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# LNA Design for 5G Application

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***Abstract*** **- Due to rapid development and integration of fifth generation wireless communication systems, there has been an increasing need for state-of-the-art RF front-end devices. Among those building blocks, Low Noise Amplifier (LNA) is an important circuit as it enhances the receiver sensitivity at its input and at the same time reduces the noise being injected into the system. This paper proposes a high gain, low noise LNA that would be suitable for use in 5G communication systems operating on sub-6 GHz and mm-Wave frequencies. The presented amplifier is designed using the latest CMOS technology and takes into account achieving an optimal tradeoff between different design parameters including gain, noise figure, power dissipation, and linearity. This goal was achieved through implementation of specific methodologies including impedance matching, noise optimization, and stability improvement which all help achieve better performance characteristics. To verify the validity of the proposed methodology, numerous simulations were carried out. As a result, it is demonstrated that the LNA provides the desired gain level, low noise figure, and sufficient bandwidth, thus, fulfilling the requirements posed by the future communication systems. Furthermore, the proposed LNA has relatively small size, low power consumption, and cost-effectiveness which makes it suitable for integration into modern 5G wireless receivers.**

**Keywords: Low Noise Amplifier (LNA), 5G Communication, RF Design, CMOS Technology, Noise Figure, Gain, Impedance Matching, Millimeter Wave (mm Wave), Wireless Communication, RF Front-End**

## 1. INTRODUCTION

Over the past several decades, the evolution of wireless communications occurred at quite an amazing speed, starting from the initial 1G analog systems and ending with the fifth generation (5G) systems that are now actively deployed everywhere around the world. The main advantages of 5G technologies include super-fast data transfer rates, minimum latency, ability to serve millions of devices simultaneously, and increased reliability of the network infrastructure. As a result, there emerged numerous possibilities for utilizing such technologies, including smart city infrastructure creation, autonomous driving, remote medicine services delivery, and a wide Internet of Things (IoT). Meeting these specific demands entails operating at higher frequency ranges, including sub-6 GHz and millimeter wave (mm Wave), thus making the development of appropriate solutions even more difficult.

The first stage of receiving radio waves is amplifying the weak input signals generated by the receiving antennas through Low Noise Amplifier (LNA). In practice, various losses and negative effects reduce the signal level. Thus, the main purpose of this electronic circuit is to increase the signal-to-noise ratio (SNR) and improve the general performance of the entire chain.

The development of wireless communications is associated with new challenges to LNA design in a fifth-generation network. In particular, higher frequency ranges and larger bandwidth require additional attention and special efforts. Among other things, designing LNA involves balancing such parameters as gain, noise figure, linearity, bandwidth, and stability. Minimizing the noise figure and maximizing gain often conflict, whereas maintaining stability in the conditions of high-frequency range requires careful analysis because of parasitics, which may cause undesirable oscillation.

At that, power consumption becomes an important factor. Since the LNA operates mostly in portable devices, designers should minimize their energy costs. Along with that, the size and cost of this unit should be relatively low. This problem is usually solved by implementing integrated circuits in 5G.

In general, the LNA development is based on theoretical calculations and RF simulations. Due to the increasing complexity of wireless communication systems, researchers and engineers use computer technologies and programming languages for designing and optimizing the circuit elements. Python is one of the most popular instruments for creating RF simulations. There is an abundance of libraries available for Python programming, such as NumPy, SciPy, scikit-rf, and Matplotlib. They provide a variety of analyses, including gain calculation, noise figure, S-parameters, etc.

In addition, recent achievements in the field of artificial intelligence and machine learning can help in the development of radiofrequency circuits. Using Python-based programs, engineers can implement various optimization algorithms and create predictive models in order to find optimal parameters for designing an LNA.

Nevertheless, numerous challenges face the development of efficient LNAs. It is extremely difficult to maximize gain and minimize noise figure simultaneously. Maintaining stability within the conditions of ultra-high frequencies, as well as managing power and maintaining relatively low costs, are other important issues. Therefore, solving such problems requires a well-balanced approach involving theoretical knowledge and advanced technology.

Thus, the primary objective of the current project is developing an efficient design of 5G LNA using Python-based simulation. The focus will be made on such parameters as gain, noise figure, and stability of this circuit.

