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The Effect of Using Array Technique on Semi-Circular Patch Microstrip Antenna with 2.4 GHz Frequency in Supporting Wireless Body Area Network Technology

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A B S T R A C T

This paper aims to design a semi-circular patch microstrip antenna that can work at a frequency of 2.4 GHz (band 2360 MHz - 2400 MHz) to support Wireless Body Area Network technology (WBAN). One of the devices connected to WBAN technology is a Holter monitor and medical data recorder that forms a medical network for post-operative or monitoring ICU patients (Intensive Care Unit). To support one of the WBAN technologies, an antenna is needed that has considerable gain and bandwidth characteristics. To increase the gain and bandwidth, the array method is used on antennas with inset feed unification. The antenna design was simulated using CST Studio Suite 2019. The use of array methods on microstrip antennas can increase the gain by 132.9%, which is 5.73 dB. The simulation results obtained a return loss of -17.223 dB with a bandwidth of 88.3 MHz in the frequency range of 2357.6 MHz - 2445.9 MHz

INTRODUCTION

Telecommunication technology with wireline media has no longer used and replaced with wireless technology that uses radio waves as its transmission media. One of the developing wireless technologies is wireless communication technology which is used for monitoring certain parameters as in a wireless sensor network (WSN) consisting of a collection of sensors that transmit data through radio wave media [1]. This technology is very closely related to the development of the Internet of Things (IoT), where various digital communication devices are connected to an internet network so that data exchange becomes much easier with wide applications [2]. One of the branches of WSN that specifically relates to sensors installed inside, on the surface, or worn by humans is called Wireless Body Area Network (WBAN). WBAN has a lot of development potential that can change the paradigm of monitoring vital parameters in the human body that are closely related to health. In addition to, its close relationship with the IoT, WBAN has the potential to provide remote health monitoring services, fitness programs, diagnosis of chronic diseases, and so on [3]. One of the WBAN technologies implemented for remote health monitoring is the IEEE 802.15.6 standard with a frequency of 2.4 GHz in the 2360 MHz - 2400 MHz band [4].

Specifically, in the field of health, WBAN has a significant influence in facilitating health services with its ability to monitor the vital functions of the human body [5] and collect physiological data and wirelessly transmit information to external medical devices in real-time [6]. Medical devices connected to WBAN include such as Holter monitors and other medical data recorders that form a medical network for post-operative or monitoring ICU (Intensive Care Unit) patients [7]. Generally, all these devices are connected using wires in transmitting data, so this method is not practical especially for patients who have special cases such as stroke, cerebral palsy, and other diseases that make the condition of the sufferer difficult to move. One device that can be used to reduce the use of cables on this device is an antenna [8].

The antenna is a device that can convert electrical signals into electromagnetic waves and then emit them into free space or vice versa, capturing electromagnetic waves from free space and converting them into electrical signals [9]. Good antenna performance will affect the quality of the transmitted and received signals, thus impacting the speed at which data is transmitted. Therefore, to support WBAN technology, an antenna is needed that has considerable gain and bandwidth characteristics [10]. To obtain these characteristics, microstrip antennas can be used that

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have been applied techniques or methods of increasing gain and bandwidth. This is because, in addition to having advantages such as low profile antenna characteristics, relatively easy to fabricate, relatively cheaper, and can be used in the frequency range from 100 MHz to above 100 GHz [11], microstrip antennas have disadvantages in the form of narrow bandwidth and limited gain [12].

In WBAN technology itself, various types of research have been carried out in designing microstrip antennas, such as designing microstrip antennas with a single patch in the form of PIFA (Planar Inverted F-Antenna) and using coplanar waveguide bonding techniques [13]. The antenna in the study [13] applied to WBAN technology can work at a frequency of 2.4 GHz with an antenna gain of 2.14 dBi.

