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GAIN IMPROVEMENT OF MIMO MICROSTRIP ANTENNA USING ARRAY 2X1 ELEMENT

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ABSTRACT

This paper proposes the design of a MIMO Array 2x1 element microstrip antenna for a fifth generation (5G) technology system at a frequency of 3.5 GHz. The antenna is designed using RT-Duroid R5880 substrate type with dielectric constant (εr) = 2.2 , thickness (h) = 1.57 mm and loss tan (tan) = 0.0009. MIMO array is applied to increase the gain and directivity of the proposed antenna. The proposed MIMO antenna design has been successfully simulated with a reflection coefficient of -22 dB, an isolation coefficient of -78 dB and a gain of 12 dB at a frequency of 3.5 GHz. Furthermore, the bandwidth of the proposed antenna is 0.32 GHz (3.32 GHz – 3.68 GHz). The application of 2x1 MIMO arrays succeeded in increasing gain and bandwidth up to 47.05 % and 91.07% compared to single element antennas. The correlation and directivity of the proposed MIMO antenna has a good value with an Envelope Correlation Coefficient (ECC) of 0.0005 and a Diversity Gain (DG) of 10 dB at a frequency of 3.5 GHz. The proposed antenna design has worked according to the criteria and can be used as a recommendation as a receiving antenna in the fifth generation (5G) communication system.

Keywords: *Antenna, Microstrip, Array, MIMO, 5G Communication System*

1. INTRODUCTION

The fifth generation (5G) communication system was introduced in 2018 and has advantages such as high data transfer speed and very wide bandwidth [1]. Based on the regulations set by [2], the resonant frequency used for the fifth generation (5G) communication system is divided into several bands, namely for high band 28 GHz, mid band 15 GHz and low band 3.5 GHz. In a wireless communication system, an antenna is needed as a sender and receiver of signals that will be converted into electrical waves so that can be used for voice and data communication purposes [3]. One of the antennas that has been widely developed for the purposes of wireless communication systems is the microstrip antenna [4]. Microstrip antennas have the advantages of compact design, affordable manufacturing costs and can work at high frequencies [5]. However, microstrip antennas have several disadvantages, including low gain and directivity [6]. The compact dimension is one of the advantages of the microstrip antenna so it is suitable for use as a receiving antenna in a wireless communication system, but to maintain optimal customer service, multi antennas are needed that work on the MIMO system for better service quality and connectivity.

The development of MIMO microstrip antennas for fifth generation communication systems has been described in several previous studies [7-8]. The research proposed by [9] has succeeded in designing an L-shaped MIMO microstrip antenna at a frequency of 3.5 GHz with a return loss value of -10 dB and an isolation loss of -18 dB and a gain of 2 dBi. Furthermore, in the research proposed by [10] a 4 port MIMO microstrip antenna was developed at a frequency of 3.5 GHz with a return loss value of -10 dB and a gain of 5.1 dBi. However, both studies still proposed low gain and low directivity so that development and optimization are needed. Several optimization methods has been proposed to improve directivity in previous studies, including arrays [11-12], and parasitic [13]. In the study conducted by [14] the plannar array MIMO method was used to increase the directional and resulted in an increase in gain of 8 dBi while the research conducted by [15] produced a gain of 12.07 dB using the 6 sector array antenna. One of the advantages of MIMO is that it increases the signal reception level in multi-user applications so that directivity is better and

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directivity is more focused. The array method aims to increase the gain of each antenna port so that the beam angle becomes narrower and the reception distance is better. The novelty of this research is the design of the MIMO array 2x1 element microstrip antenna which was developed so as to produce higher gain and directivity.

2. ANTENA DESIGN

The proposed antenna is designed using Duroid RT-5880 substrate with the specifications shown in Table 1.

