Design and Analysis of a Gain-Tunable Low Noise Amplifier for Advanced Bio-Medical Systems

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Presentation outlines

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- Application & Motivation
- Aims & Objectives
- Literature Review
- Methodology & System Details
- Results and Discussions
- Conclusion & Future works

Introduction

A **Low Noise Amplifier (LNA)** is a specialized amplifier designed to boost weak signals while adding minimal noise.

- **Working Principles:**
  They **amplify** signals with minimal added noise, ensuring reliable signal processing.
- **Key Performance Metrics:**
  LNAs are evaluated based on **noise figure, gain, power efficiency, and input impedance**.
- **Design Focus:**
  Efficient, compact, and low-power LNAs are essential for advancing biomedical technology.

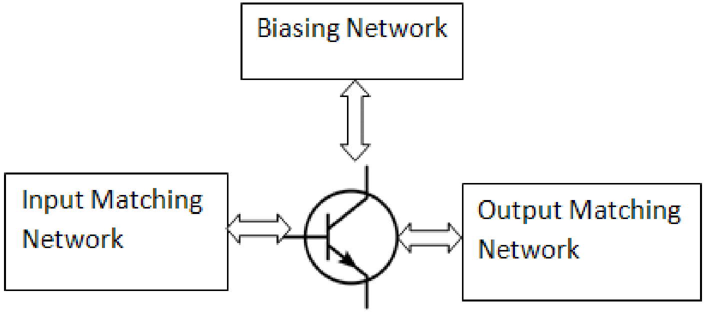


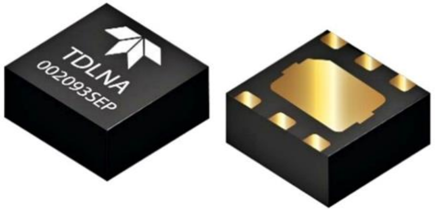
Figure 01: Block Diagram of LNA

This research introduces a modified low noise amplifier architecture that integrates an attenuator, aimed at improving gain and intended for use in medical imaging applications.

Applications

- Wireless communications
    - Cell phone
    - Radio
    - Satellite
    - Wi-fi / Bluetooth
    - Military Communication

- Medical Instruments
- Electronic Test Equipment
- Radar systems
- Earth Science Radiometry



Motivation

- To build a low noise amplifier which will minimize the noise while maximizing signal gain.
- Integrating an attenuator which will provide adjustable gain allowing the amplifier to adapt to different imaging applications.
- Using CMOS (Complementary Metal-Oxide-Semiconductor) technology in wideband low noise amplifiers offers several advantages

Problem Statement

- From previous work we can see that different topology was used but their efficiency was not so good.
- Previous work was based on 3 stage amplifier, but their impedance matching is not so good, so their gain was not so high.
- There was problem on noise and also uses a large area of chip due to the number of reactive elements which can be obstacle to gain good performance on wideband low noise amplifier.
- There is no system for variable gain Amplifier in medical imaging technique.

Research Objectives

- To design a wide band low noise amplifier for **high frequency.**
- To design **input and output matching network** for impedance matching.
- To design an **attenuator** with the amplifier for **variable gain** in medical imaging.
- To analyze the **performance** of the proposed amplifier for **high gain.**

Theoretical overview

Parameters	Meaning	Theoretical Working Range	Implication if Below Range	Implication if Above Range
S11 (Input Return Loss)	Measure of how much power is **reflected back from the input**. Indicates input matching.	**≤ -10 dB (more negative is better)**	Poor input matching; more power is reflected back, reducing efficiency	Better input matching; less reflection, more power delivered to the LNA.
S12 (Reverse Isolation)	Measure of how much **signal leaks from output to input**.	**≤ -20 dB**	Poor reverse isolation; risk of instability or unwanted feedback.	Better isolation; minimizes reverse signal leakage.
S21 (Gain)	**Forward gain** of the amplifier; output/input signal strength.	**10–30 dB**	Low amplification; weak signal output.	High gain; may cause stability or linearity issues if excessive.
S22 (Output Return Loss)	Measures how well **the output is matched**.	**≤ -10 dB (more negative is better)**	Poor output matching; more signal reflected from output, reducing efficiency	Better output matching; minimal reflection, more signal delivered to the load.
Kf (Stability Factor)	Indicates amplifier stability; Kf > 1 implies **unconditional stability**.	**> 1**	Risk of oscillation; unstable amplifier.	Stable operation ensured.
IIP3 (Input Third-Order Intercept Point)	A measure of **linearity**; higher means better handling of strong signals **without distortion.**	**> 0 dBm**	Poor linearity; more intermodulation distortion.	Better linearity; can handle stronger signals with minimal distortion.
Power Consumption	Total **DC power drawn** by the LNA	**As low as possible; typically < 100 mW for low-power applications**	Lower is generally better, but too low may reduce performance.	Higher power may offer better performance, but increases thermal issues and inefficiency.

Literature Review

Review of Related Works

Reference	Published Date	Publication Name	Author name
[3]	May 1, 2015	A low power and high gain CMOS LNA for UWB applications in 90 nm CMOS process	Sunil Pandey, Jawar Singh

- Trade-offs between trans-conductance & noise figure.
- Stability conditions and sensitivity.

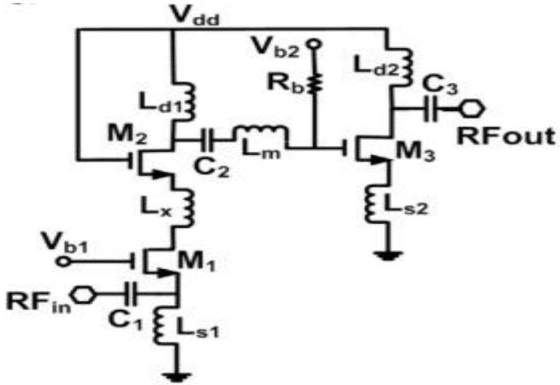


Figure 02: Common Source and Common Gate Cascaded LNA

Review of Related Works

Reference	Published Date	Publication Name	Author name
[5]	November 1, 2018	Noise suppression in a common-gate UWB LNA with an inductor resonating at the source node	Hossein Sahoolizadeh, Abumoslem Jannesari, Massoud Dousti

- Limitations of Increasing Voltage
- Complexity in designing input and output matching

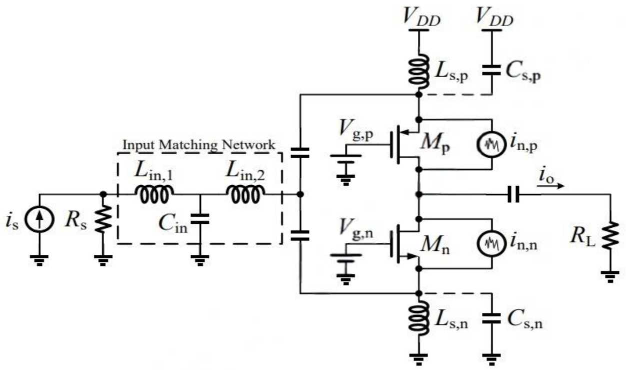


Figure 03: Common Gate LNA with biasing circuit

Review of Related Works

Reference	Published Date	Publication Name	Author name
[9]	December 2024	Design and optimization of a sub - 1dB noise figure low noise amplifier for magnetic resonance applications using CMOS technology	Bal, Ayşe Rana

- Insufficient modeling of external components.
- High parasitic resistance and capacitance

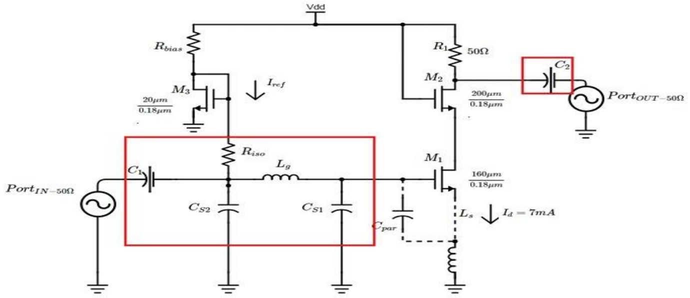


Fig 04: Cascade Common gate designed LNA with Biasing.

