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Integrated Microstrip Antenna Reflector Based on SIW for 5G Networks

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Abstract

High data rates, low latency, and low energy consumption are required for the fifth-generation (5G) mobile wireless network. One of the devices that garner interest to be developed is the antenna. Microstrip antennas are widely used in cellular communications because of their simple profile and easy fabrication. However, it has limitations in terms of performance. The millimeter-wave band has been selected to provide high-speed service in 5G wireless networks. Compared to other frequency bands, the propagation path in millimeter-wave is significantly decreased. The substrate integrated waveguide (SIW) technology aims to integrate all components on the same substrate, with low insertion loss and a low profile. Using a dielectric substrate on top and a metallic coating at the bottom with metalized holes, the SIW structure offers a compact form factor for integrating active circuits, passive components, and radiation elements within the same substrate. Therefore, this study aims to design and implement a reflector integrated microstrip antenna with a compact form and a working frequency of 26 GHz. The measurements showed the return loss value of -11 dB, voltage standing wave ratio (VSWR) of 1.9, and the antenna impedance of 63 Ω. The antenna that was designed and fabricated in this work is suitable for operation in the millimeter-wave range for 5G technology.

Keywords: microstrip antenna, SIW, millimeter-wave, reflector, 5G

I. Introduction

The year 2020 is the preparation stage for entering the 5th generation (5G). The international telecommunication union (ITU) recommends that 5G technology parameters are data rate of 10 - 20 Gbit/s, user speed of 100 Mbit/s, latency of 1 ms, mobility capability of 500 km/h, connection density of 106 devices/km^2, and the energy efficiency of 100 times the international mobile telecommunications-advanced (IMT-Advanced) standard, spectrum efficiency 3 times the IMT-Advanced standard, and a traffic area capacity of 10 Mbit/s/m^2 [1].

Puskely et al. [2] proposed an antenna array based on substrate integrated waveguide (SIW) technology for 5G base stations. The proposed antenna array has a cosecant radiation pattern in the vertical plane for uniform illumination in the sector area. An array with a pair of vias canceling reflections and a phasing element to obtain a tapered distribution in amplitude and phase for a cosecant-shaped radiation pattern. This array was designed to operate at 28 GHz and is proven to increase bandwidth by more than 10 %.

Wu et al. [3] argue that the popularity of the SIW technique is due to its ability to integrate planar and non-planar structures. Further, the development of circuits and future generation systems such as system-on-substrate (SoS) enables them to combine their advantages by reducing the potential disadvantages.

Pratomo et al. [4], in 2017, tested the bolic antenna reflector material to increase wifi reception in the wireless USB adapter reception process. The statistical analysis concludes that all types of reflector materials affect changes in signal strength. This observation has been taken into design consideration in this work to improve the performance of the antenna.

Sandy et al. [5], in 2019, designed an antenna with the SIW technique to improve antenna performance on 5G networks by providing better impedance matching to reduce surface wave loss in h-slot structure microstrip antennas, without gaps in the substrate layer. This design approach is proven to increase antenna gain. The results of the study have been considered as the basis for the proposed antenna design in this work.

Furthermore, in 2020, Sepryanto et al. [6], fabricated the same cavity hybrid slot microstrip antenna with simulation resulting in an antenna gain of 5.49 dB. Whereas the gain measurement cannot be carried out because the chamber device did not support antennas with frequency > 20 GHz. This study supports the basis that the SIW technique can improve antenna performance. A triple biquad base station broadband wireless access (BWA) antenna with a reflector was designed and fabricated in [7]. This study concludes that some of the reflectors on the antenna affect the

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characteristics of the antenna, especially on the gain and radiation pattern. This has also been used as a basis in this work for designing the proposed antenna from the reflector side.

Simple microstrip antennas were designed at 38 GHz and 54 GHz and arrays with 38.6 GHz, 47.7 GHz, and 54 GHz frequencies in [8]. The microstrip antenna provided a gain of 6.9 dB for 38 GHz and 7.4 dB for 54 GHz, respectively. The antenna with a linear array of 4 elements gave a gain of 12.2 dB for 38.6 GHz, 11.6 dB for 47.7 GHz, and 12.1 dB for 54 GHz, respectively. This shows that high gain with array techniques can also improve antenna performance on 5G networks. Thus, the microstrip patch antenna is suitable for 5G networks and has served as the basis for the proposed antenna design in this work. Then, in 2021, Simanjuntak et al. [9] designed a triangular array microstrip patch for an antenna in a 5G application that worked at a frequency of 28 GHz with a return loss value of -26.98 dB, voltage standing wave ratio (VSWR) 1.09, a gain of 8.8 dB, half power beam width (HPBW) value of 25.6° and the main lobe of 21.0 dBi.

