


# COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

# DEPARTMENT OF PHYSICS

## COMPARISON OF SINGLE STAGE AND TWO STAGE CMOS OPERATIONAL AMPLIFIERS

**A SENIOR PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN PHYSICS**

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## Abbreviations

| | |
|---|---|
| Op amp | Operational Amplifier |
| CMOS | Complementary metal oxide Semiconductor |
| CMRR | Common mode rejection ratio |
| PSRR | Power Supply Rejection |
| BJT | Bipolar Junction Transistor |
| FET | Field Effect Transistor |
| MOS | Metal Oxide Semiconductor |
| PMOS | Positive Channel Metal Oxide Semiconductor |
| NMOS | Negative Channel Metal Oxide Semiconductor |

# *Abstract*

*Operational amplifier (Op-amp) is versatile device that can be used to amplify DC as well as AC input signals. In this project work a two stage CMOS op amp and single stage CMOS op amp has been compared based on values of their performance parameters by using 0.35μm CMOS technology and the same power supply (3.5V). As the result shows that: single stage CMOS op amp has larger phase margin and smaller power dissipation than two stage CMOS op amp. This shows that single stage CMOS op amp is more stable and operates longer duration of time than two stage CMOS op amp with small energy loss. Whereas two stage op amps produces the output which is almost twice larger than single stage op amp. In addition the noise in the output of two stage op amp is less than single stage op amp. So to obtain high output it is better to use two stage op amps than single stage op amp. By results and reasons suitable choices of CMOS op amp will be done based on their performance parameters.*



## Key word

*Performance parameters; Single Stage CMOS Op Amp; two Stage CMOS Op Amp.*

# CHAPTER ONE

## 1 INTRODUCTION

### 1.1 Background of the study

An operational amplifier is direct couple amplifier usually consisting one or more differential amplifier. the op-amp is versatile device that can be used to amplify DC as well as AC input signal and was originally design for performing mathematical operation such as addition, subtraction, multiplication and integration. the op amp is a flexible device and plays a very important role in analog circuit design. it is one of the basic building blocks of linear circuit design. when we need higher gains, we can use two or more amplifier stages in structure op-amp [1].

Op-Amps are basic building blocks of a wide range of analogue and mixed signal systems. Basically, Op-Amps are voltage amplifiers being used for achieving high gain by applying differential inputs as new generations of CMOS technology tend to have shorter transistor channel length and scaled down supply voltage, the design of Op-Amps stays a challenge for designers. an operational amplifier is a direct-coupled high-gain amplifier usually consisting of one or more differential amplifiers [2]**.** an op amp is a three-pin instrument. it mainly consists of an inverting input terminal denoted by a negative sign, (-) and the other a non-inverting input denoted by a positive sign (+) in the symbol for op-amp. both inverting and non-inverting inputs are very high resistance. [3] their primary limitation is that they are not especially fast the typical performance degrades rapidly for frequencies greater then about 1MHz, although some models are designed specifically to handle higher frequencies. [4]

There are many op-amp topologies, such as single stage, two stage, folded cascade, telescopic but we have seen single stage op-amp using CMOS technology and two stage CMOS op-amps.[1] Single stage operational amplifiers have been preferred for their stable frequency response. However, CMOS technology has been constantly scaling down establishing some challenges when designing operational amplifiers and others integrated circuits. two-stage

operational amplifiers are the most common used multistage amplifier because it can provide high gain and high output swing. [5]

Single stage has smaller complexity when compared to two stage topologies the disadvantage of single stage CMOS op-amp is smaller gain because of the reality that output impedance of this class topology is commonly small but this small resistance also provides to large speed and large unity gain bandwidth than double stages. the disadvantage of two stage CMOS operational amplifier having small amplification of the one stage topology is solved by double stages. in this class of topology double stages are useable. So, one of them produces large amplification continued by next stage which produces large voltage swing. This adjustment enlarges the amplification up to some certain extent compared to single stage. However, this addition of additional stage also enlarges complexity. So, the enlarged complexity will lower the slew rate in comparison to a single stage amplifier. [3]

## 1.2 Statement of the Project

To meet continuous demand of technology for human beings, researchers highly struggle to design and create smart devices. So identifying the best type of CMOS op amp is important with great accuracy, speed, and extended battery life for day to day applications. Therefore, an op-amp is undoubtedly the functional and structural units of electronic circuitry. In this work the applications of types of CMOS op amp will be explained by considering their performance parameters. In addition to this project work will experienced user of operational amplifiers, as well as the new user, in extending the range of potential applications in which these devices can be used to advantage.

