

Design of PIFA Antenna Using Systematic Tuning for Long Range Communication

Liya Yusrina Sabila¹, Teguh Prakoso², Munawar Agus Riyadi³

¹ Department of Electrical Engineering, Universitas Ahmad Dahlan, Indonesia

^{2,3} Department of Electrical Engineering, Universitas Diponegoro, Indonesia

ARTICLE INFORMATION

Article History:

Submitted 16 December 2023

Revised 28 January 2024

Accepted 30 January 2024

Keywords:

PIFA;
Conformal;
Tuning;
900 MHz;
Long Range

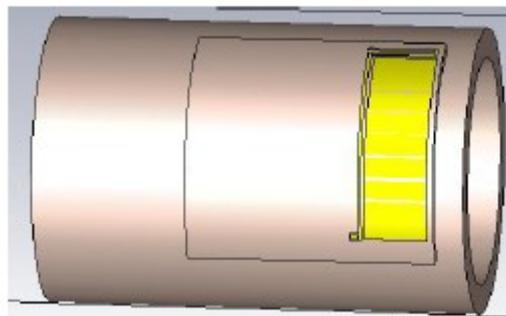
Corresponding Author:

Liya Yusrina Sabila,
Universitas Ahmad Dahlan,
Yogyakarta, Indonesia.
Email: liya.sabila@te.uad.ac.id

This work is licensed under a [Creative Commons Attribution-Share Alike 4.0](https://creativecommons.org/licenses/by-sa/4.0/)



ABSTRACT



Communication with a wireless system is one of the mainstays of communication so that communication integration is achieved. In this application, of course, an antenna is needed to send information waves to the receiver. It is also hoped that the antenna can be integrated with other components into an integrated system. There are several challenges that need to be answered to make this happen. Namely, the size of the antenna is small and the shape of the antenna can adjust to the shape of the object being integrated, for example a circle or cylinder shape. The antenna chosen to realize this challenge is the Planar Inverted F Antenna (PIFA). PIFA antennas are widely used in communication devices because their shape and size can be adjusted to the dimensions of the device. The technique used to create curved shapes is a conformal technique. To streamline the antenna design steps, the system tuning method is applied when simulating the design. The results achieved use a system tuning method which can reduce the experimental steps to just 6 experimental steps. The antenna designed works in the frequency range 916.9 – 933 MHz, the resonant frequency of 925.6 MHz with S11 is -12.5 dB, bandwidth 16.1 MHz, and the radiation pattern is omnidirectional.

Document Citation:

L. Y. Sabila, T. Prakoso, M. A. Riyadi, "Design of PIFA Antenna Using Systematic Tuning for Long Range Communication," *Buletin Ilmiah Sarjana Teknik Elektro*, vol. 5, no. 4, pp. 623-631, 2023, DOI: [10.12928/biste.v5i4.9844](https://doi.org/10.12928/biste.v5i4.9844).

1. INTRODUCTION

Telecommunication technology using cable media (wireline) has now begun to be abandoned and replaced with wireless technology which uses radio waves as a transmission medium. Communication with a wireless system is one of the mainstays of communication so that communication integration is achieved [1], [2]. The development of technology and information always occurs rapidly so that humans need adequate facilities. The communication facilities and infrastructure needed are of course to meet the communication needs between two or more people at any location and time. A telecommunication system without cables or what is called wireless is a system that connects devices without a cable and is replaced with electromagnetic waves [3], [4]. In this application, of course, an antenna is needed so that the waves sent and received can be achieved in this system [5], [6].

One antenna that can be used is PIFA. PIFA is widely used in communication devices because its shape and size match the dimensions of the device, such as cellphones and modems. PIFA has several advantages, such as its relatively light weight and relatively small dimensions, its radiation pattern is omnidirectional, its production costs are low, and its structure is simple and easy to modify [7]–[10]. However, PIFA also has a number of disadvantages, such as low efficiency, relatively narrow bandwidth and working on one frequency [11]. Therefore, PIFA development can be done by modifying its structure or shape to compensate for its deficiencies or to produce desired characteristics. In general, PIFA consists of a groundplane, patch, probe or shorting pin that connects the patch to the groundplane [12]–[14]. Sandra Costanzo et al [15] designed an antenna that covers the needs of the Medical and Wireless Body Area Sensor Network, namely at a frequency of 2.36 GHz. The created antenna shows an increase of 3 dB. Guoping Gao et al [16] designed an antenna at the 2.4 GHz frequency for wearable applications. The antenna that produces the return loss is designed to be around -30 dB with a gain of 6.72 dBi.

