Design and Performance Analysis of Microstrip Antenna using Flexible Material for 915 MHz LoRa Frequency

Nurista Wahyu Kirana and Farrah Vauzia

[1] Department of Electronic Engineering Politeknik Negeri Bandung, Bandung, Indonesia
nurista.wahyu@polban.ac.id, farrah.vauzia@polban.ac.id

Abstract. IoT (Internet of Things) is a system that allows the interconnectivity of various devices remotely via the internet. Modern IoT devices require a variety of options when it comes to connectivity. The IoT technology currently widely used isLoRaWAN (Long Range Wide Area Network) due to its low power consumption and wide transmission range. In this study, a microstrip antenna was made with a flexible material FR9111 substrate for LoRa frequency. This microstrip works at frequency 915 MHz, has a return loss of -21.52 dB, and a VSWR (Voltage Standing Wave Ratio) of 1.18 obtained from the simulation. The return loss measurement results were -33.83 dB and a gain of -5.62 dBi.

Keywords: IoT, LoRa, Microstrip, Return Loss, VSWR

I. INTRODUCTION

The development of IoT (Internet of Things) technology today allows some interconnectivity of various remote devices over the internet. IoT is an integration of users,processes, and technologies that can be connected with devices and sensors [1]. Additionally, IoT devices can be connected with many wireless networks, such as Bluetooth, Z-Wave, Zigbee, LoRa, Wi-Fi, and 3G/4G/5G, for usage in a variety of applications. [2].

LoRa (Long Range) is an IoT wireless communication system with low power for long-distance communication. In general, LoRa works well in several conditions, namely during the Line of Sight (LOS); LoRadevices can receive and send signals at a distance of 20 km. LoRa networks with many nodes can cover a wide area [3]. An antenna that works on IoT LoRa frequencies is needed to support signal transmission. In some previous studies, microstrip antennas were designed to meet these needs. Microstrips were chosen because they can be integrated well into microwave devices, and they have ease of fabrication, as well as their small size and lightweight [4]. Some studies have used microstrips as antennas in the LoRa frequency band. One of which is a microstrip made with Duroid RT6006 material and used to support a single complementary split ring

M. U. H. Al Rasyid and M. R. Mufid (eds.), *Proceedings of the International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023)*, Advances in Engineering Research 230,
https://doi.org/10.2991/978-94-6463-364-1_17

resonator (CSRR) of 924 MHz communication in anticipation of disasters [5].

Another research is the creation of FR4 substrates and multiband frequencies of 433 MHz and 868 MHz are usedin the construction of a Compact Dual Band Microstrip Patch Antenna (CDBMPA) for LoRa Internet of Things applications. [6] achieving gains of 1.7 dBi and 2.56 dBi. In addition, smart leaky wave microstrips were also designed on ISM bandwidth of 900 MHz and 2.4 GHz to be used for Wi- Fi, Bluetooth, Zigbee, LoRa, and RFID applications [7]. Microstrip antennas with high gain and omnidirectional radiation patterns have also been investigated for LoRa of 923 MHz applications. This study used a feedline microstrip enumeration type and FR4 substrates to produce VSWR ≤ 2, with a return loss of -26.94 dB [8].

Flexible substrate material was chosen because the current development of antennas is demanded to be more efficient in wireless communication, and the antennas are widely used for medical purposes. [9]. Antennas with flexible metamaterial materials could increase antenna gain in the IoT and 5G frequency ranges [10].

Microstrips with other flexible materials have also been studied for S-Band applications. The substrate material used isFR9111. Flexible materials make the antenna easier and more efficient in integrating with the device. The return loss resulting from the microstrip of this FR9111 substrate materialis -35.80 dB with a center frequency of 3.2 GHz [11]. Antennas with other flexible materials have also been studied for millimeter waves at a resonant frequency of 60 GHz. The use of flexible and wearable antenna materials shows good antenna performance; namely, radiation coverage reaches a maximum efficiency of 70%, a wide bandwidth of 9.8 GHz, and a gain of 9.6 dBi. This microstrip antenna with flexible material is the right choice with its simple structure, adjustablegeometry[12], ease of fabrication, and good performance so it can be implemented for IoT applications [13]. In this study, a microstrip antenna was made, working at a frequency of 915 MHz; and supporting efficiency because it uses flexible

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II. METHOD

This research designed and realized a microstrip antenna for LoRa with a resonant frequency of 915 MHz. The antenna was designed starting from determining antenna specifications, simulating through a software, fabricating the antenna, and measuring the antenna. The antenna obtained is based on the desired specifications, as shown in the flowchart in Figure 1.

