DESIGN AND CHARACTERIZATION OF RECTANGULAR ARRAY MICROSTRIP ANTENNA FOR CUBESAT S-BAND TRANSMITTER

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***Abstract*—Automatic Dependent Surveillance-Broadcast (ADS-B) is an air traffic surveillance technology that automatically and periodically broadcasts onboard aircraft flight information such as identity numbers, positions, speeds, and destinations during all phases of flight to avoid collisions. In the future, the radar system will be equipped or even replaced by the ADS-B ground station. Therefore, the Nano-Satellite Laboratory of Telkom University is developing a satellite technology called Tel-USat which the ADS-B receiver is one of the missions. This work focuses on the design and characterization of the antenna to send all the collected ADS-B data to the ground. This antenna is designed by using an FR-4 substrate material with two rectangular patches, linear array, T-junction power divider, and proximity coupled rationing. The results obtained during the measurement are return loss values at 2.4 GHz frequency of -18.5 dB, VSWR of 1.2, antenna bandwidth of 163 MHz, and the gain of 6.08 dB.**

***Keywords*—ADS-B, Microstrip, Nanosatellite**

I. Introduction

Automatic Dependent Surveillance-Broadcast (ADS-B) is an air traffic surveillance technology that automatically and periodically broadcasts onboard aircraft flight information such as identity numbers, positions, speeds, and destinations during all phases of flight to avoid collisions [1]. In the future, the radar system will be equipped or even replaced by a cheaper ADS-B ground station and will be integrated into the existing surveillance infrastructure. However, the ground station still has limited coverage.

In 2008 the German Aerospace Center began investigating options for receiving ADS-B signals broadcast by aircraft on satellites with low earth orbit (LEO) which have wider coverage [2]. One of the satellites that are frequently used in low earth orbit is a Nano Satellite. Nano Satellite is a type of satellite that has a mass ranging from 1-10 kg, sized 1U, 1.5U, 2U, and 3U by size CubeSat standards, and generally has a relatively simple mission [3]. By using Nano Satellites, it is expected the ADS-B signal receiver can reach airspace that cannot be reached by ground stations.

One of the satellites that have a mission as an ADS-B receiver is the Canadian Advanced Nanospace eXperiment 7 (CanX-7). The ADS-B payload carried by the CanX-7 nanosatellite consists of an ADS-B receiver antenna, Low-noise preamplifier, payload computer, and a microstrip patch antenna that works on S-band frequency [4]. Nano Satellite Laboratory Telkom University is also currently developing a satellite technology called Tel-USat and the ADS-B receiver payload is one of the missions for the development of Tel-USat 2. The Nano-Satellite Laboratory makes the ADS-B receiver payload on CanX-7 Satellite as a reference in developing the ADS-B receiver payload that will be carried by Tel-USat 2. However, this research only focuses on the design and realization of the S-band microstrip antenna that functions as ADS-B commercial aircraft data senders that have been processed by nanosatellite computer payloads to the ground station. In some previous research from the Nano-Satellite Laboratory regarding transmitter antennas at S-band frequencies, the microstrip antenna for CP-SAR using slotted patch and truncated edge techniques [5], and dual-feed circularly polarized microstrip antenna of synthetic aperture radar (SAR) system [6]. In this study, a two-tier array was used to increase the gain and connected using the T-junction.

Microstrip antenna was an antenna that became very popular in 1970 especially for the spacecraft application. A microstrip antenna is very popular because it is easy to make and analyze, lightweight, small and thin in dimensions, attractive radiation characteristic, low-profile, and easy to make using modern printed-circuit technology [7]. Microstrip antenna consists of three layers of structure, namely patch, substrate, and the ground plane. The patch is the top layer of a microstrip antenna that functions as an electromagnetic wave radiator. The forms of these patches vary in the shape of round, square, rectangular, triangle, dipole, ellipse, and so on. The substrate, the second layer after the patch serves as an insulating material. This layer is made of dielectric material with a certain permittivity value. Ground Plane is the bottom layer that functions as a reflector that reflects unwanted signals. This ground plane generally uses the same conductor material as a patch [8].

