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Design and Analysis of Microstrip Antenna Using Double Slot Patch At 28 GHz Frequency for 5G Technology

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*Abstract***—** The advancement of telecommunication technology has increased the number of wirelessly connected devices, leading to a surge in data traffic. Fifth-generation (5G) technology utilizes millimeter waves at a 28 GHz frequency to support extensive connectivity and high data transmission rates. However, these high frequencies face challenges, such as limited signal range. This study aims to design and analyze microstrip antennas with 8×8 and 16×16 configurations using a dual-slot method (T-slot and U-slot) to enhance antenna performance, particularly bandwidth and gain. The design approach involved simulations using CST Suite Studio software. The simulation results show that the 8×8 antenna achieved a return loss of -29.40 dB, a VSWR of 1.07, a bandwidth of 1.4 GHz, and a gain of 15.6 dBi. Meanwhile, the 16×16 antenna achieved a return loss of -35.95 dB, a VSWR of 1.03, a bandwidth of 1.44 GHz, and a gain of 18.6 dBi. These results demonstrate that increasing the number of antenna elements and applying dual-slot techniques significantly improves performance, making it a potential solution for 5G communication systems requiring stronger signals and wider coverage.

Keywords—Microstrip Antenna; Double Slot Patch; mmWaves; Rectangular; T-Slot; U-Slot; 5G Technology.

I. INTRODUCTION

The rapid advancement of telecommunications technology has led to the development of five generations (5G), driven by the increasing demand for higher data transmission rates as more individuals connect their mobile devices to the internet. This rise in connectivity has resulted in an unprecedented surge in data traffic, intensifying the need for faster and more efficient data access [1]. Fifth-generation (5G) technology, utilizing millimeter-wave frequencies, promises to meet these growing demands by offering extreme high-speed connectivity—up to ten times faster than previous generations. Such advancements are expected to support high-speed mobile broadband and facilitate new applications across industries, such as fixed wireless access, the Internet of Things (IoT), and smart city technologies, including autonomous transportation and smart device integration [2].

A critical aspect of 5G communication is utilizing the 28 GHz millimeter-wave frequency band, as specified by the 3rd Generation Partnership Project (3GPP) in n261 [3]. Countries like South Korea, the USA, and Japan have adopted this frequency band for their 5G networks, underscoring the global shift towards millimeter-wave communication systems [4]. However, as promising as millimeter-wave technology is, its deployment is fraught with challenges, particularly related to path loss. Path loss significantly limits the range and coverage of signals, posing a substantial obstacle to achieving the desired connectivity [5]. As a result, there is a pressing need for advanced antenna systems to mitigate these limitations and ensure optimal performance in 5G networks.

Antennas are fundamental components of wireless communication systems, serving as the interface for transmitting and receiving electromagnetic waves. Key parameters such as input impedance, bandwidth, gain, and directivity are crucial for determining an antenna's performance, particularly in signal coverage, efficiency, and overall system performance [6][7].

Microstrip antennas have emerged as a viable solution for 5G systems due to their compact design, lightweight nature, and ability to operate at high frequencies [8], including input impedance, bandwidth, gain, and directivity, which affect the signal coverage, efficiency, and linearity of the system [1][6].

One type of antenna commonly used and capable of operating at millimeter waves is the microstrip antenna. Microstrip antennae offer the advantages of small size and lightweight [8]. These advantages made the antenna compact for small wireless devices [7][8]. Microstrip antennae suffer drawbacks due to narrow bandwidth, low gain, and low efficiency. A key solution is effectively using high gain and wide-bandwidth antennas to address these challenges. Therefore, by increasing the number of antennas used on both the transmitter and receiver sides, installing array antennas can enhance the gain value [9][10]. Slot installation techniques on the microstrip patch antenna can then be applied to improve bandwidth [1].

Several existing researchers have designed microstrip antennas in their studies. A comparison was made between the design of rectangular slot-T and slot-U microstrip antennas using a T-slot on a patch antenna. This research achieved a bandwidth parameter of 0.1994 GHz, a VSWR of 1.46, and a gain of 3.31 dB. Meanwhile, using U-slot on a patch antenna achieved a bandwidth parameter of 0.19527 GHz, a VSWR of 1.52, and a gain of 3.25 dB [11]. The second study focused on designing a 1x2 MIMO microstrip antenna with the addition of U-slots on each patch antenna. This design successfully increased the bandwidth to 1.6 GHz and achieved a return loss

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of -29.38 dB and a gain of 7.52 dB [1]. The third study designed a 2x2 MIMO microstrip antenna by adding U-slots to the rectangular patch. The addition of slots successfully increased the bandwidth to 1 GHz. The achieved return loss was -18.69 dB, with a VSWR of 1.26 and a gain of 9.20 dB [12]. The fourth study involved designing a rectangular patch microstrip antenna with the addition of T-slots. This design achieved a bandwidth of up to 1.98 GHz, a return loss of -43.78 dB, a VSWR of 1.01, and a gain of 2.88 dBi [13].

