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

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Declaration

We hereby certify that this thesis is an original work and has not been previously submitted, in whole or in part, to fulfill the requirements for any degree or award at this or any other institution. To the best of our knowledge, it does not contain any previously published or authored material by others, except where duly cited. Furthermore, this thesis complies with CUET's regulations on academic integrity and plagiarism.

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Dedication

To our beloved parents, whose unwavering encouragement, motivation, and support have been our greatest strength. We would also like to thank Professor Dr. Quazi Delwar Hossain, our Supervisor, and Mr. Mohammad Mahmudul Hasan Tareq, Assistant Professor, Department of EEE, for their valuable advice and knowledge.

Approval by the Supervisor(s)

This certifies that Nishat Anjumane Salsabila and Susmita Barua completed this research under my direction and that they have complied with all applicable academic requirements set forth by the Chittagong University of Engineering and Technology. As such, they are eligible to submit the following thesis with their application for the Bachelor of Science degree in Electrical and Electronic Engineering. Additionally, the thesis conforms to CUET's regulations against plagiarism and academic integrity.

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First and foremost, we are grateful to God for enabling us to complete this work before the due date. This venture provided a unique opportunity to apply our theoretical understanding. Many people contributed to the successful completion of this work on the topic, **"Design and Analysis of a Gain-Tunable Low Noise Amplifier for Advanced Medical Imaging Systems."** Our supervisor, Professor Dr. Quazi Delwar Hossain, and Mr. Mohammad Mahmudul Hasan Tareq, Assistant Professor, Department of EEE, provided valuable advice on how to finish our task and helped, supported, and directed us in taking corrective action to achieve the intended result. Finally, we would like to express our sincere thanks to everyone who provided the required information and encouraged us throughout this project.

Abstract

A **Low Noise Amplifier (LNA)** is a crucial component in communication and signal processing systems, designed to amplify weak signals while minimizing additional noise. In the medical imaging sector, LNAs play a vital role in enhancing the sensitivity and accuracy of imaging devices such as MRI, ultrasound, and microwave imaging systems. These applications require the detection of extremely weak bio-signals, where even minimal noise can impact image resolution and diagnostic precision. By providing high gain with minimal noise contribution, LNAs improve the **Signal-to-Noise Ratio (SNR)**, enabling clearer and more detailed medical images.

The purpose of this paper is to **design a wideband low noise amplifier** with high gain for frequencies **above 6 GHz** for medical imaging applications. A large gain is required because it transforms low-intensity images into high-intensity images.

A low noise amplifier designed with a common source and a common gate in **90 nm technology** is presented in this paper. The suggested **Wide-Band LNA** achieves a **29 dB power gain** and very good impedance matching ($S_{11} < -18.14$ dB and $S_{22} < -20.23$ dB) at a supply voltage of 1.2 V, with an average noise figure of < 3 dB and a bandwidth of **1.7** GHz (from 6.6 GHz to 8.3 GHz). Without compromising the other advantages of the previous circuit, the proposed design incorporates a **gain control mechanism** by adding an attenuator on the input side.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

The precise detection and processing of incredibly faint biological signals is essential to medical imaging systems. These signals need to be amplified with great fidelity since they frequently lie within the radio-frequency (RF) or microwave band. In these systems, the front-end receiver's Low-Noise Amplifier (LNA) is essential for boosting weak signals without adding too much noise that might deteriorate image quality.

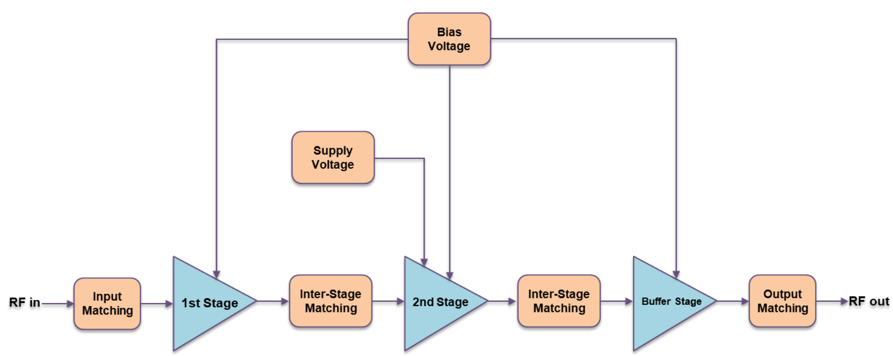


Figure 1.1: Basic Block diagram of designing method of Low Noise Amplifier

LNA is a component whose major purpose is to introduce as little noise as possible by increasing the strength of a weak signal. LNAs, enhance the performance and efficacy of imaging systems in a number of ways, making them indispensable to the medical imaging sector. The current advancements in LNA technology make it more useful in this field. Recent advances in LNA technology have focused on improving performance metrics including gain, bandwidth, and noise figure. LNAs are crucial for a number of medical imaging procedures, including as Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI), and Ultrasound. Maximizing the signal-to-noise ratio (SNR), which is essential for producing high-resolution and high-contrast pictures during diagnostic procedures, is their main duty [1].

The amount of extra noise that an amplifier adds to the system is determined by its noise figure. LNAs with ultra-low noise figures (usually below 1 dB) are required to maintain the integrity of faint biological signals because medical imaging demands great accuracy. The gain of amplifiers must be high enough (usually 20–30 dB) to raise weak signals above the noise floor without distorting them. A high-gain LNA guarantees a robust and clear signal for downstream processing stages like signal processors. Variations in tissue characteristics, patient mobility, and imaging depth can all affect the received signal intensity in various imaging systems. Gain-adjustable LNAs enhance overall imaging performance by enabling dynamic adaptability to shifting signal circumstances. In applications like MRI and ultrasound, where signal fluctuations are frequent, this is very helpful. Also non-linear amplification can introduce distortion, which leads to artifacts in medical images and reduces diagnostic accuracy. LNAs designed for medical imaging must maintain high linearity to ensure faithful signal reproduction, particularly in complex imaging systems.

1.2 LNA Fundamentals

The first block in the LNA, the input matching network, mainly the common gate amplifier, is in charge of matching the impedance between the amplifier and the signal source, which might be an RF coil in an MRI or a transducer in an ultrasound. Maintaining signal integrity in medical imaging applications requires proper impedance matching, which increases power transmission, lowers signal reflections, and enhances the noise figure.

Once the signal is properly matched, it enters the **low noise amplification stage**, which consists of a low-noise transistor (LNT). This stage provides the first level of amplification while keeping added noise as low as possible. Since the first stage has the greatest impact on the overall noise performance of the LNA, selecting a high-performance transistor is crucial for applications such as MRI, PET, and ultrasound, where weak signals need to be amplified with minimal degradation.

To enhance the flexibility of the LNA, **a gain control or attenuator stage** is often included. This stage allows the amplifier to dynamically adjust its gain based on the strength of the received signal. In ultrasound imaging, for instance, signals reflected from deeper tissues are weaker than those from shallow tissues. By using adjustable gain, the system can ensure uniform signal amplification, preventing strong signals from saturating the system while boosting weaker ones.

For the signal to go smoothly across several amplification stages, the **inter-stage matching network** is essential. To reduce signal losses and improve stability, bandwidth, and gain consistency, this block maximizes impedance matching between amplifier stages. Appropriate impedance matching is necessary to achieve consistent performance in wide band applications, such as ultrasound imaging, when the system works over many frequencies.

A **biasing circuit**, which supplies active components like transistors with the proper operating voltage and current, is necessary for the LNA to sustain stable functioning. Even in the face of fluctuating power and temperature, the biasing circuit makes sure the amplifier stays within its ideal range. In medical equipment that runs on batteries, where power efficiency is crucial, this is especially crucial.

At the output of the LNA, an **output matching network** which is the common source amplifier ensures that the amplified signal is efficiently transferred to the next stage. Just like the input matching network, this block prevents signal reflections and ensures maximum power delivery. In medical imaging systems, where precise signal processing is required, an optimized output matching network helps maintain signal integrity before further processing.

Among other frequency ranges, LNAs for a range of millimeter-wave bands may be made. The various design approaches and strategies are determined by the specific frequency range and application requirements. Complex circuit topologies and approaches, as well as careful consideration of parasitic components and transmission line phenomena, are required when developing a LNA for medical imaging.

1.2.1 PERFORMANCE PARAMETERS OF LNA

An essential part of radio frequency (RF) and microwave systems, a LNA is primarily made to amplify weak signals with the least amount of noise possible. Applications where signal integrity is crucial, such as medical imaging, wireless communications, radar, and radio astronomy, frequently employ LNAs. Noise figure (NF), gain, bandwidth, linearity, impedance matching, and power consumption are among a LNA's most crucial performance metrics.

NOISE FIGURE

The noise figure (NF) of an LNA represents the amount of noise added to a signal as it passes through the amplifier. It is measured in decibels (dB) and calculated using the ratio of input SNR to output SNR. A lower noise figure, typically ranging from 0.5 dB to 3 dB, ensures that weak signals remain detectable without significant degradation.
The Noise Figure (NF) is defined as:

$$\mathrm{NF} = 10\log\left(\frac{\mathrm{SNR}_{\mathrm{input}}}{\mathrm{SNR}_{\mathrm{output}}}\right)$$

Where:

- $\mathrm{SNR}_{\mathrm{input}}$ = Signal-to-noise ratio at the amplifier input.
- $\mathrm{SNR}_{\mathrm{output}}$ = Signal-to-noise ratio at the amplifier output.

GAIN

The gain of an LNA refers to the amplification provided to the input signal and is also measured in dB. LNAs typically provide 10 dB to 30 dB of gain, depending on the application. For medical imaging the LNA must be designed with an adjustable gain of up to 22 dB where signal strength can vary based on different imaging conditions.

The Gain is defined as:

$$\mathrm{G} = 10\log\left(\frac{\mathrm{P}_{\mathrm{out}}}{\mathrm{P}_{\mathrm{in}}}\right)$$

Where:

- P_{in} = Input Power
- $\mathrm{P}_{\mathrm{out}}$ = Output Power

BANDWIDTH

The bandwidth of a LNA is a critical parameter that determines the range of frequencies over which the amplifier can operate effectively while maintaining low noise and high gain. It is typically defined by the frequency range within which the gain remains relatively stable, often specified as the -3 dB bandwidth, where the gain drops by 3 dB from its peak value. The bandwidth of an LNA intended for medical imaging applications needs to be precisely adjusted to the desired frequency range to guarantee that the amplifier processes signals efficiently and without causing appreciable distortion or signal loss. The choice of bandwidth is contingent upon the imaging modalities being employed; for example, microwave or MRI imaging may necessitate GHz-range bandwidths, whereas ultrasonic imaging functions in the MHz range. Furthermore, the bandwidth may be restricted by parasitic components in the circuit, such as stray capacitance and inductance, which calls for careful component selection and architecture to achieve the intended performance.

LINEARITY

An LNA's linearity is a crucial performance factor, especially in applications like radar, communication systems, and medical imaging that need high-fidelity signal amplification. An LNA's linearity is essential for preventing distortion from signal amplification. The **third-order intercept point (IIP3)** is the important marker of linearity. A high IIP3 value guarantees that inter-modulation distortion stays low, maintaining signal integrity. Attaining high linearity is crucial for successful picture reconstruction in medical imaging, where exact signal integrity is needed. Medical pictures' diagnostic utility and clarity can be diminished by nonlinear distortions, which can result in signal artifacts.

IMPEDANCE MATCHING

To ensure effective signal transmission and low reflection, impedance matching is another essential component of LNA design as it has a direct impact on gain, power transfer, and amplifier performance. Impedance mismatches can cause signal reflections, decreased power transfer, and signal loss when an LNA is connected to a source, such an antenna or sensor. These issues can compromise the LNA's efficacy and Signal-to-Noise Ratio (SNR). By keeping the noise figure low and avoiding signal distortion or attenuation, proper impedance matching guarantees that the LNA is designed for optimal power transmission.

According to the Maximum Power transmission Theorem, power transmission is greatest when the load impedance matches to the source impedance, hence impedance matching is essential to reaching maximum power transfer. This means that for an LNA to operate at its best, the input impedance must match the source's impedance (such as an antenna or sensor). A widely used technique is the LC matching network, which employs inductive (L) and capacitive (C) components to adjust the input and output impedance of the LNA to match the source and load impedance. These networks can be tuned to provide the desired impedance match over a specific frequency range. In some cases, Pi (π) and T networks are also employed for impedance matching, using combinations of resistors, capacitors, and inductors to achieve the necessary impedance match. These networks are versatile and can be optimized for either narrow band or wide band applications.

S-parameters (scattering parameters) define the way RF signals interact with the amplifier. These parameters include S_{11} (input return loss), S_{22} (output return loss), S_{21} (gain), and S_{12}

(isolation). Usually 50 Ω or 75 Ω, proper impedance matching minimizes signal reflections that might impair performance and maximizes power transmission.

POWER CONSUMPTION

Power consumption is another critical factor, especially for battery-powered medical devices. LNAs must be designed for low power consumption to extend battery life while maintaining high performance. The biasing method, transistor technology, operating frequency, and supply voltage are some of the variables that affect how much power an LNA uses. Good signal amplification while preserving efficiency requires an LNA design that balances low power consumption, high gain, and low noise.

The total power consumption of an LNA is determined by its supply voltage (V_{DD}) and drain (or collector) current (I_D), following the relationship:

$$P_{\text{Total}} = V_{\text{DD}} \times I_{\text{D}}$$

Where V_{DD} is typically ranging from 0.9 V to 5 V, and I_D varies depending on the amplifier design. LNAs designed for low-power applications generally consume between 1 mW and 100 mW, while those used in medical imaging systems, such as MRI and ultrasound, may require 100 mW to 500 mW. High-performance LNAs for applications like radar and satellite communication can consume up to 2 W, depending on gain and frequency requirements.

BIASING TECHNIQUES

Proper biasing techniques such as fixed biasing, self-biasing, and active biasing ensure stable operation. Biasing is a crucial aspect of LNA design, as it determines the operating point of the transistor, ensuring stable performance, optimal gain, and minimal noise figure. The primary goal of biasing in an LNA is to keep the transistor in the linear/active region where it can provide consistent amplification with minimal distortion. Proper biasing also influences the thermal stability, power consumption, and noise performance of the amplifier.

Fixed biasing is one of the most basic biasing techniques, in which the transistor's necessary gate or base voltage is supplied by a single resistor. Self-biasing is a more stable option that introduces negative feedback by using a resistor in the emitter (for BJTs) or source (for FETs). Voltage-divider biasing is a popular technique in LNA design that uses a resistor network to produce a steady gate or base voltage. Compared to the fixed biasing, this approach eliminates gain variations brought on by changes in transistor characteristics and offers superior stability against temperature swings.

