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Design Build a 4x4 Mimo Microstrip Antenna with Artificial Dielectric Muse Array Technique to increase Antenna Gain pexisting Application 5G

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Abstract - The development of fifth-generation cellular technology, commonly referred to as "5G" networks, is believed to be able to maximize data speed access needs. In order to maximize the utilization of the existing 5G network in Indonesia, Telkomsel providers are using a frequency of 2.3 GHz with a bandwidth of 50 MHz. So we need an antenna amplifier that is easy to fabricate and place anywhere to maximize the signal capture range. A microstrip antenna is a suitable antenna for this amplifier. The advantage of this antenna is that it has a light mass and is easy to fabricate. while the drawbacks come in the form of narrow bandwidth and small gains. Therefore, an antenna design with an artificial substrate and array technique was made to overcome this. The design of this microstrip antenna was made in the CST Studio Suite 2019. The design was carried out by entering the antenna dimension values to be simulated and seeing the parameters; if they are not suitable, then they need to be optimized again, and when they are appropriate, the design results are fabricated and printed. In testing the signal capture power using the Xirrus WiFi Inspector, this antenna was able to capture the signal beam, which was 105 meters or 40 meters further than not using the antenna. In addition, from testing, it is known that this antenna has a gain of 16.15 dBi. While in the simulation, it is also known that this antenna has the following characteristics: return loss: -32,353 dB (S11), -32,737 dB (S22), -33,974 dB (S33), -34,423 dB (S44), VSWR: 1,049 (VSWR 1), 1,047 (VSWR 2), 1.040 (VSWR 3), 1.038 (VSWR 4), impedance: 50.7 -111 MHz.

Keywords* : 5G, *Microstrip Antenna*, *Bandwidth*, 2,3 GHz *Frequency*, *Substrat dielectrict artificial

1. INTRODUCTION

The development of technology that continues to undergo changes makes the mobility of data and internet access demand that they be faster. The advancement of fifth-generation cellular technology, also known as "5G," is capable of meeting the demands for high-speed data access.5G is a development of cellular technology that utilizes an intelligent network that is able to carry large quantities of data faster. 5G technology in its initial implementation uses a certain frequency spectrum. The frequency spectrum owned by cellular operators and used as the main candidate for 5G in Indonesia is at 2.3 GHz, or 2,300 KHz, or midband [1].

According to [2], the characteristics of 5G networks at high frequencies mean that to achieve certain coverage, 5G technology requires more base stations compared to 3G and 4G technology. Therefore, an electromagnetic device is needed that can maximize the response when the 5G network frequency signal is maximized, one of which is to use an antenna as a network amplifier device. One of the antennas that can be used is a microstrip antenna.

A microstrip antenna has several advantages over other types of antennas, including its light weight, ease of fabrication, ability to be placed on almost any surface, and smaller size [2].However, this antenna has the disadvantage of a narrow antenna frequency bandwidth and also in terms of radiating lectromagnetic e-wave power. According to some microstrip antenna test data, an antenna that works at a frequency of 2.3 GHz produces gains ranging from 4.5 dBi [3] to 7 dBi [4].

The design of the 4x4 MIMO microstrip antenna has been carried out pno research [6] designing a single-element square microstrip antenna using anisotropic dielectric material at a frequency of 1.8 GHz. Artificial antennas have a greater return loss than conventional antennas. Using anisotropic dielectric materials with asingle element square microstrip has been performed [7]. At [8] realization of hexagonal patch-shaped array microstrip antennas at f15 GHz recurrence for the application of 5G technology. However, the consequence of using these high frequencies is that the transmitted wavelengths become short and vulnerable to weather and obstacles.

The poor ability of electromagnetic power radiation on this antenna can be overcome by array technique or yang commonly called stacking technique [5]. The purpose of this is to increase the size of the antenna gain. In addition, in the manufacture of microstrip antennas, it is also recommended to use substrates made from dielectric materials. It is aimed at increasing the bandwidth of narrow antennas [6]. In addition to adding new substrates and array techniques to increase gain and bandwidth, microstrip antennas should also use multiple input and multiple output (MIMO) systems [6].

