Design Of a CMOS Differential Amplifier Using Current Mirror Load

(EC 782) Project Stage – I

A Project Report Submitted in Partial Fulfillment of the Requirements

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In Electronics and Communication Engineering by:

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Certificate

This is to certify that **Abhiraj Kolay, Debasmita Fouzdar, Pralay Roy Chowdhury, Tiasha Sain** has carried out his project work entitled **"Design Of a CMOS Differential Amplifier Using Current Mirror Load"** as a part of the curriculum for the **B.tech Degree** in **Electronics & Communication Engineering (ECE)** under **Maulana Abul Kalam Azad University of Technology** for the year **2020-2024.**

This project report is approved by the undersigned only for the purpose for which it is submitted. The candidate is entirely responsible for the statements, opinions and conclusions contained herein.

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1. Abstract

In this study, we will demonstrate the construction of a Complementary Metal Oxide Semiconductor (CMOS) technology differential amplifier. The article examines the model with Current Mirror load, using N-type Metal Oxide Semiconductor (NMOS) and P-type Metal Oxide Semiconductor (PMOS) for simulations. The differential amplifier is an important element in thecreation of analog circuits, and its features are assessed by gain, bandwidth results, and Common Mode Rejection Rate (CMRR). Our circuit incorporates bipolar and MOS technology, utilizing NMOS and PMOS devices to create differential pairs. The N channel is used, and the current P- channel mirror load is applied. This article presents an amplifier design that uses 180nm. To achieve the parameters and purpose of the circuit, we utilise NMOS current meter loads from various topologies.

2. Introduction

The advancement of MOS transistors has propelled the historical landscape of very-large-scale integration (VLSI) technology, leading to significant changes in the electronics industry. This evolution has laid the foundation for the exploration and refinement of the design of differential amplifiers, which have become fundamental components of electronic circuits and play a crucial role in signal processing across diverse applications.

The differential amplifier is a form of amplifier that strengthens the difference between two voltages in a circuit. In electronic designs, we use a differential amplifier to produce high voltage gain and high CMRR. Its main characteristics include very low bias current input, very high impedance input, and very low offset voltage. The essential benefit of differential mode from common mode is its higher immunity to noise. Also, differential amplifiers provide better immunity to environmental noise, improve linearity and more upper signal swing. It may operate in two modes: common mode and differential mode. The common method produces a zero voltage output result while the differential mode produces a high voltage output result. Given this, the differential amplifier generally has a high CMRR. If the two input voltages are of similar value, the amp provides an output voltage value that is almost zero. When the two input voltages are unequal, the amplifier produces a high-voltage output. The remarkable advantage of differential operation over common mode operation is its higher immunity to noise. Another advantage is the increase in voltage swings, wherein the peak-to-peak voltage swing is equal to $2\ [V_{DD} - (V_{GS} - V_{TH})]$.

Differential amplifiers are promising solutions to the growing demand for high-performance amplifiers to meet the challenges posed by modern electronic applications. In the ever-evolving landscape of electronic devices, there is a need for amplifiers that can provide high gain, exceptional common-mode rejection, and improved power efficiency concurrently.

To enhance the performance of differential amplifiers, we can integrate a current mirror load, which employs a current mirror circuit as the load for active devices. This addition offers advantages like improved biasing stability, enhanced output swing, and reduced sensitivity to process variations. The integration of a current mirror load not only contributes to the amplifier's performance but also addresses challenges associated with traditional differential amplifiers.

