B.E – ECE, VII Semester
Project Seminar (U21PW719EC)
Abstract Level Presentation on

Title: Design and Implementation of Low Noise Amplifier using Cadence Virtuoso

Batch Number : 2

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Outline of our Presentation

- Introduction
- Literature Survey
- Motivation
- Aim and Objectives of the Project
- Block Diagram
- Implementation Plan
- Expected Results
- Progress
- Conclusions
- Applications
- References

Introduction

- What is LNA?
  - A lower noise amplifier is an electronic amplifier that amplifies a very low amplitude signal without significantly degrading its signal to noise ratio.
- What are the applications of LNA?
  - Telecommunications
  - Radio Astronomy
  - Radar Systems
  - GPS Receivers
  - Wi-Fi and Wireless Communication
  - Medical Devices
  - Remote Sensing
  - Satellite Communication

Introduction

- Why is it important?
  - Improve Signal Sensitivity: Amplifies weak signals with minimal noise, crucial in communication systems.
  - Enhance Signal-to-Noise Ratio (SNR): Reduces noise addition, preserving signal integrity.
  - Enable Long-Distance Communication: Vital for receiving faint signals from satellites, radars, or remote sources.
  - Minimize Data Loss: Helps ensure accurate signal transmission and reception, reducing the risk of data corruption.
  - Optimize System Performance: Critical in systems where signal quality and reception sensitivity are paramount, like GPS, Wi-Fi, and medical devices.

Introduction

- What are the design parameters of LNA?
  - Gain: The amplification factor of the input signal. It represents how much the signal is amplified, typically measured in dB.
  - Noise Figure (NF): A measure of how much noise the LNA adds to the signal. Lower noise figures are desired, typically measured in dB.
  - IIP3 (Input Third-Order Intercept Point): Indicates the linearity of the LNA representing how well it can handle high-power signals without distortion. It is typically measured in dBm.
  - Input and Output Impedance: Refers to the impedance matching at the input and output ports, usually standardized at 50 ohms for RF systems, ensuring efficient signal transfer.
  - Power Consumption: The amount of power the LNA consumes during operation, important for battery-operated or energy-sensitive applications, usually measured in milliwatts (mW).
  - Bandwidth: The range of frequencies over which the LNA operates effectively. It defines the usable frequency range for the amplifier.

Introduction

- What are the typical values of design parameters?
  - Noise Figure: 2dB
  - IIP3: -10dBm
  - Gain: 15dB
  - Input and output impedance: 50Ohm
  - input and output return loss: -15dB
  - Reverse Isolation: 20dB
  - Stability Factor: > 1

Introduction

- What are the different configurations of LNA?
  - Common Source (CS) Configuration
  - Common Gate (CG) Configuration
  - Common Drain (CD) or Source Follower Configuration
  - Cascode Configuration
  - Differential LNA
  - Inductive Degeneration
  - Feedback Amplifier Configuration
  - Current Reuse Configuration
  - Distributed LNA

Literature Survey

S No	Paper Title: Year of publication	Implementation Techniques	Specifications
1	A Sub-mW, Ultra-Low-Voltage, Wideband Low-Noise Amplifier Design Technique.	resistive-shunt feedback low-noise amplifier (LNA)	Voltage Gain: 12.6 dB Bandwidth: 0.1-7 GHz Noise Figure (NF): 5.5 dB IIP3: -9 dBm P1dB: -18 dBm Power Consumption: 0.75 mw Technology: 90-nm CMOS
2	A 180-GHz Low-Noise Amplifier With Recursive Z-Embedding Technique in 40-nm CMOS	Z-Embedding Technique	Gain: 14.8 dB at 180 GHz 3-dB Bandwidth: 11 GHz Noise Figure (NF): 11.0 dB Power Consumption: 23.9 mw Technology: 40-nm CMOS
3	Ultralow-Power *W*-Band Low-Noise Amplifier Design in 130-nm SiGe BiCMOS	Common-source (CS)	Frequency Band: Ku-band (13 GHz) Noise Figure (NF): 1.94 dB Peak Gain: 19.98 dB Input 1-dB Compression Point (IP1dB): -7.8 dBm Output I-dB Compression Point (OP1dB): Not specified Power Consumption: 10 mA @ 1V