Review of Related Works

Reference	CMOS Technology	Gain (dB)	Frequency Range (GHz)
[1]	180 nm	16.1	0.1 – 1.4
[2]	180 nm	13	2 – 5
[4]	90 nm	16	1.85 – 2.48
[8]	130 nm	17	0.05 – 0.83

Proposed Work

- Designing 90 nm technology using one common source amplifier and gate amplifier.
- Improving the gain performance of ultra wide band low noise amplifier by tuning technique.
- Achieving excellent impedance matching through the inclusion of the matching network. An improved impedance will help to increase gain and decreasing power return loss.
- Adding attenuator for variable gain in medical imaging.

Methodology

Overview

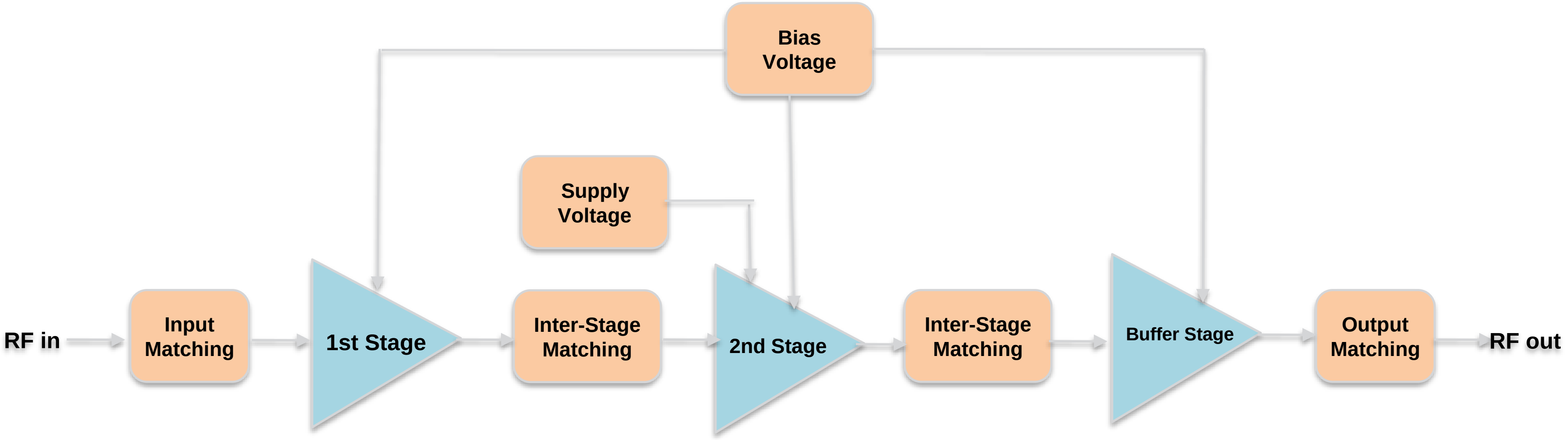


Figure 05(a): Block diagram of LNA design

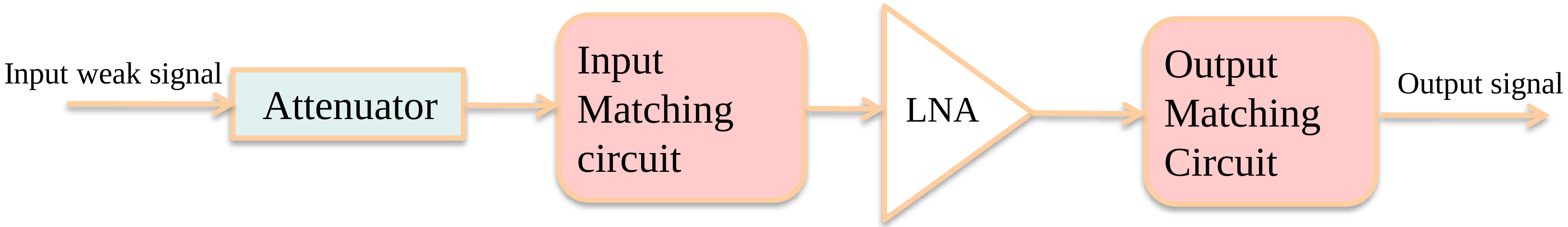


Figure 05(b): Full circuit diagram

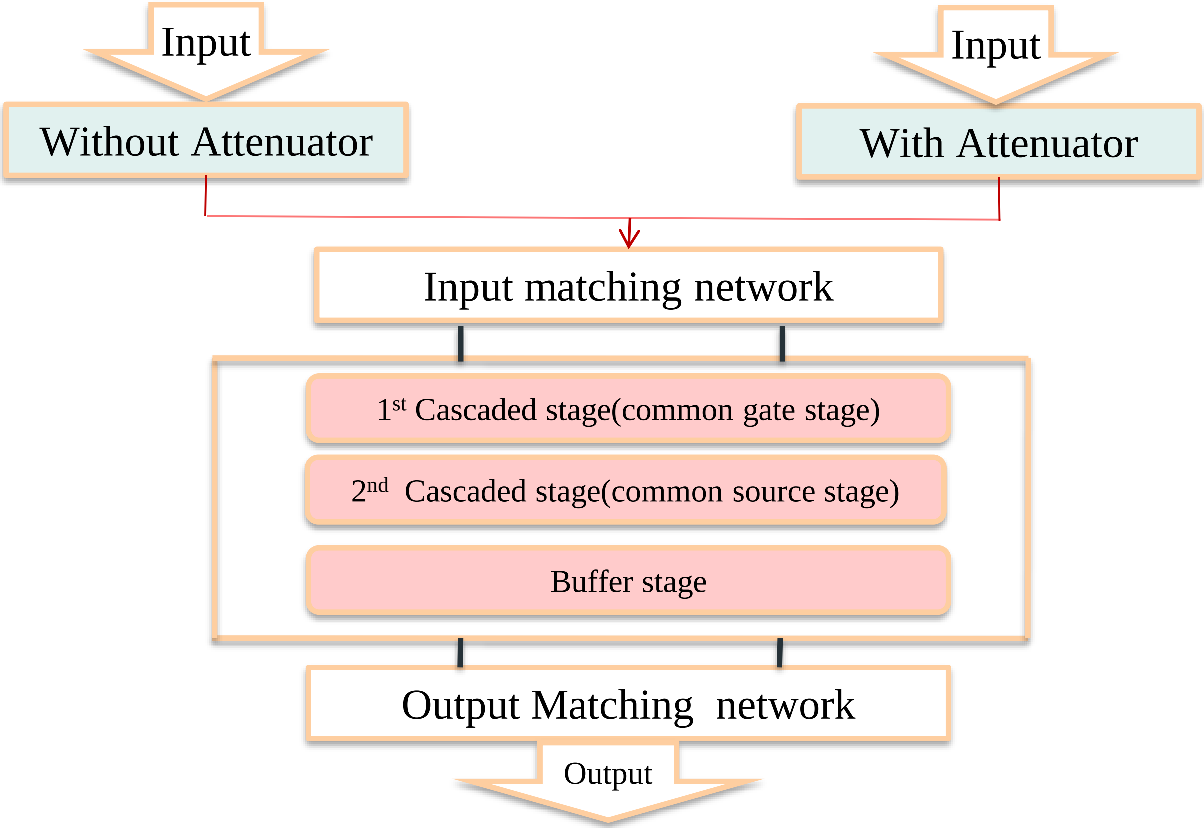
System Design

- To ensure **the most power transferred**, matching network are used to match the impedance from source to load.