Based on existing research, adding U-slots and T-slots has proven effective in improving bandwidth. However, the gain values achieved in these studies remain relatively low, indicating the need for further optimization. Therefore, this study aims to design 8×8 and 16×16 rectangular MIMO microstrip antennas operating at 28 GHz. Unlike previous studies, the antenna design in this study involves installing two types of slots simultaneously, combining slot T and slot U in the center of the patch antenna. The antenna is arranged in a two-element array for 8×8 and 16×16 configurations. This approach seeks to enhance the antenna's performance and provides wide bandwidth and higher gain to overcome the 5G wireless communication challenge.

A. *Microstrip Antenna*

An antenna, according to IEEE Std. 145-1983, is a device used to transmit or receive electromagnetic waves, playing a critical role in wireless communication systems [8][14]. Among various types of antennas, the microstrip antenna has emerged as an effective choice, especially for 5G applications, due to its small size, lightweight nature, and easy integration into compact devices or circuits. Microstrip antennas consist of a thin conductive patch placed above a ground plane, separated by a substrate material. The compact design of microstrip antennas in Fig.1 makes them highly suitable for mobile devices and other wireless communication systems that require miniaturized components without compromising performance [8].

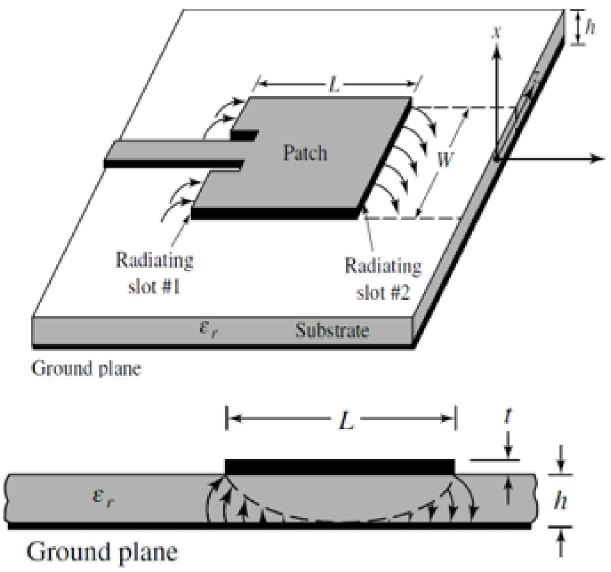

Fig.1. Microstrip Antenna

B. *The Parameter of Microstrip Antenna*

Microstrip antennas operating at 28 GHz can be used for wireless applications [3][8]. The antenna must reach a specific minimum of parameters to ensure effective performance. The specified parameter values that must be achieved are referenced from IEEE 145-1993 [8][14]. The parameter specifications of the antenna for this paper can be found in Table I.

TABLE I
THE PARAMETER OF THE MICROSTRIP ANTENNA

Parameter	Value
Return Loss	≤ -10 dB
VSWR	≤ 2 dB
Bandwidth	1 GHz
Gain	≥ 9 dB

To ensure effective antenna performance, the return loss value must be ≤ -10 dB and the VSWR value ≤ 2. These parameters indicate how well the antenna impedance matches the transmission line to minimize power reflection and enhance antenna performance. If these values are not achieved, indicates more power is lost and not fully radiated into the surrounding space [7].

The bandwidth is considered a range of frequencies required is > 1 GHz, which supports high data rate demands and reduces the potential for interference [15]. The target gain value is > 9 dB, and the gain antenna considers how well an antenna directs a radio frequency energy in a particular direction.

Combining the strengths of both T-slot and U-slot designs in a dual-slot configuration, this study contributes a unique approach to microstrip antenna design that directly addresses the need for wider bandwidth and higher gain to support the demanding requirements of 5G communication. Unlike prior works primarily focused on improving bandwidth or gain separately, the dual-slot approach introduced here is intended to optimize both parameters concurrently, pushing the boundaries of what can be achieved with microstrip antenna technology for 5G networks.

II. RESEARCH METHODOLOGY

A. *Research Method*

The antenna design simulation requires tools and materials and is carried out through several stages: determining the frequency to be used, calculate the antenna dimensions, selecting the antenna materials, simulating the antenna design, and analyse the results obtained from the software to observe the effect of the number of antennas on the return loss, VSWR, bandwidth, and gain parameters.

The software used in this research is CST Suite Studio version 2021, while the hardware consists of an ASUS laptop with an AMD 5 processor, 64-bit OS, and 8 GB of RAM. This section is unnecessary as the specific hardware and its impact on performance do not directly influence the outcomes of the antenna design simulation.