## 1.3 Objectives

### 1.3.1 General Objective

The general objective of this senior project is to identify the better CMOS op amp (single stage or two stage operational amplifiers) for real world applications.

### 1.3.2 Specific Objective

- To know the performance parameters of CMOS op amp
- To describe the single stage operational amplifiers
- To describe the two stage operational amplifiers
- To explain the difference and similarity between single and two stage CMOS op amp.

## 1.4 Scope of the Project

This project work has many explanations about the types of op amp, mainly on single stage CMOS Op amp and two stage CMOS op amp. In addition we were tried to see the performance parameters of op amp such as DC Gain, output swing, slew rate , power dissipation etc. single stage CMOS op amp, two stage CMOS op amp and also comparisons between single stage and two stage op amp by using all the necessary theories, assumptions and experimental results..

## 1.5 Significance of the Project

The main advantage of this project work is to identify the best op amp for real life applications. There are many types of CMOS operational amplifiers. Out of this op amp we identify the best op amp based on their performance parameters. Since op amp play a crucial role in various electronic circuits. Single-stage op-amps are often used in low-power devices such as battery-operated sensors, employed in sensor interfaces (e.g. Temperature sensors, pressure sensors), it can be used for basic signal conditioning tasks, such as amplification and filtering, in portable audio devices (e.g., headphones, earbuds), and also two-stage op-amps are essential for analog signal processing, such as filtering, amplification, and mixing, they play a role in analog-to-digital converters (ADCs) and digital-to-analog converters (DACs). For high-speed data communication and signal processing. And also, it is assumed that the reader will have a basic knowledge of electronics, and any other researchers who will works related to this project.

# CHAPTER TWO

# 2 LITERATURE REVIEW

## 2.1 Transistors

A transistor is a type of semiconductor device that can be used to conduct and insulate electric current or voltage. a transistor basically acts as a switch and an amplifier. in simple words, we can say that a transistor is a miniature device that is used to control or regulate the flow of electronic signals. transistors are one of the key components in most of the electronic devices that are present today. developed in the year 1947 by three American physicists, John Bardeen, Walter Brattain and William Shockley, the transistor is considered one of the most important inventions in the history of science. a typical transistor is composed of three layers of semiconductor materials or, more specifically, terminals which help to make a connection to an external circuit and carry the current. a voltage or current that is applied to any one pair of the terminals of a transistor controls the current through the other pair of terminals. there are three terminals for a transistor are base, collector and emitter. There are two types of transistors.[12]

### 2.1.1 Bipolar Junction Transistor (BJT)

The three terminals of BJT are the base, emitter and collector. a very small current flowing between the base and emitter can control a larger flow of current between the collector and emitter terminal. there are two types of BJT. PNP Transistor is a type of BJT where one n-type material is introduced or placed between two p-type materials. in such a configuration, the device will control the flow of current. PNP transistor consists of two crystal diodes which are connected in series. the right side and left side of the diodes are known as the collector-base diode and emitter-base diode, respectively. NPN Transistor: in this transistor, we will find one p-type material that is present between two n-type materials. It is basically used to amplify weak signals to strong signals. in an NPN transistor, the electrons move from the emitter to the collector region, resulting in the formation of current in the transistor. this transistor is widely used in the circuit.

There are three types of configurations, which are common base (CB), common collector (CC) and common emitter (CE).in common base (CB) configuration, the base terminal of the transistor is common between input and output terminals. in common collector (CC) configuration, the collector terminals are common between the input and output terminals. in common emitter (CE) configuration, the emitter terminal is common between the input and the output terminals.

