Design and Realization of LNA Prototype Frequency 1090 MHz for ADS-B on Nano Satellite

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Abstract

The nanosatellite is a satellite which has weight less than 10 kg and has an orbital height 500 km. One of nanosatellite payloads is Automatic Dependence Surveillance-Broadcast (ADS-B) which is an aircraft data transmission broadcast. The long-distance transmission and the space environmental disturbances can cause weak received signal. Therefore, a Low Noise Amplifier (LNA) is needed to enhance the signal to noise ratio (SNR) of received signal. In this paper, a LNA has been designed and tested to improve the ADS-B signal on a nanosatellite based on BFU520A transistor chip. Passive component values have been modified in simulation and fabrication process to ensure that the LNA is able to amplify the signal and working on ADS-B frequency. The gain of the fabricated LNA is 12.7 dB and the LNA noise figure is 0.98 dB. It successfully enhances the ADS-B coverage from 180 km to 358 km.

1. Introduction

Over the years, the needs for air transportation have been increasing and resulting crowded airplane traffic. Safety in aviation is priority, this mean the position and direction of flight path data need to be very accurate. With the Automatic Dependence Surveillance-Broadcast (ADS-B) technology, it is easier to observe air traffic. ADS-B send information about altitude, speed, wind direction and position of commercial aircrafts. ADS-B works by giving to nearby aircraft an echo signal, and then it is forwarded to the receiving station on earth or satellites. ADS-B technology has an important contribution to the world of aviation due to its less complexities. However, to expand the scope of ADS-B is to use it in satellite missions [1].

Nano Satellite is a technology whose development is quite rapid in the world. The nanosatellite itself has a size based on 1-10kg weight which makes the production price more affordable and easier to develop. For example, GomSpace Express-1 (GOMX-1) (2013) [1] and Canadian Advanced Nanospace eXperiment-7 (CanX-7) (2016) [2]. Telkom University created a project to build a CubeSat education called the Tel-U Sat 2 project. It is the second generation of Tel-U Sat project, which has used space-based ADS-B as payload and using the CubeSat 3U standard for nanosatellite design. With

experience developing the CubeSat subsystem and another payload that was carried out ~~in~~ [3-6], this ADS-B module is built on raspberry pi as a data processor and combined with Software Defined Radio (SDR) as a receiver. In order to increase the ADS-B signal reception, a LNA is needed. Some research regarding LNA design have been done for the other applications [7-10]. In 2016, Andzaz [3] designed a LNA using a e-pHEMT transistor model for for ground station Nano Satellite at frequency 2.425GHz. In 2019, Pahlevy [4] prototyped ADS-B receiver on nanosatellite. His work then continued by Suteja [5] by attached microstrip receiver antenna on nanosatellite to enhance its coverage, however the received data still resulting few detections. That result became our motivation to design a LNA which amplifies the received signal with low noise figure to enhance ADS-B receiver coverage.

Some LNA products are available on the market. All of them are built modular. However, integrating modular products increase nanosatellite vulnerability to a random vibration while it is being launched. By designing the LNA module, it gives more flexibility to increase the performance such as gain and noise figure. In this paper, an ADS-B LNA design has been proposed, designed, and fabricated by using single-stage amplifier method which fulfill the minimum specification such as working on 1090 MHz of operating frequency. It is according to the standard

released by the Federal Aviation Administration (FAA) [11]. The design is a preliminary modular LNA prior to its integration into nanosatellite system. It has a minimum 10 dB of gain. The LNA board employs array of holes to improve the loss from the material. A laboratory and real aircraft detection tests have been conducted to observe the LNA performance by installing the LNA to an ADS-B receiver. This LNA has been installed on the existing ADS-B prototype. The result shows that this LNA is able to amplify input signal up to 12.7 dB of amplification and to improve the ADS-B receiver coverage up to 358 km.

2. Literature Review

2.1 ADS-B System

ADS-B system illustration is shown at Fig 1. Unlike conventional Radio Detection and Ranging (RADAR) which sends radio waves to the object and receive an echo from the object, in the ADS-B system, the plane sends aircraft position data to receivers that are in the ground station as shown in the picture above.
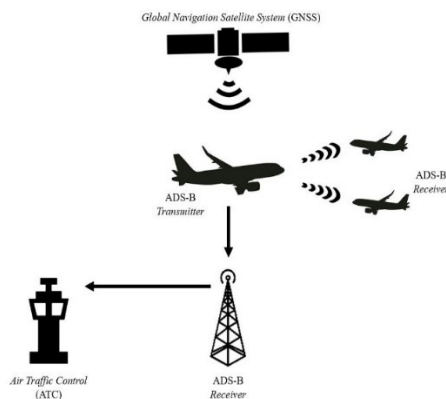

