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Scalable modular massive MIMO antenna of rectangular and circular antenna for 5G communications

Salwa Salsabila[1,*], Rina Pudjiastuti[2], Levy Olivia Nur[3], Harfan Hian Ryanu[4], Bambang Setia Nugroho[5]
[1,2,3,4,5]Telkom University
[1,2,3,4,5]Jl. Telekomunikasi, No. 1, Bandung 40257, Indonesia
[*]Corresponding email: salwaasallsabila@student.telkomuniversity.ac.id

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Abstract — This research addresses the challenges posed by massive multiple input, multiple output antenna design, which is hindered by its large size and complex arrangement of multiple antenna elements simulation. To overcome the issue, a scalability technique is employed to predict the specifications of a massive MIMO antenna array based on a simple MIMO Antenna array with 2 × 2, 4 × 4, 8 × 8, 16 × 16, and other exponential configurations. The study focuses on two antenna types: rectangular antenna with truncated corner and circular antenna with X-Slot, operating at 3.5 GHz frequency. The research reveals that with each additional element, both antenna types experience a considerable gain improvement of approximately 62.24 % and 64.45 %, respectively, from a single element to a 2 × 2 MIMO configuration. Furthermore, the gain increases by approximately 58.46 % and 56.16 % when transitioning from 2 × 2 to 4 × 4 MIMO configurations. The investigation also highlights the improvement in half-power beamwidth (HPBW) as the number of elements increases, leading to more focused directional coverage. The findings demonstrate the feasibility of using the scalability technique to predict gain and HPBW values for massive MIMO antenna arrays, providing valuable insights for their design and optimization in advanced communication systems.

Keywords – antenna design, gain improvement, half-power beamwidth, massive MIMO, scalability technique

I. Introduction

Massive multiple input multiple output (MIMO) is a wireless communication technology that uses many antennas on the base station to send and receive signals simultaneously [1], [2]. In massive MIMO technology, the base station has hundreds to thousands of antennas that simultaneously transmit data to many users. This technology is necessary to increase data throughput in response to the growing demand for wireless communication and denser data growth [3]–[5].

Several factors need to be considered to increase data throughput, such as bandwidth, latency, and data transmission speed [6], [7]. The bandwidth that can be generated is one of the things that can be studied in antenna design. The wider the bandwidth, the faster the data transmission, which is directly proportional to the throughput that can be generated [8]–[10].

In communication systems, MIMO technology in massive MIMO antennas is the core technology in 5G communication systems, used as a multi-antenna transmission that can provide increased channel capacity and signal strength by reducing multipath effects [11]–[13]. MIMO technology in antennas (MIMO antennas) causes mutual coupling between single antenna elements and multipath components that can affect wave propagation. This issue can be overcome by providing a high isolation value between single antenna elements [14]–[16]. The MIMO antenna configuration scheme needs to be considered in antenna design. Based on [17], simple MIMO antenna configuration schemes (such as 2 × 2 and 4 × 4) are still not suitable for 5G communication needs, given that their prediction speed is 1,000 times faster than 4G and requires better reliability [18], [19].

As a result of the requirements for 5G communication, the antenna configuration scheme that is carried out is the design of the massive MIMO antenna model. However, designing a massive MIMO antenna results in a larger size, which hinders the antenna design

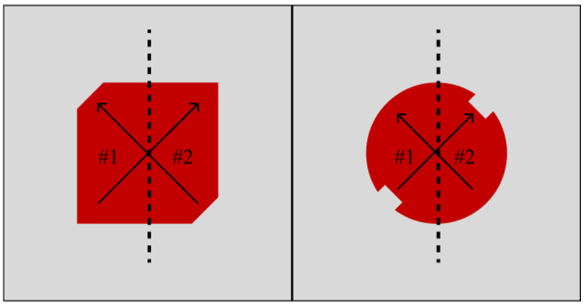

Fig. 1. Circularly polarized microstrip antenna.

