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Microstrip Antenna Gain Enhancement using Multilayer Substrate and Superstrate Structure for Space-Based ADS-B Surveillance

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Abstract

Aircraft traffic monitoring is an important part in increasing flight security. Automatic Dependent Surveillance Broadcast (ADS-B) is used to run this task. The authority usually uses ground-based ADS-B signal receiver to monitor the aircraft traffic. However, this system is unable to detect the aircraft position when it is in a remote area. Space-based ADS-B can be the solution to this problem with the increase in the surveillance coverage by installing the ADS-B receiver system on a satellite platform such a CubeSat. To enable this system, a high gain antenna is needed. This paper investigated a superstrate multilayer microstrip antenna as a candidate for this technology. The multilayer substrate and superstrate structure were combined with a microstrip antenna to achieve a high gain performance without increasing the antenna dimension significantly. The multilayer method produced 4.327 dBi of antenna gain and it was rising into 4.946 dBi after being integrated with the superstrate layer by a computer simulation. The fabricated antenna gain was 4.505 dBi which was still considerably high compared to the other previous works. This antenna was designed by following the CubeSat form factor standard so it can be installed into the spacecraft easily.

Keywords: ADS-B; cubesat; superstrate; multilayer microstrip antenna.

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1. Introduction

Automatic Dependent Surveillance–Broadcast (ADS–B) is the latest aircraft surveillance technology which combines navigation information, avionics, and a ground infrastructure to provide an accurate surveillance interface between aircraft and ATC [1]. This technology has better surveillance performance compared to other existing technologies [1]. Moreover, it also has less complex setup than other surveillance technologies and it needs lower cost to build the system [2]. Therefore, ADS-B is predicted to be the next technology to support the future ATC (Air Traffic Controller) operation [2]. The ADS-B receiver is usually installed on the ground. However, this method lacks aircraft detection range, especially when it flies through a remote area such as an ocean. To cover this blank spot, the ADS-B receiver could be installed on a satellite [3].

In order to receive ADS-B signal on a spacecraft, the utilization of a high gain antenna is suggested [4]. PROBA-V was the first microsatellite that brought ADS-B receiver to enable the space-based ADS-B system [5]. It employed a 11.2 dBi planar array antenna. It employed a 11.2 dBi planar array antenna and there is a possibility to use that system on a smaller satellite such as CubeSat. However, there will be an issue on how to increase the ADS-B receiver antenna performance.

Some works have been conducted to create a small size ADS-B antenna. A previous study [6] designed a compact ADS-B microstrip antenna with the overall antenna size is less than 10 x 10 cm. This antenna had a 3.1 dBi of gain. Another previous research [7] investigated a microstrip ADS-B antenna which was specifically designed for CubeSat. This antenna gain was 1.02 dBi, which was relatively low. Another work produced an LFM microstrip antenna for ADS-B signal reception[8]. Although this work did not mention its antenna gain, it was able to give a better reception performance compared to a regular microstrip antenna. In another work, Budroweit et al. were successfully designed a small form factor ADS-B microstrip antenna that employed a small cross slot in the middle of its patch [9]. [9]. Additionally, this antenna had a 1.75 dB gain. According to the all these works, a compact ADS-B receiver antenna design is possible to be implemented. Microstrip antenna

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design is the method used the most in this study. However, it still shows a relatively low gain antenna.

To increase the microstrip antenna gain performance, there are few methods that can be applied. A previous research [10], used a reflector to increase the microstrip antenna gain. The gap between the antenna and the reflector made the antenna greatly thicker despite its good gain performance. This is not suitable to be installed in a nanosatellite due to its limited space. Besides, this type of antenna is also more complicated because it needs to be folded which may increase the probability of antenna deployment failure increase the probability of antenna deployment failure.

The antenna microstrip gain can also be enhanced by implementing an array antenna method like the one that was done by [11–15]. However, this method employs multiple radiating patches which make this antenna dimension bigger.

Another method to improve the microstrip antenna gain is by utilizing additional layer on it. In these works, the additional layer was added underneath the microstrip antenna to increase its thickness [16, 17]. On the other works, the additional layer was used as a superstrate component which was installed in front of the microstrip antenna surface to increase the gain [18–20]. These methods, utilizing additional layer and superstrate layer, effectively improve the microstrip antenna gain without significantly change the overall antenna dimension.