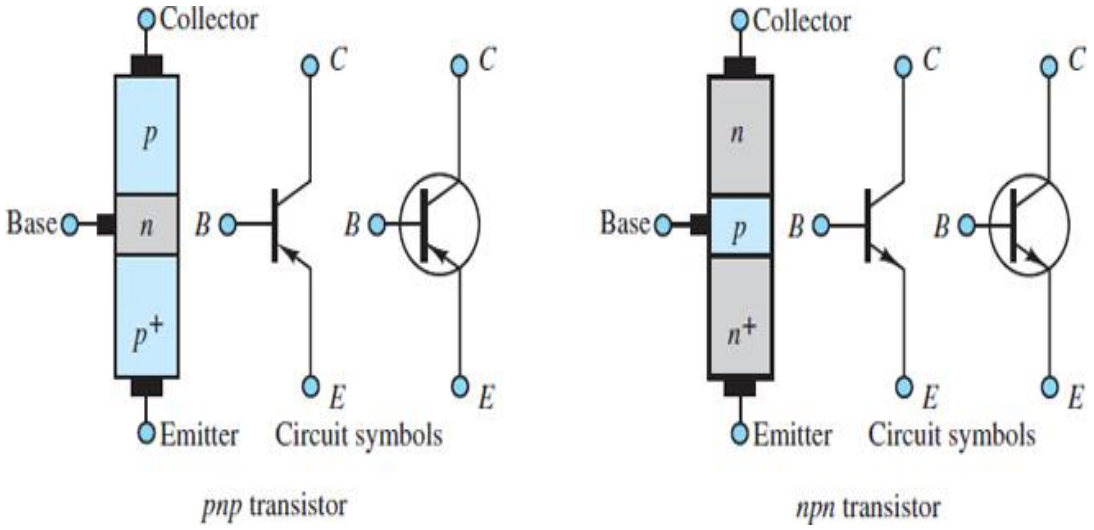



**Figure 2.1**: The Symbol of bipolar junction transistor (BJT) both pnp and npn transistors

### 2.1.2 Field Effect Transistor (FET)

For FET, the three terminals are Gate, Source and Drain. the voltage at the gate terminal can control a current between the source and the drain. FET is a unipolar transistor in which N-channel FET or P-channel FET are used for conduction. The main applications of FETs are in low noise amplifiers, buffer amplifiers and analogue switches.