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The design process in this study uses simulation software to evaluate the return loss, VSWR, bandwidth, and gain parameters of the designed antenna. After obtaining the simulation results, a comparison will be made based on the data obtained, considering the number of antennas with slots added to the patch antennas. Fig.2 shows the research flow to be followed in this study, with antenna specifications referring to Table I.

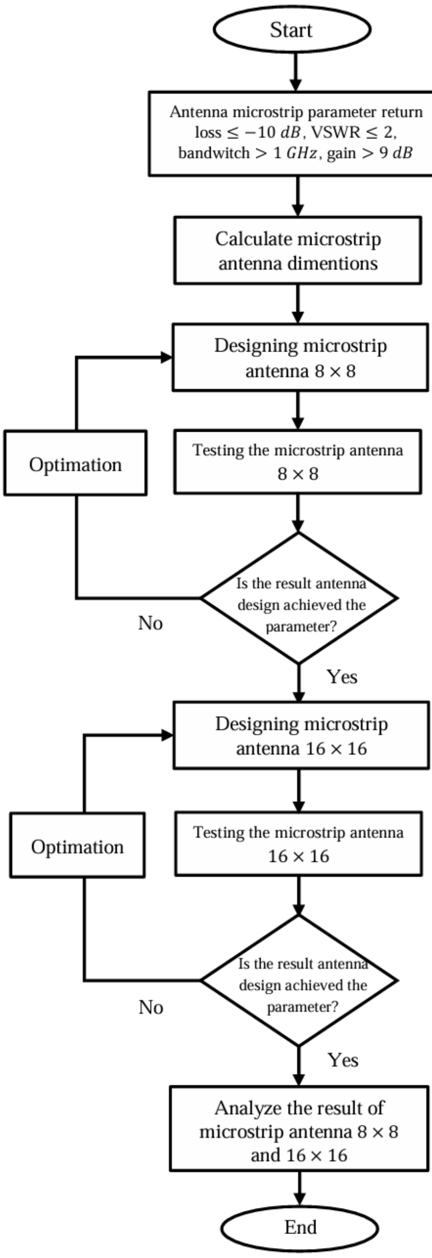

Fig.2. The Research Flowchart

The research begins by determining the parameters of the microstrip antenna, which include return loss ≤ -10 dB, VSWR ≤ 2, bandwidth > 1 GHz, and gain > 9 dB, serving as the primary benchmarks in the antenna design process. Once the parameters are set, the dimensions of the microstrip antenna are calculated using mathematical formulas, including the length and width of the patch, the dimensions of the substrate, and the size of the microstrip feed line. This step is crucial to establish the initial design dimensions for the antenna.

The next step involves designing a microstrip antenna with an 8 × 8 array configuration. This design uses a rectangular patch structure, microstrip feed line techniques, and the addition of slots to enhance the bandwidth. The antenna has three main layers: a copper ground plane, an RT Duroid 5880 material substrate, and a copper patch antenna element. Once the design is completed, the 8 × 8 antenna is tested using CST Studio Suite 2021 simulation software to evaluate its performance based on the predetermined parameters. After the simulation, the results are analyzed to determine whether the antenna design meets the required specifications. The research proceeds to the next stage if the results meet the targets. However, suppose the simulation results do not meet the specifications. In that case, optimization is done by modifying the antenna's dimensions, such as reducing the patch size or adjusting other parameters, to achieve the desired performance.

Once the 8 × 8 antenna meets the required specifications, the design is expanded to create a microstrip antenna with a 16 × 16 array. The same design principles and materials are used in this stage but with more elements to improve the antenna's performance. The 16 × 16 antenna is then tested using the same simulation procedure to evaluate its performance. The results from the 8 × 8 and 16 × 16 antenna designs are analyzed comprehensively. This evaluation includes key parameters such as return loss, VSWR, bandwidth, and gain. If both designs meet the target specifications, the research concludes with a detailed analysis and discussion of the findings. This marks the end of the research process, providing insights and conclusions regarding the effectiveness of the designed antennas.

B. Designing Microstrip Antenna

The approach to enhance the antenna's performance focuses on two main aspects: the array method and the dual-slot design. Increasing the number of antenna elements in 8×8 and 16×16 configurations in the array method improves directivity and gain, allowing for a more focused signal beam and extending the coverage range. Meanwhile, the dual-slot design, which implements T-slots and U-slots simultaneously on the patch antenna, significantly enhances the bandwidth, addressing the narrow bandwidth limitations commonly associated with microstrip antennas.

The following Equations are needed to calculate the antenna dimensions, which are used to position the ground plane in the base of the antenna, the dielectric substrate in the middle layer, the patch antenna element, and the feeding as the transmission line.