Literature Survey

S No	Paper Title: Year of publication	Implementation Techniques	Specifications
4	CMOS RF Low-Noise Amplifier Design for Variability and Reliability	adaptive substrate bias	Operating frequency: 24GHz Technology: 65nm CMOS
5	A 180-GHz Low-Noise Amplifier With Recursive Z-Embedding Technique in 40-nm CMOS	Low-imbalance active balun topology	Frequency Band: 0.2 to 3.3 GHz Gain Tuning Range: 45 dB Noise Figure (NF): 3.4 dB Power Consumption: 19 mw Supply Voltage: 1.2 V Technology: 130-nm CMOS
6	A 20 MHz–2 GHz Inductor less Two-Fold Noise-Canceling Low-Noise Amplifier in 28-nm CMOS	Common Gate and Common Source	Frequency Band: 0.02-2 GHz Minimum Noise Figure (NF): 2.5 dB Input Return Loss (SII): < -15 dB Power Gain (-3dB, S21): 18.5 dB Input Third-Order Intercept Point (IIP3): +4.25 dBm Power Consumption: 4.1 mw Technology: 28-nm CMOS
7	Ultra-Low Noise Amplifier Design for Magnetic Resonance Imaging systems	Cascode amplifier topology	Operation Frequency: 32 MHz Noise Figure (NF): 0.45 dB (at 50 Q) Gain: 11.6 dB Output Return Loss: 21.1 dB Input Return Loss: 0.12 dB Stability: Unconditionally stable up to 6 GHz

Motivation

Low-noise amplifiers (LNAs) are essential components in modern electronics.

Their importance in various applications, including wireless communication, radar, and satellite systems, motivated us to take on an LNA project.

The challenges associated with designing efficient and integrated LNAs, combined with the potential for skill development, and publication opportunities, made it a compelling choice.

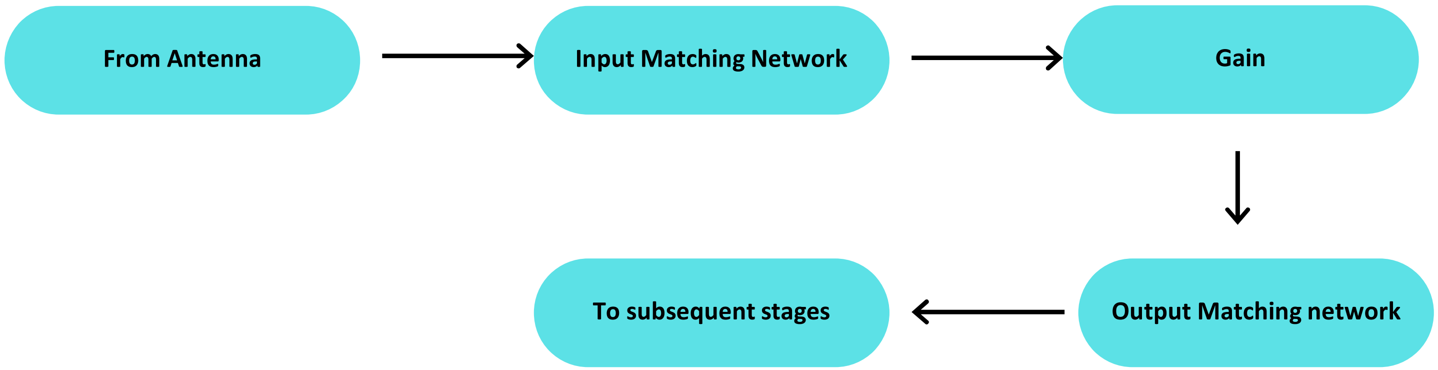
Aim and Objectives

Aim: It is proposed to design and develop a Low noise amplifier for the given specifications.

Objectives:

1. Select a Topology
2. Design using selected Topology
3. Performing initial transient analysis and frequency analysis on the designed circuit
4. DC Simulation and adjusting DC Bias to meet the necessary frequency characteristics of 2.4Ghz
5. Making circuital changes and resimulating the design until the desired noise factor of <6db is reached.
6. Re- design and resimulate until the necessary IIP3 values are fulfilled, and change the input and output sections to meet impedance requirements.

Block Diagram



Plan for the implementation of Project

- **Input Matching Network:** This circuit is used to match the impedance of the antenna to the input impedance of the amplifier, ensuring maximum power transfer.
- **Gain:** This is the core component of the amplifier, responsible for amplifying the input signal.
- **Output Matching Network:** This circuit is used to match the output impedance of the amplifier to the impedance of the subsequent stages, ensuring maximum power transfer.
- **To subsequent stages:** This indicates that the amplified signal is then passed on to the next stages in the RF system, such as a mixer or filter.