In this paper, the improvement of a microstrip antenna gain using thick substrate layer and a superstrate layer method is presented. The main application of this antenna is to increase the ADS-B receive signal level. The main purpose of the additional superstrate layer is to increase the gain performance of this antenna without significantly increasing the antenna dimension. The result of this work showed that the method was able to increase the antenna gain performance up to 14%.

2. ADS-B Receiver Antenna Design

In this section, two ADS-B antenna designs are presented. The initial design is explained at the beginning, then the explanation of the ADS-B antenna design with the superstrate layer follows.

2.1 ADS-B Antenna Initial Design

CubeSat is a nanosatellite class that has a cube form factor. Its basis dimension, which is called 1U CubeSat, is 10 × 10 × 10 cm [21]. The ADS-B antenna was designed to fit in Z-axis side of the CubeSat. Fig. 1 shows the 1U CubeSat anatomy [21]. that consists of six sides and corresponds with three axes, X (+X, -X), Y (+Y, -Y), and Z (+Z, -Z). The size of Y and X sides are identical while Z side has a different shape. In this research, the antenna was design to fulfill the shape of Z side.

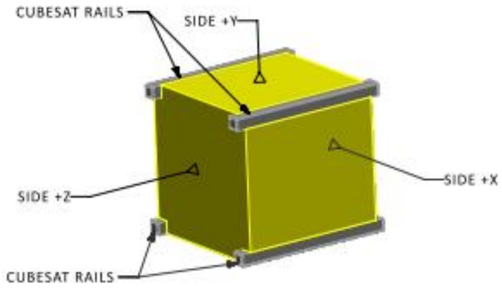


Fig 1. 1U Cubesat Form Factor Anatomy.

The ADS-B antenna was designed by using microstrip antenna method. The antenna patch design was circular patch whose radius was calculated by using Eq. (1).

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

The *a* is the patch radius size, *h* is the substrate thickness, ε_r is the substrate relative permittivity, and *F* is the logarithmic function of radiating element which can be calculated by using Eq. (2).

$$F = \frac{8{,}791\times 10^9}{F_r\sqrt{\varepsilon_r}} \quad (2)$$

The F_r is the resonance frequency. In this case is the antenna frequency center in the Hertz unit. The antenna substrate and ground plane length and width (L_g and W_g subsequently) dimension are calculated by using Eq. (3) and Eq. (4).

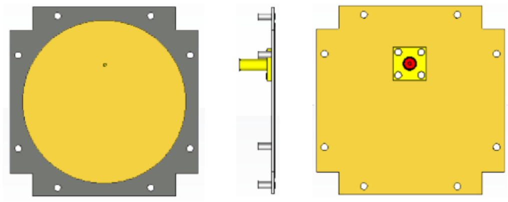
$$L_g = 6h + 2r \quad (3)$$

$$W_g = 6h + 2r \quad (4)$$

The ADS-B antenna operating frequency is 1090 MHz. The selected substrate for this antenna was RT Duroid 3006 due to its low loss characteristic. Moreover, it had a relatively high dielectric constant which can make the antenna patch design becomes smaller. The material dielectric constant is 6.5 and its thickness is 1.27 mm. The feeding method for this antenna is coaxial. The ADS-B initial design is shown in Fig. 2. The coaxial feed is installed on the top center of the patch.

2.2 ADS-B Antenna with Superstrate Layer

In this section, the final design of the ADS-B antenna is presented. Due to the optimization process, the antenna got the optimum performance which was verified through some numerical simulations. so the antenna got the optimum performance which has been verified through some numerical simulations.



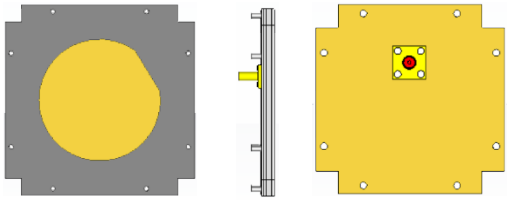
(a) (b) (c)

Fig 2. Initial Antenna Design, (a) Front Part; (b) Side Part; (c) Back Part.

Some changes were made to this final design. The first change was in the circular patch that was slightly bigger with a truncated structure employed onto it. The dimensions of the truncated patch were 2.54 mm wide, 24.863 mm long and the slope of 30^0 angle. The purpose was to improve the antenna return loss, VSWR (Voltage Standing Wave Ratio), and polarization performance. The second change was on the substrate thickness, where in this final design, it was doubled. The purpose of this change was to improve the initial antenna gain. The third change was the additional superstrate layer in front of the antenna. It had a circular patch on the top of it whose design and size are identical with the microstrip antenna patch design. The gap between the microstrip antenna and the superstrate layer was 3 mm. The layer was supported by 3D printed walls which were placed on every side of the antenna. Fig. 3 shows the final design of ADS-b antenna and Table 1 explains the dimension comparison between the antenna initial and final design.