Fig. 1. ADS-B system

2.2 Link Budget

The LNA design specification at the working frequency of 1090 MHz for nano satellites as ADS-B payload refers to the calculation of the link budget to get the gain needed so that the incoming information signal is not lost by noise.

$$P_{tx} + (-L_{tx}) + G_{tx} + FSL + G_{rx} \quad (1)$$
$$+(-L_{rx}) + (-L_{rtl-sdr}) + G_{LNA} = P_{rx}$$

$$FSL = 32.45 + 20 \log(F_{MHz}) \quad (2)$$
$$+20 \log(D_{km})$$

Where P_{tx} is the transmit power of the aircraft transponder, L_{tx} is losses receiving is the aircraft transponder gain, FSL is Free Space Loss, L_{rx} is the losses on the receiver side, $L_{rtl-sdr}$ is the RTL module losses SDR, G_{LNA} is the gain of LNA, and P_{rx} is the receiving power of the RTL-SDR module[14].

2.3 Low Noise Amplifier (LNA)

LNA is one component in a communication system that is installed in receiver to amplify a signal and to suppress its noise [11-12]. The LNA has higher sensitivity compared to other amplifiers so that the received weak signal is detected by the LNA. The LNA has a small noise so the information obtained can be passed on to the next component.

3. LNA Circuit Design

The LNA is designed through several process which is shown in Fig. 2. It is started from determining the LNA specification, then it is followed by the transmitter selection. After that, the initial LNA board is design by using software. The next step is simulating the LNA initial design. If the simulation result is not fulfilling the specification, optimization process will be conducted by adjusting the passive components value. If the optimum result is obtained, the final LNA design is fabricated. The fabricated LNA characteristic is validated through some tests such as gain test using spectrum analyzer and overall test by integrating LNA with ADS-B receiver.
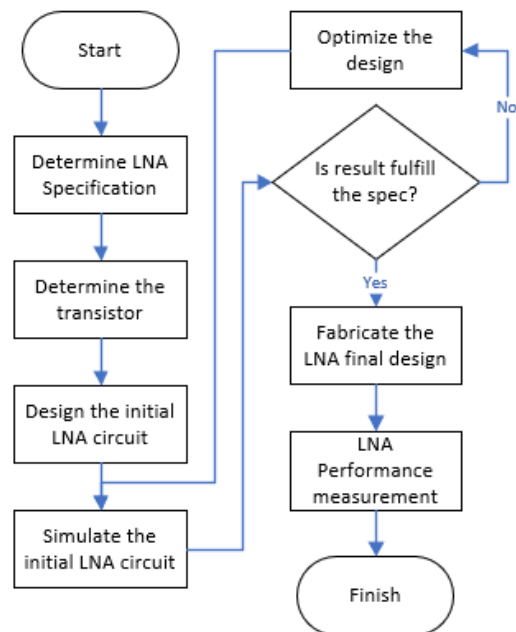

Fig. 2 LNA Design Process Flowchart

3.1 Specification

The LNA design specification at the working frequency of 1090 MHz for nano satellites as ADS-B payload refers to the calculation of the link budget by Eq. (1) and Eq. (2). Gain calculation for specifications is obtained using Eq. (1) and Eq. (2) [5] with initial parameters P_{tx} = 125W, L_{tx} = 4 dB, G_{tx} = 3 dBi, FSL is obtained 153.31 dBm with f = 1090 MHz, D = 481.71 km, L_{rx} = 3 dB, $L_{rtl-sdr}$ = 4,5 dB [13], and

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P_{rx} = –146,81 dBm [13]. Then a summary of the LNA specifications designed in this final project is shown in Table 1.

Table 1. Initial Parameter of LNA specification.