With regard to the disadvantage of the microstrip antenna, the antenna modification method is a solution to increasing the gain value and bandwidth of the antenna, one of which is by arranging antenna irradiation elements in the form of an array [14]. As in research [14], the technique of unifying feeding insets on rectangular microstrip antennas using the 2x1 array method was used. The research antenna [14] applied to Wireless Fidelity (Wi-Fi) technology can work at a frequency of 2.4 GHz with an increase in antenna gain of 6.67 dBi (↑71%). Other research such as research [15] used the technique of feeding inset on hexagonal patch microstrip antenna with 2x1 array method, the antenna applied to Wireless Local Area Network (WLAN) technology was able to work at a frequency of 2.4 GHz with an increase in antenna gain of 5.55 dBi (58.12%).

From this study, a microstrip antenna will be designed that is able to work at a frequency of 2.4 GHz (band 2360 MHz - 2400 MHz) and can be applied to support WBAN technology. The antenna to be designed in this study uses a semicircular irradiation element or also called a semi-circular patch, where this semi-circular patch is a modified form of a circular patch and the antenna with a semi-circular patch which is easier to optimize when designing the antenna because it only has one patch dimension that needs to be optimized, namely fingers or radius (α). This antenna uses the inset feed unification technique and also uses the 1x2 array method on the antenna patch, which aims to increase the gain and bandwidth of the antenna. The antenna will be designed and simulated using Studio Suite 2019 Computer Simulation Technology (CST) software.

METHODS

In this part, the research method is used to develop patches that are semi-circular in shape arranged in an array, and can work at a frequency of 2.4 GHz. The design of this antenna has the following dimensional specifications [15].

1 Antenna Substrate
2 Patch Radius Calculation
3 Feed Line Dimensions Calculation
4 Calculation of Ground plane Dimensions
5 Expected Antenna Parameters

Antenna substrate

The substrate on the microstrip antenna is made of a dielectric material, so it has a considerable influence on the value of the antenna parameter. The substrate has specifications including having dielectric constant values, dielectric loss tangent, and thickness that vary according to the type of substrate used. At the end of this task, the design of the microstrip antenna uses a substrate with type FR4 (epoxy) with specifications that can be seen in Table 1.

Table 1 Specification of FR4 substrate (Epoxy)

Spesification	Value
Dielectric Constant (ε_r)	4,3
Dielectric loss tangen	0,025
Thickness (h)	1,6 mm

Patch Radius Calculation

The patch used in the design of this microstrip antenna is a semi-circular patch, so to determine the dimensions of this patch can be done by calculating the value of the logarithmic function of the patch element first through equation 1 [16].

$$F = \frac{8{,}791\times10^{9}}{f_r\sqrt{\varepsilon_r}} \quad (1)$$

Where:
F = path logarithmic function
f_r = Resonant frequency (Hz)
ε_r = The relative dielectric permittivity of the substrate (F/m)

After the logarithmic function value of the patch element is known, then a calculation of the dimensions of the semi-circular patch is made using equation 2[16].

$$\alpha = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1{,}7726\right]\right\}^{\frac{1}{2}}} \quad (2)$$

Where:
α = Radius semicircular
h = Substrate Thickness

In the design of the semi-circular patch microstrip antenna that uses the array method, the distance of the power divider on the feeder can be calculated through equations 3 and 4[16]:

$$\lambda_0 = \frac{c}{f_r} \quad (3)$$

Where:
λ_0 = Wavelenght
c = Speed of light (3 x 10^8 m/s)
f_r = The center frequency of the antenna frequency (Hz)

and

$$d = \frac{\lambda_0}{4} \quad (4)$$

Where:
d = the distance between 2 identical patches

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Feed Line Dimensions Calculation

The feed line series is an array method formed by connecting all elements with high impedance on the transmission line and power on the first element. Because this series arrangement has smaller losses on the channel than the corporate feed-line. The disadvantage of this feed-line series is the large variation in its impedance. Corporate feed-line is an array method that has more control over the feed of each element, provides better directivity, radiation efficiency, and can reduce beam fluctuations in the frequency band compared to the series feed-line. In this method, patch elements are connected to the power supply line using the λ transformer impedance technique or often called the Wilkinson power divider technique [15]. Figure 1 shows an antenna array that uses the corporate feed-line method.