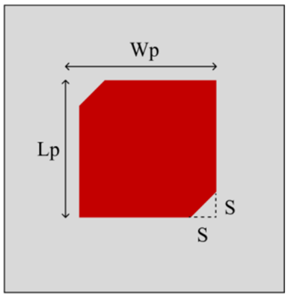

Fig. 2. Rectangular truncated corner antenna.

process [7], [19]–[21].

Designing a large-scale antenna with a massive MIMO scheme is certainly a new challenge in the antenna simulation process. Based on this, the authors propose the use of scalable techniques to predict the performance of massive MIMO antenna specifications based on simple MIMO antennas.

II. Research Method

This section discusses circular polarization, rectangular truncated corner antenna, circular slotted X antenna, 3.5 GHz for 5G communications, design method, antenna specification, single line feed, and antenna configuration on simulation.

A. Circular Polarization

Circular polarization of a microstrip antenna can be generated by adjusting the dimensions of the antenna and modifying the feed, be it a single feed or more. For simplicity, a single feed can be used with the configuration of placing the feed on a part that can produce right-handed circular polarization (RHCP) or left-handed circular polarization (LHCP) [22].

Based on Fig. 1, antenna design and simulation are carried out to produce circular polarization on two types of antennas the rectangular truncated corner antenna and the circular slotted X antenna with the MIMO configurations of 2 × 2 and 4 × 4 to analyze the difference parameter pattern obtained.

B. Rectangular Truncated Corner Antenna

Truncated corner is a method to produce circular polarization on the antenna where W_p and L_p are the values of width and length of patch respectively. This method is done by cutting the end of the patch which is located as shown in Fig. 2.

To determine the dimensions of S, calculation isperformed using (1), (2), and (3) [23].

$$Q_0 = \frac{c\sqrt{\epsilon_r}}{4f_r h} \tag{1}$$

$$\frac{\Delta s}{s} = \frac{1}{2Q_0} \tag{2}$$

$$S = L_p\sqrt{\frac{\Delta s}{s}} \tag{3}$$

Where Q_0 is a value of unloaded quality factor, $\frac{\Delta s}{s}$ is a cutting ratio, S is the length of truncated corner, ϵ_r is material value of substrate, f_r is resonantfrequency used, h is the thickness of substrate, c is thespeed of light, and L_p is the length of patch.

C. Circular Slotted X Antenna

A circular patch with an X-slot is designed to obtain the circular polarization RHCP and LHCP with the characteristic of the design in the Fig. 3. The dimension of the X-slot is obtained from carrying out the sweep parameter to the best return loss value at a frequency of 3.5 GHz.

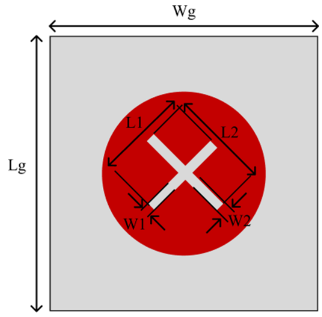

Fig. 3. Circular slotted X antenna.

From Fig. 3, L_g represents the length, and W_g represents the width of the substrate and ground plane, respectively. The dimensions of L_1, L_2, W_1 and W_2 of the circular patch were obtained with the parameter sweep method and after that, choose the dimensions with the lowest return loss value at the resonant frequency of 3.5 GHz.

D. 3.5 GHz for 5G Communications

A frequency of 3.5 GHz is a crucial choice in the development of MIMO antennas and 5G communication. In the realm of 5G, this frequency offers excellent signal penetration and supports high data capacity. By employing MIMO antennas at the 3.5 GHz frequency, we can enhance capacity and reduce interference in wireless communication systems. Therefore, a comprehensive understanding of the characteristics and performance of MIMO antennas at this frequency is pivotal in supporting the efficient and reliable development of 5G technology [24].

