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An Implementation of Rail to Rail Differential Amplifier for Wide Linear Output Range

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***Abstract*-The aim of this paper is to describe about a basic differential amplifier, and the implementation of Rail to Rail Differential Amplifier . The basic building block in the analog circuit design is Differential Amplifier. The characteristics of the differential amplifier are measured by Gain, Common mode Rejection Ratio (CMRR), and Power supply Rejection Ratio (PSRR). In this paper a differential amplifier is designed or implemented between rail to rail and the need of this rail to rail differential amplifier and the applications where it is used. The simulation are done by using 180nm technology at supply voltage 1.8v. The design is implemented using cadence EDA environment and simulated using Analog design environment.**

Key Words: *Differential Amplifier, Rail to Rail, Gain, PSRR and CMRR.*

I. INTRODUCTION

Over the past few decades there is a tremendous growth and change in electronics industry due to the invention of MOS transistors. As the technology grows there is a huge decrease in the size of IC's. Integration of IC's from SS (small scale), MS (medium scale), LS (large scale) and ULS (ultra large scale) has made many changes in the electronic industry.

CMOS (Complementary Metal Oxide Semiconductor) technology is the combination of pull-up and pull-down transistors (i.e. PMOS and NMOS). The CMOS technology leads to satisfying all the design constraints like power, area, and speed by minimizing the feature size and using the optimization techniques by lowering the supply voltage, using VTCMOS and MTCMOS etc. Hence CMOS has got a rapid acceptance in the upcoming technology in the area of analog, digital and mixed integrated circuits, like RF communication field, signal processing and biomedical applications etc.

Fig. 1 shows the basic block diagram of differential amplifier, which has two inputs and one differential output.

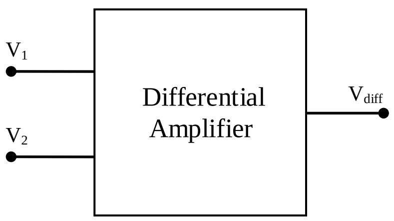

Figure 1. Block diagram of Differential Amplifier.

The basic block diagram of differential amplifier which is of two inputs and a differential output.

Section II describes about the basic differential amplifier and types. Section III describes about rail to rail differential amplifier. Section IV gives the Simulation and Expected results of the designs described in the above section. Finally, the conclusion is presented in Section V.

II. DIFFERENTIAL AMPLIFIER

Differential amplifier is one of the most important blocks in designing any analog circuit. The differential amplifiers was designed using bipolar transistors and then bipolar transistors where replaced with MOS transistors, which produces a better performance. It is a circuit that amplifies any weak signal and strengthens it which is used mainly in communication to transmit a signal over long distance and the signal may be analog or digital. This amplifier is used in many more applications and few applications are Bio-medical applications, Analog circuits and Digital circuits. The circuit diagram of differential amplifier with active load is shown in Fig. 2.

The circuit amplifies the difference between two input signals (i.e. V1 and V2) and also rejects two common signals. The ideal characteristics of a differential amplifier are infinite in all (i.e. gain, bandwidth and common mode rejection ratio, high input impedance and low output admittance, less distortion, sensitivity etc). Also it has increased output voltage swing.

Differential amplifiers are widely used due to less distortion and also in linear amplification circuits. The amplifier can be designed in many ways where the output can be single or double ended circuits. The most commonly used amplifier is double ended i.e. which has two inputs and has two outputs and is commonly called as fully differential amplifier is shown in Fig. 3.

The fully differential amplifier has the advantage over single ended are simple biasing, high immunity to noise, and high linearity. But the disadvantage is large area. The fully differential amplifier design amplifies the difference of two inputs which are out of phase and rejects the signals which have common phase due to any noise induced. This is measured as common mode rejection ratio (CMRR). An ideal amplifier circuit has infinite CMRR.