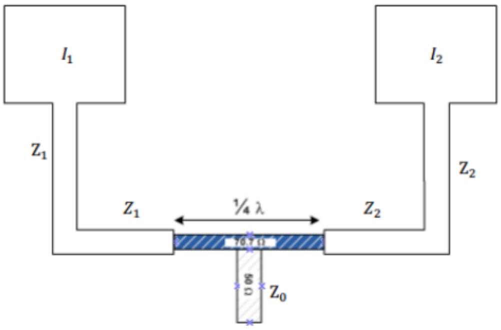

Figure 1. Two linear patch arrays with corporate feed-line [15]

Each of the same elements of the patch has an input resistance, which resistance of this element will match the channel impedances Z_1 and Z_2 and the current in each of the patches used for power sharing. The impedance and insulation characteristics of lumped resistor $2Z_0$ with all feed line conditions are of equal value $Z_1 = Z_2 = Z_0$ [15]. The Wilkinson transmission line equidistant series is shown in figure 2.

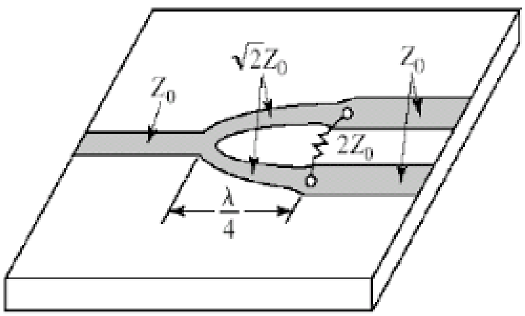

Figure 2. Equivalent series of Wilkinson transmission lines [15].

The feed line technique used in the design of the antenna in this research is the inset feed line unification technique, with a characteristic impedance (Z_0) of 50 Ω. This inset feed line has dimensions in the form of the length of the feed line channel and the width of the feed line channel. The characteristic impedance can affect the width dimension of the feed line channel. By using the array method, where this method uses the feed line divider technique on its channel, there is an addition of Z_0 characteristic impedance of 70 Ω. To determine the length dimension of the inset feed line, we can use equation 5[16].

$$L_f = \frac{c}{4 f_c \sqrt{\varepsilon_r}} \qquad 5$$

Where:
L_f = The length of feed line (m)
f_c = The operating frequency of antenna (Hz)
Ɛr = Dielectric Constant

The width of the feed line with characteristic impedance Z0 of 50 Ω and 70 Ω, it can be determined through equations 6 and 7[22].

$$A = \frac{Z_0}{60}\left[\frac{\varepsilon_r+1}{2}\right]^{0,5} + \frac{\varepsilon_r-1}{\varepsilon_r+1} \times \left[0{,}23 + \frac{0{,}11}{\varepsilon_r}\right] \qquad 6$$

Where:
Z_0 = characteristic impedance (ohm)
A = Radius of feed line (mm)

$$W_f = h \times \left(\frac{8e^A}{e^{2A}-2}\right) \qquad 7$$

Where:
W_f = Lebar saluran pencatu (mm)
h = substrat Thickness (mm)

To determine the length of the inset feed, it can use equation 8[22].

$$Y_0 = 0{,}3 \times \alpha$$

Where :
Y_0 = Inset Feed length (mm)

Calculation of Ground plane Dimensions

The ground plane in the design of this microstrip antenna is rectangular and uses the same dielectric material as the patch. The dimensions of the length and width of the ground plane can be determined using equations 9 and 10[22].

a. Ground plane length

$$L_g = 6h + 2\alpha \qquad 9$$

Where:
L_g = *ground plane lenght (mm)*

b. Wide Ground plane

$$W_g = 6h + \frac{\pi}{2}\alpha \qquad 10$$

Where:
W_g= *ground plane width (mm)*

Expected Antenna Parameters

The antenna parameters to be achieved in the design of the microstrip antenna in this research include working frequency, VSWR, return loss, gain, and bandwidth [15]. As shown in Table 2.