Rectangular patches are widely used because of its advantages that are easily fabricated, simple structure, increase the gain, and easily integrated with integrated microwave circuits [9]. To design a rectangular patch starting with the schematic model. Some equations used in designing rectangular patch microstrip antennas are equation 1, equation 2, equation 3, equation 4, and equation 5 [10].

$$W = \frac{C}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(\frac{1}{\sqrt{1+\frac{2h}{W}}}\right) \tag{2}$$

$$L_{eff} = \frac{C}{2fr\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = h \times 0{,}412 \times \frac{(\varepsilon_{eff}+0{,}3)\left(\frac{W}{h}+0{,}264\right)}{(\varepsilon_{eff}-0{,}258)\left(\frac{W}{h}+0{,}8\right)} \tag{4}$$

$$L = L_{eff} - 2\Delta L \tag{5}$$

Proximity Coupled rationing is a rationing technique where the transmission line (feed line) is placed between two substrates namely εr_1 and εr_2. By using this technique, making an antenna using two layers of the substrate. Microstrip line on the bottom substrate and patch on the top substrate. This technique is also known as electromagnetic coupled microstrip feed because there is a coupling between the patch and the feed [11]. This technique has advantages including wide bandwidth, good VSWR value, and greater gain [12]. But this technique is quite difficult in the design process, and fabrication because the placement of patches and feeds must be accurate.

Feedline dimensions of a microstrip antenna are strongly affected by the value of output impedance of the antenna design. Some equations used in designing microstrip antenna feedlines are formulated in equation 6, and equation 7 [13].

$$W_f = \frac{2h}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left(\ln(B-1)+0{,}39-\frac{0{,}61}{\varepsilon_r}\right)\right\} \tag{6}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{7}$$

The radiation pattern of a single element antenna is usually relatively wide and has a low directivity. In long-distance communication, antennas with high directivity are often needed. An antenna microstrip can be designed by using either a single element patch or an array. The compile patches or arrays are used to improve the antenna's performance such as gain, scanning directivity of system files, and other functions that are difficult to do with a single element [13]. In designing a two-element linear array microstrip antenna, the shape of the array used is like the T alphabet with two microstrip feed lines, 50 Ω and 70.7 Ω which are generally used as power dividers. The junction on this feed network is called T-junction power divider.

Link budget calculation is a calculation of the power level carried out to ensure that the reception power level is greater or equal to the level of power delivered to maintain the balance of gain and loss of the transmitting and receiving antenna. Link budget calculation will determine the quality of communication and the level of success of communication made [14]. To calculate the link budget, the components that must be considered are satellite payload, ground station, and the propagation path. Equation 8, and equation 9 are used to calculate the link budget.

$$P_{rx} = P_{tx} - FL_{tx} + G_{tx} - FSPL + G_{rx} - FL_{rx} \tag{8}$$

$$FSPL = 92{,}4 + 20\log(F) + 20\log(D) \tag{9}$$

II. Method

The method used in designing antennas in this research began with a literature study to learn the basic concepts, ways of working, and determining the specifications of the parameters of both ADS-B and antenna through written references. Then design software simulation, antenna realization, and measurement.

Determination of the specifications of the antenna designed includes the gain. The required gain value is determined through the calculation of the link budget equation 8, and equation 9. Assuming the transmitter power (Ptx) is 33 dBm or 2 watts, receiver ground station (Prx) sensitivity is -86 dBm, receiver antenna gain (Grx) on ground station at 33 dB, receiver feeder loss (FLrx) 3 dB, transmitter feeder loss (FLtx) 3 dB, and the calculation of Free Space Path Loss (FSPL) of 153.979 dB was obtained assuming a satellite altitude of 500 km at a frequency of 2.4 GHz then a transmitter antenna (Gtx) gain of at least 8 dB is required. Antenna specifications are shown in table 1.

Table 1. ADS-B transmitter antenna specifications.

Parameter	**Value**
Frequency	2,4 GHz
Bandwidth	6 MHz
Gain	8 dB
Radiation Pattern	Unidirectional
Polarization	Linear
VSWR	≤ 2
Output Impedance	± 50 Ω
Return Loss	≤ -10 dB

This antenna uses a frequency of 2.4 GHz for satellite applications that have been established in the Regulation of the Minister of Communication and Information of the Republic of Indonesia in 2018 concerning amateur radio activities and radio communication between residents. This frequency has a bandwidth of 6 MHz [15]. The design of the two array microstrip antennas begins with the design of a single patch through mathematical calculations before designing and simulating it in software. The substrate uses FR-4 material with relative permittivity of 4.3 and a thickness of 1.6 mm. Using equation 1, equation 2, equation 3, equation 4, equation 5, equation 6, and equation 7 the patch width (W) is 38 mm, patch length (L) 28.5 mm, and feedline width (Wf) 3.1 mm.