STABILITY FACTOR

The Stability Factor (K-factor) is used to assess whether the LNA will remain stable across its operating range. The stability condition is met if $K > 1$ and $|\Delta| < 1$ for all frequencies, meaning the amplifier will not oscillate under any passive source or load impedance conditions. Conditional stability, on the other hand, means that oscillations can occur for certain impedance values, which can lead to performance degradation and unwanted signal distortions.

To achieve a stable LNA design, various techniques are employed, including proper impedance matching, feedback networks, and stabilization circuits such as resistive loading, series inductors, or emitter degeneration in bipolar junction transistor (BJT) designs. Additionally, source and load stability circles can be analyzed to identify regions where instability might occur, allowing for modifications in the matching network to enhance stability.

1.3 CONTEXT

This thesis article addresses the design of a wide band LNA for the 90 m CMOS technology. An LNA plays a crucial role in medical imaging systems by amplifying weak signals while introducing minimal additional noise. By improving the signal-to-noise ratio (SNR), LNAs enable clearer, more detailed images, which are essential for detecting diseases, monitoring conditions, and guiding medical procedures. While designing, there some problems arise about maintaining flat high gain and stability. As LNA made in 90 nm technology often runs at lower supply voltages which reduces the gain margin and makes the circuit more noise sensitive. So, the biggest challenge for us is to design a circuit with a stable high gain and balancing power consumption.

Therefore, the issue statement for this thesis focuses on the challenge of creating a LNA that uses 90 nm CMOS technology and satisfies the needs of high gain, low noise, and broad bandwidth in a topology. To get the required performance levels, constructing matching networks and improving biasing conditions are crucial areas of focus.

1.4 OBJECTIVES of the THESIS

The objectives of this research are:

1. To design a wide band low noise amplifier.
2. To design a matching network for high gain and low Noise figure.
3. To design an attenuator and place it on the input side of the designed low noise amplifier.
4. To explore the performance of the proposed wide band low noise Amplifier for a variable range.

1.5 SIGNIFICANCE, SCOPE AND DEFINITIONS

Further developments in LNA design will boost medical imaging systems' capabilities as technology develops, which will help patients and healthcare professionals alike. Because they can amplify weak signals while reducing noise, LNAs are essential in medical imaging technology. This immediately improves diagnostic accuracy and picture quality in a variety of modalities. A wide band LNA with a front-end attenuator implanted in 90 nm CMOS technology is proposed here. This study is significant because it offers a high-gain, wide band solution created especially for improving medical images.

In LNA design, component selection is essential, particularly when selecting the particular type of transistor. Field-effect transistors (FETs), like CMOS transistors or GaAs MESFETs, are frequently utilized transistors. The selection of these components is based on their suitability for the desired frequency range, noise characteristics, and gain capabilities. Low-noise components are frequently given importance by designers to reduce internal noise sources such as thermal and shot noise.

The design of an LNA begins with defining specific parameters, including frequency range, gain, noise figure, input/output impedance, and power consumption. These specifications guide the overall design process to ensure that the LNA meets performance requirements effectively. For instance, a well-designed LNA typically aims for a low noise figure (NF), which indicates how much additional noise the amplifier introduces to the signal. A lower NF is essential for maintaining signal clarity and integrity, especially when dealing with weak input signals.
Overall, the scope of Low Noise Amplifiers in medical imaging encompasses their integration into various imaging systems, including MRI and ultrasound, where they enhance signal quality and contribute to improved diagnostic capabilities. The need for more effective and efficient LNAs will only increase as technology advances, hence broadening their application in imaging and medical diagnostics.

1.6 THESIS OUTLINE

The background study, objective, significance, scope, and definitions are all included in this chapter. The history of LNAs in the medical imaging sector and their motivations were explained in the background section. Following the clear definition of the objectives, the importance and scope of the work was further analyzed.
As a theoretical overview, we discussed the frequency response of a common source, common-gate power amplifier with a low noise amplifier. With the completion of this section, one will be able to identify several LNA circuit classes and become acquainted with the matching network theory.
We discussed the historical background of our literature review. At last, a summary and implications were also provided comparing the previous works. The comparison between the recent timeworks clears the fulfillment of the objectives of the proposed work.
This chapter illustrates an explanation of the research methodology. Additionally, we employed the impedance matching technique to create a low noise amplifier. The proposed schematic was also shown in this portion. Besides that, the parameter values are also defined.
This chapter presents the simulation results for the attenuated low noise amplifier and analyzed the simulation's output results. In the conclusion segment, the fulfillment of our objectives was portrayed and the recommendation of the future works are also mentioned.

Chapter 2

THEORETICAL REVIEW

Designing a CMOS LNA for wide band applications requires careful consideration of several critical performance factors to ensure optimal operation. It usually consists of several stages that are tuned for high efficiency and linearity, such as matching networks, output stages, and gain stages. For medical imaging, the frequency response of the LNA must be tailored to the specific application. LNAs play a pivotal role in amplifying extremely weak signals generated by sensors while minimizing the introduction of additional noise, thereby preserving the signal-to-noise ratio (SNR) essential for accurate diagnostics. Overall, the design of CMOS LNAs for medical imaging requires a careful balance of noise performance, power efficiency, and integration with existing systems to ensure optimal diagnostic outcomes.

2.1 CLASSIFICATION of LOW NOISE AMPLIFIER

General purpose LNAs, MMIC die wide band amplifiers, bias adjustable LNAs, broadband amplifiers, common gate LNAs, GNSS LNAs, and variable capacitance diode parametric amplifiers are examples of low noise amplifiers (LNAs) that can be categorized according to their application, circuit topology, and design considerations. Important characteristics such as noise figure, gain, bandwidth, power consumption, and linearity determine which LNAs are appropriate for a given application. Attractive characteristics of the source degeneration LNA include good input matching, minimal NF, and a respectable gain. The LNA's choice of transistor (MOS) depends on the desired frequency range. The goal of a well-thought-out DC bias technique is to identify the ideal quiescent point. A resistor bias network can likewise produce good results, while an active bias network is frequently chosen for small to moderate temperature swings. Traditional LNA noise cancellation, distributed amplifiers, and common gate stages are some methods of wide band design. The resistive shunt feedback architecture, which blends feed-forward and feedback techniques, is another practical method for designing wide band LNAs.

2.1.1 COMMON SOURCE LNA WITH RESISTIVE TERMINATION

A popular topology in RF and microwave circuit design is a common-source (CS) low-noise amplifier (LNA) with resistive termination, which provides a trade-off between noise performance, impedance matching, and gain. When steady well-matched input impedance is essential for broadband applications, this architecture is especially helpful. An LNA with regulated gain and acceptable noise performance is crucial for precise signal capture in medical imaging systems, such as MRI or ultrasound front-end receivers. In broadband applications where signal integrity is essential, like medical imaging, the resistive termination technique ensures that the amplifier maintains a steady and well-matched impedance input.

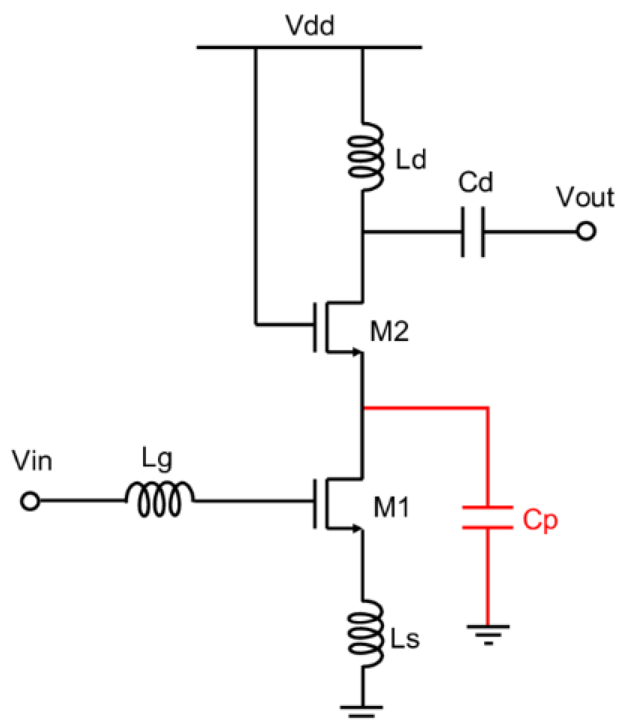


Figure 2.1: Common source LNA with resistive termination[1]

2.1.2 COMMON GATE TOPOLOGY OF LNA

The common-gate (CG) topology is a popular low-noise amplifier (LNA) configuration, especially for applications that need good linearity and broad impedance matching. The input is received by the source terminal of the common-gate amplifier, which maintains the gate at a constant bias potential in contrast to the common-source (CS) architecture, which applies the input signal to the gate. The capacity of the common-gate topology to produce low input impedance is one of its main features, which makes it ideal for wide band impedance matching. In contrast to the common-source topology with resistive termination, which has a large thermal noise contribution from the matching resistor, the common-gate LNA naturally offers effective impedance matching with little extra noise. The lower voltage gain of the common-gate layout in comparison to the common-source amplifier is one of its drawbacks.

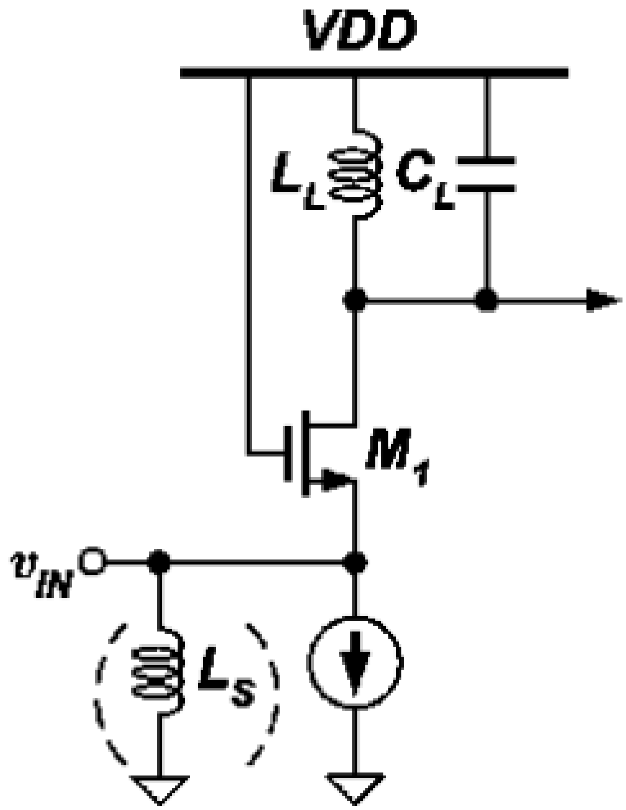


Figure 2.2: Common gate Conventional and g-boosted LNA Topology

COMMON GATE CASCADE LNA TOPOLOGY

In high-frequency and broadband applications, the Common-Gate Cascade Low-Noise Amplifier (LNA) architecture is frequently utilized because of its high gain, enhanced stability, and low noise performance. The two transistors in this design are stacked in a cascade format, with the top transistor (Q_2) in a common-source configuration to improve isolation and gain and the bottom transistor (Q_1) operating in a common-gate mode to provide broadband impedance matching. The common-gate cascade LNA's improved input-output isolation, which raises overall stability and linearity, is one of its main benefits. Because the trans-conductance (g_m) and load impedance (R_D) of the input transistor (Q_1) are the main determinants of the voltage gain. Furthermore, Q_2's high output impedance minimizes loading effects while increasing gain.

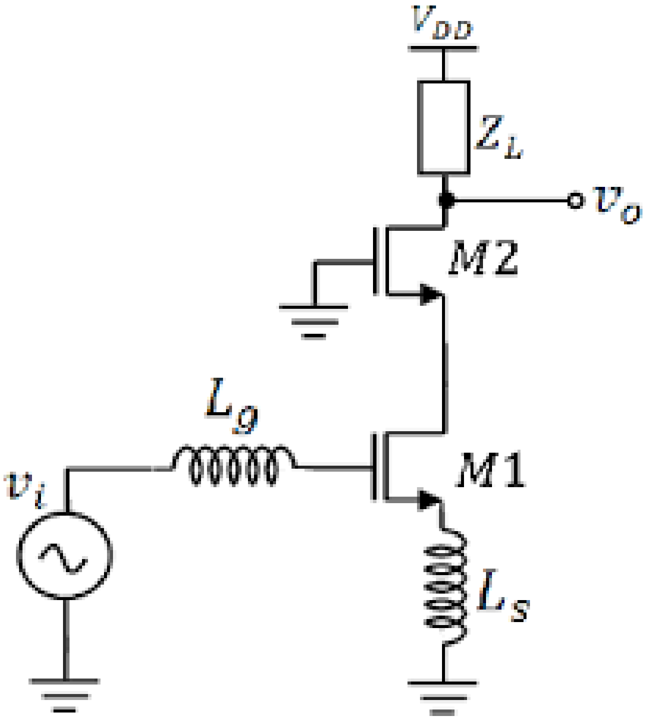


Figure 2.3: Common Gate Cascade LNA[2]

2.1.3 FEEDBACK TOPOLOGIES

With a feedback LNA (Low-Noise Amplifier) design, the amplifier's performance is enhanced in terms of bandwidth, stability, and gain linearity. Usually, feedback is provided in a series or shunt fashion from the amplifier's output back to the input. This feedback helps linearize the amplification process by altering the transistor's behavior and regulating the effective trans-conductance or impedance. Feedback LNAs are very helpful for stabilizing the gain across various frequencies and lowering distortion and nonlinearity in the amplified signal. For applications like RF communication, medical imaging, and broadband amplifiers, designers can enhance impedance matching and achieve wide band operation by managing the feedback loop. However, one downside is that feedback may increase the noise figure, which needs to be carefully managed to maintain the low-noise performance that is critical in many LNA applications.

RESISTIVE FEEDBACK LNA TOPOLOGY

The resistive feedback LNA topology is a type of low-noise amplifier (LNA) design that employs resistive feedback to improve the amplifier's performance, particularly in terms of gain stability and linearity. In this topology, a resistor is placed between the output and the input of the amplifier, often at the gate or base of the transistor. The feedback resistor serves to control the trans-conductance (g_m) of the transistor and provide positive or negative feedback, depending on its placement and the design. Resistive feedback's main advantage is that it stabilizes the gain by lessening the effects of parasitic components and transistor fluctuations, which results in more consistent and reliable amplifier performance. Additionally, it enhances linearity since the feedback lowers distortion by regulating the transistor's operating point. In addition, compared to other feedback systems, resistive feedback can provide a comparatively straightforward design, which makes it affordable and simple to use.