In antenna design, researchers often use the trial and error method to get maximum results. This method has a weakness, it does not have a benchmark or size reference and can result in many steps having to be taken. This research improves the steps in design so that become more systematic by using a systematic tuning method. Systematic tuning is one of the methods used in experiments in the form of a systematic approach to determine the ideal conditions for a production process with the minimum possible reject rate. It can also be interpreted as an experimental technique that helps to investigate the best combination of parameters to be changed in order to obtain reliable static results. The systematic tuning method uses a benchmark or reference size of $\pm 5\%$ of the nominal size. The next step is to determine the parameters that influence antenna performance.

The research that will be carried out is designing an antenna that can be used for long distance communications, at a frequency of 900 MHz. In accordance with Internet of Things (IoT) technology, long range communications can use Sigfox or LoRa technology which works at a frequency of 900 MHz [17]–[19]. LoRa is a wireless communication system for the Internet of Things, offering long distance communication (> 15 km in remote areas) and low power. Antenna design has its own challenges when it needs to be placed on a surface that is not flat or curved, such as a circle or cylinder. So that the antenna can be placed well on a curved surface, the antenna is designed using conformal techniques to give it a curved shape. With a conformal antenna shape, it will be easier to install in areas that have a curved shape. The antenna used in wireless communication is not only the most important part, but also the main design and implementation problem that affects the performance of the wireless communication system [20]–[22]. This research aims to design an antenna with a small size that can be constructed onto other objects in a circular or cylindrical shape and has good performance in terms of bandwidth, S11, and resonant frequency.

2. RESEARCH METHODS

In PIFA design, there are five important stages that will be followed, determining antenna specifications, determining antenna dimensions, carrying out design by tuning the system and analyzing the performance of the antenna design.

2.1. Antenna Specifications

Antenna specifications are something that is important to do at the beginning to meet the required performance. Specifications are determined from market needs. Antennas with a frequency of 900 MHz are designed to have the following specifications:

- Frequency Range: 919 MHz – 925 MHz
- Resonance Frequency: 922 MHz
- Bandwidth: 6 MHz
- S11: ≤ 10 dB
- Radiation Pattern: Omnidirectional

The antenna chosen is PIFA. PIFA has been widely used in mobile communication systems as mobile phones and laptops because of its compact design and is widely used in small portable devices. PIFA is like a monopole printed on a PCB, but has shorting feed points along the main resonance structure shown in Figure 1. The shorting feed point configuration can reduce the size of the antenna.

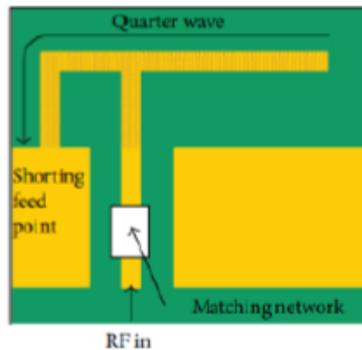


Figure 1. Planar inverted -F antenna (PIFA)

2.2. Initial Design of Antenna

The nominal design of the antenna is in Figure 2 and the dimensions are in Table 1. Initial results for the antenna are shown in Figure 3, showing that the resonance frequency does not meet the specifications, that is 922 MHz. Therefore, there is a need for a tuning process to get maximum results.

