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Design of 5G MIMO 2x2 Broadband Antenna at 26 GHz Frequency Using Double U-Slot Method and Defected Ground Structure

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ABSTRACT

The 5G technology is a telecommunications innovation that offers incredibly high-speed data transfer. It is expected to outperform its predecessors significantly. In utilizing 5G services, efficient devices are crucial, and solutions like Multiple Input Multiple Output (MIMO) systems play a key role. MIMO is an antenna system with numerous transmitting and receiving elements, enabling simultaneous transmission and reception. A 26 GHz frequency microstrip antenna is modified using a double U-slot, and the Defected Ground Structure (DGS) method is employed to reduce antenna coupling effects and enhance bandwidth. This antenna features a directional radiation pattern that focuses in a specific direction, thereby increasing efficiency. Before optimization, the return loss was at around -14.15 dB, VSWR was approximately 1.49 dB, and bandwidth was 0.65 GHz. After optimization, the return loss improved to between -27.06 and -28.09 dB, signifying performance enhancement. Despite a slight increase in VSWR to 1.08 to 1.09 dB, it remains within acceptable limits. The bandwidth increased from 1.06 to 1.13 GHz. These results indicate that optimization successfully boosted antenna performance, resulting in higher data transfer efficiency. This technology has the potential to revolutionize the telecommunications landscape with faster and more reliable services through advanced 5G networks.

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1. INTRODUCTION

The term 'antenna' refers to a device for transmitting electromagnetic waves and has a varying operational frequency depending on its application. Facing the demands of increasingly complex technology, various types of antennas have been developed to meet these needs. One popular type of antenna is the microstrip antenna. This antenna is characterized by its small dimensions in terms of shape and size, as well as its affordable cost, making it an attractive choice for various applications. With these simple characteristics, microstrip antennas can perform effectively [1].

The data transfer speed offered by 5G technology is expected to increase significantly compared to the previous generation, namely 4G technology. In providing various services offered by 5G technology, devices that can maximize 5G performance are required. One solution to achieve this is by utilizing the Multiple Input Multiple Output (MIMO) system. The MIMO system allows the use of multiple antennas on both the transmitter and receiver sides to enhance efficiency and data transfer capacity in wireless networks [2].

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The system in Multiple Input Multiple Output (MIMO) is a method that involves multiple antennas for signal transmission and reception. The MIMO method functions effectively in overcoming multipath phenomena. MIMO plays a role as a technology with a far smaller number of terminal devices compared to the total number of antennas at the cellular station. With the implementation of MIMO technology, network capacity can be increased by up to 15 times, and the effectiveness of radiation power can be enhanced by up to 100 times. To achieve this increase in power effectiveness, it is important to utilize a large number of antennas in the MIMO system [3].

The microstrip antenna is one of the widely used antenna types in communication system applications today. The choice of microstrip antennas is due to several advantages, such as compact physical size, simple profile, and easy fabrication. However, microstrip antennas also come with some drawbacks, including limited bandwidth, limited gain, and low efficiency. To address these drawbacks, various techniques have been developed, one of which is using a U-shaped slot patch. This technique aims to broaden the bandwidth by enhancing inductive coupling and reducing the quality factor (Q-factor) of the antenna. By employing a U-shaped slot patch, it is expected that the performance of microstrip antennas can be improved more effectively, thereby overcoming the limitations on bandwidth, gain, and efficiency that are commonly associated with microstrip antennas [9].

A microstrip antenna is an antenna composed of a very thin radiating element (patch) placed on a ground plane, where the space between the ground plane and the radiating element (patch) is separated by a dielectric substrate. The development of microstrip antennas originated from the fundamental idea of using printed circuit technology not only for circuit components and transmission lines in electronic systems but also as radiating elements [10].

Microstrip antennas have become one of the most popular antenna types today. Their popularity is due to their compatibility with telecommunications equipment, especially because microstrip antennas are highly suitable for cases where antenna shape and size need to be carefully considered.