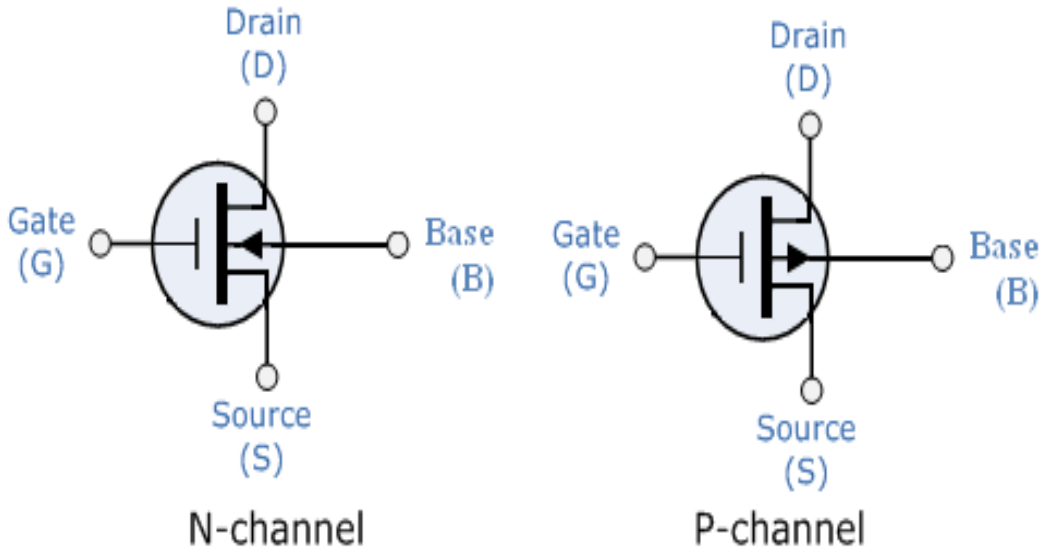



**Figure 2.2**: The Symbol of (FET) both N-channel and P-channel

## 2.2 Operational amplifiers

The name “op amp” is the standard abbreviation for operational amplifier. this name comes from the early days of amplifier design, when the op amp was used in analog computers. Rather than digital. this computer used preprogrammed equations and input data to calculate control actions. the programming was hard wired with a series of circuits that performed math operations on the data, and the hard wiring limitation eventually caused the declining popularity of the analog computer. the heart of the analog computer was a device called an operational amplifier because it could be configured to perform many mathematical operations on the input signals. the name was shortened to the familiar op amp, as we have come to know and love them. the op amp used an amplifier with a large open loop gain, and when the loop was closed, the amplifier performed the mathematical operations dictated by the external passive components. this amplifier was very large because it was built with vacuum tubes and it required a high-voltage power supply, but it was the heart of the analog computer.[6]

Op Amp was found that the application of negative feedback around a high gain DC amplifier would produce a circuit with a precise gain characteristic that depended only on the feedback used. By the proper selection of feedback components, operational amplifier circuits could be used to add, subtract average, integrate, and differentiate. [2]

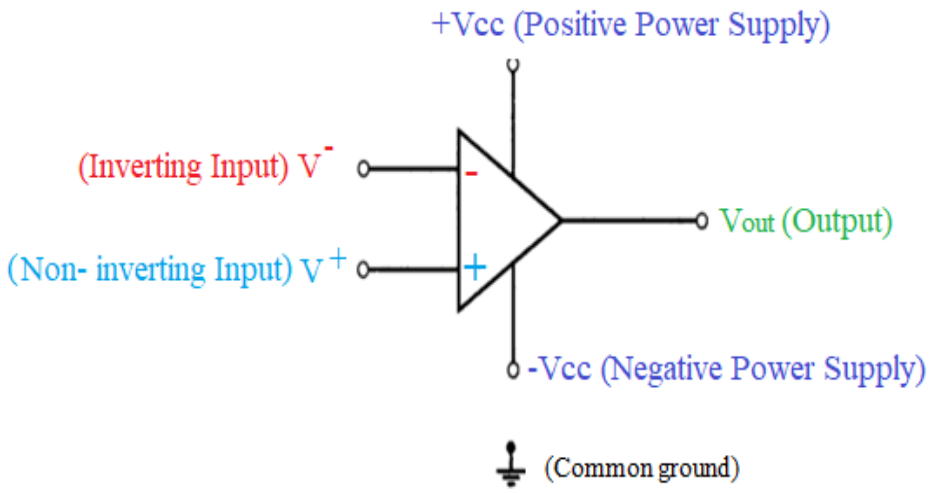



**Figure 2.3:** The Symbol of Op-Amp

Op Amp is consisting of two inputs and one output. most of the operational amplifiers consist of two power supplies. the positive and the negative power supply. But there are many op-amps which runs on the single power supply. So, now in this operational amplifier, the input terminal which is marked by this positive sign is known as the non-inverting input terminal and another input terminal which is marked by this negative sign is the known as the inverting input terminal. So, now if you see this operational amplifier, it is one kind of differential amplifier with the signal output. it means that this amplifier amplifies the difference between the two input signals.[11]

$$V_{out} = A\,(V_1 - V_2) \qquad (2.1)$$

## 2.3 performance parameter of Operational amplifiers

There are different parameters of op-amp, such as voltage gain, Power Dissipation, Power Supply Rejection Ratio (PSRR), Common Mode Rejection Ratio (CMRR), Slew rate (SR), Phase Margin etc.

**Power Dissipation (PD):** is the power consumed by an op-amp device itself. Ideally, the power consumed by the device is zero. But practically there is finite power dissipation by the device. If the power consumed by the device is small, then it can operate for longer duration of time. The smaller the power dissipation the better the device performance is.

