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RESEARCH ARTICLE

High Gain Cascaded Two-Stage Low Noise Amplifier Design Using T-Matching Stub Resonator

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Abstract

The capability improvement of a telecommunications device influences the performance aspect of the device. In order to access the signal source, repeaters are required to reach signal to subscribers or improvements to the user's device itself that are able to reach signals that are far away. One of the telecommunications devices on the user side includes a low noise amplifier (LNA) which is useful for strengthening the signals and reducing the noise level received. This equipment supports to stay within reach of small signals received by users in areas with less signal. In this research, LNA is discussed specifically, especially increasing LNA gain and impedance matching methods through resonator modification. The LNA is designed using a two-stage cascading method which has high gain and low reflection factor. The simulation results show that the proposed LNA design succeeded in obtaining a gain of 31.6 dB where the stability and noise figure values obtained 3.79 dB and I.87 dB respectively. The T-Matching stub method used to adjust input and output impedance also succeeded in having a low reflection coefficient. At a frequency of 1575 MHz, the input and output reflection coefficients were obtained -70.5 dB and 56.2 dB. LNA design is divided into three steps, such as LNA bias design, single-stage LNA and cascaded connected two-stage LNA. The simulation results show that the LNA design meets the agreement with the desired target specifications.

Keywords: LNA, t-matching, stub, cascaded, two-stage

1. Introduction

Technology in the field of communication and information is developing systematically, starting from the development of software to hardware. This development is based on the ability of the technology itself to be able to answer the challenges of the times. For example, the challenge of mobile cellular devices, which are getting smaller in size but have complete features. With the increase in system performance, there are parts that are modified and developed according to the desired goals. In wireless technology devices, connectivity between the sending and receiving devices is the main challenge. To be able to connect to each other, the transceiver device needs to pay attention to the quality of power and noise. Noise can interfere with the transmission process, where the power received at the receiver becomes low. The solution to this challenge can be overcome, one of which is by using a low noise amplifier (LNA) [1][2].

LNA is an electronic device that functions to amplify low-power signals without degrading the received signal to noise ratio value [3]. In several studies, this tool has been developed with specific goals, including increasing gain, reducing noise figure (NF), low-power LNA, multiband LNA, and others. The increase in gain can be obtained, for example, by using the inter-stage network method on a common source transistor, where the gain value achieved is 32.5 dB [4]. Research [5] focuses on the design of LNA with low NF using 22-30-GHz gallium nitride. The research produced an NF of 0.4 dB – 1.1 dB.

This research focuses on increasing LNA gain by using the two-stage cascaded LNA method. For impedance matching, this research uses a T-shaped stub located on the input and output sides. The transistor used is the FET NE3509M04 type with a dominant operating frequency at the L-Band frequency. Specifically, the frequency used operates at a frequency of 1575 MHz which is the Global Positioning System (GPS) frequency [6]. In previous research, the author has designed an LNA that is integrated with an antenna in GPS applications. The research used the cascode method with a gain value of 28.4 dBi [7]. For this reason, this research is a development of previous research, from the cascode method to the cascaded method.

Impedance matching can be achieved in several ways. As done by [8] which analyzes impedance matching using the Pie-Network and T-network methods. The T-Network in the study has a reflection coefficient of -14.73 dB and a gain of 19.52 dB. The choice of resonator can also be by configuring dual-stub matching as done by [9]. Research [9] resulted in a gain of 30.87 dB and an NF of 1.18 dB.

The research simulation uses Advanced Design System (ADS) with an operating frequency in the L-Band area. The results of one-level and two-level simulations will be compared at the analysis stage to see changes in gain values. Apart from the gain value, the parameters analyzed include the input reflection coefficient, output reflection coefficient, stability, and NF. The components designed on the LNA stand on an FR4 substrate which has a dielectric constant of 4.4 with a thickness of 1.6 mm [10], [11].