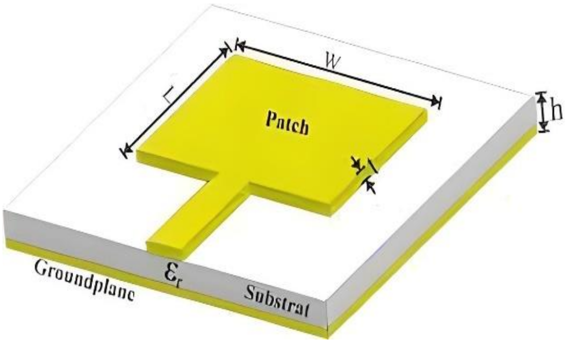

Figure 2. Common Shapes of Microstrip Antennas [1]

Figure 2 depicts a standard microstrip antenna consisting of two parallel conductor layers separated by a dielectric layer known as the substrate. In this configuration, the upper conductive layer, often referred to as the 'patch,' serves as the source of radiation. Electromagnetic energy is emitted through the patch and travels along the patch's edges into the substrate. On the other hand, the lower conductive layer acts as a fully reflective ground plane. The function of this layer is to reflect electromagnetic energy back through the substrate, allowing the energy to be radiated back into the atmosphere.

The field radiation in a microstrip antenna mainly occurs in the propagation plane between the patch edge and the ground plane. To achieve optimal antenna performance, a dielectric layer with a low dielectric constant is desired. By using a dielectric layer with a low dielectric constant, the antenna can achieve better efficiency, wider bandwidth, and improved radiation. However, it's important to note that the use of a low dielectric constant can also lead to larger antenna sizes [1].

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2. RESEARCH METHOD

This study was conducted through several stages, including literature review for antenna parameter selection, antenna dimension calculations, antenna design, and simulation, as well as analysis of simulation test results.

In the initial stage of this research, literature review was conducted to gather relevant references for the study on the design of a 5G MIMO Broadband Antenna. These references will be used as a basis during the course of this research. In this phase, information was collected through a literature review to support the antenna design theory that will be developed. The references used include reference books and published scientific journals.

The range frequency used is 24 GHz - 28 GHz with a center frequency of 26 GHz. The simulation process aims to achieve a return loss value of ≤ 10 dB with a gain of ≥ 3 dB. Copper is used as the constituent material for the patch, ground plane, and feeding line. FR 4 material is utilized as the substrate between the patch and ground plane. The designed antenna takes the form of a rectangular patch arranged in a 2x2 MIMO configuration. Each antenna in the array is connected using the proximity coupled feed method. The initial stage involves designing a single-element antenna. Subsequently, a double U-slot is added to the single patch antenna. The optimization process involves adjusting the patch width and U-slot dimensions. In the next stage, a double U-shaped Defected Ground Structure (DGS) is added. The application of DGS is influenced by the size, shape, and frequency used. This DGS technique will impact the antenna's resonance frequency, enhancing both gain and directivity.

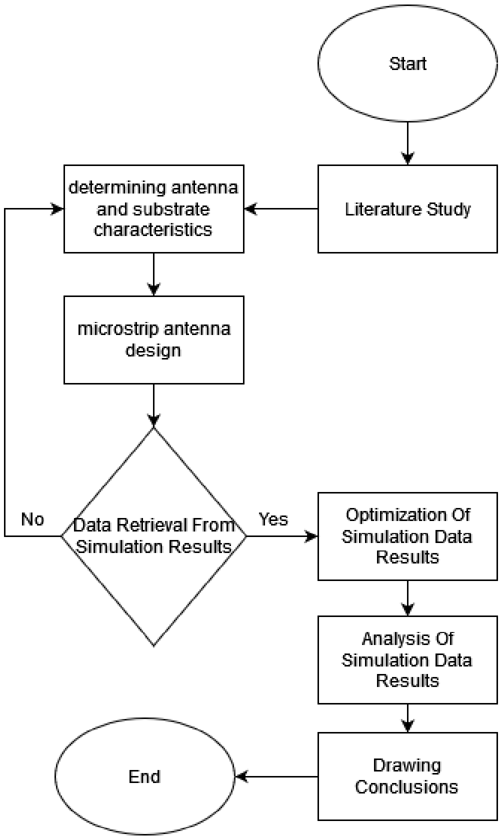

Figure 2. Research Workflow

2.1. Specification Parameters

The antenna's frequency range specification falls between 24 GHz and 28 GHz, with a center frequency of 26 GHz. The return loss is constrained to be ≤ -10 dB, and the gain should be ≥ 3 dB. For a comprehensive overview of the antenna's parameter specifications, please refer to Table 1.

