Subarray Design with Two Rectangular Elements for Massive MIMO System Development

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Abstract— **Wireless communication for the future will use 5G standards, supported by an antenna system with Massive MIMO technology incorporating subarrays. A subarray microstrip antenna that has small element spacing will result in mutual coupling effects. This paper proposes design of a two rectangular subarray antenna with coaxial feeding for massive MIMO development and analysis the effect of mutual coupling at varying spacing element. Antennas are designed and simulated, namely a single antenna, a two element antenna arrayed in the E-plane and a two element antenna arrayed in the H-plane. The simulation results show that the mutual coupling of the two antenna elements arrayed in the E-plane for all element spacing is less than -20 dB, which means the mutual coupling effect can be ignored. Whereas the mutual coupling of the two antenna elements arrayed in the H-plane for all spacing elements is greater than -20 dB, which means the value of the mutual coupling must be considered. The bandwidth of the two element subarrays on E and H-plane is 77.3-88.5 MHz depending on the element spacing, which is still below 100 MHz required for 5G application.**

Keywords—Antenna, design, rectangular, mutual coupling, return loss, Massive MIMO

I. INTRODUCTION

5G technology is the standard for future wireless communication. The advantages of this technology are the service needs of very high data speeds, great service, low latency, and high mobility support which have not been fulfilled by previous technology. Massive MIMO scheme is the core of wireless communication technology 5G. This technology is composed by antenna array system that utilizes hundreds of elements simultaneously served the dozens of active terminals (users) at the same time and frequency. This technology can increase capacity 10 times or more, simultaneously increase radiant energy efficiency up to 100 times, low cost and low power components, can reduce interference and jamming interference [1], [2], [3], [4], and also can control radiation pattern of the antenna to reduce interference. This radiation pattern is strongly influenced by the configuration of the array antenna, the distance between the antenna elements, phase, and amplitude [5].

The subarray antenna is a part of the antenna array [6]. Research in [7] has mentioned 256 antenna elements arranged in 4 subarrays, each subarray is composed by 16 elements for massive MIMO. The desired subarray antenna has a low return loss, high bandwidth, and small size. Microstrip antenna has a physical properties that are lightweight, low profile, reliability, low production cost, ease of fabrication and can be widely use in various applications. Microstrip antenna has a various geometric patch shapes such as rectangle, round, triangle, circle [8]. A subarray composed of two rectangular microstrip elements is designed and evaluated.

In this paper, coaxial feeding techniques are used, wherein the inner conductor on the coaxial connector penetrates through the dielectric and soldered to the radiating patch, while the outer conductor is connected to the ground plane. The advantage of the coaxial feeding technique is that the feeding is placed in the desired position in the patch to obtain impedance matching [8], [9], [10].

The issue that often arises in the development of antenna arrays is the very shortest spacing between element can increase the gain. However, array elements that are designed with close spacing elements cause mutual coupling problems [11]. Mutual coupling is an electromagnetic interaction and the influence of surface currents on each element of the antenna array[12]. Mutual coupling effects can cause changes in antenna parameters such as radiation pattern, return loss, directivity, low side lobe level (SLL), gain, impedance matching and transmit power [13],[14], [15], [16]. Several ways to reduce the effect of mutual coupling is to use a metamaterial structures [17], exponential corrugated truncated (ECT) structures [11], defected ground structures (DGS) [18]. To our knowledge, the effect of mutual coupling between subarray elements of a rectangular antenna and coaxial feeding has never been reported.

