McMaster University

Electrical and Computer Engineering Department

EE3EJ4 Electronic Devices and Circuits II - Fall 2020

Lab. 3 Differential Amplifiers & Current Mirrors

Lab Report Due on Nov. 8, 2020

Objective: To characterize BJT-based current mirrors and use them to design differential amplifiers for high-gain applications.

Attributes Evaluated: These are the attributes you need to demonstrate in your solutions.

- **Competence in specialized engineering knowledge.**
- **Ability to obtain substantiated conclusions resulting from a problem solution and recognize the approaches and solutions' limitations.**
- **Ability to assess the accuracy and precision of results.**

Test Equipment:

- Analog Discovery 2 (AD2)
- WaveForms from Digilent Link
- Analog Discovery 2 Quick Start Series Videos
- WaveForms Reference Manual

Components:

- Transistors: 3 × NPN-BJT 2N3904 2 × PNP-BJT 2N3906
- Resistors: 1 × 76.8 kΩ resistor 1 × 57.6 kΩ resistor 1 × 8.06 kΩ resistor

Transistors in the circuit:

For a detailed description of these transistors, please check the following websites:

https://www.onsemi.com/products/discretes-drivers/general-purpose-and-low-vcesat-transistors/2n3904 or https://www.onsemi.com/pub/Collateral/2N3903-D.PDF

https://www.onsemi.com/products/discretes-drivers/general-purpose-and-low-vcesat-transistors/2n3906 or https://www.onsemi.com/pub/Collateral/2N3906-D.PDF

Reminder: Switch off the DC power suppliers first whenever you need to change the circuit configurations. Switch on the DC power suppliers only when you don't have to change the circuit connection anymore.

<u>Part 1</u>: Differential Amplifier with Current Mirror (CM) Load

A. Pre-lab Simulation – DC Analysis of a Current Mirror

1.1 The current mirror transfers the AC signal from one side of a differential pair to the output port. To characterize a current mirror, construct the circuit in PartSim with the resistance value and supply voltages, as shown in Fig. 2. Here the current source I_{ERF} represents the reference current to be transferred, and the R_L represents the load at the output of the current mirror.

1.2 Sweep I_{REF} from 0.1 mA to 1 mA with 0.01 mA current step, measure the output current I_o, which is the current flowing into the resistor R_L, and the voltages V_{in} and V_o at the collectors of Q1 and Q2, respectively. Enter the simulated I_{REF}, I_o, V_{in}, and V_o in the sheet "Step 1.2" of the Excel file "Lab 3 – DC Amplifier.xlsx".

1.3 Sweep I_{REF} from 85 µA to 95 µA with 0.1 µA current step, measure the output current I_o, which is the current flowing into the resistor R_L, and the voltages V_{in} and V_o at the collectors of Q1 and Q2, respectively. Enter the simulated I_{REF}, I_o, V_{in}, and V_o in the sheet "Step 1.3" of the Excel file "Lab 3 – DC Amplifier.xlsx".