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Table 1. Antenna Parameter Specifications

Parameter	Specification
Center Frequency	26 Ghz
The Operating Frequency.	24 Ghz – 28 Ghz
Return Loss	≤ -10
VSWR	≤ 2
Bandwidth	>1 Ghz
Gain	≥ 3 dB
Radiation Pattern	Directional
Mutual Coupling	≤ 20 dB
Input Impedance	50Ω

2.2. Workflow

The antenna is designed to operate at a frequency of 26 GHz. The components of the 5G antenna have been estimated and are listed in Table 3.1. For the substrate, FR-4 (loss-free) material is used with a relative dielectric constant (εr) of 4.3 and a thickness (hs) of 0.79 mm. Additionally, this substrate has a dielectric loss tangent of 0.002. Furthermore, an impedance of 50 Ω is used in this research. The design of the single antenna is carried out through four stages, as depicted in Figure 3.3.

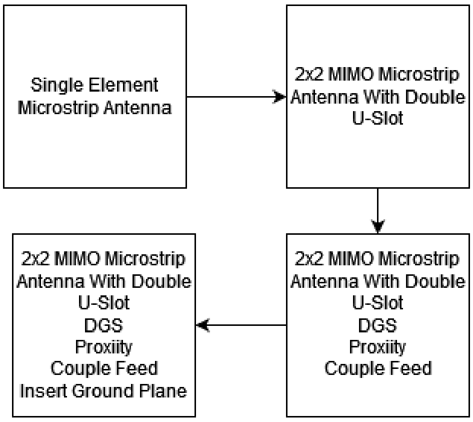

Figure 3. Flowchart of Microstrip MIMO 2x2 Antenna Design with Double U-Slot Patch and DGS

In the initial stage, to perform the design, first, input the values obtained from calculations according to Table 3.3 into the parameter list inside CST Studio. Once the parameter list in CST has been filled in, proceed to define the brick component as the ground with a width from Umin -wg/2 to Umax wg/2, for the length, specify from Vmin -lg/2 to Vmax lg/2, and for its height, use Wmin -t to Wmax 0. Next, define the substrate brick with a width from Umin -(r*hs)-(wp/2) to Umax (r*hs)+(wp/2), for the length, specify from Vmin -lf to Vmax lp+(r*hs), and for its height, use Wmin -hs to Wmax 0. Then, define the patch brick with a width from Umin -wp/2 to Umax wp/2, for the length, specify from Vmin 0 to Vmax lp, and for its height, use Wmin 0 to Wmax t. Finally, define the feedline brick with a width from Umin -wf/2 to Umax wf/2, for the length, specify from Vmin -lf to Vmax 0, and for its height, use Wmin 0 to Wmax t.

n the second stage, double U-slots are added to the single antenna's patch. Subsequently, optimization is performed by readjusting the patch width (w_p) and U-slot dimensions (D_slot). The value of Wp obtained from the first optimization serves as a reference to obtain the latest optimized patch width with a different value due to the addition of double U-slots. For the value of D_slot, optimization is carried out in a way that yields the best result. The optimization results for both values yield parameters that closely match the established criteria.

In the third stage, a double U-shaped Defected Ground Structure (DGS) is added to the antenna from the previous stage. Then, optimization is performed for the length C_dgs and D_dgs, with values of 3 mm and 1 mm, respectively, and a width of F_dgs of 0.1 mm, which will yield the best performance at the 26 GHz frequency. The fractional bandwidth or impedance bandwidth values will be determined after simulation. The initial values for C, D, and F are determined using equations (2.9) – (2.11). In the

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fourth stage, the single antenna is configured into a 2x2 MIMO antenna, and the spacing between the elements is set to 0.6 times the wavelength (λ) to achieve the optimal gain characteristics.

3. RESULTS AND DISCUSSION

The initial stage involves designing a single-element antenna. In the design of the single element, a return loss value of -30.94 dB is obtained. The VSWR result achieved in the single-element design is 1 dB. The return loss and VSWR results for the single-element antenna can be seen in the Figure 4.

