A 923 MHz Steerable Antenna for Low Power Wide Area Network (LPWAN)

Mainsuri
Electrical Engineering Department
Universitas Hasanuddin
South Sulawesi, Indonesia
mainsuri.postel@gmail.com

Elyas Palantei
Electrical Engineering Department
Universitas Hasanuddin
South Sulawesi, Indonesia
elyas_palantei@unhas.ac.id

Intan Sari Areni
Electrical Engineering Department
Universitas Hasanuddin
South Sulawesi, Indonesia
intan@unhas.ac.id

Wardi
Electrical Engineering Department
Universitas Hasanuddin
South Sulawesi, Indonesia
wardi@unhas.ac.id

Merna Baharuddin
Electrical Engineering Department
Universitas Hasanuddin
South Sulawesi, Indonesia
merna@unhas.ac.id

Dewiani
Electrical Engineering Department
Universitas Hasanuddin
South Sulawesi, Indonesia
dewiani@unhas.ac.id

Sunarno
Nuclear and Physics Engineering
Universitas Gadjah Mada (UGM)
Yogyakarta, Indonesia
E-mail: sunarno@ugm.ac.id

Eko Setijadi
Electrical Engineering Department
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
E-mail: e_setijadi@ee.its.ac.id

Arif Hidayat
LAPAN Pare-Pare
South Sulawesi, Indonesia
E-mail: arif.hidayat81@gmail.com

***Abstract*— This study aims to support the communication network in the LoRa technology application in supporting the application of the IoT system. In Indonesia, LoRa technology is included in the communication technology based on low power wide area network (LPWAN) non-cellular by utilizing the unlicensed ISM band of 915 MHz. Generally, LoRa technology is widely used in research and industry. This paper designs a smart beam steering antenna at a frequency of 923 MHz in accordance with Indonesian regulations that can guarantee data quality reception on the LoRa system. The computation results of this smart antenna design has confirmed that it allows to steer the antenna beam direction into 360˚ full azimuthal coverage. The main lobe is altered for every 60˚ step. In terms of performance parameters, this antenna design exhibits a pretty good performance with Return Loss value ≤ -10 dB, VSWR value < 1.92. The numerical gain value obtained is abruptly 8.52 dBi. This value is better than the gain used in conventional LoRa Gateway antennas, which is about 5 dBi.**

Keywords—IoT Applications, LPWAN Non-Cellular, ISM Band, LoRa Gateway and LoRa Technology

I. INTRODUCTION

Currently, the development of information and communication technology is entering the new era of the fourth industrial revolution (Industry 4.0). In this era, the use of digital technology and the internet are the major components. As a result, technology leads to the latest automation systems and data exchange easily and quickly. This is to support the development of Internet of Thing (IoT) technology which is growing rapidly today.

IoT is an interconnection network, where billions of objects, goods, sensors, or devices that are connected to others use the internet to be able to share data and resources [1]. Basically, the concept of IoT aims to expand the benefits of internet connectivity that is connected continuously [2]. This can be seen in IoT applications for the development of smart farming technology [3], smart home [4], smart city, industrial internet, health, transportation and others.

Nowadays, various communication network technologies can be used for IoT system applications. One of the technologies commonly used to build IoT applications is the long range wireless communication technologies (LoRa). In Indonesia, several LoRa technologies are communication technology based on low power wide area network (LPWAN) non-cellular that can transmit information or data over long distances at low data rates [5], [6]. LoRa technology which includes LPWAN non-cellular is a wireless communication system which utilizes the unlicensed industrial, scientific and medical (ISM) bands, namely the ISM Band of 915 MHz. LoRa technology that works in this band is widely used in research and industry including Indonesia. However, increasing interest in the use of ISM bands in large numbers of wireless applications has emerged that ISM bands is going to be fully occupied, resulting in problems in communication, including decreased quality of service [7] or there can be interference that comes from internal or external networks [8]. Meanwhile, the high quality of service (QoS) is extreemly required in the wireless communication system.

On the other hand, increasing transmit power can be used as a solution to quality of service. But it cannot be completed, because the transmit power of LPWAN non-cellular devices such as LoRa in the ISM band is limited by regulations, namely ≤ 100 mW (end node) and ≤ 400 mW (gateway) [9]. Therefore, to support guaranteed data reception, the LoRa gateway requires a device, i.e. a smart antenna that has a better gain than conventional antennas.