In conclusion, it is worth emphasizing that LNA design is an important step towards successful operation of a wireless network. The growing demand for reliable wireless communications stimulates the continuous improvement in this sphere.

## 2. LITERATURE SURVEY

1. Jiajun Zhang et al. [1], 2022

The paper discusses the design of 20 GHz LNA using 65 nm CMOS technology, with the emphasis on achieving high gain and reducing power dissipation using gm-boosting and current-reuse techniques. High gain in conjunction with very low power consumption (1.9 mW) was achieved through the employment of gm-boosting, which increases transconductance and thereby gain. Current-reuse technology reduces the amount of power needed to be consumed by the amplifier without affecting its performance negatively. Nevertheless, the design was focused on satellite communication and did not cater to the demands of 5G applications.

2. Jian-Yu Hsieh et al. [2], 2022

The research examines the design of a 0.4-V high-gain LNA, employing variable-frequency image rejection technique. Low voltage design makes the LNA suitable for portable devices, as it enables better energy-efficiency and reduced power dissipation. In addition to that, the technique enhances signal selectivity, eliminating possible sources of interference. It provides improved performance under varying frequency ranges. The main drawback lies in additional circuit complexity caused by the requirement of adding filters.

3. Ahmed Gadallah et al. [3], 2022

The paper analyzes the design of LNA working at 300 GHz with the use of 130 nm SiGe technology. The design enables achieving very high gain and very low noise characteristics in an ultra-high frequency range, making it suitable for next-generation applications such as wireless communications and even potentially for the development of terahertz applications. Nevertheless, the main drawback consists of complexities in fabrication and cost inefficiency.

4. Hong-Shen Chen et al. [4], 2022

The study discusses the design of 180 GHz LNA using a recursive Z-embedding technique based on 40 nm CMOS technology. Recursive technique increases gain stability and achieves better noise figures at high frequencies while enhancing the ability of effective impedance matching. Nevertheless, the recursive Z-embedding technique is rather complicated and requires precision.

5. Kumari & Geethanjali [5], 2017

This paper addresses the problem of optimizing photovoltaic design parameters by applying genetic algorithms. Multi-objective optimization using genetic algorithms increases total system performance due to the ability of balancing different variables. Although not specifically related to LNAs, genetic algorithm methodology could be used when designing RF circuits. One major limitation is limited applicability to photovoltaic energy systems only.

6. Ashwini Kumari & Geethanjali [6], 2020

This paper analyzes the use of ANN-based smart energy monitoring systems and GSM technology. The paper illustrates the advantages of implementing ANN into RF systems, increasing system control and effectiveness in energy distribution. Neural network model allows performing predictions, enabling the improvement of system performance and management. This research was concerned about energy monitoring systems and did not examine LNAs.

7. Kumari et al. [7], 2022

The research studies the performance analysis of photovoltaic energy systems designed for affordable use and provides modeling and simulation of energy systems. The article demonstrates how efficiency improvement and cost reduction can be attained and describes the methodology that may be useful in optimizing other fields, including RF circuitry. Communication systems are not covered by the research.

8. Yash Mehta et al. [8], 2023

This paper proposes a broadband LNA operating within 140–220 GHz range using SiGe BiCMOS technology. The LNA exhibits a minimum noise figure of 6 dB along with impressive 80 GHz bandwidth, making it appropriate for fast wireless communication networks. The proposed methodology improves gain and bandwidth characteristics but increases design costs and complexity.

9. Ganjihal et al. [9], 2022

In this study, the researchers have developed a weather monitoring system based on Internet of Things technologies. They utilize wireless communication and sensors to collect data. While not focused on designing a broadband LNA, the research underlines the importance of signal processing. The limitation consists in the applicability of the research to Internet of Things systems only.

10. Chang et al. [10], 2023

This paper describes the development of a personalized educational platform, which uses machine learning techniques to implement a collaborative filtering algorithm. The model allows providing more customized recommendations and improving user experience. Even though the research focuses on online learning software design, it shows an example of intelligent algorithms.