3. Literature Review

The initial investigation and literature survey were conducted to obtain fundamental information about the design of the CMOS Differential Amplifier utilising references from the book "CMOS ANALOG CIRCUIT DESIGN" [1] .This book was an essential element of our study because it provided us with basic knowledge of CMOS differential amplifiers and how they work when various types of loads are applied to them. A differential amplifier, as described in the research paper[2] by Saud Almusallam and Ali Ashkanani, is designed to amplify two input signals and determine their differences. A design is required to accomplish this. To analyse the model, this research employs an active load. Advance Design System presented simulations for NMOS and PMOS. Similarly, ADS displays the amplifier design. The circuit characteristics are intended for operational amplifier applications, and the W/L ratios are computed. Furthermore, the ADS improves the precision of the results.Tan Yang and Jeremy Holleman have suggested a study [3] that deals with the construction of an amplifier array with neural recording that is ultra-power and low noise and is best suited for large-scale integration. The design comprises of a single-ended supply sensitive first stage and a differential second stage. From a 1v supply, the design consumes 2.85 microamperes per channel. The proposed design makes use of 90nm CMOS technology. The input noise of the design is 3.04 microvolts.In their study[4], Monika Mehra and R P Singh demonstrated how a differential amplifier is built to amplify two input signals and determine the difference. An active load is used to analyse the model. The simulations of NMOS and PMOS were presented using the Advance Design System (ADS). ADS also displays the amplifier's architecture. The W/L ratios and circuit characteristics are established for operating amplifier applications. Furthermore, ADS improves the precision of the results. This article describes an amplifier design that uses 0.18m and a 1.8V CMOS supply voltage. They used NMOS current metre loads from several topologies to achieve the circuit's specifications and purpose.

4. Motivation.

The CMOS differential amplifier with a current mirror load finds widespread applications in various electronic systems owing to its unique characteristics and advantages. Some notable applications include:

- **Analog-to-Digital Converters (ADCs):** In the front-end stages of analog-to-digital converters, the differential amplifier with a current mirror load assists in amplifying and conditioning signals before conversion. Its ability to reject common-mode noise is crucial for achieving accurate and high-resolution analog-to-digital conversions.
- **Communication Systems:** The CMOS differential amplifier with a current mirror load is ideal for wireless communication systems due to its balanced input structure and improved linearity. It is used in transceivers, modulators, and demodulators.

- **Biomedical Applications**: CMOS differential amplifiers with current mirror loads are crucial in biomedical devices for accurate signal amplification in biosensors, medical imaging devices, and bioelectronic interfaces.

5. Problem Statement

Design and analyze a differential amplifier circuit employing a current mirror load to achieve enhanced performance in terms of gain, common-mode rejection ratio (CMRR), and power efficiency. Investigate the impact of variations in key parameters such as transistor characteristics, biasing conditions, and load resistor values on the overall circuit performance. Additionally, explore strategies to optimize the design for a specific application, considering trade-offs between performance metrics and practical implementation constraints.

From the literature review it was observed that the key areas of work and improvement can be in the areas including size reduction ,making the amplifier low noise and low power consuming.In this project the pivotal focus is reducing the size of the amplifier as semiconductor technologies continues to scale down and the impact of parameter and process variations becomes more pronounced.

6. Methodology

LTspice is a high-performance, free simulation software provided by Analog Devices, specifically by its subsidiary Linear Technology. It is widely used for simulating and analyzing the behavior of electronic circuits. LTspice allows engineers, students, and hobbyists to model and simulate the performance of analog and mixed-signal circuits.
Key features of LTspice include:

Schematic Capture: Users can create circuit schematics by placing and connecting components from an extensive library.

Simulation: LTspice enables transient, AC, DC, and various other types of simulations to analyze circuit behavior under different conditions.

