RF Design of 2.4GHz LNA



A project Report

Submitted in partial fulfillment of the requirement for the award of the degree of

## Bachelor of Technology

In

## Department of Electronics and Communication Engineering

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Signature of HOD Signature of the Examiner

# ACKNOWLEDGEMENT



The success in this project would not have been possible but for the timely help and guidance rendered by **Supervisor xxxxx**. Our wish to express my sincere thanks to all those who has assisted us in one way or the other for the completion of my project.

We express our gratitude to Head of the Department **xxxxx ,** for Electronics and Communication Engineering for providing us with adequate facilities, ways and means by which we are able to complete this project.

We would like to place on record the deep sense of gratitude to the honorable xxxx, KLH (Deemed to be) University for providing the necessary facilities to carry the project-based Lab.

Last, but not the least, we thank all Teaching and Non-Teaching Staff of our department and especially my classmates and my friends for their support in the completion of our project-based Lab.

Finally, I sincerely thank my parents, friends and classmates for their kind help and co- operation during my work.

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ABSTRACT

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**CHAPTER 1 INTRODUCTION**



In modern systems, Low Noise Amplifiers (LNAs) play a critical role in ensuring efficient reception of

weak signals. LNAs are typically the first active components in a receiver

chain, amplifying radio frequency (RF) signals captured by the antenna with minimal

added noise. The key challenge in designing an LNA is to achieve a balance between high gain, low noise figure (NF), and low power consumption.

The Noise Figure (NF) of an LNA is particularly important because it quantifies how much noise is added

to the input signal during amplification. A low NF ensures that the signal quality is preserved as much as possible. The gain of the LNA must also be high enough to amplify weak incoming signals to usable levels for further processing, while power dissipation must be minimized to meet the requirements of energy-efficient systems.

This work focuses on the design and simulation of a 2.4 GHz LNA using CMOS

technology in Cadence Virtuoso. The goal of this project is to optimize the LNA's performance with a low noise figure, adequate gain, and minimal power dissipation. The amplifier will be analyzed through various simulation techniques, including S-parameter analysis and Pnoise analysis, to assess its performance in the desired frequency range

(2.4 GHz ISM band).

The 2.4 GHz frequency band is widely used for technologies such as Wi-Fi, Bluetooth, and Zigbee, which further emphasizes the importance of designing high-performance LNAs for this band.

# CHAPTER 2 LITERATURE SURVEY



# CHAPTER 3 THEORITICAL ANALYSIS



The Low Noise Amplifier (LNA) is an important block in RF receivers, particularly for wireless communication systems, to amplify weak input signals with a very small amount of added noise.

Theoretical study of LNA performance plays an important role in evaluating its efficiency & effectiveness in practical applications. The key parameters to evaluate the LNA design are Noise Figure (NF), Gain, and Power Dissipation. There must be a balance between these parameters for a good performing amplifier.

**1. Noise Figure (NF)**  
The Noise Figure (NF) is an important performance characteristic of an amplifier that measures the amount of extra noise the amplifier adds to the input signal with respect to an ideal amplifier. It is expressed as the ratio of the input Signal-to-Noise Ratio (SNR) to the output SNR

A perfect amplifier would have an NF of 1 (0 dB), i.e., it adds no extra noise. But actual amplifiers always contribute some noise to the signal. Noise Figure is usually measured in decibels (dB) for practical applications

The NF of an LNA is a function of several factors such as:

**Transistor behavior:** The inherent noise of the transistors employed (like thermal and shot noise).

**Source impedance:** Source impedance matching with the LNA input can reduce noise contribution.

Topology and design: Specific amplifier topologies, like inductive degeneration or cascode configurations, can reduce NF.

Here, the Noise Figure is obtained with the use of S-parameters, more so through the relation between the minimum noise figure (F\_min) and reflection coefficients (S11 and S21). It is desired in the design of the LNA that NF should be low, that is ideally < 3 dB, so that the integrity of the signal can be maintained.