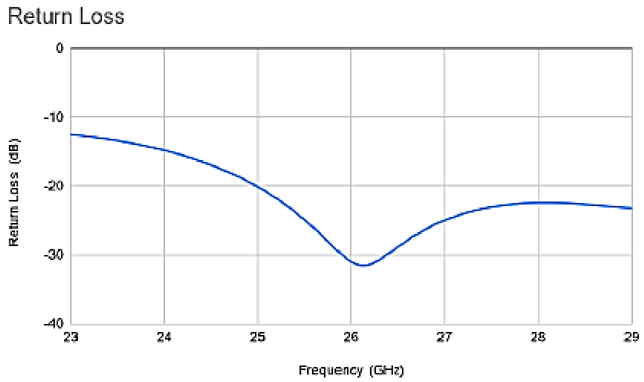

Figure 4. Return Loss Value for Single Elemen

After completing the design for the single-element antenna, the next stage involves designing a 2x2 MIMO antenna using a double U-Slot. The design of the 2x2 MIMO antenna with a double U-Slot utilizes parameters as listed in Table 2.

Table 2. Characteristics of the Used Antenna

Components	Components Symbol	Dimension (mm)
width patch	Wp	9.27 mm
length patch	Lp	4.56 mm
thickness patch	Hp	0.035 mm
width strip line	Wf	3.38 mm
length strip line	Lf	3.04 mm
width substrat	Ws	15.67 mm
thickness substrat	Ls	10.8 mm
spacing between elements	Hs	1.6 mm
U-slot		
Width Slot	F	0.19 mm
Height Slot	C	1.58 mm
Length Slot Luar	D	4.49 mm
Width Slot 2	F_2	0.1 mm
Height Slot 2	C_2	0.79 mm
Length Slot Dalam	D_2	2.25 mm
Insert Ground Plane		
Height Of the Cut		3 mm
Length Of the Cut		31.34 mm

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In the design of the 2x2 MIMO antenna with a double U-Slot, the process involves adding width to the ground plane and substrate. The design results can be observed in the Figure 5.

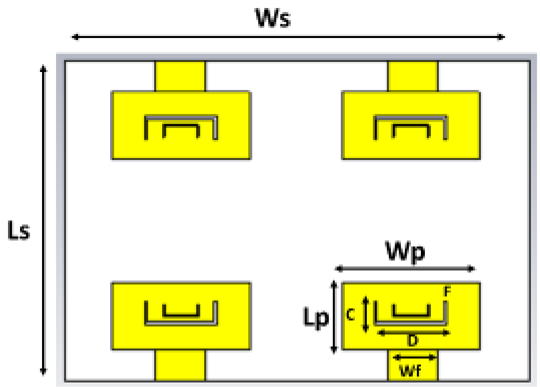

Figure 5. Desain of Antenna MIMO 2x2

The S-parameter results obtained in the 2x2 MIMO design are as follows: for S1,1 (port 1), a return loss of -29.46 dB is obtained, for S2,2 a return loss of -30.5 dB is achieved, for S3,3 a return loss of -30.5 dB is obtained, and for S4,4 a return loss of -29.32 dB is recorded. The figure represents the return loss values obtained for each port in the 2x2 MIMO antenna.

Figure 6. Desain of Antenna MIMO 2x2 with Double U-Slot

Design of 2x2 MIMO with Double U-slot Method, DGS, and Additional Insert Ground Plane as shown in the picture below:

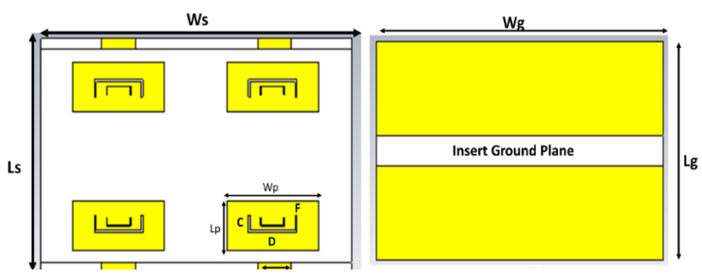

Figure 7. 2x2 MIMO Antenna Design Using Double U-Slot and DGS Method

In the creation of the design in Figure 4, a cut was made on the ground plane, which was initially connected as a whole, and the insert ground plane cutting technique was applied. The cut had a height of 3 cm and a length of 31.34 cm in order to achieve better VSWR and S-parameter results compared to the original uncut configuration. The curve obtained before the ground cutting, occurred in the range of 24.5 GHz.

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The Figure 8 represents the Return Loss of the 2x2 MIMO Design using the Double U-slot and DGS method.

