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Design of A Rectangular Patch Microstrip Array Antenna with Proximity Coupled on ADS-B Receiver

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ABSTRACT

One of the observation facilities available in Indonesia is Automatic Dependent Surveillance-Broadcast (ADS-B), a surveillance technology similar to Radio Detection and Ranging for monitoring air traffic. This system only received information transmissions from aircraft, broadcast on a frequency of 1090 MHz using a monopole antenna with large dimensions, ranging from 85 centimeters to 3,5 meters, and weighing between 1,5 kilograms to 26 kilograms. As an alternative, a microstrip antenna was chosen to reduce the large size and weight of the monopole antenna. This research aimed to design a 2x1 rectangular patch microstrip array antenna with a proximity coupled feeding method at a frequency of 1090 MHz. The antenna was designed using Antenna Design Software and fabricated using Epoxy substrate material with a copper ground plane. Return Loss, VSWR, Impedance and Gain parameters meet the specifications required for ADS-B receivers. However, the polarization parameters and radiation patterns do not yet meet the linear polarization and omnidirectional radiation patterns. And also array antenna design with proximity coupled supply can produce a high gain of more than 5 dBi, namely 6,4 dBi. The resulting antenna array has a bandwidth of between 20 – 30 MHz, namely 28 MHz. The test results demonstrated that the antenna successfully received signals from 32 aircraft, with the longest reception distance reaching 172,5 Nautical Miles (319,4 kilometer) at a maximum altitude of 36,950 feet.

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1. INTRODUCTION

As technology develops, facilities that support flight navigation services have also increased. Automatic Dependent Surveillance-Broadcast (ADS-B) technology is an observation facility where each aircraft, via its transponder, sends information twice every second to ground stations and other aircraft[1]. ADS-B operates as a receiver on the 1090 MegaHertz (MHz) frequency, requiring an antenna as a receiver device for electromagnetic signals emitted by aircraft[2]. Generally, ADS-B receivers use monopole antennas with lengths ranging from 0,85 m to 3,5 m, weights between 1,5 kg and 26 kg[3].

Monopole antennas which have quite large dimensions and weight provide opportunities for research and development with the aim of creating smaller antenna innovations. The microstrip antenna was chosen as the main variable in this research because microstrip antennas tend to be easy to manufacture, and have many other advantages[4]. The advantages of microstrip antennas include smaller size, light weight, and ease of manufacturing. Microstrip antennas are formed from three key components: radiating elements (patch), ground plane, and substrate. The ground plane is attached to the bottom of the substrate, while the metal conductor (patch) is attached to the top of the substrate. With its compact size and light weight, microstrip antennas offer a solution that is simple and easy to implement[5].

As a state of the art in this research, the design was carried out by combining antenna design methods that have been researched by previous researchers.

Table 1. The position of research on ADS-B compared with similar research

Reference	Antenna Parameter					
	Frequency (GHz)	VSWR	Bandwidth (MHz)	Radiation Pattern	Gain (dB)	Antenna Design
[6]	1,09	1,11	15,48	Uni-Directional	3,7	Rectangular Patch with proximity coupled
[7]	1,09	1,08	30	Unidirectional	4,01	Microstrip Circular Patch Array 4
[8]	1,09	1,22	44	Omnidirectional	2,53	Triangular Microstrip Patch Back to Back Structure
[9]	1,09	1,02	151	Omnidirectional	4,64	Microstrip Printed Collinear Dipole Array
[10]	1,09	1,65	57,5	Omnidirectional	4,04	Mikrostrip Circular Array 4 with MIMO 2x2
[11]	1,09	1,16	41	Uni-Directional	4,4	Microstrip Array Rectangular Patch
This research	**1,09**	**< 1,5**	**20 - 30**	**Omnidirectional**	**> 5**	**Recatangular Array 2x1 Microstrip Patch with Proximity Coupled**

2. RESEARCH METHOD

In this research, a rectangular microstrip antenna array was designed using the proximity coupled feeding method for ADS-B receivers. The patch and groundplane use copper or copper material, while the substrate uses FR-4 material with a dielectric value of 4,4. The technique that will be applied in this research is ADDIE (Analysis, Design, Development, Implementation and Evaluation). This method is a scientific approach to obtain information with specific targets and benefits. ADDIE is a framework that is often used to design a product efficiently[12].