There are two types of offset voltages. They are input offset voltage and output offset voltage, Output offset voltage is measured as the difference between the final output voltage to the ideal output voltage when a common signal is applied at both the ends of inputs, Similarly the input offset voltage is defined as when the output offset voltage is divided by the differential voltage gain.

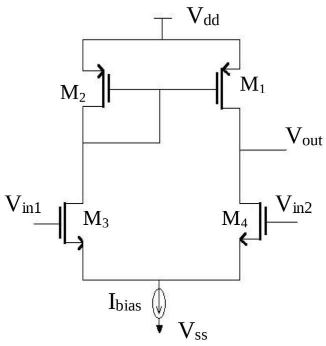

Figure 2. Differential amplifier with active load.

In the above circuit biasing is removed and a constant current source is build as active load. The main reason for this configuration is to converts a fully differential input to single-ended output. The transistors M_2 and M_1 are similar to each other. Transistor M_2 is used for enhancing the gain, i.e. if V_{GS} at M_3 is increased by a little amount, the I_{d1} increases by ΔI_{d1} and I_{d2} decreases by ΔI_{d2}.

Similarly I_{d3} and I_{d4} and also increases by ΔI, thereby increasing the output voltage and leads to high gain. This is due to reduced drain current of M_4 and increased drain current of M_1. The M_1 and M_4 are paired such that M_1 helps M_4 for a change in output voltage.

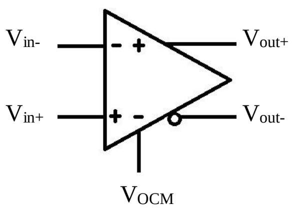

Figure 3. Fully Differential amplifier.

III. Circuits Design

A. Rail-to-Rail Differential Amplifier

Rail to Rail differential amplifier is a circuit which is designed in between V_{dd} and V_{ss} which creates a path from V_{dd} to V_{ss}. This rail to rail differential amplifier has two differential amplifiers which are connected in parallel. This contains eight transistors along with two current bias terms. But in the implemented design the current bias is replaced with an NMOS with bias voltage which acts as a constant current source as shown in Fig. 5.

The Rail to Rail differential amplifier produces the output-voltage swing and Gain. The output voltage swing means how far you can drive the amplifier output toward the positive or negative supply rail. The output voltage swing high and output voltage swing low test conditions usually take the amplifier outside its linear region.

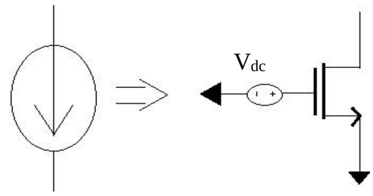

Figure 4. Constant current source.

The amplifier's open loop voltage gain specification primarily is the ratio of the closed loop, output-voltage change to the input offset voltage change. The circuit is implemented in cadence virtuoso the I_{bias} is replaced with the constant current source shown in the above Fig. 4. The constant current source has NMOS with a bias voltage (i.e. V_{dc}).

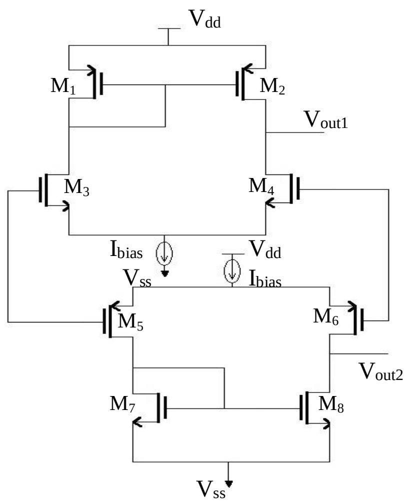

Figure 5. Rail to Rail Differential amplifier.

B. PSRR

PSRR (Power Supply Rejection Ratio) is a term widely used to describe the capability of the circuit to suppress any power supply variations to its output signal. The ability of amplifier to maintain its output voltage as its DC power-supply voltage is varied.

$$PSRR = \frac{\text{Change in Vsupply}}{\text{Change in Vout}}$$

Where PSRR can be measured in dB using

$$\mathrm{PSRR[dB]} = 20\log_{10}\left(\frac{\Delta V_{supply}}{\Delta V_{out}} \cdot A_v\right)\mathrm{dB}$$

Where, A_V = Gain in Voltage.