Furthermore, the 3.5 GHz frequency lies within the globally allocated spectrum for 5G services, making it

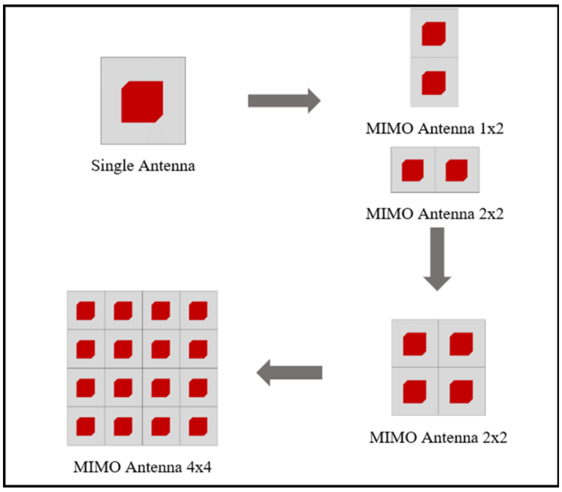

Fig. 4. MIMO antenna configurations.

a popular choice for advanced 5G network implementations. With the increasing demand forhigh-speed connectivity and complex data-driven applications, MIMO antennas at 3.5 GHz can provide efficient solutions. Further research on the design and performance of MIMO antennas at this frequency will offer valuable insights to engineers and researchers in designing efficient and reliable 5G wireless communication systems. Consequently, the study of MIMO antennas at the 3.5 GHz frequency forms acritical theoretical foundation in the development of 5G technology [25].

E. Design Method

In this study, the design and simulation process consisted of two stages, namely the design and simulation of rectangular patch antennas with truncated corners and circular patch antennas with X-slots, as shown in Fig. 4. The process in circular patch will continue until the simulation results match the specifications and continued with the stages of preparing the MIMO configuration.

The preparation of the MIMO configuration is carried out in stages starting from 2 × 2 and 4 × 4 until the simulation results show that the value tends to increase, and the increase is in a certain pattern. The pattern of increasing value is then analyzed to be compared so that it can be proven whether the scalability technique can be known or not.

F. Antenna Specification

Antenna specifications are determined as an initial stage of initiation before calculating the dimensions, designing, and simulating carried out. Following are the antenna specifications in Table 1 with an input impedance value of $Z_0 = 50\ \Omega$.

The single patch antenna element is designed using FR-4 Epoxy material as a substrate and copper material as a patch and ground plane with the material characteristics in Table 2.

Table 1. Antenna Specifications

Parameter	Specifications
Resonant frequency	3.5 GHz 5G Band
Gain	> 3 dB
VSWR	< 2
Polarization	Circular
Bandwidth	50 MHz

Table 2. Material Characteristic

Component	Materials	Thickness
Patch and ground plane	Copper	t = 0.1 mm
Substrate	FR-4 epoxy	h = 1.6 mm

G. Single Line Feed

Single line feed is used to obtain the desired circular polarization of RHCP and LHCP with the modification of feed that shown in the Fig. 5.

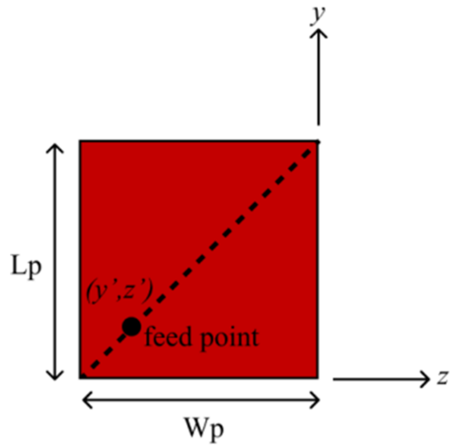

Fig. 5. Single feed arrangement for circular polarization.

III. Antenna Configuration and Simulation Results

This section discusses the configurations of single, 2 × 2, and 4 × 4 of rectangular MIMO antennas, followed by the single, 2 × 2, and 4 × 4 of circular MIMO antennas.