The previous work [17] explains the comparison of mutual coupling reduction using ring and square metamaterials on a microstrip array antenna. Rectangular shaped antenna elements using feeding lines arranged in the E-Plane plane. The distance between elements is 0.4 λ from feeding to feeding each antenna element. As a result, rectangular microstrip array antennas using ring-shaped metamaterial are better than square with a mutual coupling value of -17.8 dB at a 2.4GHz operating frequency, paper [11] discuss reducing mutual coupling in UWB Coplanar Vivaldi Array arranged on E and H-plane by combining truncated and corrugated slots at the border between adjacent elements. Exponential Corrugated Truncated (ECT) structure is effective in increasing isolation in all bands, especially at

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lower frequencies, directivity in the 2-10 GHz frequency band and SLL in the 4-9 GHz band. It can be applied to UWB CVA antenna, research in [19] explains about the effect of mutual coupling reduction, antenna elements are isolated using a split square metamaterial absorber (MMAS-SSR) resonator structure. The experiments performed were two simple linear array microstrip antennas designed in a linear array and one row of metamaterial absorber structure located between the elements as insulators. Simulation and measurement results indicate that there is a reduction in reciprocal couplings of 8 and 6 dB, respectively.

This paper proposes the design of two rectangular element subarray antennas with coaxial feeding for massive MIMO development and the evaluation of the mutual coupling effect at varying distances. Antennas designed and simulated are the single antenna, two antenna elements in E-plane based on the element spacing λ , ¾ λ, ½ λ and two-element antennas in H-plane based on the element spacing λ , ¾ λ, ½ λ, ¼ λ.The antenna is designed at a working frequency of 2.8 GHz. Then simulated and observed the results of the performance of two element antenna parameters. Two antenna elements that have the closest spacing element affect the value of mutual coupling significantly**.** The explanation of this paper is arranged as follows, in section II describes antenna design, section III describes simulation result and analysis and finally section IV conclusions.

II. ANTENNA DESIGN

The design of the microstrip antenna starts by determining the specifications of the desired microstrip antenna according to the requirements of the Massive MIMO system. In this paper, the antenna is designed in the form of a rectangle. The antenna design is made single element and two elements. The structure of the microstrip antenna consists of patches, dielectric substrate and ground plane. The specification of the substrate used by FR-4 (epoxy) with the dielectric constant (εr) is 4.4, and the substrate thickness (h) is 1.6 m. The antenna restricting technique uses a coaxial feeding probe. The antenna design parameters that are desired at the operating frequency are 2.8 GHz, bandwidth greater than 100 MHz, side lobe level (SLL) is smaller than -13 dB, Mutual coupling is less than -20 dB, return loss is shorter than -10 dB.

The process of calculating a rectangular antenna design uses mathematical equations to calculate the width and length of the patch, the width and length of the substrate section equals ground and determines the coordinates of the coaxial probe [20], [21]. Based on the results of the calculation of a single antenna design can be seen in Table 1 and dimension single antenna will be displayed using CST software shown in Fig.1.

TABLE I. DIMENSIONS OF SINGLE ANTENNA

Parameter	Value (mm)
Patch Width (Wp)	32.60
Patch Length (Lp)	24.05
Subtrate and Ground Width (Wg)	42.20
Subtrate andLength Ground (Lg)	33.65
Coordinate Length of Feeding (xf)	5.97
Coordinate Width of Feeding (yf)	16.30

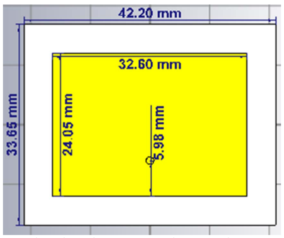


Fig.1. Single element microstrip antenna

III. SIMULATION RESULT AND ANALYSIS

Calculations for the dimensions of the two-element antenna design on the E-plane are shown in table 1 and the two-element antenna on the H-plane in table 2. Furthermore, observing the performance of antenna parameters, namely gain, return loss (S11), bandwidth, side lobe level (SLL), beamwidth and mutual coupling (S21) using CST.

A. Antena Array Simulation Method

The spacing of element antenna on E-plane and H-plane can be explained in Table 2 and Table 3, respectively.

