in simulations.

D. Simulation and Fabrication

The antenna was modeled and optimized using CST Studio Suite. Once simulated performance met the design criteria—bandwidth ≥ 100 MHz, return loss ≤ -10 dB—the prototype was fabricated and measured using a Vector Network Analyzer [30].

III. RESULTS AND DISCUSSION

A. Antena Design Result

The dimensions were calculated based on transmission line and cavity model theory. Key design parameters are summarized as follows.

TABLE II
MICROSTRIP ANTENNA DESIGN PARAMETERS

Parameter	Before Optimization	After Optimization
Patch Width, *W* (mm)	35,1	19
Patch Length, L (mm)	27,14	25.5
Ground width, Wg (mm)	44,7	29
Ground Length, Lg (mm)	36,62	80.5
Feed Width, Wf (mm)	2,77	3.14
Feed Length, Lf (mm)	13,75	55
Substrate Thickness, h (mm)	1,6	1,6
Conductor Thickness, t (mm)	0,035	0,035

After the optimization process was carried out in CST software, a 4-element array antenna was obtained, as shown in Figure 1.

Figure 2 shows th S11 results with the following details.

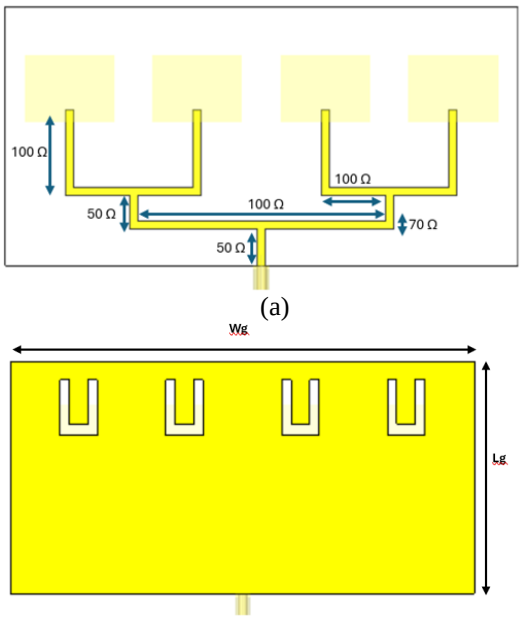


Fig. 1. (a) Front view of the 4-element microstrip array antenna design (b) Rear view of the 4-element microstrip array antenna design

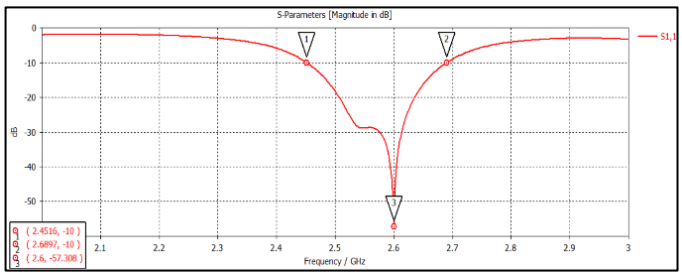


Fig. 2. S11 Value of the 4-Element Microstrip Array Antenna

TABLE III
4-ELEMENT MICROSTRIP ARRAY PARAMETER RESULT

Band Frequency	2451 MHz – 2689 MHz
Return Loss	57.30 dB
Bandwidth	238 MHz

The designed 4-element microstrip antenna array achieved a gain of 6.817 dBi at an operating frequency of 2.6 GHz, as shown in Fig. 3.