**Power Supply Rejection Ratio (PSRR):** The power supply rejection ratio specification quantifies the amplifier's sensitivity to power supply changes. Ideally, the power supply rejection ratio should be infinite. typical specifications for a power supply rejection ratio o. f an amplifier range from 60dB to 100dB. As is with the open loop gain (AOL) characteristics of an amplifier, DC and lower frequency power supply noise is rejected more than at higher frequencies. In a closed loop system, a less than ideal power supply rejection capability of an amplifier manifests. The formula that describes power supply rejection is: [7]

$$PSR(V/V) = \Delta V_{OS} / \Delta V_{SUPPLY}, \text{ Where: } V_{SUPPLY} = V_{DD} - V_{SS} \quad (2.2)$$

**Input impedance:** The second term is an input impedance the resistance offered by the input terminals of an op-amp is called as an input impedance. The voltage drop at the input of an op-amp must be very high hence the input impedance of an op-amp is always very high due to equation V equals I into R.

**Output impedance:** The fact that the output impedance of an op amp is low, makes the device useful in terms of "isolating" the impedance of two portions of a circuit. For this reason, low output impedance of an op amp is an important characteristic, but the precise output impedance is usually is not specified.

**Common Mode Rejection Ratio (CMRR):** is defined as the ratio of the differential voltage amplification to the common-mode voltage amplification. Ideally this ratio would be infinite with common mode voltages being totally rejected. the common-mode input voltage affects the bias point of the input differential pair. because of the inherent mismatches in the input circuitry, changing the bias point changes the offset voltage, which, in turn, changes the output voltage.

**Voltage gain** is the ratio between output voltage and differential input voltage. Because the output signal is much larger than the input signal, so it is commonly called as large signal voltage gain.

**Input Offset Voltage:** The input offset voltage specification of an amplifier defines the maximum voltage difference that will occur between the two input terminals in a closed loop circuit while the amplifier is operating in its linear region. The fourth term that we learn is an input offset voltage when input to an op-amp is zero the output should be zero ideally but if it's

not zero we need to apply some DC voltage at the input terminal to force the output voltage to be zero this applied voltage is called as an input offset voltage.

$$V_{OUT} = (1 + RF / R_{IN}) (V_{IN} + V_{OS}) \quad (2.3)$$

**Input offset current:** The next term we study is an input offset current. The difference between the currents into the two input terminals when the output is held at zero is called as an input offset current.

**Input Bias Current:** all op amps have a leakage current that sources or sinks at both input terminals. typically, this leakage current is called input bias current. The input offset current is equal to the difference between the input bias current at the non-inverting terminal (IB+) minus the input bias current at the inverting (IB-) terminal of the amplifier.

**Slew rate (SR)** is the rate of change in the output voltage caused by a step input. Its units are V/us or V/ms. It indecates the speed of op amp. Larger SR op amp produce more output voltage in a short period of time.

**Phase Margin:** Is the phase shift of an amplifier. So, it is a measure of stability of the system.

## 2.4 Types of CMOS operational amplifier topologies

There are many CMOS op-amp topologies, such as single state, two stage, folded cascade, telescopic but we have seen single stage op-amp using CMOS technology and two stage CMOS op-amps.

### 2.4.1 Single stage CMOS operational amplifier

Figure 2.4 shows the Single stage CMOS operational amplifier. NMOS transistors M1 and M2 form the basic differential input stage of a single stage CMOS op-amp. The gate of M2 is the inverting input terminal and the gate of M1 is the non-inverting input terminal. he NMOS transistors M3 and M4 are used to convert the differential input signal in to a single ended output signal.[4]

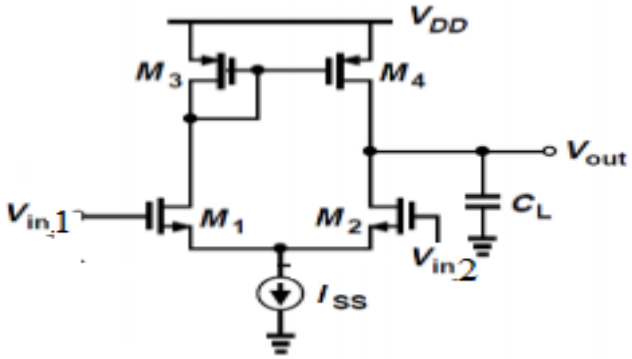
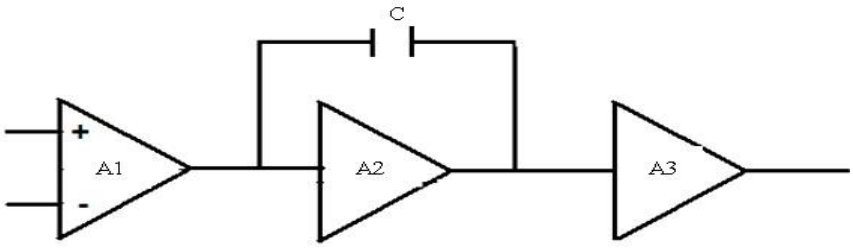