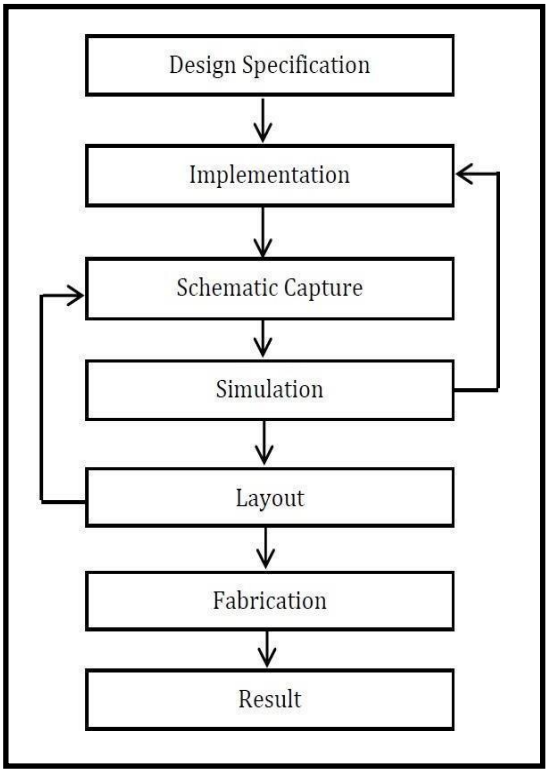
Waveform Viewer: The software provides a powerful waveform viewer, allowing users to visualize simulation results, such as voltage and current waveforms.

Component Library: LTspice comes with a comprehensive library of analog and digital components, and users can also add custom components.

Parameter Sweeps: Users can perform parameter sweeps to analyze the impact of varying component values on circuit performance.

6.1 Planning and Approach

The flow chart illustrates the steps involved in executing our project.



1.The first step is to collect the specification data required for designing a CMOS differential amplifier with a current mirror load. This data includes small signal gain, ICMR, Slew rate, etc.

1. Next, we will create a schematic of the amplifier, which in our project is a current mirror load CMOS differential amplifier.

2. After creating the schematic, we will determine the (W/L) ratio of the CMOS transistors to meet the given constraints and optimize the length and width of the MOS transistors.

3. Once this is done, we will simulate the schematic captured with the optimized length and width using the simulation tool with 180nm technology.

4. If the simulation produces the expected results, we will move on to the next step, which is the layout formation of the amplifier.

5. If the simulation does not produce expected results, we will iterate again from the implementation step until we obtain the expected result.

6. If any issues arise in the layout, we will restart the process from the schematic capture stage.

6.2 Design Analysis

The starting point of design consists of two types of information. One is the design constraints such as the power supply, the technology, and the temperature. The other type of information is the specifications. The specifications for the differential amplifier might consist of:

- Small-signal gain A_v: - Small signal gain is a measure used in electronics to quantify how much an electronic circuit amplifies a small input signal. It is particularly important in the analysis anddesign of amplifiers. When an electronic circuit is designed to amplify signals, it is often assumed that the input signal is small enough to be treated linearly, allowing for a simpler analysis.

$$A_v = g_{m1}R_{\text{out}}$$

Frequency response for a given load capacitance, $\omega_{\text{-3 dB}}$

$$\omega_{-3\text{ dB}} = \frac{1}{R_{\text{out}}C_L}$$

- Input common-mode range (ICMR) or maximum and minimum input common-mode voltage [V_{IC} (max) and V_{IC}(min)]:- The ICMR specifies the minimum and maximum common-mode voltages that can be applied to the inputs of a device while maintaining proper operation. It ensures that the circuit remains linear and functional within this voltage range. The ICMR is crucial for applications where the input signals may vary over a wide range, and it helps designers ensure that the circuit can handle different common-mode voltage levels withoutintroducing distortion or other undesired effects.