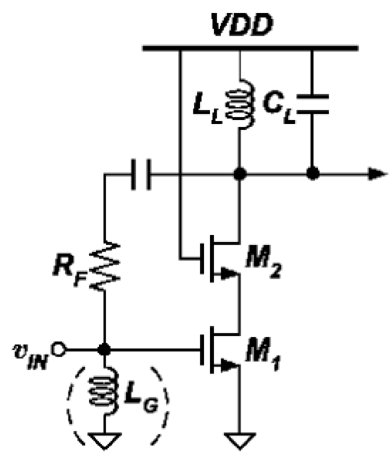


Figure 2.4: Resistive Feedback LNA Topology

REACTIVE FEEDBACK LNA TOPOLOGY

A Reactive Feedback LNA is a kind of feedback amplifier in which reactive, as opposed to resistive, components make up the feedback network, such as inductors and capacitors. The low-noise amplifier's (LNA) bandwidth, stability, and impedance matching are all enhanced by this reactive feedback. The feedback elements of this design are selected to produce a frequency-dependent response, enabling the amplifier to operate over a wide frequency. Phase-shifted feedback, which can affect the amplifier's gain and frequency response, is the main purpose of reactive feedback in an LNA. The feedback loop's use of inductors and capacitors allows the amplifier to better match the source impedance and sustain a steady gain throughout a broad frequency range. Moreover, reactive feedback can help reduce noise by shaping the amplifier's frequency response, preventing the amplification of unwanted noise at certain frequencies. An active element, such as a transistor, is usually used to apply the feedback from the output back to the input in an active feedback LNA. The amplifier's overall gain linearity is improved and its sensitivity to temperature changes and other parasitic factors is reduced thanks to this active feedback, which also helps linearize the amplifier's transfer function. Better impedance matching is another benefit it may offer, particularly in broadband systems where it's critical to maintain steady performance across a broad frequency range. One of the key benefits of the active feedback LNA is its ability to achieve low noise figure (NF), as the feedback loop helps to reduce the noise contribution from the active device, ensuring that the signal-to-noise ratio (SNR) is preserved.

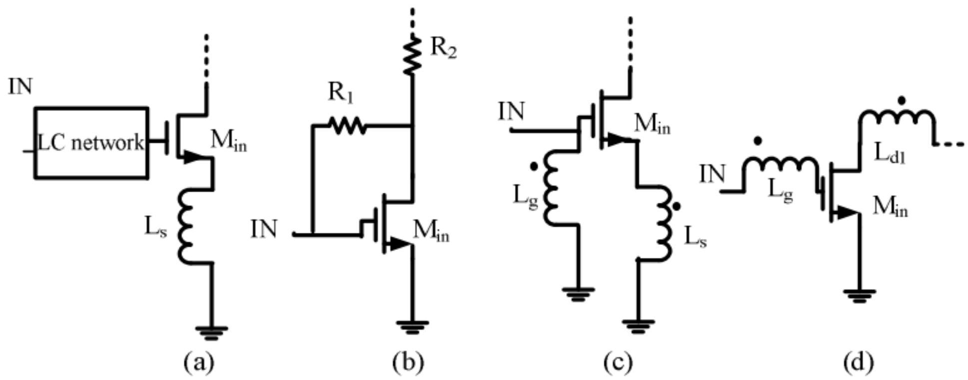


Figure 2.5: Some topologies of wide band CS-LNA

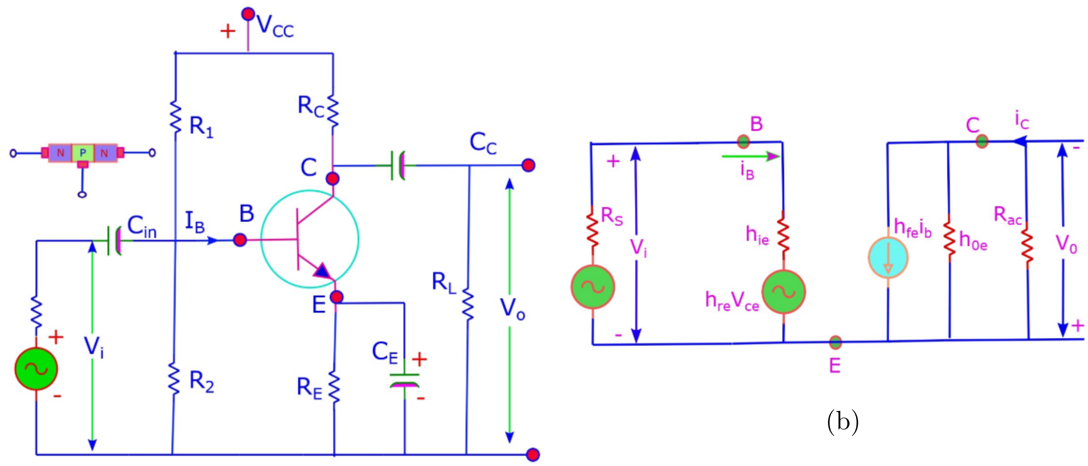
2.2 SUPERIMPOSED WIDE BAND LNA

A superimposed wide band LNA uses multi-path methods or integrates many amplifier stages to provide both low noise and a broad frequency response. To concurrently improve gain, noise figure (NF), and bandwidth, the word "superimposed" sometimes refers to mixing several amplifier topologies, such as common-source and common-gate designs.

2.2.1 CE, CB & CC AMPLIFIER CIRCUITS

Common Emitter

One of the most popular amplifier circuit topologies is the common emitter (CE) amplifier. In this configuration, the emitter is shared by the input and output, the base receives the input signal, and the collector receives the output. Applications requiring amplification can benefit from this configuration's notable voltage and current gain. Nevertheless, it causes the input and output signals to phase shift by 1800. A CE amplifier has modest input impedance and a comparatively high output impedance. It is frequently utilized in signal processing circuits, RF amplifiers, and audio amplifiers because of its strong amplification capabilities.



(a)

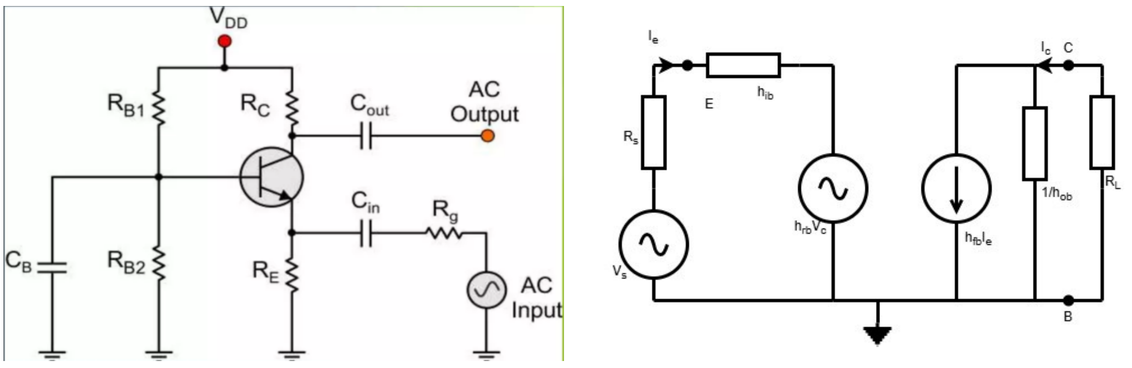
(b)

Figure 2.6: (a) The common emitter configuration n-p-n transistor single stage amplifier circuit, (b) The common emitter single stage amplifier in its hybrid circuit form.[3]

The single-stage common emitter amplifier circuit is shown in figure 2.5(a). It is made up of capacitors to provide the necessary effects and resistors positioned specifically for voltage divider type bias. By identifying the operating point in the active zone (in the center of the AC load line), the biasing circuit is made up of three resistances, stabilizes the amplifier.

Common Base

The base terminal of the common base (CB) amplifier is shared by the input and output. The emitter receives the input, while the collector receives the output. Since the current gain is usually less than unity, this design is characterized by a high voltage gain but a low current gain. It is appropriate for applications requiring impedance matching because of its extremely low input impedance and high output impedance. Furthermore, the input and output signals are in phase as the CB amplifier does not induce a phase shift. It is frequently utilized in RF amplifiers and high-speed circuits because of its effective handling of high-frequency signals.



(a) (b)

Figure 2.7: (a) The common base configuration n-p-n transistor single stage amplifier circuit[4], (b) The common base single stage amplifier in its hybrid circuit form[5].

A common base circuit can be shown in Figure 2.6. The transistor's emitter is connected to the signal source via C_{in}. Through C_{out}, the load resistance is connected to the transistor's collector.

Common Collector

Both the input and the output of the common collector (CC) amplifier, also known as an emitter follower, have a same collector terminal. The output is obtained from the emitter after the base receives the input signal. The CC arrangement differs from the CE and CB amplifiers in that it delivers a high current gain but a voltage gain of around unity. In circuits where impedance matching is required, its high input impedance and low output impedance make it a great buffer stage. This is one of its main features. Phase shift does not occur since the emitter's signal follows the input signal without inversion. The CC amplifier is frequently utilized in buffering applications, impedance matching, and other applications because it can offer current amplification without significantly increasing voltage.

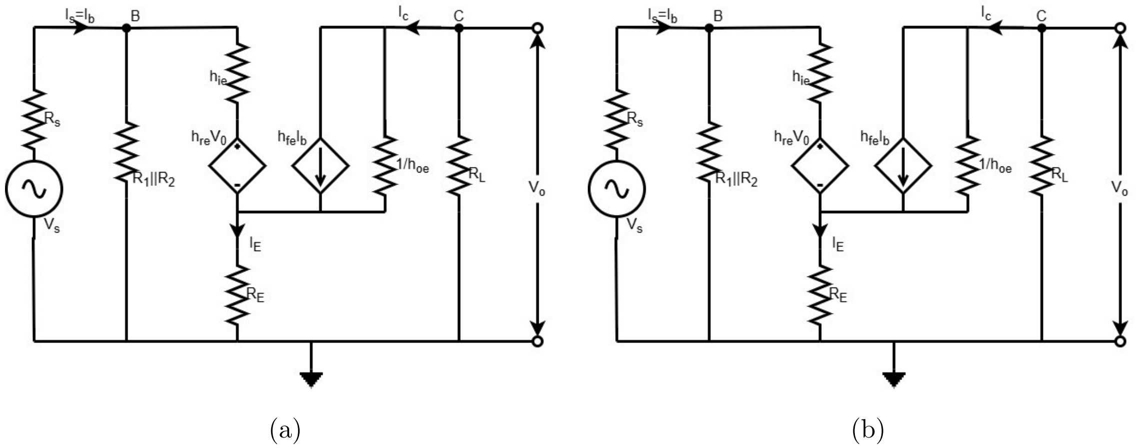


Figure 2.8: (a) The common collector configuration n-p-n transistor single stage amplifier circuit[6], (b) The common collector single stage amplifier in its hybrid circuit form[7].

2.2.2 SMALL SIGNAL LOW FREQUENCY h-PARAMETER MODEL

When examining a transistor's behavior in amplifier circuits, the small-signal low-frequency h-parameter model is a popular analogous circuit approximation. This model is based on hybrid parameters, also known as h-parameters, which characterize a transistor's input and output properties in a linear, small-signal region. It works well at low frequencies, when inductive and capacitive effects are minimal. A transistor is represented as a two-port network using the h-parameter model, which has four parameters: input impedance (h_{11}), reverse voltage gain (h_{12}), forward current gain (h_{21}), and output admittance (h_{22}). The small-signal response of the transistor in a certain configuration, such as common-emitter, common-base, or common-collector, is measured experimentally to determine the characteristics. In the common-emitter configuration, which is the most commonly used for amplification, the small-signal equivalent circuit consists of the following elements:

1. h_{11} (h_{ie}) – This is the current gain, also known as β, which defines the relationship between the small-signal collector current and the small-signal base current.

2. h_{21} (h_{fe}) – This is the current gain, also known as β, which defines the relationship between the small-signal collector current and the small-signal base current.

3. h_{12} (h_{re}) – This is the reverse voltage gain, a small feedback parameter indicating how much the output voltage affects the input voltage.

4. h_{22} (h_{oe}) – This is the output admittance, representing the small-signal conductance at the collector.

By making the low-frequency assumption, the model may be reduced to a purely resistive network and capacitive and high-frequency effects like parasitic inductance and Miller capacitance can be ignored. This model is widely used in beginning electronic circuit design and is still a vital tool in basic transistor circuit analysis, despite its shortcomings at high frequencies.

2.2.3 MOSFET SMALL SIGNAL AMPLIFIERS

Both common source voltage amplifiers and common drain voltage followers, often known as source followers, can be made with MOSFETs. Because MOSFETs deliver a very low gate current, both circuits have the potential for high input impedance. With modestly sized input signals, MOSFET amplifiers typically offer low noise, low distortion, and good high frequency performance. Their voltage gain magnitude is smaller than that of BJTs. The device's trans-conductance, or gm, is a crucial factor in calculating gain. The bias form chosen determines whether the common source amplifiers are swamped or not. Swamping is not possible if the bias type does not make use of a source resistor. Since the impedance facing the gate itself is extremely high at low frequencies, the input impedance depends on the biasing resistor arrangement in front of the gate.

Common Source Amplifier at High Frequency

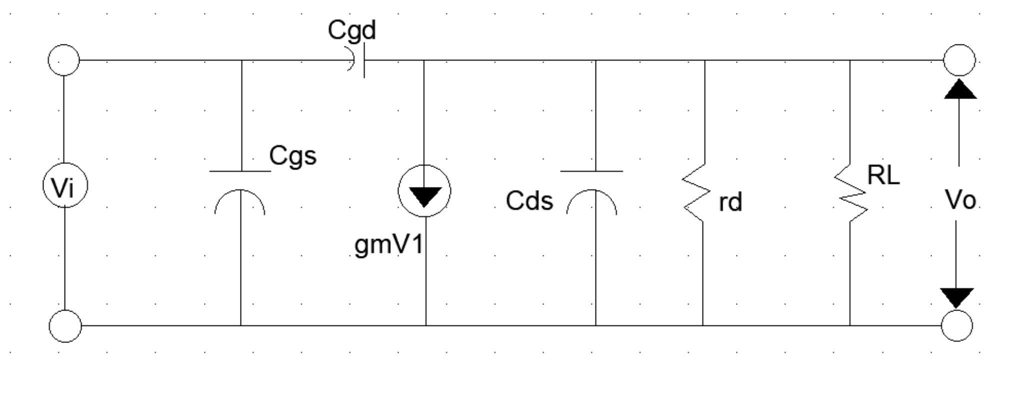


Figure 2.9: Small signal equivalent circuit at high frequencies

Here,

$$Y = \frac{1}{z} = Y_L + Y_{ds} + g_d + Y_{gd}; \tag{2.1}$$

Where,

$$Y_L = \frac{1}{R_L} \text{ : admittance corresponding to } R_L$$

$$Y_{ds} = j\omega C_{ds} \text{ : admittance corresponding to } C_{ds}$$

$$g_d = \frac{1}{r_d} \text{ : admittance corresponding to } r_d$$

$$Y_{gd} = j\omega C_{gd} \text{ : admittance corresponding to } C_{gd}$$

The current equations:

$$I = -g_m V_i + V_i Y_{gd} = V_i(-g_m + Y_{gd})$$

Voltage gain: The voltage gain for a common source amplifier circuit with the load R_L is given by

$$A_v = \frac{V_o}{V_i} = \frac{IZ}{V_i} = \frac{I}{YV_i}$$

Substituting the value of I & Y from previous equations:

$$A_v = \frac{(-g_m + Y_{gd})}{Y_L + Y_{ds} + g_d + Y_{gd}};$$

At low frequencies where Y_{ds} & Y_{gd} negligible (i.e. $Y_{ds} = 0$ & $Y_{gd} = 0$), the equation simplifies to

$$A_v = \frac{-g_m}{Y_L + g_d}$$

Input Admittance:

$$Y_i = Y_{gs} + (1 - A_v)Y_{gd}$$

Input Capacitance (Miller Effect):

$$A_v = -g_m R'_d;$$

Where, $R'_d = r_d + R_d$

Substituting the value of A_v:

$$Y_{ij} = C_i = C_{gs} + (1 + g_m R'_d)C_{gd}$$

This increase in input capacitance C_is over the capacitance from gate to source is called Miller effect.
This input capacitance affects the gain at high frequencies in the operation of cascaded amplifiers. In cascaded amplifiers, the output from one stage is used as the input to a second amplifier. The input impedance of a second stage acts as a shunt across output of the first stage and R_d is shunted by the capacitance, C_i.