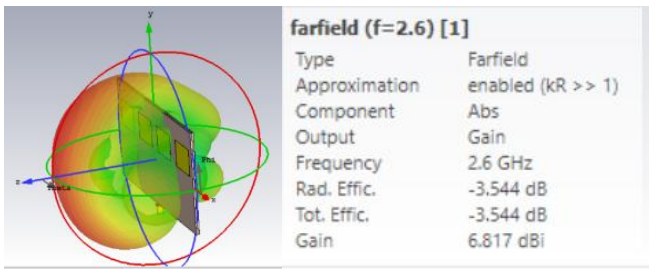


Fig. 3. Gain Value of the 4-Element Microstrip Array Antenna

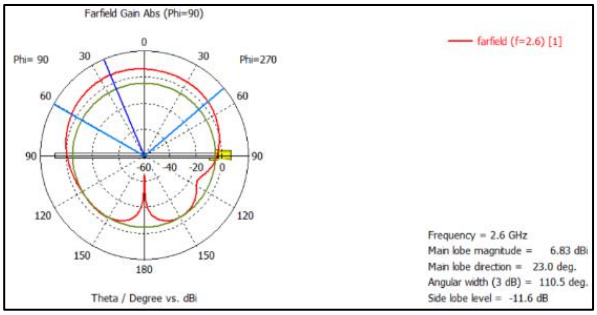


Fig. 4. E-Plane Phi = 90 Radiation Patern of the 4-Element Microstrip Array Antenna

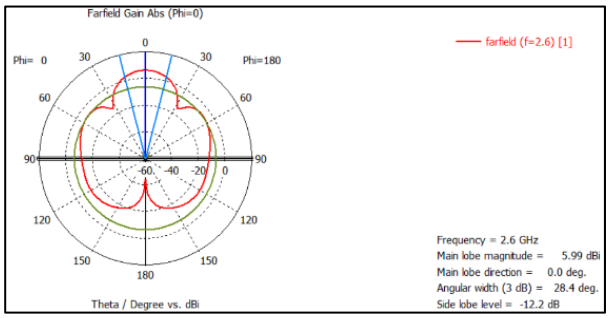
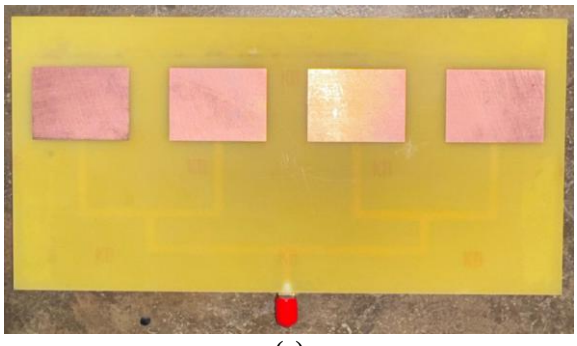


Fig. 5. H-Plane Phi = 0 Radiation Patern of the 4-Element Microstrip Array Antenna

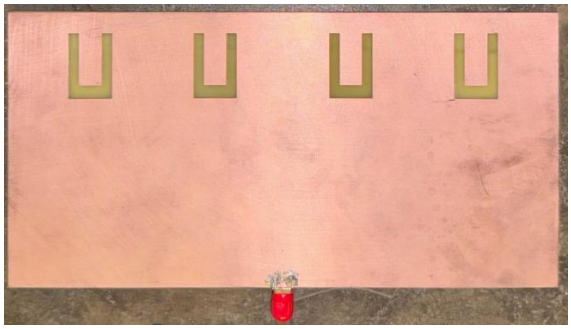
The figure below shows the radiation pattern of the 1×4 microstrip antenna. The result indicates that the antenna exhibits a directional radiation pattern. Based on the data in the table, the simulation results of the microstrip antenna design using the proximity-coupled technique and the U-Slot type DGS method, intended for 5G frequencies in the range of 2500 MHz – 2700 MHz, show that the 1x4 array configuration of the microstrip antenna has met the minimum bandwidth specifications required for 5G network radio communications in accordance with ITU regulations in the IMT-2020 Radio Interface(s).

B. Realization

The testing was carried out by measuring the fabricated antenna and comparing the results with the previous simulation.