Expected Results

Parameter	Value
Noise Figure	<6dB
Gain	>15dB
IIP3	>-10dBm
Input Impedance	50ohm
Output Impedance	50ohm
Frequency of operation	2.4Ghz

Progress so far

What we have done?

- Researched about different available LNA topologies.
- Performed Noise factor calculations for all the existing topologies.
- Decided upon inductive degenerated LNA for optimal noise performance.

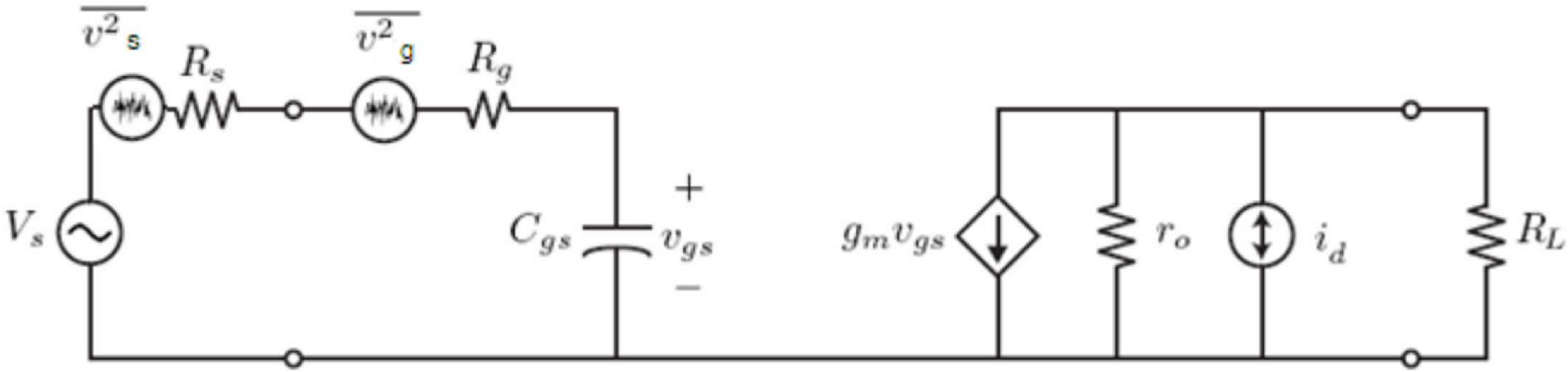
Important Formulae and equations

- Amplifier S matrix: $[S] = \begin{pmatrix} s_{11} & s_{21} \\ s_{12} & s_{22} \end{pmatrix}$
- Source reflection coefficient: Γ_S
- Load reflection coefficient: Γ_L
- Input reflection coefficient: $\Gamma_{in} = s_{11} + \dfrac{s_{12}s_{21}\Gamma_L}{1 - s_{22}\Gamma_L}$
- Output reflection coefficient: $\Gamma_{out} = s_{22} + \dfrac{s_{12}s_{21}\Gamma_S}{1 - s_{11}\Gamma_S}$

$$F_{tot} = F_{LNA} + \frac{F_{afterLNA} - 1}{G_{LNA}}$$

Important Formulae and equations

Mosfet high frequency model with noise sources



$$F = 1 + \frac{R_g}{R_s} + \frac{\left(\frac{\gamma}{\alpha}\right) g_m}{R_s} \left(\frac{\omega}{\omega_T}\right)^2 (R_s + R_g)^2$$

$$\approx 1 + \frac{R_g}{R_s} + \left(\frac{\gamma}{\alpha}\right)\left(\frac{\omega}{\omega_T}\right)^2 g_m R_s$$

$$F_{\min} = 1 + 2\left(\frac{\omega}{\omega_T}\right)\sqrt{\left(\frac{\gamma}{\alpha}\right) g_m R_g}$$

$$R_{s,opt} = R_s = \frac{\omega_T}{\omega}\sqrt{\frac{R_g}{\left(\frac{\gamma}{\alpha}\right) g_m}}$$