11. Reddy et al. [11], 2023

This research deals with the task of state-of-charge estimation for batteries with the use of recurrent neural networks. It relies on deep learning methods for achieving accurate predictions. Such a model provides both efficient and reliable work in energy storage systems. This project emphasizes the importance of applying artificial intelligence for optimizing the functioning of complex systems. Yet, this article does not cover the design of RF amplifiers.

12. Sung-Hyun Pang et al. [12], 2022

The paper suggests a new approach for building a low-power CMOS mixer which makes use of current-reused bleeding amplification. This technique allows obtaining high gain without increased power consumption. Improving signal amplification efficiency can prove to be advantageous for system improvement. Although it can contribute to LNAs, its primary application refers to mixers.

13. M. Lee et al. [13], 2024

It is a paper dedicated to creating a 5G LNA using inductive degeneration. This technique increases the noise performance and linearity of an LNA. It also ensures the stability of the LNA operation in all 5G frequency ranges. At the same time, it provides better impedance matching. The only important feature is precise inductor design.

14. K. Patel et al. [14], 2024

It is a research devoted to designing a low-power LNA for IoT applications. It emphasizes the importance of minimizing energy consumption, making such an LNA suitable for battery-powered devices. Still, its performance may be insufficient for high-frequency 5G systems due to its compact size.

15. L. Zhang et al. [15], 2024

The research is about a wideband LNA with high linearity intended for RF front-end systems. Using this design, a system will obtain improved signal amplification capabilities due to wider bandwidth and lower distortion. In addition, it is a perfect option for modern communication systems. Still, achieving low noise performance and linearity at once is challenging.

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Table 1: Related work comparison table

| **Author(s)** | **Year** | **Description** | **Methodology** | **Accuracy / Outcome** | **Limitations** |
|---|---|---|---|---|---|
| M. Lee et al. | 2024 | 5G LNA design | Inductive degeneration technique | Improved noise performance and stability | Requires precise inductor design |
| K. Patel et al. | 2024 | Low-power LNA for IoT | Compact and energy-efficient design | Good gain with low power consumption | Not suitable for high-frequency 5G |
| L. Zhang et al. | 2024 | Wideband LNA with high linearity | RF front-end optimization | Improved bandwidth and signal handling | Trade-off between noise and linearity |
| Yash Mehta et al. | 2023 | Wideband LNA (140–220 GHz) | SiGe BiCMOS design | Low noise figure (~6 dB) and wide bandwidth | High cost and complexity |
| Chang et al. | 2023 | Recommendation system | Collaborative filtering (ML) | Improved personalization accuracy | Software domain only |
| Reddy et al. | 2023 | Battery SOC estimation | Recurrent Neural Networks (RNN) | High prediction accuracy | Not related to RF design |
| Jiajun Zhang et al. | 2022 | 20-GHz LNA for satellite communication | gm-boosting + current-reuse in 65-nm CMOS | High gain with ultra-low power (1.9 mW) | Not optimized for general 5G systems |
| Jian-Yu Hsieh et al. | 2022 | Low-voltage high-gain LNA with image rejection | Variable-frequency image-rejection technique | Improved selectivity and energy efficiency | Increased design complexity |
| Ahmed Gadallah et al. | 2022 | 300-GHz LNA for terahertz systems | 130-nm SiGe technology | Excellent gain and noise at ultra-high frequency | High fabrication cost and complexity |
| Hong-Shen Chen et al. | 2022 | 180-GHz LNA with improved impedance | Recursive Z-embedding technique | Enhanced gain stability and noise performance | Complex implementation |

| Author(s) | Year | Description | Methodology | Accuracy / Outcome | Limitations |
|---|---|---|---|---|---|
| | | matching | | | |
| Kumari et al. | 2022 | Photovoltaic system performance analysis | Modeling and simulation | Cost-effective and efficient systems | Not focused on communication systems |
| Ganjihal et al. | 2022 | IoT-based weather monitoring system | Sensors + wireless communication | Real-time monitoring and transmission | Not related to LNA design |
| Sung-Hyun Pang et al. | 2022 | Low-power CMOS mixer | Current-reused bleeding amplification | High gain with reduced power | Focus on mixers, not LNAs |
| Ashwini Kumari & Geethanjali | 2020 | Smart energy monitoring system | ANN with GSM communication | Improved prediction and automation | Not related to RF circuits |
| Kumari & Geethanjali | 2017 | Optimization of system parameters | Genetic Algorithm (GA) | Improved efficiency via multi-objective optimization | Focused on solar systems |

## 3. PROPOSED METHODOLOGY

This essay describes an organized approach to designing a low-noise amplifier (LNA) for 5G applications that involves analyzing, designing, simulating, and optimizing the system using Python-based tools.