Output Admittance:

From above figure, the output impedance is obtained by looking into the drain with the input voltage set equal to zero. If $V_i = 0$ in figure, r_d, C_{ds} and C_{gdin} parallel. Hence the output admittance with R_L considered external to the amplifier is given by, amplifier is given by:

$$Y_o = Y_{ds} + g_d + Y_{gd}$$

Common Drain Amplifier at High Frequencies

Voltage gain: The output voltage Vo can be found from the product of the short circuit and the impedance between terminals S and N. Voltage gain is given by,

$$\frac{V_o}{V_i} = \frac{(-g_m + j\omega C_{gs})}{R_s + g_m + g_d + j\omega C_T}$$

Where,

$$C_T = C_{gs} + C_{ds} + C_{sn}$$

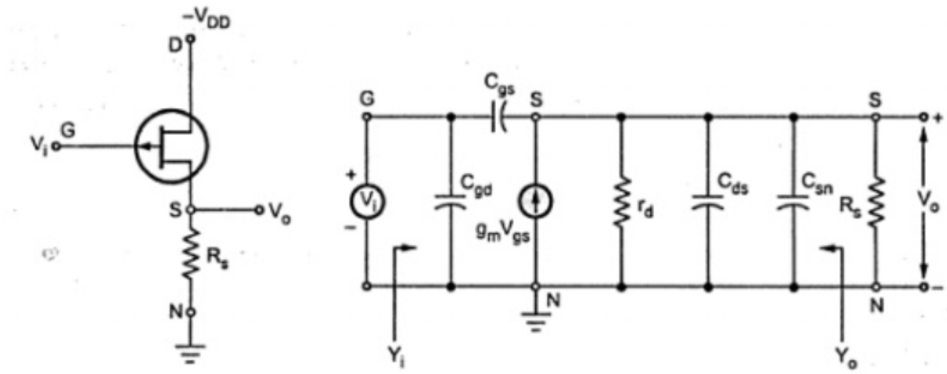


Figure 2.10: Common Drain Amplifier Circuit and Small signal equivalent circuit at high frequencies[8].

$$A_v = \frac{(-g_m + j\omega C_{gs})R_s}{1 + R_s(g_m + g_d + j\omega C_T)}$$

At low frequencies, the gain reduces to:

$$A_v = \frac{g_m R_s}{1 + R_s(g_m + g_d)}$$

Input Admittance: Input Admittance Y_i can be obtained by applying **Miller's theorem** to C_{gs}. It is given by,

$$Y_i = j\omega C_{gd} + j\omega C_{gs}(1 - A_v) = j\omega C_{gd} \quad (A_v = 1)$$

Output Admittance: Output admittance Yo with Rs considered external to the amplifier is given by:

$$Y_o = g_m + g_d + j\omega C_T$$

At low frequencies the output resistance R_o is given by:

$$R_o = \frac{1}{(g_m + g_d)} = \frac{1}{(g_m)} \quad (g_d \ll g_m)$$

Chapter 3

LITERATURE REVIEW

An analysis on wide band CMOS low noise amplifiers in the medical imaging area indicates that a substantial amount of research has been done to address the difficulties involved in creating amplifiers that can function across a broad range of frequencies. According to studies, attaining high power, efficiency and bandwidth is essential, especially when considering medical imaging, which requires the ability to detect faint biological signals with great sensitivity. Additionally, research has looked at how process technologies, such CMOS, affect amplifier design, with an emphasis on how improvements in fabrication methods affect the performance of wide band amplifiers. When considered collectively, literature emphasizes the difficulties in developing wide band CMOS LNAs and the need for creative solutions to meet the intricate needs which also highlights the challenges associated with creating wide band CMOS LNAs and the necessity for innovative approaches to satisfy the complex requirements of high gain, low noise and bandwidth in the medical imaging sector.

3.1 OVERVIEW OF LNA

Designing LNAs involves several challenges, especially suitability for low-power or high-performance applications. Narrow band impedance matching using LC networks limits the frequency range and makes it inappropriate for wide band. Achieving selective gain reduces the linearity or stability by restricting bandwidth. Cascaded topologies require high supply voltage, unsuitable for low-voltage systems, while low-power design increases noise. So, balancing low noise, high gain, wide bandwidth, and low power at the same time is a major challenge in LNA design [14][15]. Limiting overall performance, traditional designs optimize a few parameters as it is difficult to design in all aspects at once. Optimizing one feature often compromises others, making full performance hard to achieve [16][10]. For example, existing designs like resistive shunt-feedback LNAs, and UWB LNAs address noise and bandwidth issues but many multi-stage designs consume high power and occupy more area, further complicating the balance of performance parameters [17][18].
Traditional LNA architecture with narrow band techniques have limited bandwidth, in contrast, CMOS based design offers better linearity, improved frequency response, low power consumption and high integration, making them ideal for noise suppression and bandwidth optimization which is suitable for modern wide band communication systems [19][20][21][22]. A variety of advancements in LNA design have been explored to meet the needs of modern communication and biomedical

systems. CMOS LNA design optimization techniques focus on device sizing, biasing, and topology selection to balance linearity, noise, gain, and power consumption [23]. A packaged noise-canceling, high-gain wide band LNA enhances the performance, addressing integration challenges through compact packaging for broadband wireless applications. Sub-threshold LNA's noise canceling power across the bandwidth and low power operation, make it appropriate for wireless applications [9][24]. A reconfigurable CMOS LNA design using SPICE and ADS RFIC dynamic links in 90 nm technology provides adaptability to vary systems ensuring performance optimization [25]. A new CMOS LNA design for ultra-wide band (UWB) wireless receiver is aimed at low noise and high amplification for use in broadband applications. A low-noise preamplifier customized for use in Magnetic Particle Imaging minimizes noise while delivering signal integrity in medical applications [26][27]. A low-noise cascaded amplifier for UWB receivers in bio-sensing systems underscores the need for low noise in precise biomedical measurements [28][29][30]. A low-power LNA customized for use in biomedical applications minimizes power usage but preserves a low noise figure for use in health monitoring devices [31][32]. Optimized magnetic resonance fingerprinting method based on a stationary steady-state Cartesian approach with accelerated acquisition schedules, significantly enhancing the speed of imaging with high-quality quantitative output in low-field environments, suitable for application in fast-imaging applications with low signal distortion [33][34][35]. Optimized magnetic resonance fingerprinting technique based on a stationary steady-state Cartesian approach with accelerated schedules of acquisition, greatly improving the speed of imaging while maintaining high-quality quantitative output in low-field settings, ideal for use in applications demanding fast imaging with low signal distortion [36][37][38].An optical pre-amplification is introduced in [39] for MR imaging but faces limitations like comparable yet suboptimal signal-to-noise ratio, narrow bandwidth, and excess noise [40][41]. Though the bandwidth is narrow compared to standard pre-amplifiers, a limited bandwidth can restrict the amount of data captured during imaging, potentially affecting the overall image quality and acquisition speed [42][43]. Noise performance understanding for inductive sensors, presenting noise-matching techniques validated experimentally and applicable to biomedical imaging systems like MPI and low-field MRI are described in [44][45][46]. Additionally, transformer-coupled networks achieve a maximum noise-matched bandwidth π times lower than the theoretical ideal, limiting real-world performance [47][48]. For designing a wide band preamplifier various techniques are introduced in [49][50][51] that minimizes noise which includes considerations of bandwidth, averaging and input stage topologies [52][53]. This paper explores Cascade amplifiers for low-noise MRI, achieving a noise figure of 0.45 dB, 11.6 dB gain at 32 MHz, and stability up to 6 GHz which presents a detailed design methodology focusing on DC biasing, stability, and linearity to enhance LNA reliability and performance. For designing an LNA specifically for magnetic resonance imaging (MRI) scanners is introduced in [54][55][56] where the inherent weakness of the MRI signal necessitates amplification for transmission along long cables and further signal processing [57][58][40].

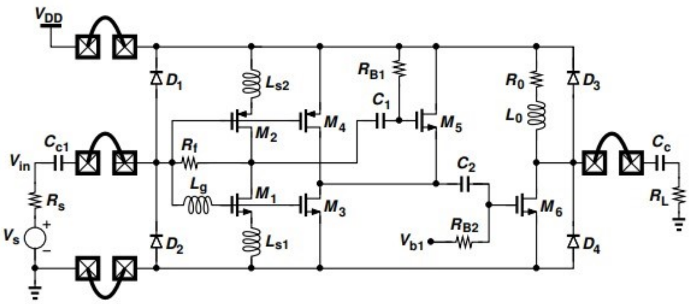


Fig. 2: Proposed LNA along with the bond-wire and the external DC blocking capacitors (C_{c1} and C_{c2}).

Figure 3.1: Proposed LNA with DC blocking capacitors [9]

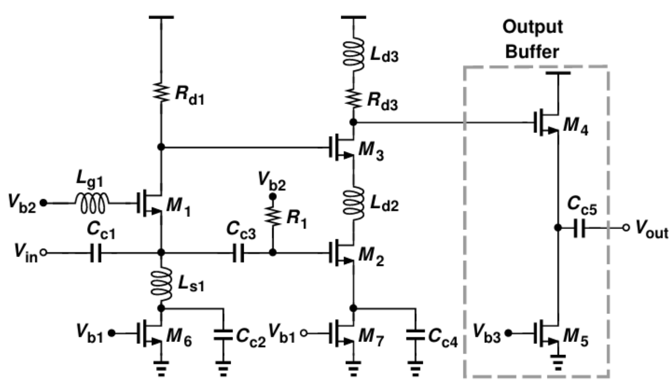


Fig. 1: Proposed subthreshold UWB LNA.

Figure 3.2: Proposed sub-threshold UWB LNA [10]

Chapter 4

RESEARCH METHODOLOGY

The Wide band LNA design is a multi-step process that includes specific definition, component and topology selection, biasing network design, matching network, simulation and optimization, layout and fabrication, testing and characterization, iterative optimization, finalization, and documentation. The design of a wide band LNA typically involves selecting the appropriate transistor technologies, determining the desired frequency range, optimizing circuit topologies for wide band performance, and implementing different matching networks and biasing techniques to achieve the desired power output, efficiency and linearity across the bandwidth. Simulations, like those created using CAD programs like Cadence Virtuoso, are commonly used to model and optimize the amplifier's performance. Empirical testing and tuning are also crucial to validate the design and assure that it meets the requirements.

4.1 Procedure

The Cadence Virtuoso software will be used in this simulation-based study, in which the values of the component parts (capacitors, inductors, and resistors) are selected using an appropriate matching network. Matching networks are used to match the impedance from source to load to guarantee the maximum amount of power transfer. The input and output impedance values must first be ascertained, which can be accomplished via simulation tools. Next, we will select the appropriate network topology. L-networks, π-networks, and transformer-coupled networks are examples of frequent topologies. Simulation is used to analyze the matching network's performance, taking into account factors like bandwidth, return loss, gain, and efficiency. The design can be repeated multiple times by modifying the component value or topology until the intended outcome is achieved if the performance is not adequate. The suggested network's noise figure was then simulated. Without compromising the other advantages of the previous circuit, the proposed design incorporates a gain control mechanism by adding an attenuator on the input side.

4.2 DESIGN OF MATCHING NETWORKS

The purpose of matching networks is to maximize the amount of power that can be transferred from the source to the load by matching the impedance of the source and the load. To match the

source and load impedance, the amount of resistor, capacitor, and inductor to employ is determined during the matching network design process. Designing matching networks for LNAs is crucial for optimizing performance parameters such as gain, noise figure, and impedance matching. Cadence Virtuoso is a popular tool used for simulating and designing these networks, particularly in RF applications.
When building a matching network, the following steps can be used as a general guideline:

- Determine the impedance values
- Ascertain the impedance values
- Select the suitable network topology
- Evaluate the performance
- Iterate

4.3 L-MATCHING NETWORK

To maximize signal transfer between different components inside an electronic circuit, matching circuits are essential. Impedance matching is essential for optimizing power transmission and reducing signal loss when constructing a microwave system, radio frequency (RF) amplifier, or any other high-frequency application.

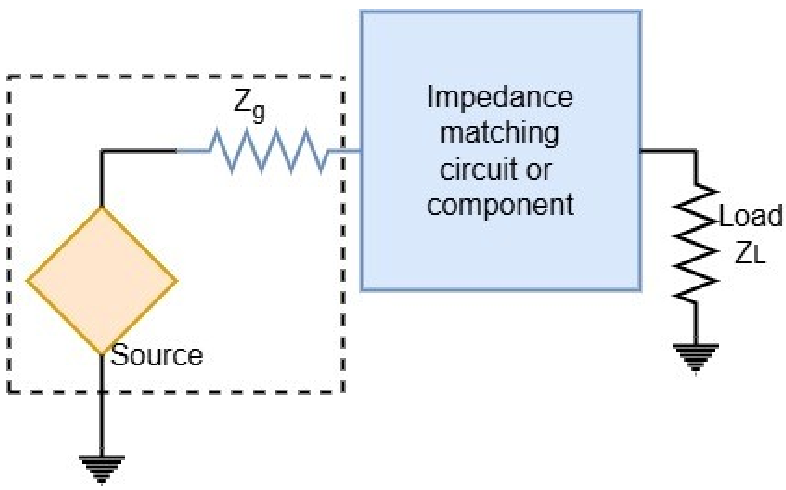


Figure 4.1: Block Diagram of the matching network[11]

The simplest way to supply equal resistance to the source and account for the imaginary components of the load and source impedance is to use L-shaped matching networks. The circuit is matched in this way, and the source will supply the load with the maximum amount of power. The L-shaped impedance transformer, which is made up of both shunt and series components, is a fundamental type of impedance matching network. A lumped element at the load impedance (Z_L) and another in series are necessary because the load impedance (Z_L) in a LNA design is usually

larger than the source impedance (Z_g).
Four distinct L-shaped matching networks are shown below. A series capacitor is needed for the high pass to block DC voltage, whereas a parallel capacitor is needed for the low pass matching network. Figure 4.1 displays two L-match networks constructed using capacitors and inductors.