Important Formulae and equations

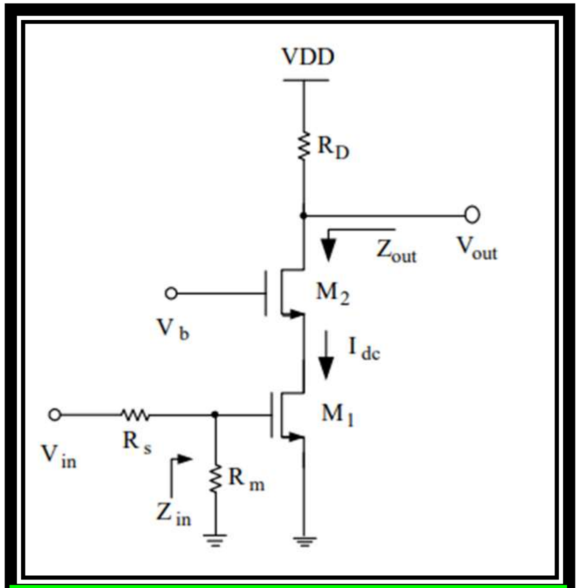
Thermal noise for resister and mosfet are:

Resistor: $\overline{v_g^2} = 4kTR_g$

Mosfet: $\overline{i_d^2} = 4kT\dfrac{\gamma}{\alpha}g_m$

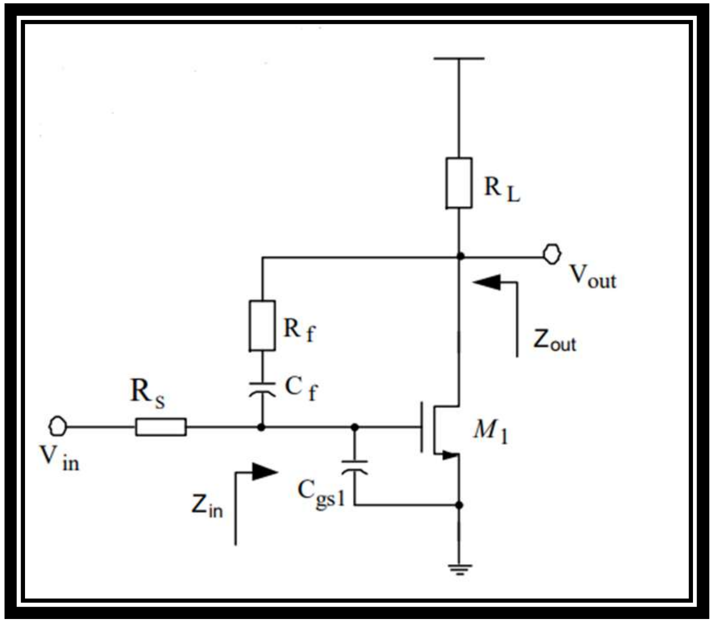
Different Topologies and their noise factors

$$Noise\ Factor = \frac{Signal\ to\ noise\ ratio\ at\ input}{Signal\ to\ noise\ ratio\ at\ output}$$



Resistive Termination LNA

$$F = 1 + \frac{R_m^2}{R_s^2} + \frac{4\gamma}{\alpha g_{m1} R_s} = 2 + \frac{4\gamma}{\alpha g_{m1} R_s}$$

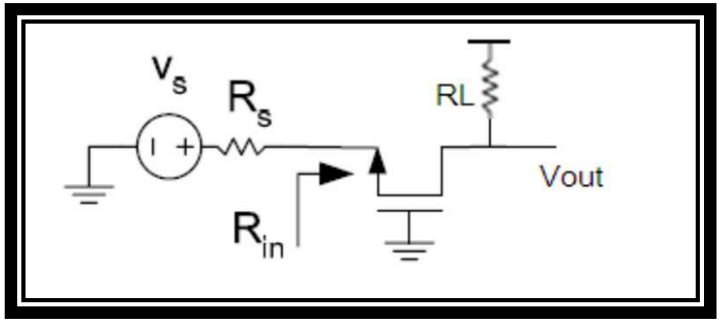


Resistive Shunt Feedback LNA

$$F = 1 + \frac{R_f}{R_s}\left(\frac{1+g_{m1}R_s}{1-g_{m1}R_f}\right)^2 + \frac{1}{R_s R_L}\left(\frac{R_f+R_s}{1-g_{m1}R_f}\right)^2 + \frac{\gamma g_{m1}}{\alpha R_s}\left(\frac{R_f+R_s}{1-g_{m1}R_f}\right)^2$$

Different Topologies and their noise factors

$$Noise\ Factor = \frac{Signal\ to\ noise\ ratio\ at\ input}{Signal\ to\ noise\ ratio\ at\ output}$$