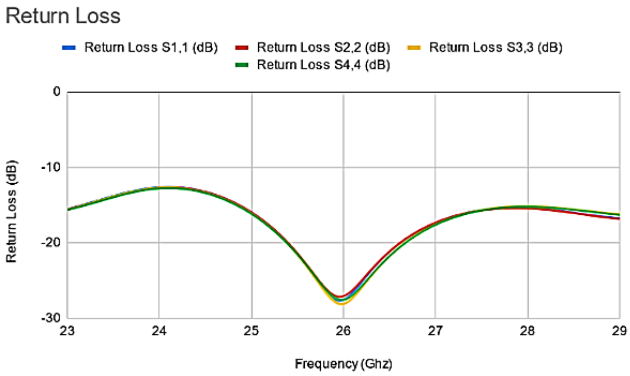

Figure 8. The Return Loss After Optimization of the 2x2 MIMO Antenna Design Using the Double U-Slot and DGS Method

In Figure 8, it shows the Return Loss results of the 2x2 MIMO antenna using the double U-slot and DGS method. In the S1,1 axis marker, it yielded a result of -27.55838 dB, and for the first curve marker, it was at 25.54176 GHz with a value of -22.12081 dB. As for the second curve marker, it was at 26.41587 GHz with a value of -22.14267 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 0.87408 GHz. These results are not considered satisfactory yet as they are just approaching a bandwidth of ≥ 1 GHz. The curve's drop point aligns with the desired frequency of 26 GHz.

In the S2,2 axis marker, it yielded a result of -27.061711 dB, and for the first curve marker, it was at 25.6656 GHz with a value of -23.95635 dB. As for the second curve marker, it was at 26.27062 GHz with a value of -23.97058 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 0.60502 GHz. These results are still not considered satisfactory as the bandwidth is less than 1 GHz. However, the curve's drop point aligns with the predetermined frequency of 26 GHz.

In the S3,3 axis marker, it yielded a result of -28.090594 dB, and for the first curve marker, it was at 25.65263 GHz with a value of -24.02982 dB. As for the second curve marker, it was at 26.32604 GHz with a value of -24.01999 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 0.67341 GHz. These results are still not considered satisfactory as the bandwidth is less than 1 GHz. However, the curve's drop point aligns with the predetermined frequency of 26 GHz.

In the S4,4 axis marker, it yielded a result of -27.554559 dB, and for the first curve marker, it was at 25.6642 GHz with a value of -24.02397 dB. As for the second curve marker, it was at 26.32353 GHz with a value of -23.97189 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 0.65933 GHz. These results are still not considered satisfactory as the bandwidth is less than 1 GHz. However, the curve's drop point aligns with the predetermined frequency of 26 GHz.

The figure below represents the VSWR of the 2x2 MIMO Antenna Design using the Double U-Slot and DGS method.

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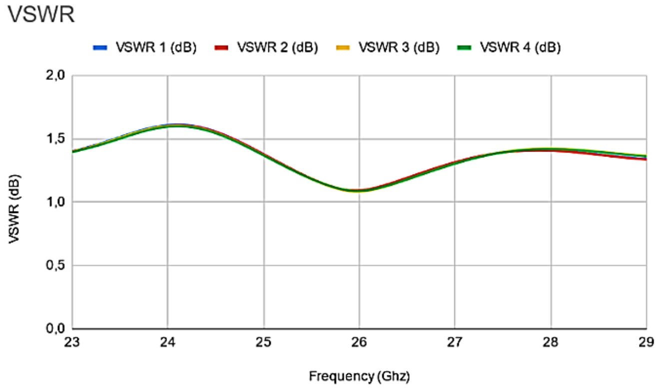

Figure 9. The VSWR Results After Optimization of the 2x2 MIMO Antenna Design Using the Double U-Slot and DGS Method

In Figure 6, it shows the VSWR results of the 2x2 MIMO Antenna Design using the Double U-Slot and DGS method. In the VSWR-1 axis marker, it yielded a result of 1.0874368 dB, and for the first curve marker, it was at 25.46208 GHz with a value of 1.197378 dB. As for the second curve marker, it was at 26.53089 GHz with a value of 1.199771 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 1.06881 GHz. These results are good as they meet the criterion of a bandwidth ≥ 1 GHz. The curve's drop point aligns with the predetermined frequency of 26 GHz.