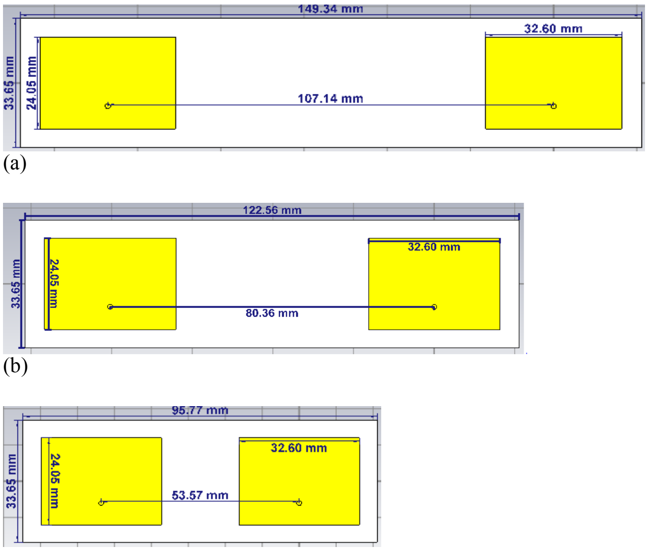
TABLE 2. CALCULATION RESULTS OF THE TWO ANTENNA ELEMENTS ON THE E-PLANE

Parameter	Value (mm)		
	d=λ 107.14	d=3/4λ 80.36	d=½ λ 53.57
Subtrate and Ground Width (Wg)	149.34	122.56	95.77

TABLE 3. THE CALCULATION RESULTS OF TWO ANTENNA ELEMENTS ON THE H-PLANE

Parameter	Value (mm)			
	d=λ 107.14	d=3/4λ 80.36	d=½ λ 53.57	d=¼ λ 26.78
Subtrate and Ground Width (Wg)	140.80	114.01	87.23	60.44

Therefore, according the two tables above, the simulation results of the two antenna element can be seen in Fig.3 and Fig.4 for E-plane and H-plane, respectively.

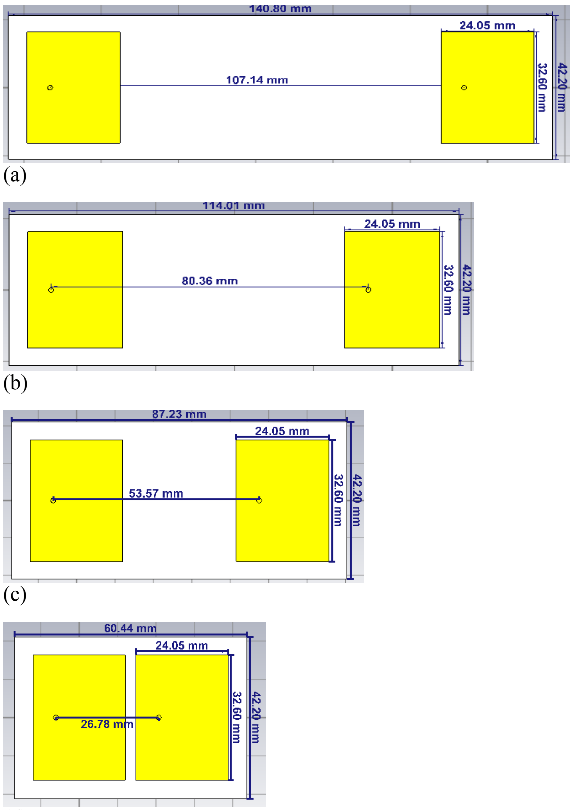


(a)

(b)

(c)

Fig.3. Microstrip antenna design of two elements in E-plane (a) λ, (b) ¾ λ, (c) ½ λ



(a)

(b)

(c)

(d)

Fig. 4. Microstrip antenna design of two elements in H-plane (a) λ, (b) ¾ λ, (c) ½ λ, (d) ¼ λ

B. *Return Loss and Bandwidth of Single Antenna Element*

The return loss and bandwidth of single antenna element according to simulation results can be seen in Fig. 5. In this design, return loss (S11) is obtained at -30.28 dB in a 2.8 GHz. It shows that, the reflected power of antenna is lower than the received power. The bandwidth of the antenna can be calculated from the return loss value below -10 dB. For the single element antenna, the bandwidth shows 88.2 MHz or fractional bandwidth is around 3.15%.