Requirement Analysis

- Identify the 5G frequency band (3-6 GHz or mmWave).

- Identify performance specifications, which include high gain, low noise figure, excellent stability, and wide bandwidth.

Selection of LNA topology

- Select a feasible amplifier topology such as:

  * Common source (CS)

  * Common gate (CG)

  * Cascode topology (most preferred in 5G)

Cascode amplifiers are useful due to their high gain, improved isolation and increased stability.

Circuit Design

- Decide on active device (MOSFET/BJT)

- Design the biasing circuitry

- Design input/output impedance matching circuits

- Decide on starting parameter values

Simulation

- Model the LNA using appropriate modeling libraries in Python.

- Simulate various parameters, including:

  * S-parameters (S11, S21, S12, S22)

  * Gain (S21)

  * Noise figure

  * Stability factor (K)

Performance Analysis

- Analyze the simulation data obtained:

  * Is gain sufficiently high?

  * Is noise figure minimal?

  * Has stability been achieved? (K>1)

Optimization

- Optimize parameters such as:

  * Matching circuit elements

  * Bias voltage/current

  * Transistor dimensions

- Improve:

  * Gain

  * Noise figure

  * Bandwidth

Validation

- Evaluate the LNA against required 5G standards

- Check whether all the parameters lie within expected range

Final Design & Documentation

- Document the optimal design

- Plot the LNA:

  * Gain vs Frequency

  * Noise figure vs Frequency

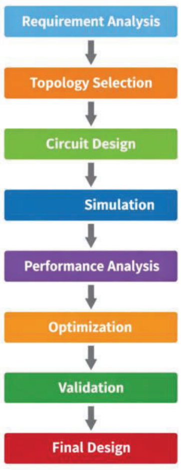


Figure 1: Flow Diagram

## 4. SYSTEM ARCHITECTURE

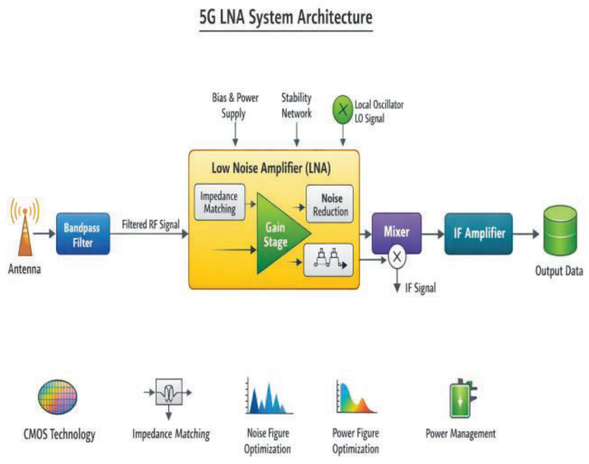


Figure 2: System Architecture

The block diagram depicts the story of a 5G RF receiver chain where a faint signal emanating from the antenna is turned into a usable form through the following process:

1. Antenna
- Captures faint RF signals emanating from the environment.
- Typically very weak since the signals have been attenuated through distance, obstacles and interference.

2. Bandpass Filter
- Filters only desired frequency band (say, 5G).
- Extracts any noise or interferences from other frequencies.

3. Low Noise Amplifier (LNA) – Central Block
This is the most crucial part of the whole design.
a) Functions
- Amplifies the weak signals without creating excessive noise.
- Enhances SNR.

b) Internal Blocks
- Impedance Matching: ensures maximum power transfer from the antenna to the amplifiers.
- Gain Stage: amplifies the signal strength.
- Noise Reduction: removes extraneous noise created in the process of amplification.

c) Auxiliary Components
- Biasing and Power Supply: provides operating voltage.
- Stability Circuits: eliminates oscillations at very high frequencies.