1) Substrate: The type of substrate that can be used for microstrip antennas is RT Duroid 5880, with a dielectric constant (ε_r) of 2.2. This type of substrate has a low relative permittivity, which increases the bandwidth value when the

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relative dielectric constant is low [15]. Table II presents the types of RT Duroid 5880 substrate materials and their specifications for this study.

TABLE II
MATERIAL OF SUBSTRATE

RT Duroid 5880 Materials	Value (mm)
Dielectric Constant	2.2
Dielectric Loss Tangen	0.009
Height of Substrate	0.325

2) Rectangular Patch: A Rectangular Patch is a microstrip antenna with a rectangular shape. Rectangular patches are easy to analyze as they use a transmission line model and are simple to fabricate, making them commonly used for microstrip antenna designs [16]. The calculation for the width (*W*) of the rectangular patch can be done using the following Equation (1) [17]. Where *c* is the velocity of an electromagnetic wave in free space ($3x10^8$ m/s), f is for operating frequency (Hz), ε_r is dielectric constant of the substrate.

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

To calculate the patch length (L) length in a microstrip antenna, we need to calculate *ΔL*, which represents the increase in patch length due to the fringing effect [17]. The parameter ΔL can be calculated using the following Equation (2). h is the height of the substrate, while ε_{eff} is the effective dielectric constant, which is calculated using Equation (3) [17]

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}\frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right) \quad (3)$$

Thus, the patch length (L) can be calculated using Equation (4).

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (4)$$

3) Slotted Patch: The disadvantage of microstrip antennas is their narrow bandwidth. One method that can be used to increase the bandwidth is by adding slots to the antenna patch. The slot shapes that can be applied to the antenna patch include U, H, T, E, and V [1]. Installing a T-slot on a rectangular antenna patch increased the bandwidth to 1.89 GHz [13]. Meanwhile, a U-slot has successfully increased the bandwidth to 1.62 GHz [1].

4) Ground Plane: The ground plane is the bottom part of the element arrangement in a microstrip antenna, serving as the grounding or earthing due to its position at the base. The ground plane acts as a reflector that reflects unwanted signals [15]. The length and width dimensions of the ground plane can be calculated using Equations (5) and (6). Where the h variable is the height of the ground plane, W is the width of the patch antenna, and L is the length of the patch antenna.

$$W_g = 6h + W \quad (5)$$

$$L_g = 6h + L \quad (6)$$

5) Microstrip Transmission Line: The feed technique connects the microstrip antenna to the transmission line, which is attached to the edge of the antenna patch. The transmission line serves as the power supply that can support the performance of the designed antenna [18]. Table III presents the calculated dimensions of the microstrip antenna.

$$B = \frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}} \quad (7)$$

$$W_f = \frac{2h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(2B-1) + 0.39 - \frac{\varepsilon_r-1}{2\varepsilon_r}\right]\right\} \quad (8)$$

TABLE III
DIMENSIONS OF MICROSTRIP ANTENNA

Antenna Dimension	Size
Width patch (W_p)	4.235 mm
Length patch (L_p)	3.373 mm
Height patch (T_p)	0.035 mm
Width slot (*D*)	3,015 mm
Length slot (C)	1,27 mm
Width slot 2 (*F*)	0,17 mm
Width substrate (W_s)	6.185 mm
Length substrate (L_s)	5.323 mm
Height substrate (T_s)	0.324 mm
Width feed 50Ω (W_f)	1.042 mm
Length feed 50Ω (L_f)	1.933 mm
Width feed 100Ω (W_{f1})	0.221 mm
Length feed 100Ω ((L_{f1})	2.028 mm
Distance between the antenna (d)	2.677 mm

Fig.3. shows the design of the microstrip antenna model development proposed in this study. The initial design simulates a regular rectangular microstrip antenna with an array configuration of two antenna elements. The two antenna elements are connected using the T-Junction technique to distribute power from the transmission line to the antenna. The next step involves cutting the center of the patch antenna to implement the dual-slot method and inset-fed. This is to improve the bandwidth and reflection coefficient values. Subsequently, the antenna is developed into 8x8 and 16x16 arrays. Increasing the number of antennas aims to enhance the antenna's gain.