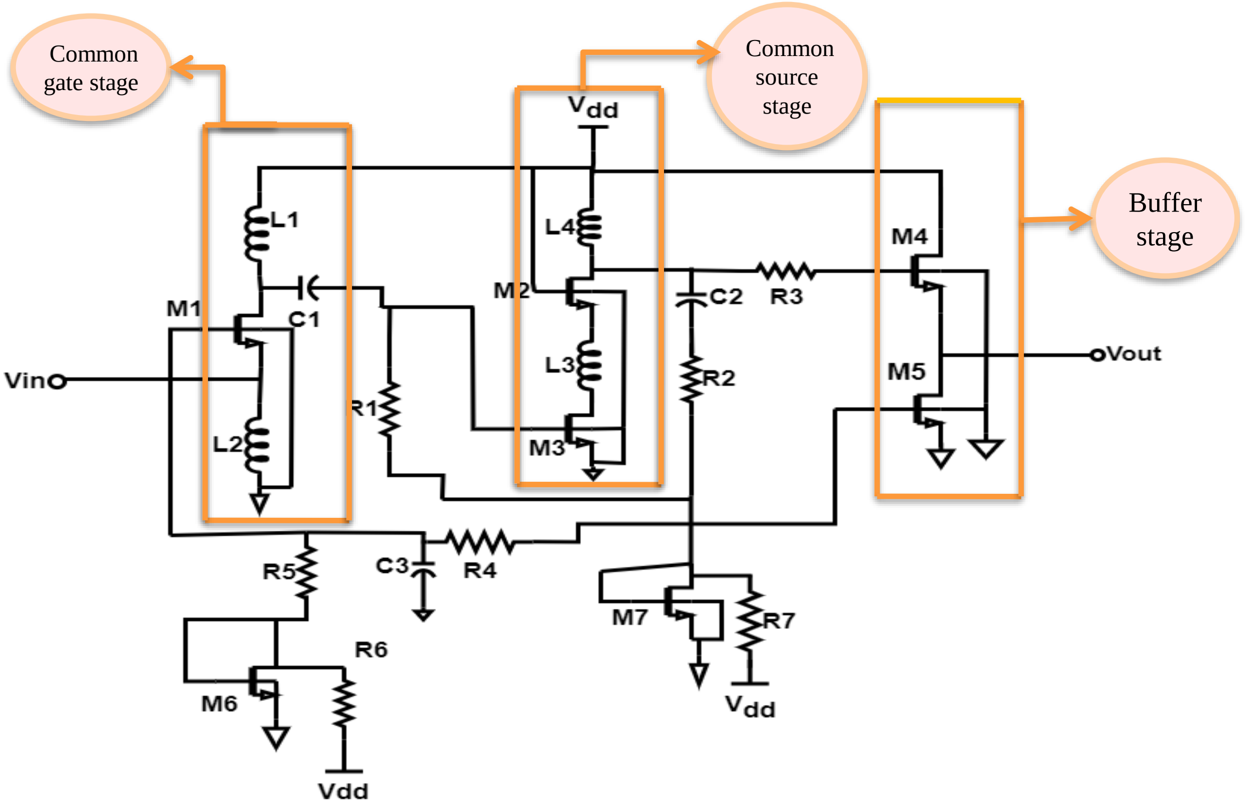
- At first, we have to determine the **input and output impedance** value which can be done using simulation tools.

- The performance of the matching network is analyzed using simulation and this analyze include **bandwidth, return loss, gain.**