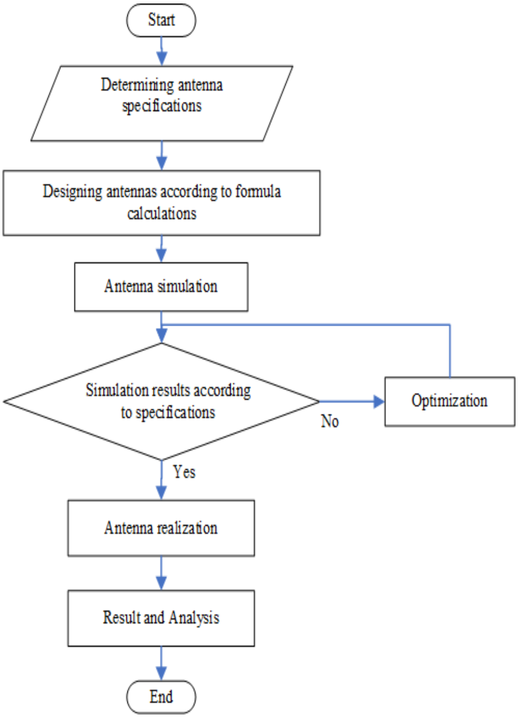


Figure 1. Research methodology flowchart

A. Specifications and Design

The microstrip antenna itself consists of a thin patch layer (t << λ0), of which λ0 is the wavelength in free space. The substrate is the layer below the patch with a thickness of h << λ0, and below the substrate is a ground plane layer as shown in Figure 2 [14].

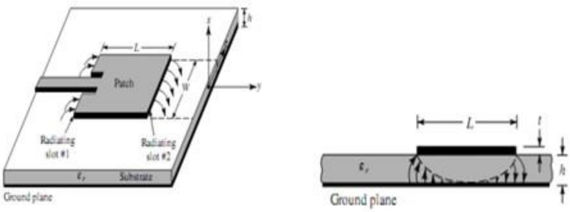


Figure 2. Microstrip layer arrangement (a) top view (b) side view

In this study, the microstrip antenna was designed with a patch arrangement made of copper with a thickness of 0.035 mm. The layer below it is a substrate of FR9111 material which has a dielectric constant value of εr = 3 and a thickness of h = 0.025 mm. A ground plane comprised of copper material is located at the bottom of the substrate. The designed microstrip antenna works at a LoRa frequency of 915 MHz. Before designing an antenna using simulation, the dimensional value of the microstrip antenna was calculated using the following equation:

$$f_c = \frac{c}{2\pi\sqrt{\varepsilon_r}} \sqrt{\left(\frac{\pi}{L}\right)^2 + \left(\frac{\pi}{W}\right)^2} \quad (1)$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \quad (2)$$

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

A rectangular patch is used in the design of a microstrip antenna. the resonant frequency of the antenna was determined by the patch dimensions and the dielectric constant of the substrate [15] as written in Equation 1, where fc is the resonant frequency (Hz), and *c* is the speed of light (3×10^8 m/s). The microstrip patch's length (m), width (m), and substrate dielectric constant (εr) are denoted as, L, and W, respectively. From Equation 1, the W value can be calculated by:

$$W = \frac{c}{2f_c} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad (4)$$

The value of the effective dielectric constant ($\varepsilon_r$eff) was calculated using Equation 5:

$$\varepsilon_{r\,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + \frac{12h}{W}}}\right] \quad (5)$$

where *h* represents the height of the substrate. The addition of

length (ΔL) can be calculated using Equation 6:

$$\Delta L = 0.412h \frac{\left(\varepsilon_{r\,eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{r\,eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (6)$$

From Equation 6, the value of patch length (L) can be obtained:

$$L = \frac{1}{2fc\sqrt{\varepsilon_{r\,eff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \quad (6)$$

Based on the calculation of the microstrip equation, microstrip dimensions were obtained, which were then applied by simulation using CST Studio Suite 2019. The material was inputted according to the characteristics of the antenna to be made, starting from the characteristics of the patch, substrate, and ground plane so the antenna design results are obtained as in Figure 3.