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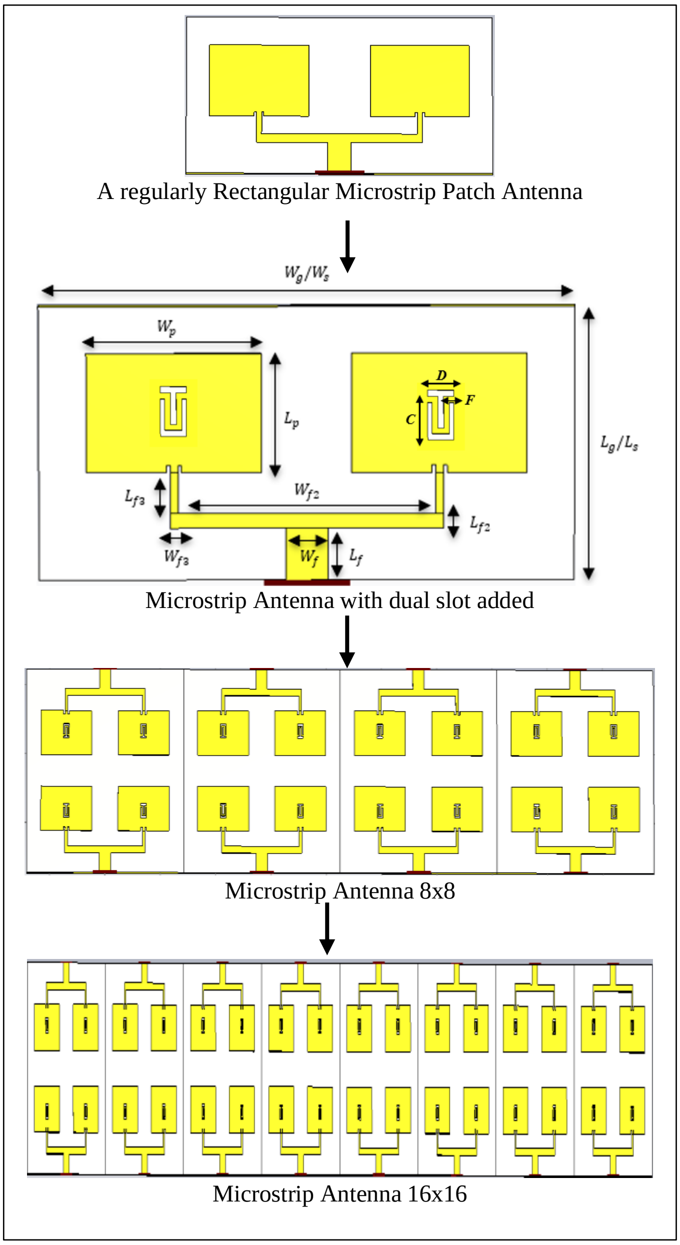

Fig.3. Design model of the proposed microstrip antenna

III. Result and Discussion

This section contains an analysis of the proposed microstrip antenna design results. The design simulation and data conducted were obtained using CST Suite Studio software.

A. *Microstrip Antenna 8 x 8*

This design is implemented using the array method, where a single port consists of two rows of antenna elements connected by a transmission line using the T-junction power divider technique. The T-junction configuration is used to distribute energy to each antenna element. Fig.4. shows the layout of the Microstrip Antenna Array 8×8 design.

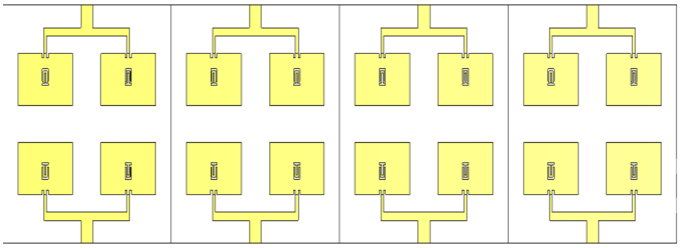

Fig.4. Microstrip Antenna 8×8

Return loss has a synergistic relationship with VSWR, which determines the matching between the transmitter and the antenna. Return loss is a parameter used to determine how much power is lost during transmission and how much power the receiver receives. The lower the return loss, the better the antenna's performance. Fig.5 shows the return loss parameters (S-Parameters) represented as S11, S22, S33, S44, S55, S66, S77, and S88, with an average of -29.40 dB. This return loss result indicates that the antenna can radiate power effectively, and the proposed 8×8 microstrip antenna meets the return loss specification of ≤ -10 dB at the operating frequency of 28 GHz. The bandwidth value is calculated based on the return loss threshold of -10 dB. The bandwidth obtained for the 8×8 microstrip antenna is 1.4 GHz.

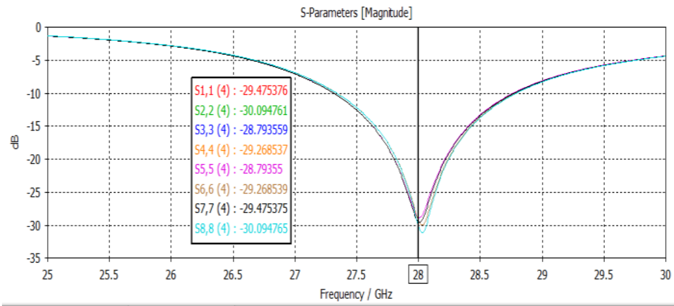

Fig.5. Result of Return Loss Microstrip Antenna 8×8

The low return loss value indicates that the antenna effectively receives most of the transmitted power with minimal energy loss. This suggests high efficiency in the antenna design, which is crucial for high-frequency communication applications such as 28 GHz. Additionally, the wider bandwidth allows the antenna to be used in various applications with different types of signals, providing greater flexibility in communication applications.