Table 2 Antenna parameters to be achieved

Parameter of Antenna	Value
Operating Frequency	2.4 GHz
VSWR	1 ≤ VSWR ≤ 2
Return Loss	≤ -10 dB
Gain	≥ 0
Bandwidth	≥ 40 MHz

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After the antenna dimensions based on calculations were obtained, then the antenna was designed and simulated using CST Studio Suite 2019 software. In this design, the simulated antenna used only one semi-circular patch that aimed to determine the working frequency of the antenna as a result of the calculation and makes it easier to apply the array method to the antenna. To make the antenna works according to the expected parameters, optimizing the patch dimensions, feed line channel, and substrate/ground plane dimensions are required.

After the antenna parameters such as return loss, VSWR, bandwidth, and gain were set as required, then the application of the array method was carried out on the antenna design of the previous optimization results. The purpose of applying the array method was to increase the gain value generated by the antenna at a frequency of 2.4 GHz. This method is not only able to increase the gain, but the array method can also increase the bandwidth on the antenna.

RESULTS AND DISCUSSIONS

The design of the microstrip antenna has already sufficiently acceptable to the desired antenna parameters and its capability of working at 2.4 GHz frequency. The final result of designing this antenna had the form of 2 identical semi-circular patches.

The final result of designing the microstrip antenna using the array method had a dimension size of 85 mm x 195 mm. It happened because the design used the array method that could make the size of the patch to be 2 times larger than the previous patch size. Thus, the width size of the ground plane/ substrate was assumed to be 3 times greater than the previous size because in the use of the array method there is a feeder that functioned as a power dividing channel in a feed line that has a length of 31.25 mm. Overall, the dimensions of the microstrip antenna design from the initial design to the final design can be seen in Table 3.

Table 3. Radius Optimization Results of Microstrip Antenna Patch Array Per 0.01 mm

Radius *Patch* (mm)	Frequency (GHz)	*Return Loss* (dB)	VSWR	*Gain* (dBi)	*Bandwidth* (MHz)
26.70	2.410	-16.2567	1.363	5.68	88.1
26.71	2.409	-16.3170	1.361	5.68	88.1
26.72	2.408	-16.3748	1.358	5.69	88.1
26.73	2.408	-16.4796	1.353	5.69	88.3
26.74	2.407	-16.5424	1.349	5.69	88.3
26.75	2.406	-16.6611	1.344	5.69	88.6
26.76	2.405	-16.7208	1.342	5.70	88.6
26.77	2.405	-16.7859	1.339	5.70	88.6
26.78	2.404	-16.4881	1.336	5.71	88.5
26.79	2.402	-17.0282	1.328	5.72	88.4
26.80	2.401	-17.0941	1.325	5.72	88.3
26.81	2.401	-17.1593	1.322	5.73	88.3
26.82	2.400	-17.2233	1.319	5.73	88.3

In Table 3, it can be seen that the optimization of patch radius can shift the frequency closer to 2.4 GHz. The patch radius optimization result was at a dimension of 26.82 mm which resulted in a precise frequency of 2.4 GHz and an increase in antenna gain to 5.73 dBi. Not only that, other antenna parameters such as return loss and VSWR were performed more optimally than before, where the value of return loss was -17.2233 dB and VSWR was 1.319. Not only that, this optimization resulted in an increase in bandwidth to 88.3 MHz.

After simulating and optimizing the semi-circular patch microstrip antenna design using the array method, the antenna parameters were analyzed which included return loss, VSWR, gain, bandwidth, and radiation pattern.

Return Loss

The target return loss target value in the microstrip antenna design was ≤ -10 dB at the frequency of 2.4 GHz. The smaller return loss value produced by an antenna indicated that the antenna worked more optimally in a certain frequency range because this indicated that the wave reflection that occurred would be smaller. In the design of the semi-circular patch microstrip antenna with the array method, a small return loss value of -10 dB was obtained. This showed that this antenna could work properly because it met the desired return loss target. The comparison of the return loss graph of antenna design can be seen in Table 4.