**2. Gain (S21)**

The Gain of an amplifier describes the amount by which it boosts the amplitude of the input signal. The forward gain (S21), i.e., the ratio of output signal to input signal, is the most important parameter for LNAs. The gain is usually measured in dB

For an LNA, greater gain is necessary to make weak signals strong enough for processing in the subsequent receiver chain. Yet, additional gain can translate into increased power dissipation and noise figure. Therefore, there has to be a balance, usually aiming at 15–20 dB gain for an LNA working within the 2.4 GHz ISM band.

**3. Power Dissipation (Ptotal)**

The Total Power Dissipation of the LNA is a way of measuring the power that is used by the amplifier. This is important in portable wireless and battery-powered systems, where low-power consumption is important.



To gain low power dissipation, the designer resort to methods such as:

**Biasing:** Optimum biasing of the transistors results in their optimal working regions so that they draw current unnecessarily.

**Current Reuse:** Utilization of current reuse topologies (cascode or folded cascode architecture) makes

high gain feasible while consuming reduced currents.

**Technology Choice:** CMOS technology selection ensures power dissipation reduction without affecting performance as a result of CMOS devices having inherent low power.

In the case of the given design, under the assumption that the total current consumption is 10 mA, the overall power dissipation amounts to 33 mW.

**4. Design Techniques and Trade-offs**

Designing an LNA has trade-offs between power dissipation, gain, and noise performance. Some

techniques that are utilized to optimize these parameters include:

**Inductive Source Degeneration:** This is applied to stabilize the gain and lower the noise figure by adding

an inductor to the source leg of the transistor. It enhances linearity as well as decreases the noise contribution of the transistor at higher frequencies.

**Cascode Configuration:** Cascode amplifier offers high gain with a lower noise figure through the isolation

of the input and output stages, thereby minimizing the overall noise contribution.

**Current Reuse**: Reuse of the same current in the different stages minimizes the power dissipation while the gain is high and noise is low.

**Impedance Matching:** Accurate impedance matching at the input and output is essential to ensure

maximum power transfer and minimum reflection losses. Methods like L-network matching or

matching transmission lines are usually used.

**Fully Integrated Designs:** CMOS technology enables the integration of the LNA with other RF

components, minimizing area and reducing power consumption.

In practice, one needs to optimize these parameters in the design of an LNA so that the amplifier has the system requirements of low NF, sufficient gain, and low power consumption, along with good linearity

and stability throughout the operating frequency range.

Low Noise Amplifier (LNA) is a crucial element in the amplification of low-power RF signals with low added noise. The theoretical examination of LNA design deals with understanding its fundamental parameters—Noise Figure (NF), Gain (S21), and Total Power Dissipation (P\_total).

The Noise Figure must be made as small as possible to maintain that the signal quality does not degrade in the amplifier.

The Gain must be high enough to boost weak signals but not so high as to add large amounts of noise or power consumption.

The Power Dissipation must be low, particularly in battery powered equipment without compromising performance.

Using design principles such as cascode configurations, inductive degeneration, and current reuse allows

For the proper balance of the parameters and hence designing an effective and high performing LNA that

can suit wireless communication devices that work based on the ISM band frequency of 2.4GHz.



**CHAPTER 4**



# EXPERIMENTAL INVESTIGATION

### Methodology:

### Design and analysis of 2.4 GHz Low Noise Amplifier (LNA) were done under Cadence Virtuoso employing models of 45nm CMOS technology. Methodology is a step-by-step method comprising schematic design, testbench configuration, S-parameter analysis, and periodic noise (Pnoise) simulation to validate the RF performance specifications.

### 1. Schematic Design

### The LNA circuit was designed by applying a common-source structure with inductive source degeneration. Major components were NMOS transistors (M1, M2 of 200 μm width, and M3 of 60 μm width), inductors (L1 = 700 pH, L2 = 12 nH, L3 = 6 nH), and a 700 Ω resistor for biasing and stabilization. Coupling and load capacitors (C1, C2 = 10 nF, CL = 500 fF) were also used in the design. The supply voltage (Vdd) was 3.3V.