Fig.6 shows that the 8×8 microstrip antenna design has an average VSWR value of 1.07. VSWR determines the matching between the microstrip antenna and the transmission line. A VSWR value ≤ 2 is suitable for wireless applications [19]. The closer the VSWR value is to 1, the more power will be delivered to the antenna. Therefore, the VSWR value of the 8×8 microstrip antenna operating at 28 GHz has met the minimum parameter requirements. A VSWR value approaching 1 indicates that most transmitted power is delivered to the antenna. This demonstrates high power efficiency, essential for optimal communication performance, especially in wireless applications sensitive to power loss and weak signals.

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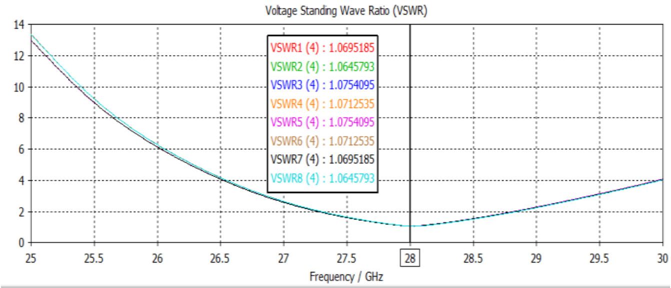

Fig.6. Result of VSWR Microstrip Antenna 8×8

The radiation produced by the antenna represents the energy it emits. As shown in Fig.7, the 8×8 microstrip antenna design results in a gain value of 15.5 dB. This gain value meets the required specification of ≥ 10 dB.

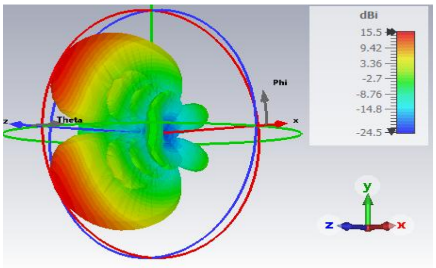

Fig.7. Gain of Microstrip Antenna 8×8

A higher gain value indicates that the antenna can produce a stronger signal, critical for applications requiring long-range communication and strong signal transmission, such as satellite and long-distance communications. A higher gain also means the antenna can focus power more precisely in specific directions, improving energy efficiency.

B. *Microstrip Antenna 16 x 16*

The design of the 16×16 microstrip antenna was duplicated from the 8×8 microstrip antenna. Fig.9. shows the design of the 16×16 microstrip antenna.

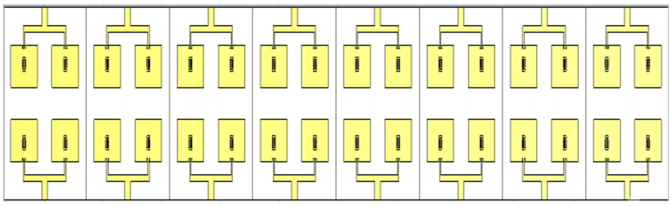

Fig.8. Microstrip Antenna 16×16

The return loss results for the 16×16 microstrip antenna design shown in Fig.9 and Fig.10 from port 1 to port 16, the average is -30.50 dB for each port. This return loss result indicates that each port has good reflection characteristics, minimizing power loss due to reflection, and thus can radiate power effectively [1]. Therefore, the return loss value of the 16×16 microstrip antenna operating at 28 GHz has met the minimum parameter requirements. With the return loss threshold set at -10 dB, the bandwidth of the 16×16 microstrip antenna is 1.44 GHz, calculated by the difference between the upper and lower frequency range.