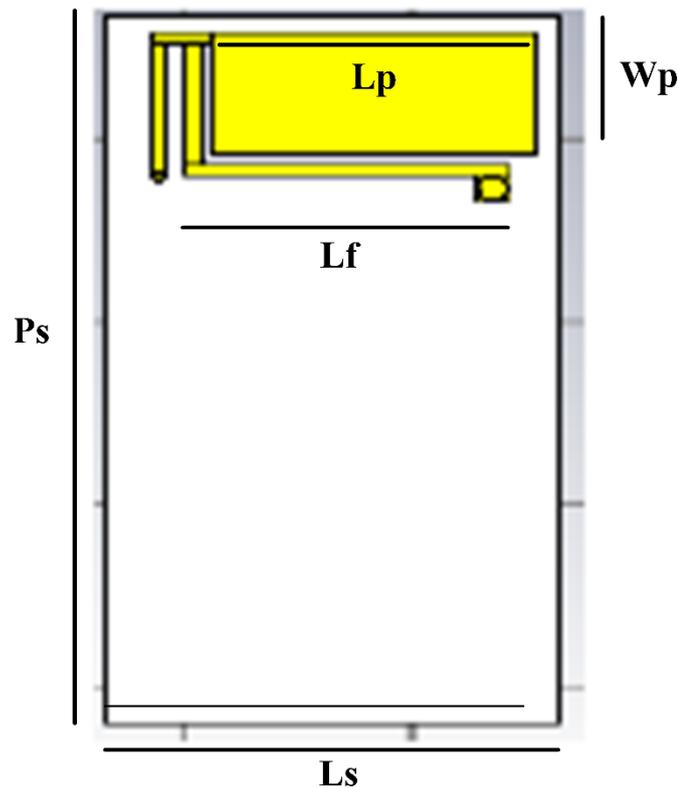


Figure 2. PIFA design

Table 1. Size of initial design of antenna

Variable	Size (mm)
Ls	20.7502
Ps	28.53
Wp	10.23
Lp	15
Lf	15
G	0.9502

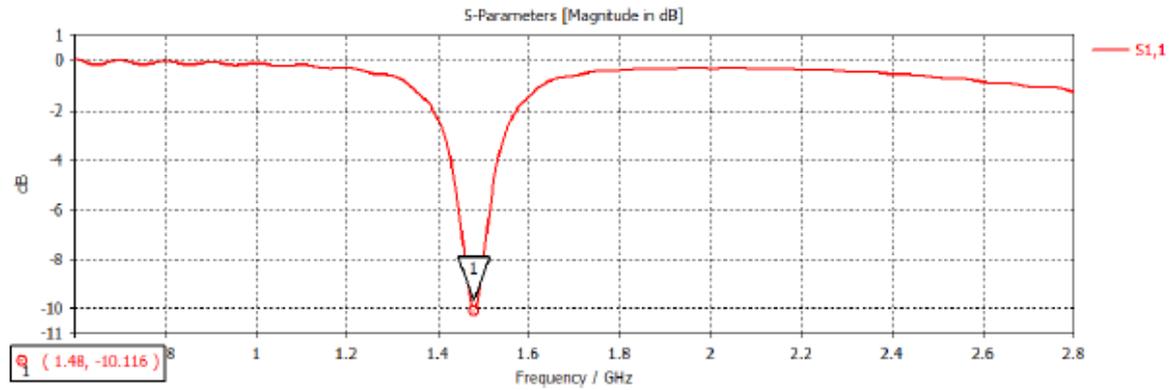


Figure 3. Initial results of PIFA design

2.3. Design Using Conformal Techniques

The antenna varied in curvature with a radius of 25 mm. Figure 4 is a simulation of the antenna when it is varied using conformal techniques and Figure 5 is a simulation of the antenna when it is added with other materials, namely silicon. Silicone was chosen as another material because it refers to the material used in prosthetic hands. Prosthetic hands are known to have a curved shape and use materials, one of which is silicon. Conformal techniques are used to meet the need for curved antennas to adjust when the antenna is integrated with a cylindrical or circular plane.

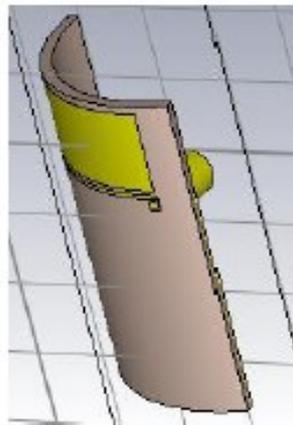


Figure 4. PIFA with conformal technique

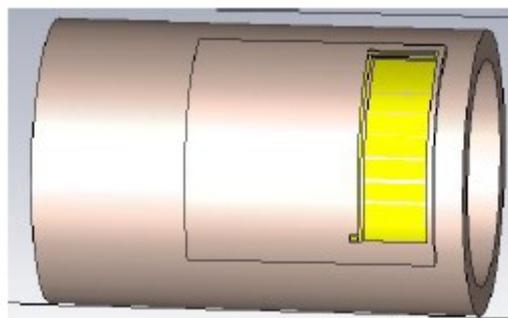


Figure 5. PIFA with silicone material

The simulation results in Figure 4 and Figure 5 are tabulated in Table 2. Differences occur when the antenna is varied conformally in the form of a shift in frequency and S11 value. However, this time the difference looks more prominent. When applied with additional material the S11 value improves but the frequency range shifts to a lower frequency. So the antenna needs to be tuned again to get a frequency of 922 MHz. A comparison of the results of the original flat, conformal PIFA and the influence of the bionic hand can

be seen in Table 2. The frequency range and bandwidth of the antenna shape when applied to the bionic hand are not written because the upper and lower frequency limits do not have an S11 value of less than -10 dB.