However, when the software simulation is performed on the dimensions of the results of mathematical calculations, the results obtained will not be directly appropriate to the desired specifications. Optimization is needed to get the appropriate results. Then the dimensions of the single patch antenna optimization results of the software simulation are shown in table 2.

Table 2. Dimension of Single patch antenna optimization result

Symbol	Value
W	28 mm
L	27,45 mm
Wf	1,4 mm
Lf	40 mm
Wp	100 mm
Lp	80 mm
h	1,6 mm
Tc	0,035 mm

Feedline length (Lf), the width of the substrate and ground plane (Wp), length of substrate and ground plane (Lp), thickness of the substrate (h), the thickness of copper (Tc), and making portholes on the second layer substrate by 4 mm × 4 mm. The single patch antenna design model in the software is shown in Figure 1.

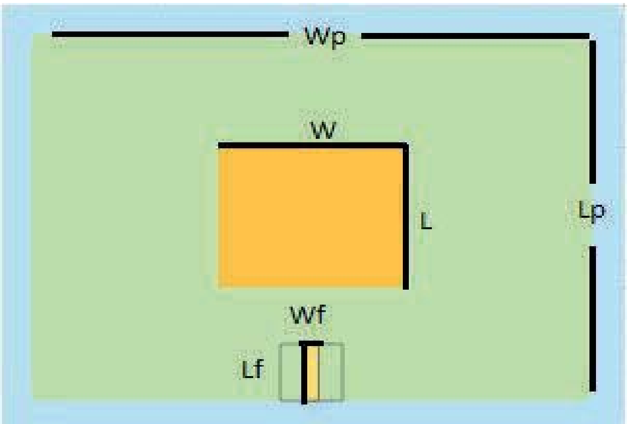


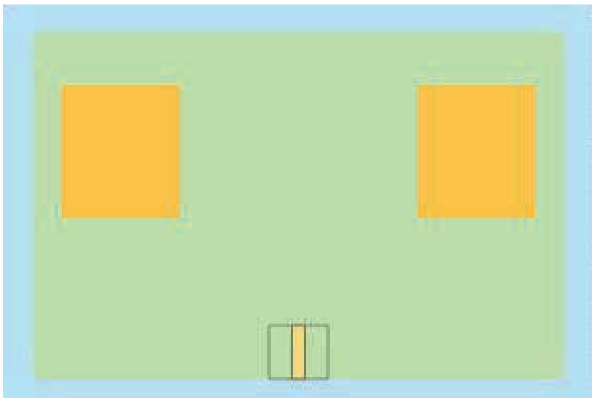
Figure 1. Model of *single patch* microstrip antenna optimization result.

The required gain is quite large therefore it is not possible to only use a single patch antenna. Furthermore, the design of two array microstrip antennas is expected to meet the needs of the gain. The two patches are separated by a distance of λ/2 then connected by a feed network with a T-junction standard that has a microstrip feedline impedance value of 70,7 Ω which is a λ/4 transformer. By using a λ/4 transformer it is expected that the power distribution in each patch can be maximized.

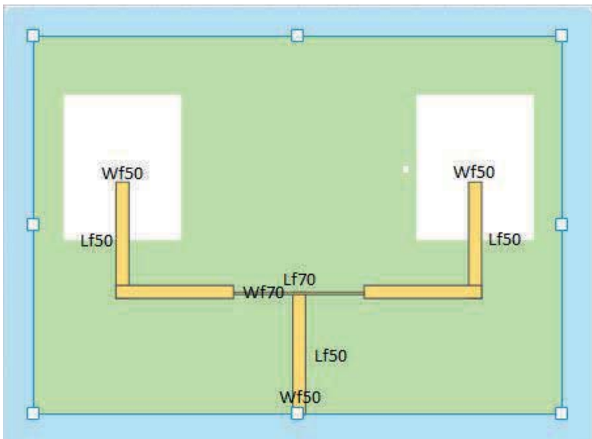
Feedline width 50 Ω (Wf50), Feedline length 50 Ω (Lf50), Feedline width 70,7 Ω (Wf70), and Feedline length 70,7 Ω (Lf70) the values are shown in the table 3 and the models are shown in figure 2.