Table 1: Specification of Duroid RT-5880

Parameter	Value
Dielectric Constant (ε_r)	2.2
Thickness (h)	1.575 mm
Loss Tan (tan α)	0.0009
Cooper Cladding	1 Oz, 35 µm
Volume Resistivity	2 x 10 ^{7} M Ohm.cm

In this paper, the microstrip antenna is designed to work in the frequency range of 3.4 – 3.6 GHz with a resonant frequency of 3.5 GHz for the application of the fifth generation (5G) communication system. The initial stage in the design process is to calculate the dimensions of a single element microstrip antenna that operates at a frequency of 3.5 GHz. The microstrip antenna proposed in this study has a rectangular shape with length (L) and width (W). In addition, the microstrip antenna will be connected to a female SMA connector with an impedance of 50 Ohms using a microstrip line. The function of the microstrip line is as an impedance matching between the antenna and the connector used. The antenna and connector must have the appropriate impedance to radiate electromagnetic waves at the proposed antenna. To calculate the dimensions of a rectangular microstrip antenna, equations (1), (2), (3), (4) and (5) is used while for the microstrip line feeder used equations (6) and (7) [16].

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon r+1}{2}}} \qquad (1)$$

$$L = L_{eff} - 2\Delta L \qquad (2)$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \qquad (3)$$

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (4)$$

$$\Delta_L = 0.412 \cdot h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (5)$$

$$W_z = \frac{2h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\}. \qquad (6)$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}}. \qquad (7)$$

The next step is to design a MIMO microstrip antenna with 2 x 1 elements. The 2 x 1 element MIMO antenna is designed by separating the intial designed antennas using insets and slits with a distance (d_1). The distance between the patch of MIMO antennas is obtained by using equation (8)

$$d_1 = ½\,\lambda \qquad (8)$$

The development of the array 2x1 and array MIMO microstrip antenna model is shown in the Figure 1 and Figure 2.

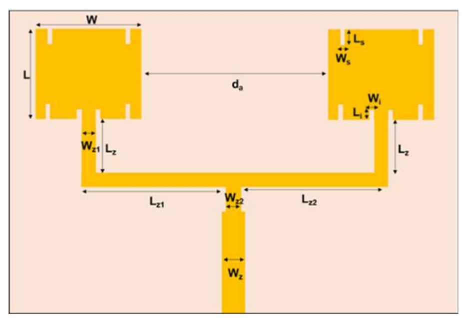

Figure 1: Design of Microstrip Antenna With Array 2x1

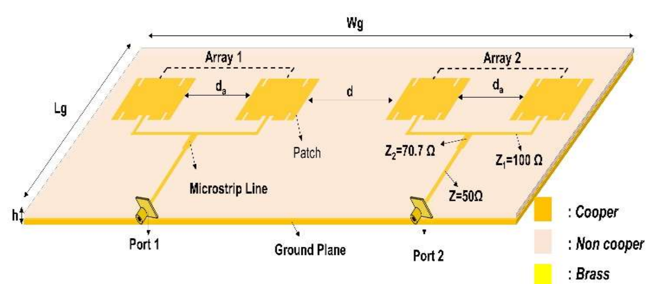

Figure 2: Design of MIMO Array 2x1

Figure 1 shows the parameters of a 2x1 element antenna array while Figure 2 shows the structure of a MIMO array 2x1 antenna consisting of a patch antenna, a feed line (Z = 50, Z2 = 70.7 and Z1 = 100 Ohms) and SMA connectors. The use of a feed line with an impedance of 70.7 and 100 Ohms serves as an impedance adjuster to get a good reflection coefficient so that the antenna can work optimally. Furthermore, a microstrip line with an impedance of 50 ohms is used as the main impedance which is directly connected to the SMA connector which also has an impedance of 50 Ohms. The design of the 2x1 element MIMO array antenna has the similar dimensions and size as the 2x1 element array antenna, but there is an additional 1 port that aims to increase the gain and directivity of the proposed antenna. The dimensions of the distance between array elements (d_a) are 43 mm and gap with MIMO element (d) are 40 mm, while the length and width of the ground plane are Wg = 300 mm and Lg = 120 mm. The dimensions of the 2x1 element MIMO array antenna are shown in Table 2.