Table 4. Antenna Return Loss Chart Comparison

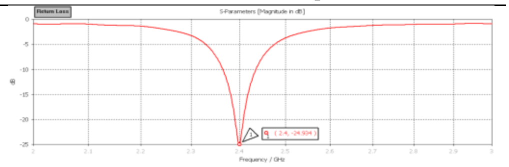
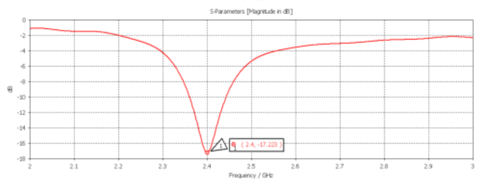
Design	*Return Loss Graphs*
Single Patch	
1x2 *Array Patch*	

Table 4 shows the comparison of return loss values obtained during antenna design. At a frequency of 2.4 GHz, the design of the semi-circular patch microstrip antenna without using the array method (single patch) and the design that used the array method (array patch) have met the desired return loss value standard. However, the design of the single patch microstrip antenna has a more optimal return loss value than the design of the microstrip antenna that used the array method.

VSWR

Similar to return loss, antenna VSWR also determined how much wave reflection was generated by the antenna. If the value of minimum return loss that must be obtained was ≤ -10 dB, then the value of antenna VSWR that might be fulfilled was ≤ 2 and would be optimally increased if it was close to the value of 1. This happened because when VSWR is worth 1, then no reflection occurred on the wave, and this also indicated that the transmission channel and antenna were in a perfect matching state. The comparison of the VSWR chart values of the antenna designs is shown in Table 5.

Table 5. Comparison of VSWR Antenna Graphs

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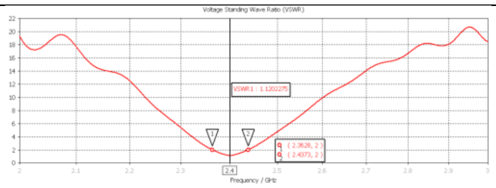
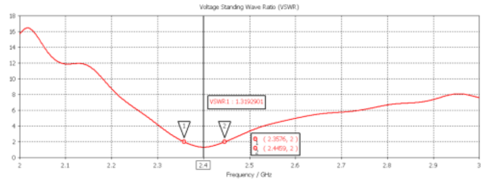
Design	VSWR graphs
Single Patch	
1x2 *Array Patch*	

Tabel 5 is a comparison of VSWR charts obtained during antenna design. At a frequency of 2.4 GHz, the design of the semi-circular patch microstrip antenna without using the array method (single patch) and the design using the array method (array patch) have met the desired VSWR value standard. However, the design of the microstrip antenna with a single patch had a more optimal VSWR value than the design of the microstrip antenna that used the array method.

Gain

As the purpose of this research was to find out the effect of the application of the array method on semi-circular patch microstrip antennas that could support WBAN technology at 2.4 GHz frequency, the gain parameter became the main factor that had to be significantly increased. The desired gain value standard was > 0 dB. The comparison of gain values of antenna design can be seen in Table 6

Table 6. Comparison of Antenna Gain Values

No	Design	*Gain Value* (dB)
1	Design previous (Calculation)	-11,01
2	Single Patch (Optimization Results)	2.46
3	1x2 Array Patch	5.76 (↑132.9 %)

Table 6 is the gain value of each antenna design. Based on the gain value shown in table 6, it could be obtained that the gain value in the patch array antenna design had the highest value compared to the gain value of the single patch antenna design. In the patch array antenna, there was an increase in gain ↑value of 132.9% from the gain value of the single patch antenna, which was 2.46 dB to 5.73 dB.

Bandwidth

The bandwidth showed the width of the frequency that worked at a certain frequency while still noticing the value of antenna parameters such as return loss and VSWR. The desired large bandwidth target at 2.4 GHz frequencies was > 40 MHz. A comparison of bandwidth values at antenna design is shown in Table 7.

