Design of a Low-Noise Amplifier without Inductors for 2.4 GHz Applications

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Abstract
This project presents the design and simulation of a Low Noise Amplifier (LNA) optimized for operation at 2.4 GHz, a frequency widely used in wireless communication technologies such as Wi-Fi and Bluetooth. The amplifier operates with a 3V DC power supply, aiming for low power consumption while ensuring effective signal amplification. Simulation results indicate that the amplifier achieves a maximum gain of 3.512 dB at 2.4 GHz. Furthermore, the design exhibits a minimum noise figure of 1.509 dB, which helps maintain a high signal-to-noise ratio at the receiver's front end. The LNA design incorporates proper impedance matching and stability considerations to ensure consistent and reliable performance across the operating frequency. This makes it suitable for integration in sensitive RF front-end applications where low noise and moderate gain are essential.

Keywords RF Amplifier, Gain, Impedance Matching, GaAs, Pseudomorphic High Electron Mobility Transistor, Advance Design System, S parameter, Noise Margin.

I. Introduction

The Low Noise Amplifier (LNA) constitutes the principal component and represents the initial tier of the RF receiver, frequently employed in Wireless Communication systems. It is predominantly utilized for the enhancement of feeble signals captured by the receiver antenna. The LNA is characterized by a minimal level of internal noise, thereby contributing insignificantly to the overall system noise [1]-[2]. Given that the LNA serves as the critical segment of the RF front-end receiver, parameters such as low noise figure (NF) and high gain must be considered during the design process to ensure that the overall receiver NF remains low. Numerous applications of the LNA exist within the communication domain, including but not limited to wireless communications, astronomical observations, radar operations, and satellite communications, as well as telecommunications. Fundamental specifications of the LNA encompass Gain, Noise Figure, and Input/Output Return Loss. The representation of these specifications is facilitated through the utilization of S-Parameters of an amplifier. Additionally, other important design considerations for the LNA include linearity, stability, power dissipation, and bandwidth.

Many LNAs have been engineered for diverse applications within the 3G and 4G frequency spectrums; however, with recent advancements in wireless technology, the LNAs devised for the 4G frequency spectrum have nearly reached their operational limits, leaving only marginal opportunities for further enhancements. Presently, the anticipated quality of communication and the required data rates are escalating at an exponential rate. In the imminent future, LNAs designed for the 4G frequency spectrum are unlikely to satisfy these evolving demands.

Engineers are actively engaged in the development of various circuits and the enhancement of existing topologies to ensure that devices can function effectively within the frequency spectrum. Upon evaluating the performance of LNAs operating within the 0–2.5 GHz band across different technologies such as CMOS, SiGe, InP, GaAs p-HEMT, GaAs m-HEMT, GaN, etc., it has been

DOI: https://doi.org/10.5281/zenodo.15288887

determined that GaAs p-HEMT demonstrates superior performance [4]. Recent advancements in GaAs high electron mobility density have enabled GaAs p-HEMT to facilitate devices that exhibit commendable performance at elevated frequencies. In high-frequency circuits, GaAs is notably more efficient compared to silicon semiconductors, attributed to its expedited operational speed and reduced heat generation. Given that these advantages are particularly pronounced within the high-frequency domain, GaAs-based devices are predominantly favored for applications requiring high frequencies [8–10], particularly in the design of LNAs.

An in-depth analysis was carried out on various amplifier configurations, such as the Common Source Amplifier, Common Gate Amplifier, Inductive Source Degenerated Amplifier [12,13], and the Resistive Shunt Feedback Amplifier [14,15]. Among these, the Inductive Source Degenerated and Resistive Shunt Feedback designs demonstrated an optimal compromise between gain and noise performance, making them well-suited for the intended design application.

This manuscript is structured into five sections, with Section II providing a Literature Survey of the LNA design process, Section III presenting the design of the LNA, Section IV presenting results of simulations and discussions, and Section V culminating with the conclusion.

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II. Literature Survey

GSMA [1]

In this document, the authors elucidate the prospective advantages associated with the utilization of the 5G millimeter-wave spectrum and the frequency bands that are anticipated to be employed in India. According to GSMA, India is poised to derive significant benefits from the deployment of 25 GHz and 28 GHz millimeter-wave-enabled 5G frequency bands.

Lakshmi Balla, Venkata Krishna Sharma Gollakota, Sandhya Teku [2]

In this study, the authors conducted an exhaustive analysis of various low-noise amplifier (LNA) topologies employing high electron mobility transistor (HEMT) technologies over several decades. Their primary focus was on the comparative evaluation of noise figure (NF) and gain parameters across different topologies. Among the various configurations analyzed, the resistive feedback topology utilizing 0.15 µm E-mode GaAs pHEMT exhibited superior performance at the Ka band; however, its efficacy diminished at the L band, whereas the 0.15 µm GaAs pHEMT with a common source and inductor source degeneration topology yielded optimal results at the Q band.