Currently, the conventional LoRa Gateway in the band 0f 915 MHz which is quite often used in several studies has the highest gain of approximately 5 dBi [10], [11], [12].

Smart antenna computation is presented in this paper which can show better performance than conventional LoRa Gateway antennas. This smart antenna is a beam steering, which is an antenna that can alter the antenna's radiation pattern into a specific direction without changing the antenna structure. This method is really powerful to apply in order to obtain a better gain generated in the desired direction. This may guarantee the optimum data reception. Several previous studies have tried to design an antenna with beam steering, both Electronically Steerable Parasitic Array Radiator (ESPAR) [13] and Switched Parasitic Array (SPA) [14]. From these studies, it is shown that an antenna model that can form a specific beam as a potential solution to increase data rates and increase signal-to-noise ratio (SNR) [13], overcomes interference which is a major factor in limiting signal quality and capacity [15].

From several previous studies, either another steerable antenna design [7] or research related to IoT applications based on LoRa technology [10] which uses the ISM band of 915 MHz, generally operates at a frequency of 915 MHz. However, antenna design and research at these frequencies are not in accordance with current regulations in Indonesia. In Indonesia, it is determined that the LPWAN non-cellular technologies work in the frequency of 920–923 MHz [16]. In addition, the frequency of 915 MHz in Indonesia is still used for the operation of cellular mobile telecommunication networks based on applicable regulations [17], [18].

In this paper, the smart antenna design and structure were configured and researched using CST Microwave Studio software. The performance parameters used are the return loss, gain, and VSWR values .The smart antenna design and structure are optimized to obtain better performance than conventional antennas. Antenna design optimization at a frequency of 923 MHz in the ISM band of 915 MHz according to applicable regulations in Indonesia.

II. ANTENNA DESIGN AND STRUCTURE

In this section, the beam steering smart antenna design is showed in Figure 1 and Figure 2 that operates at a frequency of 923 MHz for IoT technology implementation, especially communication based on LPWAN non-cellular such as LoRa technologies. This smart antenna only receives signals from the transmitter, because its purpose is to guarantee data quality reception at the LoRa gateway side.

A. Design of Proposed Smart Antenna

The design of the proposed smart antenna is shown in Figure 1. This antenna system is a monopole antenna with a circular ground plane. The proposed smart antenna consists of seven monopole elements, which differentiates it from other smart antenna studies [7], which only use five monopole elements. A monopole element as an active element is placed in the center of the ground plane. Meanwhile, the other six parasitic monopole elements are placed symmetrically to form a geometric circular array configuration. The passive parasitic monopole elements are separated from each other by an angle of 60˚.

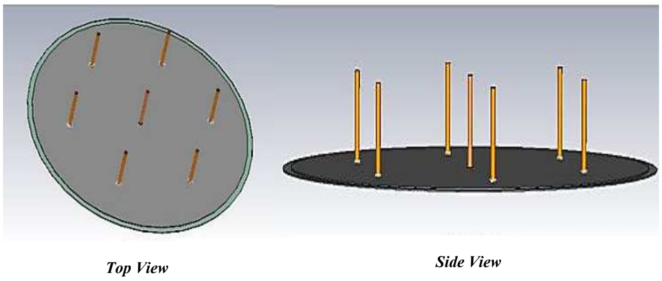


Fig. 1. Design of Smart antenna without protective casing

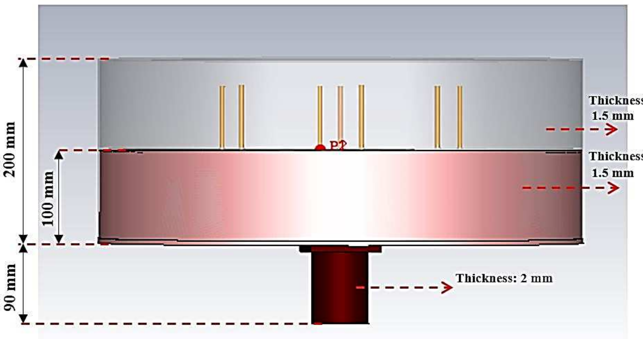


Fig. 2. Design of Smart antenna with protective casing

Elements of this monopole antenna are simulated using a hollow aluminum cylinder with an outer diameter of 5.9 mm and an inner diameter of 4.8 mm. While the ground plane is designed in a circular shape and simulated using aluminum which is 1 mm thick. Next, the ground plane is placed on a base made of FR-4 (loss free, $\varepsilon_r = 4.3$) with a diameter of 530 mm and a thickness of 1.6 mm.