The use of a microstrip antenna on a repeater is to improve the quality of the receiving antenna (the transmitter) so that it can handle multipath fading. Multipath fading itself is a condition where the signal emitted is diffracted due to the reflection of surrounding objects, which results in a signal being emitted and having a different phase [7].

This antenna has several functions, for example, in satellite communication, such as Wimax, radar, and gain. In addition to this, the use of this antenna is not only limited to one frequency but can also work at more than one frequency and is modified on the array of the antenna to produce good antenna parameters [8].

Modified substrates are insertion techniques on microstrip antenna substrates that utilize materials that have electromagnetic material properties, where the materials used are available in nature to increase the value of permittivity [13]. Dielectric materials can be made by utilizing material hosts such as acrylic. The properties of the dielectric are further generated by dipping a thin conductor wire with a diameter of 1 mm and a height of 10 mm; the wires are given to the lower right and top. The installation of the conductor wires refers to the distribution of the electric field in mode 11 [5].

The array technique is a technique of creating antennas consisting of two or more identical antennas that are then combined on a source or load that has been arranged based on certain geometric and electrical configurations to obtain a directive radiation pattern [11].

MIMO is a system that employs multiple antennas on both the transmitter and receiver sides.The system makes use of M transmitting antennas and N receiving antennas [3]. As a result, it is frequently written with the writing system MIMO (M x N). Thus, MIMO 4x4 states that the number of antennas on the transmitter side and the receiver side are equal to four. This MIMO antenna system has its own advantages in that the MIMO antenna system in high-speed wireless communication is able to overcome multipath fading. The main cause of multipath fading itself is the user's erratic mobility, which makes the signal trajectory different from the base station to the user's handset. Multipath fading itself causes the signal received on the user's side to be weak, defective, or interfered with [3].

II. METODE DAN DESAIN

This antenna manufacturing method begins with designing and manufacturing a research flowchart. The following in Figure 1 is the flowchart used in this study:

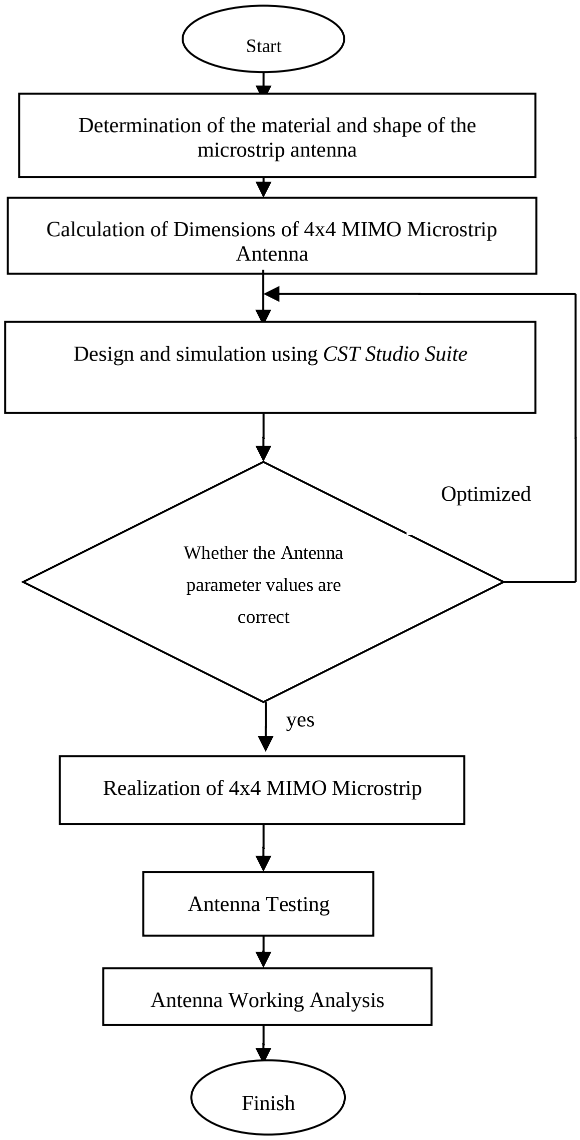


Figure 1. *Flowchart*

Based on the flowchart, the work process of making a 4x4 MIMO antenna begins with determining the raw materials you want to use. At the next stage the researcher performs useful calculations to determine the magnitude of the value of the antenna parameter to be created. These parameters are determined in such a way as to match the specifications of the antenna to be created.

A. Antenna Dimensions Calculation

The first stage of antenna design is the calculation of the antenna dimension value required for the antenna design process. Where the dimensions of the antenna include:

1. Patch Section

In the Patch section are searched for the values of patch width (Wp) and patch length (Lp) with the following equation:

a. Patch width : $Wp = \frac{C}{2fr\sqrt{\frac{\varepsilon r+1}{2}}}$ = **40.062 mm** (1)

b. Patch length :

a) value ε_{reff} :

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left|\frac{1}{\sqrt{1+\frac{12h}{wp}}}\right| = 3{,}3976 \text{ mm} \quad (2)$$

b) antenna length value :

$$Lp = L_{eff} - 2\Delta L \quad (3)$$

$$= \frac{C}{2fr\sqrt{\varepsilon reff}} - 2 \times 0{,}412 \times h\left(\frac{(\varepsilon reff+0.3)\left(\frac{W}{h}+0{,}264\right)}{(\varepsilon reff-0{,}258)\left(\frac{W}{h}+0{,}8\right)}\right)$$

= **33,0315 mm**

2. Logging Section

After obtaining the large values of the dimensions of the length and width of the patch, the researcher then calculated the width (wf) and length (lf) of the first supply channel for $Z_0 = 50\ \Omega$, which previously had to look for variable B as follows :

$$B = \frac{60\pi^2}{Zo\sqrt{\varepsilon r}} = 5{,}707477 \quad (4)$$

a. Width feeder 50 ohm (Wf)

The following is the value of the width of the antenna supply channel obtained by calculating mathematically:

$$Wf = \frac{2h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon r-1}{2\varepsilon r}\left[\ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon r}\right]\right\}$$

= **4,8625 mm** (5)

b. Feeder Length 50 ohm (Lf)

The following is the value of the length of the antenna supply channel obtained by calculating mathematically:

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left|\frac{1}{\sqrt{1+\frac{12h}{wf}}}\right| = 2{,}7662 \quad (6)$$

After getting the value of reff, calculate the length of the antenna supply channel with the following formula:

$$Lf = \frac{1}{4}\left(\frac{\frac{C}{fr}}{\sqrt{\varepsilon reff}}\right) = \frac{1}{4}\left(\frac{\frac{3.10^8}{23.10^8}}{\sqrt{2{,}7662}}\right) = \mathbf{19{,}6061\ mm} \quad (7)$$

3. T-Junction (*Matching Impedance*)

After obtaining the Length and Width of the logging channel for $Z_0 = 50\ \Omega$, next the researcher looked for the Length (wfi) and Width (Lt) of the next logging channel for the previous one should look for variable B as follows :

$$Z_{0,1} = \sqrt{50 \times 100} = \sqrt{5000} = 70{,}71 \text{ ohm} \quad (8)$$

$$B = \frac{60\pi^2}{Zo\sqrt{\varepsilon r}} = \frac{60(3{,}14)^2}{70{,}71\sqrt{4{,}3}} = 4{,}0358344 \quad (9)$$

a. *T-Junction* Width(Wfi)

The following is the value of the antenna *impedance matching* channel width obtained by calculating mathematically:

$$Wfi = \frac{2h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon r-1}{2\varepsilon r}\left[\ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon r}\right]\right\}$$