Table 3. Dimension of Two array antenna as the result of optimization

Symbol	Value
W	22 mm
L	27,45 mm
Wf50	1,4 mm
Lf50	17 mm
Wf70	0,63 mm
Lf70	25 mm
Wp	100 mm
Lp	80 mm
H	1,6 mm
Tc	0,035 mm



(a)



(b)

Figure 2. The model of two array antenna (a) Patch design on first layer (b) feedline design on second layer.

After the design and simulation of the antenna in the software are complete, next is the fabrication and measurement of the antenna. Antenna measurements are made to ensure that the fabricated antenna matches the required specifications and compares the results with simulation. Figure 3 shows the fabricated antenna.

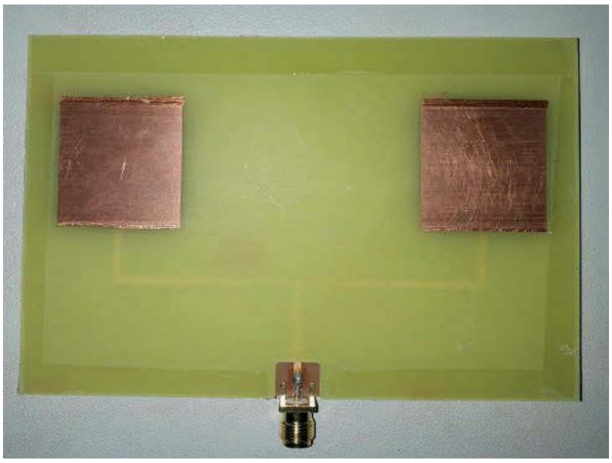


Figure 3. fabricated antenna.

III. Result and Discussion

The software simulation results for a single patch obtained return loss values of -23,38 dB, VSWR of 1,145, reference impedance of 59.57 Ω, and gain of 4.063 dB are shown in figure 4, figure 5, and figure 6.

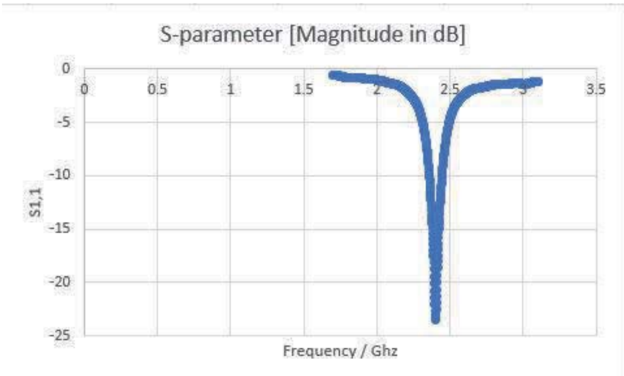


Figure 4. *S-Parameter of single patch.*

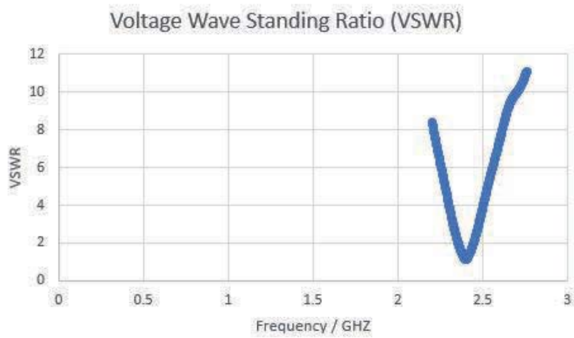


Figure 5. VSWR of *single patch.*

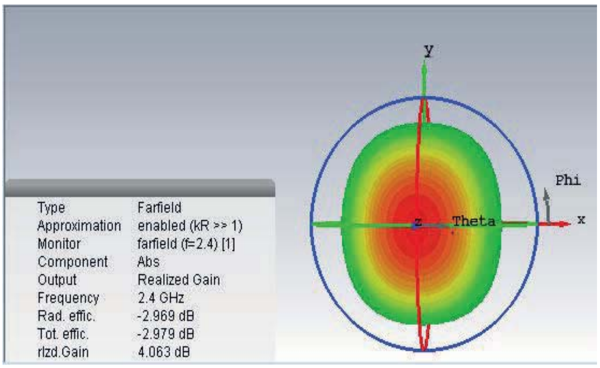


Figure 6. Gain of single patch.