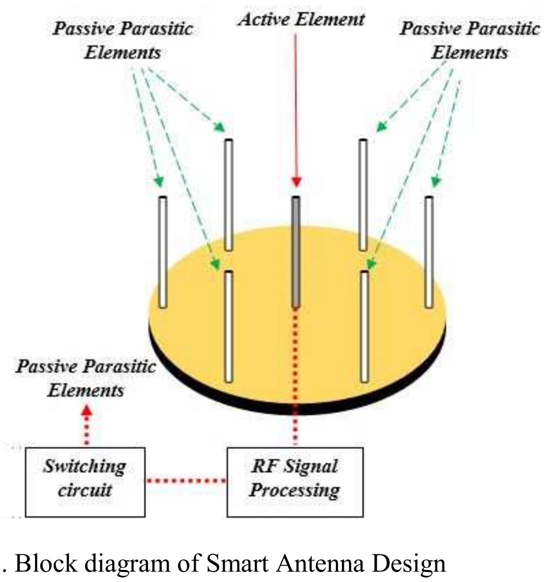


Fig. 3. Block diagram of Smart Antenna Design

The smart antenna computation is designed using a protective casing which consists of three parts (Figure 2). The first part is the bottom casing to hold the antenna's ground plane, has a thickness of 1.5 mm and a height of 100 mm. The second part is a cover casing which has a thickness of 1.5 mm anda height of 200 mm. And the last part is the antenna pole which has a thickness of 2 mm, a height of 90 mm and 54 mm in diameter. Protective casing which was simulated using epoxy resin ($\varepsilon_r = 4$).

The block diagram of a smart antenna design that determines the correct beam direction according to its signal direction is shown in Figure 3. In simple terms, the beam direction adjustment is based on the short or open conditions of the six parasitic elements to the ground plane. Changes in this condition are controlled by the switching circuit based on the signal processing results received from the RF Signal Processing. The decision to choose the right beam in RF Signal Processing is based on control from the microcontroller using a certain algorithm after receiving a signal from the Lora Gateway Module.

B. *Dimensions of Proposed Smart Antenna Design*

The antenna design that operates at a frequency of 923 MHz uses aluminum material on the monopole elements and ground plan. After obtained the lambda (λ) value, then each size of each element must consider the aluminum velocity factor of 0.95 [19].

The dimensions of the proposed antenna system design can be seen in Figure 4. The length of the antenna monopole element is designed to be the same as the concept size of the monopole antenna in general (= 0.25λ) [20]. The length of these elements is the same for both active monopole element and parasitic monopole elements. While, the ground plane used in this antenna design has a proposed diameter of 1.6λ. Then, distance of the parasitic monopole elements from the ground plane center point is 0.9λ.

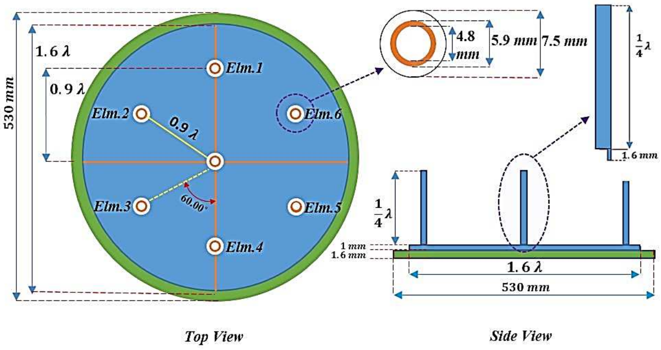


Fig. 4. Layout of Proposed Smart Antenna Dimension

III. Result And Discussions

The numerical computation method for This smart antenna design is computed with CST Microwave Studio software, which is different from previous study using NEC Winpro [7]. The optimal smart antenna design results are obtained with the appropriate performance parameters of return loss, gain, and VSWR.

