Design and Analysis of Two Stage Op-Amp for Bio-Medical Application

Wang Jin¹⁾, Praful Ranjan²⁾

Abstract

Op Amps are the main building block in analog IC designing. Most of the real world signals are mostly analog and they need to be converted into digital signals to analyze and process them. So, analog circuits are of significant importance for us. We have been able to implement a Two Stage Op-Amp using Cadence Tools. We successfully achieved the specifications that we took as a reference in our design, and accordingly were able to design a high gain Op-Amp with low power dissipation. We started with our work keeping in mind the biomedical applications like ECG and EMG. After critically analyzing the design, gain of 72.54db and power consumption of 1.02mW is achieved with CMMR 60 and gain bandwidth product 16.653.

Keywords : Op-amp, Cadence virtuoso, Gain, CMRR, Bio-Medical application

1. Introduction

Operational Amplifier (Op-Amp) is the important basic building block of any analog circuit. The conventional operational amplifier has a high voltage gain differential input stage with a second stage having high voltage gain with a last stage called buffer stage. Buffer stage provides stumpy voltage gain and large current gain. The first two stages are responsible for providing the overall voltage gain of the operational amplifier circuit. This operational amplifier circuit sometimes called as the Widlar architecture [1-2]. Compensating capacitor is placed between the output of the first stage and the input of the second stage. CMOS (Complementary metal - oxide - semiconductor) circuit is basic building block for designing operational amplifier because CMOS circuits have various advantages over BJT (Bipolar Junction Transistor) including power consumption and noise reduction. The CMOS required less fabrication steps than BJT.

We mainly needed to concentrate on designing a low power CMOS amplifier that would need low supply voltages, and will still have the capability to amplify very weak signals to

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¹Yangzhou University, 88 South University Ave., Yangzhou, Jiangsu 225009, P. R. China
email: jinwang@yzu.edu.cn

²THDC-Institute of Hydropower Engineering & Technology, Tehri, India
email: prafulmirchi@gmail.com

make them suitably strong for further processing [3-5]. Our main aim is to keep biomedical applications in mind while designing the Op-Amp. In such applications, the amplifier (along with other necessary circuits) comes in direct contact with the human body. It is mandatory to keep power requirements and supplied voltages under control so that the user doesn't get an electric shock. We have tried to address this issue to some extent in our Op-Amp.

2. Block Diagram of the Proposed Design

The first stage of an op-amp is a differential amplifier stage. Differential Amplifier having two inputs and the difference of these two input will be amplified [6-9]. The first stage provides the maximum gain of an op-amp. The second stage is a common source stage. The compensation capacitance (CC) is placed between first stage and second stage. The CC provides the stability to the op-amp. The CC increase the phase margin of the design and for a stable system the phase margin is should be greater than 450. The second stage increases the gain of the op-amp and converts the second stage input voltage into the current.

The second stage is nothing more than the current sink inverter [10-12]. The second stage is a common source stage which increases the DC voltage gain and improve the output signal swing for a given power supply voltage. The second stage is followed by a buffer stage, which provides a lower the output resistance and maintains a large voltage swing. The buffer stage also provides better slew rate (SR) of an Op-Amp. It is not necessary all applications require low output impedance. If the Op-Amp is intended to drive a small purely capacitive load, which is the case in many switched capacitor or data conversion applications, the output buffer is not used. The Biasing current is used to provide to keep all the transistors in saturation region [13-15]. The purpose of the compensation circuit or compensation capacitance is to reduce the overall gain at higher frequencies and provides stability when negative feedback is applied to the Op-Amp.

[Fig. 1] Block Diagram of Two Stage Differential Amplifier

3. Simulation Set Up

Cadence Virtuoso 6.1.5 is used as a simulation tool for simulating Op-amp design. Advanced features like Cadence Virtuoso Schematic Editor for providing high speed and easy design methods, Cadence Virtuoso Layout Suite for speeding up the physical layout of the design, Cadence Virtuoso Visualization and Analysis for efficiently analyzing the performance of the design and Cadence Assura Physical Verification for reducing overall verification time, because a quick and instinctive debug capability is incorporated within the Virtuoso custom design environment. It easily compares, repair, remove and distinguish errors.

4. Performance Parameters of High Gain Amplifier

4.1 Open Loop Gain

The ratio of the output voltage and differential input voltage is called open loop gain of op-amp. Since the output signal is much larger than the input signal, therefore it is termed as large signal voltage gain. It may be expressed in decibels using the following relation,

$$A_V \text{ (dB)} = 20 \log_{10} (V_{\text{out}} / V_{\text{DM}}) \quad (1)$$

where, V_{DM} is the differential input voltage and V_{out} is the output voltage.

4.2 Miller Effect

The effective input impedance of an amplifier depends on the impedance connected from input to output of the amplifier. The perceptible scaling of this impedance often dominates the input impedance and frequency response of the amplifier. This type of phenomena commonly known as the Miller Effect. The virtually increased input capacitance due to the Miller effect is given by:

$$C_M = C (1 + A_V) \quad (2)$$

where, A_V is the gain of the amplifier and C is the feedback capacitance.