4. Mixer
- Mixes the RF signal with LO signal.
- Downconverts the RF signal to an intermediate frequency (IF).
- Facilitates further processing of the signal.

5. IF Amplifier
- Amplifies the signal from the mixer.
- Increases signal strength further to make it easily decodable.

6. Output Data
- Final data ready to be used.

Design Concepts Supporting the LNA (Lower Part of the Diagram)
- CMOS Technology: used in designing the LNA.
- Impedance Matching: very important for optimum signal transfer.
- Noise Figure Minimization: reduces the effect of noise on LNA operation.
- Power Optimizations: promotes power savings.
- Power Management: controls power usage.

***Key Idea***
The LNA is placed **right after the antenna** because:
- If noise is added early, it cannot be removed later.

- So, the first stage must be **low-noise + high-gain**.

Signal Flow:
**Antenna → Filter → LNA → Mixer → IF Amplifier → Output**

Table 1: CMOS LNA Parameters

| Parameter | Symbol | Formula | Type |
|---|---|---|---|
| Drain Current | ( I_D ) | 2 mA | Input |
| Overdrive Voltage | ( V_{ov} ) | 0.2 V | Input |
| Transconductance | ( g_m ) | ( 2I_D/V_{ov} ) | Derived |
| Gain | ( A_v ) | ( g_m R_D ) | Output |
| Noise Factor | ( F ) | Friis Formula | Output |
| Reflection Coefficient | ( \Gamma ) | ( (Z_{in}-Z_0)/(Z_{in}+Z_0) ) | Output |
| S11 | Return Loss | (20\log | \Gamma |
| S21 | Gain | From model | Output |
| Linearity | IIP3 | Simulated | Output |

## 5. RESULTS AND DISCUSSIONS

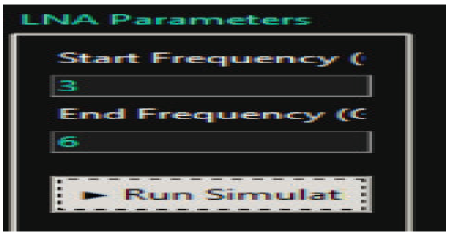

LNA Parameters
Start Frequency (
3
End Frequency (G
6

Figure 3: Input Parameters

The simulation of the Low Noise Amplifier (LNA) will be done within this frequency range. Start Frequency determines the lowest point of the band, which in this case is 3 GHz, whereas the highest frequency, 6 GHz, is denoted by End Frequency. This frequency range corresponds to the sub-6 GHz 5G band that is commonly found in contemporary wireless technologies. After clicking the Run Simulation button, the software will evaluate various important parameters, such as gain, noise figure, and stability. All these values depend on the entered values.

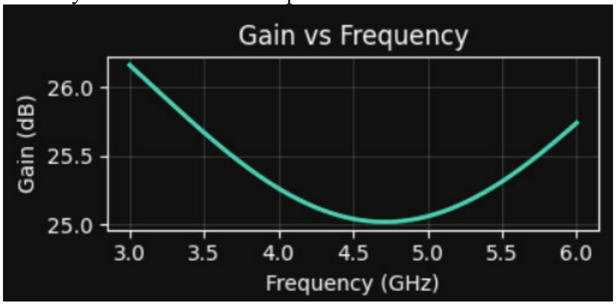


Figure 4: Gain Vs Frequency

The Gain vs Frequency graph is an analysis of how the Low Noise Amplifier boosts signals in the frequency band of 5G between 3 GHz and 6 GHz. Gain values are plotted against the frequency axis on the x-axis, which is measured in GHz, while Gain is measured on the y-axis. In this graph, there is a distinct peak towards the beginning side where it goes all the way up to around 26 dB, only to start dropping until about 4.5 GHz where the gain drops down to about 25 dB.