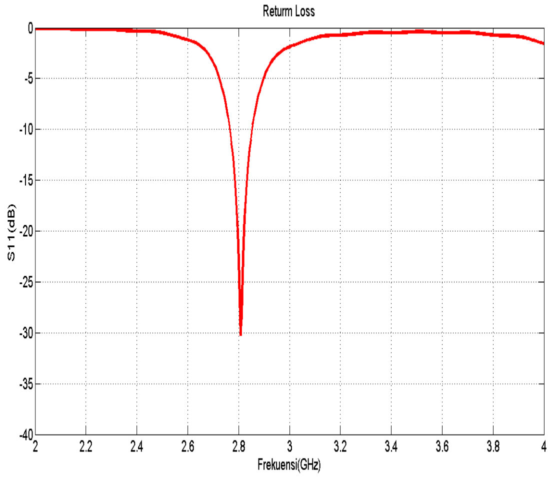


Fig. 5. Return loss (S11) and bandwidth

B. *Radiation Pattern of single Antenna Element*

The farfield radiation pattern of single antenna element is shown in Fig.6. The gain of antenna is 2.35 dB in 2.8 GHz. The highest gain part is displayed in red area, which is only one main lobe and no side lobe.

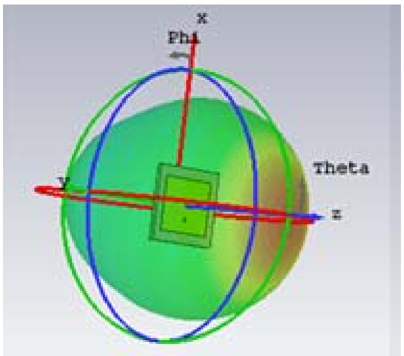


Fig. 6. Gain

The polar radiation pattern simulation for the single element antenna in fig. 7 below can be seen that the main lobe magnitude is 2.35 dB, main lobe direction is 0.0 dB, Side lobe level (SLL) is -6.8 dB and angular beamwidth (3dB) is 91.20^0 .

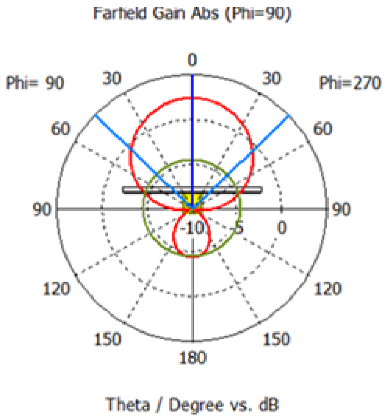


Fig.7. SLL and beam width

C. *Return Loss and bandwidth of Two Antenna Elements for E-Plane*

In Fig. 8, the return loss and bandwidth results for the element spacing λ, ¾ λ, and ½ λ are -33.03 dB, -33.43 dB, -34.60 dB, respectively. So, it can be concluded that the sub array antenna performance parameters of the two elements are sufficient because they meet the return loss criteria below -10 dB. The antenna bandwidth of the two-elements sub array based on the distance are, at a distance of λ of 83.5 MHz or 2.98%, the distance of ¾ λ is 83, 4 MHz or 2.97% and the distance of ½ λ is 83.2 MHz or 2.97% .

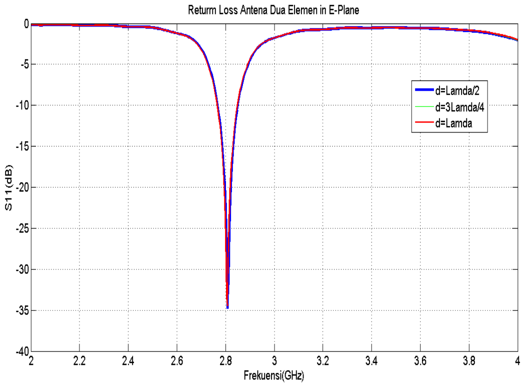


Fig. 8. Return loss and bandwidth based on the element spacing

D. Mutual Coupling of Two Antenna Elements for E-plane

The mutual coupling (S12, S21) of the two antenna elements which works at 2.8 GHz is shown in Fig. 9, and Table 3.