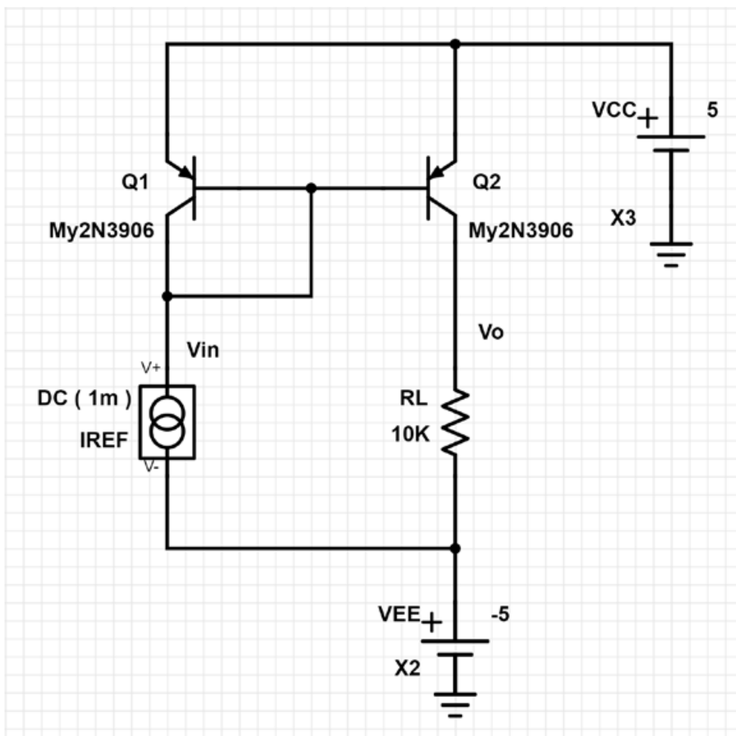

Fig. 1 Schematic diagram of the current mirror for the DC analysis

B. Pre-lab Simulation – AC Analysis of a Current Mirror

1.4 Construct the circuit, as shown in Fig. 2, in PartSim. Here C_2 is a dummy bypass capacitor with 100 TF, and V_2 is a dummy AC voltage source as the port 2 stimulus used in the AC analysis.

1.5 Set the DC value of I_{REF} = 91.0 µA (which is the DC current of each differential pair amplifier in Part 1.C) and its AC value to 1 µA. Set the DC and AC voltages of V_2 equal to zero. Conduct AC analysis to measure V_{in} and I_2 (taken from the negative terminal of C_2) in LIN with start frequency = 100 Hz, stop frequency = 200 Hz, and 11 frequency points in total. Choose REAL for magnitude unit and degree (DEG) for phase unit. Enter the simulated V_{in} and I_L in the sheet "Step 1.5" of the Excel file "Lab 3 – DC Amplifier.xlsx".

1.6 Set the DC value of I_{REF} = 91.0 µA and its AC value to 0 µA. Set the DC value of V_2 to 0 V and the AC voltage of V_2 to 1 µV. Conduct AC analysis to measure V_{in} and I_2 (taken from the negative terminal of C_2) in LIN with start frequency = 100 Hz, stop frequency = 200 Hz, and 11 frequency points in total. Choose REAL for magnitude unit and degree (DEG) for phase unit. Enter the simulated V_{in} and I_L in the sheet "Step 1.6" of the Excel file "Lab 3 – DC Amplifier.xlsx".

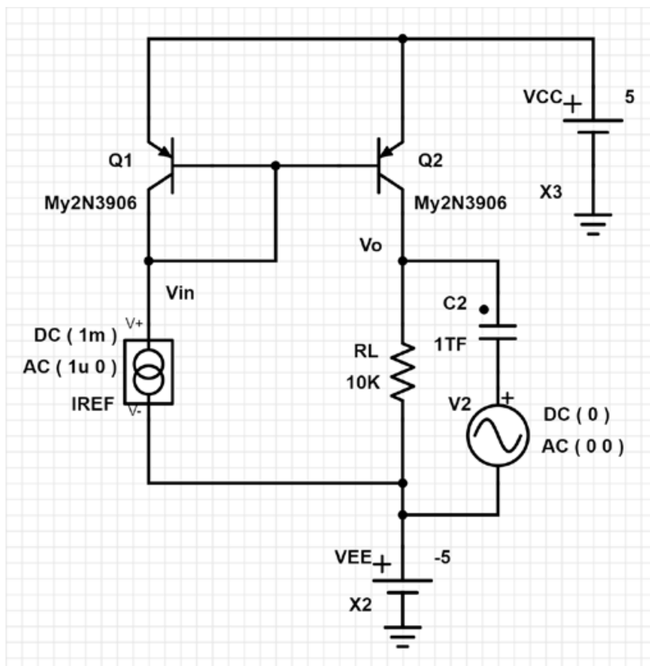

Fig. 2 Schematic diagram of the current mirror for the AC analysis

C. Questions for Part 1:

For the current mirror designed, answer the following questions with simulated data, and justify the simulation results.