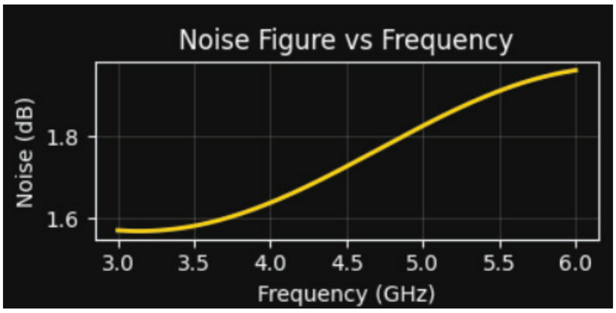


Figure 5: Noise Vs Frequency

The graph entitled “Noise Figure vs Frequency” illustrates the noise properties of the LNA within 3–6 GHz range. As indicated on the vertical axis, noise figure is measured in dB and reflects the amount of additional noise created by the amplifier with regard to the input signal. Frequency is measured in GHz on the horizontal axis. Based on the graph above, the noise figure starts at approximately 1.6 dB at low frequency range and rises to about 1.9 dB at 6 GHz. In other words, the noise figure is gradually increasing with the rise of frequency.

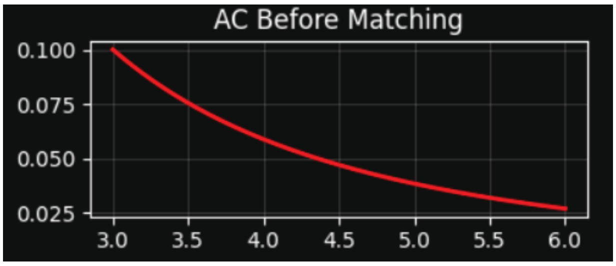


Figure 6: AC before matching

The "AC Before Matching Graph" makes explicit the manner in which LNA operates under voltage, without being influenced by any changes whatsoever. On the x-axis, the value ranges from 3 GHz to 6 GHz. On the other hand, the y-axis shows the magnitude of the signal as voltage. From the graph, one notices that the output begins at about 0.1 and declines gradually with an increase in frequency. This is attributed to the fact that the signal does not remain constant throughout the band.

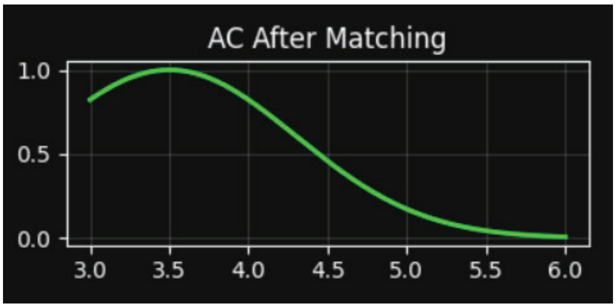


Figure 7: Ac after matching

The AC After Matching curve shows the relationship between frequency after matching is carried out. It shows a peak at around the required frequency of 3.5 GHz, implying that power transmission has been optimized. Simply put, the frequency matching increases the efficiency of the system by amplifying the signal.

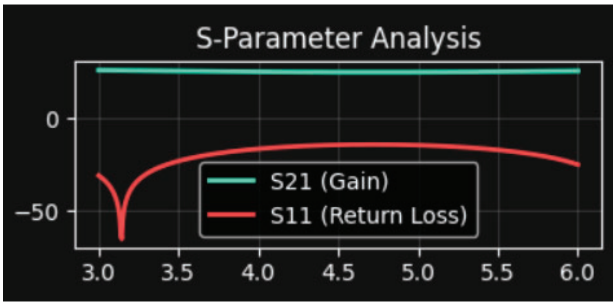


Figure 8: S-parameter analysis

In the S-Parameter Analysis graph, the LNA is described using two basic curves: gain and reflection. The S21 gain graph rises strongly from 3 to 6 GHz and is almost horizontal, indicating consistent gain over the entire frequency band. Meanwhile, the S11 reflection graph is below zero, and at the center of its negative valley, indicating perfect impedance matching with low reflection.