A summary of previous research relevant to this work is available in Table 1. Imran et al. [10], in 2018, designed a microstrip patch antenna for 5G communication with a working frequency of 38 GHz and 54 GHz which have bandwidths of 1.94 GHz and 2 GHz, respectively. From this study, it was found that the microstrip patch model has reached a minimum bandwidth of 1 GHz to support 5G applications. Conventional microstrip patch antennas are manufactured using printed circuit board technology, as shown in Figure 1 [10].

The design consists of a radiating patch, a substrate with a dielectric constant, a feed line, and a ground. So far, most of the studies have used various designs and have developed new shapes for radiation patches. Some of the studies listed in Table 1 have made improvements to several antenna parameters which improve the antenna performance.

Through a brief description listed in Table 1, we have proposed to design a microstrip antenna with SIW technology and the addition of a reflector to the 5G network. The working frequency used was 26 GHz to be able to support 5G networks in the millimeter-waveband. This antenna was expected to increase its bandwidth and beam gain with a fairly small dimension and low level of complexity for a low-cost manufacturing process. This paper outlines the literature studies, design, simulation, implementation, measurement, results, and analysis of the results of the current work. The parameters further presented in this paper are the value of working frequency, return loss, impedance, and VSWR of simulated and fabricated antennas.

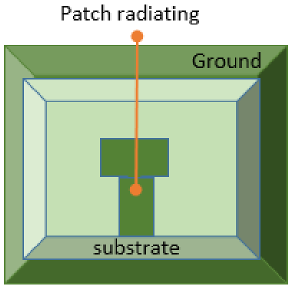


Figure 1. Conventional microstrip patch antenna [10]

TABLE 1
STATE OF THE ART RESEARCH

Authors	Title	Antenna	Freq.	Result
Sandi et al. (2019)	Design of substrate integrated waveguide to improve antenna performances for 5G mobile communication application	Microstrip circular SIW 5G	28 GHz	Gain increases
Se-pryanto et al. (2020)	SIW cavity-backed modified dumbell-shaped slot microstrip antenna design for applications in 5G	Microstrip patch SIW 5G	28 GHz	Antenna perfor-mance complies with 5G require-ments
Azis et al. (2016)	Design and realization of a triple biquad microstrip antenna with flat reflector for access point on site WLAN 2,4 GHz	Microstrip patch reflector WLAN	2.4 GHz	Gain increases
Imran et al. (2018)	Millimeter-wave microstrip patch antenna for 5G mobile communication	Microstrip patch 5G	38 – 54 GHz	Antenna perfor-mance complies with 5G require-ments
Siman-juntak et al. (2021)	Design of triangular array microstrip patch for antenna 5G application	Microstrip patch triangular 5G	28 GHz	Antenna perfor-mance complies with 5G require-ments

II. METHOD

A. Microstrip Antenna Design Flowchart

Figure 2 presents the steps taken antenna to the final stage of the desired antenna design. After performing a literature study, this work proceeded with designing by performing calculations according to the formulas used in the works of literature, followed by simulations until the results conformed to the designated values, then fabrication was carried out. Measurements were carried out after the fabrication, analysis, and conclusions.

