
Design and Implementation of Low Noise Amplifier Using ATF54143 Transistor with Lumped-Element Impedance Matching for C-band Satellite Receiver**Hnin Yu Wai¹, Pa Pa Winn San²**powerlay@gmail.com¹, papawinsan.1@gmail.com²^{1,2} Department of Electronic Engineering, Technological University (Mandalay), Myanmar

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Abstract

The increasing demand for high performance C-band receiver front-ends requires Low Noise Amplifiers (LNAs) with high gain, low noise figure, and effective impedance matching. This paper presents the design, simulation and verification of a single-stage 4 GHz LNA using the ATF-54143 field-effect transistor (FET) in Advanced Design System (ADS) software. The input and output matching networks are designed using both the graphical Smith Chart and ADS Smith Chart Utility Auto Matching methods to achieve 50 Ω impedance matching. The optimized LNA achieves a forward gain (S_{21}) of 14.87 dB, a noise figure of 1.48 dB, an input return loss (S_{11}) of -37 dB, and an output return loss (S_{22}) of -44 dB at 4 GHz. These results demonstrate that the proposed LNA provides high gain, low noise, and good impedance matching, making it suitable for C-band receiver front-end applications.

A. Introduction

The rapid development of wireless communication systems has increased the demand for high-performance receiver front-end circuits capable of detecting weak microwave signals with high sensitivity. C-band systems operating around 4 GHz are widely used in satellite communication, radar, and wireless applications, where receiver sensitivity is strongly influenced by the performance of the Low Noise Amplifier (LNA). As the first active component in the receiver chain, the LNA must provide high gain, low noise figure, good impedance matching, and stable operation to preserve signal quality.

Several LNA designs have been reported to improve the performance of receiver front-end systems for different frequency applications. Su *et al.* [1] presented a Ka-band GaAs pHEMT LNA using an R-L-C feedback technique to enhance gain and stability at millimeter-wave frequencies. Zhang *et al.* [6] proposed a C-band LNA based on a GaAs pHEMT process, focusing on improving gain and noise performance for microwave applications. In addition, Wang *et al.* [8] investigated a high-gain LNA design for C-band satellite communication systems, demonstrating the importance of optimizing amplifier characteristics for receiver applications. These studies show that achieving high gain and low noise performance is possible; however, maintaining a balance between noise performance, gain, and impedance matching remains a significant challenge in LNA design.

Designing an LNA with these characteristics simultaneously is challenging because improving one parameter may negatively affect other performance parameters. Therefore, careful transistor selection and matching network design are essential to achieve balanced performance. The ATF-54143 field-effect transistor (FET) is selected in this study due to its low noise characteristics and high gain capability at microwave frequencies. Although previous studies have achieved considerable improvements in LNA performance, some designs require complex optimization techniques or focus mainly on individual parameters rather than achieving an overall optimized design with simple implementation.

This research presents the design and simulation of a single-stage 4 GHz C-band LNA using the ATF-54143 transistor in Advanced Design System (ADS) software. The proposed LNA is designed with input and output impedance matching networks using two approaches. The first approach employs the graphical Smith Chart method, while the second approach utilizes the ADS Auto Matching tool. The performance of the proposed LNA is evaluated based on gain, noise figure, and S-parameters. The main contribution of this work is the comparison and verification of lumped-element impedance matching network design techniques to achieve improved impedance matching while maintaining high gain and low noise performance for C-band receiver front-end applications.

B. Research Method

This research applies a simulation-based design methodology to develop a 4 GHz Low Noise Amplifier (LNA) for C-band receiver applications. The design process involves transistor selection, parameter extraction, s2p file and model creation, matching network design, circuit implementation, and performance evaluation using Advanced Design System (ADS).

B.1. LNA Specifications

The LNA is designed according to the following target specifications:

- Input Return Loss (S_{11}) < -10 dB
- Output Return Loss (S_{22}) < -10 dB
- Gain (S_{21}) > 10 dB
- Noise Figure < 2 dB
- Matching technique: Two-element LC Matching
- Matching Tools: Both Smith Chart and ADS software

The ATF-54143 low noise FET is selected as the active device because of its suitable gain and low noise performance at microwave frequencies. In the ADS environment, the transistor is represented by a two-port Touchstone (*.s2p) model containing S-parameters and noise parameters. These data are used for gain matching, noise optimization, and stability evaluation.

B.2. Stability Analysis and Maximum Available Gain (MAG) Calculation

The extracted transistor data were analyzed using microwave design equations to determine important parameters, including the Rollett stability factor (K), determinant (Δ), maximum available gain (MAG), and optimum source and load reflection coefficients. These calculations were used to establish the requirements for the input and output matching networks.

Stability analysis was conducted before circuit implementation because instability can cause unwanted oscillations and reduce receiver performance. The ATF-54143 transistor stability was evaluated using its S-parameters with $V_{DS} = 3V$ and $I_D = 60mA$ at 4 GHz. The device is considered unconditionally stable when $K > 1$. If stability requirements are not achieved, additional stabilization methods or matching network modifications must be introduced.

$$\Delta = S_{11}S_{22} - S_{12}S_{21} = 0.372 \angle -122.8^\circ \quad (1)$$

$$K = \frac{1 + |\Delta|^2 - |S_{22}|^2 - |S_{11}|^2}{2 \cdot |S_{12}| \cdot |S_{21}|} = 1.1 \text{ (Unconditionally Stable)} \quad (2)$$

The Maximum Available Gain (MAG) of the ATF-54143 transistor with $V_{DS} = 3V$ and $I_D = 60mA$ at 4 GHz is calculated by using equations 3 and 4.

$$B_1 = |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 + 1 = 1.236 \quad (3)$$

$$MAG = 10 \log \left| \frac{S_{21}}{S_{12}} \right| + 10 \log \left| K \pm \sqrt{K^2 - 1} \right| = 14.44 \text{ dB} \quad (4)$$

The opposite sign of B_1 is used in ($\pm$) to get the MAG.