A. *Optimization of the proposed Smart Antenna Design*

The dimensional comparisons between the calculation results and the optimization results from the CST simulation are shown in Table I.

TABLE I. ANTENNA DIMENSION OPTIMIZATION

Parameter	Antenna dimension		
	Lambda (λ)	*Calculation Resulst (mm)*	*Optimization Results (mm)*
Monopole Element Length	0.25	77.1	69.2
Ground Plane Diameter	1.6	493.6	510
Monopole Element Distance to Ground Plane Center Point	0.9	138.825	142.021

B. *The proposed Parasitic Element Configuration*

In obtaining the expected performance parameter results from this proposed smart antenna design, the short or open configuration of the six parasitic elements of the antenna design is carried out against the ground plane (the positions of the six parasitic elements are shown in Figure 4). The short / open condition of the parasitic elements to the ground plane is carried out by the switching circuit. However, this simulation is carried out with a lumped element type RLC serial, where the value of R entered for the short condition is 1Ω and in the open condition is 1 MΩ.

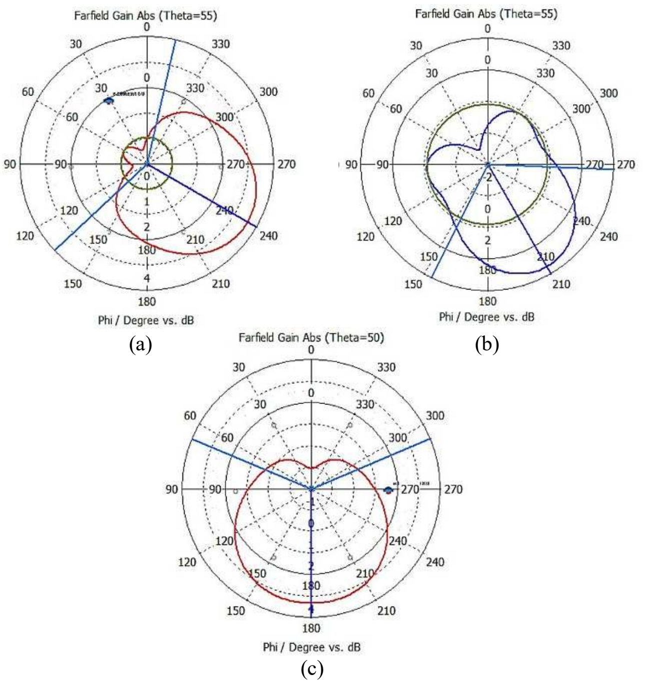


Fig. 5. Configuration of the parasitic elements to the ground plane, (a). two parasitic elements are shorted, (b). Three parasitic elements are shorted, (c). four parasitic elements are shorted

By using a ground plane measuring 1λ, three configuration patterns shown in Figure 5 are simulated. The first, two parasitic elements are shorted to the ground plane and a gain of 4.5 dB is obtained. Then, the three parasitic elements are shorted to the ground plane and get a gain of 5.4 dB. And finally, the four parasitic elements are shorted to the ground plane and a gain of 4.3 dB is obtained. The parasitic elements that are not shorted for each of the three simulated patterns are in open condition.

From the simulation results, the configuration pattern of the three parasitic elements is shorted to the ground plane which shows a better gain value. This configuration is used to simulate and see the performance parameters of the proposed antenna design as seen in Table II. There are six patterns that will form six different gain angles.

TABLE II. SHORT / OPEN ELEMENT PARASITIC ANTENNA

Pattern	Condition of Parasitic Elements to Ground Plane					
	Elem.1	*Elem.2*	*Elem.3*	*Elem.4*	*Elem.5*	*Elem.6*
1	short	short	short	open	open	open
2	open	short	short	short	open	open
3	open	open	short	short	short	open
4	open	open	open	short	short	short
5	short	open	open	open	short	short
6	short	short	open	open	open	short

C. The proposed smart antenna performance parameters

The simulation of the optimization results and configuration of the parasitic elements of this smart antenna provide performance parameters values in form of return loss, gain, and VSWR results.