In the VSWR-2 axis marker, it yielded a result of 1.0928211 dB, and for the first curve marker, it was at 25.46672 GHz with a value of 1.196703 dB. As for the second curve marker, it was at 26.52191 GHz with a value of 1.197867 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 1.05519 GHz. These results are good as they meet the criterion of a bandwidth ≥ 1 GHz. The curve's drop point aligns with the predetermined frequency of 26 GHz.

In the VSWR-3 axis marker, it yielded a result of 1.082027 dB, and for the first curve marker, it was at 25.45382 GHz with a value of 1.196835 dB. As for the second curve marker, it was at 26.58405 GHz with a value of 1.199743 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 1.13023 GHz. These results are good as they meet the criterion of a bandwidth ≥ 1 GHz. The curve's drop point aligns with the predetermined frequency of 26 GHz.

In the VSWR-4 axis marker, it yielded a result of 1.087477 dB, and for the first curve marker, it was at 25.44822 GHz with a value of 1.1994 dB. As for the second curve marker, it was at 26.59523 GHz with a value of 1.202519 dB. The bandwidth was calculated by subtracting the second curve marker from the first, resulting in 1.14701 GHz. These results are good as they meet the criterion of a bandwidth ≥ 1 GHz. The curve's drop point aligns with the predetermined frequency of 26 GHz.

The figure below represents the far-field with the output Directivity of the 2x2 MIMO Antenna Design using the Double U-Slot and DGS method.

To perform a comparison between the data before and after optimization, several metrics are used, as seen in Table 3.

Table 3. Return Loss, VSWR, and Bandwidth

Port	Before Optimization			After Optimization		
	Return Loss (dB)	**VSWR (dB)**	**Bandwidth (Ghz)**	**Return Loss (dB)**	**VSWR (dB)**	**Bandwidth (Ghz)**
1	-14.152173	1.4877511	0.64677	- 27.55838	1.0874368	1.06881
2	-14.197253	1.4846144	0.65541	-27.061711	1.0928211	1.05519
3	-14.193865	1.4848494	0.89161	-28.090594	1.082027	1.13023
4	-14.263401	1.4800553	0.92235	-27.554559	1.087477	1.1.14701

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In this case, the metrics used are return loss, VSWR, and bandwidth. Before optimization, the initial data indicated a measured return loss of approximately -14.152173 dB, a VSWR value of around 1.4877511 dB, and a bandwidth value of about 0.64677 GHz. After optimization, the results for return loss ranged from -14.15 to -14.26 dB, VSWR ranged from 1.48 to 1.49 dB, and bandwidth ranged from 0.65 to 0.92 GHz, as shown in Table 2.

After optimization, the return loss has improved and ranges from -27.06 to -28.09 dB. The increase in return loss indicates that the optimization has successfully enhanced the antenna's performance at that port, achieving better values. VSWR after optimization has slightly increased from the previous values and ranges from 1.08 to 1.09 dB. Although there is an increase, VSWR values remaining below 2 are still considered good. Furthermore, the bandwidth after optimization has also increased and ranges from 1.06 to 1.13 GHz. This demonstrates that the optimization has successfully improved the bandwidth width accommodated by the system, resulting in better antenna performance.

4. CONCLUSION

The obtained results include return loss, VSWR, and bandwidth. Before optimization, the initial data indicated a measured return loss of approximately -14.152173 dB, a VSWR value of around 1.4877511 dB, and a bandwidth value of about 0.64677 GHz. After optimization, the results for return loss ranged from -14.15 to -14.26 dB, VSWR ranged from 1.48 to 1.49 dB, and bandwidth ranged from 0.65 to 0.92 GHz. Following optimization, return loss experienced a significant increase, ranging from -27.06 to -28.09 dB. This increase in return loss indicates that the optimization successfully enhanced the antenna's performance at that port, achieving better values. VSWR after optimization showed a slight increase from the previous values and ranged from 1.08 to 1.09 dB. Although there was an increase, VSWR values remaining below 2 are considered acceptable. Furthermore, bandwidth after optimization also increased significantly, ranging from 1.06 to 1.13 GHz. This demonstrates that the optimization successfully improved the bandwidth width accommodated by the system, leading to improved antenna performance overall.

The design can be implemented in 5G technology; however, further evaluation and field testing are required to ensure that the antenna's performance aligns with the desired needs and objectives.

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