Table 2: Dimension of Proposed Antenna

Parameter	Dimension
Wg	300 mm
Lg	120 mm
W	35 mm
L	28.3 mm
W_z	5 mm
L_z	13 mm
W_s	1 mm
L_s	6.6 mm
W_i	1 mm
L_i	6 mm
W_{z1}	2 mm
W_{z2}	3 mm
L_{z1}	35.5 mm
L_{z2}	41.5 mm
d_a	43 mm
d	40mm

3. RESULT AND DISCUSSION

To obtain the optimal directionality and isolation coefficient, iteration is carried out by adjusting the distance between MIMO elements (d). The optimization steps of the proposed antenna are shown in Table 3 and the simulation results of the reflection (S11) and isolation coefficient (S12 and S21) parameters are shown in Figure 5.

Parameters S12 and S21 indicate the independence of each antenna on port 1 and port 2, the minimum value that is a feasibility requirement for a MIMO antenna is -20 dB. In addition, the isolation coefficient also depends on the Envelope Correlation Coefficient (ECC) and diversity gain (DG). Eligibility requirements for the MIMO antenna for ECC are 0.5 and diversity gain is 10 dB. The ECC parameter relates to the correlation between the two ports of the MIMO antenna while the DG relates to the MIMO antenna's ability to direct the signal to the receiver. These two parameters are very important parameters in MIMO antennas, a good ECC value will produce good directivity and vice versa.

Table 3: Iteration Process of gap of MIMO (d)

Iteration	Dimension of d
1	10 mm
2	20 mm
3	30 mm
4	40 mm

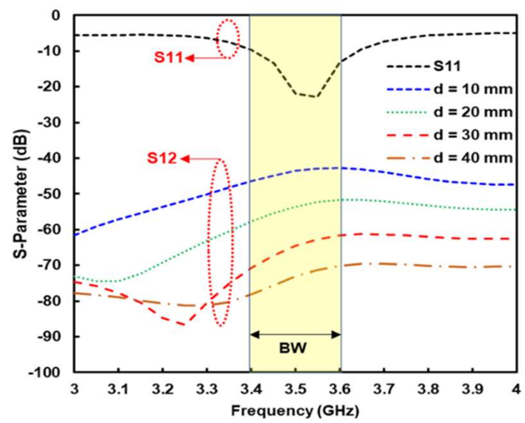

Figure 3: Simulation Result of S-Parameter

Figure 3 shows the simulation results of S11 and S12 from the optimization process for the distance between MIMO elements (d). The gap of element affects the isolation coefficient (S12 and S21) of the MIMO antenna. S12 and S21 show the independence of each antenna on port 1 and port 2, the minimum limit that is a requirement for the feasibility of a MIMO antenna system is -20 dB. In addition, isolation coefficient also depends on the Envelope Correlation Coefficient (ECC) and diversity gain (DG). The comparison of the gain simulation results from the optimization process is shown in Figure 4.

Figure 4 shows that the spacing between MIMO elements (d) affects the gain of the proposed antenna. The maximum gain obtained from the iteration 4 while gain is 13 dB at a frequency of 3.5 GHz with a directional radiation pattern as shown in Figure 5. Furthermore, the current distribution of the MIMO element at a frequency of 3.5 GHz also shows that the antennas at port 1 and port 2 are independent of each other and do not affect each other as shown by the current value of 3.4 e+0.002 V/m in Figure 5. This is in accordance with the

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results of the gain and directivity of the proposed antenna.