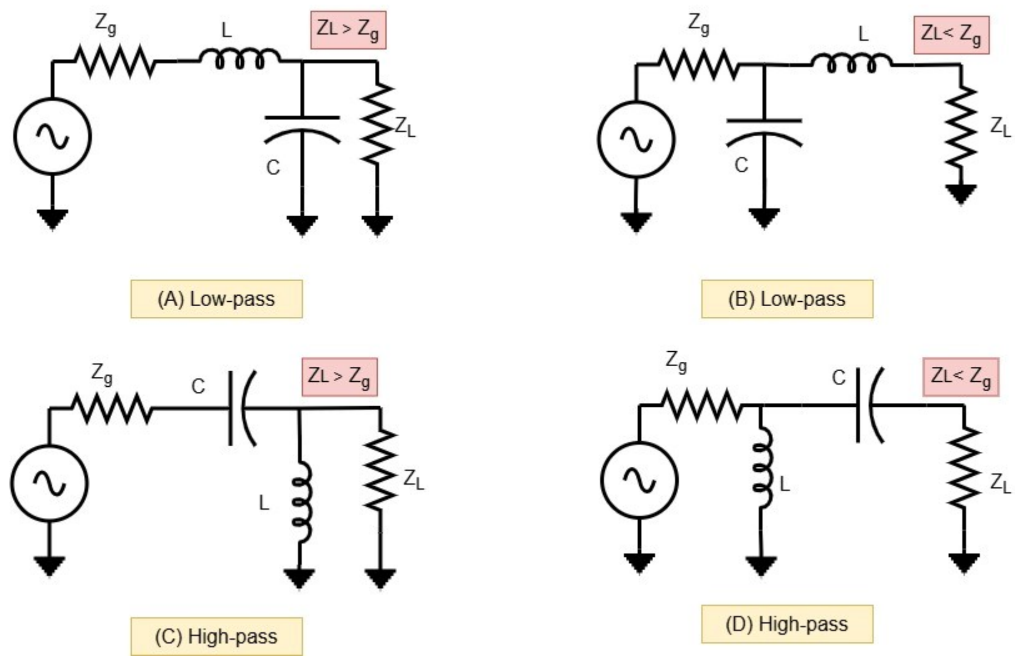


Figure 4.2: Lumped-element L-match network[12]

Figure 4.1(A) displays the L-match impedance transformation network's low-pass variant for lumped analysis. When Z_L and C are connected in parallel, the impedance of

$$Z_{ZLC} = \frac{Z_{L1}}{1 + j\omega Z_L C} = \frac{Z_{L1}}{1 + (\frac{Z_L}{Z_C})^2} - jX_C \frac{(\frac{Z_L}{Z_C})^2}{1 + (\frac{Z_L}{Z_C})^2} \tag{4.1}$$

As a result, the values of capacitance and inductance are selected so that the actual component of Z_{ZLC} generates the proper load resistance, or Z_g, while the inductor eliminates the fictitious part. The definition of the impedance transformation factor is $m = \left(\frac{Z_L}{Z_C}\right)^2$. We may calculate the values of X_L and X_C using equation (4.1).

$$X_L = Z_L\sqrt{m-1} \tag{4.2}$$

$$X_C = \frac{Z_L}{\sqrt{m-1}} \tag{4.3}$$

The load resistance is shown here by Z_L.
The ratio of an inductor's inductive reactance to its resistance at a specific frequency is known as

the "quality factor" (often abbreviated as "Q"). This ratio essentially indicates how effectively the inductor stores energy and is a crucial parameter influencing the noise performance of the LNA; a higher Q typically results in a lower noise figure, meaning that a higher quality inductor improves LNA performance.

$$Q = \frac{\text{(resonant frequency)}}{\text{bandwidth}}$$

$$Q = \frac{f_0}{BW}$$

The symbol f_0 represents the resonance frequency. As a result, the network's bandwidth and Q are inversely related. In contrast to resonator, the impedance matching network is powered by a source, which may be an active device that has been adapted to function as a source for output-matching or an actual signal source for input-matching. In impedance matching applications, the bandwidth of the network is therefore called "loaded Q." The loaded Q, or Q_L, is powered by a source with an estimated source impedance around the matching frequency of the impedance matching network. Q_L is the Q factor of a measurement system that includes the resonator and the instrument used to observe it. It's a measurement of how energy dissipates within the system.
The Q of the L C network for the lumped L C, L match can be calculated as-

$$Q_L = \frac{R_L}{X_C} = \sqrt{m-1} \quad \text{and} \quad Q = \frac{1}{2}Q_L = \frac{1}{2}\sqrt{m-1}$$

For Fig-4.4 (B),

$$Q = \sqrt{\frac{Z_g}{Z_L} - 1}, \quad L = QZ_L\omega_0, \quad C = \frac{1}{L\omega_0^2}\left(\frac{Q^2}{1+Q^2}\right)$$

For Fig-4.4 (D),

$$Q = \sqrt{\frac{Z_g}{Z_L} - 1}, \quad L = \frac{1}{C\omega_0}\left(1 + \frac{1}{Q^2}\right), \quad C = \frac{1}{QR_L\omega_0}$$

The Q is determined by the impedance ratio m when a lumped L C matching topology is employed. To maximize the power or efficiency performance of the LNA, the source resistance (Z_g) is chosen and the load resistance (Z_L) is typically set at 50 Ω. Consequently, the lumped L-C matching network is not flexible enough to be designed for Q.

4.4 π-MATCHING NETWORK

An impedance matching network with three reactive components arranged in a form that resembles the Greek letter π is called a π-match network, or π-network. A π-match network typically consists of

1. Two capacitors (or inductors) connected in parallel to the source and load.

2. Between these two parallel components is a single inductor (or capacitor) connected in series.

Transistors used in LNAs usually have a high parasitic capacitance at the output. Furthermore, at radio frequencies, inductance from the bond wires connecting the package to the on-chip output node cannot be disregarded. Since these features are disregarded, a straightforward L-match design will not produce the appropriate impedance transformation. This is addressed by adding an additional capacitor C_1 to the inductor's end to create a π-match network, as shown in Figure 4.3. It is possible to combine the package and PCB trace capacitance into C_2, and the output capacitance of the LNA transistor into $C-1$.

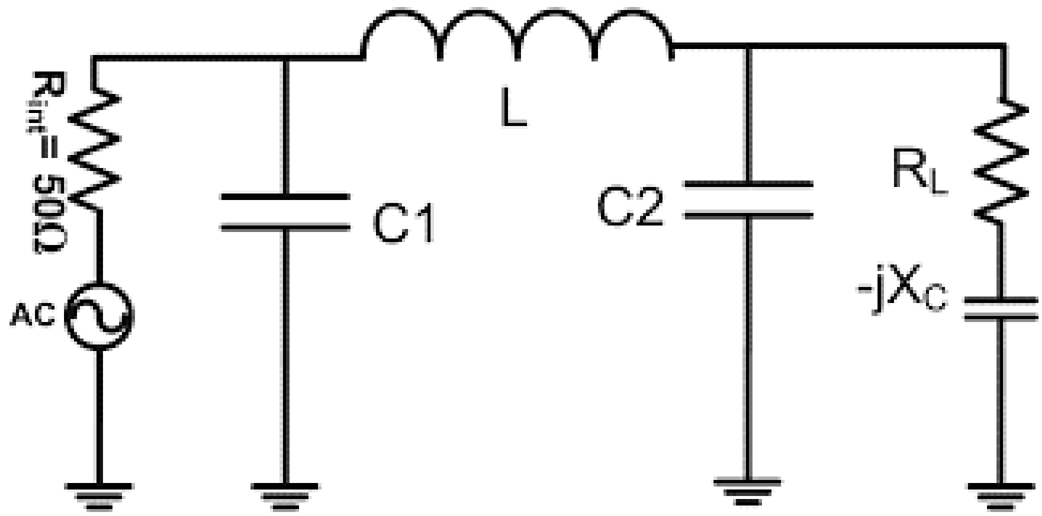


Figure 4.3: π-match network in output matching applications[13]

Because of the extra component, the π-match network has greater control over the loaded Q and a larger range of matchable values on the Smith chart than the L-match network. π-match is frequently used for inter-stage, input, and output matching. When one capacitance is zero, an example of an L-match is comparable to a particularπ-match.
Combining two L networks with a layout that uses two parallel components (connected to ground on one side) and one series component, the π-network is a more sophisticated design. This choice is not easy because adding network components results in higher losses at high speeds. However, when dealing with high quality factor values (sometimes called Q-factors), antenna-side matching may require a three-component network (similar to a π). For power efficiency and downsizing, a high Q-factor is preferred; however, as the bandwidth decreases, broad applicability suffers accordingly. Therefore, a more generalized form of the π-match network, as shown in Fig-4.4, where the network is powered by Vs and matches R_1 and R_2 at a specific frequency, is used to begin the investigation. In output-matching applications, the Thevenin equivalent of the LNA is V_s, where R_1 represents the LNA's ideal output impedance and R_2 represents the load impedance.

There is an additional degree of freedom to specify the network's loaded Q while constructing the π-match. As a result, it is presumed that the following analysis has already established Q_L, R_1, R_2, and the frequency of interest. The objective is to derive design equations to determine L, C_1, and C_2.

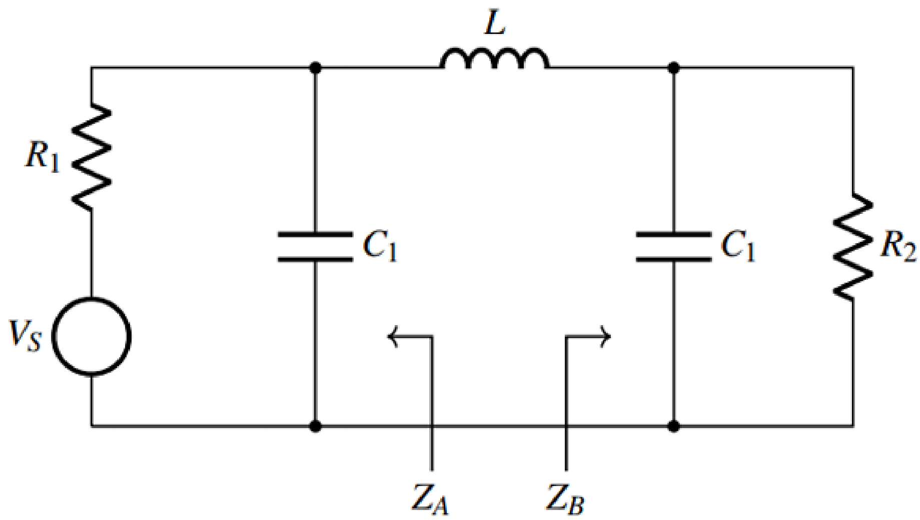


Figure 4.4: A circuit example for a π-match network[13]

Now,

$$
\begin{aligned}
&Q_1 = \omega_{c1} R_1 \quad \& \quad Q_2 = \omega_{c2} R_2 \\
&Z_A = R_A - jX_A \quad \& \quad Z_B = R_B - jX_B \\
&R_A = \frac{R_1}{1+Q_1^2}, \quad X_A = R_A Q_1, \quad R_B = \frac{R_2}{1+Q_2^2}, \quad X_B = R_B Q_2
\end{aligned}
$$

A conjugate pair then matches, with $X_L = X_A + X_B$ and $R_A = R_B$. Moreover, the loaded Q at resonance can be represented by $Q_L = \frac{X_L}{(R_A+R_B)}$. Under the above described circumstances, the following connections can be obtained using equations (4.16 and 4.17).

$$
\begin{aligned}
Q_L &= (1/2)(Q_1 + Q_2) \\
\frac{R_1}{R_2} &= \frac{1+Q_1^2}{1+Q_2^2} \\
X_L = R_1 \frac{2Q_1}{1+Q_1^2} &= R_2 \frac{2Q_L}{1+Q_2^2} \\
Q_2^2 &= \frac{R_1}{R_2}(1+Q_1^2) - 1
\end{aligned}
$$

It is necessary to have either $R_1 > R_2$ with $Q_1 \geq \sqrt{\frac{R_1}{R_2} - 1}$ or $R_2 > R_1$ with $Q_2 \geq \sqrt{\frac{R_2}{R_1} - 1}$ to ensure +ve Q_2. Alternatively, the following, expressed in terms of Q_L from equation (4.18), is a prerequisite for the design of a Π-match:

$$
Q_L \geq \begin{cases} \frac{1}{2}\sqrt{\frac{R_1}{R_2} - 1} & \text{if } R_1 > R_2 \\ \frac{1}{2}\sqrt{\frac{R_2}{R_1} - 1} & \text{if } R_2 > R_1 \end{cases}
$$

Equations (4.22) and (4.23) can be used to determine the values of Q_1 and Q_2 once the condition in equation (4.22) is met.

$$Q_1 = \frac{2Q_L R_1 - \sqrt{4Q_L^2 R_1 R_2 - (R_1 - R_2)^2}}{(R_1 - R_2)}$$

$$Q_2 = \frac{2Q_L R_2 - \sqrt{4Q_L^2 R_1 R_2 - (R_1 - R_2)^2}}{(R_2 - R_1)}$$

The following is the procedure for creating a Π-match network:

i. **Define Impedance Values**

ii. **Choose Quality Factor (Q)**

iii. **Ascertain the reactive components**

- *Regarding the source side of the 1st L-section:* Determine the capacitor C_1 and inductor L_1.
- *Regarding the source side of the second L-section:* The inductor L_2 and capacitor C_2 should be calculated, based on the required Q.

iv. **Establish Component Values**

v. **Calculation**: After assigning R_1, R_2 and Q_L, confirm that the condition of (4.22) is satisfied. Otherwise, continue allocating new values until the condition is met, which is typically Q_L. Then after verifying that the condition in (4.22) is met, solve for Q_1 and Q_2 using (4.23) and (4.24), respectively. Determine C_1, C_2 and X_L using equations (4.14) and (4.20). Determine C_1 and L at the frequency of interest using equation (4.13).