TABLE III. RETURN LOSS, VSWR, AND GAIN VALUE

Pattern	Shorted Element	Return Loss (dB)	VSWR	Gain (dBi)	Sudut Beam (°)
1	1 ; 2 ; 3	-30.55	1.06	8.44	211
2	2 ; 3 ; 4	-30.53	1.06	8.44	149
3	3 ; 4 ; 5	-29.15	1.07	8.45	90
4	4 ; 5 ; 6	-31.08	1.06	8.52	31
5	5 ; 6 ; 1	-31.11	1.06	8.52	329
6	6 ; 1 ; 2	-29.20	1.07	8.45	270

1) *Value of Return Loss*: The simulation result that shows the value of Return Loss obtained is shown in Figure 6 and Table III. The value obtained is different from each pattern, but the value obtained for the whole pattern is still included in the good performance parameter value for an antenna, based on the value of Return Loss ≤ -10 dB [20].

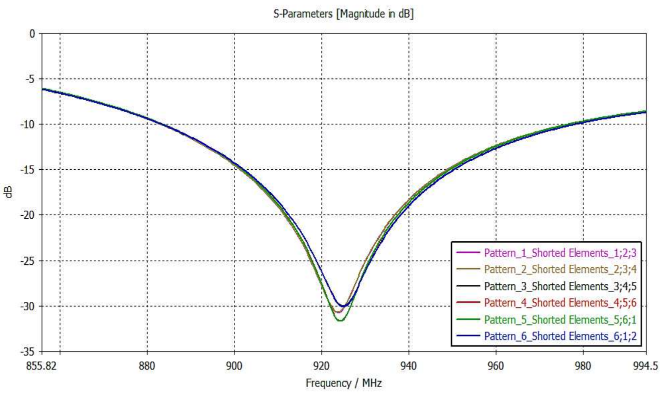


Fig. 6. Return Loss Value of the proposed smart antenna

2) *VSWR Value*: The simulation results that show the VSWR value obtained are shown in Figure 7 and Table III. Although the values obtained are different for each pattern, the values for the whole pattern are considered a good performance value for an antenna, because the VSWR value < 1.92 [20].

3) *Gain value*: The simulation results that show the gain value obtained are shown in Figure 8 and Table III. The highest gain value obtained from these patterns is about 8.52 dBi. The performance values obtained for this smart antenna are still better than the conventional LoRa Gateway antenna which has the highest gain of abruptly 5 dBi. Meanwhile, in another study of smart antennas [7], the simulation results vary from 7 - 10 dBi.

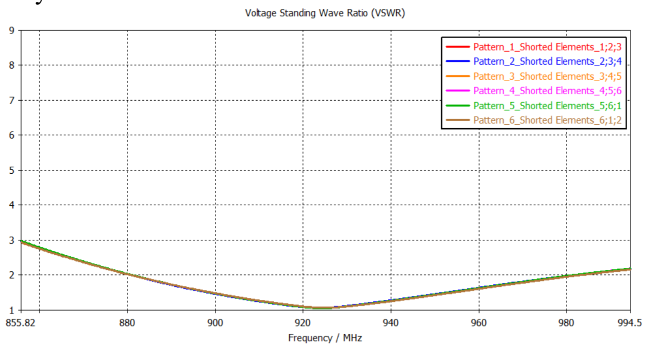
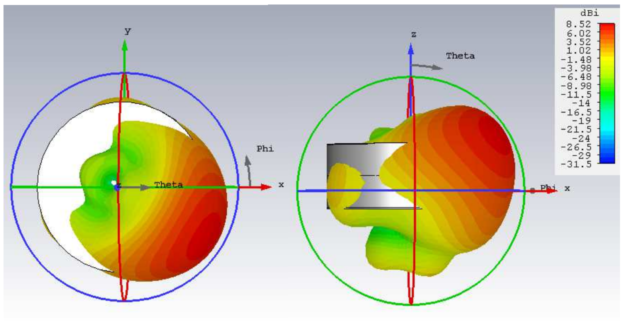


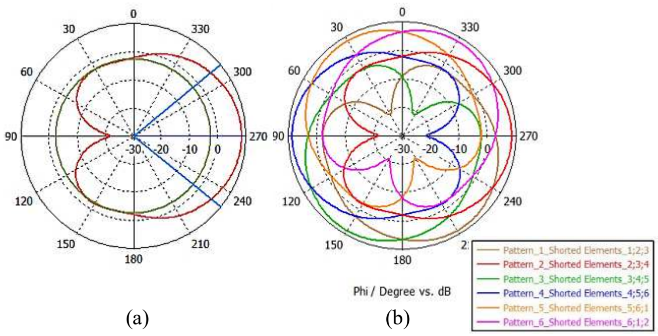
Fig. 7. VSWR value of the proposed smart antenna