B.3. Input and Output Impedance Matching Design

Impedance matching network design is implemented using two techniques. The first technique will employ the theoretical and graphical Smith Chart method. The second technique will utilize the Auto Matching tool available in ADS.

Firstly and theoretically as the graphical Smith Chart method, equations 5 to 8 are used to find the load and source reflection coefficients for input and output impedance matching.

$$C_2 = S_{22} - \Delta S_{11}^* = 0.208 \angle -105.6^\circ \quad (5)$$

$$B_2 = |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 + 1 = 0.487 \quad (6)$$

$$|\gamma_L| = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2|C_2|} = 0.562 \angle 105.6^\circ \quad (7)$$

The angle of γ_L is simply equal to opposite sign of the angle of C_2 .

$$\gamma_s = [S_{11} + \frac{S_{12}S_{21}\gamma_L}{1 - (\gamma_L \cdot S_{22})}]^* = 0.812 \angle -140.3^\circ \quad (8)$$

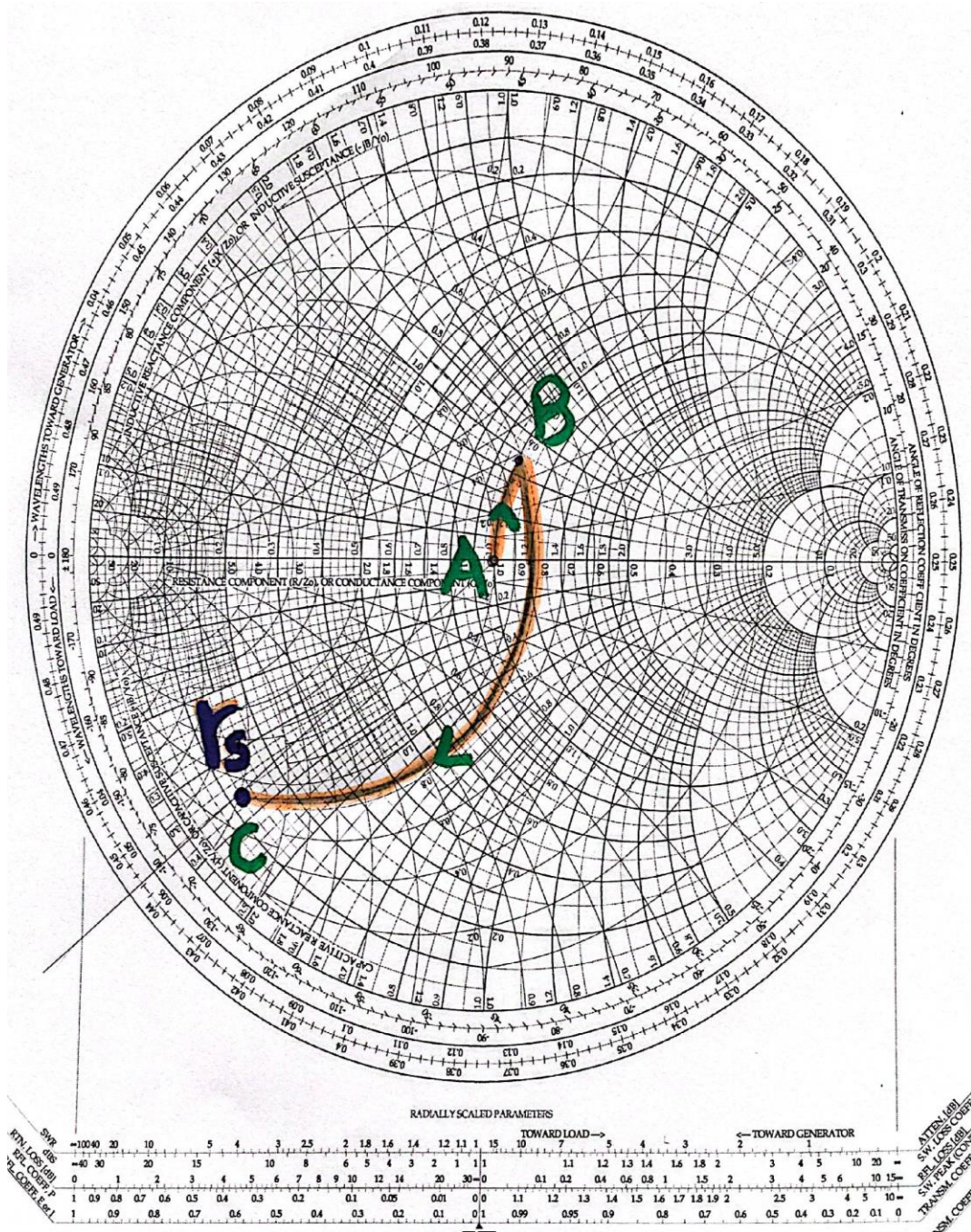


Figure 1. Input Matching Network Design With Smith Chart

After calculating load reflection coefficient (γ_L) and source reflection coefficient (γ_s), firstly, the input and output matching are designed by using two-element matching networks with the aid of graphical Smith Chart. After plotting γ_L and γ_s on the Smith Chart, series and shunt lumped-elements (inductor and capacitor) are added on the Smith Chart as desired.