It is significant to remember that all of the π-match equations equal the L match equations when one of the capacitance is set to zero. This supports the idea that the match for L is a particular instance of the match of π. As previously stated, the primary considerations for choosing R_1 & R_2 RF power amplifier applications are power optimization, efficiency optimization, and load requirements. Thus, the next conversation will center on the design considerations for Q_L. Q_L determines the associated network's bandwidth based on its definition.

4.5 PROPOSED LNA DESIGN WITH ATTENEUATOR

The main function of an LNA component is to boost a weak signal's strength while introducing the least amount of noise possible. LNAs, or LNAs, improve efficiency and performance of imaging systems in several ways, which makes them essential to the field of medical imaging. LNA technology is more beneficial in this industry now that it has advanced. The improvement of performance measures including gain, bandwidth, and noise figure has been the main emphasis of recent developments in LNA technology. An attenuator is a passive broadband electronic device that reduces the power of a signal without appreciably distorting its waveform. There are several ways to classify attenuators. Whether they are fixed, programmable or variable, or designed to handle low or high power levels. They can be classified by package style, and there's a distinction between audio

attenuators and L pads and between RF attenuators and limiters.
Even though sub-threshold biasing provides higher $\frac{g_m}{I_d}$ than strong inversion, wide band LNA design becomes very difficult when analog and RF circuits operating in the sub-threshold zone exhibit increased thermal noise, worse bandwidth, and poor linearity. High linearity, a wide bandwidth, a modest gain, and a respectable noise figure are all offered by our recommended LNA. When building an LNA, several important factors (such as frequency range, gain, noise figure, input/output impedance, and power consumption) must be considered to ensure optimal performance. First, we determined that 6.6 GHz to 8.3 GHz is the operational frequency range. The suggested LNA includes both a common gate (CG) stage and a CS-CG stage with a gain-boosted, source follower buffer circuit.

4.5.1 BLOCK DIAGRAM OF THE PROPOSED WORK

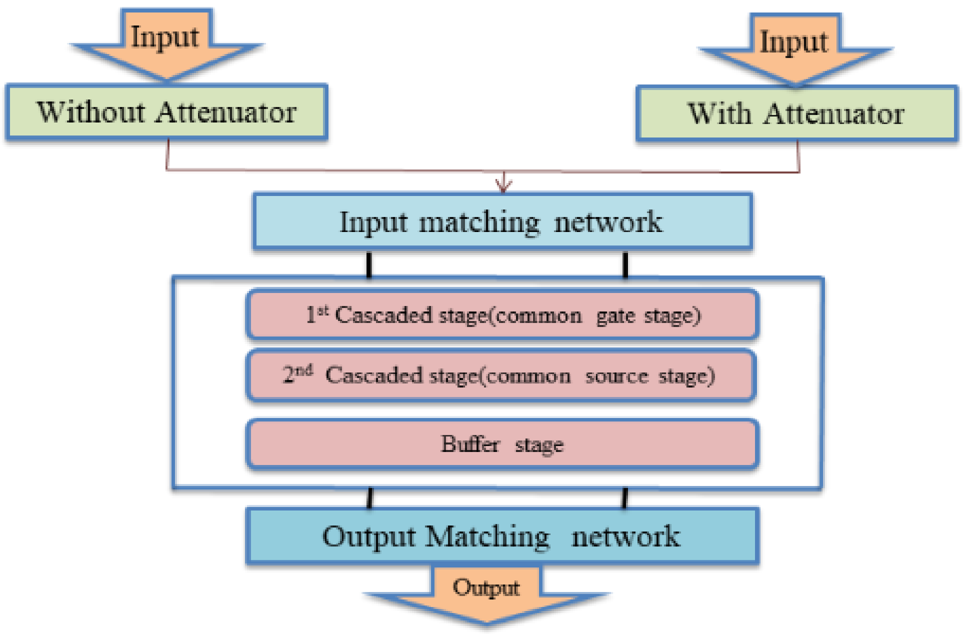


Figure 4.5: Block diagram of the proposed wide band LNA design

The recommended wide band LNA should have a cascaded two-stage amplifying network, an LC matching network, and a resistive biasing network, as shown in the flow chart. Power consumption is reduced by using a cascaded structure. A wide band is produced by staggered tuning two steps.

4.5.2 DESIGN PARAMETER OF LNA

This covers variables including power consumption, input/output impedance, noise figure, frequency range, and gain. These requirements will serve as a road map for the design process and guarantee that the LNA satisfies the necessary performance standards.

1. **Frequency range**: Specify the frequency range that the LNA will function within.
2. **Gain**: To bring weak signals to a usable level, calculate the desired gain.
3. **Noise figure**: To preserve signal integrity, specify the highest permitted noise figure.
4. **Input/output Impedance**: Define the input and output impedance such that they correspond with those of the other parts of the system.
5. **Linearity**: LNA linearity is most often specified as a third order intercept point (**IIP3**). Third order cross-modulation products decrease by 2 dB for every 1 dB increase in LNA IIP3.
6. **Stability**: The **Stability Factor (K-factor)**, which is essential for figuring out whether the amplifier will operate steadily under different source and load impedance conditions, is the main characteristic that defines the stability parameter of a LNA circuit.
7. **Power Consumption**:Set limits on power consumption to ensure efficiency.

4.6 PROPOSED LNA

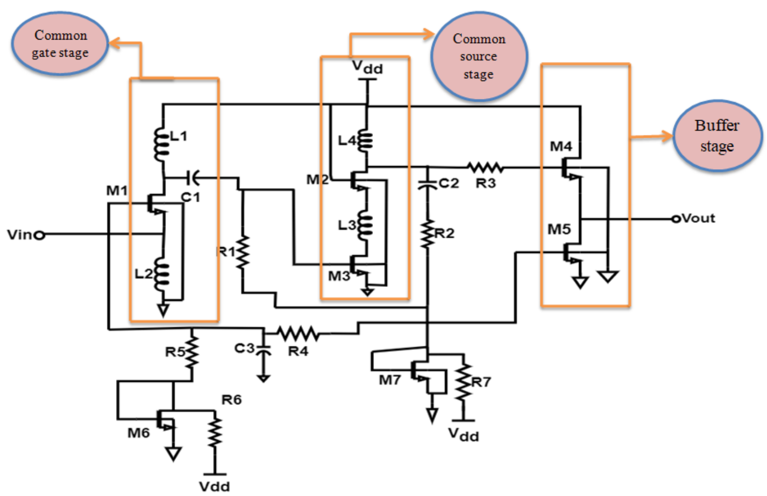


Figure 4.6: Proposed LNA with matching network

Resistors, inductors, and capacitors are among the components whose values will be estimated using a suitable matching network. Matching networks are used to match the impedance from gate to source and source to load to get the best possible power transmission. First, we might use simulation tools to calculate the input and output impedance values. The appropriate network topology will then be selected; popular topologies include transformer linked networks, π-networks, and L-networks. Through simulation, the matching network's performance is examined, with particular attention paid to return loss, bandwidth, gain, and efficiency. The design can be done multiple times by altering the component value or topology until the desired result is obtained if the performance is subpar.

Table 4.1: COMPONENT VALUES OF LOW NOISE AMPLIFIER

Component Name	**Value**
L_1	3.1 nH
L_2	1 nH
L_3	5.3 nH
L_4	3.5 nH
C_1	5 pF
C_2	7 pF
C_3	60 pF
R_1	400 Ω
R_2	15 kΩ
R_3	1 kΩ
R_4	50 Ω
R_5	500 Ω
R_6	50 Ω
R_7	40 Ω
$\left(\frac{W}{L}\right)_{M1}$	57u/100n
$\left(\frac{W}{L}\right)_{M2}$	120u/100n
$\left(\frac{W}{L}\right)_{M3}$	60u/100n
$\left(\frac{W}{L}\right)_{M4}$	30u/100n
$\left(\frac{W}{L}\right)_{M5}$	60u/100n
$\left(\frac{W}{L}\right)_{M6}$	60u/100n
$\left(\frac{W}{L}\right)_{M7}$	60u/100n

4.6.1 Noise Analysis

The noise performance of an LNA is directly proportional to how well its input matches. The noise performance of wide-band input matching is inherently noisier than that of its narrow-band counterpart since it cannot be adjusted for a specific frequency. Consequently, the rigorous trade-off between the wide-band input matching and the wide band LNA's noise figure must be thoroughly considered and decided. A wide band LNA with little noise generated should be used to boost the signal. For this reason, the first stage should have a high gain and a low NF. Total NF can be expressed using equation 4.44.

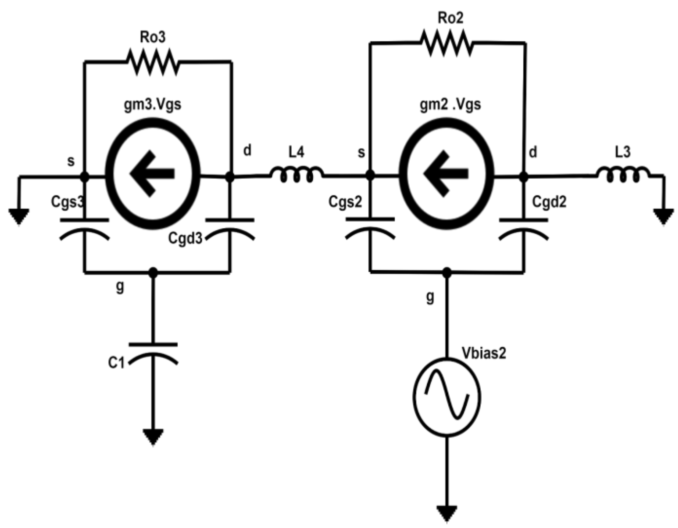


Figure 4.7: Small signal in Common Source

The noise factor due to termination is given by the following expression,

$$F = \frac{\text{Total power of output noise}}{\text{Total power of output noise due to source alone}}$$

$$F = 2 + \frac{4\gamma}{\alpha} \cdot \frac{1}{g_m R};$$

Where, is the MOS transistor's coefficient of γ channel thermal noise and is defined as the ratio of the α trans-conductance and the zero-bias drain conductance.
For first stage,

$$F = 1 + \frac{\gamma}{\alpha} + 4\frac{R_5 + R_{L2}}{R_{L1}};$$

Where, γ is the parasitic resistance of the drain inductor; and $(R_{L1} \cdot L_1)$ is the input source signal; and $R_5 + R_{L2}$ (or R_{L2}) is the parasitic resistance of the source inductor.

NF is equal to $10 * \log_{10}(F)$.

This 4.10 (b) configuration's noise factor is determined by the following formula,

$$F = 1 + \gamma g_m R \left(\frac{\omega_o}{\omega_T}\right)^2;$$

Where,

- Transit or Cut off frequency, $T = g_{m_3} C_1 + C_{gs_3} + 2C_{gd}$
- Trans-conductance, g_m
- Total effective input capacitance, $C_T = (C_1 + C_{gs_3} + 2C_{gd})$
- Drain current I_d

4.6.2 GAIN ANALYSIS

An essential feature of a LNA is its gain parameter, which establishes how much the LNA can amplify weak input signals so that later stages of the receiver circuitry can detect and process them more easily. To guarantee that the amplified signal can tolerate further losses and noise produced by the remainder of the receiver system, a high gain is necessary.
The first stage gain can be calculated by using the formula,

$$A_{v1} = g_{m1}(1-\alpha)Z'_L;$$

where,

$$\alpha = \frac{sC_{gs1}p + sC_{gd1}g_{m1}}{pq + sC_{gd1}(g_{m1} - sC_{gd1})},$$

$$Z_{L1} = [s(C_{db1} + C_{gs3})]^{-1},$$

$$p = (1/Z_{L1} + sC_{gd1}),$$

$$Z_{G1} = (sL_1 + R_{L1})||(1/sC_{gb1}),$$

$$q = (1/Z_{G1} + sC_{gs1} + sC_{gd1});$$

The second stage gain from the gate of M_2,

$$A_{v2} = \frac{g_{m2}Z_{L3}}{1 + g_{m2}Z_{dg3}}$$

Here,

$$Z_{dg3} = (1/sC_{sb2})||\left(sL_4 + 1/(sC_{db3} + sC_{gd3} + 1/r_{o3})\right),$$

and

$$A_{v3} = \left(\frac{g_{m2}Z_{L3}}{g_{m2} + sC_{sb2} + sC_{gs2}}\right) - \left(\frac{g_{m1}}{(1 + sZ_{g3}C_{db3})}\right) \quad \text{[from the gate of } M_3\text{]}$$

where,

$$Z_{g3} = sL_4 + 1/(sC_{sb2} + sC_{gs2} + g_{m2}) \quad \&$$

$$Z_{L3} = (R_{L3} + sL_3)||(1/sC_{db2})||Z_L,$$

LNA's total gain: $A_v = A_{v1} \cdot A_{v2} + A_{v3}$

4.6.3 INPU MATCHING

Input matching is crucial for LNAs to achieve optimal performance, especially concerning noise figure and gain, trade-offs Between Noise, Gain, and Linearity, for Maximum Power Transfer, Matching Network Losses, Gain and Input Match, Single-Amplifier Solutions & Stability.
Setting the trans-conductance of a wide band CG-LNA to $g_m = 1/R_s$, where $R_s = 50\Omega$ denotes the source impedance, allows for input matching. The input from the LNA must match 50Ω to minimize mismatching problems. Getting a 50Ω input impedance requires knowing the proper techniques. Furthermore, a 50Ω impedance match also allows for a simultaneous conjugate power match because impedance is completely real meeting the system requirements and producing the optimal power transmission.
The small-signal equivalent circuit for the impedance calculation,

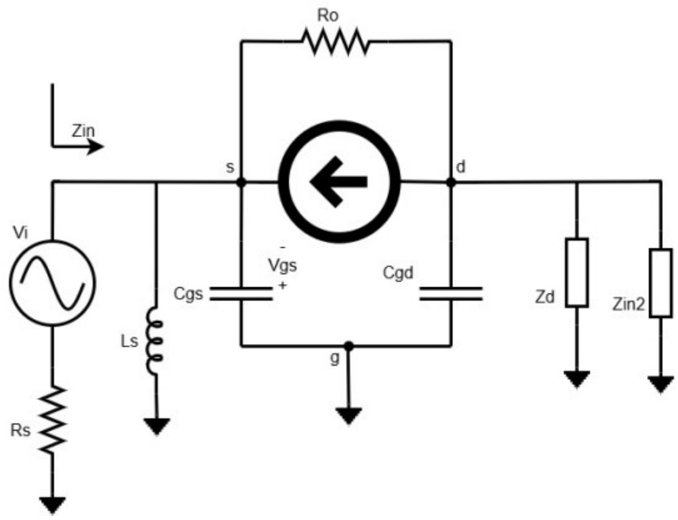


Figure 4.8: (a) Configuration of a Common Gate input stage, (b) Small signal in Common Gate

Here,

$$Z_{\text{in}} = \frac{1}{g_{m1} + \frac{1}{Z_r} + \frac{1-g_{m1}Z_o}{R_o+Z_o}} \quad \text{where,}$$

$$Z_s = j\omega L_s \left\| \frac{1}{j\omega C_{gs}} \right. \quad \& \quad Z_o = \frac{1}{j\omega C_{gd}} \left\| Z_d \right\| Z_{\text{in}2};$$

4.6.4 IIP3

An essential characteristic for LNAs is the Input Third-Order Intercept Point (IIP3), which shows how linear the LNA is and how well it can handle powerful signals without producing appreciable distortion. Good linearity, which is necessary for optimum performance, is indicated by a high IIP3 number. Its significance can be noticed in linearity indicator, distortion, inter-modulation products, high performance, dynamic range, signal handling, mitigating variations. Fig. 11 displays the input referred third-order intercept point (IIP3). To test the LNA's IIP3, a single tone is chosen. The measured IIP3 is 21.1537 dBm.