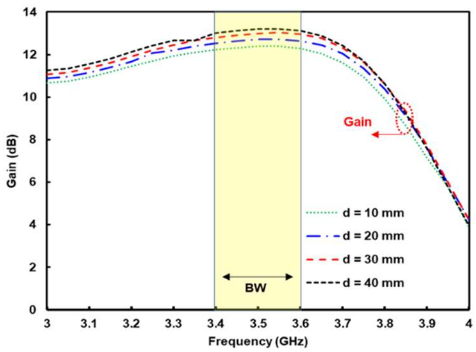

Figure 4: Simulation Result of Gain

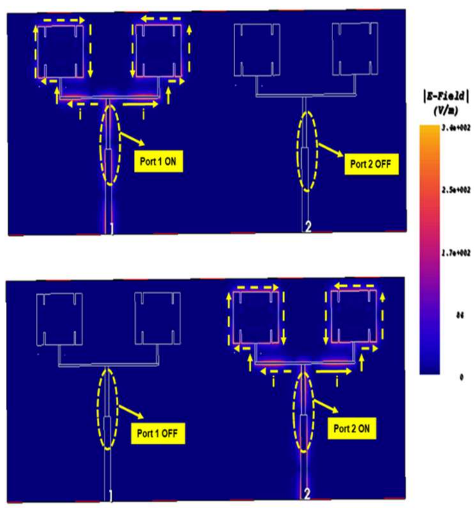

Figure 5: Simulation Result of Current Distribution

Furthermore, the radiation pattern from the MIMO array 2x1 antenna with a distance of d = 40 mm has a beamwidth (ϕ) which is much narrower than the other iterations as shown in Figure 6. The increase in gain has an impact on the narrower beamwidth, the effect of the narrow beamwidth creates a side lobe beside the main lobe which has a maximum radiation point.

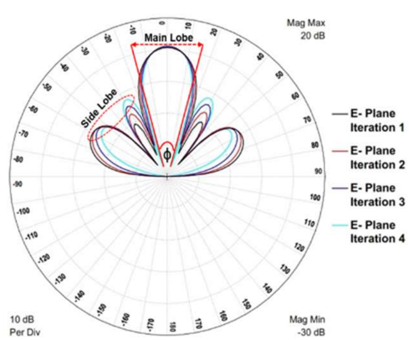

Figure 6: Simulation Result of Radiation Pattern

After the optimization and simulation process using EM simulation software, several stages of analysis were carried out on the parameters of the Envelope Correlation Coefficient (ECC) and Diversity Gain (DG). The ECC parameter relates to the correlation between the two designed antenna ports while the DG relates to the MIMO antenna's ability to direct the signal to the receiver. These two parameters are very important parameters in MIMO antennas, a good ECC will produce good directional and gain and vice versa. The threshold value for ECC is 0.5 for each working frequency, while the maximum DG value for a 2-element MIMO antenna is 10 dB. The ECC and DG values were obtained by calculation using equations (9) and (10) and observed at each frequency and the reflection coefficient (S11) and isolation coefficient (S12) of the proposed antenna [16]. The comparison of ECC and DG of the designed MIMO antenna is shown in Figure 7.

$$ECC = \frac{\left|S_{11}^{*}\,S_{12} + S_{21}^{*}\,S_{22}\right|}{(1-|S_{11}|^2-|S_{21}|^2)\,(1-|S_{22}|^2-|S_{12}|^2)} \quad (9)$$