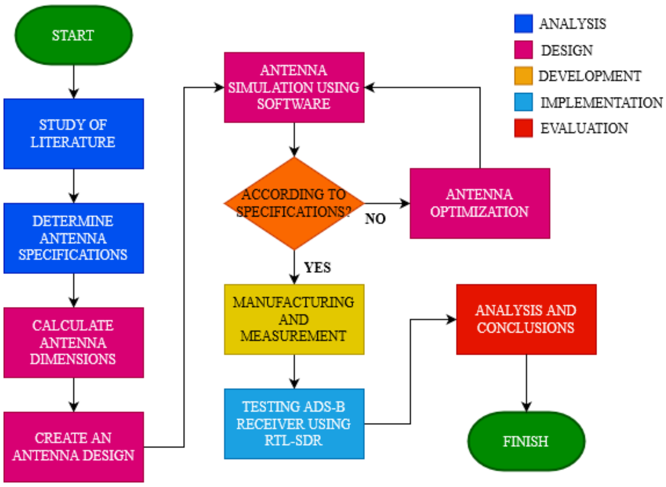

Figure 1. Flowchart antenna design

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2.1. Analysis

In this section, a literature evaluation is carried out to explore reference parameters which will be the basis for designing the antenna being planned. This reference refers to regulation KP 331 of 2016 concerning "Operational technical guidelines 171-08, Certification of ADS-B system equipment types"[13]. The following are standard parameter values that indicate good antenna performance.

Table 2. Antenna parameter

Parameter	Value
Frequency of Work	1090 MHz
Return Loss	< -10 dB
VSWR	< 2
Bandwidth	20 – 30 MHz
Radiation Pattern	Omnidirectional

2.2. Design

At this section, This design process was carried out using the Antenna Design Software application and a simulation was carried out to evaluate the performance of the antenna created.

Table 3. Antenna materials and design

Parameter	Materials	Design
Patch	Copper	Array 2x1 Rectangular
Feedline	Copper	Proximity Couple Feed
Substrate	FR-4 Epoxy	Double Layer
Ground	Copper	Rectangular

Calculations are carried out to determine the length (L) and width (W) of the patch. Before calculating the length (L) and width (W), the length of the patch on the microstrip antenna must be adjusted carefully because it can impact return loss, while the width of the patch on the microstrip antenna affects the input impedance. Information regarding the material used such as dielectric thickness (h), dielectric constant (εr), and conductor thickness (t) must be known first. Therefore, With the values f = 1090 MHz, εr = 4,3, h = 1,6 mm entered into the equation, the patch dimensions can be calculated as follows:

a. Patch Width (Wp)

$$Wp = \frac{C}{2\,fo\sqrt{\frac{\varepsilon r+1}{2}}} \tag{1}$$

Where :
C = Speed of Light (3×10^8 m/s)
fo = Frequency of Work (MHz)
ε_r = Dielectric Constant

b. Patch Length (Lp)

$$\lambda = \frac{C}{f} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}}\right] \tag{3}$$

$$\lambda_f = \frac{\lambda}{\varepsilon_{eff}} \tag{4}$$

Where:
λ = Wave Length
λ_f = Feedline Wave Length

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C = Speed of Light ($3{\times}10^8$ m/s)
f = Frequency of Work (MHz)
ε_{eff} = Effective Dielectric Constant
h = Substrate Thickness

Table 4. Calculation of Initial Parameters of Antenna Dimensions

No	Parameters	Initial Size	Information
1	Wp	83,74 mm	Patch Width
2	Lp	65,39 mm	Patch Length
3	Wg	138,74 mm	Groundplane Width
4	Lg	120,39 mm	Groundplane Length
5	Wf	3,05 mm	Feed Width 50 Ω
6	Lf	33,45 mm	Feed Length 50 Ω
7	$Wf2$	1,53 mm	T-Junction Feed Width 70 Ω
8	ε_r	4,4	Relative Permittivity
9	h	1,6 mm	Thick Dielectric Substrate
10	t	0,0335 mm	Groundplane Thickness
11	r	38,39 mm	Distance between patches/feed length 70Ω

2.3. Development

The next step is the development stage. At this stage, the antenna with the best parameters will be manufactured in physical form according to the equipment specifications.