(a)



(b)

Fig. 6. (a) Front view of the fabricated 4-element microstrip array antenna (b) Rear view of the fabricated 4-element microstrip array antenna

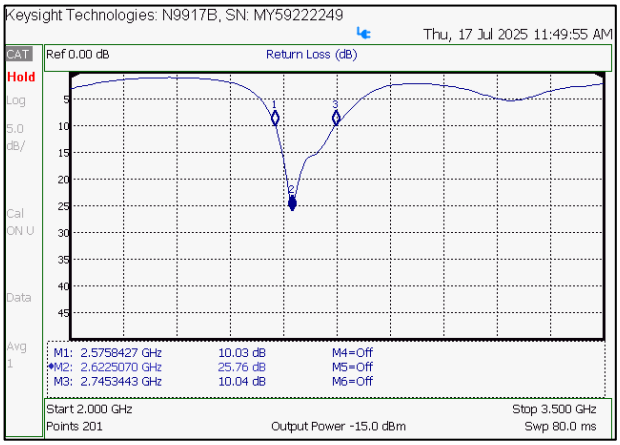


Fig. 7. S11 Value of the Fabricated 4-Element Microstrip Array Antenna

1) S11 Value

According to the data presented in Figure 8, the simulation results indicated a bandwidth of 238 MHz. In contrast, the fabricated antenna exhibited a reduction of 68 MHz relative to the simulation, resulting in a measured bandwidth of 170 MHz. Despite this reduction, the measured value remains within the predetermined specification threshold of ≥ 100 MHz.

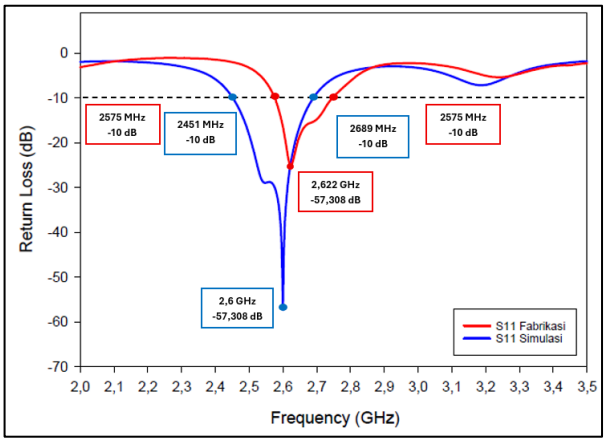


Fig. 8. Comparison Graph of Simulation and Fabrication Results of the 4-Element Microstrip Array Antenna

The experimental evaluation of the fabricated antenna further confirms that the Proximity Coupled feeding technique is effective for the design of antennas requiring wide bandwidth, particularly when compared to alternative feeding methods. Moreover, the implementation of a Defected Ground Structure (DGS) with a U-Slot configuration demonstrably contributes to bandwidth enhancement in microstrip antennas, which are generally characterized by inherently narrow bandwidth.

In this bandwidth assessment, the Return Loss was also measured, with the fabricated antenna achieving a value of 25.76 dB. This is lower than the simulated value of 57.30 dB. Such discrepancies are likely attributable to fabrication tolerances and the influence of the indoor measurement environment during antenna testing.

2) Gain

The power value obtained from the gain measurement using a horn antenna as a reference antenna for the transmitter antenna is -39.91 dBm. Based on the measurement results, the resulting gain can be calculated as follows [8]:

$$Gain = PA\text{-}PR + 12 \text{ dBi}$$

Which is:

1. GR = Gain of the reference antenna
2. PA = Power of the receiving antenna
3. PR = Power of the reference antenna

$$Gain = PA\text{-}PR + 12 \text{ dBi} = -44.41 - (-39.91) + 12 = 7.5 \text{dBi}$$

Based on the measurement results, the realized 4-element array antenna achieved a gain of 7.5 dB, thereby fulfilling the specified design requirements. When compared to the simulated result of 6.817 dB, this represents an increase of 0.683 dB, corresponding to approximately 10.02% relative to the simulated gain. This improvement is likely attributable to fabrication process tolerances. Furthermore, the environmental conditions during antenna testing may have influenced the measured parameters. Specifically, factors such as the measurement distance and constructive reflections from surrounding surfaces (e.g., the floor or walls of the testing facility) could have indirectly enhanced the main lobe radiation of the antenna.