### 2. Testbench Setup

### To analyze the performance of the LNA, a two-port testbench was set up. The input (Port 1) and output (Port 2) were both terminated in a resistance of 50 Ω. At Port 1, a sine wave input source with frequency of 2.4 GHz and amplitude of -20 dBm, simulating a weak RF signal, was applied.

### 3. S-Parameter Analysis

### S-parameter analysis was used to find the amplifier's gain, input/output reflection, and reverse transmission characteristics within a frequency span of 1 GHz to 5 GHz. Sweep was taken in automatic mode with frequency increment of about 80 MHz. The analysis revealed important parameters including:

### S11: Input reflection coefficient

### S21: Forward transmission (gain)

### S12: Reverse isolation

### S22: Output reflection coefficient

### The Noise Figure (NF) was also derived from the S-parameter simulation through

### the use of the function "NF" with a dB10 modifier to assess the level of noise introduced by the amplifier.

### 4. Periodic Noise (Pnoise) Simulation

### Large signal noise performance was evaluated through Pnoise simulation. This simulation took into account the input noise, output noise, and noise transfer function in periodic steady-state operation. This analysis is particularly valuable for the examination of circuits working with time-varying signals, like RF LNAs.

### 5. Visualization and Results

### Simulation results such as S-parameters and noise figures were plotted through the Direct Plot feature of ADE L. Two major plots were produced:

### Comparison of output vs. input noise from Pnoise analysis

### Noise Figure curve over the frequency range (NF in dB10)

### This approach guarantees a complete understanding of the LNA's behavior over the desired ISM frequency band (2.4 GHz), verifying its appropriateness for wireless receiver applications.

## Chapter 5 EXPERIMENT RESULTS

The 2.4 GHz Low Noise Amplifier (LNA) was simulated using Cadence Virtuoso with 45nm

CMOS technology. The S-parameter and Pnoise analysis results are as follows:

**1. S-Parameter Results**

S11 (Input Reflection): < -10 dB, which is good input matching.

S21 (Gain): 15–18 dB at 2.4 GHz, which is sufficient amplification.

S22 (Output Reflection): < -10 dB, which verifies output matching.

S12 (Reverse Isolation): < -30 dB, which is excellent isolation.

**2. Noise Figure (NF)**

The Noise Figure (NF) at 2.4 GHz was measured to be 1.8 dB, demonstrating low noise performance

over the entire frequency range.

**3. Pnoise Analysis**

The input and output noise performance was analyzed, demonstrating effective amplification with very

little noise contribution.

**4. Calculations:**

Noise Figure (NF): The Noise Figure was read from the simulation as 1.8 dB, which ensures the

LNA's capability to reduce noise and improve signal quality.

**Total Power Dissipation (Ptotal):**

The total power dissipation is determined by the supply voltage (VDD = 3.3 V) and the total

current consumed by the LNA. For a total current of 10 mA, the total power dissipation is:

**Ptotal = 3.3V × 10mA = 33mW**

# CHAPTER 6 RESULTS AND DISCUSSION

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* fig 1 : Comparing output noise and input  
  (pnoise – periodic noise)

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* fig2 : Noise Figure for NF(dB10) and NF mag (dB10)



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The simulation is performing a **S-parameter analysis** over a **frequency range of 1 GHz to 5 GHz**.

The sweep is done in **steps of 80 MHz**, meaning it checks circuit behavior at many points between 1 and 5 GHz.

Each frequency point (e.g., 1.00 GHz, 1.08 GHz, …) shows the **S-parameter results**, typically S11, S21, S12, S22, etc.

# CHAPTER 7 CONCLUSION



2.4 GHz Low Noise Amplifier (LNA) Design and Simulation with Cadence Virtuoso and 45nm CMOS is

all about optimizing the most crucial RF performance metrics like high gain, low noise figure, and good impedance matching. LNAs are critical elements in wireless receivers that amplify weak incoming signals with minimal additional noise introduced. By going through literature reviews, various design requirements were realized, which include trade-offs between area, noise performance, gain, and power efficiency. Inductive source degeneration and current reuse are some of the techniques that are utilized to achieve these design specifications in order to be integration compatible.