4.6.5 STABILITY ANALYSIS

In LNA design, the K_f parameter—also referred to as the K-factor or Rollet's stability factor—is an essential indicator for evaluating the amplifier's stability. The LNA is unconditionally stable if its K-factor is larger than 1, which means that it won't oscillate in the presence of any passive load or source impedance & the LNA is conditionally stable if its K-factor is smaller than 1, which means only under particular load and source impedance circumstances is the LNA stable, oscillations may result from mismatches. The K-factor is calculated using S-parameters, which characterize the behavior of the LNA as a two-port network. The formula is:

$$K_f = \frac{(1 - |s_{11}|^2 - |s_{22}|^2 + |\Delta|^2)}{2|s_{12}s_{21}|}; \quad \text{where, } \Delta = s_{11}s_{22} - s_{12}s_{21}$$

The K_f of the proposed LNA is less than 1, the amplifier is said to be conditionally stable, meaning that it may only be stable within a particular range of impedance, requiring careful design considerations.

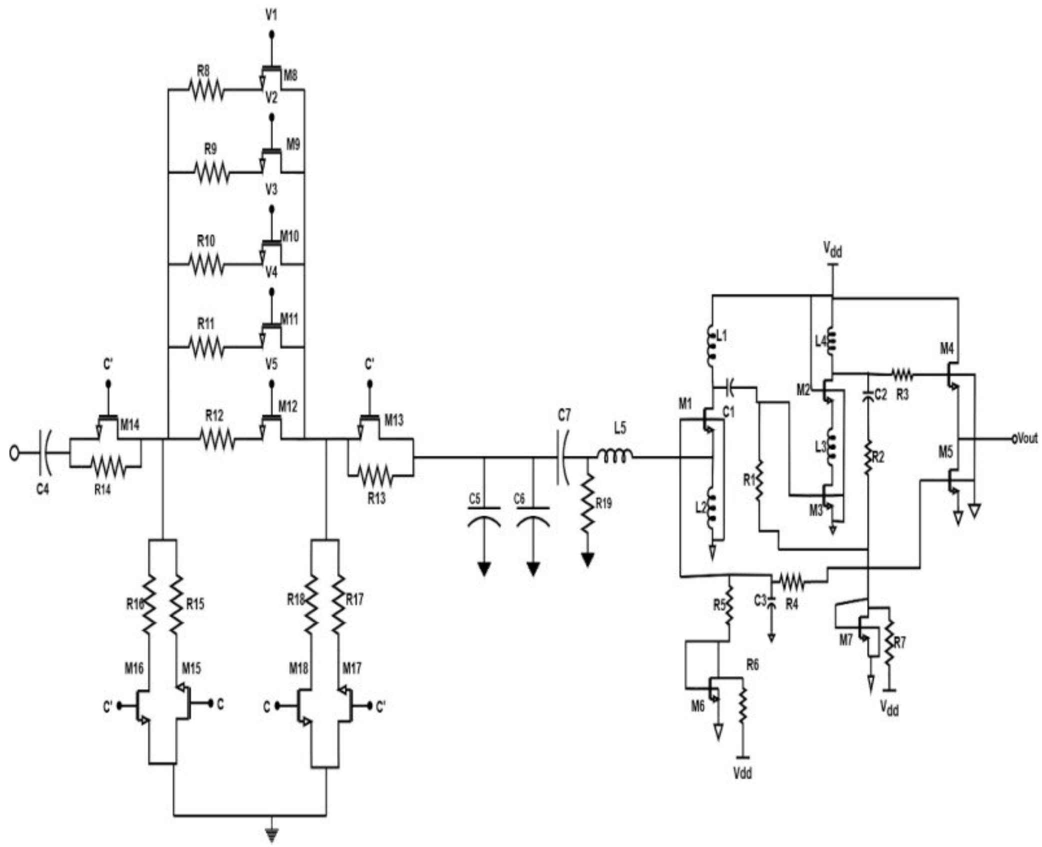


Figure 4.9: (a) Proposed attenuator with 5 stages, added with proposed LNA; (b) Proposed LNA with attenuator

4.7 DESIGNED LNA WITH ATTENUATOR

Some conventional attenuators employ T and bridged T topologies with series and shunt resistance changes. When the shunt resistances are large and the series resistance is small, the attenuator suffers the least amount of attenuation due to the control of the FET switches. In that case, the loss at the lowest frequencies is solely due to the nonzero on-resistance of the series switch. As this resistance drops, so does the insertion loss brought on by the attenuator's minimum insertion. Reducing the parasitic capacitors lowers the insertion loss since they produce more loss to ground at higher frequencies. Similarly, the series components are fully on and the shunt component is off when the T-attenuator is set to low gain. In contrast to T-topology, -topology showed a larger frequency response in our investigation. Additionally, there is a trade-off between T-topology attenuator attenuation and increased impedance matching. As a result, we chose the topology. The schematic of the proposed variable attenuator design is shown in Fig. 1(a). Its single stage topology consists of five sequential phases. To improve the input/output impedance matching of the attenuator, two shunt branch pairs of resistors (3R/10R) and transistors ($M_{15,18}/M_{16,17}$) are used. We optimized the parameter using S-parameter simulation; each FET switch's gate width was set to 2 m, and its resistance value, R, was set to 10 Ω.

Table 4.2: COMPONENT VALUES OF ATTENUATOR AND INTERMATCHING NETWORK:

Component Values	**Values**
L_s	1 nH
C_4	400 pF
C_5	95 pF
C_6	40 fF
C_7	3 pF
R_8	12 Ω
R_9	8 Ω
R_{10}	4 Ω
R_{11}	2 Ω
R_{12}	1 Ω
R_{13}	5 Ω
R_{14}	5 Ω
R_{15}	3 Ω
R_{16}	10 Ω
R_{17}	10 Ω
R_{18}	3 Ω
R_{19}	1.04 $k\Omega$
$(\frac{W}{l})_8 - (\frac{W}{l})_{19}$	2u/100n

4.8 GAIN ANALYSIS OF DESIGNED LNA WITH ATTENUATOR

Attenuation ranges from 15.97 dB to 22.70 dB with the developed attenuator's simple shift register control bit V_c and V_c', where V_c' is the complementary of V_c. When transistors M_{16} and M_{19} are turned off, that is, when V_c is low and V_c' is high, the attenuation stages will attain a lesser attenuation state from 15.97 dB to 22.70 dB. Similarly, when M_{17} to M_{18} are switched off (V_c is high and V_c' is low), the transistors of the five stages show a higher attenuation state from 16 dB to 22.52 dB. The proposed attenuator uses six digital control voltages [39]. Table 2 lists the digital control voltage choices for selecting the attenuation stat. Table 3 shows the performance summaries of the suggested LNA along with a comparison to other wide band LNAs that have been previously published.

Table 4.3: THE PERFORMANCE OF LNA WITH THE ATTENUATOR

Control bias							**Attenuation**	$\mathbf{S_{11}}$	$\mathbf{S_{22}}$	$\mathbf{S_{12}}$
$\mathbf{V_1}$	$\mathbf{V_2}$	$\mathbf{V_3}$	$\mathbf{V_4}$	$\mathbf{V_5}$	$\mathbf{V_C}$	$\mathbf{V_{C'}}$	$\mathbf{S_{21}}$ (dB)	(dB)	(dB)	(dB)
High	Low	Low	Low	Low	Low	Low	16	-7.19	-18.43	-72
High	High	Low	Low	Low	Low	Low	19.34	-9.58	-18.1	-68.44
High	High	High	Low	Low	Low	Low	20.97	-11.39	-18	-66.8
High	High	High	High	Low	Low	Low	21.91	-12.83	-17.95	-65.87
High	High	High	High	High	Low	Low	22.52	-14.03	-17.9	-65.26
High	High	High	High	High	High	Low	22.70	-13.52	-17.86	-65.24
High	High	High	High	Low	High	Low	22.15	-12.31	-17.91	-65.88
High	High	Low	Low	Low	High	Low	21.23	-10.99	-18	-66.79
High	High	Low	Low	Low	High	Low	19.63	-9.30	-18.16	-68.39
High	Low	Low	Low	Low	High	Low	15.97	-7.08	-18.34	-71.93

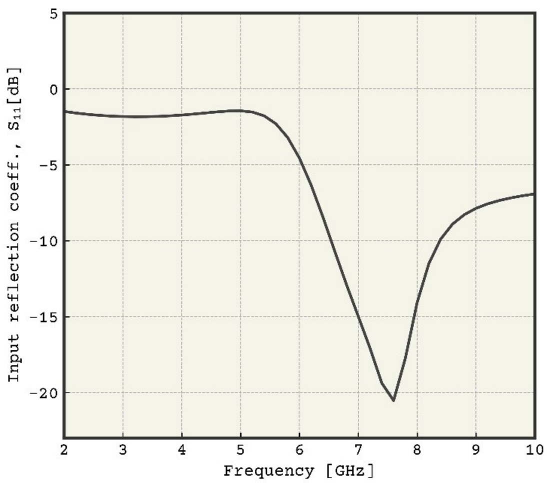
Chapter 5

RESULT ANALYSIS

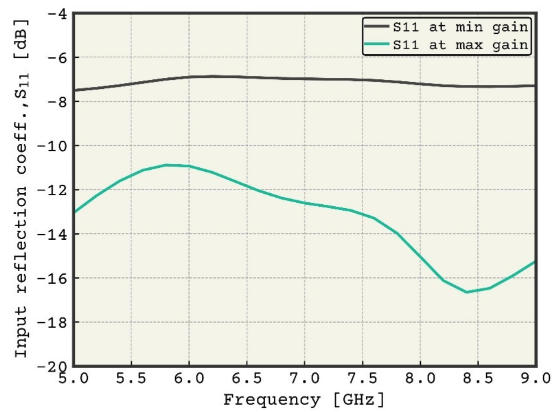
Analyzing a wide band LNA's S-parameters requires describing the input and output behavior of the amplifier across a range of frequencies. Examples of this include analyzing factors such as gain, return loss, and stability within the targeted bandwidth. Techniques including load-pull simulations, stability factor calculations, and Smith chart analysis are commonly used to maximize performance and ensure accurate matching across the frequency range.The results detail the performance of a LNA circuit and how it can be improved by including a second stage and matching networks. The following lists the key findings and implications of each stage. An inter-stage matching network and an input matching network were developed to improve impedance matching. The two-stage low noise amplifier shown in Figure 4.12 and the S parameter simulation results $S_{11}, S_{12}, S_{21}, S_{22}$& noise factors are shown in Figures 5.1, 5.2, 5.3, 5.4 and 5.5 respectively.

5.1 INPUT REFLECTION COEFFICIENT

S_{11} the parameter, commonly known as the input reflection coefficient, is crucial for wide band LNAs because it indicates how well the amplifier input matches the source impedance. In a wide band situation, maintaining a good match across a wide frequency range is essential for minimizing reflections and maximizing power transfer. To obtain a low S_{11} over a broad bandwidth, it is frequently required to carefully build matching networks and employ impedance tuning techniques unique to the amplifier's frequency characteristics. To improve input impedance matching and inter-stage impedance matching, an input matching network is added to the input side of the proposed LNA and an inter-stage matching network is introduced between the first and second stages. The proposed LNA network, which has S_{11} values of 20.53 dB at 7.6 GHz, achieves better input matching.



(a) Without attenuator



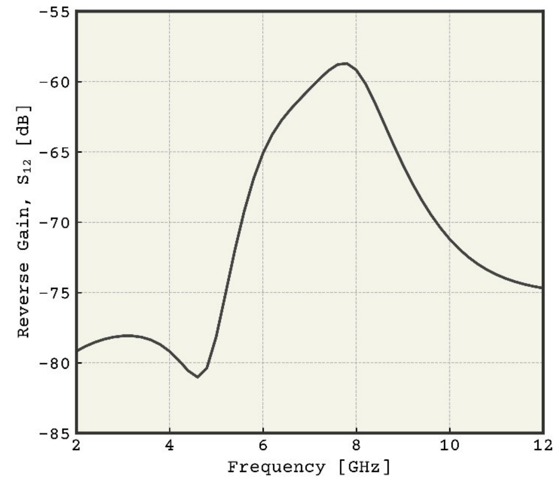
With attenuator

Figure 5.1: S_{11} parameter of a two stages LNA with input and inter-stage matching network (a) without attenuator, (b) with attenuator

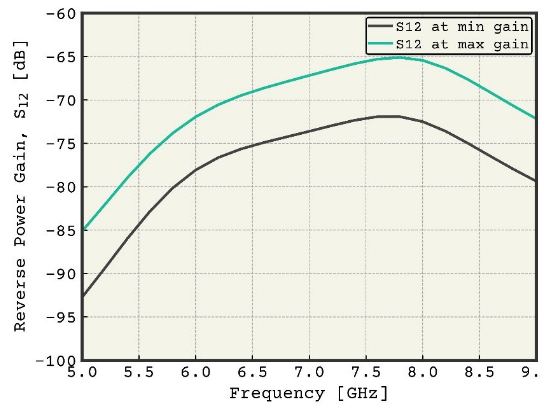
The proposed LNA network with the attenuator has variable S_{11} values. The values vary from -13.29 dB to 7.12 dB at 7.6 GHz, better input matching.

5.2 REVERSE ISOLATION

The S_{12} Parameter, also known as reverse isolation or transmission from output to input, is crucial in wide band power amplifiers because it indicates the amount of signal coupling or leakage that takes place from the output back to the input. In high-power amplifiers, lowering S_{12} is crucial to prevent unwanted feedback that could make the amplifier unstable or distort the output signal. Maintaining a low S_{12} throughout a broad frequency range improves signal integrity and stability in broadband applications, particularly when dealing with several frequency bands or complex modulation methods. Furthermore, at 7.6 GHz, the recommended low noise amplifier exhibits good reverse isolation (S_{12}) of - 58.7924 dB.