**Figure 2.4:** Single stage CMOS operational amplifier

This single stage is less complex compare to other types of topologies. Because of its less complex property its speed is higher compare to another topology. The drawback of this type of is lower gain due to the fact that output impedance of this type configuration is relatively low. However, this low impedance also leads to high unity gain bandwidth and high speeds.[9]

### 2.4.2 Two Stage CMOS Operational Amplifier

Two stage consists of first is differential stage and second is the gain stage. Output buffer is also used. in CMOS Op-Amp compensation network is used to which a feedback network is applied around the amplifier in virtually all op-amp applications. therefore, to obtain stable performance the amplifier must be compensated. there are many types of compensation network used but we used miller compensation. in miller capacitance is used for feeding back around a high-gain, inverting stage. Miller capacitor used with a unity gain buffer block the forward path and also eliminates the RHP zero. also, miller with a nulling resistor is used which is similar to miller but a series resistance is added which control the gain over the RHP zero. [2]




**Differential input first stage** **common source second stage** **buffer stage**

**Figure 2.5:** Block diagram of the two-stage op amp

The topology of the circuit designed is that of a standard CMOS two stage op-amp. it comprised of three subsections of circuits, first is differential gain stage, second gain stage and bias strings. Differential Gain Stage: The first section of interest is the differential gain stage which is comprised of transistor M1 to M4. In figure 2.6 transistor M1 and M2 are Channels MOSFET transistor which from the basic input stage of the amplifier. The gate of M1 is the inverting input and the gate M2 is non-inverting input. A differential input signal applied across the two input terminals will be amplified according to the gain of the differential stage. The transconductance of this stage is simply the transconductance of M1 or M2.