A. Configuration of Single Rectangular Antenna

The configuration of single rectangular antenna is shown in Fig. 6. While the following result of gain value and angular width are obtained in Fig. 7 and Fig. 8.

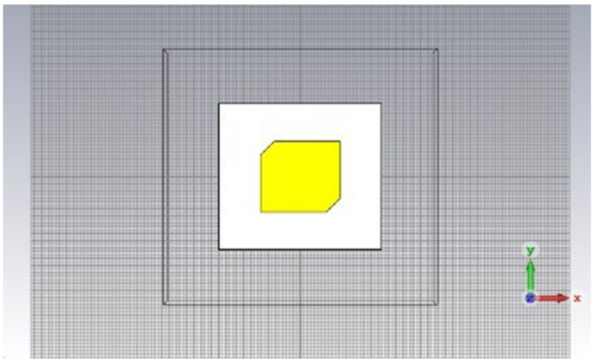

Fig. 6. Simulation of a single rectangular antenna.

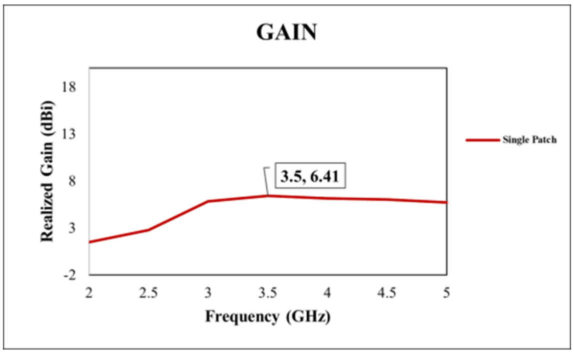

Fig. 7. Gain value of single rectangular antenna.

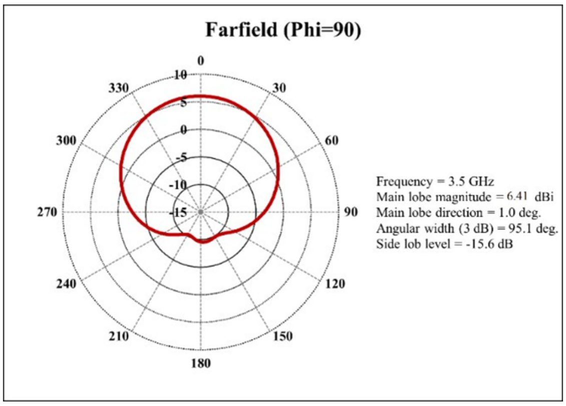

Fig. 8. Angular width of single rectangular antenna.

B. Configuration of 2 × 2 Rectangular MIMO Antenna

The configuration of 2 × 2 rectangular antenna is shown in Fig. 9. While the following result of gain value and angular width are obtained in Fig. 10 and Fig. 11.

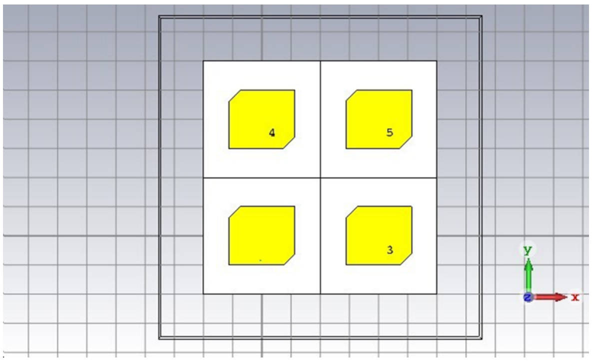

Fig. 9. Simulation of 2 × 2 rectangular MIMO antenna.