(a) Without attenuator



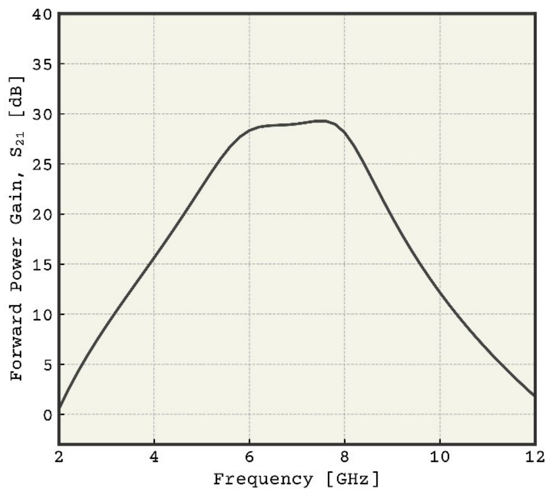
With attenuator

Figure 5.2: S_{12} parameter of a two stages LNA with input and inter-stage matching network (a) without attenuator, (b) with attenuator

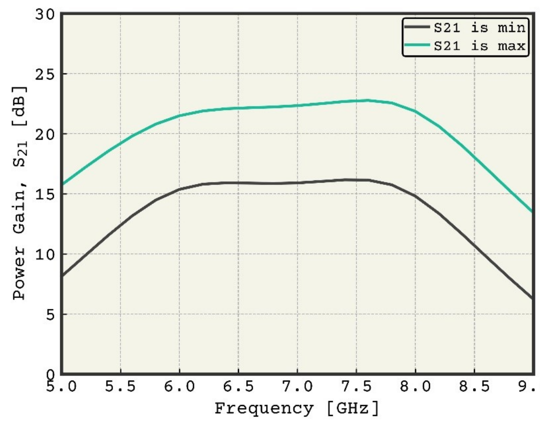
After adding the attenuator at input side of the LNA, it gives a variable S_{12} values. The values vary from -71.93 dB to 65.31 dB at 7.6 GHz, better reverse isolation which means how well a signal applied to the output port of a device is isolated from its input port.

5.3 FORWARD GAIN

The S_{21} parameter, which is often represented in terms of magnitude and phase, indicates the forward gain, often referred to as the transmission coefficient, of a wide band power amplifier. It shows how much input signal power is transferred to the output by accounting for both the amplitude and phase relationships throughout a wide frequency range. A high S_{21} value indicates strong amplification and excellent signal transfer via the amplifier; nevertheless, linearity and performance may be impacted by deviations or fluctuations in S_{21} across frequencies.
The maximum value of S_{21} at the matching frequency of 7.6 GHz is 29.28 dB, which indicates a higher power gain than the other stage. These improvements demonstrate how the matching network improved the situation.



(a) Without attenuator



With attenuator

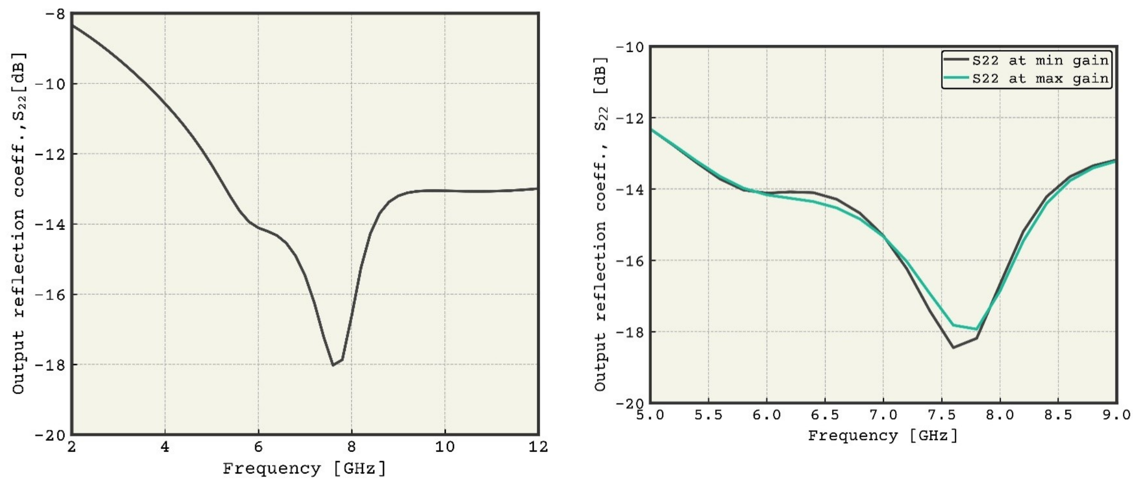
Figure 5.3: S_{21} parameter of a two stages LNA with input and inter-stage matching network (a) without attenuator, (b) with attenuator

After adding the attenuator at input side of the LNA, it gives a variable S_{21} (power gain) values. The values varies from 16.14 dB to 22.76 dB at 7.6 GHz, better power gain which means showing how much power is amplified as it passes through the device.

5.4 OUTPUT RETURN LOSS

In a wide band low noise amplifier, the "S_{22}" parameter, also known as the return loss of amplifier or reverse transmission coefficient, measures the amount of signal linked from the amplifier's output back to its input. It is essential to comprehend how well the amplifier isolates the input from the output, prevents signal reflections, and maintains system stability. A lower S_{22} value indicates greater isolation and less signal feedback for effective amplifier operation.

The recommended LNA exhibits good output matching and only a small amount of output power is reflected back, with an S_{22} value of less than -18.024 dB. The graph shows that the value is -18.024 dB.



With attenuator

(a) Without attenuator

Figure 5.4: S_{22} parameter of a two stages LNA with input and inter-stage matching network (a) without attenuator, (b) with attenuator

After adding the attenuator at input side of the LNA, it gives a variable S_{22} (return loss) values. The values vary from -18.45dB to -17.82dB at 7.6 GHz, better power gain which means showing how much power is amplified as it passes through the device.

5.5 NOISE FIGURE

The noise factor of the power amplifier measures how much the amplifier lowers the signal-to-noise ratio of the input signal. A lower noise factor, which indicates that the amplifier is introducing less noise to the signal, indicates better performance. At 7.6 GHz, the suggested low noise amplifier's noise factor is 2.715 dB. After adding the attenuator, this noise factor become 9.488 dB.

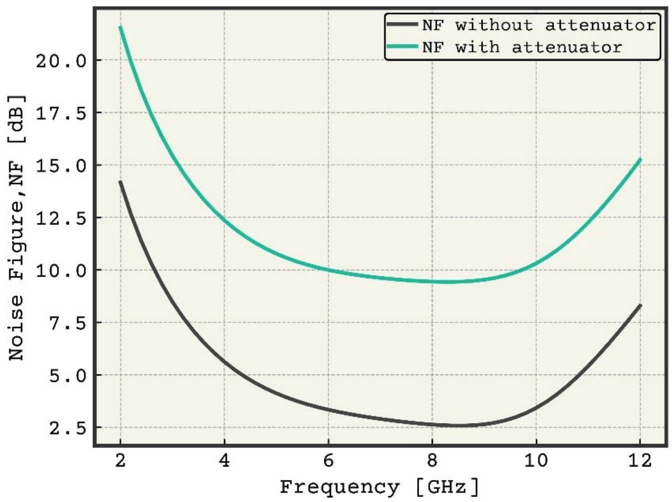
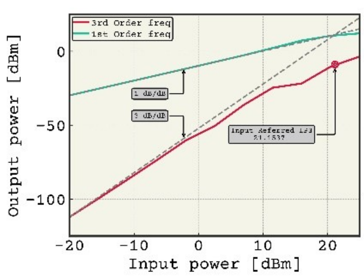
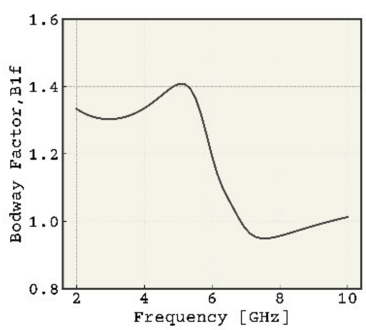


Figure 5.5: Noise Figure parameter of a two stages LNA with input and inter-stage matching network without attenuator

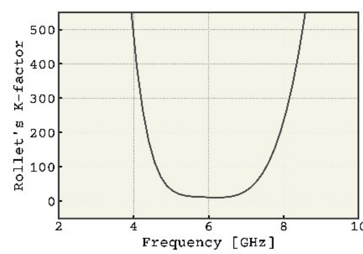
5.6 STABILITY AND LINEARITY



(a) IIP3



(b) Bodway K-factor



(c) Rollett's K-factor

Figure 5.6: IIP3, K-factor, B1f factor of a two-stage LNA demonstrating (a) Input-output linearity, (b) Bodway factor, and (c) Rollett's K-factor (stability) across frequency.

It is evident from the IIP3 value that our Low-Noise Amplifier (LNA) is linear. Additionally, the LNA is stable, as indicated by the values of Kf and B1f, which are greater than 1 and 0, respectively.

5.7 PERFORMANCE COMPARISON

The comparison table indicates that the suggested work performs better in terms of gain (S_{21}) than the other references. In comparison to the earlier works, the other values of S_{11}, S_{12}, and S_{22} also show good performance, indicating proper input matching, less reverse isolation, and less output return loss. Our suggested LNA work of 6.6 GHz to 8.4 GHz bandwidth is applicable to a wide range of applications in diverse industries.

Table 5.1: Performance summaries of the proposed LNA and comparison to previously reported wide band LNAs

Ref.	**CMOS Tech.** (nm)	V_S (V)	**Gain** (dB)	**Freq.** (GHz)	S_{11} (dB)	S_{12} (dB)	S_{22} (dB)	**IIP3** (dBm)
This work (without attenuator)	90	1.2	29.25	7.616	-20.31	-58.78	-18.01	21.1537
This work (with attenuator)	90	1.2	15.97 to 22.7	7.616	-13.52 to -7.08	-71.93 to –65.24	–18.34 to -17.86	—
[13]	180	1.8	13	2 to 5	< -10			-9.5
[14]	90	1.2	11.2 to 12.4	1.6 to 2.4	-25.26 to -21.4			-3.12 to -2.14
[39]	180	1.8	6 to 24	DC-4	< -10			
[5]	130	1.8	17	0.05 to 0.83	< -8.9		< -8.5	-6.3
[7]	180	1.8	16.1	0.1 to 1.4	< -9			13 to 18.9

For medical imaging, advanced low noise amplifiers (LNAs) are essential for boosting weak signals from sensors and detectors while reducing noise introduction and guaranteeing a high signal-to-noise ratio (SNR). For example, they are utilized in medical imaging devices like as computed tomography (CT) scanners and magnetic resonance imaging (MRI). LNAs in MRI can even be made for ultra-low-field MRI measurements without adding further noise since they can amplify very weak signals to a level that is sufficient for transmission. Additionally, specific instrumentation amplifiers with low power and low noise are made for biomedical applications. Using the 90 nm technology node, a sophisticated LNA optimized for high-precision navigation applications was created.

To identify weak bio-signals, medical imaging devices like MRI, ultrasound, and PET scanners need extremely sensitive and accurate signal amplification. By reducing noise and boosting weak signals, advanced low noise amplifiers, or LNAs, are essential for improving signal quality.

A gain-adjustable LNA ensures optimal signal reception without distortion by offering flexibility in adjusting to various imaging circumstances. The system can improve picture quality and diagnostic accuracy by balancing sensitivity and signal clarity through dynamic gain management. Advanced LNA designs are also perfect for portable and real-time medical imaging systems because

they use CMOS or GaAs-based technology to improve bandwidth, power efficiency, and thermal stability.
In contemporary medical imaging systems, this technique is essential for lowering artifacts, boosting contrast, and boosting overall diagnostic dependability.

Chapter 6

CONCLUSION

6.1 GENERAL

In this paper, we designed a low noise amplifier with an attenuator that primarily regulates the originally designed LNA circuit's linearity and gain across a wide frequency range. A low-noise amplifier circuit including an attenuator and one common-gate common-source (CG-CS) stage is contributed by this study. The CG-CS stages reduced the power consumption, and the attenuator adjusted the gain, noise performance, and wide band width range. Because of body biasing, S-parameter values are enhanced. Eliminating the passive L-C component improves the performance of the gain and output noise. The suggested LNA is simulated, with results and a thorough mathematical analysis offered. Using Cadence Virtuoso, designs for GPDK 90 nm technologies are examined and simulated. The proposed LNA topology with a 1.2V supply voltage and an operating frequency of 7.616 GHz achieves a power gain of 29.25dB using a 90nm CMOS process. Considering the performance achieved, the proposed technique is suitable for the implementation of wideband LNAs in medical imaging sectors. With the integrated attenuator the gain of the designed Low Noise Amplifier varies from 15.97dB to 22.7dB by maintaining a good impedance matching.

6.2 KEY FINDINGS

Table 6.1: Key Findings of the proposed work

This work	**Gain** (dB)	**Freq.** (GHz)	S_{11} (dB)	S_{12} (dB)	S_{22} (dB)	**IIP3** (dB m)
Without attenuator	29.25	7.616	-20.31	-58.78	-18.01	21.1537
With attenuator	$15.97-22.7$	7.616	$-13.52 to -7.08$	$-71.93 to -65.24$	-18.34 to -17.86	

6.3 LIMITATION OF THE STUDY

- Bandwidth of the designed Low noise amplifier can be increased from wide frequency range to ultra-wide frequency range.
- Noise factor of low noise amplifier after adding attenuator get increased slightly. The noise factor can be decreased by following proper path.

6.4 RECOMMENDATION FOR THE FURTHER STUDY

The applicability of the designed low-noise amplifier (LNA) with an input-side attenuation in biomedical imaging and sensing technologies can be optimized in future research. To increase signal quality and diagnostic accuracy, one important field of study is customizing the LNA for certain medical imaging modalities, such as microwave imaging, ultrasound, and magnetic resonance imaging (MRI). Another interesting possibility is the incorporation of the LNA into wearable and implantable medical devices, as its low-noise properties can greatly enhance the detection of weak bio-signals in applications such as biosensors, electrocardiography (ECG), and electroencephalography (EEG). To ensure maximum performance in actual biomedical settings, it might also be helpful to examine how biological tissue affects signal attenuation and penetration at various frequencies. To increase lifespan and usefulness in continuous patient monitoring, energy-efficient and compact designs are essential for portable and battery-operated medical equipment. For the LNA to operate safely inside or close to the human body, its thermal behaviour and biocompatibility need also be examined. Medical monitoring systems can perform even better when machine learning techniques are used to provide adaptive gain control based on real-time signal fluctuations. This will result in more precise and responsive diagnosis. By lowering interference and noise-related distortions and improving signal amplification and frequency range, the developed LNA can help enhance biomedical signal processing and enable breakthroughs in non-invasive and real-time medical diagnostics.

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