C. CMRR

CMRR (Common Mode Rejection Ratio) of a differential amplifier is used to quantify the ability of a device to reject common-mode signals that appear simultaneously and when they are in-phase on both inputs. An ideal differential amplifier would have infinite CMRR; however this is not achievable in practical. A high CMRR is required, when a differential signal to be amplified in the presence of a possibly large common-mode input.

$$\mathrm{CMRR} = 20\log_{10}\left(\frac{A_d}{|A_{cm}|}\right)\mathrm{dB}$$

Where A_d = Differential mode gain

A_{cm} = Common mode gain

D. Other Parameters

The other parameters to measure the Rail to Rail differential amplifier such as Power, Current, Area, supply voltage and delay etc. where power is the product of voltage and current. Current is obtained across the output terminal through DC analysis which can be seen in the simulation section. As the referred paper for Rail to Rail differential amplifier which is used for Bio-medical applications has designed in 350nm compared to it the area can be reduced in this due to 180nm technology.

IV. SIMULATIONS AND EXPECTED RESULTS

The simulations are done with the help of ADE L. Here the simulation results such as frequency response, Gain and phase response along with transient analysis of the basic differential amplifier and Rail to Rail differential amplifier are presented. The design was implemented using cadence EDA tool, 180nm technology.

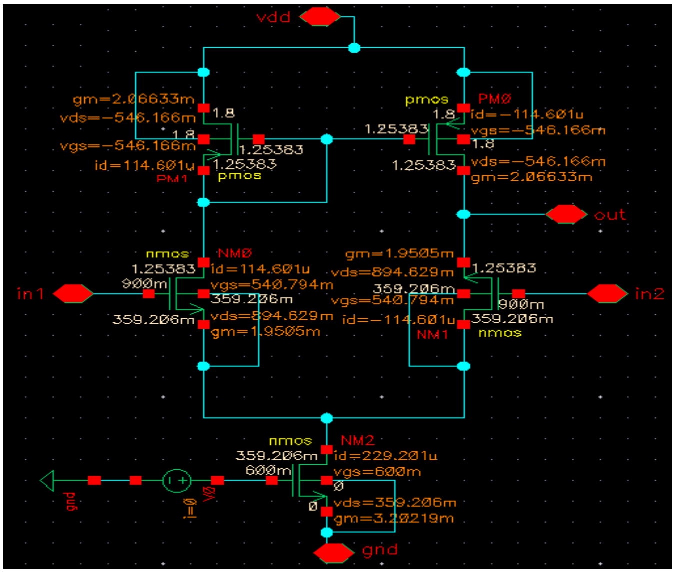

Figure 6. Differential Amplifier