$= \mathbf{4{,}3194\ mm}$ (10)

b. T-junction length (Lt)

The following is the value of the antenna *impedance matching* channel length obtained by calculating mathematically:

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left|\frac{1}{\sqrt{1+\frac{12h}{wf}}}\right| = 2{,}7354 \quad (11)$$

Once you can get the ε value of the$_{chorus}$, then calculate the length of the supply channel ante the length of the *channel matching the antenna impedance* with the following formula :

$$Lt = \frac{1}{4}\left(\frac{\frac{C}{fr}}{\sqrt{\varepsilon reff}}\right) = \mathbf{19{,}711\ \ mm} \quad (12)$$

4. Substrate Parts

The material used for the substrate is FR-4 (*Flame Reterdant* 4). with a thickness of h = 2.5 mm. After knowing the value of h, calculate the value of Ls by entering the value of h = 2.5 mm , Lp = 33.0315 mm, Lf = 19.6061 mm , and Wp = 40.062 mm in the following formula :

a. Substrate Length

Ls = 6h + Lp + Lf = **67,6376mm** (13)

b. Substrate Width :

Ws = 6h + 2Wp = **95,124 mm** (14)

5. Groundplane Section

The size of the ground plane will be equal to the substrate, by k arena we already get the values of the length of the substrate (Ls) and the width of thesubstrate (Ws) then, the length of the groundplane (Lg) and the width of the groundplane (Wg) can be determined as follows:

Lg = Ls = 67,6376 mm

Wg = Ws = 95,124 mm

B. Antenna Dimension Calculation Results and Their Optimization

The following is a table of antenna dimension calculation results :

Table 1. Antenna Dimensions Calculation Results

Variable	Size (mm)
Lp	33,0315
Wp	40,062
ε_{eff} (untuk Z_0 = 50 ohm)	2,7662
ε_{eff} (untuk Z_0 = 70,71 ohm)	2,7354
ε_r	4,3
Lf	19,6061
Wf	4,8625
Lt	19,711
Wfi	4,3194
H	2,5
Ls	67,6376
Ws	95,124
Lg	67,6376
Wg	95,124
T	0,036

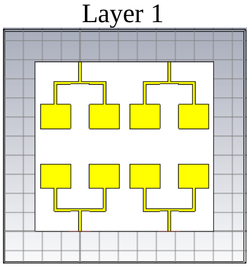
Table 2. Antenna Dimension Optimization Results

Variable	Size (mm)
Lp	25.2700
Wp	31.7650
ε_{eff} (untuk Z_0 = 50 ohm)	2,7662
ε_{eff} (untuk Z_0 = 70,71 ohm)	2,7354
ε_r	4,3
Lf	21.1291
Wf	2.9451
Lt	19,6711
Wfi	2,41546
H	2,5
Ls	88.82075
Ws	93.884
Lg	88.82075
Wg	93.884
T	0,036

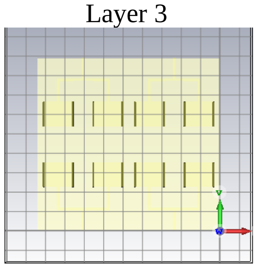
C. Antenna Design Display On Application And Antenna After Fabrication

The following is the appearance of the antenna that has been optimized and in accordance with the desired specifications:

Layer 1



Layer 3



Layer 3

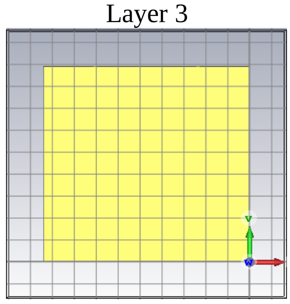


Figure 2 Display Mimo 4x4 antenna design

While the following is the appearance of the antenna after being fabricated into a Mimo 4x4 microstrip antenna :