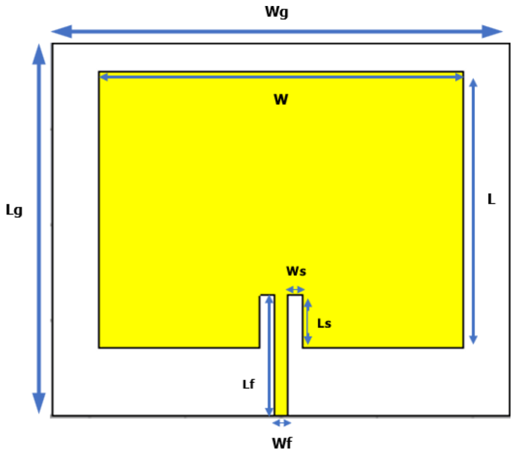


Figure 3. Microstrip antenna geometry for LoRa IoT applications

The dimensions of the microstrip antenna designed with CST Studio Suite simulation are 47.64 mm x 39.04 mm. The width and length of the ground plane are equal to the substrate. FR9111 substrate material is flexible between the patch and the ground plane. The enumeration used on antennas is microstrip line enumeration. This enumeration technique is a type of direct enumeration technique that is very easy to fabricate, has a simple model, and is easy to adjust the position of the enumeration. In the microstrip line enumeration technique, an additional feedline is directly connected to the antenna patch. This feedline is connected with an RSMA connector so it can be connected to a cable or device. The description of microstrip antenna parameters and dimensions for IoT LoRa applications can be seen in Table 1.

TABLE 1. MICROSTRIP DIMENSIONS

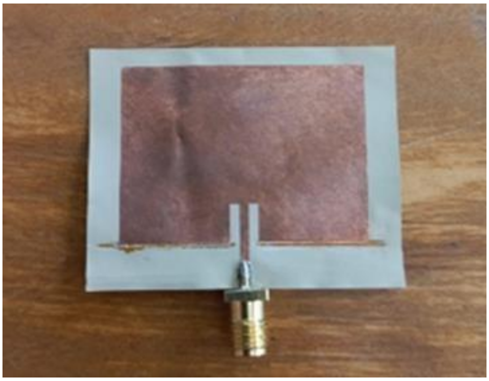
Parameters	**Size (mm)**
W (patch width)	38
L (patch length)	28.92
Wg (ground plane/substrate width)	47.64
Lg (ground plane/substrate length)	39.04
Wf (feedline width)	1.4

Lf (feedline length)	12.62
Ws (slot width)	1.5
Ls (slot length)	5.5

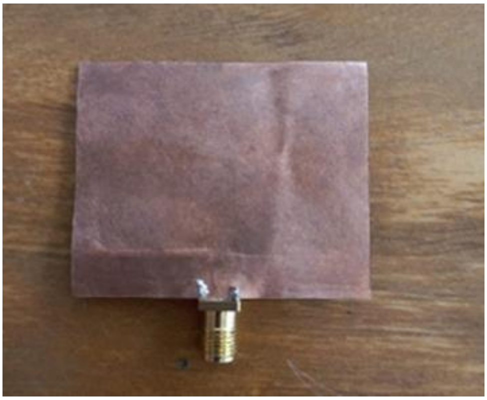
The antenna design was simulated with CST Studio Suite 2019 to obtain antenna parameter values, namely return loss, VSWR, bandwidth, gain, and antenna radiation patterns.

B. Antenna Realization

After being designed using simulation, the antenna fabricated using pyralux FR9111 material which has a dielectric constant εr=3 and substrate thickness of h=0.025 mm, and copper thickness of 0.035 mm. FR9111 material was chosen because it is flexible and easy to fabricate. The rectangular patch is etching on top of the FR9111 pyralux substrate and ground plane with copper material below the substrate. This antenna is expected to work well at the LoRa frequency of 915 MHz. Figure 4 represents the realization of the microstrip antenna.



(a)



(b)

Figure 4. Antenna realization (a) front view (b) rear view

After antenna fabrication, the next step is the measurement process using VNA (Vector Network Analyzer). Setup measurement is done by connecting the RSMA connector on the microstrip with the cable on the vector network analyzer where the vector network analyzer has been matched impedance. The process of measuring the S-parameter antenna using VNA is shown in Figure 5.