Q1. (1) Based on Section 8.2.3 in the textbook, derivate the relationship to express I_o as a function of I_{REF}. (2) Based on the simulation data obtained in Step 1.2, when I_{REF} is 0.1 mA, how is I_o compared with I_{ERF}? When I_{REF} is 1 mA, how is I_o compared with I_{ERF}? (3) Justify the observation between the theoretical prediction and the simulated result at I_{REF} is 0.1 mA and 1 mA, respectively.

Q2. (1) Based on the simulation data obtained in Step 1.5, what is the input impedance R_{in} looking from V_{in} toward the collector of Q1? What is the current gain A_i of the current mirror? (2) Based on the simulation data obtained in 1.6, what is the output impedance R_o of the current mirror looking into the collector of Q2? (3) Based on the information obtained in (1) and (2), draw the linear two-port network for the current mirror using its h-parameters.

<u>Part 2</u>: Differential Amplifier with a Current Mirror (CM) Load

A. Pre-lab Simulation

2.1 In PartSim, construct a differential amplifier, as shown in Fig. 3, using the current mirror (CM) load characterized in Part 1.

2.2 Set the DC values of V_1 and V_2 = 0 V, and their AC amplitude 1 mV. For differential mode signal, set the phases of the AC signal V_1 and V_2 to be 0° and 180°, respectively, as shown in Fig. 3. In this setting, the differential-model signal $v_{id} = V_1 - V_2$ = 1 mV – (–1 mV) = 2 mV. Conduct AC analysis for V_o in DEC with start frequency = 100 Hz, stop frequency = 100 kHz and 101 frequency points per decade. Choose REAL for magnitude unit and degree (DEG) for phase unit. Enter the measured $|V_o|$ and $\angle V_o$ in the sheet "Step 2.2" of the Excel file "Lab 3 – DC Amplifier.xlsx".

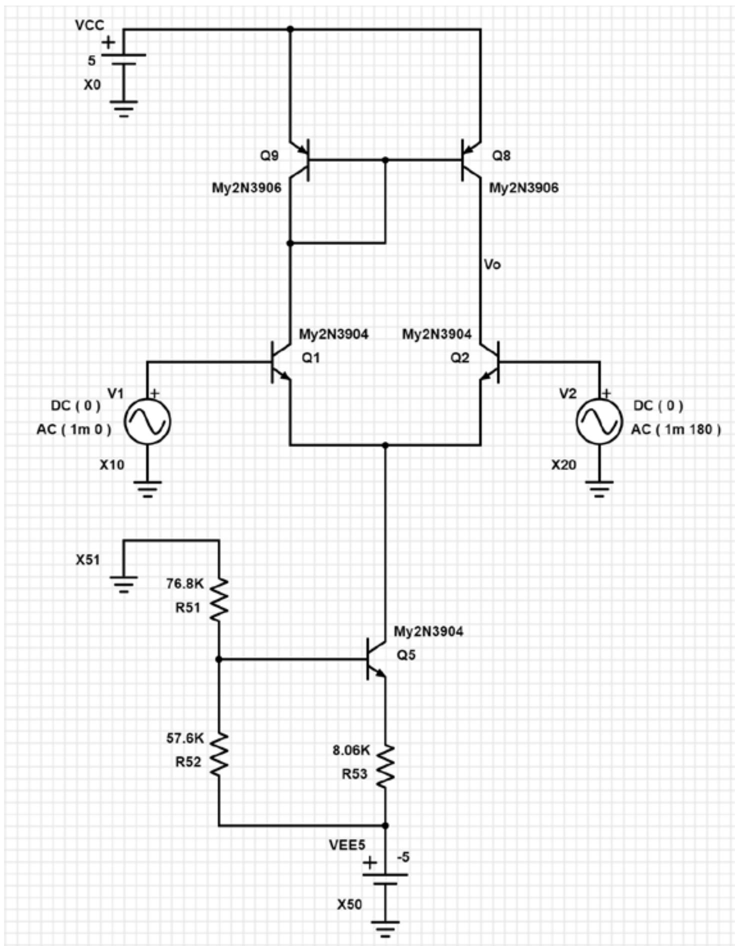

Fig. 3 Schematic diagram of the differential amplifier with a CM load for differential-mode analysis

B. In-lab Measurement

2.3 Use the port definition diagram of the AD2 shown in Fig. 4 when setting up your circuits.

2.4 Based on Fig. 3, construct the measurement setup for the differential amplifier with a current mirror load. Note: You can replace the two 8.25 kΩ resistors in Lab 2 with the current mirror.