3) E-Plane Phi = 90 Radiation Patern

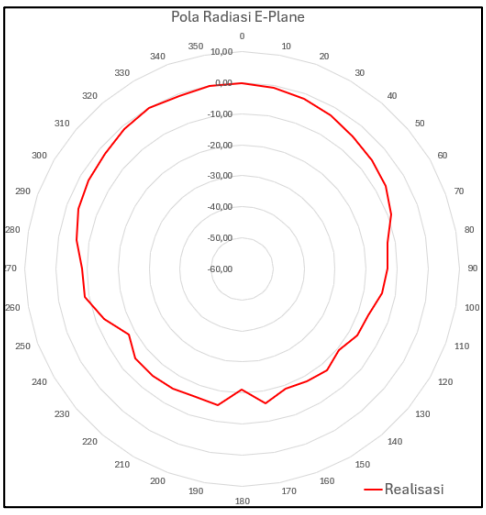


Fig. 9. E-Plane Radiation Pattern of the Realized Microstrip Array Antenna

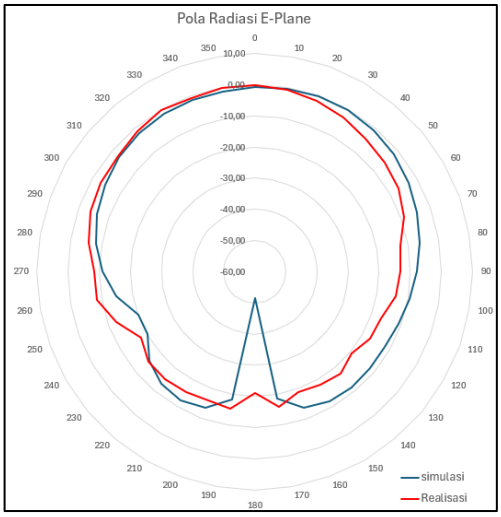


Fig. 10. Comparison of E-Plane Radiation Patterns Between Simulated and Realized Antennas

4) H-Plane Phi = 0 Radiation Patern

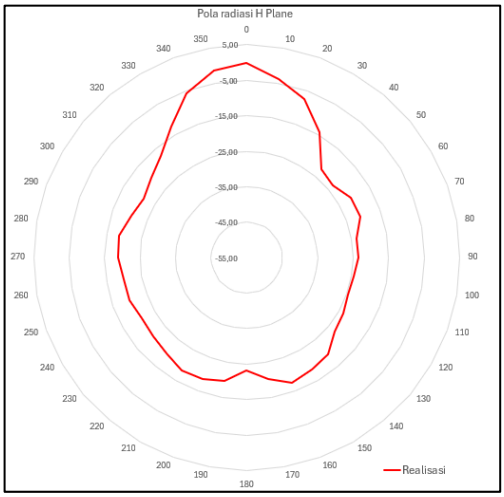


Fig. 11. H-Plane Radiation Pattern of the Realized Microstrip Array Antenna

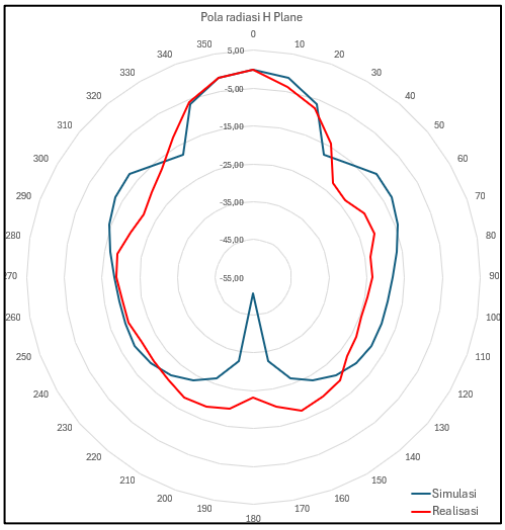


Fig. 12. Comparison of H-Plane Radiation Patterns Between Simulated and Realized Antennas