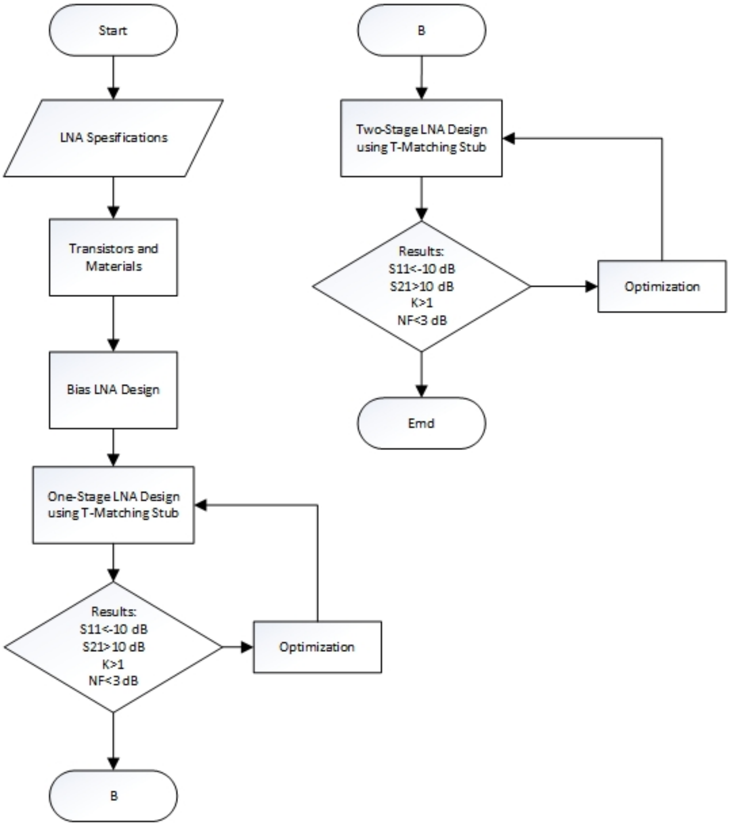

Figure 1. Flowchart

2. Research Methods

LNA design is carried out in the form of modeling and simulation on ADS software. The initial stage of design is to determine the LNA specifications in the form of operating frequency, target achievement of results parameters and material determination. The LNA model design is divided into three stages, including LNA bias design, single-stage LNA design and two-stage cascaded LNA design. Each model must achieve minimum results on LNA parameters such as gain, NF, reflection coefficient and stability. If the simulation results are not appropriate, optimization can be carried out on each LNA component, especially on the stub section which affects impedance matching. The complete research flow can be seen in Figure 1.

2.1 LNA Specifications and Materials

The subsection text goes here. This research aims to analyze a T-shaped stub resonator which has high gain. Specifically, the desired operating frequency is at a frequency of 1575 MHz which is the frequency band for GPS applications [12]. Based on these operating frequency specifications, the NE3509M04 transistor is very suitable to be applied in this research because it can operate at L-Band frequencies, has low noise and is capable of producing high gain [13]. Complete LNA specifications and materials can be seen in Table 1.

Table 1. LNA SPECIFICATIONS

No	Parameter	Value
1	Operation Frequency	1575 MHz
2	Reflection coefficient	< -10 dB
3	Gain	> 10 dB
4	Stability	> 1
5	Noise Figure	< 3 dB
6	Dielectric Constant of Substrate	4,4
7	Substrate Thickness	1,6 mm

2.2 LNA Design

The LNA design consists of 3 parts, as shown by the block diagram in Figure 2. The first step is to design the bias of the NE3509M04 transistor to find out the stability value (K) in the circuit. The LNA bias circuit is the basic circuit before being combined with the resonator on the input and output sides. If the bias stability value is above 1, then the system is considered stable.

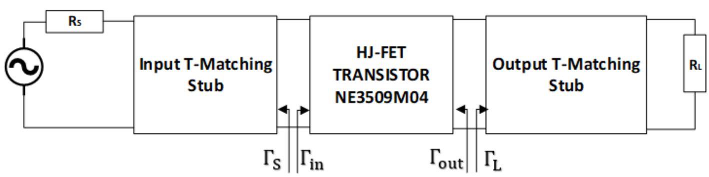

Figure 2. LNA Block Diagram

The proposed LNA bias design in this research can be seen in Figure 3. The values in the bias circuit are taken from the transistor data sheet table [13], where the V_{DS} value is known to be 2 V while ID = 10 mA. At a frequency of 1575 MHz, the S-Parameter table values (S_{11}, S_{21}, S_{12}, S_{22}) are known to be 0.876 ∠ -45.7°, 6.189 ∠ 136°, 0.057 ∠ 64.3°, and 0.488 dB ∠ -31°.