For the input matching network, series-L and shunt-C elements are added on the Smith Chart (Figure 1). The inductor and capacitor values are calculated by using equations 9 and 10.

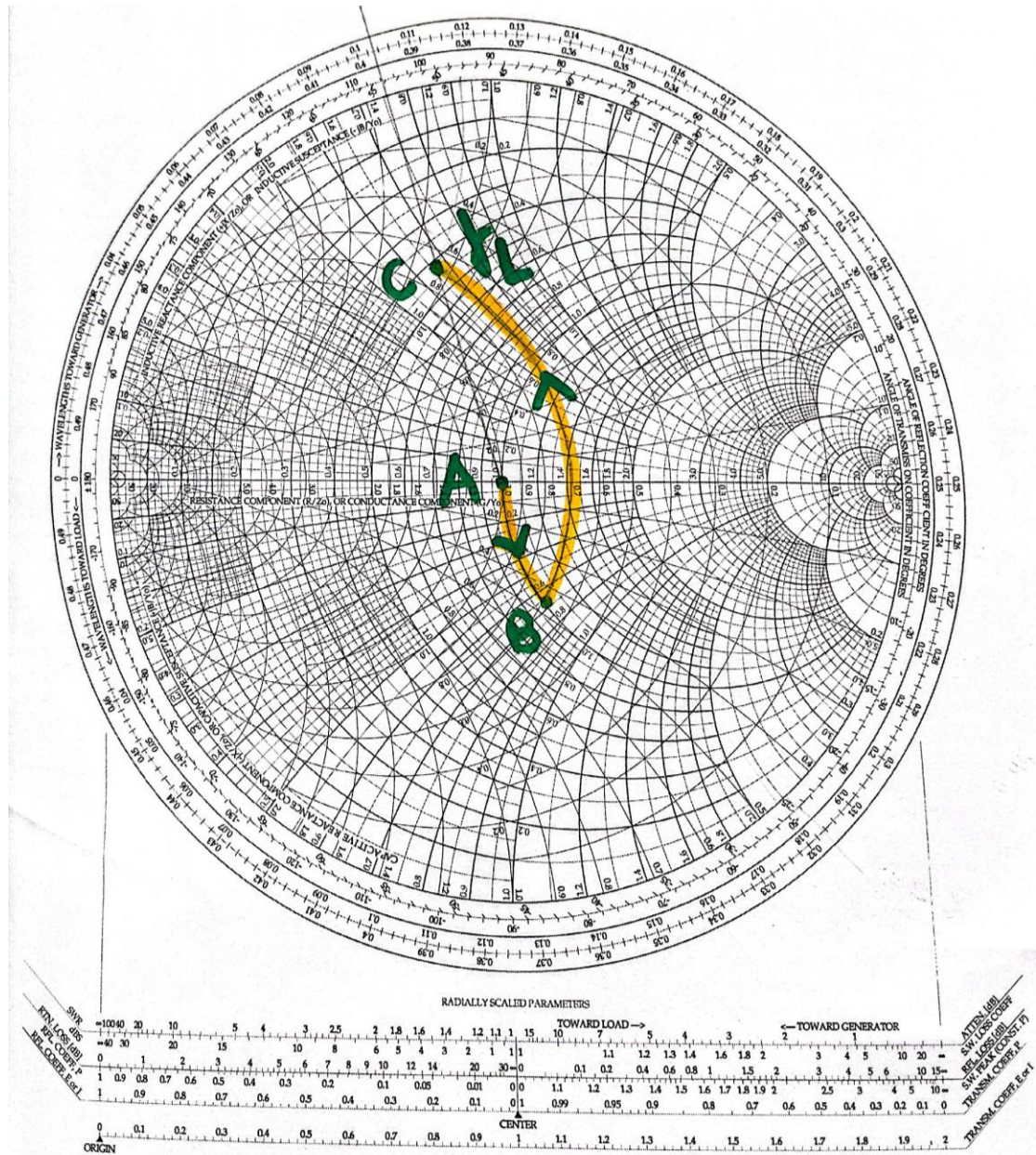


Figure 2. Output Matching Network Design with Smith Chart

For a series-L element, $L = \frac{XN}{\omega} = 895 \text{ pH}$ (9)

$$\text{For a shunt-C element, } C = \frac{B}{\omega N} = 2.4 \text{ pF} \quad (10)$$

Where,

$$\text{Arc AB} = \text{Series L} = +jX = 0.45 \text{ ohm}$$

$$\text{Arc BC} = \text{Shunt C} = +jB = 3 \text{ mhos}$$

The output matching network is designed by adding series-C and shunt-L elements on the Smith Chart (Figure 2). The required inductor and capacitor values are calculated by using equations 11 and 12.

$$\text{For a series-C element, } C = \frac{1}{\omega XN} = 1.17 \text{ pF} \quad (11)$$

$$\text{For a shunt-L element, } L = \frac{N}{\omega B} = 1.28 \text{ nH} \quad (12)$$

Where,

$$\text{Arc AB} = \text{Series C} = -jX = 0.68 \text{ ohm}$$

$$\text{Arc BC} = \text{Shunt L} = -jB = 1.55 \text{ mho}$$

B.4. Impedance Matching Circuit Verification with ADS Software

The impedance matching design networks are further verified by using the ADS Smith Chart Utility Auto 2-Element Matching Method. The Auto 2-Element input matching designs showing with Series-L and Shunt-C values are shown in Figure 3 and Figure 4. According to the result values, the series inductor value is 896 pH and the shunt capacitor value is 2.3 pF.