Architecture of Proposed LNA



Designed LNA Circuit Analysis



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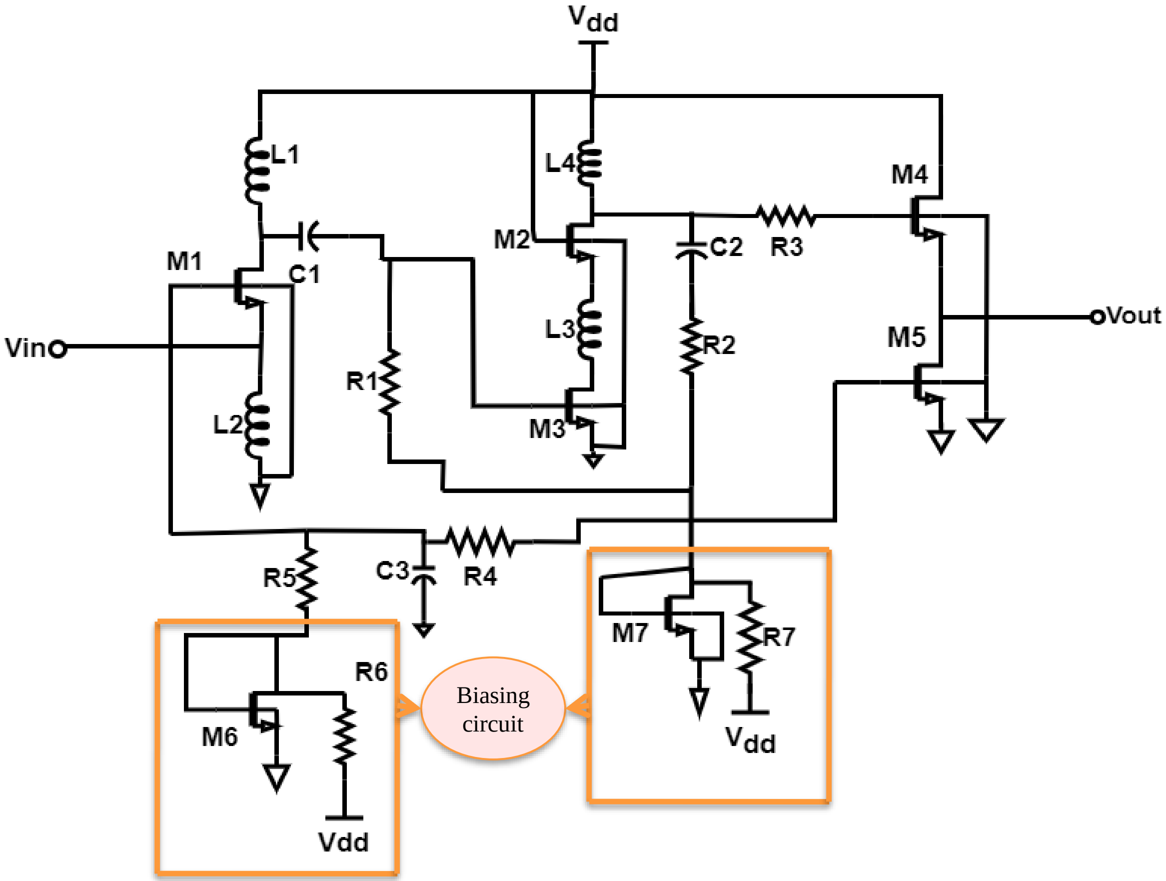
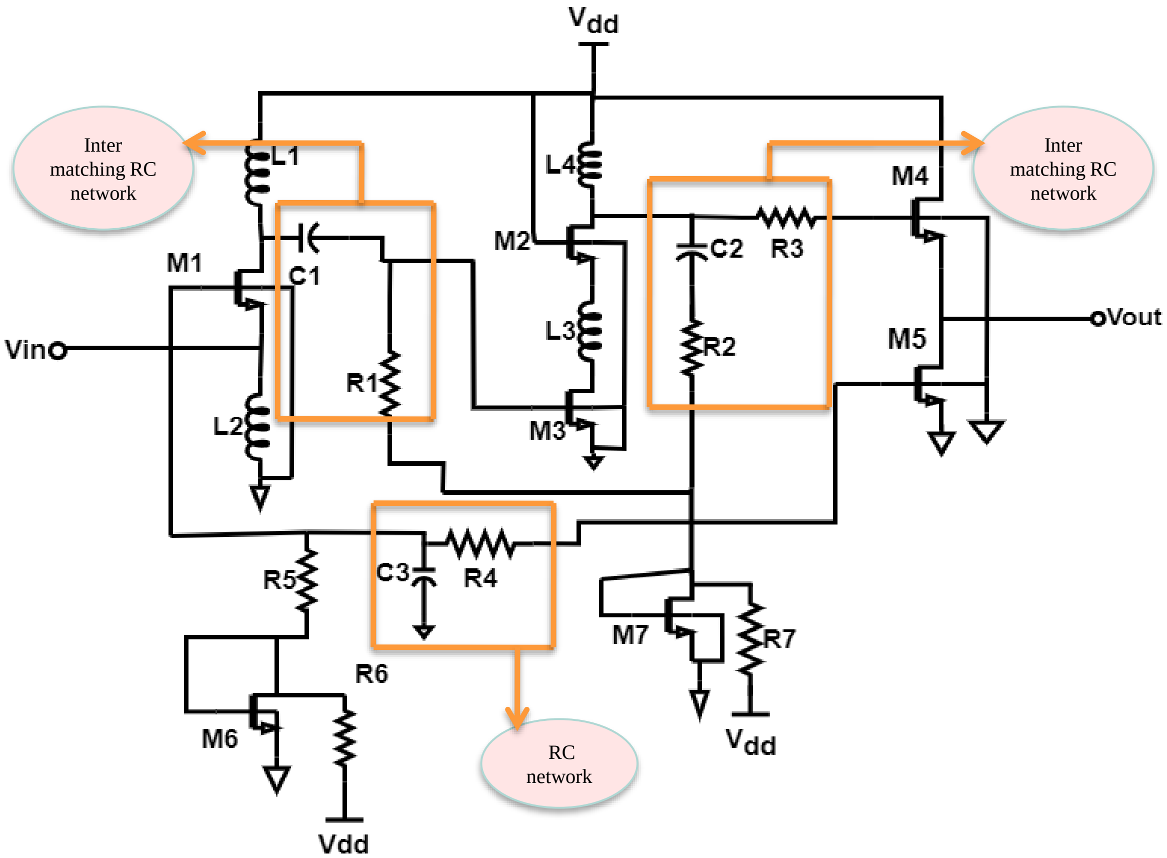
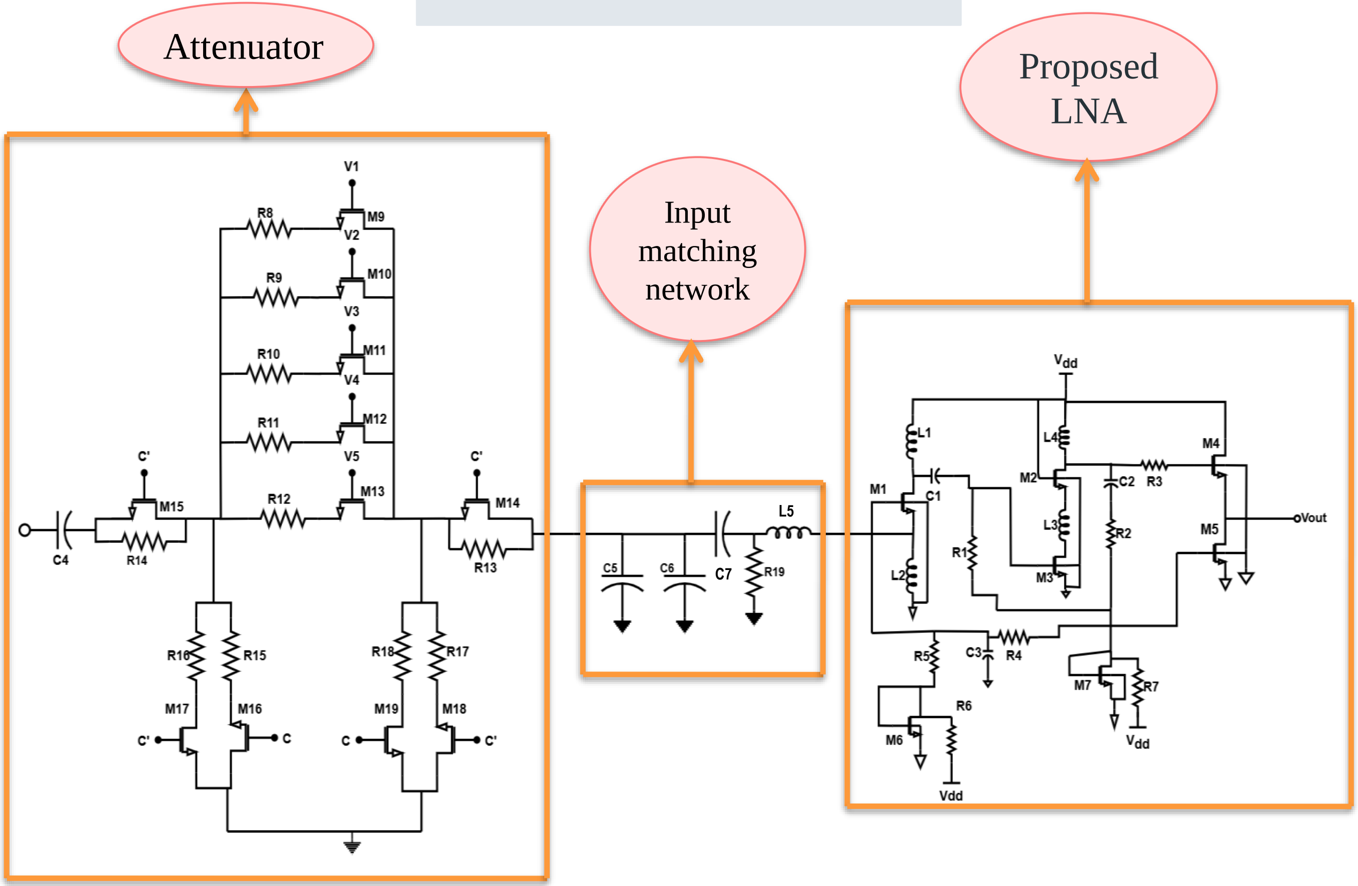


Designed LNA Circuit Analysis



Final Schematic



Results & Discussion

Key Findings

Our LNA **demonstrates excellent gain** of 29.21dB across the **operating frequency band**, ensuring reliable signal amplification.