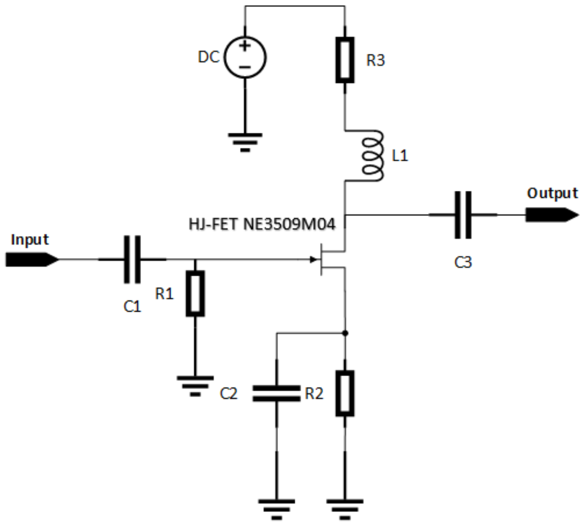

Figure 3. LNA Bias

From the S-Parameter table value, the K value can be known by (1)[14].

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + \Delta^2}{2\,|S_{12}S_{21}|} \tag{1}$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| \tag{2}$$

The Voltage Standing Wave Ratio (VSWR) parameter is a parameter used to determine the impedance matching of the transmission line connected to the LNA. VSWR originates from the standing wave ratio (SWR) that occurs if the transmission line impedance does not match the load impedance. VSWR is a function of the reflection coefficient Γ , which describes the power reflected from the LNA. By using the reflection coefficient, VSWR is determined by (3)[15]:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{3}$$

Where the reflection coefficient is determined from the ratio between the input voltage and the reflected voltage and its relationship with the input impedance and load impedance can be seen from (4):

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{4}$$

To find the S_{11} (dB) value, it can be used:

$$S_{11}\,(dB) = 20log\,|\Gamma_{in}| \tag{5}$$

Where

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{6}$$

while the reflection coefficient at the output port S_{22} (dB) is determined by:

$$S_{22}\,(dB) = 20log\,|\Gamma_{out}| \tag{7}$$

Where

$$\Gamma_{out} = \frac{Z_{out} - Z_0}{Z_{out} + Z_0} \tag{8}$$

The parameter that also affects the LNA performance is the noise figure (NF), where NF is related to the signal power (S) and noise power (N) which is determined by the following equation:

$$NF = 10log\left(\frac{S_{in}/N_{in}}{S_{out}/N_{out}}\right) \tag{9}$$

3. Results and Discussion

The LNA design was carried out by simulating the design of a single-stage and two-stage LNA. The results compare the parameter values resulting from each level consisting of the input and output reflection coefficient values, gain, stability, and noise figure. The LNA modeling is also displayed where at each level there is a stub-shaped impedance matching like the letter T which is on the input and output sides.

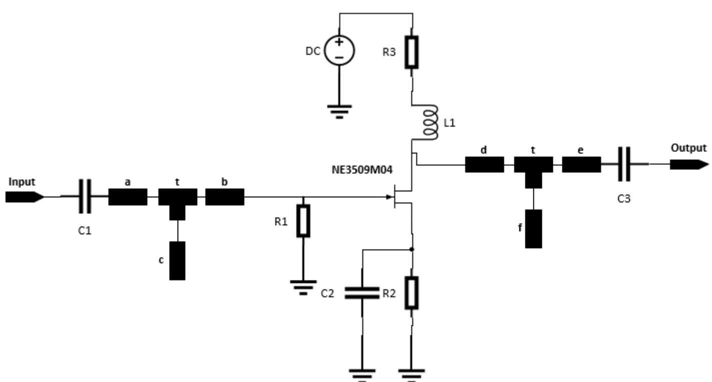

Figure 4. One-stage LNA Design

3.1 One-stage LNA Design Results

The design of a single-stage LNA can be seen in Figure 4. Figure 4 shows an LNA that uses one transistor and the input and output impedance uses a T-Matching model in the form of a stub. This T-Matching replaces the role of RLC where its dimensions can be adjusted flexibly but still apply symmetrical rules so that if printing is carried out the results remain the same.

The values of each component and the T-Matching LNA stub can be seen in table 2. These values are the result of iterations with the optimum target to be achieved seen in the gain parameters, input and output reflection coefficients, as well as stability and noise figure.

Table 2. ONE-STAGE LNA PARAMETER VALUES

Parameter	Value
a	1 mm x 1 mm
b	1 mm x 20,7 mm
c	1 mm x 14 mm
d	1 mm x 10,7 mm
e	1 mm x 1 mm
f	1 mm x 2 mm
t	1 mm x 1 mm x 1 mm
R1	270 Ohm
R2	51 Ohm
R3	220 Ohm
C1	10 pF
C2	1 nF
C3	10 pF
L1	1 nH

Figure 5 shows the simulation results of the input and output reflection coefficient values of a single-stage LNA. From the picture it is shown that the input and output impedance have achieved optimal results where at a frequency of 1575 MHZ the S11 and S22 values obtained are -14.6 dB and -18.2 dB respectively. These results indicate that the single-stage LNA has a good reflection factor from the input and output sides. The gain value can be seen from the S21 parameter where this single-stage LNA produces a gain of 15.7 dB.