2.4. Implementation

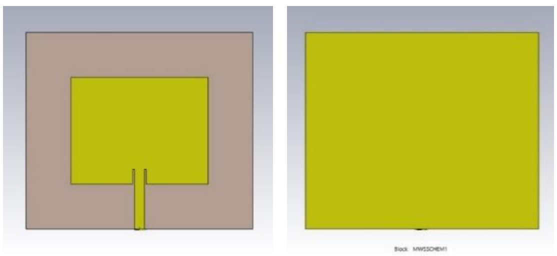
The next step is to carry out measurements and testing using a Vector Network Analyzer (VNA), Spectrum Analyzer, Signal Generator, and Antenna Tester. At this stage, the antenna will be measured in a laboratory to evaluate its physical performance after production. This measurement aims to obtain data regarding antenna parameters. This parameter data will be compared with the parameter values resulting from simulations using Antenna Design Software. Apart from that, the antenna will also be tested using an ADS-B receiver to test its ability to receive ADS-B signals at the 1090 MHz frequency and display targets or not.

2.5. Evaluation

The final step is product evaluation. By carrying out measurements in the laboratory, we can evaluate whether the parameters measured using the VNA, Spectrum Analyzer, Signal Generator, and Antenna Tester match the planned requirements or not. Next, we will analyze the causes of differences in values between simulation results and direct measurement results in the laboratory.

3. RESULTS AND DISCUSSION

3.1. Single Patch Microstrip Antenna Design



(a) (b)

Figure 2. (a) Single patch antenna front view and (b) Single patch antenna rear view

This antenna has been made according to the initial calculations in Table 4. The simulation results of this design do not meet the ADS-B antenna parameter values which are limited by the maximum

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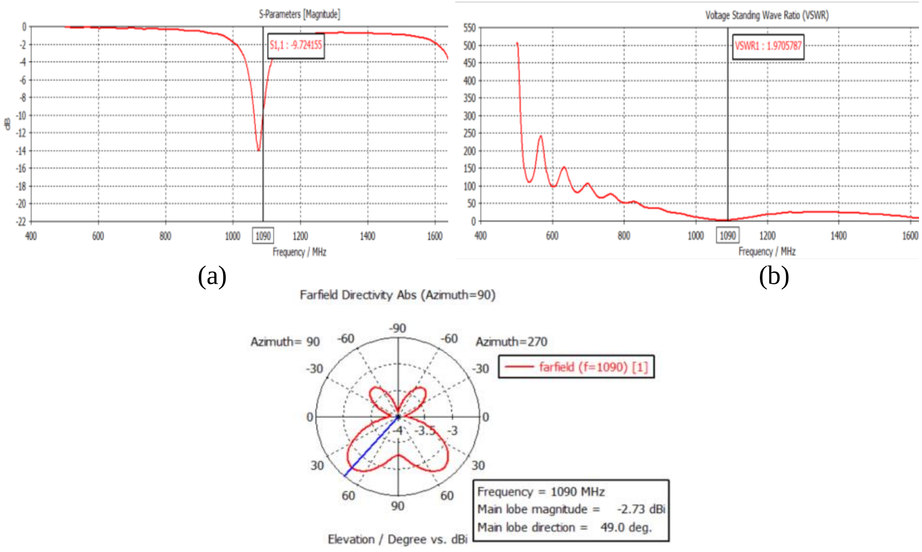
standards for an antenna. The following are the simulation results of the single patch microstrip antenna design.