Common Gate LNA

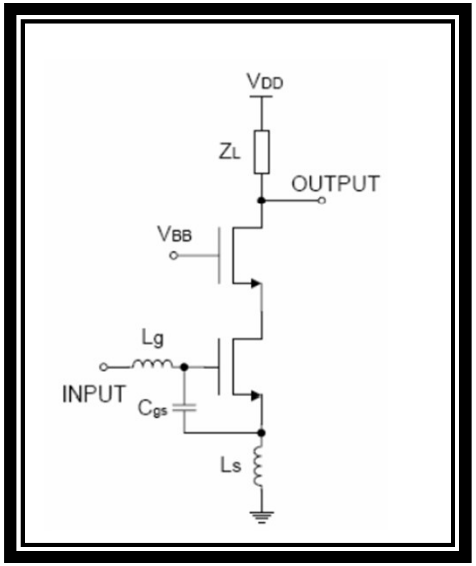
$$F = 1 + \frac{\overline{i_{nd}^2}\left(\frac{1}{1+g_m R_s}\right)^2}{e_{ns}^2\left(\frac{g_m}{1+g_m R_s}\right)^2} = 1 + \frac{\gamma g_{d0}}{g_m^2 R_s}$$

Under the input matching condition: Rs=1/gm we have:

$$F = 1 + \frac{\gamma g_{d0}}{g_m} = 1 + \frac{\gamma}{\alpha} = \begin{cases} \frac{5}{3} = 2.2dB & \text{Long channel} \\ \geq 3 = 4.8dB & \text{Short channel} \end{cases}$$

Different Topologies and their noise factors

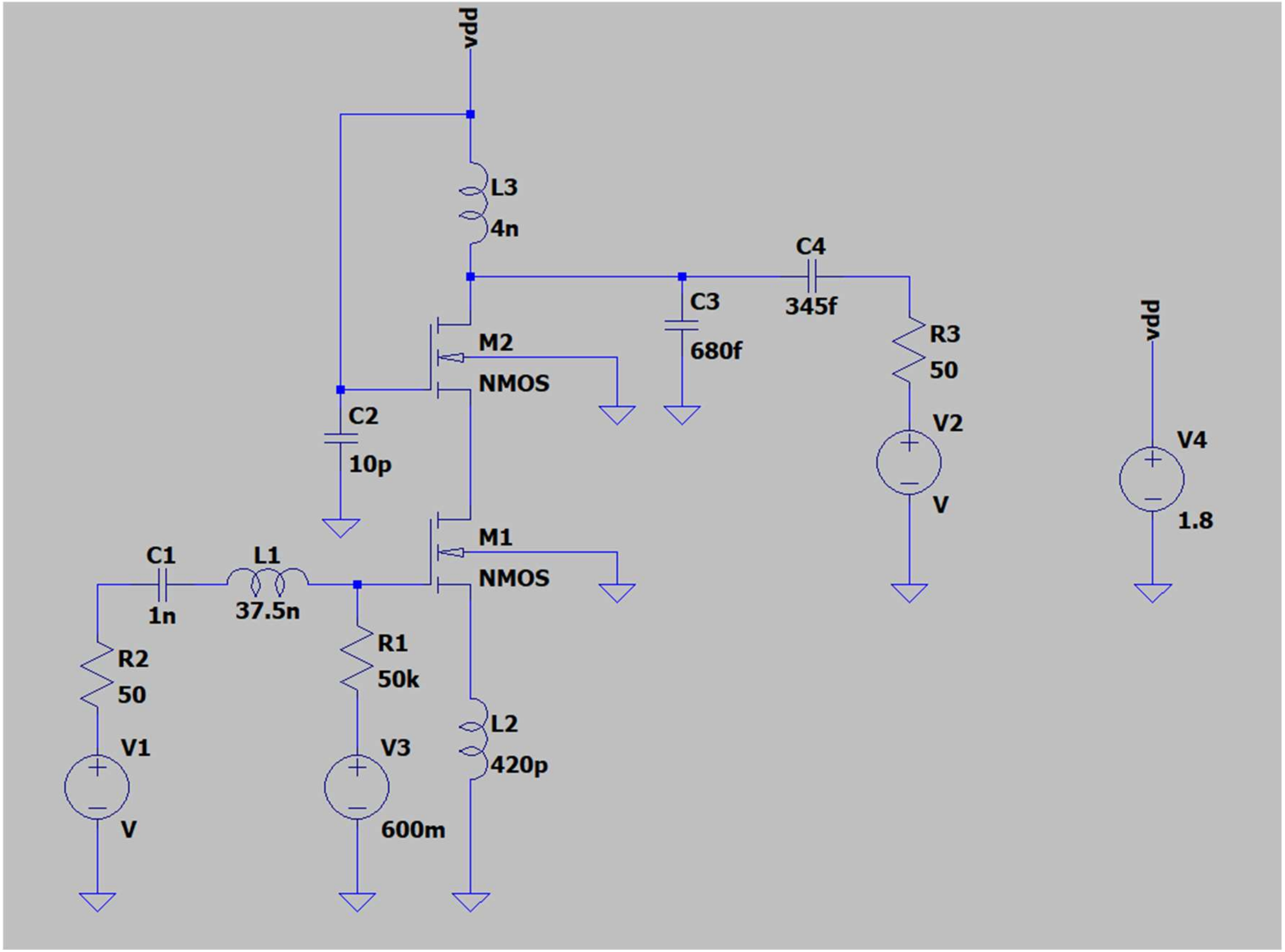
$$Noise\ Factor = \frac{Signal\ to\ noise\ ratio\ at\ input}{Signal\ to\ noise\ ratio\ at\ output}$$