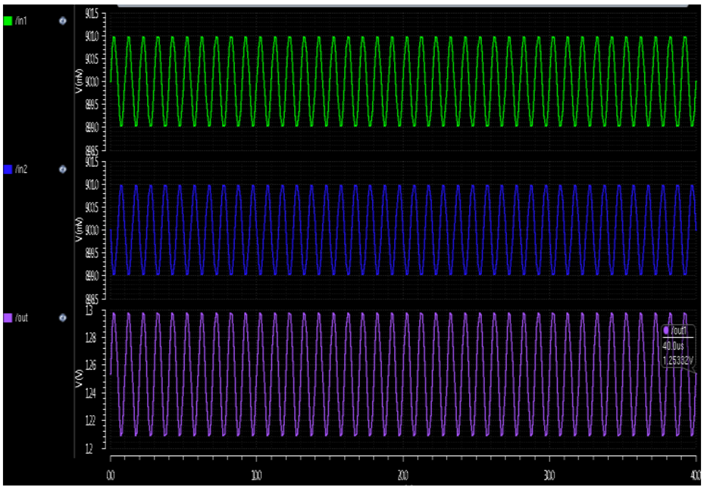

Figure 7. Transient Analysis of Differential Amplifier

Rail to Rail Differential Amplifier

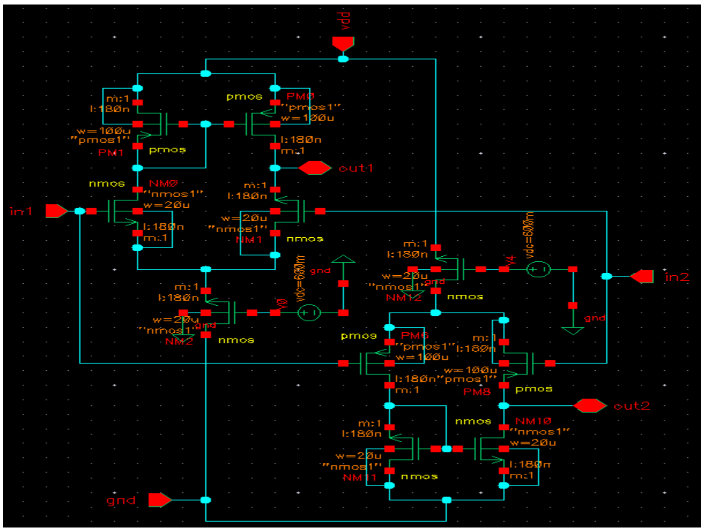

Figure 8. Rail to Rail Differential Amplifier

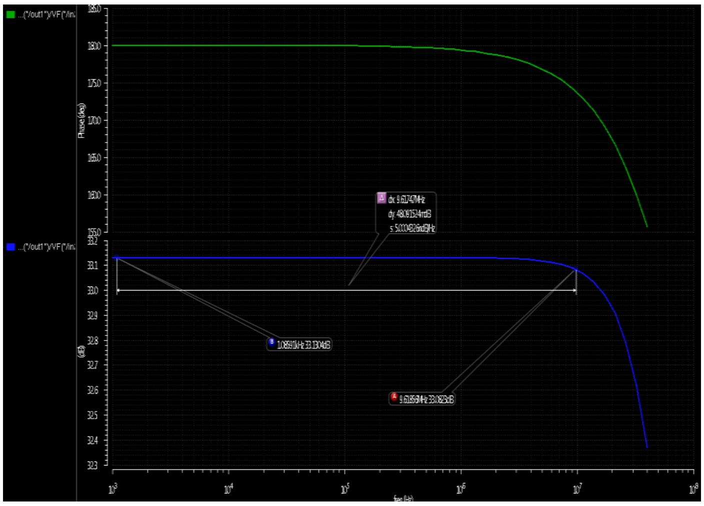

Figure 9. Phase and Gain of Rail to Rail Differential Amplifier.

Table 1 show the results which are obtained by simulating the circuits using virtuoso 6.1.

Table-1: Design specifications

Specifications	**Proposed Value**
Technology	180nm
Supply Voltage	1.8V
Gain	≥30dB
Power	1.62mW
Current	9mA
Area	reduced compared to 350nm

The comparison between all the different topologies is given below

Topology	**Voltage Gain (dB)**	**Power Dissipation (mW)**
Differential Amplifier with Passive Load	16.01	6.04
Differential Amplifier with Active Load	21.19	2.13
Rail to Rail Differential Amplifier	33.13	1.62

V. Conclusion

Basically a differential amplifier is used to differentiate the two input signals and produces an output. These differential amplifier are used in main designs and application as a block or a part of block. But in this paper we are concentrating on the rail to rail differential amplifier which is a block or a part of block implemented in the devices which are used in Bio-medical applications.

Here in this the circuit is designed in 180nm Technology with a supply voltage of 1.8. This is used to amplify the noisy signals and produces large output voltage swing along with high gain with less supply voltage.

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