Nur Syahadah Yusof [3]

A GaAs-based Low Noise Amplifier (LNA) designed for operation at 28 GHz is presented. The Fujitsu FHR02X was used as the active device for simulation. The LNA was configured with a common-source topology and included source inductive degeneration. The simulation results indicated a power gain of 9.185 dB, with input and output return losses of -13.124 dB and -15.455 dB, respectively. Additionally, the amplifier exhibited a noise figure of 9.185 dB.

Armagan Dascurcu and Yasar Gurbuz [4]

Introduce a wideband low-noise amplifier designed for the K-Ka band, using IHP Microelectronics' 0.13 µm SiGe HBT technology. The proposed LNA design achieves a 16 dB gain, ensures linear performance across the full band, and demonstrates a noise figure of 2.2 dB at 28 GHz.

Murod Kurbano et al. [5]

In this study, the authors designed a Low Noise Amplifier (LNA) utilizing a source inductive degeneration differential topology, operating at 24 GHz. The LNA was fabricated using TSMC's 130 nm RF CMOS technology and was biased with a 3V supply voltage. The amplifier was matched to an input impedance of 50 Ω. The simulation results for the single-stage LNA indicated a noise figure of 2.87 dB, a power gain of 18.37 dB, and a total power consumption of 7.82 mW.

DOI: https://doi.org/10.5281/zenodo.15288887

III. Design of LNA

In this research, a Low Noise Amplifier (LNA) is designed to operate within the 2.4 GHz frequency band. The design and simulation of the amplifier are carried out using the Advanced Design System (ADS), a powerful simulation tool equipped with a wide range of libraries. For this investigation, an active component from the S-parameter library is used, along with an S-parameter simulation controller to analyze the stability and relevant performance characteristics of the device. To assess the linearity of the amplifier, harmonic balance simulation techniques are employed.

The amplifier is designed using Gallium Arsenide Pseudomorphic High Electron Mobility Transistor technology to achieve a minimal noise figure. The core active component is the **ATF-21170**, a Pseudomorphic High Electron Mobility Transistor (p-HEMT) known for its ultra-low noise performance. This transistor is selected for its remarkably low noise resistance, which maintains a stable noise figure even when input impedance matching conditions vary. This contributes to the LNA's reliable performance. To ensure correct biasing and impedance matching at both input and output, passive elements like resistors and capacitors are incorporated into the design. The amplifier architecture Employs a blend of inductive source degeneration and resistive shunt feedback techniques, offering a well-balanced trade-off between noise reduction and gain enhancement.

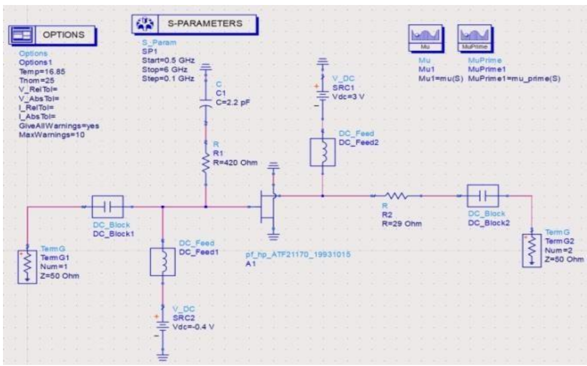

Figure1. Circuit Design of LNA

As shown in Figure 1, the input stage of the Low Noise Amplifier (LNA) is designed using a resistive shunt feedback configuration to effectively reduce the noise figure. The following stages implement an inductive source degeneration topology, which contributes to improving the amplifier's overall gain. The circuit operates with a supply voltage of 3V.

IV. Analysis of Result

The schematic of the proposed Low Noise Amplifier (LNA), illustrated in Fig. 1, was developed and examined using the Advanced Design System (ADS) simulation platform. A crucial part of the design validation involves assessing the circuit's stability. To ensure unconditional stability across the operating frequency range, the stability factor (K) must exceed unity (K > 1) and the determinant's magnitude (|Δ|) must remain below one (|Δ| < 1). These conditions confirm that the amplifier will not oscillate under any passive source or load termination.

Where:

$S11$ represents the input return loss, $S22$ indicates the output return loss, $S12$ corresponds to the reverse transmission (gain),

$S21$ denotes the forward transmission (gain).

The stability factor of the designed LNA is shown in **Figure. 2**. The results indicate that the amplifier operates reliably, with the stability factor being greater than 1.

