Talentsprint: Analog VLSI
Assignment – 5: Amplifier Design

November 2024

INTRODUCTION

The objective of this lab is to familiarize with simple amplifier design. We will use the following analysis tools.

DC analysis:

AC analysis:

Transient analysis:

Noise analysis:

General Steps to Design an Analog Circuit

1. Identify if the design is multi-stage or a single-stage design. If the design is multi-stage, then one stage must me biased at a time.
2. Start with DC biasing of the MOSFETs. Pick the first branch which has a constant current source and fix the W/L of the transistors to bias it. If there are a series of transistors, then the bias can be fixed such that the full available voltage is equally divided among the Vov of the series transistors and the same current as in the current source is flowing through them.
3. If the branch belongs to a current mirror, then the ratio can be used to bias the corresponding branches of the mirror.
4. Follow this by DC biasing the corresponding branches of the design in a similar fashion.
5. For the final branch corrected to Vout, maximum swing can be obtained if Vout is a (VDD-VSS)/2. Thus, the design can be made accordingly.
6. If there are no current sources specified and only the power budget is given then the Maximum flowable current in one branch connected to VDD is I = P/(n*VDD) where n is the total number of branches connected to the VDD.
7. Once the DC biases are fixed and all the transistors are in saturation, a small ac signal can be given to the circuit to understand its small signal performance.
8. Addition of passive elements in an all-active component circuit may alter its performance and hence must be pre-accounted for during the design phase.

Problem 1: Single ended source follower

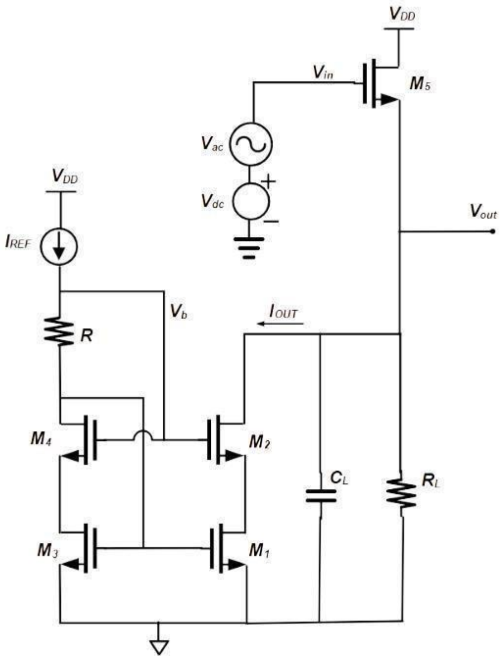

Figure 1: Source follower with current source

Figure 1 shows a source follower with current source biasing. Design the circuit with the following specification:

I_{REF} = 10µA, V_{DD} = 1.8V, V_{dc} = 1.25V, C_L = 1pF, R_L = 1GΩ

Bandwidth = 50 MHz.

a. Write design parameters I_{out}, R, W/L ratio of M1 to M5.
b. Sweep V_{dc}. $V_{error} = V_{out} – V_{in}$. Plot V_{error} vs. V_{in}. Identify the region of linearity.
c. Calculate the low frequency AC gain of the circuit using the DC operating point obtained from the DC simulation. Plot AC gain (dB20) vs. frequency 1Hz to 10GHz withlogscale in the x axis (30 points/decade). Compare the low frequency AC gain betweencalculation and simulation.
d. Calculate the low frequency input referred noise using the DC operating point. Plot output noise vs. frequency. Plot input referred noise vs. frequency. Compare with the simulation with calculation.
e. Give a step input of 0.1V and plot the output vs. time.
f. Calculate the output impedance of the amplifier. Modify the circuit to simulate the output impedance. Run AC simulation to plot output impedance and compare the low frequency results.