3. Result and Discussion

In this section, the simulation result of the antenna initial and final design as well as the measurement result are presented. An analysis of the result is also explained.



(a) (b) (c)

Fig. 3. Final Antenna Design, (a) Front Part; (b) Side Part; (c) Back Part.

Table 1. Comparison of Initial and Final Antenna Design Dimension

Parameters	Dimension (mm)	
	Initial Design	Final Design
r	30.62	31.53
W_g	70.84	98
L_g	70.84	98

3.1 Initial Antenna Simulation Result

Based on the results of the initial antenna simulation, it was found that this VSWR of this antenna was 11.404 and the return loss was -1.257 at the center operating frequency of 1090 MHz as shown by Fig. 4 and Fig. 5respectively. This antenna gain was -4.980 dBi which was poor. The results indicate that the antenna has not reached the required specifications thus an optimization process is done to improve this result.

3.2 Final Design Antenna Simulation Result

The previous simulation suggests that some modifications are needed to make this antenna meet its requirements. Furthermore, some improvements have been made to respond to that need by adding the truncated method, increasing the substrate thickness and employing a superstrate layer. These modifications yielded some significant results. The VSWR and the return loss of this final design were 1.246 and -19.208 dB subsequently at 1090 MHz. Fig. 6 and Fig. 7 show the VSWR and return loss result respectively.