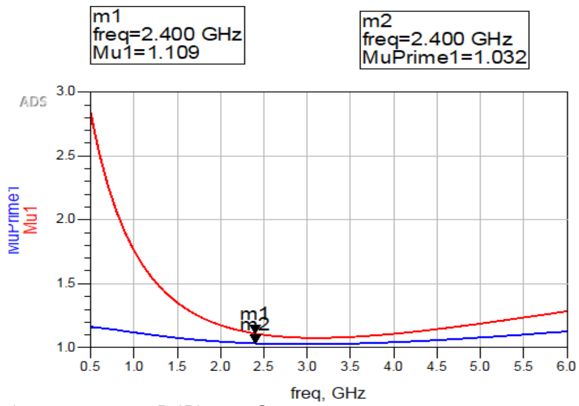

Figure2. Stability of LNA

Figure 2 shows the stability factor of the LNA. The results suggest that the designed system maintains linearity throughout its entire operating range.

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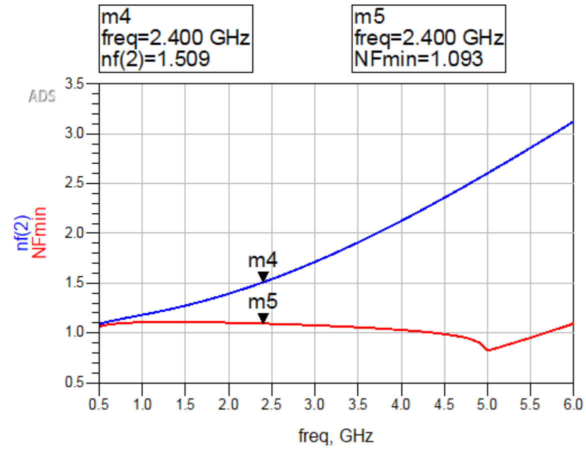

Figure 3. Noise figure of LNA

Figure 3 illustrates the simulation results for the noise figure of the final LNA design. The results demonstrate that the noise figure is optimized within the 2.4 GHz band, with values ranging from 1.467 dB to 1.64 dB, achieving a minimum of approximately 1.5 dB.

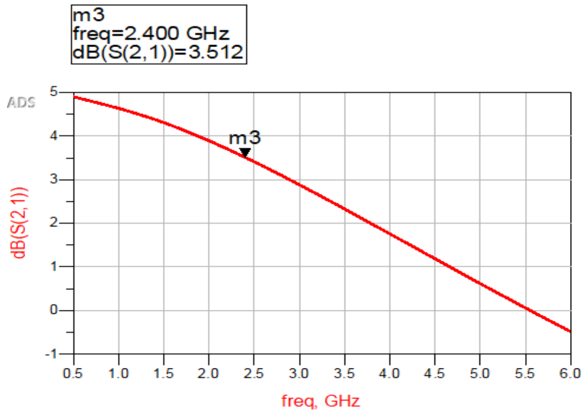

Figure 4. Gain of LNA

Figure 4 presents the simulation results for the forward gain (S_{21}**)** of the final LNA design. The gain is optimized, achieving a peak value of 3.512 dB within the 2.4 GHz frequency band.

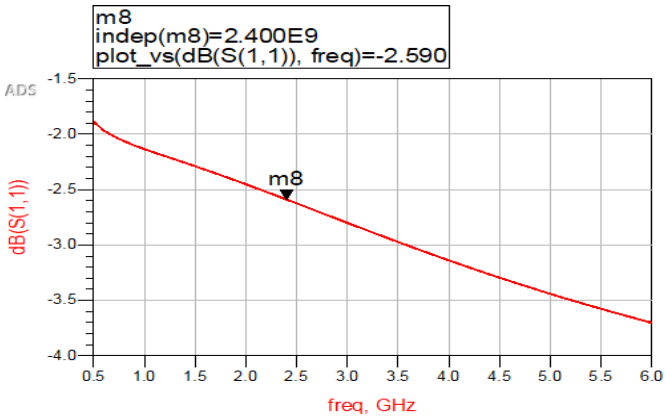

Figure 5. S_{11} of LNA

Figure 5 presents the simulation results of $S11$ for the final LNA circuit. The data reveals that $S11$ exhibits a negative value within the 2.4 GHz frequency range.