Parameters	Value
Frequency	1090 MHz
Gain	≥ 10 dB
NF	≤ 2 dB

3.2 LNA Initial Design

The first step of designing the LNA is selecting the transistor. In this work, the BFU520A transistor has been selected. Its operating frequency is from 1 MHz to 2000 MHz, which covers the ADS-B frequency, according to its datasheet [15]. This chip has a lower noise figure, which is down to 0.7 dB, higher gain which is up to 18 dB, and wide operating temperature, which is from -40˚ - 150˚ Celsius. This specification is fit with the common temperature of the satellite orbiting at the low altitude. The first LNA design, which is shown by Fig. 3, follows the circuit design recommendation in the datasheet. That initial design has been simulated and the result showed that the optimum LNA characteristic occurred at 866 MHz of frequency which is miss the specification. An optimization is needed to fix this problem.
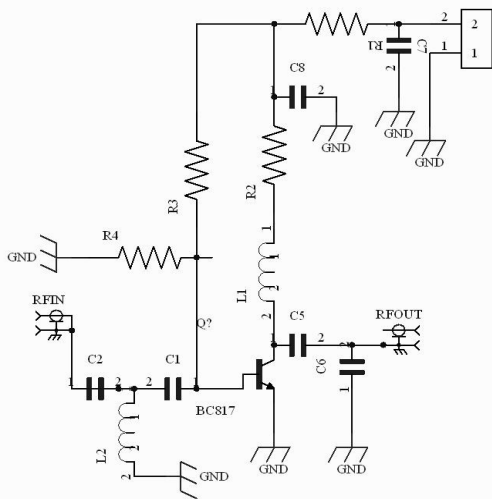

Fig. 3. LNA Initial Design using BFU520A

3.3 First LNA Optimization

The first optimization has been done by adjusting the passive components value and adding 2nd order low pass filter before the RF out section. The filters is added to prevent any interference from harmonic signal. Table 2 shows the components value changes.

Table 2. First Optimization

Component	Initial Design	1st Optimization
L1 (nH)	8,2	78,202
L2 (nH)	82	8,407
L3 (nH)	-	5,018
R1 (Ω)	22	299,474
R2 (Ω)	2,2	$5,431e^{-3}$
R3 (KΩ)	8,2	10,769
R4 (KΩ)	3,3	5,173
C1 (pF)	18	61498,467
C2 (pF)	82	26,209
C3 (pF)	-	3,25
C4 (pF)	-	5
C5 (pF)	6.8	0,407
C6 (pF)	2.7	3,517
C7 (pF)	220	338,558
C8 (pF)	27	2,076

Fig. 4 shows the LNA circuit after the first optimization. This design has been simulated and the result is shown by Fig. 5. According to Fig. 5, the LNA response is relatively wide, and it covers the ADS-B frequency. The LNA gain and noise figure are 15.933 dB and 0.958 dB respectively. It already meets the specification of this research. Unfortunately, all the passive component value does not follow the common component value available in the market. Another optimization is needed so the LNA design will be able to be implanted. The next optimization step is adapting all the passive component value to the standardized value without changing the configuration.
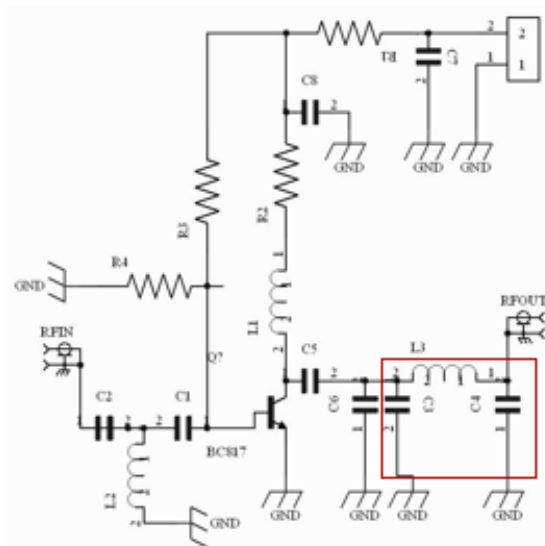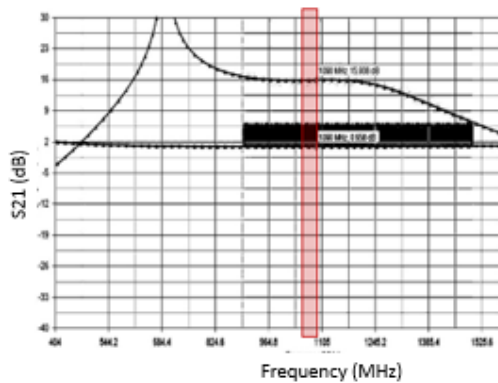

Fig. 4. LNA First Optimized Circuit

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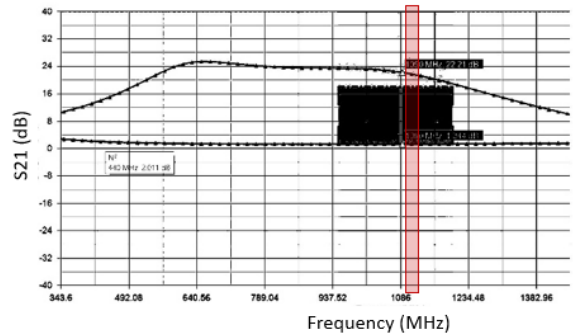Fig. 5. First Optimization Result. Angka dan axis ditimpa dan diperjelas

3.4 Second LNA Optimization

The second optimization purpose is to standardize the component value in optimized LNA design. The method is replacing the component value with the closest standardized component value which is available in the market. Table 3 shows the changes from previous design and its update.