Figure 5. Antenna measurement using a vector network analyzer

III. RESULTS AND DISCUSSION

The simulation results show a return loss parameter value of -21.52 dB; and the value is obtained when the slot width value is 6.4 mm. The bandwidth value obtained from the simulation results is 41.428 MHz, as shown in Figure 6 and Figure 7.

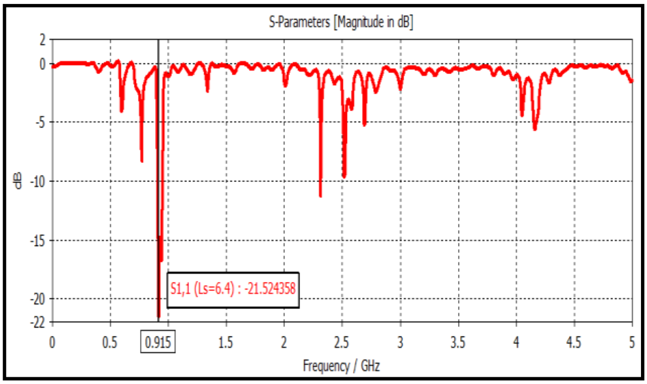


Figure 6. Final result of S-parameters

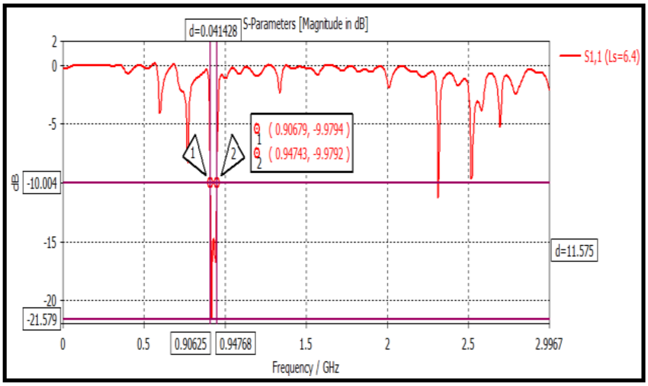


Figure 7. Bandwidth obtained from simulation results

By setting the measured line at -10 dB and obtaining the bandwidth from the simulation results, the low-frequency band is obtained at 906 MHz, and the high frequency is obtained at 947 MHz. Meanwhile, the measurement results obtained dual-band frequency. The first is at the 915 MHz center frequency with a return loss value of -33.83 dB, and the second is at the 2.95 GHz center frequency with a return loss value of -23.07 dB.

The antenna bandwidth obtained from the measurement results is 500.9 MHz with a low frequency of 743.6 MHz and a high frequency of 1.2445 GHz. Meanwhile, in the second frequency band, a bandwidth of 130 MHz is obtained with a low frequency of 2.877 GHz and a high frequency of 3.007 GHz as shown in Figure 8.

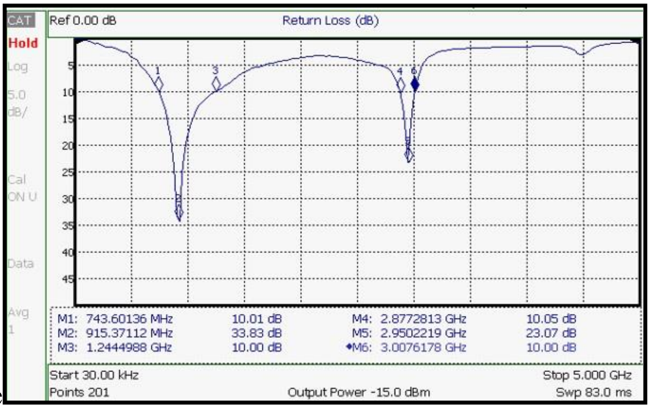


Figure 8. S-parameters obtained from measurement results

From the simulation and measurement results, a comparison of the return loss value is obtained, as shown in Table 2.

TABLE 2 COMPARISON BETWEEN SIMULATION AND MEASUREMENT RESULT

	Resonant Frequency (MHz)	**S_{11}(dB)**	**Bandwidth (MHz)**
Simulation	915	-21.52	41.428
Measurement	915	-33.83	500.9
	2950	-23.07	130

From the simulation and measurement results, a satisfactory return loss value is obtained. Still, the best return loss value is in the measurement, where the magnitude is 57.2% better than the simulation at the same frequency. In contrast, the size of the measurement and simulation bandwidth is also significant difference. The measurement results show a wider bandwidth in the 915 MHz frequency range. In addition, the realization of the antenna obtained dual band frequency. In comparison, the VSWR (Voltage Standing Wave Ratio) value obtained from the simulation results is 1.18, proving the requirements of an antenna that can work well because VSWR is less than 2, as shown in Figure 9.