We demonstrated **Superior linearity (IIP3)** results in minimal distortion, preserving signal integrity and enabling high-fidelity amplification.

Additionally, we achieved **exceptional stability** maintaining consistent performance even under varying input power levels.

Result Analysis : Power Gain

S_{21} VS Frequency

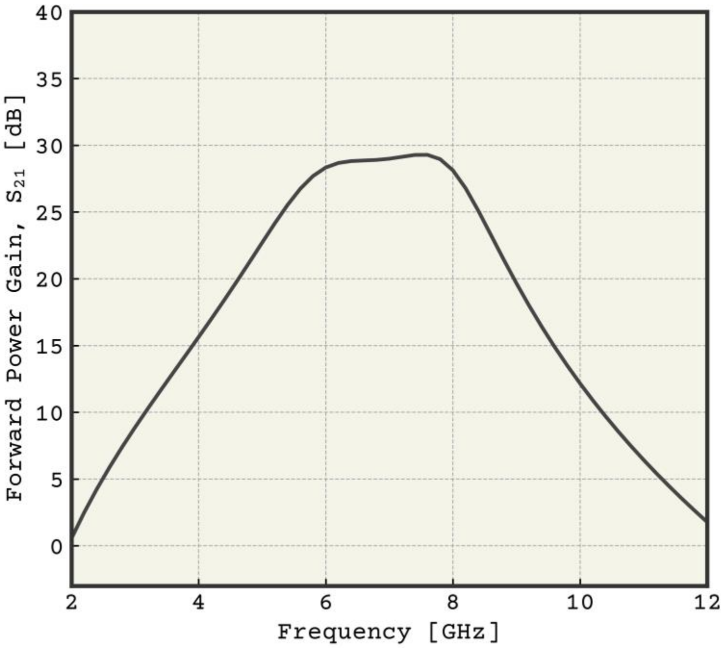


Figure 06: S21 parameter of a two-stage Low noise amplifier

Observation

Maximum value of **S21** parameter at **7.6 GHz** is **29.28 dB**

Showing a larger power gain(Output power is 631 times larger than the input power)

Result Analysis : Input Reflection Coefficient

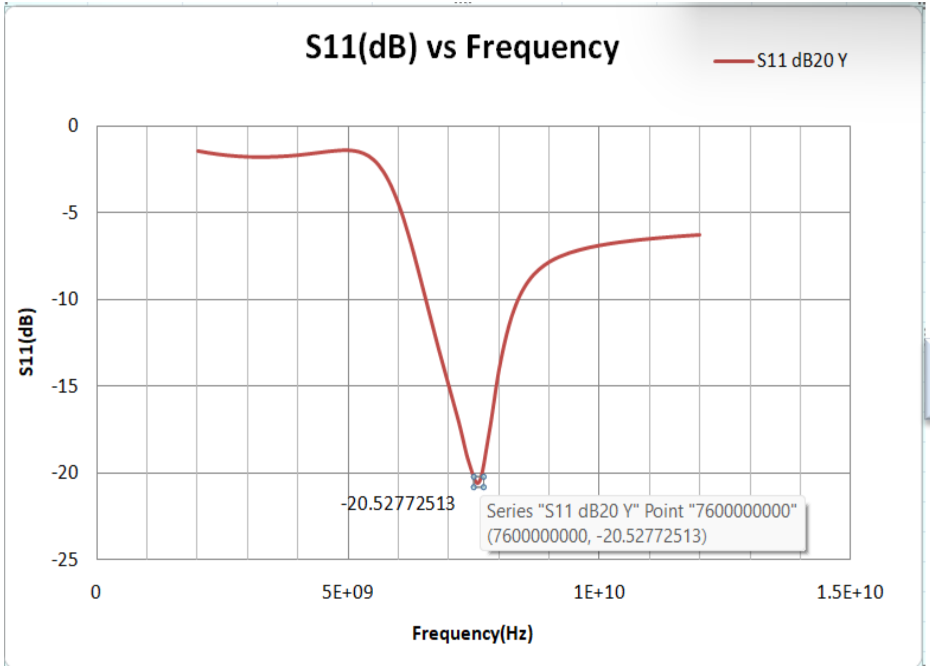


Figure 07: S11 parameter of a two-stage Low noise amplifier

Observation

The value of **S11** parameter at **7.6 GHz** is **-20.528** dB

Suggesting better input matching (Only small amount of power is reflected back at input port)

Result Analysis : Reverse Isolation

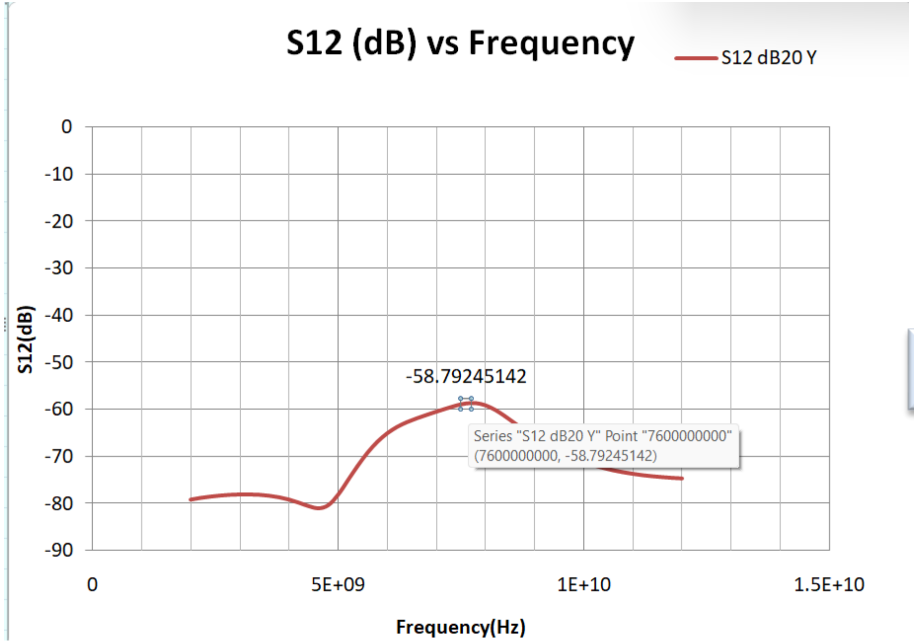


Figure 08: S12 parameter of a two-stage Low noise amplifier

Observation

The value of **S12** parameter at **7.6 GHz** is – **58.792 dB**

Showing good **reverse** isolation (little signal is leaking backward)