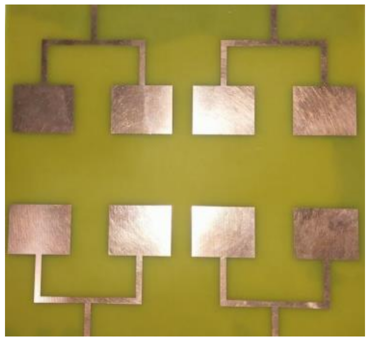


Figure 3. 4x4 MIMO Microstrip Antenna after fabrication

D. Specifications of the designed Antenna

The manufacture of antennas is inseparable from an antenna parameter specification. Specifications are the benchmark for an antenna whether it is in accordance or not with the wishes of the researcher. The design of this antenna has the following specifications :

The parameters of the antenna measured are :

a. Working Frequency : 2,3 GHz
b. Terminal impedance : 50 Ohm
c. VSWR : ≤ 2
d. Radiation patterns : Directive
e. Gain : $\geq$2.5 dB
f. Returnloss : $\leq$ -10 dB
g. Bandwidth : $\geq$ 100 MHz
h. Patch Form : Rectangle

III. RESULTS AND DISCUSSION

A. Antenna Characteristics

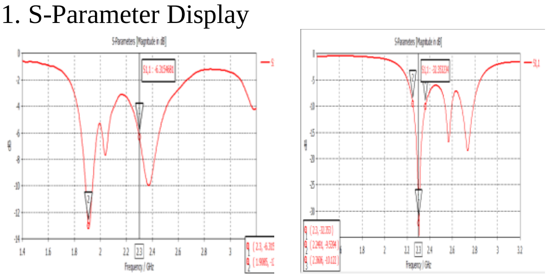
Based on the Calculation Results and after optimization (CST Studio Microwave Suite Simulation Results). From the results of calculations and optimizations, it is known that both of them have different parameter values, to see the difference, shown in table 3.

Table 3. Antenna parameter value comparison After and Before Optimization

Parameters	Calculation Results (Mathematically)	Optimization Results
Working Frequency	1,9 GHz	2,3 GHz
Return Loss :		
a. S1.1	-6,3155 dB	-32,353 dB
b. S2.2	-6,3373 dB	-32,737 dB
c. S3.3	-6,4129 dB	-33,974 dB
d. S4.4	-6,4342 dB	-34,423 dB
VSWR :		
a. VSWR 1	2,870	1,049
b. VSWR 2	2,861	1,047
c. VSWR 3	2,830	1,040
d. VSWR 4	2,822	1,038
Impedance :		
a. S1.1	31,234 ohm	50,756 ohm
b. S2.2	31,201 ohm	50,997 ohm
c. S3.3	32,364 ohm	50,562 ohm
d. S4.4	32,324 ohm	50,801 ohm
Gain	3,768 dB	5,901 dB

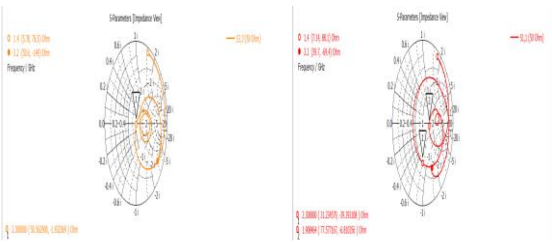
In Figures (4) and (5) is a display of the characteristics of the antenna as a result of simulation and what has beendone:

1. S-Parameter Display



(a) (b)

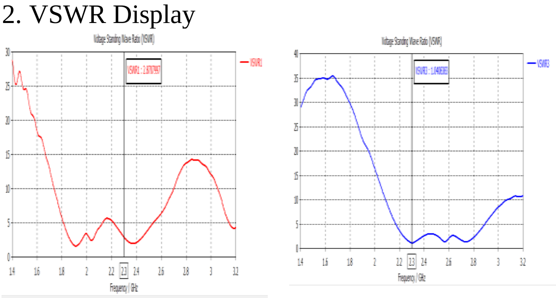
Figure 4. (a) Return loss Calculation Results (b) Return loss Optimization Results



(a) (b)