(a) (b)

(c)

Figure 3. (a) Return loss value of S11 (b) VSWR and (c) Radiation pattern

The illustration of Figure 3 indicates that the antenna has not achieved optimal performance at the desired frequency, namely 1090 MHz. Apart from that, the VSWR, Return Loss and radiation pattern values of the antenna do not match the expected specifications.

3.2. Microstrip Array Antenna Design Without Proximity Couple

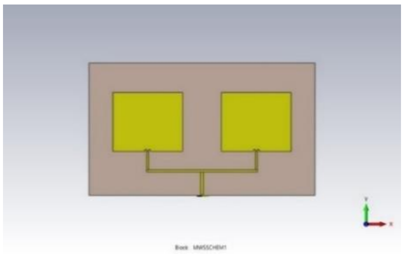
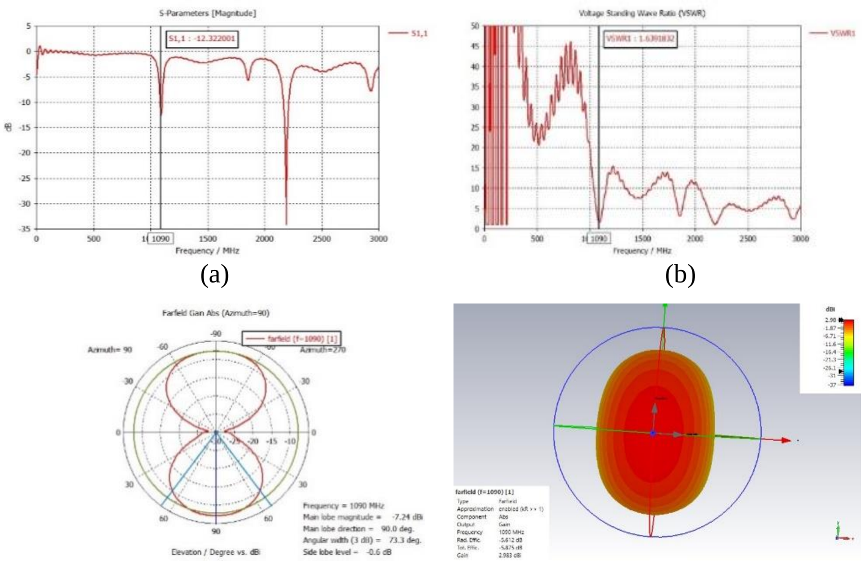


Figure 4. 2x1 Rectangular array antenna design without proximity couple



(a) (b)

(c) (d)

Figure 5. (a) Return loss value of S11 (b) VSWR (c) Radiation pattern (d) Gain

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In the picture of Figure 5, it can be seen that the return loss parameter value has reached -12,3 dB, and the VSWR value has reached 1,6, indicating that the antenna performance has improved compared to the previous design. Apart from that, the antenna radiation pattern has begun to form, although it is still bidirectional, whereas what is desired is an omnidirectional antenna radiation pattern. There is also an increase in the antenna gain value in this design, where the initial value of -2,73 dB increases to 2,98 dB.

3.3. Microstrip Array Antenna Design Using the Proximity Coupled Method

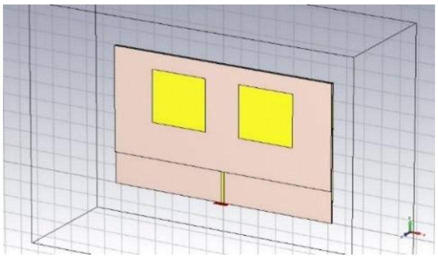
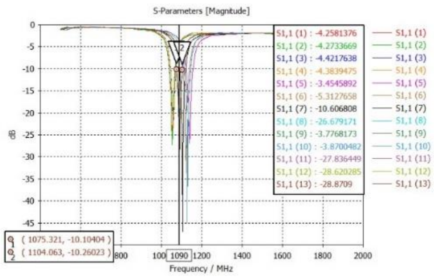
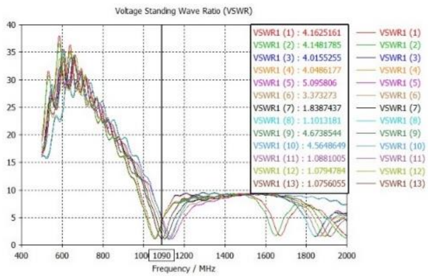