The simulation approach involves S-parameter analysis as well as periodic noise (Pnoise) simulation.

The S-parameters (S11, S21, S12, and S22) give information on reflection and transmission behavior over frequencies from 1 GHz to 5 GHz. Noise Figure (NF) is measured in dB10 format to determine how effectively the amplifier reduces added noise. Pnoise analysis allows for further comprehension of how the noise travels throughout the system during conditions of large signal, exploring input and output noise as well as the transfer of noise. The test circuit consists of 50-ohm ports, a -20 dBm sine input at 2.4 GHz, NMOS transistors (M1, M2 = 200μm, M3 = 60μm), inductors (L1 = 700 pH, L2 = 12 nH, L3 = 6 nH), a 700 Ω resistor, and capacitors (C1, C2 = 10 nF, CL = 500 fF).

To conclude, simulation results validate the design, demonstrating a well-balanced LNA with favorable

gain, low noise, and proper impedance characteristics at 2.4 GHz. This confirms the effectiveness of the chosen design strategy and simulation approach, providing a reliable solution for ISM band applications.

# CHAPTER 8 SUMMARY



This project deals with the design and simulation of a 2.4 GHz Low Noise Amplifier (LNA) based on Cadence Virtuoso in 45nm CMOS technology. The primary goal is to obtain high gain, low noise figure,

and correct impedance matching for effective RF performance in wireless receivers. LNAs play an important role in amplifying low-level radio frequency signals with very little added noise, hence being

vital for receiving clear and strong signals. Main design challenges are low noise figure maintenance, gain satisfaction, and minimizing power consumption and area. Fully integrated CMOS designs, inductive

source degeneration, and current reuse are the usual ways of meeting these challenges.

S-parameter analysis and periodic noise (Pnoise) analysis are done during the simulation process. S-parameters (S11, S21, S12, S22) are utilized to analyze input/output matching and forward/reverse gain

over a frequency range of 1 GHz to 5 GHz with an 80 MHz step. Noise Figure (NF) is graphed using the dB10 scale to examine how much noise is introduced by the LNA. The Pnoise simulation analyzes the

input noise, output noise, and noise transfer function, giving insight into large signal noise behavior. The testbench employs 50-ohm ports and a -20 dBm sine input of 2.4 GHz. The LNA circuit consists of capacitors (C1, C2 = 10nF, CL = 500fF), NMOS transistors (M1, M2 = 200μm, M3 = 60μm), and passive components (L1 = 700pH, L2 = 12nH, L3 = 6nH, R = 700Ω). The simulation outputs are plots of the noise figure and input and output noise comparison, which assist in verifying the LNA performance and design objectives.

# CHAPTER 9 REFERENCES



# <https://www.ijert.org/research/design-of-a-2.4-ghz-common-source-lna-with-inductive-degeneration-for-rf-ic-IJERTV6IS020078.pdf>

# Tutorial 1: Step-by-Step Guide to Designing a Low Noise Amplifier for the ISM Band (2400MHz To 2500MHz) - <https://innowave.co/2022/11/29/low-noise-amplifier-design/>

# Thesis Paper and Research Papers regarding LNA

# [(PDF) Optimum Design of 2.4GHz Low Noise Amplifier (LNA)](https://www.researchgate.net/publication/344742866_Optimum_Design_of_24GHz_Low_Noise_Amplifier_LNA)

# [Optimum Design of 2.4GHz Low Noise Amplifier (LNA) | Semantic Scholar](https://www.semanticscholar.org/paper/Optimum-Design-of-2.4GHz-Low-Noise-Amplifier-%28LNA%29-Abdo-Younis/76512fefb2f2e08733f311bf9ea8291583b14224?utm_source=chatgpt.com)



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