Figure 5. (a) Impedance of Calculation Results (b) Impedance Optimization Results

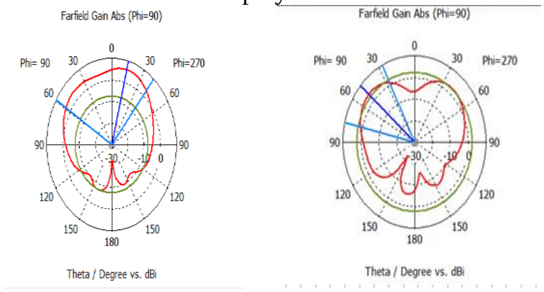
2. VSWR Display



(a) (b)

Figure 6. (a) VSWR Calculation Results (b) VSWR Optimization Results

3. Radiation Pattern Display



(a) (b)

Figure 7. (a) Radiation Pattern Optimization Results (b) Calculated Radiation Patterns

According to the data, the parameter values obtained from the simulation of antenna dimensions did not correspond to the characteristics of the antenna to be made, where the characteristics of the antenna parameters sought were: working frequency: 2.3 GHz, return loss: -10 dB, vswr 2, impedance: 50 ohms, and a directional radiation pattern. Therefore, it is necessary to optimize again. Meanwhile, after being optimized, which has been done, it produces parameter values according to the characteristics of the antenna, which will have a decent gain compared to before it was optimized.

B. Antenna Measurement

The antenna measurement carried out by the researcher is to measure the power that the antenna receives as a receiver or rectifier. where the rated power is the Rx power of the antenna. The tool used to see the power that this antenna detects is a spectrum analyzer. Measurements are carried out at the Telecommunication Engineering Laboratory by utilizing a signal generator as a source of transmitting frequencies. Here's what the measurement result data looks like :

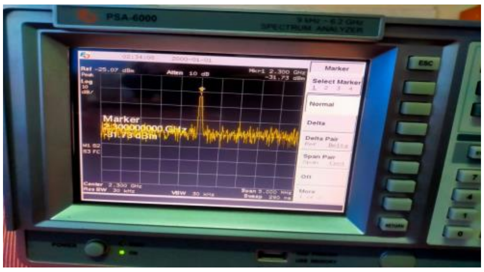


Figure 8 Measurement Results

From the display spectrum analyzer in Figure 8, it is known that in the power measurement on the receiving antenna using a signal generator and spectrum analyzer, it is obtained that the antenna can capture a signal with a working frequency of 2.3 GHz and an Rx (PRX) power of -31.73 dBm. So it can be said that the antenna can function as it should at a predetermined frequency.

C. Antenna Testing

Antenna testing activities are carried out to determine the gain and performance of the antenna and the progress that has been made in strengthening the captured network, as well as to find out how far the antenna capture distance has been increased for the 5G network being tested. This test was carried out by utilizing hotspots from cellphones that have been integrated with 5G networks and testing in areas that have been covered by Telkomsel's 5G provider network, which is at a frequency of 2300 MHz. The antenna testing procedure is performed by measuring the signal capture capability within the range of the antenna at each variation of the measurement distance. Signal measurement is carried out by comparing the signal power received by the assistive device (in this case, a laptop) without using the antenna with the power received when wearing the mimo antenna. This test was carried out by utilizing hotspots from cellphones that have been integrated with 5G networks and testing in areas that have been covered by Telkomsel's 5G provider network, which is at a frequency of 2300 MHz. The location chosen for this test is Jalan Raya Serpong, Pakulonan, North Serpong District, and South Tangerang. Here are the antenna testing steps performed for data retrieval:

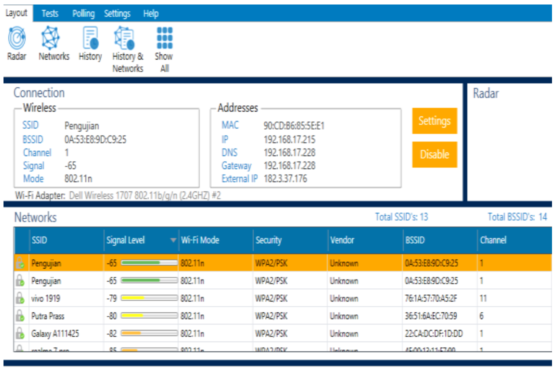
1. Prepare antennas, cables, as well as antenna posts. Where the antenna pole is installed in the position facing each other with the cellphone as a signal source. Here the hotspot used is named/labeled "Test".
2. Connect the USB adapter TP-link WN722N to the laptop, in this test the USB also connected it with a MIMO microstrip antenna.
3. After the USB adapter is connected to the laptop, it is continued by opening the Xirrus Wifi Inspector application.
4. Measurements are made by observing the power strength of the signal captured and displayed on the xirrus application. In addition to theobserved power, it also observes the internet capabilities of the signal captured by the antenna.
5. The test was carried out with a range variance of 5 meters until the antenna was no longer able to perform signal capture anymore.

Table 4. Antenna Test Results Data

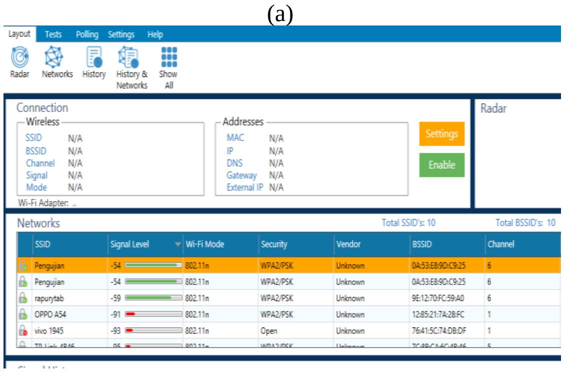
Distance (m)	Internet Connection Conditions			Gain (dBi)
	Antenna	Antennaless	Antenna	
5	-54	Connected	Connected	13,15
10	-59	Connected	Connected	16,15
15	-65	Connected	Connected	10,15
20	-68	Connected	Connected	9,15
25	-68	Connected	Connected	8,15
30	-71	Connected	Connected	10,15
35	-71	Connected	Connected	12,15
40	-71	Connected	Connected	13,15
45	-71	Connected	Connected	15,15
50	-73	Connected but *buffering*	Connected	14,15
55	-75	Connected but buffering	Connected	13,15
60	-79	Connected but buffering	Connected	10,15

After conducting field testing according to the procedure, the following MIMO microstrip antenna testing observation data were obtained

From table 4. data is displayed in Figure 8. is the state that the laptop is not connected to the antenna and when connected to the antenna, the name of the hotspot used is named "**Testing**". The following is a display of data when without using an antenna on the Xirrus wifi application :



(a)



(b)

Figure 8. (a) Xirrus display without antenna
(b) Xirrus display with antenna

In tests without antennas, data was obtained that the signal could only be captured at a distance of ≤ 60 meters from the source of the beam. With the power captured and can be seen in table 4. Where in testing the speed of internet access, at a distance of 50 meters, it has begun to slow / buffering while at a distance of 65 meters the signal cannot be measured and internet access is no longer connected. Meanwhile, in testing using an antenna, data was obtained that the signal could capture signals up to a radius of 105 meters from the source of the beam. This shows that the antenna is able to maximize the 5G network with a more optimal signal capture distance. Where in testing the speed of internet access, at a distance of 50 meters, it has begun to be slow / buffering while at a distance of 105 meters the antenna is still able to capture the signal, and the signal can still be measured but for the internet access connection is no longer connected.

The cause of buffering is due to the antenna coverage distance at each variance of the pengukura n65-105m distance. In addition, the test showed that the power captured by the antenna is greater than when without using an antenna, this can be seen in table 4.