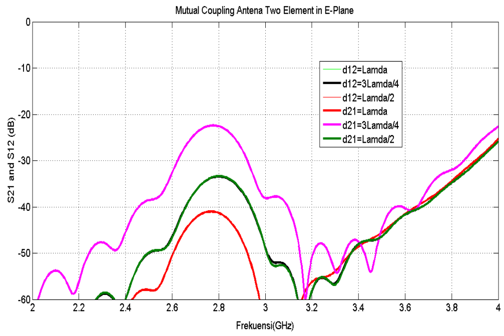


Fig. 9. Mutual coupling based on the element spacing λ, ¾ λ and ½ λ

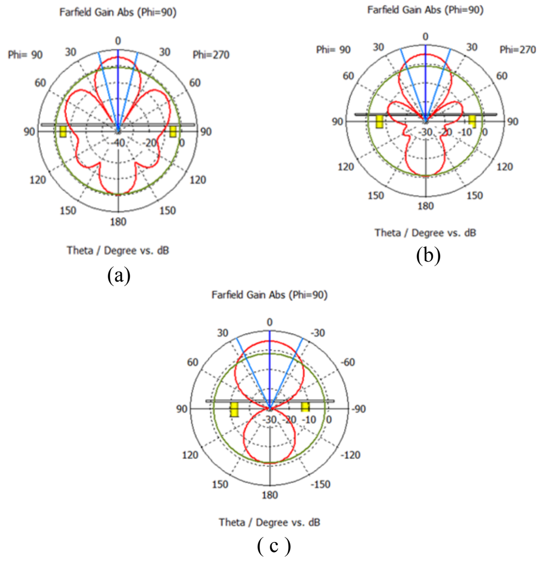
TABLE 3. MUTUAL COUPLING TWO ANTENNA ELEMENTS FOR E-PLANE

Element Spacing (d)	S12 (dB)	S21(dB)
λ	-41.35	-41.35
¾ λ	-33.47	-33.37
½ λ	-22.59	-22.59

Table 3 explains that S12 and S21 values for the λ element spacing are greater than the other element spacing. The results of the mutual coupling of the two antenna elements for E-plane are following the parameters smaller than -20 dB.

E. Radiation Pattern of Two Antenna Elements for E-plane

The polar radiation pattern is shown in Fig. 10 below, the gain of the two antenna elements for λ, ¾ λ and ½ λ is 4.55 dB, 5.05 dB and 5.21 dB, respectively. It has the main lobe magnitude is 5.21 dB, main lobe direction is 0.0 dB, SLL is -6.1 dB and angular beamwidth (3dB) is 28.50^0 based on the element spacing λ, ¾ λ the main lobe magnitude is 5.05 dB, main lobe direction is 0.0 dB, SLL is -6.1 dB and angular beamwidth (3dB) is 36.90^0 and ½ λ the main lobe magnitude is 4.55 dB, main lobe direction is 0.0 dB, SLL is -6.2 dB and angular beamwidth (3dB) is 49.60^0. So, the gain smaller than the others for λ/2, while the SLL and beamwidth are greater than the others.