Figure 6 is the simulation result of the NF and stability of a single-stage LNA. In the stability parameter, the value generated is 1.48. While the NF value it has is 2.99 dB. This NF value is already below 3 dB, so it can be said that these two parameters are in accordance with the design target. These results can be further optimized through the iteration process, but with the existing results it is considered sufficient to proceed to the two-level design.

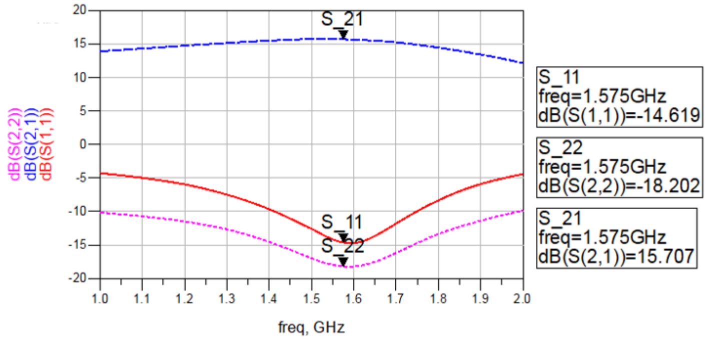

Figure 5. Simulation results of S_{11}, S_{21}, and S_{22} Single Stage LNA

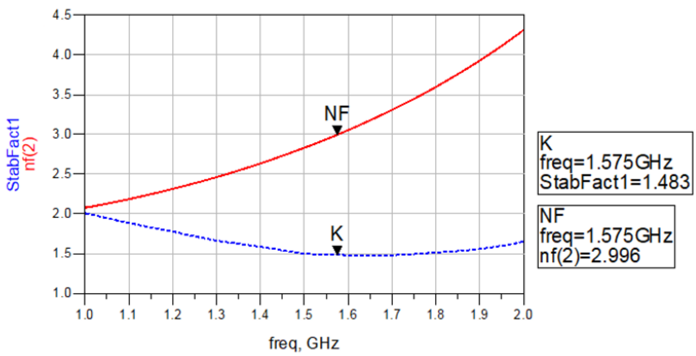

Figure 6. Simulation results of NF and stability of One-Stage LNA

3.2 Cascaded Two-stage LNA Design Results

The next step is to design a two-stage LNA where the transistors are arranged in a cascaded manner with the aim of achieving greater gain. In general, the structure of this two-stage LNA is not much different from the single-stage LNA where impedance matching still uses a T-Matching stub. The geometry of the two-stage LNA can be seen in Figure 7.

The value of each parameter from the two-stage LNA geometry can be seen in table 2. The dimensions of the stub on both the input and output sides are different compared to the dimensions of the stub on one level. This is because the cascaded LNA structure and the addition of several RLC components affect a number of parameters so that a re-optimization process is needed.

The optimization process on the T-Matching stub has a major influence on the reflection coefficient value as shown in Figure 8. In Figure 8, the reflection coefficients S_{11} and S_{22} appear quite deep with values of -70.51 dB and -56.23 dB respectively at a frequency of 1575 MHz. From the gain side, it can be seen that the two-stage LNA simulation obtained 31.6 dB. This value has more than doubled from the gain value of a single-stage LNA.

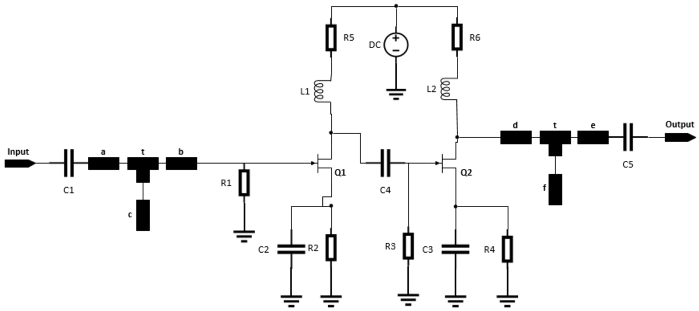

Figure 7. Two-stage LNA Design

Table 3. TWO-STAGE LNA PARAMETER VALUES

Parameter	Value	Parameter	Value
a	1 mm x 2,8 mm	R4	51 Ohm
b	1 mm x 11,5 mm	R5	51 Ohm
c	1 mm x 18,3 mm	R6	51 Ohm
d	1 mm x 9,7 mm	C1	10 pF
e	1 mm x 12 mm	C2	1 nF
f	1 mm x 10 mm	C3	1 nF
t	1 mm x 1 mm x 1 mm	C4	10 pF
R1	475 Ohm	C5	10 pF
R2	51 Ohm	L1	47 nH
R3	475 Ohm	L2	47 nH