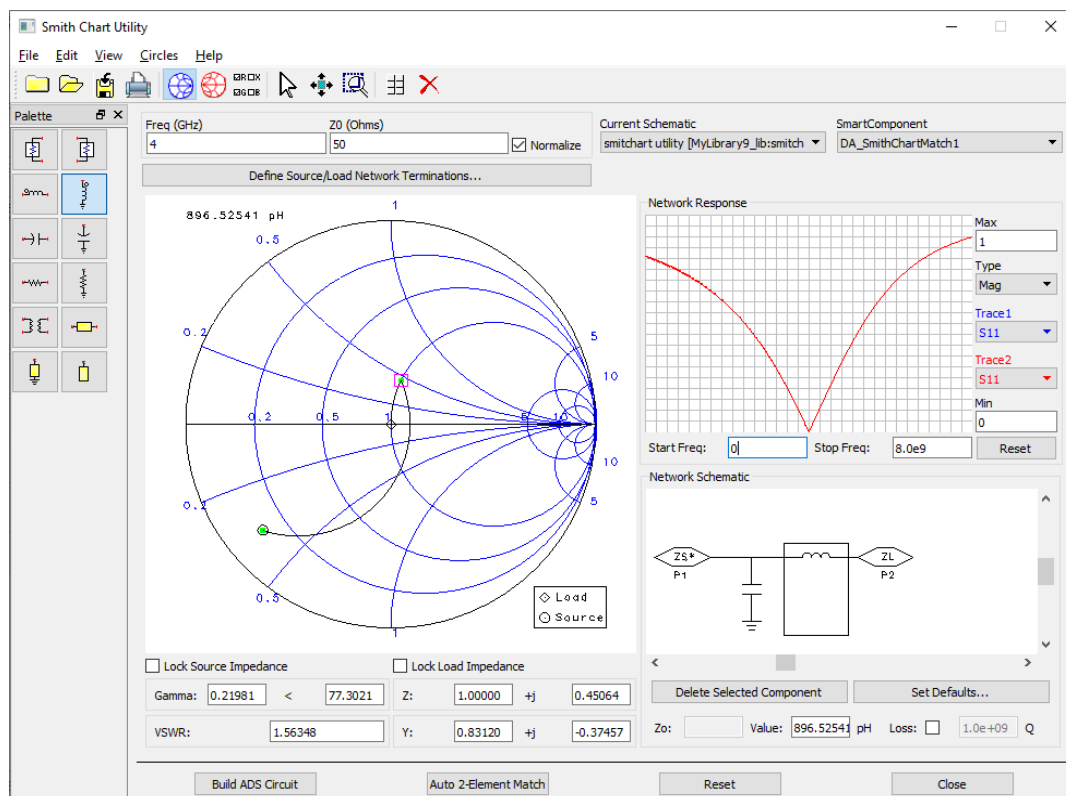


Figure 3. Auto 2-Element Input Matching Design Showing With Series-L Value

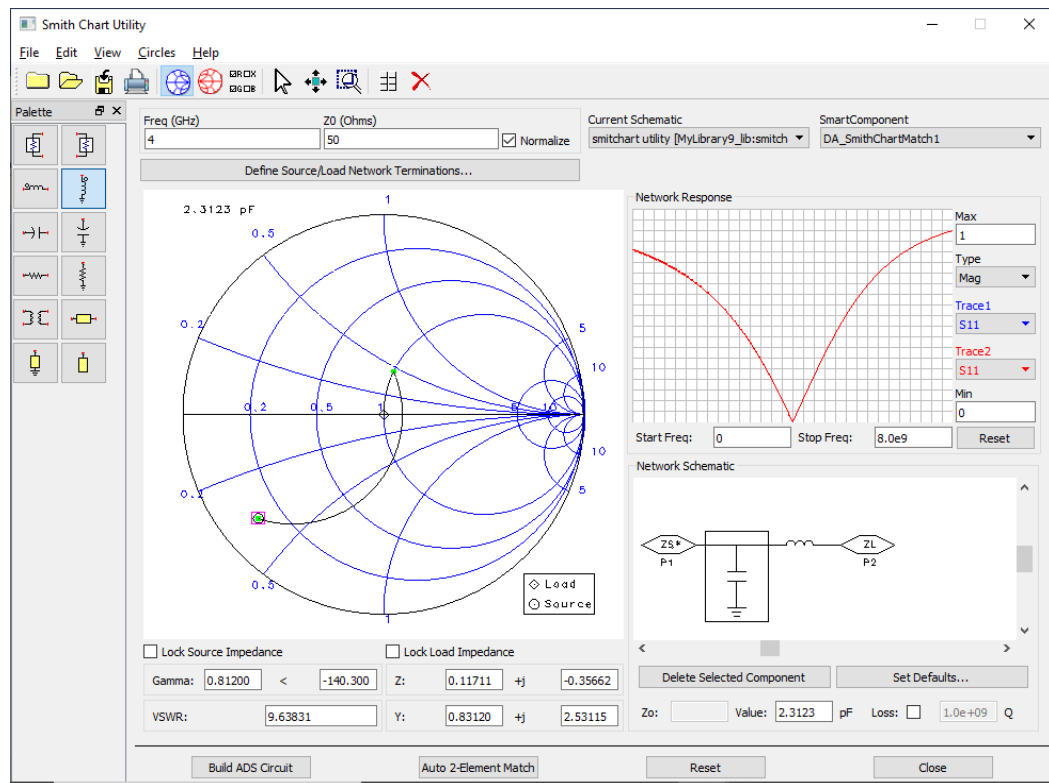


Figure 4. Auto 2-Element Input Matching Design Showing With Shunt-C Value

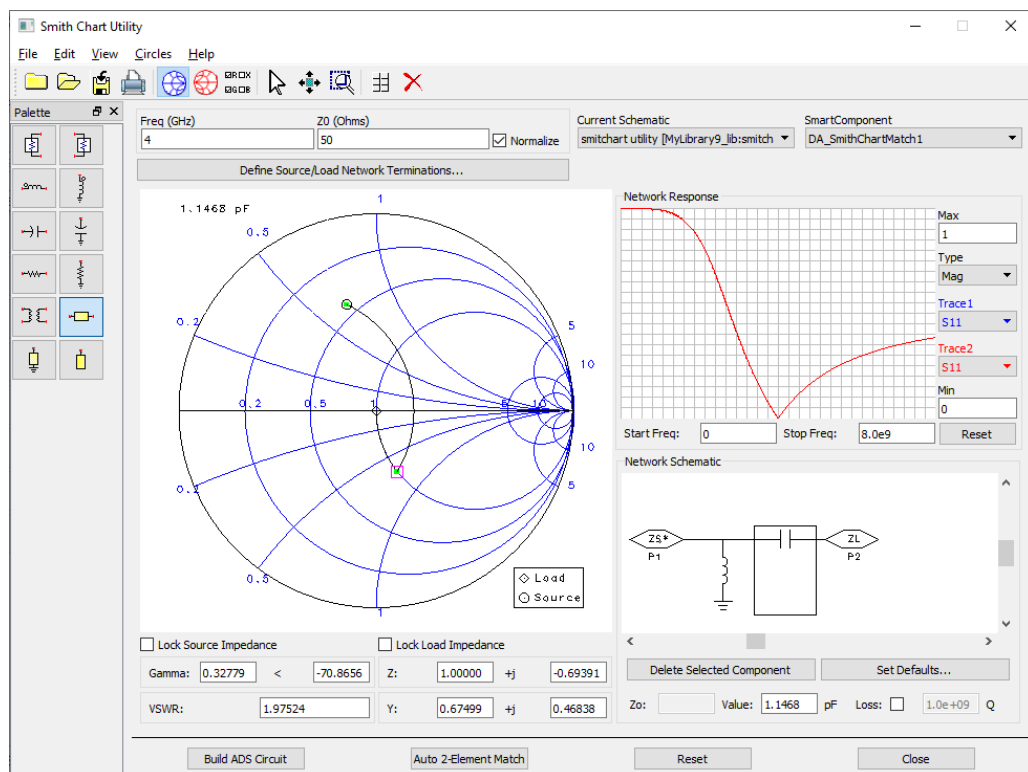


Figure 5. Auto 2-Element Output Matching Design With Series-C Value

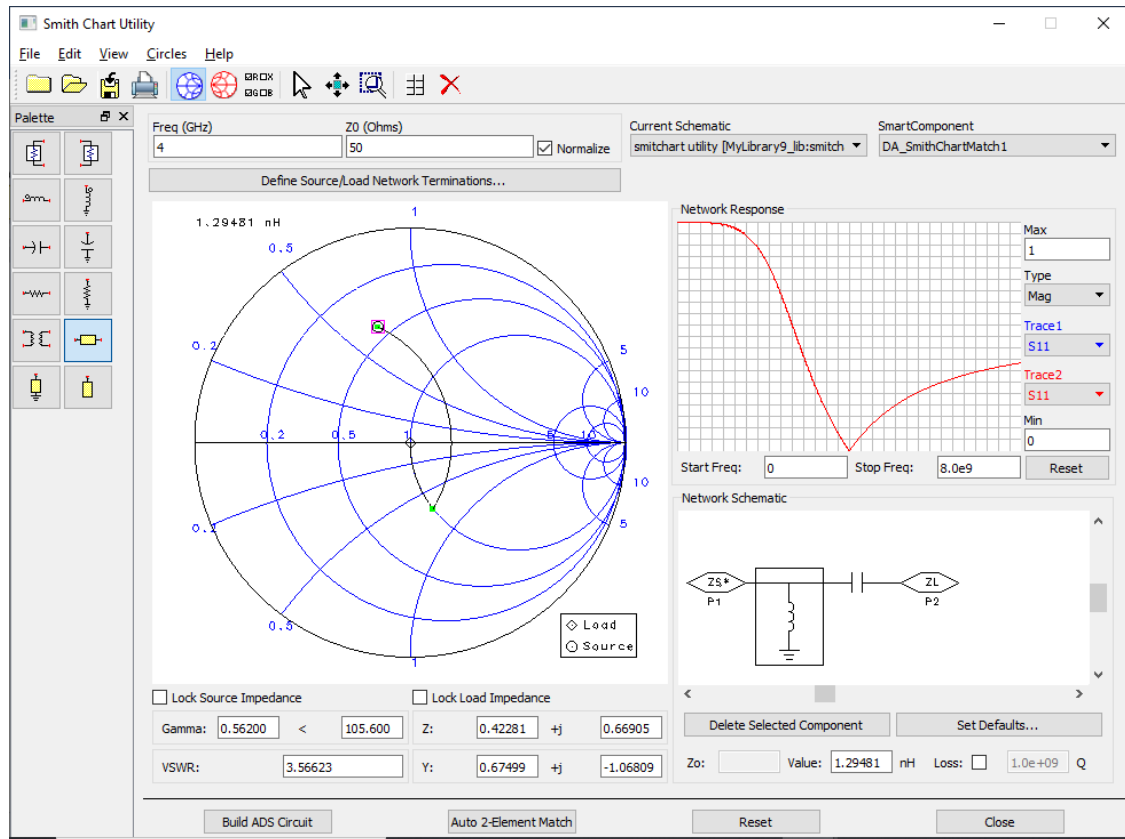


Figure 6. Auto 2-Element Output Matching Design With Shunt-L Value

The Auto 2-Element output matching designs showing with Series-C and Shunt-L values are shown in Figure 5 and Figure 6. According to the result values, the series capacitor value is 1.14 pF and the shunt inductor value is 1.29 nH. Therefore, it is verified that the simulated matching results agree with the theoretical design values. Comparison of Impedance Matching Lumped-Element Parameters are shown in Table 1.

