McGill

Microelectronics ECSE 335

Laboratory No. 3

Design, Simulation and Validation of a High-Gain Single-Stage Differential Amplifier

Purpose:

Design and validate the operation of a high-gain single-stage differential amplifier to have a nominal voltage gain of 250 V/V using a discrete prototype involving commercially available BJT transistors.

Equipment Required:

a. Computer
b. SPICE Simulator (student choice)
c. Test Bench: DC Voltage supplies, Function Generator and Oscilloscope
d. Components:
   i. Student decision but must be available from the parts-master on the 4^{th} floor service counter in the Trottier building.
   ii. It is suggested to assemble some of the circuit components prior to entering the laboratory to save time.

Write-Up Requirements:

A good laboratory report should contain a **brief** description of what the experiment was about, including circuit diagrams, and what you did, your data, your results, and anything else called for in the assignment, such as questions inserted in the laboratory description. Answers to these questions require observations that need to be made at the time you do the experiment.

While not always explicitly spelled out in any one laboratory, the use of SPICE should be used by the student to predict the experimental outcomes. SPICE results should be compared to that obtained by measurement, and any differences explained or justified.

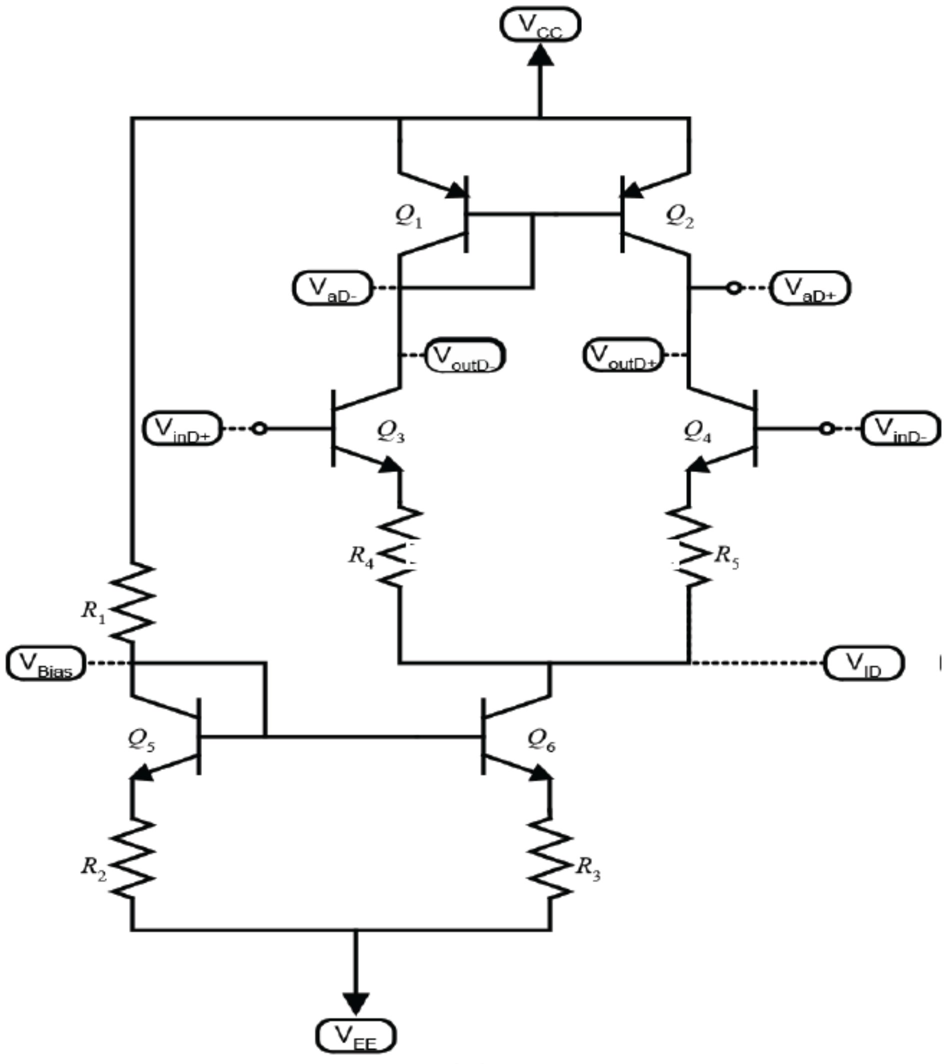

Figure 3.1: Differential Amplifier with active load.