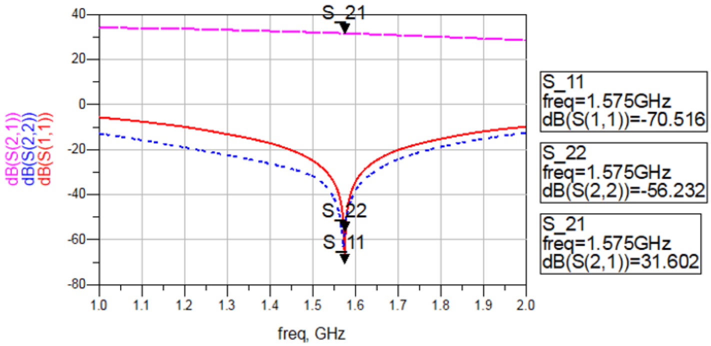

Figure 8. Simulation results of S_{11}, S_{21}, and S_{22} Two-Stage LNA

Figure 9 shows the simulation results of the stability value and noise figure. The stability of this two-stage LNA gains 3.79 while its NF value has 1.87 dB. These results are in accordance with the desired specifications.

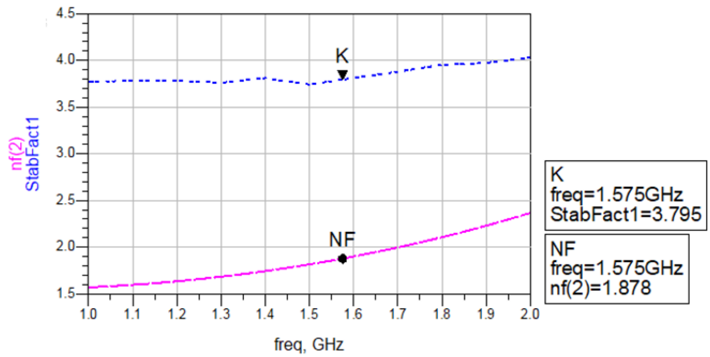

Figure 9. Simulation results of NF and stability of Two-Stage LNA

A comparison of the simulation results of the two LNA designs can be seen in Table 4. The simulation results show that the LNA parameters are in accordance with the desired target specifications. The T-Matching method has produced suitable conditions which can be seen from the input and output reflection factors of the LNA, where the values are already well below – 10 dB. In the single-stage LNA design, the reflection coefficient value can be improved through an iteration process by making several changes to the stub values on the input and output sides. However, in the process, this change has a major influence on the NF value which can cause it to increase. So that accuracy is needed in carrying out optimization to achieve results like the desired target.

In the design of a two-stage LNA, several variables also influence each other's parameter results. The RC component in the middle of the transistor can make a significant difference in results. Therefore, the installation of transistors in a cascaded manner has been proven to increase LNA gain. Variable optimization also has a good effect on the NF value. This can be proven by the NF value of the two-level design being better than the one-level design. Comparison of study results with previous research can be seen in table 4.

Table 4. COMPARISON WITH OTHER RESEARCH

			Parameters		
Ref	**Methods**	**Frequency**	**NF (dB)**	**Stability**	**Gain (dB)**
[12]	T-Junction	3 GHz	1.449	1.117	14.64
[14]	Two-Stage LNA and single stub	2.45 GHz	1.258	1.0004	30.06
This Work	Cascaded Two-Stage LNA and T-Stub Resonator	1.575 GHz	1.878 dB	3.79	31.6

4. Conclusion

The design of a low noise amplifier has been carried out where the system is made in stages with the design of a single-stage LNA then developed into two stages. LNA is designed using a T-shaped stub resonator (T-Matching). T-Matching is proven to produce suitable impedance both from the input and output sides of the LNA at a frequency of 1575 MHz. The two-stage LNA obtained a high gain of 31.6 dB, increased by 15.9 dB from the single stage. In addition, this LNA has achieved unconditionally stable where the K value obtained is 3.79, so the transistor used is difficult to oscillate. The resulting NF value is also as expected, where the value is below 3 dB. These results indicate that the design of a two-stage LNA has been proven to produce high gain and the T-Matching stub has worked as a suitable impedance resonator.

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