(a)

(b)

(c)

Fig. 10. Side lobe level and beam width based on the element spacing (a)λ, (b)¾ λ and (c) ½ λ

F. Return Loss and bandwidth of Two Antenna Elements for H-Plane

The return loss and bandwidth is shown in Fig.11 for λ is 18.61 dB, ¾ λ is -21.33 dB, ½ λ is -17.84 dB and ¼ λ is -31.75. So, it can be concluded that the sub array antenna performance parameters of the two elements are good because they meet the return loss criteria less than - 10 dB. Moreover, the bandwidth of the antenna can be calculated from the return loss value below -10 dB. Thus the antenna bandwidth of the two-element is based on the distance at a distance of distance λ is 77.3 MHz or 2.76%, ¾ λ is 86.6 MHz or 3.09 %, ½ λ of 87.7 MHz or 3.13% and ¼ λ is 88.5 MHz or 3.16% .

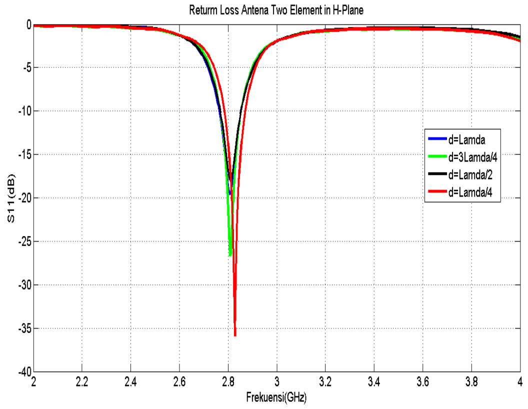


Fig. 11. Return loss and bandwidth based on the element spacing λ, ¾ λ, ½ λ dan ¼ λ

G. Mutual Coupling of Two Antenna Elements for H-plane

Fig. 12 shows the mutual coupling based on the element spacing λ, ¾ λ, ½ λ and ¼ λ on the table 4. So, The simulation results of two elements antenna in the H-plane are not suitable for desired performance, because the value of mutual coupling is more than -20 dB.

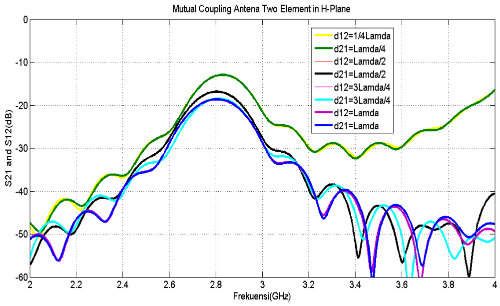


Fig. 12. Mutual coupling based on the element spacing λ, ¾ λ, ½ λ and ¼ λ

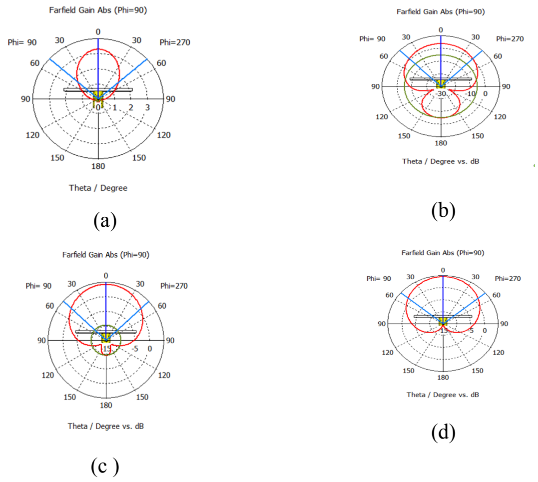
TABLE 4. MUTUAL COUPLING TWO ANTENNA ELEMENTS FOR H-PLANE

Element Spacing (d)	S12 (dB)	S21(dB)
λ	-18.63	-18.62
¾ λ	-18.46	-18.46
½ λ	-16.84	-16.84
¼ λ	-13.19	-13.17

The value of S12 and S21 can be seen in Table 4. It shows that λ is greater than the other. The value of mutual coupling does not meet the parameter because of more than -20 dB. Thus not following the desired mutual coupling parameter is shorter than -20 dB.