Table 1. Comparison of Impedance Matching Lumped-Element Parameters

No.	Parameters	Theoretical	ADS Software
1	Series L (Input)	895 pH	896 pH
2	Shunt C (Input)	2.4 pF	2.3 pF
3	Series C (Output)	1.17 pF	1.14 pF
4	Shunt L (Output)	1.28 nH	1.29 nH

C. Result and Discussion

The results and discussion of the proposed LNA are presented in this section. Before the implementation of the input and output matching networks (Figure 7), the LNA exhibited poor input impedance matching. As shown in Figure 8, the simulated input return loss (S_{11}) was -4.152 dB, which did not meet the design requirement of $S_{11} < -10$ dB. The simulated forward gain (S_{21}) was 11.821 dB, as presented in Figure 9. In addition, the simulated minimum noise figure (NF_{min}) and the actual noise figure, $nf(2)$ were 0.721 dB and 0.917 dB, respectively, before

impedance matching, as shown in Figure 10. These results indicate that, although the unmatched LNA achieved acceptable gain and low noise performance, its input matching was insufficient to satisfy the design specification. Therefore, input and output matching networks were designed to improve the impedance matching while preserving the gain and noise performance.

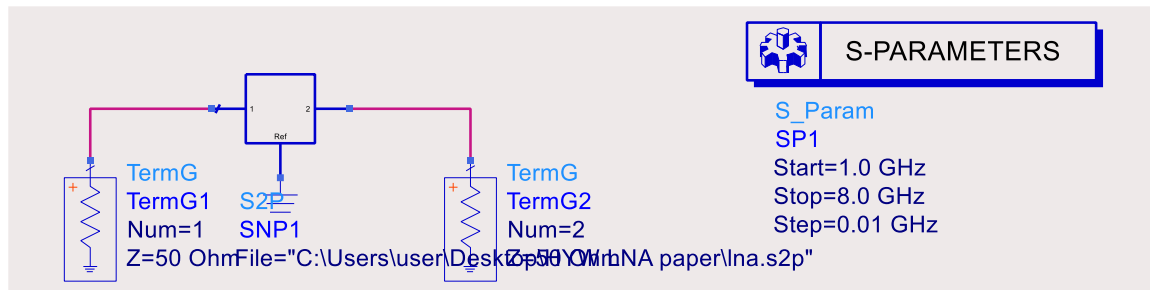


Figure 7. Schematic Diagram of LNA Before Impedance Matching

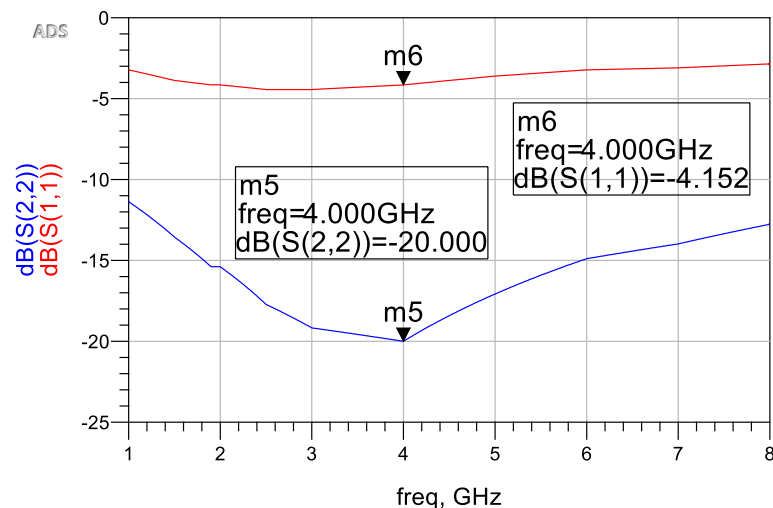


Figure 8. Simulated Results of S_{11} and S_{22} Before Impedance Matching

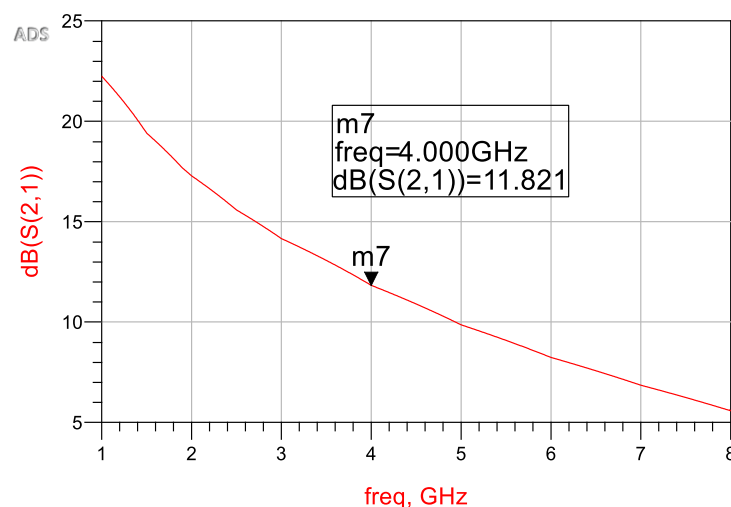


Figure 9. Simulated Result of Gain (S_{21}) Before Impedance Matching

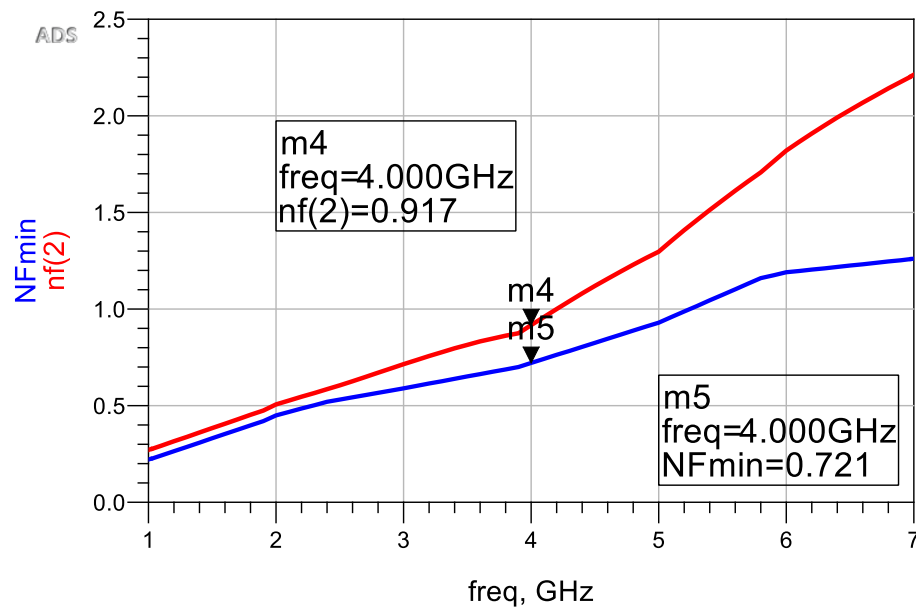


Figure 10. Simulated Results of NF_{min} and $nf(2)$ Before Impedance Matching

The simulated performance of the matched LNA will present in the following section to demonstrate the effectiveness of the proposed matching networks. The complete LNA circuit, including the input and output matching networks, was implemented in ADS software for simulation, as shown in Figure 11. The matching parameters obtained from the ADS Auto Matching tool were adopted as the design parameters for the LC matching networks.

After implementing the matching networks, the LNA performance was significantly improved. As shown in Figure 12, the simulated input and output return losses were $S_{11} = -37$ dB and $S_{22} = -44$ dB, respectively, indicating excellent impedance matching at both ports. In addition, the simulated forward gain (S_{21}) increased to 14.87 dB, as illustrated in Figure 13. Compared with the unmatched LNA, the gain improved by approximately 3.05 dB, while the input and output return losses were significantly enhanced, confirming the effectiveness of the proposed LC matching networks and demonstrating that the LNA satisfies the design requirements.