Result Analysis : Output Return Loss

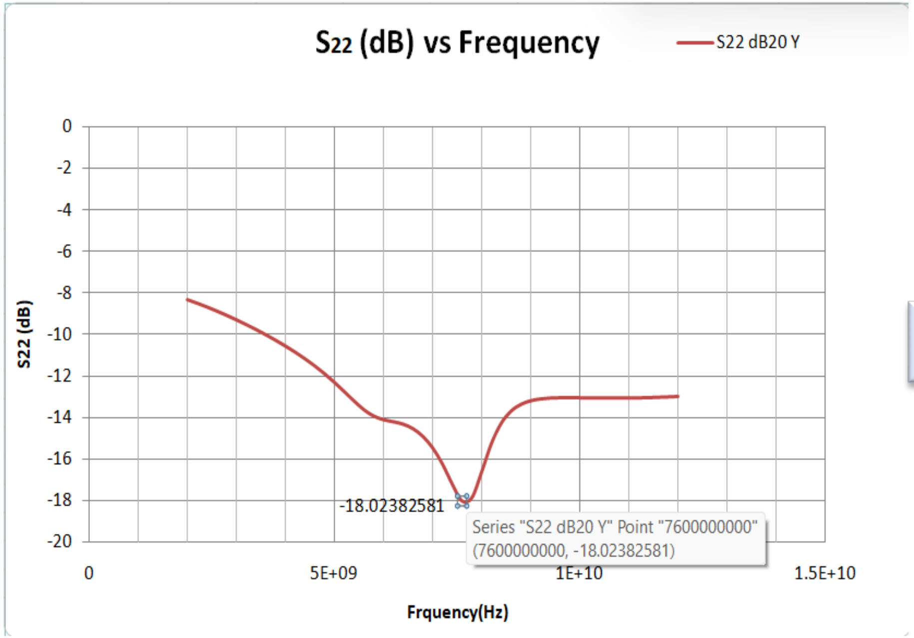


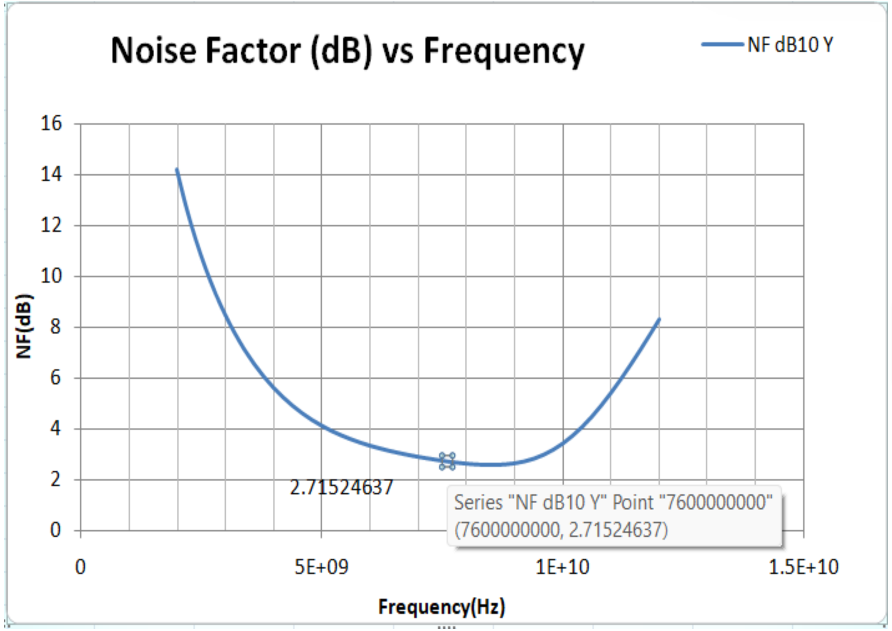
Figure 09: S22 parameter of a two-stage Low noise amplifier

Observation

The value of **S22** parameter at **7.6 GHz** is **-18.024 dB**

Indicating good output matching (minor amount of output power is reflected back at output port)

Result Analysis : Noise Figure



Observation

The value of Noise figure at **7.6 GHz** is **2.715 dB** (amplify signal without adding much additional noise)

Figure 10 : Noise parameter of a two-stage Low noise amplifier

Result Analysis : IIP3 (Linearity)

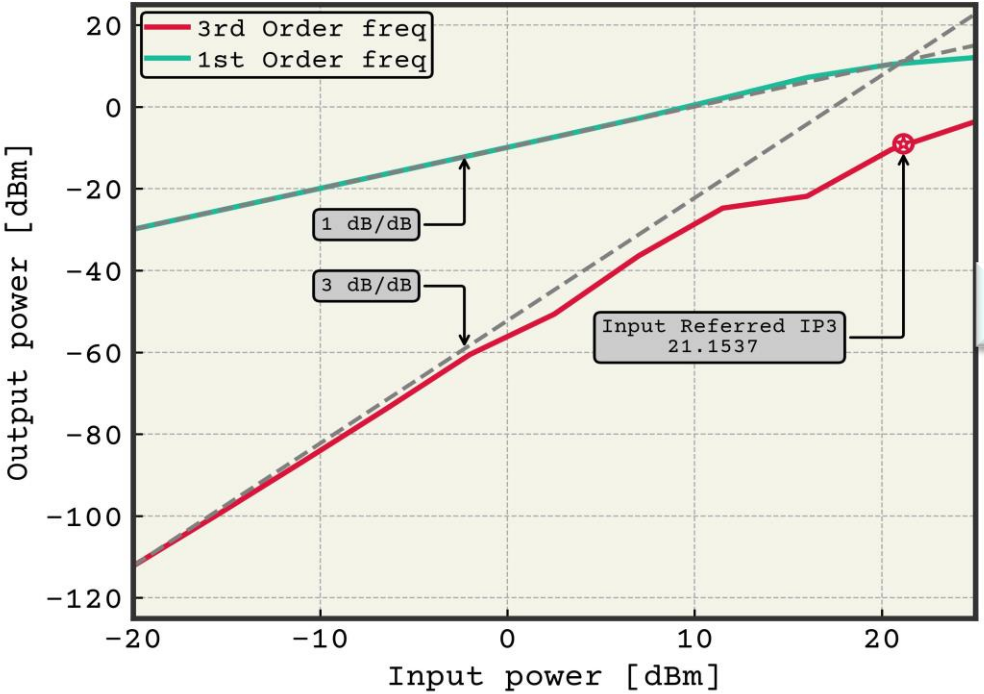


Figure 11: IIP3 (linearity result) of the proposed LNA

Observation

Here we found IIP3 is about **21.1537 dBm** which means that the proposed Low Noise Amplifier has **better linearity and less distortion.**