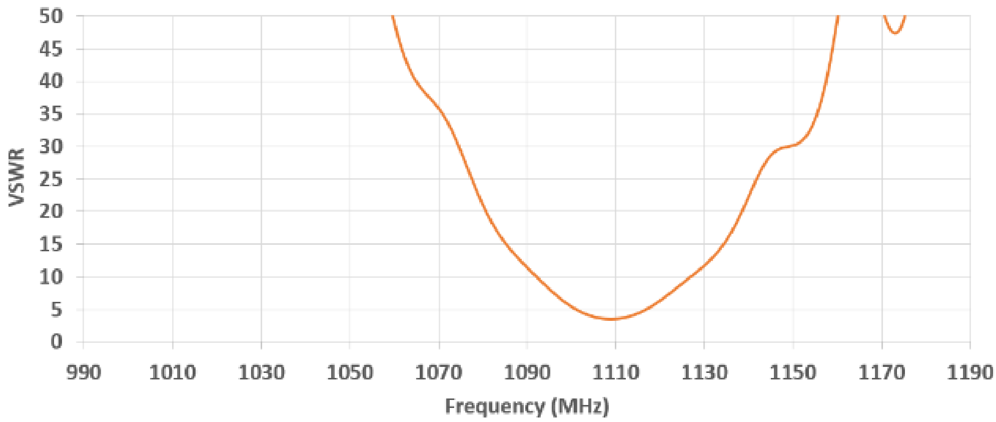


Fig. 4. Initial Antenna VSWR Result

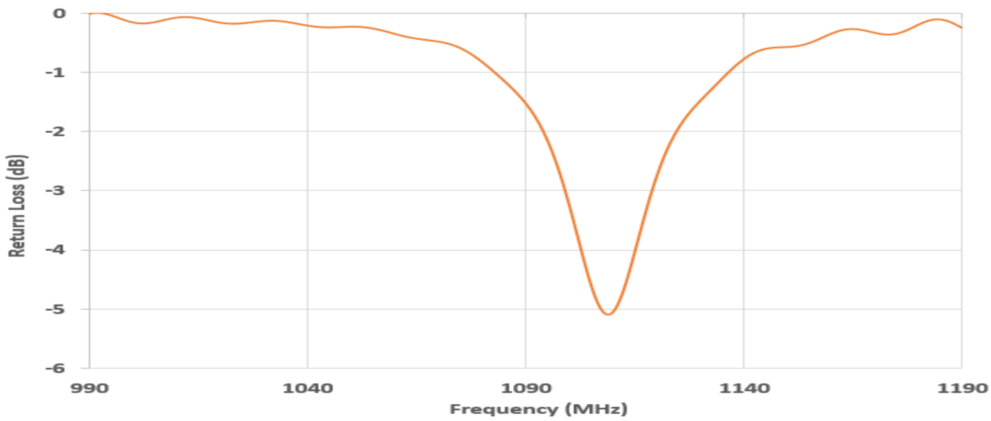


Fig. 5. Initial Antenna Return Loss Result

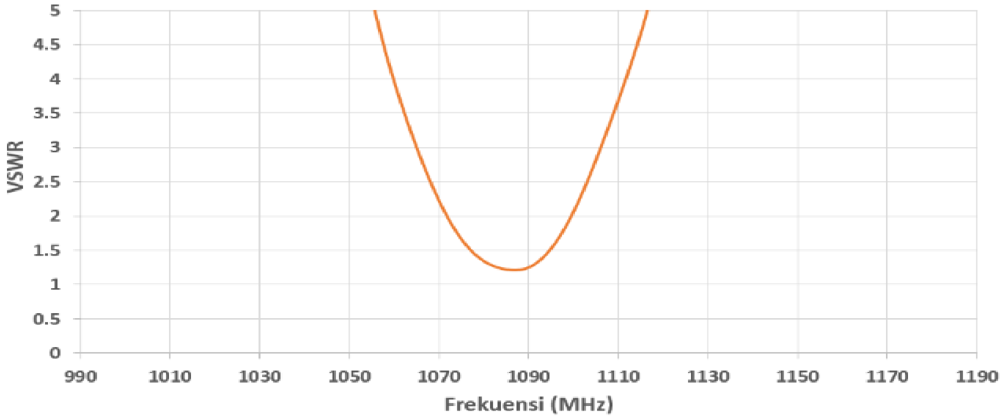


Fig. 6. Final Antenna VSWR Result

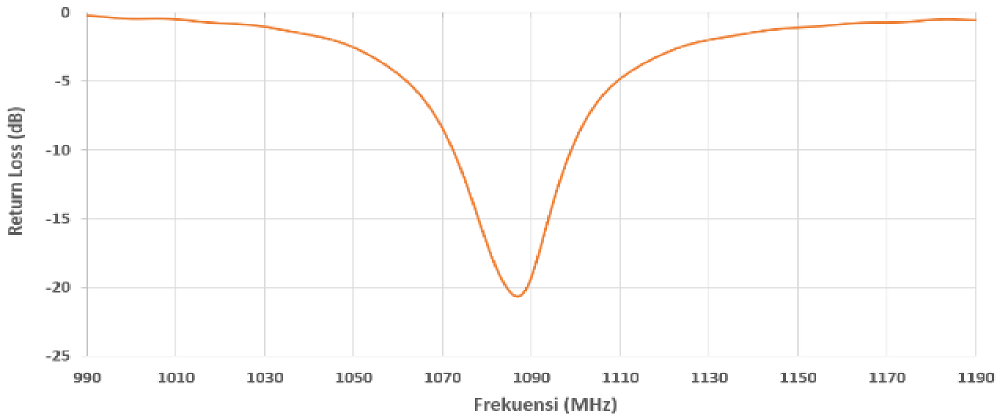


Fig. 7. Final Antenna Return Loss Result

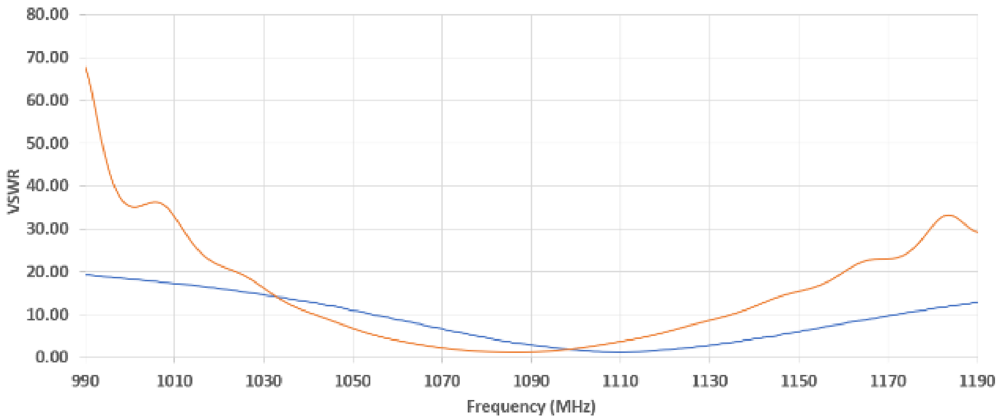


Fig 10. Simulated VSWR (Yellow Line) and Measurement Result (Blue Line)