Table 3. Second optimization

Component	Before	After
L1 (nH)	78,202	68
L2 (nH)	8,407	10
L3 (nH)	5,018	5,6
R1 (Ω)	299,474	270
R2 (Ω)	$5,431e^{-3}$	22
R3 (KΩ)	10,769	15
R4 (KΩ)	5,173	3,9
C1 (pF)	61498,4 67	20
C2 (pF)	26,209	56
C3 (pF)	3,25	3,9
C4 (pF)	5	5,6
C5 (pF)	0,407	1
C6 (pF)	3,517	2,7
C7 (pF)	338,558	0,1
C8 (pF)	2,076	8

A simulation has been conducted to check the updated LNA response due to component changes. Fig. 6 shows the simulation result. The LNA response is still as wide as previous result. The overall gain of the updated LNA design is increasing. At the 1090 MHz (ADS-B frequency) the curve is slightly decreasing, yet the gain performance is still higher than previous result, which is 22.21 dB. The noise figure level is slightly higher than previous result, which is 1.344 dB. This result still met the specification.

Fig.6. Final Optimization Result. Angka dan axis ditimpa dan diperjelas

3.5 LNA Board Design

After the final optimization, the LNA board was designed before entering the fabrication process. The dimension of the LNA board is 4.114 cm × 2.743 cm. the Fig. 7 shows the LNA board design in a software. That design was fabricated on a single layer FR-4 dielectric. The Fig. 8 shows the fabricated LNA board
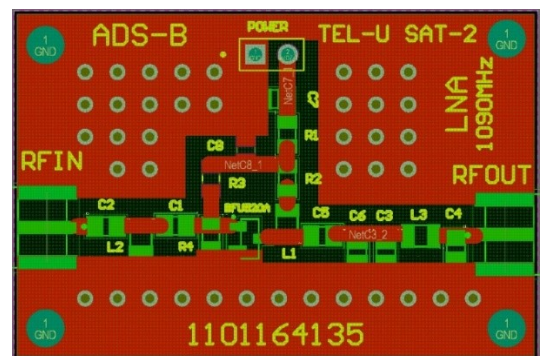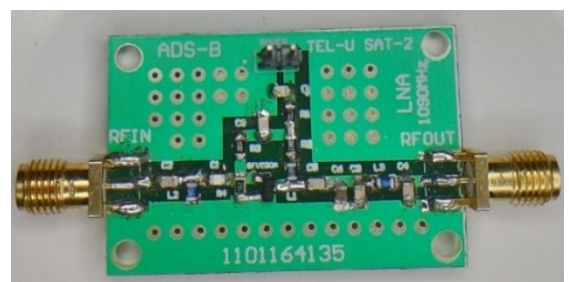

Fig. 7. PCB design

Fig. 8. Fabricated LNA board

A laboratory test has been conducted to verify the fabricated LNA performance. The first measurement showed that the LNA failed to amplify the input signal. To fix that problem, some modifications have been done by re-checking the solder paste on the board, increasing the resistance value in the DC block section from 3.9 KΩ to 7.8 KΩ, and removing the C3 capacitor. The result of this improvement is shown by Fig. 9 and the final LNA board is shown by Fig. 10.
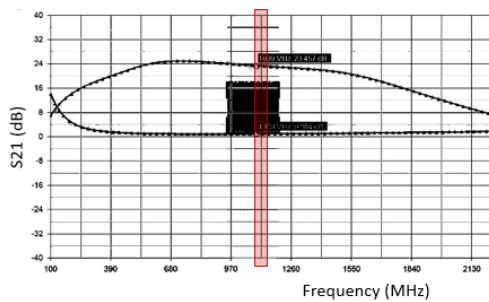
Fig. 9. LNA Fabricated Measurement Result