4.3 Gain Bandwidth Product

For an amplifier the gain bandwidth product designated as GB is the product of the amplifier's gain and the bandwidth. For devices such as Op-Amps that are designed to have a simple one-pole frequency response. In case of that type of design the GB is nearly independent of the gain at which it is measured. So in this kind of devices the gain bandwidth product will also be equal to the unity gain bandwidth of the amplifier.

4.4 Slew Rate

Slew rate (SR) is the rate of change of output voltage caused by changed in input. Its units are V/ms or V/ μ s.

Internal compensation capacitor CC is the primary factor controlling slew rate in most Op-Amps, which makes the Op-Amp unity gain stable. Charging and discharging of the compensation capacitor CC limits the voltage change in the second stage. The maximum rate of change is when either side of the differential pair is conducting $2I_E$. All Op-Amps do not have compensation capacitors. In Op-Amps without internal compensation capacitors, the slew rate is determined by internal Op-Amp parasitic capacitances.

4.5 Gain Margin and Phase Margin

The amount of gain increase or decrease required to make the loop gain unity at the frequency ω_{gm} (phase crossover frequency, where the phase angle is -180°) is called the gain margin. The gain margin is $1/f$ if f is the gain at the -180° phase frequency.

The difference between the phase of the response and -180° is called the phase margin when the loop gain is 1.0 (or 0 dB). The unity-gain frequency or gain crossover frequency is that frequency ω_{pm} at which the magnitude is 1.0.

5. Designing of Op-Amp

The Op-Amp design process mainly involves the two major steps. First one is called Design conception while another one is termed as Design optimization. An architecture is proposed to meet the given specifications in design conception. This step is usually done to calculate the design values by hand calculations which is necessary for choices that must be made. The "first-cut" design is taken & verified for the specifications and then optimized in the second step of the design optimization. The optimization can include different environmental influences

or process variations and is usually done by using Computer simulation.

[Fig. 2] Architecture of 2-stage Op-Amp

Model or Device Parameters:

$$K_p = \mu_p C_{ox} = 60 \mu A/V^2$$

$$K_n = \mu_n C_{ox} = 300 \mu A/V^2$$

Threshold Voltage $V_{TH(n)} = 0.61 V$, $V_{TH(p)} = 0.46 V$.

First Stage (Differential Amplifier) Design Values:

The values of the (W/L) were calculated as follows:

$$S_{1,2} = 28, S_{3,4} = 84, S_{5,8} = 4.$$

DC current $I_C = 50 \mu A$, $V_{DD} = 1.8 V$, $V_{SS} = -1.8 V$, $C_L = 10 pF$.

5.1 Circuits and Simulated Outputs of First Stage (Differential Amplifier)

[Fig. 3] Schematic of First Stage Op-Amp

[Fig. 4] Transient Response of First Stage Op-Amp

[Fig. 5] A.C Response of First Stage of Op-Amp

Second Stage Design Values:

The aspect ratio (W/L) values for different transistors were calculated as follows:

$$S_{1,2} = 6, S_{3,4} = 8, S_{5,8} = 8, S_6 = 154, S_7 = 102.$$

DC current $I_C = 15\mu\text{m}$, $V_{DD} = 1.8\text{V}$, $V_{SS} = -1.8\text{V}$, $C_C = 2.2\text{pF}$, $C_L = 10\text{pF}$.

5.2 Circuits and Simulated Outputs after addition of Second Stage

[Fig. 6] Two Stage Op-Amp Schematic

[Fig. 7] AC dB 20 Plot for Gain and Bandwidth

6. Result and Conclusion

Design specification values obtained after simulation are tabulated in Table 1. The obtained results are further compared with the reference papers and shown in table 2.

[Table 1] Values obtained after simulation

S. No.	Specifications	Proposed Values	Obtained Values
1	Technology	180 nanometres	Used
2	Power Supply (V_{dd})	1.8 V	1.8 V
3	Load Capacitance (C_L)	10 pF	10 pF
4	Coupling Capacitance (C_c)	2.2 pF	2.2 pF
5	Power dissipation (P_D)	≤ 2 mW	1.003 mW
6	Differential DC gain (A_v)	≥ 60 dB	72.54 dB
7	Unity Gain Bandwidth	> 10 Mega hertz	16.653 MHz
8	Phase Margin (PM)	≥ 60 deg	61.417 deg
9	Common Mode Rejection(CMRR)	≥ 60 dB	60 dB

[Table 2] Comparison of Obtained Results with Reference Papers

Parameters	References							Results of Proposed Design
	[6]	[9]	[11]	[12]	[13]	[14]	[16]	
Gain (dB)	36.747	67	78	71	51	50	70	72.54
Gain BW Product (MHz)	16	12	11	5	-	10	14	16.653
Power Dissipation (mW)	0.804	-	-	< 2	-	2.4	2.1	1.003
CMRR (dB)	-	78	60	-	64	-	-	60

Phase Margin (deg)	48.1	59	85.85	-	-	175	65	61.417
Power Supply (V)	-	-	5	2.5	2.3	-	-	1.8
Technology (nm)	180	-	tsmc 350	180	90	90	180	180

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