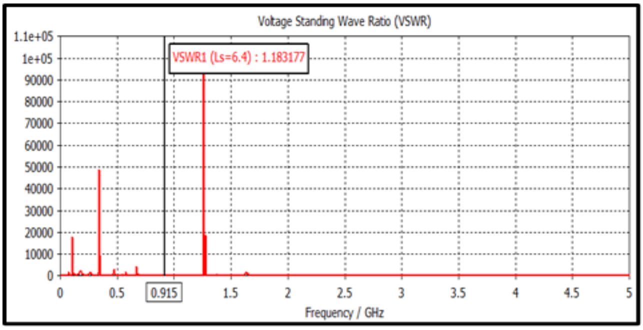


Figure 9. Final result of VSWR

In the simulation, the value of the Ls parameter was changed on the microstrip patch to prove whether the FR9111 material affected resonant frequency and bandwidth. Ls values are changed from 6 mm, 6.2 mm, 6.4 mm, 6.6 mm, and 6.8 mm. The return loss value obtained from the modeling findings produced the best return loss value at Ls = 6.4 mm, or -21.52 dB, in the experimental results of changing these parameters. In other Ls values, a return loss value met the specifications, namely -15.69 dB when Ls was at 6.6 mm and -11.55 dB at 6.2 mm.

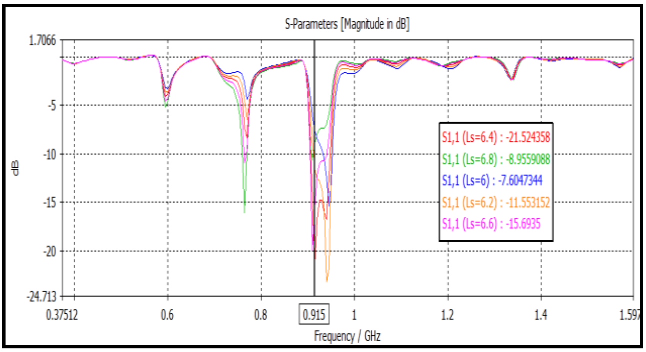
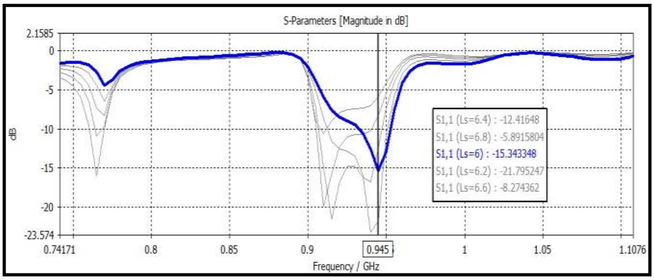
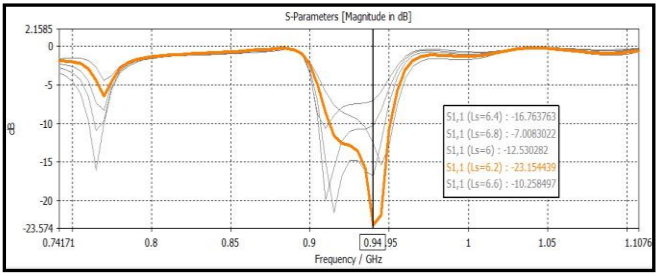


Figure 10. S-parameter with the changing of Ls

The graph of changes in the value of Ls above shows that when the value of Ls is changed to be larger, it will also affect the change in resonance frequency. The greater the Ls value, the resonant frequency will also shift to the left. This can be shown when the value of Ls = 6 mm, then the antenna resonance frequency is at 945 MHz while at Ls = 6.2 mm, the resonant frequency shifts to 940 MHz. When the value is changed back to 6.4 mm, the resonant frequency becomes 915 MHz and 6.6 mm at 910 MHz. The graph of the change can be seen in Figure 11.