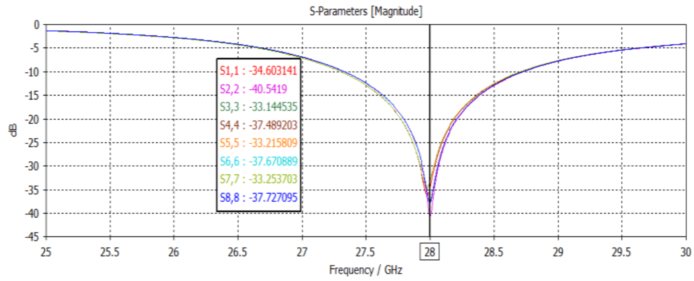

Fig.9. Return Loss of Antena Microstrip Array 16×16

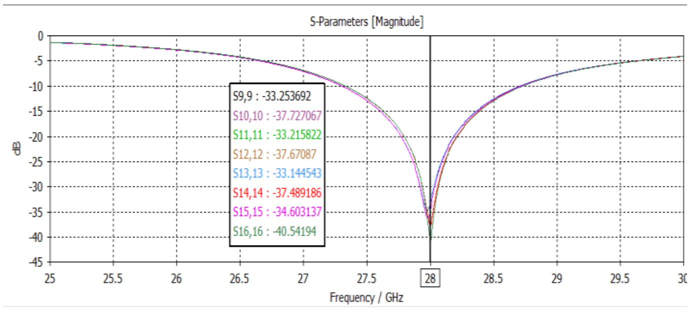

Fig.10. Return Loss of Microstrip Antenna 16×16

The VSWR results of the 16×16 microstrip antenna design are shown in Fig.11 and Fig.12. The average VSWR obtained is 1.03, which is close to 1 and indicates that the microstrip antenna functions are good due to its impedance matching between the transmission line and the antenna. A low VSWR can minimize power loss caused by reflections, enhancing the antenna's efficiency in transmitting or receiving signals.

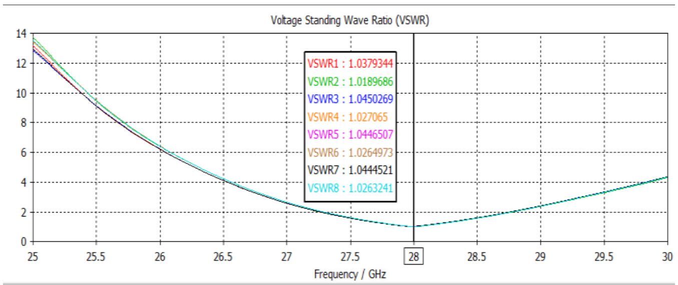

Fig.11. VSWR of Microstrip Antenna 16×16

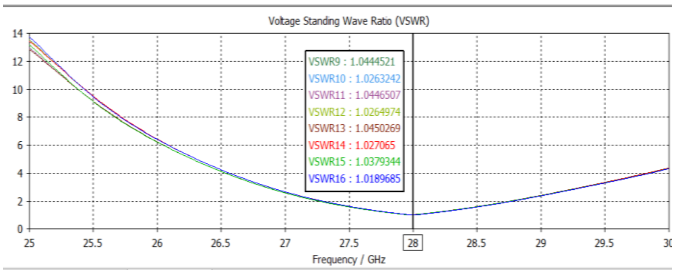

Fig.12. VSWR of Microstrip Antenna 16×16

Based on Fig.13, the gain value of the 16×16 microstrip antenna is 18.6 dB. This value is greater than the gain of the

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8×8 microstrip antenna and successfully meets the required gain parameter of ≥ 10 dB. This gain value indicates that the antenna can more efficiently convert electrical power into radiated electromagnetic waves. This gain value indicates that the transmitted power can effectively enhance the signal's directionality.

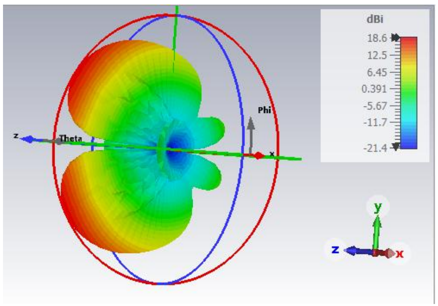

Fig. 13. Gain of Microstrip Antenna 8×8

C. *Comparison of Result Microstrip Antenna 8×8 dan 16×16*

After conducting simulation, design, and optimization through various configurations in the program, the optimal design obtained is the performance of the 16×16 microstrip antenna. The comparison is based on the values of return loss, VSWR, gain, and bandwidth. Table IV compares the parameter values resulting from the design and testing of the 8×8 and 16×16 microstrip antennas.

TABLE IV
COMPARISON OF RESULT MICROSTRIP ANTENNA 8×8 DAN 16×16

Parameter	**Antena Mikrostrip**	
	8x8	**16x16**
Return loss	-29,40 dB	-35,95 dB
VSWR	1.07	1.03
Bandwidth	1,4 GHz	1.44 GHz
Gain	15.6 dBi	18.6 dBi

Based on Table IV and Table V, the result shows that the proposed microstrip antenna design provides a good performance against all the parameters. The return loss value of the 16×16 microstrip antenna is -35.955 dB, which is better than the -29.408 dB value of the 8×8 microstrip antenna. Return loss has a synergistic relationship with VSWR in determining the matching between the transmitter and the antenna to measure the amount of power reflected. The reflected power can cause standing waves on the transmission line, leading to power losses and not optimally radiating into the surrounding space [7].