Table 7. Comparison of Antenna Bandwidth Values

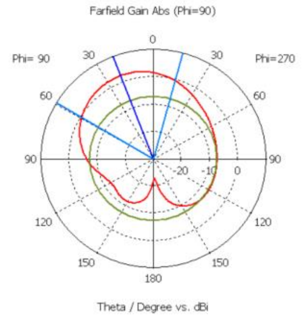
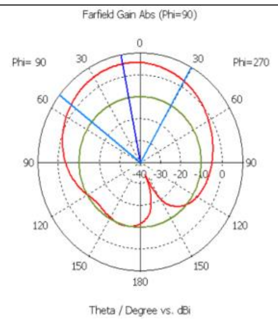
No	Design	Operating Frequency (MHz)	*Bandwidth value* (MHz)
1	Design previous (Calculation)	-	-
2	*Single Patch* (Optimization Results)	2362.8 - 2437.3	74.5
3	1x2 *Array Patch*	2357.6 - 2445.9	88.3

Table 7 is the bandwidth value presented from the results design of each antenna. Based on these data, the antenna patches that implemented the array method had a greater increase in bandwidth compared to single patch antennas. Where the bandwidth value generated in the patch array was 88.3 MHz in the frequency range of 2357.6 MHz - 2445.9 MHz. This shows that the array method can not only increase the gain but can also increase the bandwidth value of an antenna.

Radiation Patterns

The radiation pattern of the single patch antenna design and the patch array antenna design can be seen in Table 8.

Table 8 Antenna Radiation Patterns

No.	Design	Radiation pattern
1.	Single Patch (optimization)	
2.	1x2 Array Patch	

Based on table 8, the radiation pattern of the single patch microstrip antenna design and the patch array antenna design had the same pattern and the type of radiation pattern between the two designs was a directional radiation pattern because the maximum radiation (major lobe) was directed in one direction. However, both designs had a difference in the maximum radiation generated, where the antenna design with the array method had a maximum radiation greater than the antenna design that did not use the array method.

To sump up, a microstrip antenna with a semi-circular patch and inset feed distribution technique as well as the application of the array method to the patch can significantly increase the gain of the microstrip antenna and also can be used as a basis for the microstrip antenna fabrication process that can be applied to WBAN technology devices with a frequency of 2.4 GHz, or other devices that work on that frequency.

In general, a microstrip antenna with one patch element generates a low gain so that the radiation pattern of the resulting antenna widens. Therefore, some applications need to design antennas with high directivity characteristics, this aims to meet the needs of long-distance communication. One of the methods used to improve this directivity is the array method. In a microstrip antenna, the array method is an identical array of multiple microstrip antenna patches so as to form a particular patch pattern. Using the array method, we can improve antenna performance such as increasing gain, directivity scanning beam of the antenna system, and other functions that are difficult to perform with a single element [19]. The higher the gain of the antenna, the greater and more directed the directivity of the antenna, while the radiation pattern tends to narrow [16].
Generally, the design methods used in array microstrip antennas are series feed-line and corporate feed-line [18].

CONCLUSION

The semi-circular patch microstrip antenna designed in this research can work at a frequency of 2.4 GHz in the band 2360 MHz - 2400 MHz by using an array method. It can make the semi-circular patch into 2 identical patch forms by applying the simulation of feed line inset feed in the CST Studio Suite 2019 software. Thus, it can be concluded that microstrip antennas that used the array method had an increase in antenna gain to 5.73 dB. On the other hand, this antenna had an increase in antenna gain to 5.73 dB. On the other hand, this antenna had an increase in gain of ↑132.9% from the previous gain which was only 2.46 dB. The application of the array method on microstrip antenna could increase the antenna bandwidth which initially was only 74.5 MHz increasing to 88.3 MHz in the frequency range of 2357.6 MHz - 2445.9 MHz. By applying the array method, the microstrip antenna had an increase in the width of the substrate/ground plane dimension of the antenna which initially was only 65 mm to 195 mm.

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