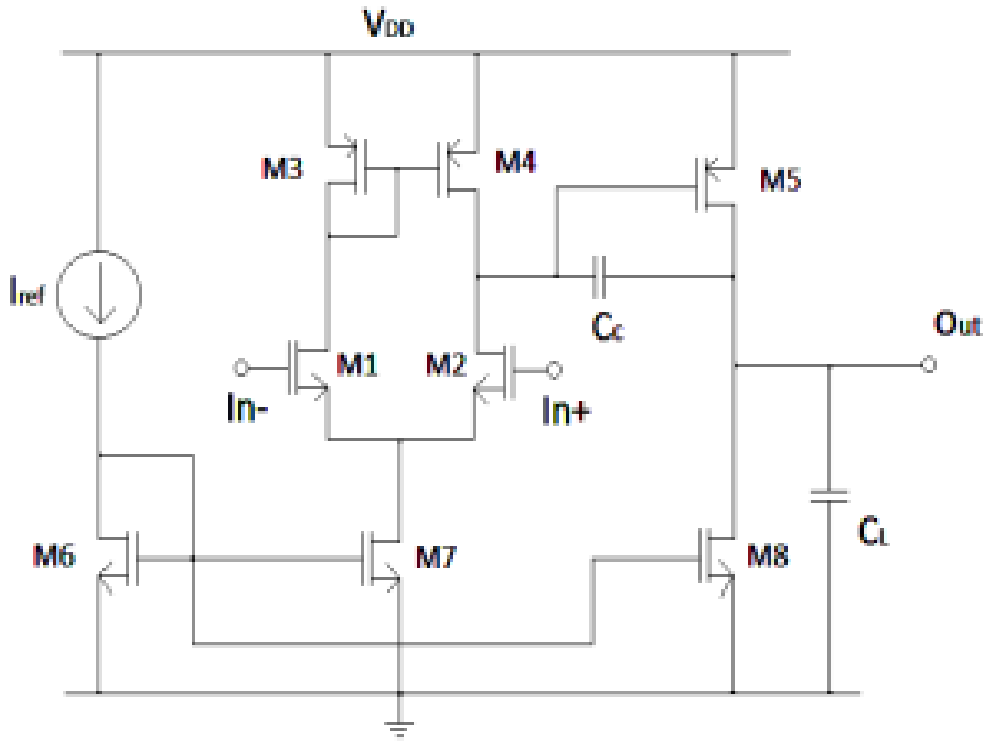



**Figure 2.6**: Two stage op-amp design

M3 and M4 is the active load transistor of the differential amplifier. the current mirror active load used in this circuit has three distinct advantages. First, the uses of active load devices create a large output resistance in a relatively small amount die area. the current mirror topology performs the differential to single-ended conversion of the input signal, and finally, the load also helps with common mode rejection ratio. in this stage, the conversion from differential to single

ended is achieved by using a current mirror (M3 and M4). The current from M1 is mirrored by M3 and M4 and subtracted from the current from M2. [10]

Advantage: It has high output voltage swing and it has higher gain compare to single stage. Disadvantage: It has a compromised frequency response, this topology has high power consumption because of two Stages in its design and it has a poor negative Power Supply Rejection at higher Frequencies.[9]

# CHAPTER THREE

## 3. METHODOLOGY

To conduct this project work we followed: we first chose the schematic layout of the op amp to be designed i.e. single stage CMOS op amp and two stage CMOS op amp. Then the circuit was designed and stimulated by using PSPICE OR CAD software to obtain performance parameters of CMOS op- amp.

### 3.1 data

The following table shows that the performance parameters of CMOS op amps which were collected by using PSPICE Or CAD software.

**Data table 3.1**

| Design Specification | Single Stage OP-AMP | Two Stage OP-AMP |
|---|---|---|
| Technology | 0.35µm | 0.35µm |
| Supply voltage | 3.5V | 3.5V |
| Dc gain | 39dB | 78dB |
| Output swing | 4.2V | 5.1V |
| CMRR | 35dB | 71dB |
| Slew rate | 137V/µs | 72V/µs |
| PSRR | 29dB | 51dB |
| Power dissipation | 0.5mV | 1.2mV |
| Capacitance | 2pF | 2Pf |
| Phase margin | 69˚ | 56˚ |

# CHAPTER FOUR

## 4 RESULTS AND DISCUSSION

### 4.1 Result

Show that the Comparison parameters of single stage CMOS op amp and two stage CMOS op amp.