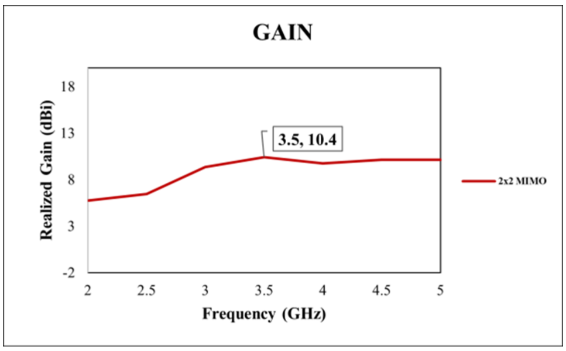

Fig. 10. Gain value of 2 × 2 rectangular MIMO antenna.

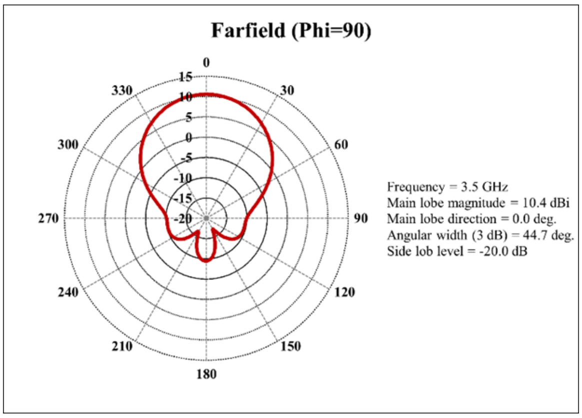

Fig. 11. Angular width of 2 × 2 rectangular MIMO antenna.

C. Configuration of 4 × 4 Rectangular MIMO Antenna

The configuration of 4 × 4 rectangular antenna is shown in Fig. 12. While the following result of gain value and angular width are obtained in Fig. 13 and Fig. 14.

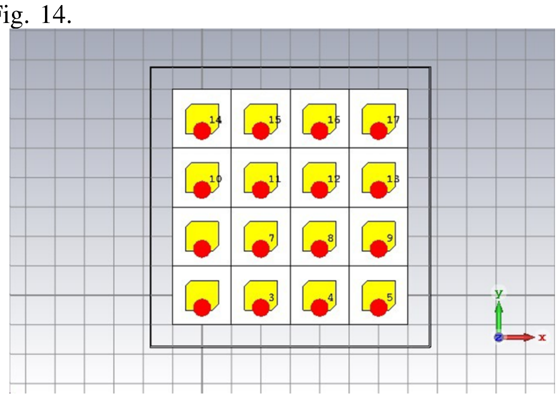

Fig. 12. Simulation of 4 × 4 rectangular MIMO antenna.

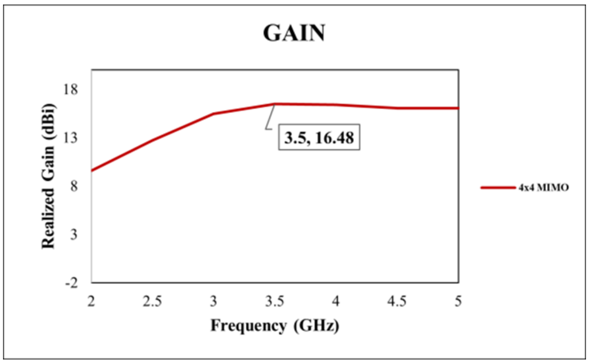

Fig. 13. Gain value of 4 × 4 rectangular MIMO antenna.

With the configuration of single, 2 × 2 and 4 × 4 MIMO antenna as in the Table 3.

Table 3. Simulation Result of Rectangular MIMO Configurations

MIMO Configuration	HPBW	Gain (dBi)
1	95.1°	6.410
2 × 2	55.7°	10.400
4 × 4	26.6°	16.480

D. Configuration of Single Circular Antenna

The configuration of single circular antenna is shown in Fig. 15. While the following result of gain value and angular width are obtained in Fig. 16 and Fig. 17.