Result Analysis : Variable Power Gain

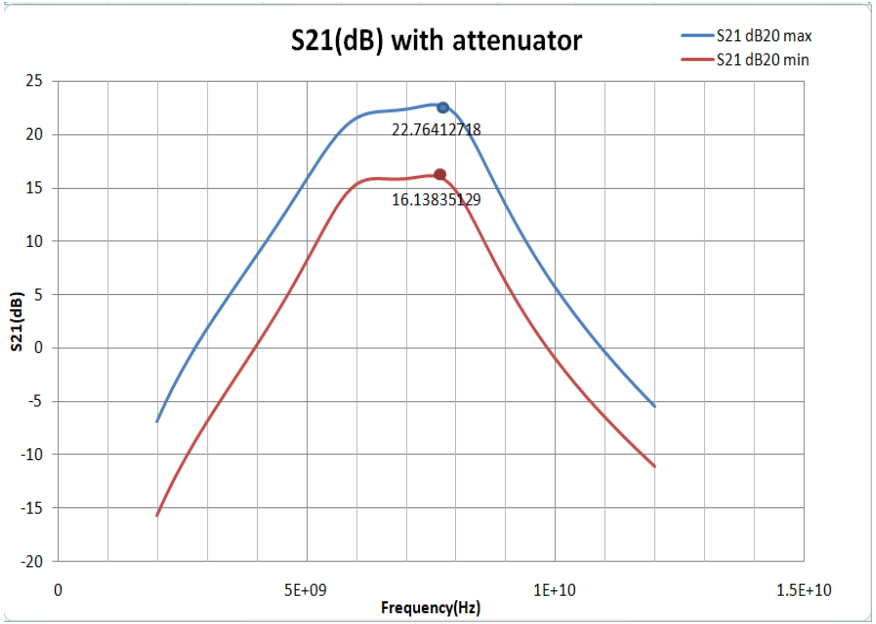


Figure 13: S21 parameter of a two-stage Low noise amplifier with attenuator

Observation

The value of S21 parameter at 7.6 GHz is verified from 15.97 dB to 22.7 dB

Showing good range of **variation** in power gain

Result Analysis : Variable Input Reflection Coefficient

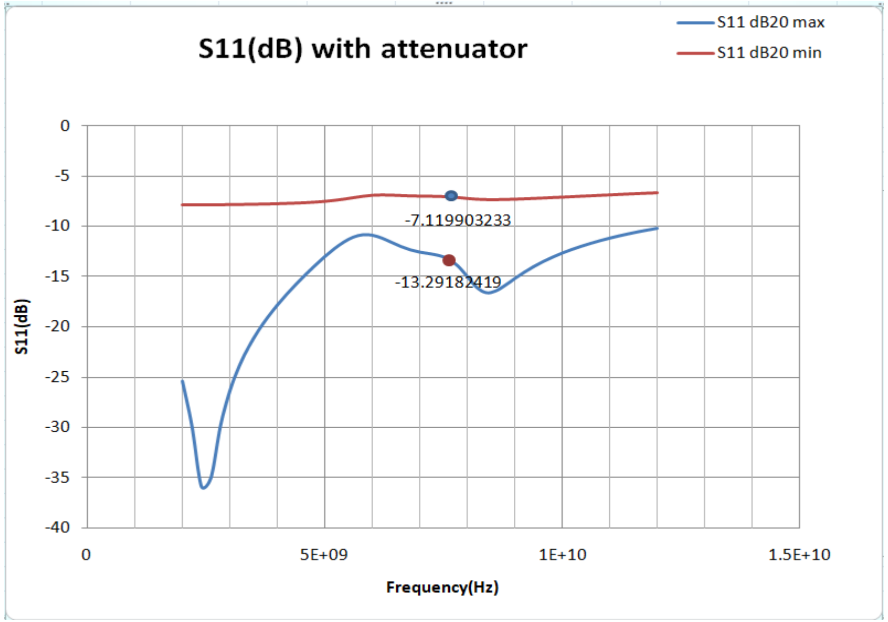


Figure 14: S11 parameter of a two-stage Low noise amplifier with attenuator

Observation

The value of S11 parameter at **7.6 GHz** is veried from **- 13.29 dB to -7.12 dB**

Suggesting **variable** better input matching

Result Analysis : Variable Reverse Isolation

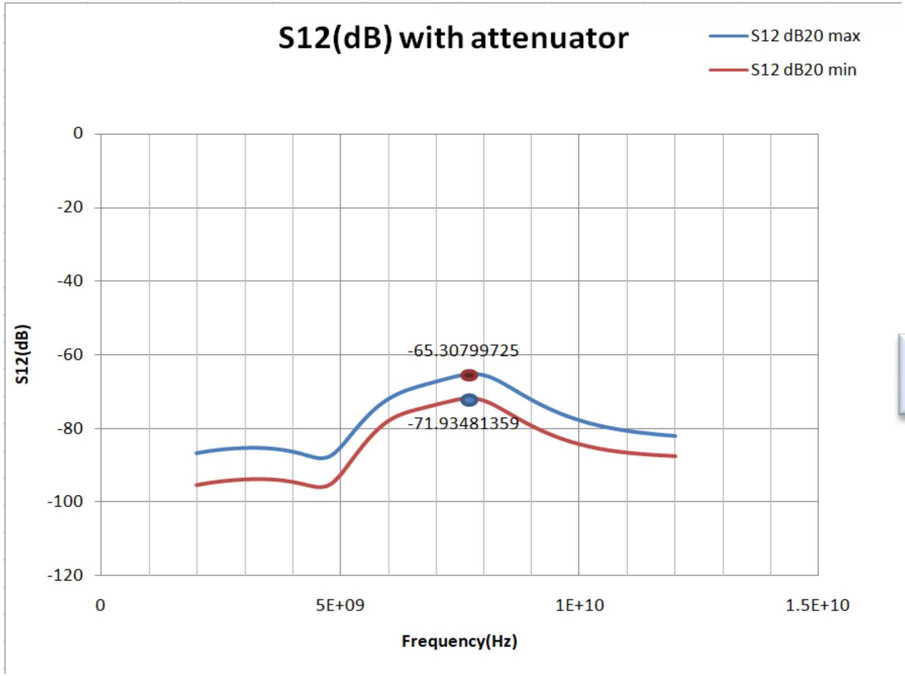


Figure 16: S12 parameter of a two-stage Low noise amplifier with attenuator

Observation

The value of **S12** parameter at **7.6 GHz** is **-71.935dB to -65.31dB**

Showing **variable** good reverse isolation

Result Analysis : Variable Output Return Loss

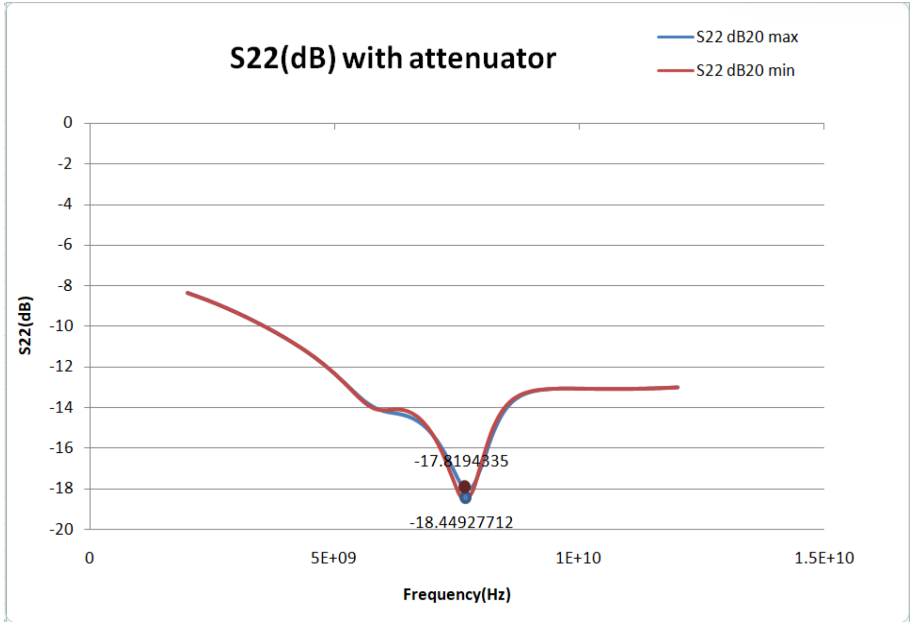


Figure 15: S22 parameter of a two-stage Low noise amplifier with attenuator

Observation

The value of S22 parameter at **7.6 GHz** is verified from **-18.45 dB to -17.82 dB**