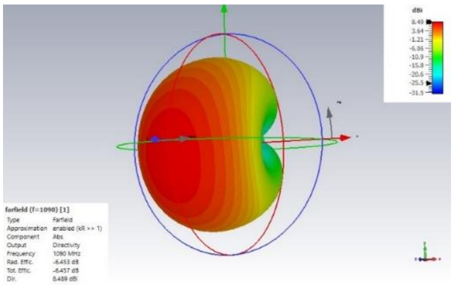
Figure 6. Microstrip array antenna design using the proximity couple method



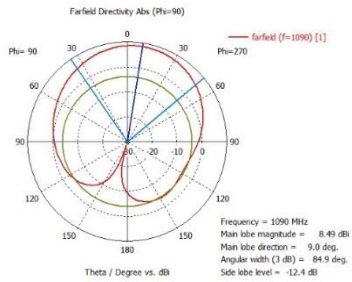
(a)



(b)



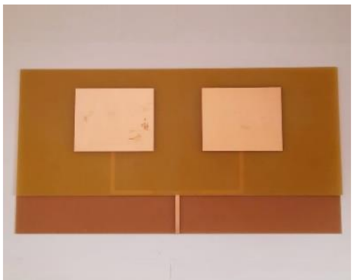
(c)



(d)

Figure 7. (a) Return loss value of S11 (b) VSWR optimization (c) Gain (d) Radiation pattern

The illustration of Figure 7 shows the design and simulation results with optimization of a microstrip antenna that applies the proximity couple method and patch array configuration. By applying this technique, a return loss parameter value of -28,8 dB, a VSWR value of 1,07, a bandwidth of 28 MHz, and a gain of 8,49 dBi were obtained. This indicates that the performance of the antenna is significantly superior to previous antenna designs.



(a)

(b)

Figure 8. (a) Physical antenna front view and (b) Physical antenna rear view

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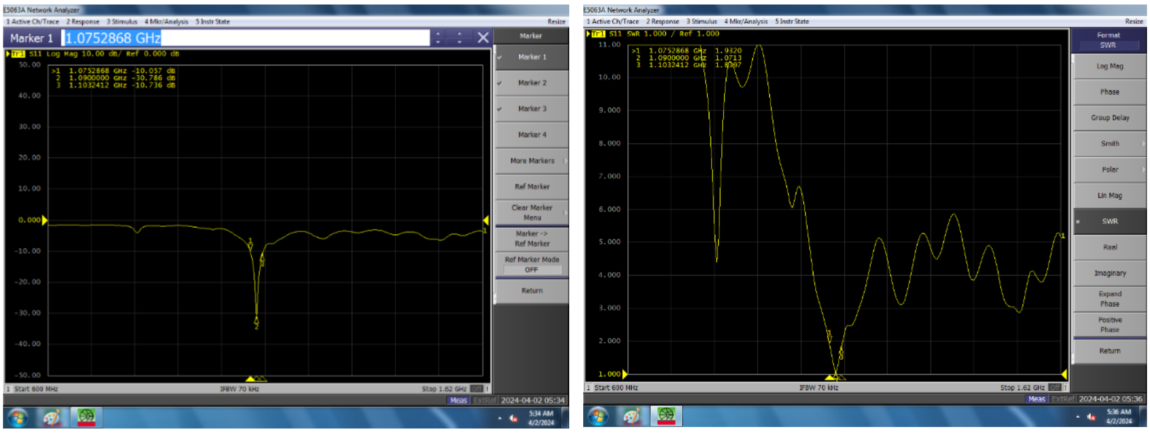
Table 5. Size Data Results After Optimization and Final Size Results for Antenna Dimensions