Problem 2: Differential amplifier with resistive load

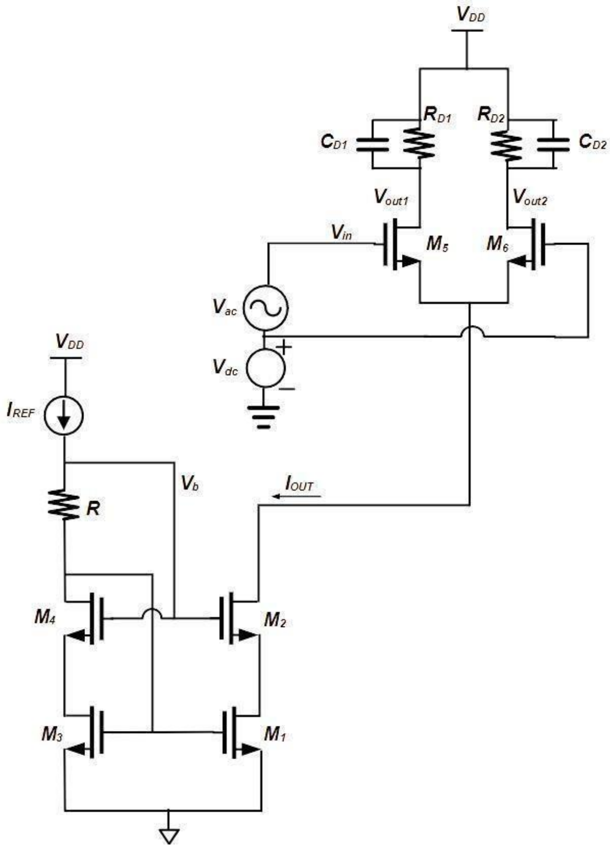

Figure 2: Differential amplifier with resistive load

Figure 2 shows the design the differential amplifier circuit with resistive load. Differential output voltage $V_{out} = V_{out1} - V_{out2}$. While the input terminal is differential, in the circuit the applied input voltage is single ended. This is one way to generate differential output from single-ended input. Design the circuit with the following specification:

I_{REF} = 10μA, V_{DD} = 1.8V, V_{dc} = 1.25V, $C_{D1} = C_{D2}$ = 0.1pF

3- dB bandwidth = 5 MHz, Gain = 10 V/V

a. Write design parameters I_{out}, R_{D1}, R_{D2}, W/L ratio of M1 to M6.
b. Write the range of V_{dc} for which the amplifier works properly (input-output linearity is preserved). This range of V_{dc} is called input common mode range.
c. Calculate the low frequency AC gain of the circuit using the DC operating point obtained from the DC simulation. Apply AC voltage V_{ac} in an AC simulation. Plot AC gain ($=V_{out}/V_{in}$) in dB20 vs. sweeping frequency from 1Hz to 10GHz with logscale in the x axis (30 points/decade). Compare the low frequency AC gain between calculation and simulation.
d. Sweep DC input voltage using V_{ac} in a DC simulation. Plot V_{out1}, V_{out2}, and V_{out}, vs. $V_{dc,sweep}$. Note the range of $V_{dc,sweep}$ for which the output is linear. Beyond that the output saturates. This range of voltage limits the maximum input differential voltage.
e. Calculate the low frequency input referred noise using the DC operating point. Plot output noise vs. frequency. Plot input referred noise vs. frequency. Compare with the simulation with calculation.
f. Give a step input of 1mV and plot the output vs. time.
g. Calculate the output impedance of the amplifier. Modify the circuit to simulate the output impedance. Run AC simulation to plot output impedance and compare the low frequency results with the calculated value.

Problem 3: Differential amplifier with active load

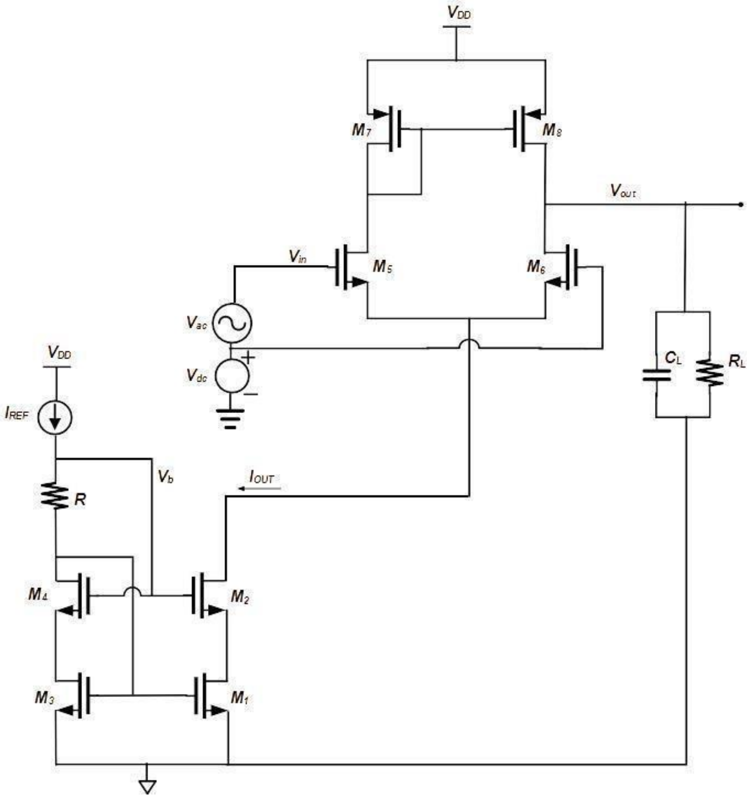

Figure 3: Differential amplifier with active load

Figure 3 shows the design the differential amplifier circuit with active load. The output is single ended. Design the circuit with the following specification:

I_{REF} = 10μA, V_{DD} = 1.8V, V_{dc} = 1.25V, C_L = 0.1pF, R_L = 1GΩ

Gain-bandwidth = 1GHz

a. Write design parameters I_{out}, W/L ratio of M1 to M8.
b. Write the range of V_{dc} for which the amplifier works properly. This range of V_{dc} is called input common mode range.
c. Calculate the low frequency AC gain of the circuit using the DC operating point obtained from the DC simulation. Plot AC gain (dB20) vs. frequency 1Hz to 10GHz withlogscale in the x axis (30 points/decade). Compare the low frequency AC gain betweencalculation and simulation. Compare with the simulation with calculation.
d. Sweep DC input voltage using V_{ac} in a DC simulation. Plot V_{out}, vs. $V_{dc,sweep}$ to obtain the input differential voltage range. Compare the range with the results of Problem 2d.
e. Calculate the low frequency input referred noise using the DC operating point. Plot output noise vs. frequency. Plot input referred noise vs. frequency. Compare with the simulation with calculation.
f. Give a step input of 10μV and plot the output vs. time.
g. Calculate the output impedance of the amplifier. Modify the circuit to simulate the output impedance. Run AC simulation to plot output impedance and compare the low frequency results.

Problem 4: Common gate amplifier with current source input

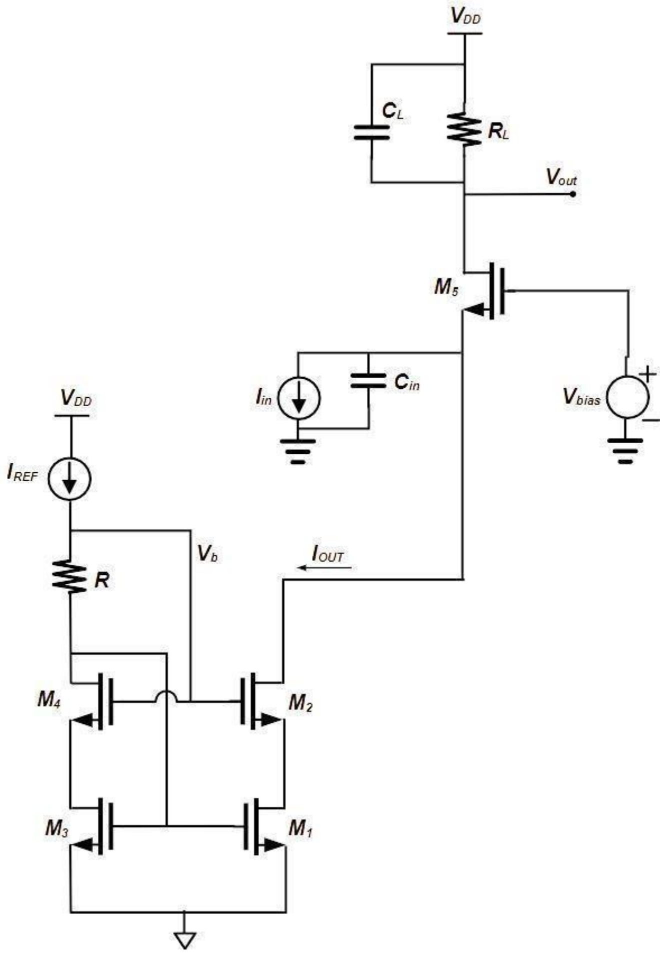

Figure 4: Common gate amplifier with current input

Figure 4 shows a common gate amplifier with current source biasing. CG amplifier can be used as transimpedance amplifier for current input sources such as photodiode. Design the circuit with the following specification:

I_{REF} = 10µA, V_{DD} = 1.8V, V_{bias} = 1.25V, C_{in} = 0.1pF

Gain = 10 kΩ, Bandwidth = 50 MHz

a. Write design parameters *Iout*, *RL*, *CL*, W/L ratio of M1 to M5.

b. Calculate the low frequency transimpedance gain *GT* of the circuit using the DC operating point obtained from the DC simulation. Plot AC gain (dB20 = $20\log_{10}$GT) vs. frequency 1Hz to 10GHz with logscale in the x axis (30 points/decade). Compare the low frequency AC gain between calculation and simulation.

c. Calculate the low frequency input referred noise using the DC operating point. Plot output noise vs. frequency. Plot input referred noise vs. frequency. Compare with the simulation with calculation.

d. Give a step input of 100nA and plot the output vs. time.

e. Calculate the input impedance of the amplifier. Run AC simulation to plot input impedance and compare the low frequency results.