(a) (b)

Fig. 8. Radiation Diagram of The proposed Smart Antenna: (a). Top View, and (b). Side View

While the direction of the radiation pattern can be seen in Figure 9 with the angle value of each pattern in Table III. So that, the proposed smart antenna is able to adjust the beam direction by 360°, with a stepwidth of about 60°. It is different from other smart antenna study [7], which is able to adjust the beam direction with a stepwidth of about 90°.



(a) (b)

Fig. 9. Beam direction pattern of the proposed smart antenna (a). Beam direction with one pattern, and (b). Beam direction with six patterns

IV. CONCLUSIONS

The proposed beam steering of switched parasitic smart antenna (SPSA) 923 MHz has been numerically computed and analyzed. The computational optimization was performed to obtain the precise parasitic element configuration. This was required to set the electrical properties of the proposed smart antenna properly and to meet the Indonesia national standard requirements. The simulation results show that by using six parasitic elements configuration, this antenna design can alter the beam pattern direction of 360° full coverage area of services with every step of angle beam alteration 60°, whereas in other study 90° [7]. In terms of performance parameters, this antenna design shows good performance with a Return Loss value ≤ - 10 dB, a VSWR value <1.92, not different from the value of previous study. The highest gain value obtained is 8.52 dBi, better than the gain value used in conventional LoRa gateway antennas, which is about 5 dBi, and other study results that vary from 7-10 dBi [7]. Thus, the beam steering technique integrated with SPSA design can be an alternative to IoT technologies. This is specifically applied for the communication system based on LPWAN non-cellular, such as LoRa technologies to ensure better data quality reception, In the future, this antenna could be developed and manufactured for other applications with limited gain, especially in the ISM band.

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REFERENCES

[1] Chahal, R. K., Kumar, N. and Batra, S. “Trust management in social Internet of Things: A taxonomy, open issues, and challenges”, *Computer Communications*, Vol. 150, pp. 13–46, Januari 2020.

[2] D. K. Hendraningrat, andD. Setiawan, “*Broadband Roadmap: Indonesia Towards the Age of Technology* [in Indonesian]”, PT. Elex Media Komputindo: Jakarta, 2017.

[3] R. Dagar, Su. Som, S. K. Khatri,“Smart Farming–IoT in Agriculture”, *International Conference on Inventive Research in Computing Applications (ICIRCA) 2018 IEEE*, pp.1052–1056, Jul 2018.

[4] I. S. Areni, A. Waridi, I. Amirullah, C. Yohannes, A. Lawi, A. Bustamin, “IoT-Based of Automatic Electrical Appliance for Smart Home” *International Journal of Interactive Mobile Technologies (IJIM)*, Vol. 14, No. 18, pp. 204 – 212, , Nopember 2020.

[5] O. Elijah, T. A. Rahman, H. .I Saharuddin, F. .N Khairodin, “Factors that Impact LoRa IoT Communication Technology”, *Malaysia International Conference on Communication (MICC) 14th 2019 IEEE*. December 2019.

[6] A. Lavric, V. Popa “Internet of Things and LoRaTM Low-Power WideArea Networks: A Survey”, *International Symposium on Signals, Circuits and Systems (ISSCS) 2017 IEEE*, July 2017.

[7] E. Palantei and D. V. Thiel, “Dual Frequency, Plug and Play Steerable Antenna for ISM band Communications”, *Proceedings of the International Conference on Electrical Engineering and Informatics Institut Teknologi Bandung*, pp. 156-159, Juni 2007

[8] B. Vejlgaard, M. Lauridsen, H. Nguyen, I. Z. Kovacs, P. Mogensen, M. Sørensen.“Interference Impact on Coverage and Capacity for Low Power Wide Area IoT Networks”, *IEEE Wireless Communications and Networking Conference (WCNC) 2017*, March 2017.