Table 2. Size of initial design of antenna

Specification	Flat	Conformal	Additional Other Materials
Frequency Range	1475 – 1493 MHz	1387 – 1409 MHz	-
Resonance Frequency	1480 MHz	1397 MHz	1139 MHz
Bandwidth	8.2 MHz	22.4 MHz	-
S11	-10.2 dB	-11.7 dB	-4.7 dB

Table 2 shows the influence of antenna performance on the conformal shape and the addition of other materials. From experiments on flat shapes, third conformal shapes and additional materials have not shown performance in accordance with the specified specifications. Therefore, it is necessary to optimize using system tuning.

3. RESULTS AND DISCUSSION

In the systematic tuning process there are four variables that will be varied in the CST simulation, there is Lf, G, Lp and Wp. These four variables determine the number of experiments that must be carried out. For each factor a value of -1 and +1 is set as shown in Table 3. The value in Table 3 represents $\pm 5\%$ of the nominal value. The (-1) label represents a -5% variation and the (+1) label represents a +5% variation from the nominal value of the component.

Table 3. Size of initial design of antenna

Variable	-1	+1
Lf	14.25	15.75
G	0.9027	0.9977
Lp	14.25	15.75
Wp	9.7185	10.7415

3.1. Interaction Between Variables on Response

Response is the parameter that will seek the best results. The response used is the resonant frequency and S11. The relationship between response and antenna size variables is obtained from data processing using Minitab software. Figure 6 is the result of an analysis of interactions between variables that influence each response using systematic tuning by taking significant factors that have a slope above 0.005 for the frequency response and 0.07 for the S11 response. If we want to change the resonant frequency, then we can choose the parameter to be changed, namely Lp, f or Lf, as well as S11.

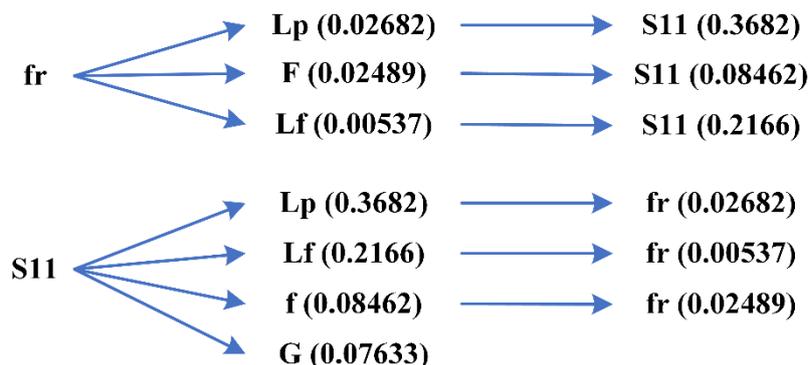


Figure 6. Interaction tree diagram between factors

3.2. System Tuning

• Tuning 1

The tuning process is carried out to adjust the antenna performance. In this case adjust the resonant frequency and S11 with several tuning steps. The center frequency (f_r) of 1139 MHz will be shifted to 922 MHz. According to the tree diagram, the most significant factor for shifting frequency is Lp with a coefficient of 0.02682 for every -5% change in nominal length. In order for the frequency to shift to 922 MHz, Lp must

be changed by 40.4549%. If 40.4549% of 15 mm is 6.0682 mm. Then L_p becomes $15 + 6.0682 = 21.0682$ mm. From tuning 1 you can shift the frequency to 927.8 MHz.

- **Tuning 2**

In tuning 2, changes are made to L_f with a coefficient of -0.2166 for every change of +5% of the nominal length. The coefficients used in this case are the two coefficients of L_p and L_f , being -0.5848. In order for the S11 value to be -20 dB, L_f must be changed by 142.6171% from 15 mm, namely 21.3926 mm. Then L_p becomes $15 + 21.3926 = 36.3926$ mm. Tuning 2 has the effect of changing the S11 value to -16.7 dB with a FR of 971.8 MHz.