No	Symbol	Initial Size	Final Size	Information	Deviation
1	Wp	83,74 mm	62,56 mm	Patch Width	-25,28 %
2	Lp	65,39 mm	61,39 mm	Patch Length	-6,11%
3	Wg	138,74 mm	250 mm	Groundplane Width	+44,5%
4	Lg	120,39 mm	160 mm	Groundplane Length	+32,9%
5	Wf	3,05 mm	2,95 mm	Feed Width 50 Ω	-3,28%
6	Lf	33,45 mm	38,39 mm	Feed Length 50 Ω	+12,84%
7	$Wf2$	1,53 mm	1,53 mm	T-Junction Feed Width 70 Ω	-
8	ε_r	4,4	4,4	Relative Permittivity	-
9	h	1,6 mm	1,6 mm	Thick Dielectic Substrate	-
10	t	0,0335 mm	0,0335 mm	Groundplane Thickness	-
11	r	38,39 mm	38,39 mm	Distance between patches/feed length 70Ω	-

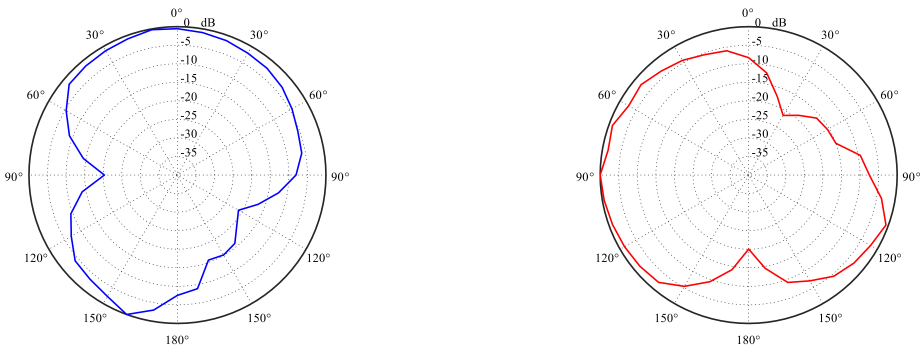
3.4 Results of Direct Measurements of Antenna Parameters



(a) (b)

Figure 9. (a) Return loss value on VNA and (b) VSWR on VNA

In this test, we will discuss measurements of a rectangular patch array antenna with prefabricated proximity couple supply. The aim is to verify whether the manufactured antenna has properties that correspond to the initial parameters that have been set.



(a) (b)

Figure 10. (a) Azimuth radiation pattern and (b) Elevation radiation pattern

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3.5 Antenna Test Results with RTL-SDR