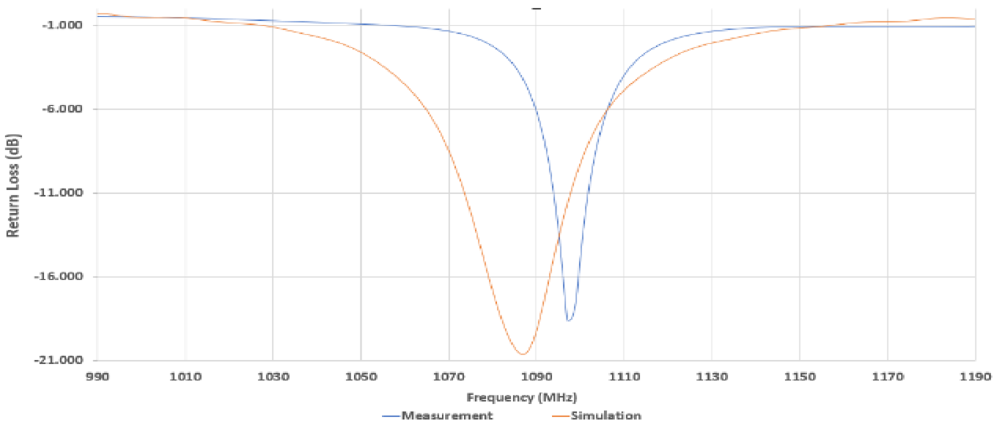


Fig. 11. Antenna Result Return Loss Simulation and Measurement Comparison

The multilayer microstrip antenna with truncated patch gain was 4.327 dBi. When the superstrate layer was added, the final design antenna gain became 4.946 dBi which was a great improvement compared to the initial result. The antenna axial ratio was about 6 dB which means that the antenna polarization approaches the circular polarization type. Fig. 8 shows the characteristic of the axial ratio of the final design antenna on a polar coordinate.

3.3 Antenna Fabrication and Measurement Result and Discussion

When the ADS-B antenna final design met the requirements, the next action was the antenna fabrication. Fig. 9 shows the antenna fabrication result. The total thickness of this antenna is 6.81 mm.

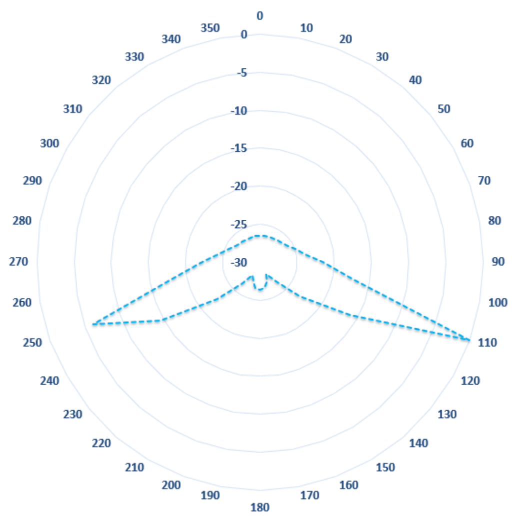
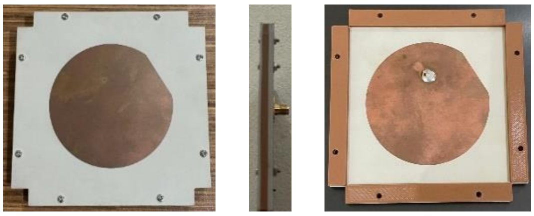


Fig. 8. Final Antenna Polarization Result



(a) (b) (c)

Fig 9. (a) Superstrate layer; (b) Antenna Side-View; (c) Microstrip Antenna Front View.

Some measurements such as VSWR, return loss, gain, radiation pattern, and polarization, were done to verify the fabricated antenna performance. The best measured VSWR was 1.256. The antenna frequency center was slightly shifted due to the characteristic of the substrate when it was used for low frequency application. Fig. 10 shows the VSWR measurement result and the comparison with the simulation result.

Fig. 11 shows the fabricated antenna return loss which is compared with its simulation result. The best return loss level of the fabricated antenna is -18.940 dB. It is slightly lower than simulation result which is -19.208. According to this result, the fabricated antenna has a 23 MHz of bandwidth. It is 4.5 MHz lower than the simulation one.