[9] Director General of Resources and Equipment of Post and Information Technology, “Regulation of the Director General of Resources and Equipment of Post and Information Technology Number 3 of 2019 about Technical Requirements of Low Power Wide Area Telecommunication Tools and / or Equipment”, Jakarta: Ministry of Communications and Informatics of the Republic of Indonesia, 2019. [Online]. Available: https://web.kominfo.go.id/sites/default/files/users/3997/PERDIRJEN%20SDPPI%20NO%203%20TAHUN%202019%20LPWA.pdf

[10] A. Rahman and M. Suryanegara “The Development of IoT LoRa: A Performance Evaluation on LoS and Non-LoS Environment at 915 MHz ISM Frequency”, *International Conference on Signals and Systems (ICSigSys) 2017 IEEE*, pp. 163 – 167, May 2017

[11] Adnan, A. E. U. Salam, A. Arifin “Forest Fire Detection using LoRa Wireless Mesh Topology”, *2nd East Indonesia Conference on Computer and Information Technology (EIConCIT) 2018 IEEE*, pp. 184 – 187, Nopember 2018.

[12] N. Hayati and M. Suryanegara, “The IoT LoRa System Design for Tracking and Monitoring Patient with Mental Disorder”, *International Conference on Communication, Networks and Satellite (Comnetsat) 2017 IEEE*, pp. 135 – 139, October 2017.

[13] A. Kausar, H. Mehrpouyan, M. Sellathurai, R. Qian, and S. Kausar. “Energy efficient switched parasitic array antenna for 5G networks and IoT”, *Loughborough Antennas & Propagation Conference (LAPC) 2016 IEEE*, pp. 1–5, Nopember 2016.

[14] R. Konch, A. Sarma, S. Goswami, K. Sarmah, “Design of a Pattern Reconfigurable Switched Parasitic Array for Null Steering Application”, *2nd International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech) 2018 IEEE*, May 2018.

[15] A. Kausar, H. U. Rahman, S. Kausar, and T. Hassan, “Smart Adaptive Beam Forming Antenna for Interference Minimization”, *Second International Conference on Future Generation Communication Technologies (FGCT 2013) 2013 IEEE,* pp. 6 – 9, Nopember 2013.

[16] Minister of Communications and Informatics of the Republic of Indonesia, “Regulation of the Minister of Communications and Informatics Number 1 of 2019 about use of a radio frequency spectrum based on a class license [in Indonesian]”, Jakarta: Ministry of Communications and Informatics of the Republic of Indonesia, 2019. [Online]. Available: https://jdih.kominfo.go.id/produk_hukum/view/id/676/t/peraturan+menteri+komunikasi+dan+informatika+nomor+1+tahun+2019+tanggal+24+april+2019

[17] Minister of Communications and Informatics of the Republic of Indonesia, “Regulation of the Minister of Communications and Informatics Number 25 of 2014 about table of allocation of radio frequency spectrum of Indonesia [in Indonesian] , Jakarta: Ministry of Communications and Informatics of the Republic of Indonesia, 2014. [Online]. Available: https://jdih.kominfo.go.id/produk_hukum/view/id/222/t/peraturan+menteri+komunikasi+dan+informatika+nomor+25+tahun+2014+tanggal+18+agustus+2014

[18] Minister of Communications and Informatics of the Republic of Indonesia, “Regulation of the Minister of Communications and Informatics Number 12 of 2017 about Use of Technology in Radio Frequency Bands of 450 Mhz, 900 Mhz, 2.1 Ghz, and 2.3 Ghz For Organizing Cellular Mobile Networks [in Indonesian]”, Jakarta: Ministry of Communications and Informatics of the Republic of Indonesia,2017. [Online]. Available: https://jdih.kominfo.go.id/produk_hukum/view/id/573/t/peraturan+menteri+komunikasi+dan+informatika+nomor+12+tahun+2017+tanggal+9+juni+2017

[19] Y. Rafsyam, Indra, E. E. Khairas, Jonifan and W.A. Karimah,“Design of Double Cross Dipole Antenna as NOAA Satellite Signal Receiver for Monitor Cloud Conditions Application”, *Journal of Physics: Conference Series - 1st Workshop on Engineering, Education, Applied Sciences, and Technology*, Volume 1364, pp. 1–8, Aug. 2018.

[20] M. Alaydrus, “*Antenna Principles and Applications* [in Indonesian]”, Graha Ilmu, Yogykakarta, 2011, ISBN 978-979-756-731-6.