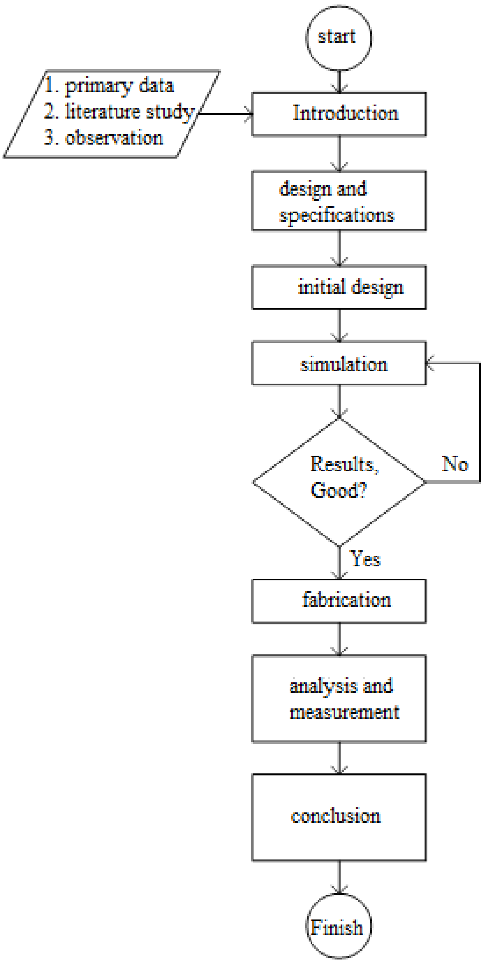


Figure 2. Antenna design and manufacture flowchart

B. Antenna Structure Design

The microstrip patch antenna is designed using the transmission line model with the formula (1) and (2) [11].

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

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

$$\frac{\Delta}{H} = 0.412\,\frac{\epsilon_{eff}+0.300}{\epsilon_{eff}-0.258}\,\frac{W/_H+0.262}{W/_H+0.813} \quad (3)$$

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+\frac{10H}{W}\right)^{-1/2}$$

where ϵ_r is dielectric constant, Δ is effective cutting distance, C is the speed of light, F is middle frequency, and H is the thickness of the substrate. The conductance radiation for parallel plate radiation G is formulated in (4) [11].

$$G = \frac{\pi W}{\eta\lambda_0}\left[1-\frac{(kH)^2}{24}\right] \quad (4)$$

$$\mathrm{Re} = \frac{1}{2G} \quad (5)$$

$$\mathrm{Ri} = \mathrm{Re}\ sin^2\ \frac{\pi x}{L} \quad (6)$$

where $0 <= x <= \frac{L}{2}$
or it can be written in another form as (7).

$$X = \frac{L}{\pi}\ sin^{-1}\sqrt{\frac{Ri}{Re}} \quad (7)$$

where X is the distance of the feeder to the center of the antenna, Re is resistance at the end of the antenna, Ri is input resistance on the SMA jack (50 Ω), and G is radiation conductance for parallel plate radiation.

After performing calculations from (1) to (7), the obtained parameters of the proposed antenna are listed in Table 2. The proposed antenna structure shown in Figure 3 contains an air cavity used to increase radiation. However, the slot excitations that control reflection, bandwidth, and polarization are different. Both structures have three metal layers. The air cavities with SIW are integrated into two dielectric layers to amplify the signal feeder. The whole design of the waveguide's fundamental mode through the narrow slot.

In Figure 3, the antenna is excited by a transverse SIW slot that must be positioned in the center of the SIW at an equal distance for half the guided wavelength of the short-circuited SIW. However, the non-centralized longitudinal slots are positioned at a distance equal to one-quarter of the guided wavelength from the short-circuited SIW as shown on the top view in Figure 4.

TABLE 2
PARAMETERS FOR THE PROPOSED ANTENNA

Parameter	Value
W	8.5 mm
L	8.5 mm
X	6 mm
Y	9.5 mm
Substrate 1	0.8 mm FR4
Substrate 2	0.8 mm FR4
ε_{r1}	4.4 (constant)
ε_{r2}	4.4 (constant)
d1 = d2 (diameter via)	1 mm (constant)
l1 = l2 (distance between via)	2 mm (constant)
Box	10 mm x 10 mm
Air	4 mm
Middle frequency	26 GHz
Δ = edge distance	1 mm