- **Tuning 3**

In the 3rd tuning it will shift the resonant frequency (f_r) again because it is still not in accordance with the planned specifications, namely 922 MHz. W_p is selected as the variable to be changed. In the previous tuning, changes were made to L_p and L_f , so the coefficients used were these three coefficients, becoming 0.0571. W_p should be changed by 4.3624%. Where 4.3624% of 10.23 is 0.4463 mm. So, L_f becomes $10.23 + 0.4463 = 10.6763$ mm. Tuning 3 has the effect of shifting the frequency to a lower frequency, namely 956.4 MHz and an S11 value of -15.7 dB.

- **Tuning 4**

The center frequency on S11 (f_r) of 956.4 MHz will be shifted to 922 MHz. In tuning 4, the L_p changes are made. The coefficient of frequency response used is twice L_p , L_f , and f , being 0.0839. In order for f_r to shift to 922 MHz, L_p must be changed by 2.05% from 21.0682 which is 0.4319 mm. So, L_p becomes $21.0682 + 0.4319 = 21.5002$ mm. Tuning 4 is able to shift the resonant frequency to 941 MHz with S11 of -16.8 dB.

- **Tuning 5**

In tuning 5, the L_p is changed again to shift the frequency to 922 MHz. In tuning 5, the same coefficient as tuning 4 is used by adding L_p , to 0.11072. L_p must be changed by 0.858% from 21.5002 which is 0.1845 mm. So, L_p becomes $21.5002 + 0.1845 = 21.6846$ mm. Tuning 5 has the effect of shifting the frequency to 934.4 MHz and has an S11 value of -18.2 dB.

- **Tuning 6**

The center frequency on S11 (f_r) of 934.4 MHz will be shifted to 922 MHz. In tuning 6, the L_p changes again. In tuning 6, the same coefficient as tuning 5 is used by adding L_p , to 0.1375. In order for f_r to shift to 922 MHz, L_p must be changed by 0.451% from 21.6846 which is 0.0978 mm. So, L_p becomes $21.6846 + 0.0978 = 21.7824$ mm. Tuning 6 is carried out by changing the L_p value to 21.7824 mm and has the effect of shifting the f_r to 925.6 MHz and has an S11 value of -12.5 dB.

Table 4 shows the tuning stages carried out and Figure 7 shows the final results of S11. In this case, tuning stops at tuning 6 because at tuning 6, the antenna performance already meets the specified specifications. The comparison of the resonant frequency and S11 for each tuning is tabulated in Table 5. The resulting frequency range is 916.9 – 933 MHz and the omnidirectional radiation pattern is shown in Figure 8 and Figure 9. So it can be said that the Original PIFA for a frequency of 900 MHz meets the specifications. Figure 8 and Figure 9 show that the omnidirectional radiation pattern is fulfilled due to the circular shape of the radiation area spreading in all directions, not just in one direction, so it can receive waves or signals from any direction.

Table 4. Systematic tuning process

Variable	Nominal	Tuning 1	Tuning 2	Tuning 3	Tuning 4	Tuning 5	Tuning 6
L_f	15	15	36.3926	36.3926	36.3926	36.3926	36.3926
G	0.9502	0.9502	0.9502	0.9502	0.9502	0.9502	0.9502
L_p	15	21.0682	21.0682	21.0682	21.5002	21.6846	21.7824
W_p	10.23	10.23	10.23	10.6763	10.6763	10.6763	10.6763

Table 5. Comparison of the results of each tuning

Specification	Nominal	Tuning 1	Tuning 2	Tuning 3	Tuning 4	Tuning 5	Tuning 6
Resonance Frequency	1139 MHz	927.8 MHz	971.8 MHz	956.4 MHz	941 MHz	934.4 MHz	925.6 MHz
S11	-4.7 dB	-3.3 dB	-16.7 dB	-15.7	-16.8	-18.2	-12.5