The laboratory report should be written using the IEEE paper style consisting of a **double-column single-space format**, and must adhere to the following when necessary:

1. Title page - Title of the assignment/project, authors' name, and course name.
2. Abstract - Abstract of the assignment/project report.
3. Introduction
4. Main body of the assignment/project report including figures.
6. Conclusions
7. References
8. Appendices

Differential Amplifier

The circuit shown in Figure 3.1 is an active load differential amplifier configuration. It is to be biased using the Widlar current reference circuit used in Lab. 1. The purpose of this circuit is to provide an output signal that is an amplified version of the difference between two input signals. A differential amplifier is considered the electronics workhorse and is found in numerous analog and digital circuit applications.

> **Note 1:**
>
> Some oscilloscope probes can be used in 1X mode or 10X mode. The equivalent circuit models of such probes (including the oscilloscope) for each mode can be quite different:
>
> - 1X mode: 1 MΩ in parallel with a 110 pF capacitance to ground.
> - 10X mode: 10 MΩ in parallel with a 17 pF capacitance to ground.
>
> Usually, the probe should be used in the 10X mode if possible, to reduce loading effects (both capacitive and resistive). Note that a 10X probe attenuates signals by 10 times, so it may not be optimal to use the probe in this mode to measure very small signals.
>
> Make sure to compensate your probe (see oscilloscope/probe manual) before taking measurements, in order to ensure that your measured voltages are valid! If you use the oscilloscope directly with no probe (through an RG-58 coaxial cable), the load on the circuit will be similar to that of the probe in the 1X mode. More specifically, the load resistance will be 1 MΩ, and the parallel capacitance will be estimated by adding the 20 pF load of the oscilloscope to ~80 pF per meter of cable used between the circuit and oscilloscope (e.g., total capacitive load of ~100 pF for a 1 m cable).

Preparation

The student should make use of hand analysis and/or a circuit simulation tool such as SPICE to answer the following questions.

1. Get familiar with Chapter 9 in Sedra and Smith, 8th Ed.

2. Considering this circuit will be used as a voltage gain stage in an operational amplifier, what are the main characteristics that it must have?

3. What is the purpose of R_2 and R_3? There values have been pre-arranged as per Table 3.1.

4. Using V_{EE} = -5 V and V_{CC} = 5 V, design the current source of the differential pair so that it sinks a current of 0.25 mA. These power supply values will be used throughout the experiment. Determine the required value of R_1.

5. Considering the current source only, plot the source's output current versus the output voltage and comment on the results.

6. Design the circuit of Figure 3.1 in order to obtain a gain of 250 V/V ± 10%. Determine the

Table 3.1: Resistor components used.

Component	Value
R_1	
R_2	2 kΩ
R_3	2 kΩ
R_4	
R_5	

values of R_1, R_4 and R_5 and complete the data in Table 3.1. Discuss. At the output, take into account the loading caused by a 10X oscilloscope probe – see note 1 above.

7. Plot the voltage transfer characteristics and accompany it with the corresponding time domain waveform plot. Discuss the curve and maximal output swing.

8. Determine, if any, the input DC offset required to maximize the output swing. Document the maximum output swing. Discuss.

9. Plot the differential mode frequency response and determine the 3-dB points. Also, take into account the parasitic resistor and capacitor values of the 10X oscilloscope probe at the output. Discuss.

10. Plot the common mode frequency response. Also, take into account the parasitic resistor and capacitor values of the 10X oscilloscope probe at the output. Discuss.

11. Find the input and output resistances of the circuit. Discuss.

12. In summary, what are the advantages and limitations of this circuit setup?

Experiment

For the differential setup, perform the following in succession (make sure to use a 10X probe when required!):

1. Connect your circuit according to the setup you have determined when laying it out.

2. Measure all DC voltages and infer the DC currents, where possible. As for all results in this experiment, compare with expected (simulations and calculations) values.

3. Plot the voltage transfer characteristic of the circuit and plot the output and input signals.

4. Determine the optimal input DC offset that results in a maximum output swing. Measure the maximal output swing achieved. You may trim the bias current slightly if you deem it

necessary.

5. Plot the differential mode frequency response and find the 3-dB points. Use the 10X probe.

6. Plot the common mode frequency response. Use the 10X probe.

7. Determine the CMRR.

8. Measure the differential input resistance and the output resistance.

9. Can you suggest a practical method of measuring the common mode input resistance of the circuit?

This concludes this lab.