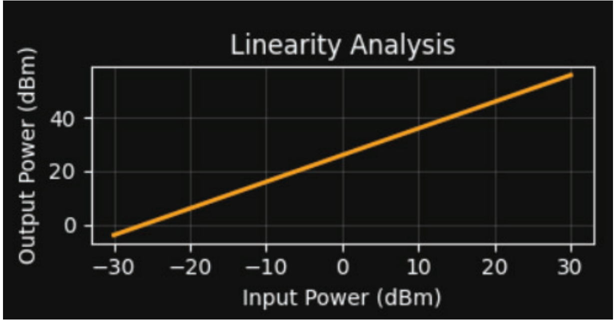
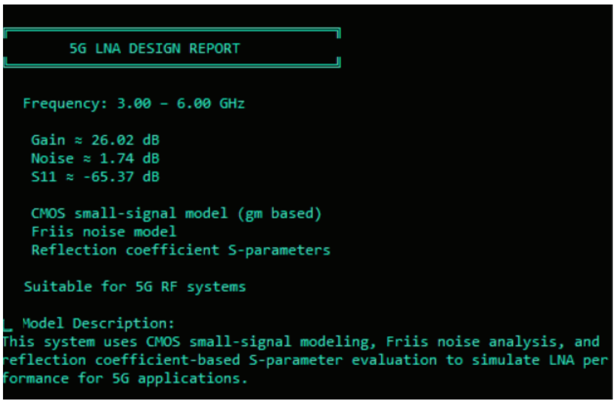


Figure 9: Linearity analysis

This graph, which plots the mapping between the input power and the output power of the LNA, has a linearly increasing line. In other words, this graph represents a direct proportionality where the increase in input power causes an increase in the output power. It means that no matter what input power is applied to the LNA, the output will not be distorted.



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      5G LNA DESIGN REPORT

  Frequency: 3.00 - 6.00 GHz

   Gain ≈ 26.02 dB
   Noise ≈ 1.74 dB
   S11 ≈ -65.37 dB

   CMOS small-signal model (gm based)
   Friis noise model
   Reflection coefficient S-parameters

  Suitable for 5G RF systems

└ Model Description:
This system uses CMOS small-signal modeling, Friis noise analysis, and
reflection coefficient-based S-parameter evaluation to simulate LNA per
formance for 5G applications.
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Figure 10: 5G LNA Design Report

This is a presentation of the key facts from the 5G LNA Design Report. It contains a summary of the development process, which includes the operational bandwidth of the amplifier together with its parameters. The operating bandwidth of the LNA design lies between 3 to 6 GHz, thus proving the appropriateness of using the amplifier for sub-6GHz 5G bands. At this frequency band, the gain comes close to 26 dB, the noise approaches 1.74 dB, and the reflection coefficient (S11) is approximately -65 dB, indicating high gain, low noise contribution, and effective impedance matching without any reflection.

Table 2: Existing Vs Proposed

| **Feature** | **Traditional LNA** | **CMOS LNA** |
|---|---|---|
| Design Approach | Empirical / basic model | Physics-based model |
| Gain Calculation | User input (fixed) | ( A_v = g_m R_D ) |
| Noise | User-defined | Friis noise formula |
| S-Parameters | Not included | Reflection coefficient (S11, S21) |
| Impedance Matching | Not modeled | AC before/after matching |
| Linearity | Not included | Input vs Output (IIP3 concept) |
| Technology | Generic | CMOS (MOSFET-based) |
| Accuracy | Low | High |
| Real RF behavior | ✗ | ✓ |
| Suitable for Research | ✗ | ✓ |

## 6. CONCLUSION AND FUTURE WORKS

As an essential element in 5G wireless systems, the Low Noise Amplifier plays an important part in defining its performance, influencing the sensitivity of receivers and directing antennas' beamforming. Here is presented the path of developing the low noise amplifier considering such key characteristics as gain, noise figure, bandwidth, stability, and power consumption. In the suggested scheme, the LNA is used as a first stage in the receiving chain being designed specifically for increasing signal gain and avoiding additional noises.

Modern design methods using computer simulation tools and algorithms provide substantial help during designing. As such, by employing optimization algorithms, the optimal solutions concerning a trade-off between gain and noise figure can be developed. At the same time, impedance matching and stability problems become particularly significant due to extremely high working frequency ranges in 5G and mmWave applications. The proposed low-noise amplifier represents an efficient and compact solution suitable for use in the next generation wireless systems.

### *A. Future Scope*

Expand the coverage of the LNA to include mm Wave and future 6G frequencies, which will provide increased bandwidth and improved performance.

- Apply AI and ML optimizations using Python to optimize gain, noise figure, and power consumption.

- Adopt cutting-edge materials such as FinFET, GaN, and SiGe along with cutting-edge RF frontend technology.

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