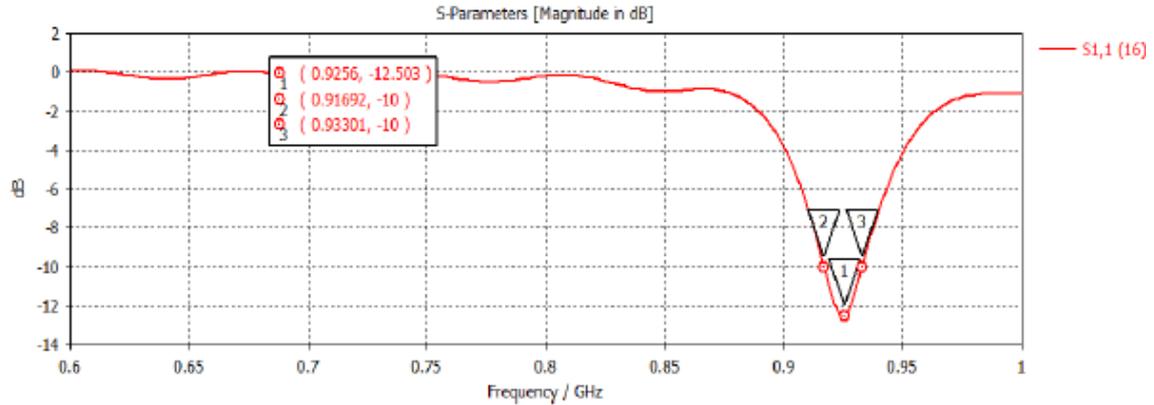


Figure 7. Final S11 results

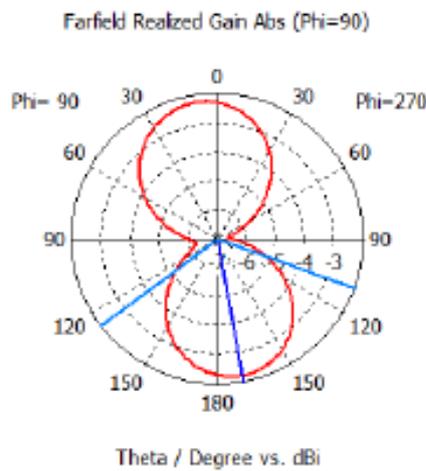


Figure 8. PIFA azimuth radiation pattern

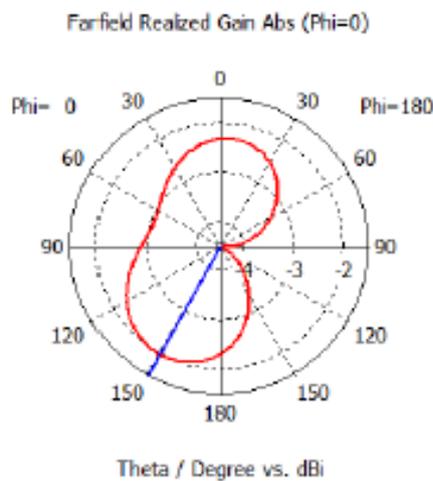


Figure 9. PIFA elevation radiation pattern

3.3. Antenna Performance Evaluation

Based on the systematic tuning process up to tuning 6, it shows that the PIFA plan can meet the specified specifications. It can be seen in Table 6 that PIFA has the appropriate bandwidth and S11 values. From the experiments that have been carried out, the final antenna design meets the required performance. It can be seen that the antenna design in this research has performance that is in accordance with the references provided. This means that the antenna that has been designed can then be implemented can be seen in Table 7.

Table 6. Antenna performance

Specification	Flat PIFA	Conformal PIFA
Frequency Range	919 – 925 MHz	916.9 – 933 MHz
Resonance Frequency	922 MHz	925.6 MHz
Bandwidth	6 MHz	16.1 MHz
S11	≤ - 10 dB	-12.5 dB
Radiation Patterns	Omnidirectional	Omnidirectional

Table 7. Comparison with the others antenna

Ref.	Resonance Frequency	S11	Radiation Pattern
[23]	2.4 GHz	-15 dB	Omnidirectional
[24]	911 MHz	-10 dB	Omnidirectional
[25]	957.2 MHz	-16.1 dB	Omnidirectional
This Research	925.6 MHz	-12.5 dB	Omnidirectional

4. CONCLUSIONS

From this research it can also be concluded that by changing the shape of the antenna to a curved shape and adding other materials, there will be a shift in frequency and changes in antenna performance. For this reason, it is necessary to change the size. From research, it has been proven that using the systematic analysis shows more effective steps. Just using 6 steps can get the best results. This proves that using a systematic tuning method can increase time and step efficiency in achieving appropriate and best performance. The frequency shift from nominal size to tuning 6 is 213.4 MHz and the S11 value has a difference of 7.8 dB. The final results obtained for the resonant frequency are 925.6 MHz with a bandwidth of 16.1 MHz, S11 -12.5 dB and an omnidirectional radiation pattern. From the results obtained, the antenna design that was carried out met the required performance. So, the antenna can be recommended for further exploration, realization and integration with other components and application in areas with curved shapes.