H. Radiation Pattern of Two Antenna Elements for H-plane

In the result of the polar radiation pattern shown in Fig. 13 below, the gain of the two elements antenna supplied on all ports is based on the element spacing λ is 3.29 dB, ¾ λ is 3.68 dB, ½ λ is 4.21 dB and ¼ λ is 4.48 dB. It has λ is the main lobe magnitude is 3.29 dB, main lobe direction is 0.0 dB, SLL is -11.7 dB and angular beamwidth (3dB) is 96,5^0, ¾ λ is the main lobe magnitude is 3.68 dB, main lobe direction is 0.0 dB, SLL is –8.8 dB and angular beamwidth (3dB) is 89.0^0 ,½ λ the main lobe magnitude is 4.21 dB, main lobe direction is 0.0 dB, SLL is -14.0 dB and angular beamwidth (3dB) is 95,3^0 and ¼ λ the main lobe magnitude is 4.48 dB, main lobe direction is 0.0 dB, SLL does not exist and angular beamwidth (3dB) is 99,8^0. Thus, the two antenna elements in H-plane for the element spacing ¼ λ produce gain and beamwidth greater than the others.



(a) (b) (c) (d)

Figure 13. SLL and beam width based on the element spacing ((a) λ, (b)¾ λ, (c) ½ λ (d) ¼ λ

TABLE 5. PARAMETER PERFORMANCE OF SINGLE ELEMENT AND TWO ANTENNA ELEMENTS IN E-PLANE ACCORDING TO SIMULATION RESULTS

Paramater Performance	Single Element	Two Element in E-plane		
		d=λ	d = 3λ/4	d = λ/2
Gain (dB)	2.35	5.21	5.05	4.55
Return Loss (dB)	-30.28	-33.03	-33.43	-34.60
Bandwith (MHz)	88.2	83.5	83.4	83.2
Side Lobe Level (dB)	-6.8	-6.1	-6.1	-6.2
Mutual Coupling (dB)	N/A	-41.03	-33.49	-22.49
Beamwidth (deg)	91.7	28.5	36.9	49.6

The performance of the single element antenna parameters and the two antenna elements in the E-plane are shown in Table 5. The performance of the two antenna elements in the E-plane has a greater gain than the single element. Two antenna elements based on the element spacing λ has gain and bandwidth greater than ¾ λ and ½ λ. While the performance of two antenna elements parameters based on the element spacing λ has return loss, SLL, mutual coupling, the beamwidth results are smaller than ¾ and ½ λ. The results of the mutual coupling of the two element antennas for E-plane are following with the parameters less than - 20 dB.

TABLE 6. PARAMETER PERFORMANCE OF TWO ANTENNA ELEMENTS IN H-PLANE ACCORDING TO SIMULATION RESULTS

Paramater Performance	Two Element in H-plane			
	d=λ	d = 3λ/4	d = λ/2	d = λ/4
Gain (dB)	3.29	3.68	4.21	4.48
Return Loss (dB)	-18.61	-21.33	-17.84	-31.75
Bandwith (MHz)	77.3	86.6	87.7	88.5
Side Lobe Level (dB)	-11.7	-8.8	-14.0	NA
Mutual Coupling (dB)	-18.62	-18.46	-16.84	-13.17
Beamwidth (deg)	96.5	89.0	95.3	99.8

The performance of the two antenna elements in the H-plane is shown in Table 6. Two antenna elements based on the element spacing ¼ λ has gain, bandwidth, beamwidth and mutual coupling greater than others, λ has return loss and SLL greater than others. The result is that all element spacing the mutual coupling greater than -20 dB.

IV. CONCULUSION

The simulation results show that the mutual coupling of the two antenna elements arrayed in the E-plane for all element spacing is less than -20 dB, which means the mutual coupling effect can be ignored. Whereas the mutual coupling of the two antenna elements arrayed in the H-plane for all element spacing is more than -20 dB which means the value of the mutual coupling is considered. So, arrays in the H-plane need to be applied to mutual coupling reduction. The bandwidth of the two sub-array elements on the E and H-planes is 77.3-88.5 MHz on various spacing elements, which is still below 100 MHz for 5G applications.

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