The software simulation results for two array microstrip antennas, the return loss value is -28.29 dB, VSWR value of 1.08, reference impedance of 63.92 Ω, the gain of 5.966 dB, unidirectional radiation pattern, and the axial ratio at phi 90° frequency 2.4 GHz is 40 dB so it shows linear polarization. Simulation results are shown in Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11.

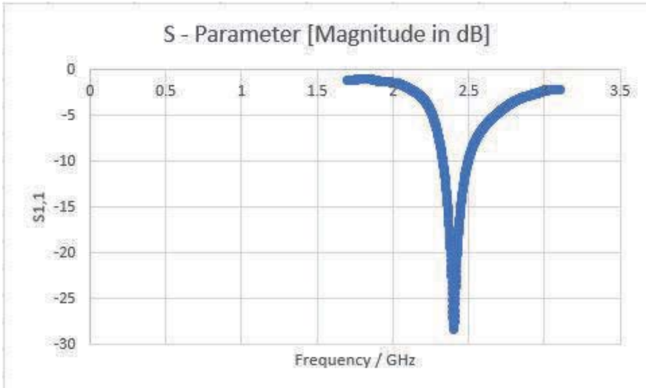


Figure 7. S-Parameter of two array microstrip antenna.

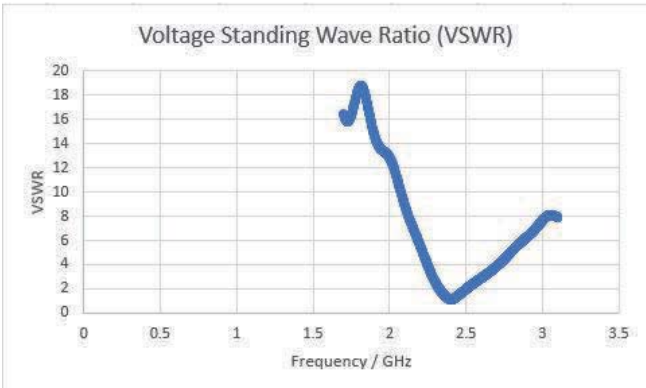


Figure 8. VSWR of two array microstrip antenna.

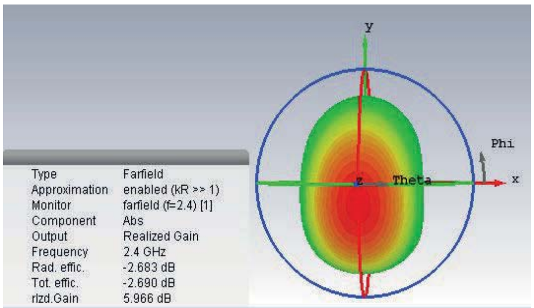
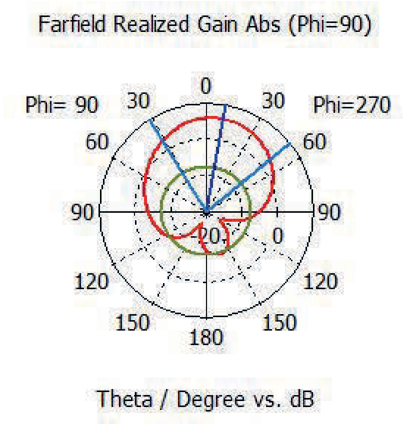
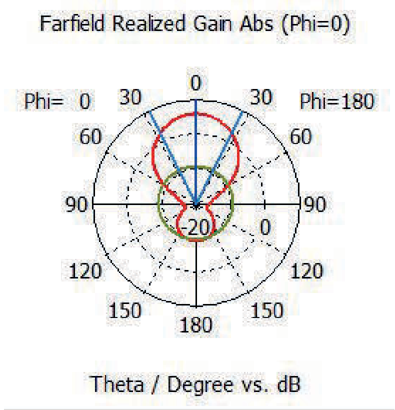


Figure 9. Gain of two array microstrip antenna.



(a)



(b)

Figure 10. Radiation Pattern of two array microstrip antenna (a) Phi = 90º (b) Phi = 0º.