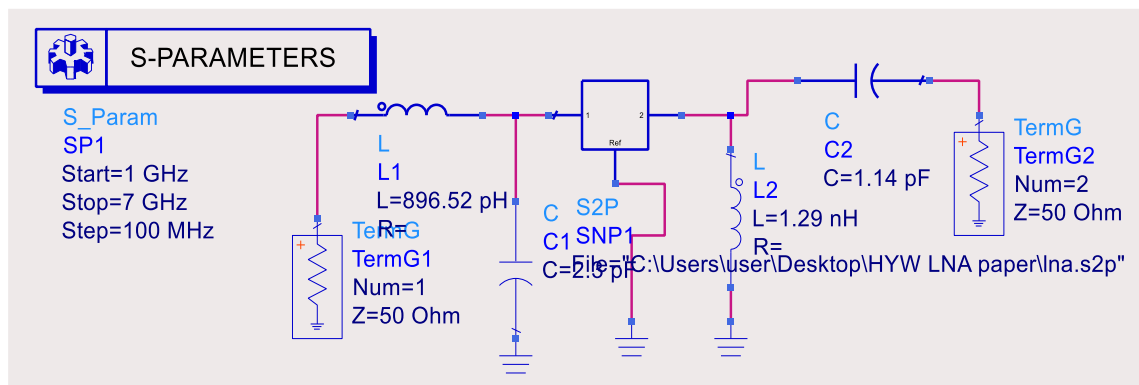


Figure 11. Schematic Diagram of LNA with Input and Output Matching Networks

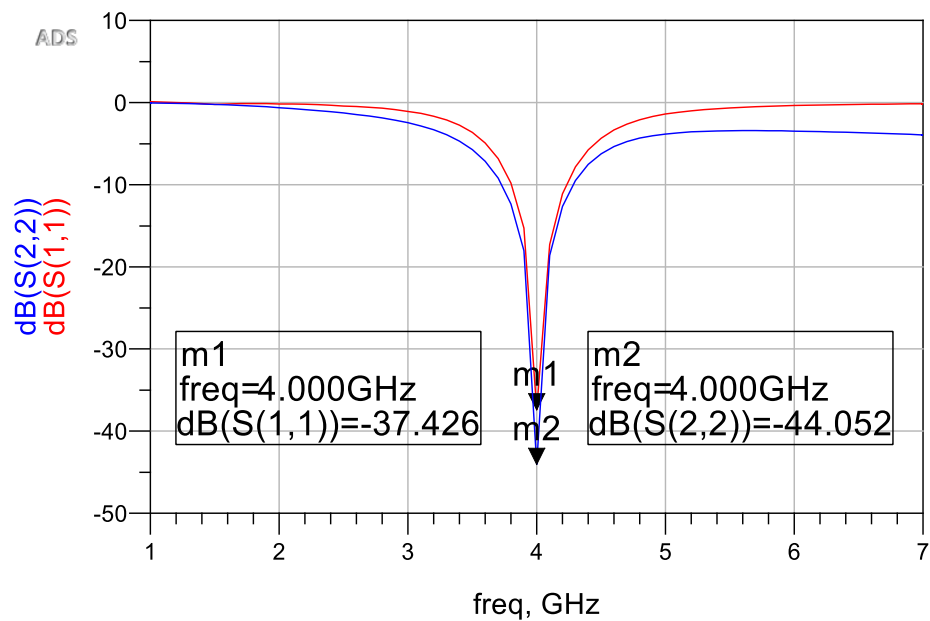


Figure 12. Simulated Results of S_{11} and S_{22} After Impedance Matching

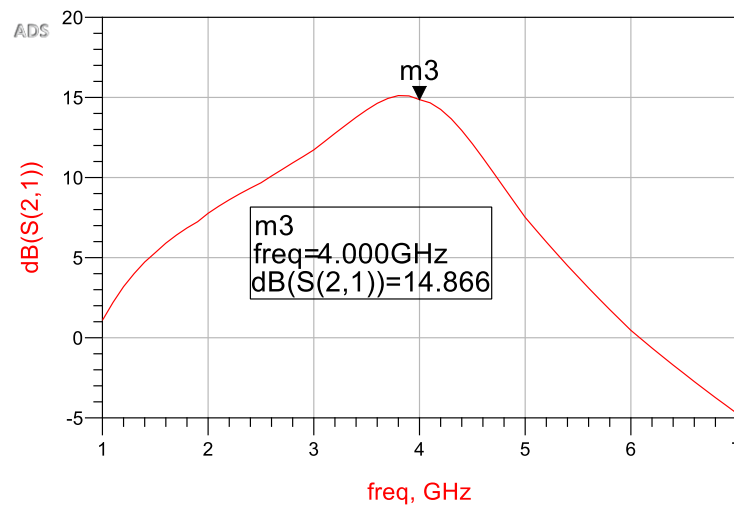


Figure 13. Simulated Result of LNA Gain (S_{21}) After Impedance Matching

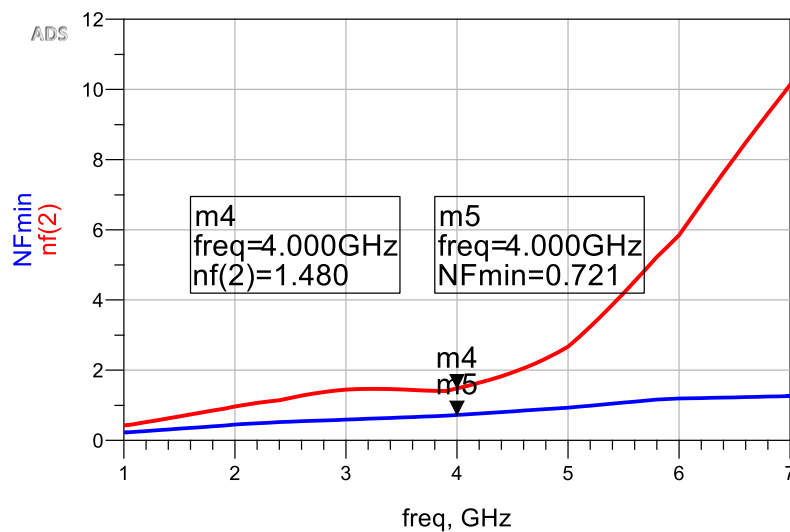


Figure 14. Simulated Result of Noise Figures After Impedance Matching

The implementation of the LC matching networks resulted in a slight increase in the simulated noise figure. As illustrated in Figure 14, the noise figure reached 1.48 dB, which is attributed to the inherent trade-off between noise optimization and impedance matching in RF amplifier design. Despite this increase, the simulated value remains within the target specification and is suitable for the intended application. To provide a clear evaluation of the matching network, the simulated performance of the LNA before and after impedance matching is summarized and compared in Table 2.

Table 2. Comparison of LNA Results Before and After Impedance Matching

No.	Parameters	<i>Desired Values</i>	<i>Before Impedance Matching</i>	<i>After Impedance Matching</i>
1	Input Return Loss, S_{11}	<-10 dB	-4.152 dB	-37 dB
2	Output Return Loss, S_{22}	< -10 dB	-20 dB	-44 dB
3	Gain, S_{21}	> 10 dB	11.821 dB	14.866 dB
4	Noise Figure, $nf(2)$	< 2 dB	0.917 dB	1.48 dB

D. Conclusion

This research presented the design of a 4 GHz Low Noise Amplifier (LNA) using the ATF-54143 transistor. The transistor S-parameters were extracted from the datasheet and converted into an S2P file for implementation in ADS. The input and output matching networks were designed using theoretical calculations, graphical Smith Chart techniques, and the ADS Smith Chart Utility.

The LNA achieved S_{11} and S_{22} values of -37 dB and -44 dB, respectively, with a gain of 14.87 dB at 4 GHz. Although the noise figure increased slightly to 1.48 dB, it remained within an acceptable range for LNA applications. These results demonstrate that the proposed design methodology provides effective impedance matching and improved amplifier performance for C-band receiver front-end applications.

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