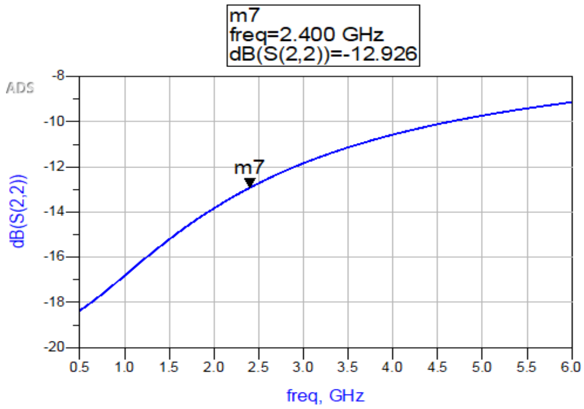

Figure 6 S_{22} of LNA

Figure6 displays the simulation results of $S22$ for the final LNA circuit. The findings show that $S22$ is negative within the 2.4GHz frequency range.

V. Conclusion

This paper outlines the design of a GaAs p-HEMT-based Low Noise Amplifier (LNA) operating in the 2.4 GHz frequency range. The circuit design is verified to be unconditionally stable. A 3 V power supply is used for the operation of the amplifier. The simulation results demonstrate a maximum gain of 3.512 dB at 2.4 GHz, with a minimum noise figure of 1.5 dB. Additionally, the input and output reflection coefficients (S_{11} and S_{22}) are both negative at the operating frequency of 2.4 GHz.

References

1. Moerman J.P.D., Rovers M.C.M.O., and Wevers F.J.M.A.V.R.K., "Design of a high-linearity LNA operating at 2.4 GHz for wireless applications," IEEE Microw. Wireless Compon. Lett., vol. 29, no. 6, pp. 381–383, June 2019.
2. Published in IJITEE, Special Issue Vol. 9, No. 2S3, Dec. 2019.
3. Featured in IJITEE, Vol. 9, No. 3, Jan. 2020.

DOI: https://doi.org/10.5281/zenodo.15288887

4. A. Dascurcu and Y. Gurbuz, "LNA design for 5G using 0.13 µm SiGe HBT process," presented at [IEEE], [2022].
5. J. A. Shatzman, "Electronically tunable tri-band LNA in 0.5 µm GaAs pHEMT," [Source, e.g., conference or thesis], May 2011.
6. B. Streetman and S. Banerjee, Solid State Electronic Devices, 6th ed., Prentice Hall, 2006, Appendix III, p. 540.
7. A. Higashiosaka, Y. Takayama, and F. Hasegawa, "Development of a high-power GaAs MESFET using optimized device patterns," IEEE Trans. Electron Devices, vol. 27, pp. 1025–1029, Jun. 1980.
8. V. Markovic, B. Milovanovic, and N. Males-Illic, "Accurate noise modeling in MESFETs considering correlation effects," in Proc. Int. Conf. Microelectronics, vol. 1, pp. 245–248, Sep. 1997.
9. K. Joshin, T. Ohori, and M. Takikawa, "Extremely low-noise HEMT based on an advanced noise model," in Eur. Microw. Conf., pp. 102–104, Sep. 1993.
10. R. M. Singh, A. N. Tiwari, and S. A. T. D. Kumar, "Simulation-based design of a low-noise amplifier using 45 nm CMOS for wireless communication," Int. J. RF Microw. Comput.-Aided Eng., vol. 30, no. 10, pp. 1–11, Oct. 2020.
11. F. Abbasi, J. Salazar, A. C. Zoubir, and L. M. R. A. M. M. Shaba, "Design of a GaAs p-HEMT LNA for millimeter-wave frequency bands," IEEE Trans. Microw. Theory Tech., vol. 68, no. 3, pp. 1894–1903, Mar. 2020.
12. T. G. I. A. Akhlaghi, "Energy-efficient LNA architecture for 5G implemented in 22nm FD-SOI CMOS," IEEE Access, vol. 8, pp. 120136–120144, Jul. 2020.
13. S. Voinigescu, High-Frequency Integrated Circuits, 1st ed., Cambridge University Press, 2013.
14. B. G. Perumana, J. H. C. Zhan, S. S. Taylor, B. R. Carlton, andJ. Laskar, "Multib and resistive-feedback CMOS LNAs with low noise," IEEE Trans. Microw. Theory Tech., vol. 56, pp. 1218–1225, May 2008.
15. D. P. Navaratne, "Broadband CMOS low-noise amplification for SKA radio telescopes," Master's thesis, Univ. of Calgary, Alberta, Canada, Aug. 2011
16. C.S.B.A.K.K.Patel,"Optimizednoisefigur eLNA design in 0.18-µm CMOS for 5G," IEEE Microw. Wireless Compon. Lett., vol. 31, no. 4, pp. 104–106, Apr.2021.
17. Y. Zhang and L. Lu, "Tunable noise figure LNA for advanced communication systems," IEEE J. Solid-StateCircuits,vol.56,no.7,pp.1565–1572,Jul. 2021.

DOI: https://doi.org/10.5281/zenodo.15288887