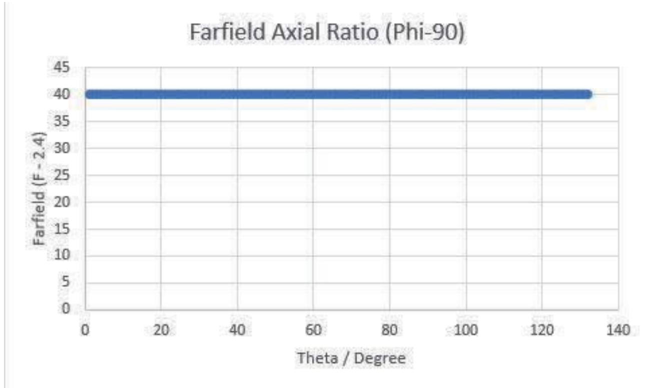


Figure 11. Axial Ratio of two array microstrip antenna.

Next, the parameter measurement results obtained S-parameters of -18.5 dB, VSWR 1.2 and impedance of 57.8 Ω which are shown in Figure 12, and Figure 13.

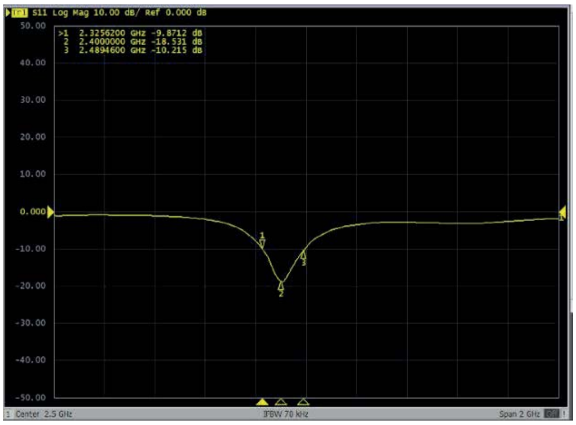


Figure 12. S-Parameter of two array antenna measurement result.

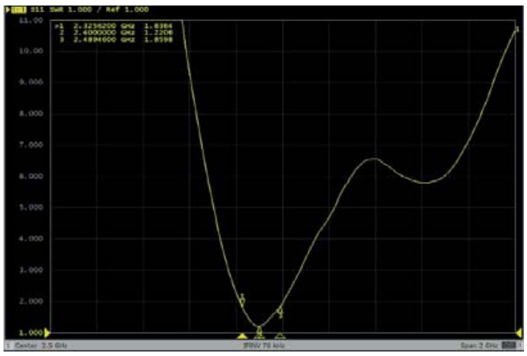
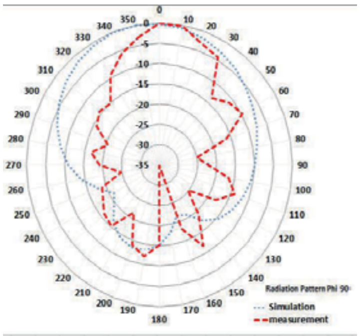
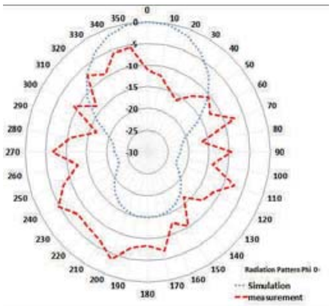


Figure 13. VSWR of two array antenna measurement result.

Based on the measurements of radiation patterns carried out, the results obtained are shown through the polar coordinate graph in figure 14. To make a comparison, the blue line shows the simulation results while the red line is the result of the measurement.



(a)



(b)

Figure 14. Radiation pattern (a) Phi = 90º (b) Phi = 0º

When compared with the simulation, the measurement results show that they are quite large on the back lobe side when Phi = 90º while back lobe and side lobe on Phi = 0º. The measurement results are far different from the simulation results.

The results of the polarization measurements are also shown through the polar coordinate graph in Figure 15. and the comparison of the received power level through calculations using equation 8. The measurement results show that the polarization of the antenna is an ellipse with an axial ratio of 20.2 dB.