(a)



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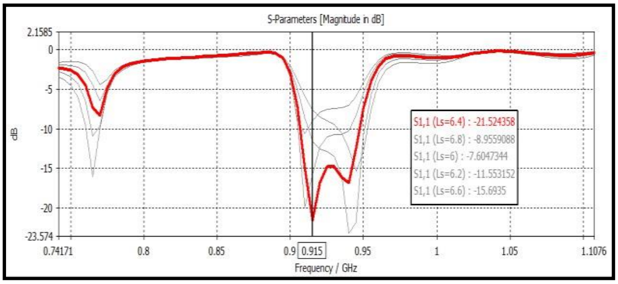
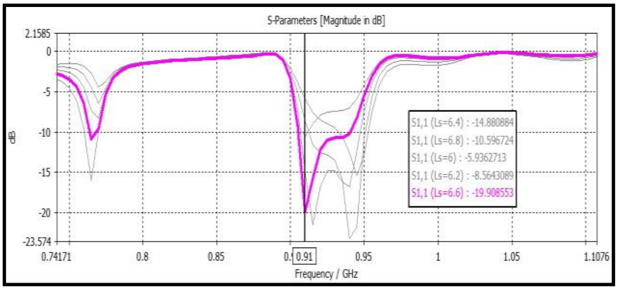


(c)



(d)

Figure 11. Change of parameter value of Ls vs resonant frequency(a)Ls = 6 mm (b) Ls = 6,2 mm (c)Ls = 6.4 mm (d) Ls = 6.6 mm

VSWR values that meet the specification requirements are VSWR values that are less than 2. VSWR obtained from changes in the value of Ls gets the best value at the value of Ls = 6.4 mm, with a VSWR value of 1.18. Other values meet when Ls = 6.6 mm with a VSWR value of 1.39, Ls = 6.2 mm, and a VSWR of 1.71. The VSWR graph can be seen in Figure 12.

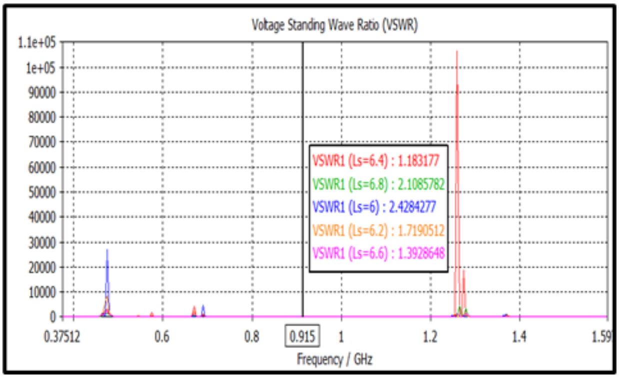


Figure 12. VSWR with the changing of Ls

Based on the measurement results, a gain value is obtained at -5.62 dBi, while the gain from the simulation results can be obtained from polar charts, which can be seen from the main lobe magnitude produced by radiation patterns microstrip antenna, as shown in Figure 13.

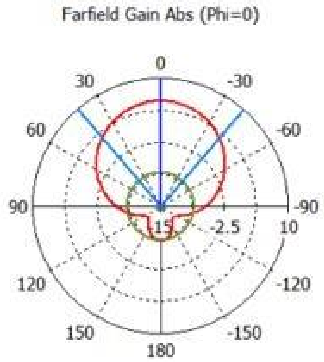


Figure 13. Simulated results of microstrip radiation patterns

IV. CONCLUSION

The results of simulations and measurements obtained in this study prove that microstrip antennas can meet the specifications of antennas that work at the LoRa frequency of 915 MHz. The flexible materials can support the efficient use of antennas in wireless communication. In comparison to the modeling results, which showed a return loss value of -21.52 dB with a VSWR of 1.18, the measurement data showed a return loss value of -33.83 dB, which is 57.2% lower. The bandwidth generated from the simulation is 41.428 MHz, while the measurement results get a wider bandwidth of 500.9 MHz. Changes in the Ls dimension on the microstrip antenna significantly affect the antenna resonance frequency shift. This microstrip has a gain of -5.62 dBi. It has a VSWR< 2 value, wide bandwidth and radiation pattern according to antenna specifications, so this microstrip can work well at Lora frequency of 915 MHz.

ACKNOWLEDGMENT

The authors thank to Community Service & Research Unit of Bandung State Polytechnic for the financial support research program.

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