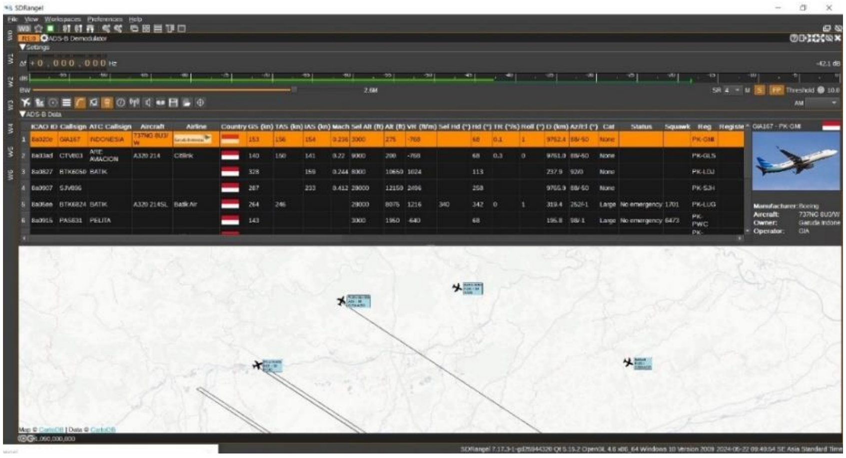


Figure 11. Display of Antenna Test Results using RTL-SDR

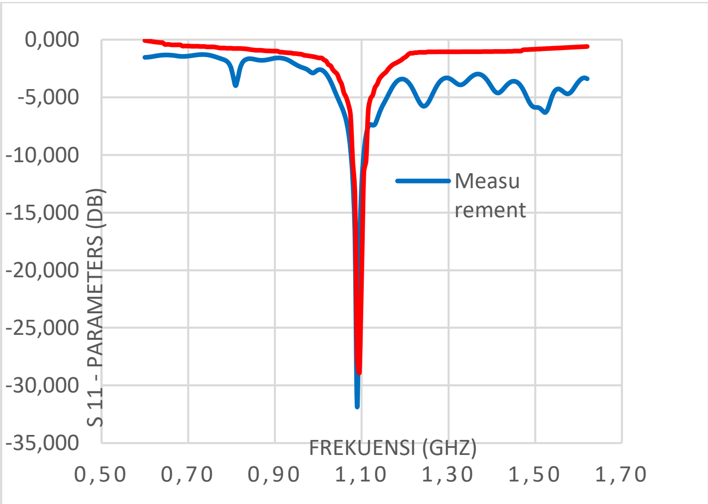
Based on design testing with RTL-SDR, it shows quite good results. During testing, 32 aircraft were received, with the longest distance being 172,5 NM (319,4 km) and the maximum altitude achieved was 36,950 feet.

3.6 Comparative Evaluation of Measurement and Simulation Results

Table 6. Comparison of Parameter Values from Simulation Results and Measurement Results

Parameters	Spesification	Simulation	Measurement	Information
Return loss	≤ -10 dB	-28,87 dB	-30,78 dB	Memenuhi
VSWR	≤ 1,5	1,07	1,07	Memenuhi
Impedansi	± 50 Ω	52,4 Ω	48,91 Ω	Memenuhi
Bandwidth	≤ 30 MHz	28,7 MHz	28 MHz	Memenuhi
Gain	> 5 dBi	8,49 dBi	6,4 dBi	Memenuhi

Figure 12 shows a comparison between the graph of the measured return loss value and the simulated value resulting from the Antenna Design Software.



(a)

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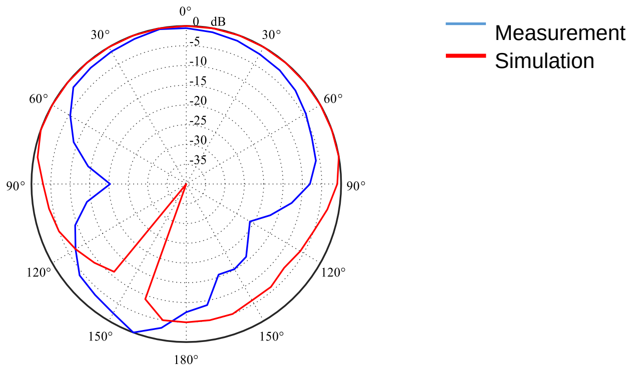

(b)

Figure 12. (a) Comparison of return loss results and (b) Comparison of radiation pattern results

4. CONCLUSION

Based on research from studies that have been carried out, the following conclusions can be drawn:

1. Obtaining a rectangular microstrip patch antenna array design using FR-4 Epoxy material using proximity couple feeding which operates at a frequency of 1090 MHz.
2. Return Loss, VSWR, Impedance and Gain parameters meet the specifications required for ADS-B receivers. However, the polarization parameters and radiation patterns do not yet meet the linear polarization and omnidirectional radiation patterns.
3. An array antenna design with proximity coupled supply can produce a high gain of more than 5 dBi, namely 6,4 dBi.
4. The resulting antenna array has a bandwidth of between 20 – 30 MHz, namely 28 MHz.

Based on the conclusions above, there are several recommendations for further research that can be considered in order to achieve better antenna performance, including:

1. Optimize and modify existing patch antenna designs, as well as designing antennas using other methods such as making them sectoral directional using three antennas combined into one to achieve an omnidirectional radiation pattern and linear polarization.
2. Develop research by trying various types of substrate materials which have a big influence on the results of the simulation and design, even though some materials may have a high price.
3. Carry out antenna trials in locations with minimal obstacles, to increase antenna power reception and widen the antenna coverage area.

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