REFERENCES / REFERENCES

- [1] I. F. Akyildiz, A. Kak, and S. Nie, "6G and Beyond: The Future of Wireless Communications Systems," *IEEE Access*, vol. 8, pp. 133995–134030, 2020, <https://doi.org/10.1109/ACCESS.2020.3010896>.
- [2] Q. Wu, "4G Communication Technology Wireless Network Secure Communication," *2021 Int. Wirel. Commun. Mob. Comput. IWCMC 2021*, pp. 915–918, 2021, <https://doi.org/10.1109/IWCMC51323.2021.9498797>.
- [3] M. Islam and S. Jin, "An Overview Research on Wireless Communication Network," *Adv. Wirel. Commun. Networks*, vol. 5, no. 1, p. 19, 2019, <https://doi.org/10.11648/j.awcn.20190501.13>.
- [4] S. Alfattani, "Review of LiFi Technology and Its Future Applications," *J. Opt. Commun.*, vol. 42, no. 1, pp. 121–132, 2021, <https://doi.org/10.1515/joc-2018-0025>.
- [5] H. Karami, H. Tabarsa, G. B. Gharehpetian, Y. Norouzi, and M. A. Hejazi, "Feasibility study on simultaneous detection of partial discharge and axial displacement of HV transformer winding using electromagnetic waves," *IEEE Trans. Ind. Informatics*, vol. 16, no. 1, pp. 67–76, 2020, <https://doi.org/10.1109/TII.2019.2915685>.
- [6] S. Ghosh and D. Sen, "An Inclusive Survey on Array Antenna Design for Millimeter-Wave Communications," *IEEE Access*, vol. 7, pp. 83137–83161, 2019, <https://doi.org/10.1109/ACCESS.2019.2924805>.
- [7] K. Kundu, A. Dubey, A. Dhama, and N. N. Pathak, "Planar inverted F antenna, PIFA array in 5G applications," In *Journal of Physics: Conference Series*, vol. 2062, no. 1, p. 012002, 2021, <https://doi.org/10.1088/1742-6596/2062/1/012002>.
- [8] M. Ikram, Y. Wang, M. S. Sharawi, and A. Abbosh, "A novel connected PIFA array with MIMO configuration for 5G mobile applications," *2018 Aust. Microw. Symp. AMS 2018 - Conf. Proc.*, vol. 2018-Janua, pp. 19–20, 2018, <https://doi.org/10.1109/AUSMS.2018.8346961>.
- [9] K. Kundu, A. Dubey, A. Dhama, and N. N. Pathak, "Planar inverted F Antenna, PIFA array in 5G applications," *J. Phys. Conf. Ser.*, vol. 2062, no. 1, 2021, <https://doi.org/10.1088/1742-6596/2062/1/012002>.
- [10] S. S. Md. Enan, A. Istiaque and M. A. Hossain, "Design and Characterization of Miniaturized Implantable PIFA Antenna for MICS Band Application," *2020 IEEE Region 10 Symposium (TENSYP)*, pp. 254–257, 2020, <https://doi.org/10.1109/TENSYP50017.2020.9230999>.
- [11] M. Nahas, "A Super High Gain L-Slotted Microstrip Patch Antenna For 5G Mobile Systems Operating at 26 and 28 GHz," *Eng. Technol. Appl. Sci. Res.*, vol. 12, no. 1, pp. 8053–8057, 2022, <https://doi.org/10.48084/etasr.4657>.
- [12] A. Ahmadihaji, H. Aliakbarian, N. M. Saaid, and P. J. Soh, "Design, simulation, fabrication and evaluation of a textile pifa for wearable iot application," *ECTI Trans. Comput. Inf. Technol.*, vol. 15, no. 3, pp. 289–302, 2021, <https://doi.org/10.37936/ecti-cit.2021153.241779>.
- [13] R. Kumar, L. S. Solanki, and S. Singh, "Miniature Archimedean Spiral PIFA Antennas for Biomedical Implantable Devices," *2019 6th Int. Conf. Signal Process. Integr. Networks, SPIN 2019*, no. 2, pp. 162–167, 2019, <https://doi.org/10.1109/SPIN.2019.8711600>.
- [14] R. Del-Rio-Ruiz, J. M. Lopez-Garde, and J. Legarda, "Planar textile off-body communication antennas: A survey," *Electron.*, vol. 8, no. 6, 2019, <https://doi.org/10.3390/electronics8060714>.