4. Evaluation and Analysis

4.1 Gain and Noise Figure

The LNA characterization through some tests has been conducted to observe the performance of fabricated LNA board. The first test has been conducted to check the LNA gain and bandwidth. Fig. 11 displays the LNA signal response in a spectrum analyzer. A -20 dBm signal was feed from the spectrum analyzer output port to the LNA. The output of LNA was connected back to the spectrum analyzer input port. The LNA output power level shown in the spectrum analyzer is -9.8 dB, which means the LNA has successfully amplify the input signal about 12.7dB. The gain performance is about 10 dB lower than the simulation result. Some losses are suspected due to the loss of passive components used in this board. Cable attenuation contributes to about 2.5 dB loss, while the LNA printed board seems gives the rest of the system loss. The bandwidth of this LNA is 52 MHz, narrower than the simulation result, yet it is sufficient to receive ADS-B signal.
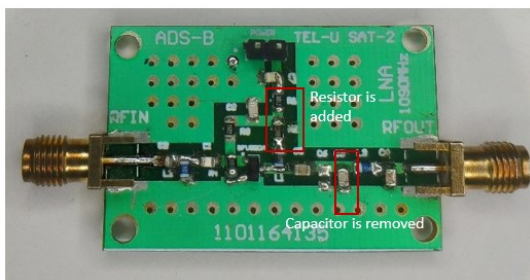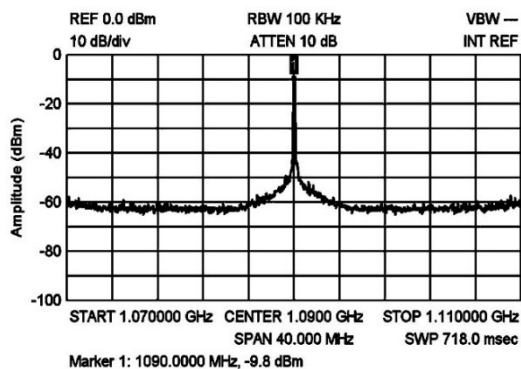

Fig. 10. Optimization of LNA Board

Fig. 11. Gain measurement result

Noise figure of this LNA design has been obtained from calculation by generated noise level data from computer simulation. The noise figure result is 0.98 which meet the LNA specification. The laboratory measurement to validate the fabricated LNA noise figure could not be conducted due to the absence of Noise Figure Analyzer tool.

4.2 Aircraft Detection Test

A real aircraft detection test has been conducted to observe the LNA performance when it is connected to the other ADS-B receiver components such as antenna and ADS-B receiver. This test took place on the top of 3-floor building. It was conducted at noon when the weather is clear. The test setup is from Ref. [5] and the result is compared that work. The result is the ADS-B receiver equipped with this LNA has successfully detected 13 airplanes and the longer aircraft is detected at 358.16 km. Compared with the [5] work, ADS-B receiver performance experiences 93% improvement on the detection range. The Fig. 12 shows the real-time aircraft detection using ADS-B receiver which is equipped with this LNA.
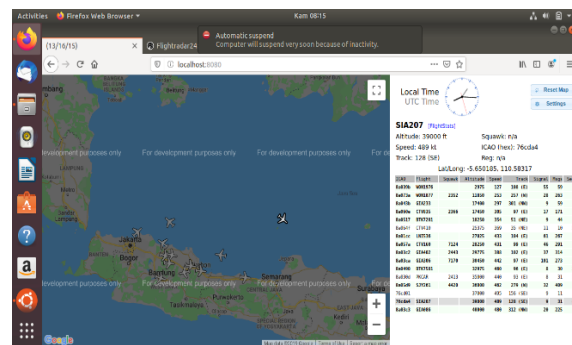

Fig. 12. Aircraft detection result

4.3 Overall LNA Analysis

The LNA performance which is simulated in a software is compared with the result of laboratory measurement. Table 4 shows the comparison result. The fabricated gain result is 12.7 dB which is 1.6 dB higher than simulation result. Meanwhile, both simulation and measurement noise figure result is the same.

Table 4. LNA Simulation and Fabricated Result Comparison

Parameter	Simulation	Measurement
Frequency	1090MHz	1090MHz
Gain	11.1 dB	12.7 dB
Noise Figure	0.98 dB	0.98 dB

5. Conclusions

The LNA for ADS-B receiver has been successfully designed and tested with small dimension which is fit into the nanosatellite form factor. It successfully amplifies the signal at the 1090 MHz.

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This LNA has been integrated with ADS-B receiver and it improves the ADS-B detection range. An improvement is needed especially for the fabricated board so its performance can be matched with the simulation result.

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Biography

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