The fabricated antenna polarization characteristic was measured in this work. Fig. 14 shows the polarization measurement result and its comparison with the simulation result. The fabricated antenna axial ratio is under 3 dB, which proves that this antenna has a circular polarization. The comparison of the gain, axial ration, and bandwidth from the simulation and measurement result is concluded in Table 2. The fabricated antenna radiation pattern was relatively similar with the simulated one. However, the fabricated antenna has a better front-to-back ratio compared to the simulation result. It can be seen in Fig. 12 and Fig. 13. The fabricated antenna had a 4.505 dBi of gain which was lower than the simulation result.

Compared to the other works done by [6,7], and [9], this antenna produces higher gain performance which meets this research purpose. This antenna also has a circular polarization which will be able to anticipate polarization loss due to the faraday effect. Another important thing is this antenna form factor is suitable with the CubeSat standard. Table 3 shows the overall result.

Table 1. Simulation and Measurement Antenna Performance Comparison

Parameter	Simulation	Measurement
Gain	4.946 dBi	4.505 dBi
Axial Ratio	< 3 dB	< 3 dB
Bandwidth	28 MHz	23 MHz

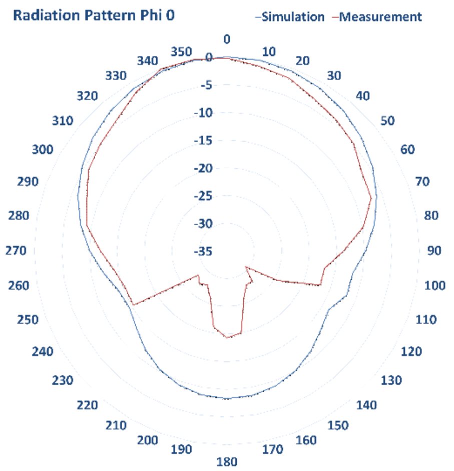


Fig 12. Comparison of Azimuth Radiation Pattern

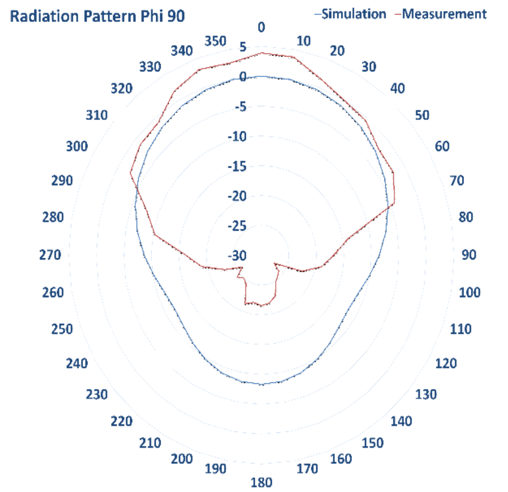


Fig 13. Comparison of Elevation Radiation Result

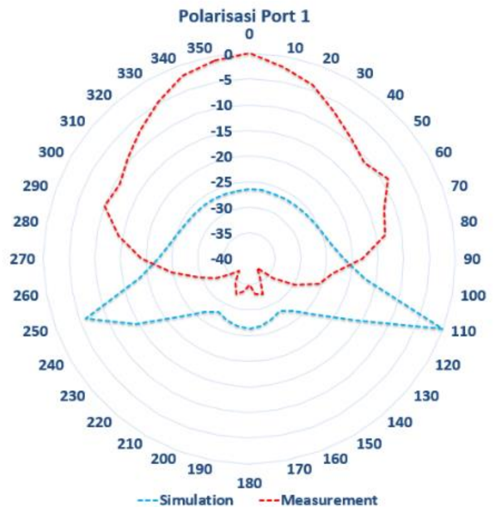


Fig 14. Result Polarization

Table 3. Antenna Gain Comparison

Antenna	Gain	Form Factor	Ref
Rectangular Patch with Slot	3.1 dBi	Non-Cubesat	[6]
Circular Patch with Slot	1.02 dBi	Cubesat	[7]
Circular Patch with Cross Slot	1.75 dBi	Non-Cubesat	[9]
This Work	4.505 dBi	Cubesat	

4. Conclusions

The ADS-B antenna using superstrate and additional substrate layer for CubeSat is successfully designed, simulated, and measured. The antenna form factor is made to meet the CubeSat standard. The gain improvements was done with the result of 4.505 dBi. The return loss and the bandwidth of the antenna is -18.940 dB and 23 Mhz respectively. This antenna axial ratio is less than 3 dB which means that this antenna has a circular polarization. This result is obtained by managing the antenna patch dimension, adding truncated structure, increasing the substrate layer, and integrating the antenna with a superstrate layer. The combination of these methods successfully increases the antenna performance while maintaining its compact dimension.

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