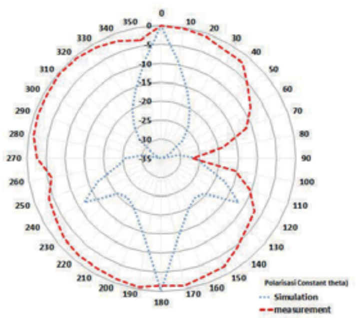


Figure 15. Polarization of two array antenna measurement result.

Through this measurement, the antenna gain results are also obtained at 6.08 dB. A comparison of all results from each design stage is shown in table 4.

Table 4. Comparison of results for each design stage

Parameter	Single Patch	Two Array Patches	Measure ment
Return Loss	-23,38 dB	-28,29 dB	-18,5 dB
VSWR	1,145	1,08	1,2
Impedance	59,57 Ω	63,9 Ω	57,8 Ω
Bandwidth	846 MHz	1,59 GHz	163 MHz
Radiation Pattern	Unidirecti onal	Unidirectional	Unidirecti onal
Polarization	Linear	Linear	Ellipse
Gain	4,06 dB	5,966 dB	6,08 dB

IV. Conclusion

The microstrip antenna for transmitting the collected ADS-B data has been designed and presented in this paper. The result shows that this work has successfully created a small rectangular array antenna which fit with the cubesat form factor. Some modifications may be needed to be applied to achieve the linear polarization of the radiated wave.

V. Acknowledgement

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References

[1] Administration, F. A., "Govinfo," 28 May 2010. [Online]. Available: https://www.govinfo.gov/content/pkg/FR-2010-05-28/pdf/2010-12645.pdf. [Accessed 12 November 2019].

[2] Delovski T., Werner, K., Rawlik, T., Behrens, J., Bredemeyer, J., & Wendel, R., "ADS-B over Satellite The world's first ADS-B receiver in Space," in Small Satellites Systems and Services Symposium, 2014.

[3] Bouwmeester, J., & Guo, J., "Survey of worldwide pico- and nanosatellite missions, distributions and subsystem technology," in Acta Astronautica, 2010.

[4] Vincent, R., & Van Der Pryt, R., "The CanX-7 Nanosatellite ADS-B Mission: A Preliminary Assessment. Positioning, 8, 1–11," 2017.

[5] Freddy Heryanto, Heroe Wijanto, Agus D. Prasetya, Edwar, "Slotted Patch and Truncated Edge Techniques on Microstrip Antenna for CP-SAR S-Band Data Transmitter," in 2018 International Conference on Signals and Systems (ICSigSys), Bali, 2018.

[6] Anggit Dwi Novella, Heroe Wijanto, Agus Dwi Prasetya, "Dual-Feed Circularly Polarized Microstrip Antenna for S-band Transmitter of Synthetic Aperture Radar (SAR) System," in 2015 International Conference on Quality in Research (QiR), Lombok, 2015.

[7] Balanis, C. A., Antenna Theory Analysis and Design Third Edition, 2005.

[8] James, J. R., Hall, P. S., & Wood, C., MICROSTRIP ANTENNA THEORY AND DESIGN, London, 1961.

[9] Mathur, V., "Comparison of Performance Characteristics of Rectangular, Square and Hexagonal Microstrip Patch Antennas, 0–5," 2014.

[10] Werfelli H., Tayari, K., Chaoui, M., Lahiani, M., & Ghariani, H., "Design of Rectangular Microstrip Patch Antenna, 798-803," in 2016 2nd International Conference on Advanced Technologies for Signal and Image Processing (ATSIP), 2016.

[11] Garg, R., Bhartia, P., Bahl, I., & Ittipiboon, A., Microstrip Antenna Design Handbook Artech House Antennas and Propagation Library.

[12] Sinaga, R., & Rambe, A. H., "Pencatu Feed Line dan Proximity Coupled," vol. 6(3), pp. 135-140, 2014.

[13] Alsager, A. F., "Design and Analysis of Microstrip Patch Antenna Arrays," pp. 1 - 80, 2011.

[14] Saad, R., Fayakun, K., & Ramza, H., "Perhitungan Link Budget Satelit Telkom-1," pp. 20-24.

[15] RI, M. K. dan I., Pita Frekuensi Radio, Mode, dan Aplikasi dalam Penyelenggaraan Kegiatan Amatir Radio Umum Untuk mencegah terjadinya gangguan atau interferensi, 2018.