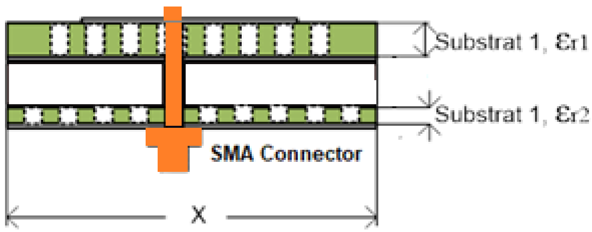


Figure 3. Side view of the antenna

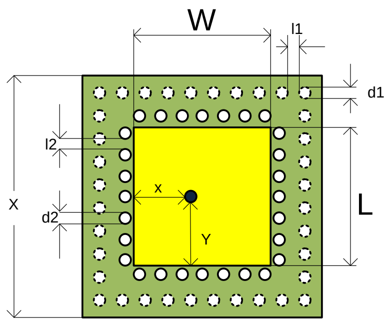


Figure 4. Top view of the antenna

C. Simulation

The SIW microstrip antenna has a size of 18 mm × 18 mm, with a patch antenna width of 8.5 mm × 8.5 mm, and the planned working frequency at 26 GHz is the 5G operating frequency. For the millimeter-wave group simulation process, Sonnet project editor 15.52 professional software was used.

As seen in Figure 5, the proposed antenna is in the form of a SIW microstrip with additional reflectors on each side.

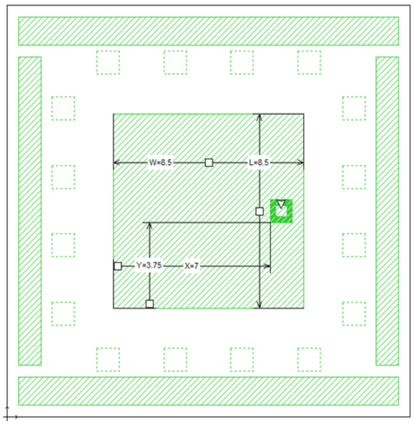


Figure 5. The proposed antenna model

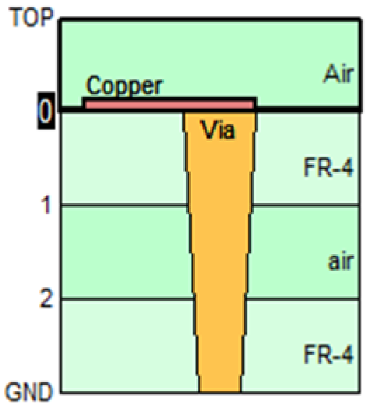


Figure 6. Antenna cross-section

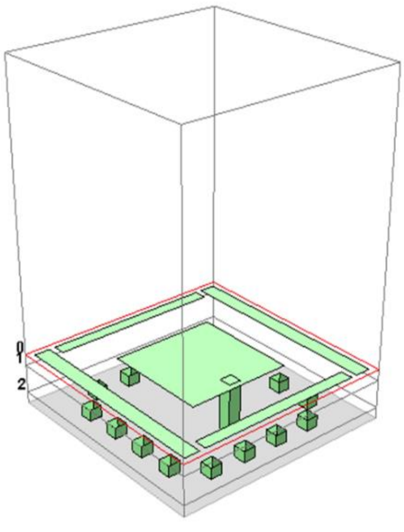


Figure 7. The appearance of a 3D drawing

The SIW microstrip antenna in Figure 6 consists of 4 layers, the first layer is air, the second layer is FR4 type substrate, the third layer is air, and the fourth layer is FR4 type substrate. After making a technical drawing using sonnet software, an initial 3-dimensional (3D) image was obtained and shown in Figure 7.

Figure 8 compares the return loss antenna at 26 GHz frequency without SIW obtained in [12] and from the simulation obtained in this work. Based on the graphs in Figure 8, the amount of return loss increases by using the SIW technique, which also increases the bandwidth. Also, after iterating using Sonnet software, the S_{11} as a representation of attenuation was obtained at around -40 dB.

A comparison of S_{11} parameters after using a SIW and without SIW whose frequency deviates from 26 GHz is shown in Figure 8. After using the SIW method, the results were improved. The value of -40 dB informs that the simulated antenna can radiate due to an attenuation value below -10 dB. In the S_{11} curve, the bandwidth value is around 400 Mb.7

In Figure 9, it can be seen that there are 8 (eight) pairs of points on the antenna that emit current radiation at the working frequency of 26 GHz.