TABLE IV
PERFORMANCE COMPARISON OF THE PROPOSED ANTENNA SYSTEM

Reff	**Freq (GHz)**	**Antenna Element**	**Slot Method**	**Return Loss (dB)**	**Bandwidth (GHz)**	**VSWR**	**Gain (dBi)**
[1]	28	1x2	U Slot	-29.38	1.6	-	7.52
[11]	2.3	1	U Slot	-	0.19527	1.5152	3.2545
			T Slot	-	0.19947	1.4659	3.31
[12]	15	2x2	U Slot	-18.69	1	1.26	9.20
[13]	3.5	1	T Slot	-44.37	2.08	1.01	2.88
[20]	25.75	2x2	T Slot	-23.28	-	1.15	-
Proposed	28	8x8	Combining	-29,40	1.4	1.07	15.6
		16x16	T Slot and U slot	-35,95	1.44	1.03	18.6

This baseline return loss value of -10 dB is a threshold favorable for wireless communication. The proposed microstrip antenna in this study obtained the VSWR value of the 16×16 microstrip antenna is 1.03, compared to 1.07 for the 8×8 microstrip antenna. The VSWR values for both antennas are close to 1, indicating a good match between the feeding system and the antenna. Thus, this study has successfully maintained a low VSWR, which is crucial to ensuring efficient power transfer, minimizing power losses, and preventing potential damage to the transmitter and receiver in the antenna system.

Adding T-slots and U-slots on the antenna patch helps widen the bandwidth, thereby expanding the frequency range. In this study, the bandwidth of the 16×16 microstrip antenna is 1.44 GHz, while the bandwidth of the 8×8 microstrip antenna is 1.4 GHz. The bandwidth of the proposed antenna is sufficient to cover the 28 GHz frequency (27.70 GHz–28.35 GHz), which is considered essential for achieving high data rates and low latency in 5G systems. The gain value of the 16×16 microstrip antenna is 18.6 dBi, which is higher than the 15.6 dBi gain of the 8×8 microstrip antenna. Adding more antenna elements enhances the system's performance. This is because using more antenna elements directs more power and effectively increases the gain strength.

However, while these results show an improvement in performance compared to the 8×8 microstrip antenna, comparing them with previous studies is important. In a prior study, a microstrip antenna design for 5G technology at 28 GHz frequency achieved several performance parameters: a bandwidth of 454 MHz, VSWR of 1.03, beam width of 74.4 degrees, and a gain of 6.72 dBi. This antenna design used an inset feed technique with a patch dimension of 3.57 mm × 4.26 mm and a Taconic TLY-5 substrate. While this design shows good performance characteristics and meets the needs of wireless communication for 5G applications, the smaller bandwidth and gain suggest that designs with more elements, like the one presented in this study, can significantly improve gain and bandwidth [18].

Additionally, the limitations of the proposed antenna design should be considered. One potential drawback is the antenna's larger physical size, which is due to the addition of more elements. This could affect the integration of the antenna in

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smaller, more portable 5G devices. Furthermore, while the wider bandwidth supports 5G applications, another challenge is controlling the radiation pattern and power distribution, which becomes more complex with antennas having more elements. Therefore, further research is needed to optimize this antenna design to balance size, performance, and manufacturing costs while ensuring efficient implementation in real-world 5G systems.

IV. CONCLUSION

The proposed 8×8 and 16×16 microstrip antenna designs were evaluated, with the 16×16 configuration demonstrating better performance across key parameters when compared to the 8×8 design. Both antennas met the target specifications, demonstrating their 5G wireless communication potential. By incorporating T-slot and U-slot methods into the patch antenna, bandwidth was enhanced by up to 1.4 GHz, covering the millimeter-wave 28 GHz frequency range (27.7 GHz–28.3 GHz) as outlined by the 3rd Generation Partnership Project (3GPP) for 5G. At the 28 GHz frequency, the antennas achieved excellent impedance matching with return losses of –29 dB and –35 dB and very low VSWR values of 1.07 and 1.03, which are well within acceptable limits for wireless applications. Additionally, by increasing the number of antennas, the array method successfully enhanced the gain, with peak values reaching 15.6 dBi for the 8×8 configuration and 18.6 dBi for the 16×16 configuration. This dual-slot and array-based design optimized radiated power, minimized reflected power, and improved gain values, making it a strong candidate for 5G wireless communication systems.

However, some limitations should be considered. The design complexity could increase with further refinements, and the scalability of the antenna may require additional considerations, particularly in larger array configurations. For future work, exploring different slot shapes and optimizing array configurations with a single-port transmission could improve the radiation characteristics and efficiency of the antenna, addressing potential design challenges and expanding its applicability for next-generation wireless technologies.

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