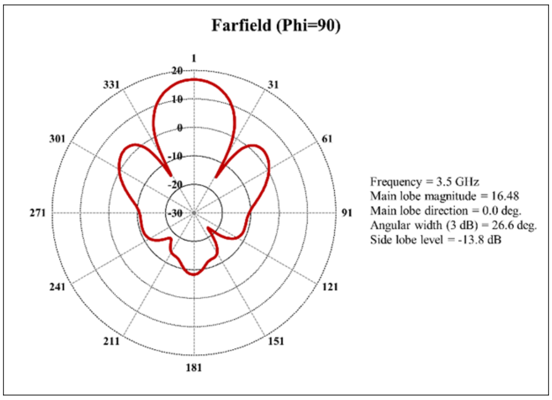

Fig. 14. Angular width of 4 × 4 rectangular MIMO antenna.

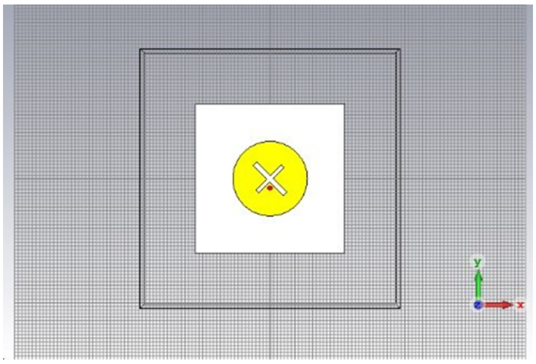

Fig. 15. Simulation of a single circular antenna.

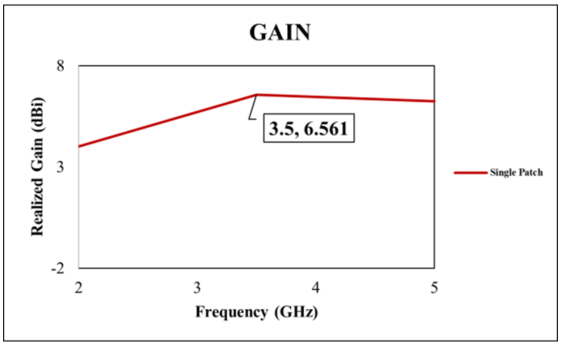

Fig. 16. Gain value of single circular antenna.

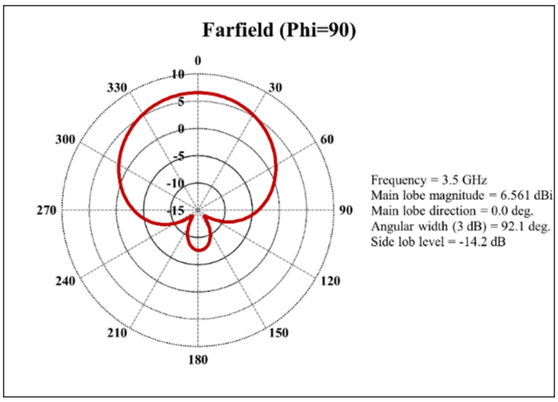

Fig. 17. Angular width of the single circular antenna.

E. Configuration of 2 × 2 Circular MIMO Antenna

The configuration of 2 × 2 circular antenna is shown in Fig. 18. While the following result of gain value and angular width are obtained in Fig. 19 and Fig. 20.

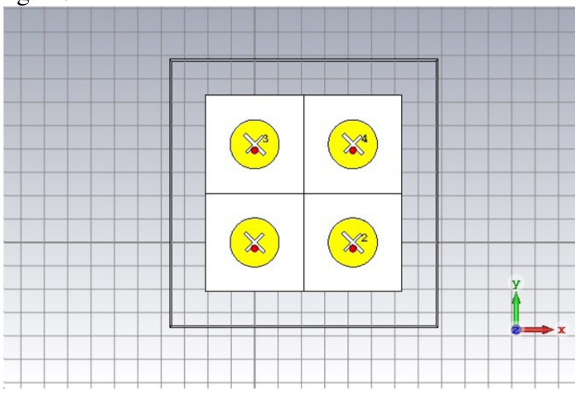

Fig. 18. Simulation of a 2 × 2 circular antenna.