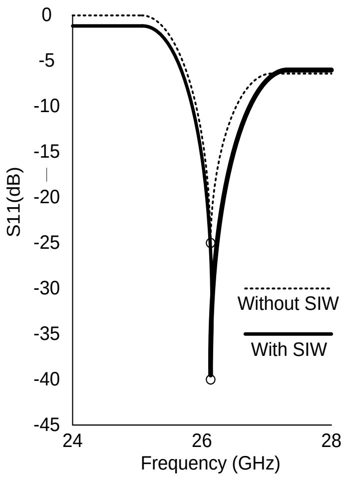


Figure 8. Comparison of S_{11} parameters of the antenna with SIW and without SIW [12] S_{11} at 26 GHz

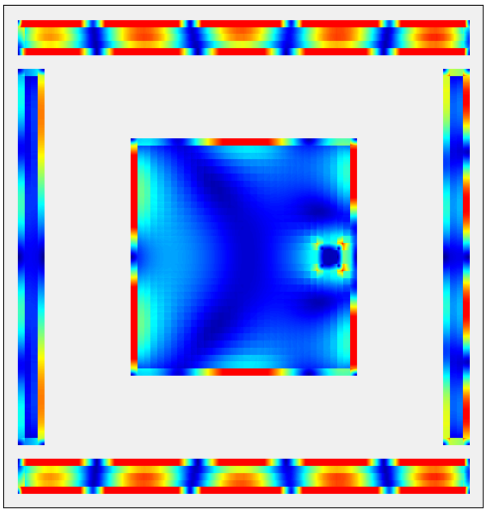


Figure 9. 8 (Eight) points of current radiation at the working frequency

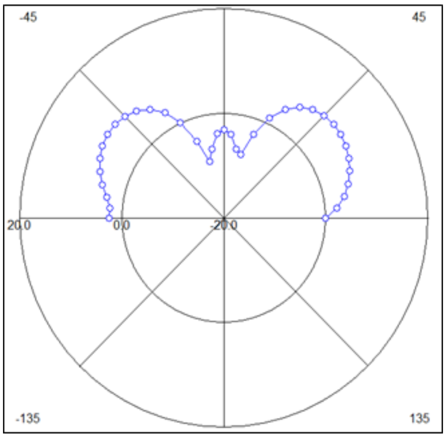


Figure 10. The antenna transmit direction

In Figure 10, the observed direction of the antenna beam is wide and reaches a peak at -45º and 45º. The radiation pattern resembles a shorted monopole because the antenna was designed as a type of waveguide antenna that focuses in one direction. Using the SIW method, the bandwidth is predicted to be wider.

D. Fabrication

The dimension of the fabricated antenna was 1.5 cm × 1 cm, as derived from simulation results. Thin material was selected instead of the common material used for microstrip, i.e. duroid, to ensure the dimension closely matches the dimension derived from the simulation.

As seen in Figure 11, the small dimension of the antenna was due to the frequency used of 26 GHz. Then the SMA female plug straight solder PCB connector mount connector was installed, as depicted in Figure 12.

After the connector was installed, then it was connected to the vector network analyzer (VNA) Anritsu MS46322A, which can measure up to a frequency of 40 GHz. The results are shown in Figure 12.

Next, S_{11} antenna parameters were measured and discussed in the next chapter to evaluate the performance of the proposed microstrip antenna as setup seen in Figure 13.

III. Results and Discussion

A. Measurement of Return Loss

After the fabrication was completed, it was followed by the measurement of the antenna. The measurement of return loss parameters for the microstrip antenna was performed using the Anritsu MS46322A network analyzer. The S_{11} value, i.e. the ratio of the reflected wave to the transmitted wave, can be seen in Figure 14.

Table 3 summarizes the value of the return loss and its frequency. At the center frequency of 26 GHz, the return loss value is -11.2315 dB. This value meets the standard value, which is < -10 dB. The best measurement result was at a frequency of 27.6 GHz with a return loss of -24.43379 dB which lies within the frequency range of 20 – 30 GHz. The return loss at 26 GHz is considered adequate since it complies with the ideal antenna specifications, which is < -10 dB.