Based on the measurement results of both the simulated and fabricated 4-element microstrip array antenna, a comparison of the radiation pattern graphs indicates that the H-plane and E-plane exhibit a focused beam oriented in a single direction, demonstrating a directional characteristic. This outcome is consistent with the design specifications for microstrip antennas intended for 5G radio communication applications, which inherently require a directional radiation pattern. Therefore, the measurement results confirm compliance with the specified design criteria. The observed differences between the measured and simulated radiation patterns are attributed to the data acquisition process in the fabricated antenna, in which measurements were taken at 10° intervals. This angular resolution resulted in a less smooth radiation pattern compared to the simulation output.

TABLE IV
4-ELEMENT MICROSTRIP ARRAY PARAMETER RESULT

Parameter	Simulation	Realized
Range frequency	2451-2689 MHz	2575-2745 MHz
Center frequency	2.6 GHz	2.622 GHz
Bandwidth	238 MHz	170 MHz
Return loss	- 57.30 dB	- 25.76 dB
Gain	6.817 dBi	7.5 dBi

Based on the data presented in the Table, the simulation results indicate that the 4-element microstrip array antenna operates within a frequency range of 2451–2689 MHz, with a center frequency of 2.600 GHz. Measurements of the fabricated prototype reveal a frequency range shift to 2575–2745 MHz, with a center frequency of 2.622 GHz. This frequency shift is likely attributed to fabrication tolerances, variations in substrate material properties, and environmental conditions during testing that influence the antenna's characteristics.

For the bandwidth parameter, a reduction from 238 MHz in the simulation to 170 MHz in the fabricated prototype was observed. Nevertheless, this value exceeds the minimum specification requirement (≥ 100 MHz), thereby confirming that the antenna satisfies the performance criteria for 5G network applications.

The simulated return loss value was recorded at –57.30 dB, whereas the measured result showed a decrease to –25.76 dB. This discrepancy is most likely due to fabrication imperfections, connector quality, and the influence of signal reflections from the testing environment, which affect impedance matching.

Interestingly, the gain parameter exhibited an improvement, increasing from 6.817 dBi in the simulation to 7.5 dBi in the measurement, representing a difference of 0.683 dB or approximately 10.02%. This enhancement is presumed to result from constructive reflections from surrounding surfaces, such as the floor or walls of the testing room, which indirectly reinforced the antenna's main lobe radiation.

IV. CONCLUSION

The design and realization of a 4-element microstrip antenna array operating at 2.6 GHz for 5G mid-band applications have been successfully completed using a proximity coupled feeding technique and a U-slot Defected Ground Structure (DGS). The

fabricated antenna, developed on an FR4 Epoxy substrate, achieved a return loss of −25.75 dB, indicating excellent impedance matching. The measured bandwidth reached 170 MHz, covering a frequency range from 2.5 GHz to 2.7 GHz. This bandwidth exceeds the minimum 100 MHz requirement defined by the ITU IMT-2020 standard for 5G systems, demonstrating the effectiveness of the combined proximity coupling and DGS methods in improving antenna performance. Additionally, the realized antenna produced a gain of 7.5 dBi, which is 0.683 dB or approximately 10.02% higher than the simulated gain of 6.817 dBi. This increase is attributed to fabrication tolerances and environmental conditions during measurement, such as the test distance and signal reflections from surrounding surfaces, which may have reinforced the antenna's main lobe. The measured radiation pattern also confirms the directional characteristics of the antenna, aligning with the intended design specifications and indicating its capability to concentrate radiated energy in a specific direction. The close agreement between simulation and measurement results validates the design approach and confirms the antenna's performance for real-world deployment in 5G networks.

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