Inductive Degenerated LNA

$$F = \frac{\overline{i_{no}^2}}{G_m^2 \overline{v_{R_s}^2}} = 1 + \frac{R_g}{R_s} + \frac{\gamma}{\alpha} g_m R_s \left(\frac{\omega_o}{\omega_T}\right)^2$$

Current LNA design we are working on:



Consolidated report of available topologies and their noise factors

Topology	Noise factor	Input matching
Mos amplifier	$1+\frac{R_g}{R_s}+\left(\frac{\gamma}{\alpha}\right)\left(\frac{\omega}{\omega_T}\right)^2 g_m R_s$	No
Resistive Termination LNA	$1+\frac{R_m^2}{R_s^2}+\frac{4\gamma}{\alpha g_{m1} R_s}=2+\frac{4\gamma}{\alpha g_{m1} R_s}$	No
Resistive Shunt Feedback LNA	$1+\frac{R_f}{R_s}\left(\frac{1+g_{m1}R_s}{1-g_{m1}R_f}\right)^2+\frac{1}{R_s R_L}\left(\frac{R_f+R_s}{1-g_{m1}R_f}\right)^2+\frac{\gamma g_{m1}}{\alpha R_s}\left(\frac{R_f+R_s}{1-g_{m1}R_f}\right)^2$	No
Common Gate LNA	$1+\frac{\overline{i_{nd}^2}\left(\frac{1}{1+g_m R_s}\right)^2}{e_{ns}^2\left(\frac{g_m}{1+g_m R_s}\right)^2}=1+\frac{\gamma g_{d0}}{g_m^2 R_s}$	No
Inductive Degenerated LNA	$\frac{\overline{i_{no}^2}}{G_m^2 v_{R_s}^2}=1+\frac{R_g}{R_s}+\frac{\gamma}{\alpha} g_m R_s\left(\frac{\omega_o}{\omega_T}\right)^2$	matched

Consolidated report of available topologies

	Resistive Termination	Common Gate	Shunt Feedback	Inductive Degeneration
Noise Figure	>6dB	3~5dB	2.8~5dB	~2dB
Gain	10~20dB	10~20dB	10~20dB	15~25dB
Sensitivity to Parasitic	Less	Less	Less	Large
Input Matching	Easy	Easy	Easy	Complex
Linearity	-10~10dBm	-5~5dBm	-5~5dBm	-10~0dBm
Power	1~50mW	~5mW	>15mW	>10mW
Highlight	Effortless input matching	Easy input matching	Broadband input/out matching	Good narrowband Matching, small NF
Drawback	Large NF	Large NF	Stability	Large area

Conclusions

The LNA developed for long-distance communication successfully addresses the challenges of noise reduction and bandwidth limitations. By effectively amplifying weak signals while minimizing noise, this LNA enhances the sensitivity and reliability of communication systems over vast distances. The optimized design and implementation of the LNA contribute to improved data transmission and reception, enabling more efficient and reliable long-distance communication services.

Applications

- Telecommunications
- Radio Astronomy
- Radar Systems
- GPS Receivers
- Wi-Fi and Wireless Communication
- Medical Devices
- Remote Sensing
- Satellite Communication

References

- A Sub-mW, Ultra-Low-Voltage, Wideband Low-Noise Amplifier Design Technique.
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- CMOS Analog Circuit Design by Phillip E. Allen, Douglas R. Holber

Thank You