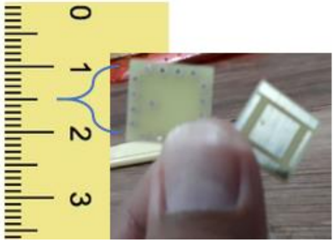
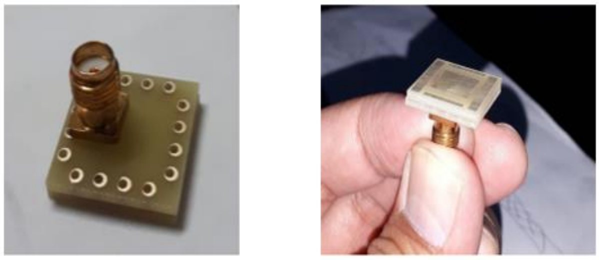


Figure 11. Fabricated antenna



(a) (b)

Figure 12. Antenna plugged with the connector, (a) Antenna top view; (b) Antenna bottom view

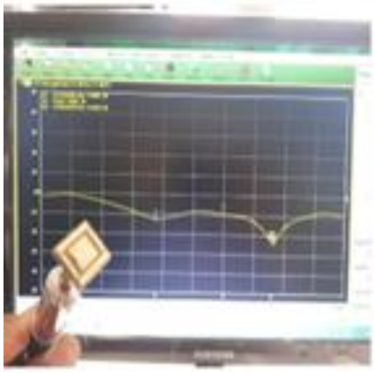


Figure 13. The antenna is connected to the network analyzer

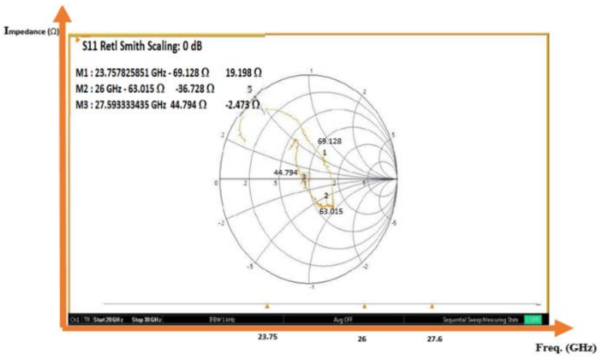


Figure 14. Return loss measurement results

TABLE 3
RETURN LOSS MEASUREMENT RESULTS

Frequency (GHz)	Return Loss
23.75	-13.1927
26	-11.2315
27.6	-24.4337

B. Measurement of VSWR

For the VSWR measurement, VNA Anritsu MS46322A was equipped again using a working frequency of 300 kHz - 40 GHz. The graph of the VSWR measurement results is presented in Figure 15. Table 4 lists the VSWR values based on the graph in Figure 15.

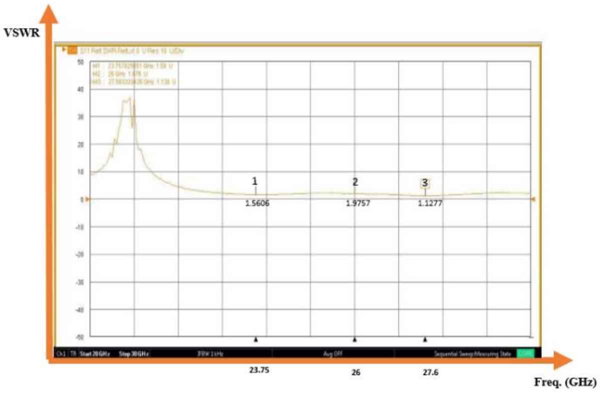


Figure 15. VSWR measurement chart

TABLE 4
VSWR MEASUREMENT RESULTS

Frequency (GHz)	VSWR
23.75	1.5606
26	1.9757
26.9	1.6073
27.6	1.1277

It is divided into four frequencies that each frequency has significant features. From Table 4, the VSWR value for the microstrip antenna at a frequency of 26 GHz is 1.9757. This value meets the ideal specification with a value of < 2. However, the VSWR value is considered better at a frequency of 27.6 GHz. Also, The VSWR value at 27.6 GHz is closest to the simulation value at 1.6073 This value also meets the ideal antenna VSWR parameter standard, which is < 2.

C. Impedance Measurement

Then, the third stage of measurement was to measure the impedance of the proposed antenna. The results can be seen in Figure 16. The magnitude of the measured return loss value accounts for the largest impedance mismatch.

Based on the smith chart data in Figure 16, the values of the input impedance measurement in the frequency range of 23 GHz – 27.6 GHz are listed in Table 5. The input impedance value of 63.015 Ω at a frequency of 26 GHz affects the VSWR value. This occurs due to the characteristic impedance of 50 Ohm when the microstrip antenna is connected to the transmission line and yields a large reflected wave.