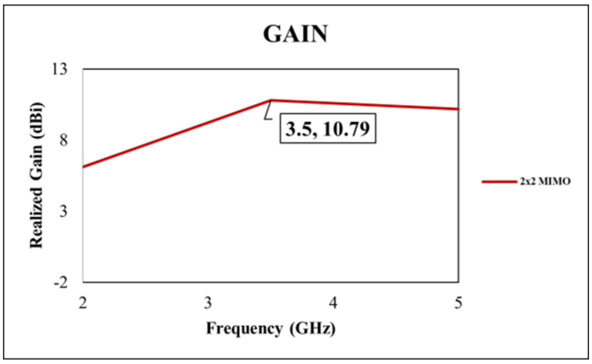

Fig. 19. Gain value of 2 × 2 circular antenna.

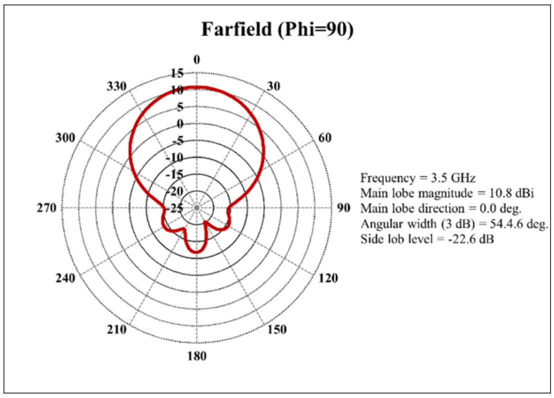

Fig. 20. Angular width of the 2 × 2 circular antenna.

F. Configuration of 4 × 4 Circular MIMO Antenna

The configuration of 4 × 4 circular antenna is shown in Fig. 21. While the following result of gain value and angular width are obtained in Fig. 22 and Fig. 23.

Table 4. Simulation Result of Circular MIMO Configurations

MIMO Configuration	HPBW	Gain (dBi)
1	92.1°	6.651
2 × 2	54.4°	10.790
4 × 4	26.1°	16.850

With configuration of single, 2 × 2, and 4 × 4 MIMO antenna, the simulation result of circular MIMO configurations is shown Table 4.

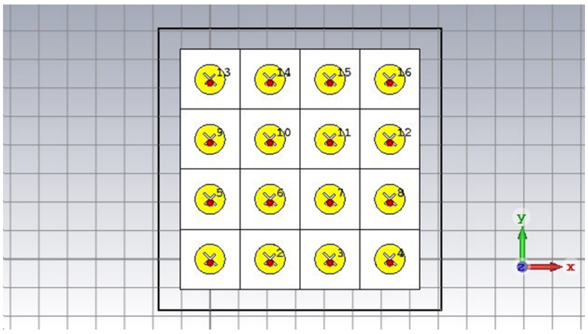

Fig. 21. Simulation of a 4 × 4 circular antenna.

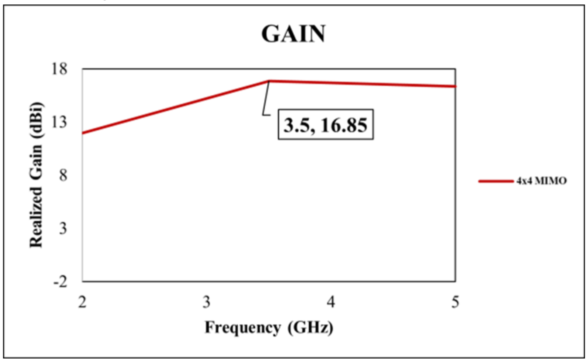

Fig. 22. Gain value of 4 × 4 circular antenna.