$$DG = 10\sqrt{1-ECC^2} \quad (10)$$

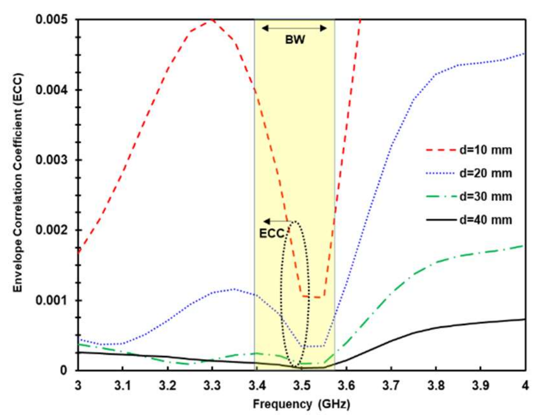

Figure 7: ECC from Proposed Antenna

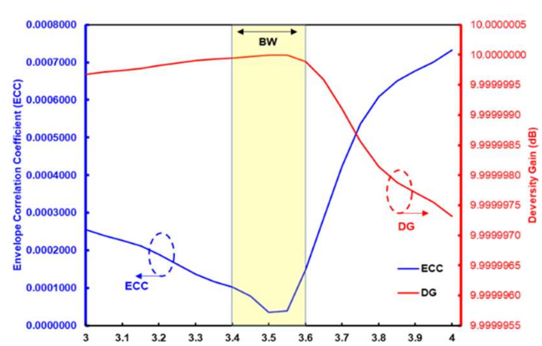

Figure 8: DG from Proposed Antenna

Figure 8 shows that the ECC of the proposed antenna is 0.0005 with a DG of 10 dB at frequency of 3.5 GHz. Both parameter have met the required threshold for MIMO antennas. In addition, ECC and DG from the operating frequency range of 3-4 GHz have stable values, so it can be concluded that the proposed antenna has met the criteria to be applied as a receiving antenna in the fifth generation (5G) communication system. High diversity gain is obtained when the ECC is lowest and vice versa, this shows that when the correlation between ports of the MIMO antenna is not significant while the gain and directionality of the antenna is more optimal. The best value is obtained in the iteration 4 with the isolation loss of -78 dB, ECC of 0.0005 and DG of 10 dB at a frequency of 3.5 GHz.

Figure 9 shows that the development of a microstrip array antenna 2x1 can increase gain up to 47.05% while MIMO array 91.17% compared with single element antennas. In addition, the radiation pattern of the antenna before and after optimization with MIMO also changes as shown in Figure 10.

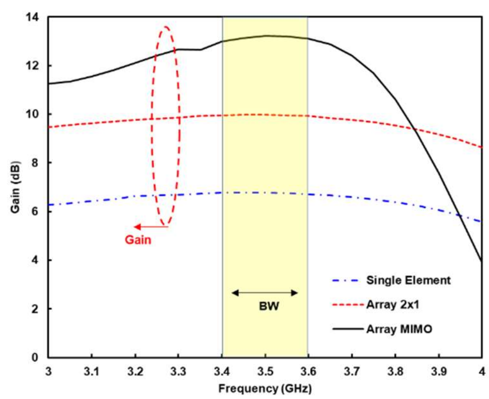

Figure 9: Comparison Gain of Proposed Antenna

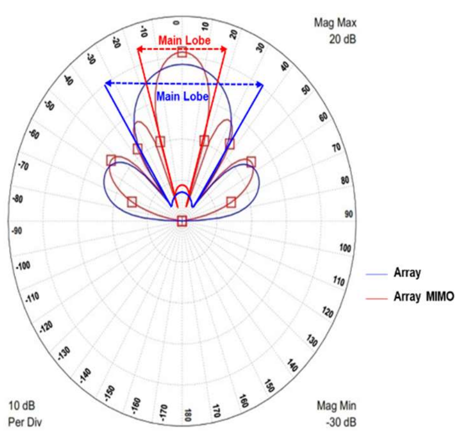

Figure 10: Comparison Of Pattern Radiation

Figure 10 shows that the application of arrays MIMO has succeeded in increasing the directivity o and radiation pattern of the antenna. The beamwith of the radiation pattern of antenna gets narrower so that the focus beamforming of antenna improved.