In testing this antenna, it can also be known that this antenna has a fairly large gain of 16.15 dBi (maximum) and 8.15 dBi (minimum). Where this gain is greater than the estimated estimate of only 5.91 dBi. And some other examples of antenna gain in other scientific literature that range only 4-7 dBi. Despite the condition of the testing field in the middle of the city where there are many buildings around it which causes multipath fading. However, this antenna can handle these problems and still produce maximum gain. This shows that the antenna made by the researcher has a good gain value, all these things happen because this antenna applies array techniques and also the manufacture of artificial dielectric substrates after the selection of thick materials that are able to increase the gain value and *bandwidth* of the antenna, as well as the application of a MIMO system that is able to overcome multipath fading in urban areas.

In the implementation of design, measurement, and testing, the following results were obtained :

1. In the design with the input antenna dimension value is the result of mathematical calculations, so that the following parameter values are obtained:
   a. Working frequency : 1,9 GHz,
   b. Return loss : -6,3155 dB (S_{11}), -6,3373 dB (S_{22}), -6,4342 dB (S_{33}), -6,4129 dB (S_{44})
   c. VSWR : 2,870 (VSWR1), 2,861 (VSWR 2), 2,830 (VSWR 3), 2,822 (VSWR 4)
   d. Impedance : 31,234 ohm (S_{11}), 31,201 ohm (S_{22}), 32,364 ohm (S_{33}), 32,324 ohm (S_{44})
   e. Gain : 3,768 dBi

   From this data, it can be analyzed that in the simulation the parameter values obtained from the simulation of antenna dimensions the calculation results are not in accordance with the characteristics of the antenna to be made, where the characteristics of the antenna parameters sought are: working frequency: 2.3 GHz, return loss ≤ -10 dB, vswr ≤ 2, impedance 50 ohms and radiation patterns in the form of directives. Therefore, it is necessary to optimize again.

2. In the design with the input antenna dimension values are the result of optimization, so that the following parameter values are obtained :
   a. Working frequency : 2,3 GHz
   b. Return loss : -32,353 dB dB (S_{11}), -32,737 dB (S_{22}), -33,974 dB (S_{33}), -34,423 dB (S_{44})
   c. VSWR : 1,049 (VSWR1), 1,047 (VSWR 2), 1,040 (VSWR 3), 1,038 (VSWR 4)
   d. Impedance : 50,756 ohm (S_{11}), 50,997 ohm (S_{22}), 50,562 ohm (S_{33}), 50,801 ohm (S_{44})
   e. Gain : 5,91 dBi

   From this data, it can be analyzed that the optimization of antenna dimensions that have been carried out produces parameter values in accordance with the characteristics of the antenna to be made. Where the characteristics of the antenna parameters sought are: working frequency: 2.3 GHz, return loss ≤ -10 dB, vswr ≤ 2, Impedance of 50 ohms and radiation pattern in the form of directors with a decent gain compared to before optimization.

IV. Conclusion

The 4x4 MIMO microstrip antenna with artificial dielectric uses array techniques to increase the gain of the repeater antenna in 5G applications that have been made to meet the desired specifications and work accordingly at a frequency of 2300 MHz or 2.3 GHz such as the frequency control data provider. In the CST Studio Simulation, the antenna gain obtained was 5.91 dBi, but at the time of testing the antenna had a Gain of 16.15 dBi (maximum) and 9.15 dBi (minimum). Based on this, the antenna gain has a difference of 2.24 to 10.24 dBi from the simulation results in the CST studio. This can be due to many factors such as weather and the condition of the testing field in the middle of the city where there are many buildings around it that cause multipath fading. Thus it can be concluded that this antenna can handle multipath fading and still produce maximum gain. In testing, it can be known that the antenna is able to capture the emitted signal as far as 105 meters or 40 meters farther than without an antenna. For other specifications, it can be seen in sub-chapter 4.4, with such specifications designed 4x4 MIMO microstrip antennas with artificial dielectrics using array techniques to increase the gain of repeater antennas in 5G applications successfully created.

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