IV. Analysis

This section shows the results of the simulations carried out on a rectangular antenna with a truncated corner and a circular antenna with an X-slot. MIMO configuration of 1 × 2, 2 × 1, 2 × 2, and 4 × 4 for each type of antenna is performed to find gain and HPBW rvalues and analyze these values to be then used as a reference in predicting the achievement of values that can be generated on massive MIMO antennas (a large number of elements).

A. Analysis of Gain Value

The gain value analyzed is the gain value of the exponential pattern MIMO antenna configuration with the number of elements 1, 2 × 2 (4 elements), and 4 × 4 (16 elements).

Based on Table 5, the increment of the gain value obtained for each MIMO Antenna configuration for the two types of antennas has a value that tends to be the same. Thus, the gain value for the massive MIMO antenna can be predicted by referring to the pattern of increasing values obtained. The gain value increases for each additional element which indicates that the more elements used, the greater the gain value obtained.

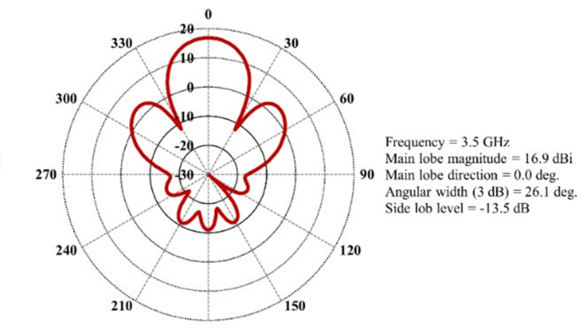

Fig. 23. Angular width of the 4 × 4 circular antenna.

B. Analysis of Angular Width

Similar to the analysis of gain, the angular width analyzed is the angular width of the exponential pattern MIMO antenna configuration with the number of elements 1, 2 × 2 (4 elements), and 4 × 4 (16 elements).

Based on Table 6, the decrement of angular width obtained for each MIMO Antenna configuration for the two types of antennas has a value that tends to be the same. Thus, the gain value for the massive MIMO antenna can be predicted by referring to the pattern of decrement values obtained. HPBW is getting sharper for each added element which shows that the more elements used, the HPBW angle will be sharper.

V. Conclusion

MIMO configuration research was carried out on two antennas: Rectangular Antenna with Truncated Corners, and Circular Antenna with X-Slots. Both types of antennas were simulated with exponential MIMO configurations of 1, 2 × 2 (4 elements), 4 × 4 (16 elements), and 1 × 2 (2 elements) vertical configurations. elements) and horizontal (2 × 1). The results show that there is a change in the resulting gain and HPBW values for each additional number of elements. The gain value increases for each additional element, indicating that the more elements used, the greater the gain value. In addition to the gain value, an analysis was also carried out on the HPBW, and the result was that the HPBW was getting sharper for each added element, indicating that the more elements used, the more acute the HPBW angle would be. The increase in gain and decrease in HPBW for the two types of antennas tend to have the same value. Thus, the gain and HPBW values for massive MIMO Antenna configurations can be predicted based on the pattern of increasing gain and decreasing HPBW obtained.

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Table 5. Increment Percentage of Gain Value

MIMO Configurations (Element)	**Rectangular Truncated Corner**		**Circular Slotted X**	
	Gain (dBi)	**Percentage of Increment**	**Gain (dBi)**	**Percentage of Increment**
1	6.410	100 %	6.561	100 %
2 × 2 (4)	10.4	62.24 %	10.79	64.45 %
4 × 4 (16)	16.48	58.46 %	16.85	56.16 %

Table 6. Decrement Percentage of HPBW

MIMO Configurations (Element)	**Rectangular Truncated Corner**		**Circular Slotted X**	
	HPBW	**Percentage of Decrement**	**HPBW**	**Percentage of Decrement**
1	95.1°	100 %	92.1°	100 %
2 × 2 (4)	55.6°	-41.43 %	54.4°	-39.52 %
4 × 4 (16)	26.6°	-52.24 %	26.1°	-52.24 %

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