4. CONCLUSION

The design and development of the MIMO Array 2x1 element antenna has been described and presented in this paper. From the simulation and optimization results, the distance between the MIMO elements (d) is 40 mm. The application of MIMO array has succeeded in increasing the antenna gain until 91.17 % compared to single element antennas. Furthermore, the radiation pattern and directivity also increased after the application of MIMO arrays. The proposed antenna produces ECC 0.0005 and diversity gain 10 dB at a frequency of 3.5 GHz. The proposed antenna can be recommended and proposed as a receiving antenna in the fifth generation (5G) communication system. Future work of this research is fabricated the proposed antenna and verification simulation result with measurement result using Vector Network Analyzer.

REFRENCES:

[1] Höyhtyä, M., Apilo, O. and Lasanen, M., 2018. Review of latest advances in 3GPP standardization: D2D communication in 5G systems and its energy consumption models. *Future Internet*, *10*(1), p.3..

[2] Hikmaturokhman, A., Ramli, K. and Suryanegara, M., 2018, October. Spectrum Considerations for 5G in Indonesia. *In 2018 International Conference on ICT for Rural Development (IC-ICTRuDev)* (pp. 23-28). IEEE.

[3] Balanis, C.A., 2015. *Antenna theory: analysis and design*. John wiley & sons..

[4] Pandey, A., 2019. *Practical microstrip and printed antenna design*. Artech House.

[5] Alam, S. et al., 2021. Bandwidth Enhancement of Square Microstrip Antennas Using Dual Feed Line Techniques. *International Journal of Electrical and Electronic Engineering & Telecommunications*, pp.60–65.

[6] Fang, D.G., 2017. *Antenna theory and microstrip antennas*. CRC Press.

[7] Wang, Q., Mu, N., Wang, L., Safavi-Naeini, S. and Liu, J., 2017. 5G MIMO conformal microstrip antenna design. *Wireless*

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Communications and Mobile Computing, 2017.

[8] Parchin, N.O., Al-Yasir, Y.I.A., Ali, A.H., Elfergani, I., Noras, J.M., Rodriguez, J. and Abd-Alhameed, R.A., 2019. Eight-element dual-polarized MIMO slot antenna system for 5G smartphone applications. *IEEE Access*, 7, pp.15612-15622.

[9] Biswas, A. and Gupta, V.R., 2020. Design and development of low profile MIMO antenna for 5G new radio smartphone applications. *Wireless Personal Communications*, 111(3), pp.1695-1706.

[10] Abdullah, M., Ban, Y.L., Kang, K., Li, M.Y. and Amin, M., 2017, March. Compact four-port MIMO antenna system at 3.5 GHz. *In 2017 IEEE 2nd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)* (pp. 656-660). IEEE.

[11] Bhattacharya, A. and Vaughan, R., 2017, July. Dual-polarized fixed-beam high-gain array antenna for microwave and mm-wave applications. *In 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting* (pp. 631-632). IEEE.

[12] Stanley, M., Huang, Y., Wang, H., Zhou, H., Alieldin, A. and Joseph, S., 2018. A capacitive coupled patch antenna array with high gain and wide coverage for 5G smartphone applications. *IEEE Access*, 6, pp.41942-41954.

[13] Chu, Q.X., Li, X.R. and Ye, M., 2017. High-gain printed log-periodic dipole array antenna with parasitic cell for 5G communication. *IEEE Transactions on Antennas and Propagation*, 65(12), pp.6338-6344.

[14] Hussain, R., Alreshaid, A.T., Podilchak, S.K. and Sharawi, M.S., 2017. Compact 4G MIMO antenna integrated with a 5G array for current and future mobile handsets. *IET Microwaves, Antennas & Propagation*, 11(2), pp.271-279.

[15] Ali, M.M.M. and Sebak, A.R., 2016, July. Design of compact millimeter wave massive MIMO dual-band (28/38 GHz) antenna array for future 5G communication systems. In 2016 *17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)* (pp. 1-2). IEEE.

[16] Rahayu, Y. and Mustofa, I.R., 2017, November. Design of 2× 2 MIMO microstrip antenna rectangular patch array for 5G wireless communication network. In *2017 Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL)* (pp. 2679-2683). IEEE.