Indicating **variable** good output matching

Result Analysis : Noise Figure (with Attenuator)

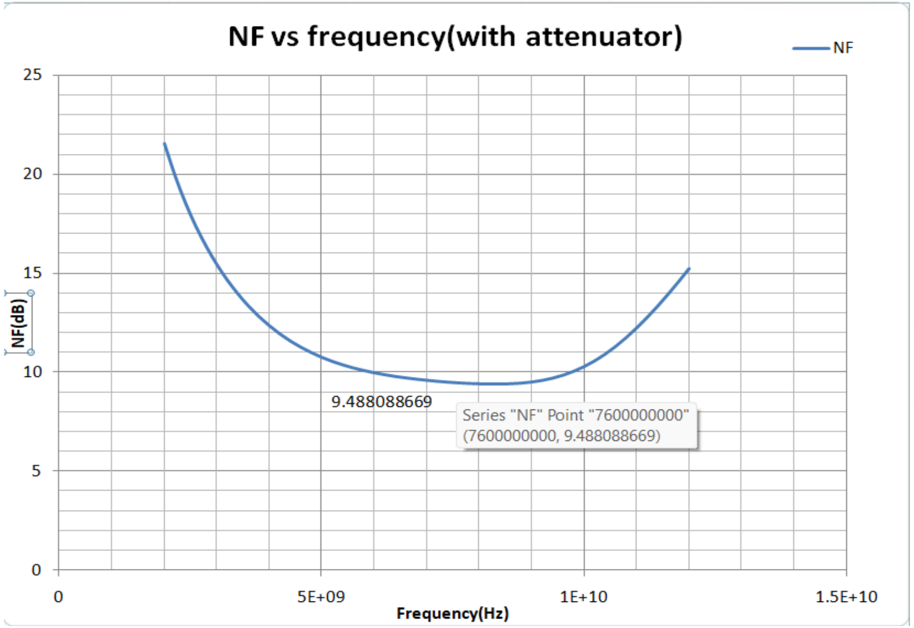


Figure 17: Noise parameter of a two-stage Low noise amplifier with attenuator

Observation

The value of Noise figure at **7.6 GHz** is **9.488 dB**

Conclusion

Research Summery

Performance parameter of the proposed LNA:

Parameters	This work (without attenuator)	This work (with attenuator)
Technology	90nm	90nm
Transistor Length	90nm	90nm
Supply Voltage	1.2V	1.2V
Operating Frequency	7.6(GHz)	7.6(GHz)
Gain(dB)	29.28	22.7
Power Dissipation	83 mW	83.45 mW
NF(dB)	2.715	9.488
Kf	10	

Considering the achieved performance, the proposed technique is suitable for the implementation of wideband LNAs in Biomedical application.

Contribution to the Work

Designed LNA

The designed low-noise amplifier (LNA) enhances the circuit's linearity, gain, improving noise immunity and Bandwidth over a wide frequency range.

Attenuator Integration

The attenuator adjusts the incoming signal level and enables variable gain to ensure the LNA operates within its optimal range.

Design Performance

The proposed LNA circuit incorporates an attenuator and a common-gate common-source (CG-CS) stage, which together optimize power consumption, gain control, noise performance, and bandwidth. Body biasing improves S-parameters, enhances gain and reduces output noise.

Comparison with Previous Work

Reference	CMOS Tech. (nm)	Supply Voltage	Gain (dB)	Frequency (GHz)	S11 (dB)	S12 (dB)	S22(dB)	IIP3 (dBm)
This Work (without attenuator)	90nm	1.2V	29.25	7.616	-20.31	-58.78	-18.01	21.1537
This Work (with attenuator)	90nm	1.2V	15.97-22.7	7.616	–13.52 to -7.08	-71.93 to -65.24	-18.34 to -17.86	
[2]	180	1.8V	13	2 - 5	< -10	—-	—--	−9.5
[8]	130	1.8V	17	0.05-0.83	< -8.9	—--	<-8.5	-6.3
[1]	180	1.8	16.1	0.1 - 1.4	< -9	—---	—---	13-18.9

Future Work

Designing the **Layout** of the proposed Low Noise Amplifier

Implementation and fabrication of the designed LNA

Real-World **Validation** and **Expansion**

References

[1] "A 0.1–1.4 GHz inductorless low-noise amplifier with 13 dBm IIP3 and 24 dBm IIP2 in 180 nm CMOS," Benqing Guo, Jun Chen, Hongpeng Chen and Xuebing Wang, Modern Physics Letters B, pp.1850009, vol. 32, no 2, January 20, 2018.

[2] "A wideband 2–5 GHz noise canceling subthreshold low noise amplifier," A.R. Aravinth Kumar,Bibhu Datta Sahoo and Ashudeb Dutta, IEEE Transactions on Circuits and Systems II: Express Briefs, pp. 834-838, vol. 65, no. 7, June 26, 2017.

[3] "A low power and high gain CMOS LNA for UWB applications in a 90 nm CMOS process." Sunil Pandey, Jawar Singh. Microelectronics Journal, vol. 46, no. 5, pp. 390-397, May 1, 2015.

[4] "Design of a 1-V 90-nm CMOS adaptive LNA for multi-standard wireless receivers" Becerra-Alvarez, E. C., Sandoval-Ibarra, F., & de La Rosa, J. M, Revista mexicana de física, pp. 322-328, vol. 54, issue. 4, 2015.

[5] "Noise suppression in a common-gate UWB LNA with an inductor resonating at the source node," Hossein Sahoolizadeh, Abumoslem Jannesari, Massoud Dousti, AEU International Journal of Electronics and Communications, vol. 96 , pp. 144-153 , November 1, 2018.

[6] "A Wideband Noise-Canceling CMOS LNA With Enhanced Linearity by Using Complementary nMOS and pMOS Configurations , " Benqing Guo, Jun Chen, Lei li, Haiyan Jin, Guoning Yang, IEEE Journal of Solid-State Circuits, pp. 1331-1344, vol. 52, no. 5, May 4, 2018.

[7] "A Low Power Low Noise Amplifier for Biomedical Applications , " Deepansh Dubey, Anu Gaupta, *2015 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, pp. 1-6, vol. 52, no. 5, March 5, 2015.

[8] "50–830 MHz noise and distortion canceling CMOS low noise amplifier," Sana Arshada, Rashad Ramzanb, Qamar-ul Wahabc, Integration, pp.63-73 vol. 60, January 1, 2018.

[9] Bal, Ayşe Rana, “Design and optimization of a sub - 1dB noise figure low noise amplifier for magnetic resonance applications using CMOS technology," PhD diss., December 2024.

Image Sources

- https://maurymw.com/applications/noise-figure-noise-parameters-extraction/
- https://www.linkedin.com/pulse/development-wireless-communication-sriram-s-aqzsc/
- https://pixabay.com/vectors/antenna-parabolic-reflector-307223/
- https://cgaxis.com/product/mri-scanner/
- https://www.microwavejournal.com/articles/40855-teledyne-e2v-hirel-releases-ultra-low-noise-amplifier-for-space-applications
- https://www.aliexpress.us/item/3256802720168498.html?gatewayAdapt=glo2usa4itemAdapt

Thank You

Please let us know if you have any questions !