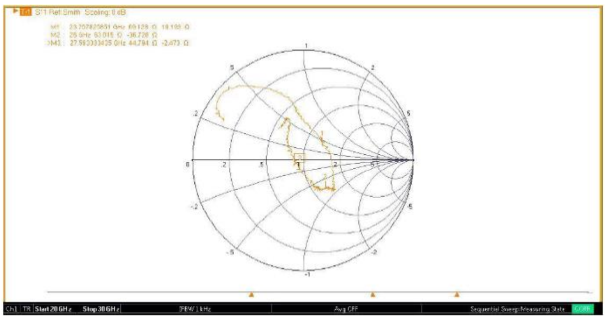


Figure 16. Microstrip antenna impedance measurement

TABLE 5
MEASUREMENT OF IMPEDANCE

Frequency (GHz)	Impedance Measurement Results (Ω)
23.75	69.128
26	63.015
27.6	44.794

D. Discussion

After obtaining the measurement results of the antenna parameters, e.g. VSWR, then these results were compared with the simulation results, provided in Table 6. The performance of the proposed antenna parameters from the VSWR side, the simulation value was 1.997, and the measurement results were 1.9577. The VSWR value of the measurement and simulation results were not considerably different. The fabrication of microstrip antennas that require high precision can cause a slight shift in the dimension that further can affect significant changes in the VSWR value. The resulting input impedance value alters with changes in the VSWR value.

Impedance values that do not match well cause the VSWR value to shift, even though the value is still within the ideal threshold. However, the attenuation is still tolerable, rendering this antenna applicable.

After comparing the simulated and fabricated antenna parameters, there are several influencing factors for the discrepancies. The minuscule dimensions of the antenna require the fabrication of high-precision antenna PCBs. Thus, improper installation of connectors dramatically affects the measurement. The room conditions that allow the presence of reflected waves also affect the discrepancies.

As seen in Table 7 as compared with similar studies, the results of the antenna parameters proposed in this work are not significantly different and the listed parameters have fulfilled the 5G antenna requirements. Therefore, the performance of the proposed antenna meets the standard requirements for 5G antennas. High precision and tools are required to ensure precise dimensions.

TABLE 6
INPUT IMPEDANCE, AND GAIN RESULTING FROM MEASUREMENTS AND SIMULATION RESULTS

Freq. (GHz)	Simulation			Measurement		
	Return Loss (dB)	Impe-dance (Ω)	VSWR	Return Loss (dB)	Impe-dance (Ω)	VSWR
26	< -10	50	1.9977	-11.2315	63.015	1.9757

TABLE 7
INPUT IMPEDANCE, AND GAIN RESULTING FROM MEASUREMENTS AND SIMULATION RESULTS

Reference	Frequency	Return Loss (dB)	VSWR	Band-width
[3]	28 GHz	-22.5	1.16	1.65 MHz
[4]	28 GHz	-24.35	1.039	1.1 GHz
[5]	2.4 GHz	-17.0774	1.328	120 MHz
[7]	28 GHz	-3.81	4.68	1.5 GHz
[8]	38 – 54 GHz	-15.5 – -12	1.3 – 1.64	1.94 – 2 GHz
This work	26 GHz	-11.2315	1.9757	400 MHz

VI. CONCLUSION

Based on the measurement results of the proposed fabricated antenna, the proposed antenna operates at a frequency of 26 GHz with a return loss of -11.231 dB, an impedance of 63.015, and a VSWR of 1.9757. These values are not significantly different from the simulation. It caused etching, incorrect PCB sizes, and improper antenna connector installation. Precision is a significant issue in fabrication and measurement due to the antenna's tiny dimensions. Precision dimensions necessitate high precision and tools. Despite this issue, the antenna fabricated with SIW in this work conforms to the 5G antenna requirements.

DECLARATIONS

Conflict of Interest

The authors have declared that no competing interests exist.

CRediT Authorship Contribution

I. U. V. Simanjuntak: Conceptualization, Methodology, Writing-Original draft, Supervision; A. D. Rochendi: Software, Data curation, Funding Acquisition; L. M. Silalahi: Visualization, Investigation, Writing - Review & Editing.

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