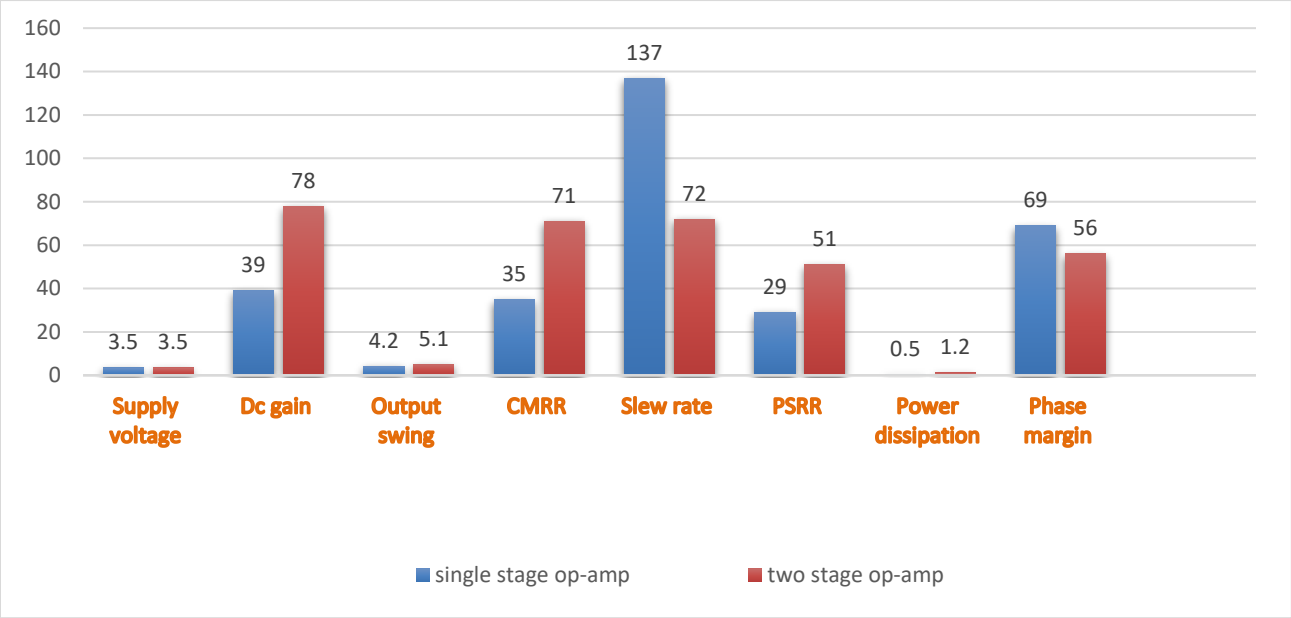



**Figure 3.1**: Performance parameters of single stage CMOS op amp and two stage CMOS op amp.

### 4.2 Discussion

Figure 3.1 shows the performance parameters of single stage CMOS op amp and two stage CMOS op amp. As we seen from the graph we were used the same technology, 0.35µm and the same power supply to analysis the performance parameters of single stage and two stage CMOS op amp. Both op amps have the same capacitance (2pF), suggesting that they have similar frequency response characteristics. Thus we were explaining the performance parameters of CMOS op amps of single stage and two stage as follow as.

- **DC Gain**: The two-stage CMOS op amp has a significantly higher DC gain of 78dB compared to the 39dB of the single stage op amp. This shows that the two-stage CMOS op amp produces the larger output than the single stage CMOS op amp by using the same input.
- **Output Swing**: The two-stage op amp has a larger output swing of 5.1V compared to the 4.2V of the single stage op amp. This indicates that the two-stage op amp can output a larger voltage range than single stage.
- **Common Mode Rejection Ratio (CMRR)**: The two-stage op amp has a higher CMRR of 71dB compared to the 35dB of the single stage op amp. This indecates that the two-stage op amp is better rejecting ability of noise (common mode signals) than two stage.
- **Slew Rate**: The single-stage CMOS op amp has a higher slew rate of 137V/μs compared to the 72V/μs of the two stage op amp. This indecates that the single-stage op amp can produce output more quickly two stage CMOS op amp.
- **Power Supply Rejection Ratio (PSRR)**: The two-stage op amp has a higher PSRR of 51dB compared to the 29dB of the single stage op amp. This means the two-stage op amp is better at rejecting power supply noise.
- **Power Dissipation**: The two-stage op amp dissipates more power (1.2mV) compared to single stage op amp (0.5mV). This could make the two-stage op amp less energy efficient. In addition this indicates that two-stage op amp consumes more power than single stage CMOS op amp.
- **Phase Margin**: The single stage op amp has a larger phase margin of 69˚ compared to the 56˚ of the two-stage op amps. This means the single stage op amp has better stability than two stage CMOS op amp.

# CHAPTER FIVE

## 5 CONCLUSIONS

In this paper, performance parameters of the two stages and single stage CMOS op amp has been analyzed by using 0.35µm CMOS technology. Based on the results we will conclude that: single stage CMOS op amp may not be suitable for high-gain applications. Rather two-stage CMOS op-amps are used when higher gain and better performance are necessary and they are commonly found in more complex circuits and precision applications. It also consumes more power and has a lower phase margin than single stage CMOS op amp. The choice between the two would depend on the specific requirements of the application. For instance, if power consumption is a concern, the Single Stage op amp might be a better choice because single stage CMOS op amp has lower power dissipation. However, if high gain response is required, the Two Stage op amp would be more suitable.

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