- [15] S. Costanzo and A. M. Qureshi, "Compact and wideband PIFA design for wireless body area sensor networks," *Electron.*, vol. 10, no. 21, 2021, <https://doi.org/10.3390/electronics10212576>.
- [16] G. Gao, S. Wang, R. Zhang, C. Yang, and B. Hu, "Flexible EBG-backed PIFA based on conductive textile and PDMS for wearable applications," *Microw. Opt. Technol. Lett.*, vol. 62, no. 4, pp. 1733–1741, 2020, <https://doi.org/10.1002/mop.32224>.
- [17] P. D. P. Adi and A. Kitagawa, "Performance evaluation of E32 long range radio frequency 915 MHz based on internet of things and micro sensors data," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 11, pp. 38–49, 2019, <https://doi.org/10.14569/IJACSA.2019.0101106>.
- [18] A. Ikpehai *et al.*, "Low-power wide area network technologies for internet-of-things: A comparative review," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 2225–2240, 2019, <https://doi.org/10.1109/JIOT.2018.2883728>.
- [19] N. Islam, B. Ray, and F. Pasandideh, "IoT Based Smart Farming: Are the LPWAN Technologies Suitable for Remote Communication?," *Proc. - 2020 IEEE Int. Conf. Smart Internet Things, SmartIoT 2020*, pp. 270–276, 2020, <https://doi.org/10.1109/SmartIoT49966.2020.00048>.
- [20] M. A. Jamshed, A. Nauman, M. A. B. Abbasi, and S. W. Kim, "Antenna Selection and Designing for THz Applications: Suitability and Performance Evaluation: A Survey," *IEEE Access*, vol. 8, pp. 113246–113261, 2020, <https://doi.org/10.1109/ACCESS.2020.3002989>.
- [21] L. Dai *et al.*, "Reconfigurable Intelligent Surface-Based Wireless Communications: Antenna Design, Prototyping, and Experimental Results," *IEEE Access*, vol. 8, pp. 45913–45923, 2020, <https://doi.org/10.1109/ACCESS.2020.2977772>.
- [22] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions," *IEEE Open J. Commun. Soc.*, no. i, 2020, <https://doi.org/10.1109/OJCOMS.2020.3010270>.
- [23] S. Kumar *et al.*, "A 915 MHz Wristwatch-Integrated Antenna for Wireless Health Monitoring," *14th Eur. Conf. Antennas Propagation, EuCAP 2020*, 2020, <https://doi.org/10.23919/EuCAP48036.2020.9135360>.
- [24] T. N. Kapetanakis *et al.*, "Embroidered bow-tie wearable antenna for the 868 and 915 mhz ism bands," *Electron.*, vol. 10, no. 16, pp. 1–14, 2021, <https://doi.org/10.3390/electronics10161983>.
- [25] J. Gui, A. Andújar, and J. Anguera, "On the Reuse of a Matching Network for IoT Devices Operating at 900 MHz Embedding Antenna Boosters," *Electron.*, vol. 11, no. 8, 2022, <https://doi.org/10.3390/electronics11081267>.

AUTHOR BIOGRAPHY



Liya Yusrina Sabila received a B.Eng. degree in 2017 and a Master's degree in engineering in 2021 from Electrical Engineering Department at Diponegoro University, Semarang, Indonesia. Currently, I am working as a Junior Lecturer and a researcher at the Electrical Engineering Department, Faculty of Industrial Technology, Ahmad Dahlan University in Yogyakarta, Indonesia. My research interests are in antenna and propagation, especially small antenna design.



Teguh Prakoso received a B.Eng. degree in 2002 from Institut Teknologi Bandung, Jawa Barat, a Master's degree in engineering in 2006 from Institut Teknologi Bandung, Jawa Barat and a PhD degree in Engineering from the Universiti Teknologi Malaysia in 2014. Currently, He is working as a Senior Lecturer and a researcher at the Electrical Engineering Department, Faculty of Engineering, Diponegoro University in Semarang, Indonesia. His research interests in antenna, wireless propagation, radio over fiber and RF/microwave circuit.



Munawar Agus Riyadi received a B.Eng. degree in 2000 from Institut Teknologi Bandung, Jawa Barat, a Master's degree in engineering in 2002 from Institut Teknologi Bandung, Jawa Barat and a PhD degree in Engineering from the Universiti Teknologi Malaysia in 2012. Currently, He is working as a Senior Lecturer and a researcher at the Electrical Engineering Department, Faculty of Engineering, Diponegoro University in Semarang, Indonesia. His research interests in telecommunications electronics.