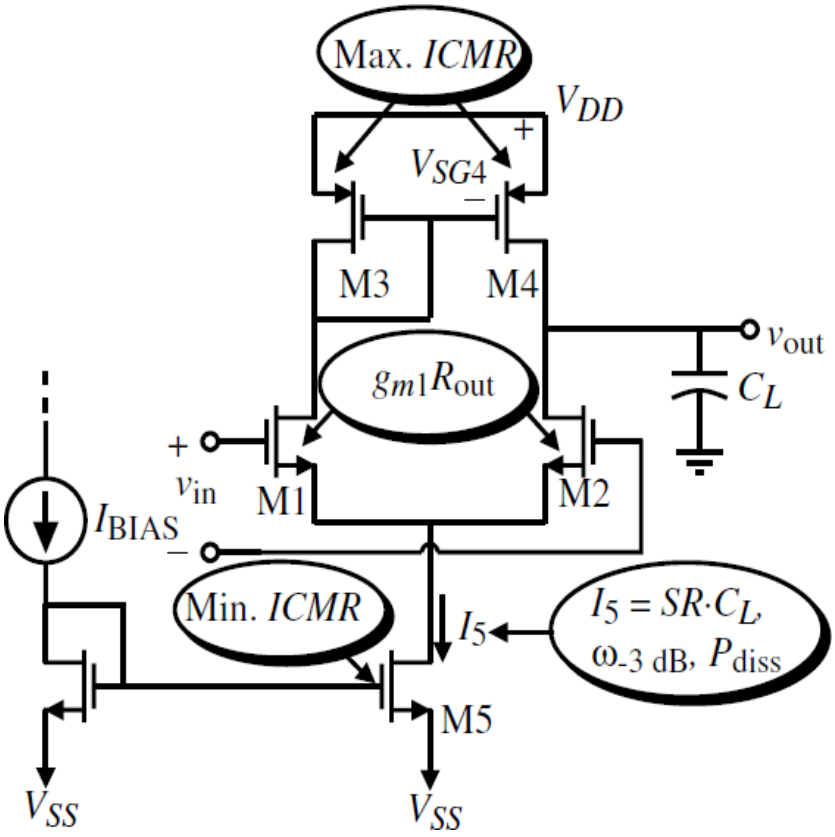
$$V_{IC}(\text{max}) = V_{DD} - V_{SG3} + V_{TN1}$$
$$V_{IC}(\text{min}) = V_{DS5}(\text{sat}) + V_{GS1} = V_{DS5}(\text{sat}) + V_{GS2}$$

- Slew rate for a given load capacitance, *SR*:- Slew rate is a parameter used to characterize the rate at which an amplifier can change its output voltage in response to a step change in the input signal. It is a critical specification where the ability to respond quickly to changes in the input signal is important. A higher slew rate indicates that the amplifier can respond to changes in the input signal more quickly. It is a measure of the amplifier's ability to follow rapid changes in theinput without introducing distortion.

$$SR = I_5/C_L$$

- Power dissipation P_{diss}

$$P_{\text{diss}} = (V_{DD} + |V_{SS}|)(I_5) = (V_{DD} + |V_{SS}|)(I_3 + I_4)$$



This circuit diagram illustrates the relationships that are typically used to design the various parameters of the current-mirror load differential amplifier.

This design procedure assumes that the small-signal differential voltage gain, A_v; the -3 dB frequency, $\omega_{-3\ dB}$; the maximum input common mode voltage, V_{IC} (max); the minimum common mode voltage, V_{IC} (min); the slew rate, SR; and the power dissipation, P_{diss}, are given.

(1) Choose I_5 to satisfy the slew rate knowing C_L or the power dissipation, P_{diss}

(2) Check to see if R out will satisfy the frequency response and if not, change I_5 or modify the circuit (choose a different topology).

(3) Design W_3/L_3 (W_4/L_4) to satisfy the upper ICMR.

(4) Design W_1/L_1 (W_2/L_2) to satisfy the small-signal differential voltage gain, A_v.

(5) Design W_5/L_5 to satisfy the lower ICMR.

(6) Iterate where necessary.

7. References

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[4] CMOS Technology Differential Amplifier Monika Mehra, R P Singh RIMT University, Mandi Gobindgarh, Punjab

[5] International Research Journal of Engineering and Technology (IRJET) Design of Low Noise CMOS Differential Amplifier using 180nmTechnology Nanditha S1, Janaki S2 Department of Electronics and Communication, University Visvesvaraya College of Engineering, Karnataka, India 2Department of Electronics and Communication, Sapthagiri College of Engineering, Karnataka, India