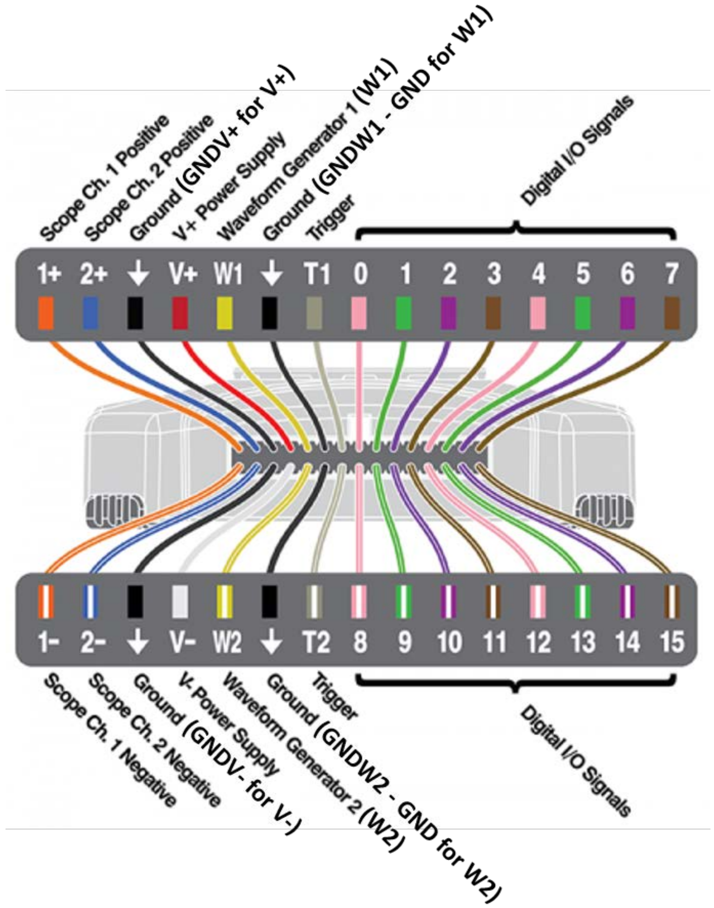

Fig. 4 Diagram for the port definition of an Analog Discovery 2 (AD2)

2.5 Use V+ = 5V for V_{CC}, V- = -5V for V_{EE}, Wavegen 1 (W1) for V_1 and Wavegen 2 (W2) for V_2. Connect GNDV+, GNDV-, GNDW1, and GNDW2 to a common ground line.

2.6 Connect Scope Ch. 1 Positive (1+) to the collector of Q_1, and Scope Ch. 2 Positive (2+) to V_o (or V_{C2}, the collector of Q_2). Set the DC voltages of Wavegen 1 (W1) and Wavegen 2 (W2) to 0 V. Use the Voltmeter in WaveForms to measure the DC voltages V_{C1} at the collector of Q_1 and V_o at the collector of Q_2, respectively. Enter the measured V_{C1} and V_o in the sheet "Step 2.6" of the Excel file "Lab 3 – DC Amplifier.xlsx". Calculate V_{BC8} of Q_8 by $V_{BC8} = V_{C1} – V_o$ to ensure V_{BC8} is larger than -0.4 V to have Q_8 work in the active region. If Q_8 is not in the active region (e.g., V_{C1} = 4.39 V and V_o = 4.91V), there must exist a mismatch between Q_1 and Q_2 (or Q_3 and Q_4), which will result in the currents I_{C1} and I_{C2} not the same. In this case, you need to apply a small offset voltage at V_2 to compensate for the mismatch in the differential pair to achieve the maximum differential-mode gain.

2.7 Connect Scope Ch. 1 Positive (1+) to Wavegen 1 (W1), Scope Ch. 2 Positive (2+) to V_o (the collector of Q_2). In WaveForms, Wavegen Window, enable both Channel 1 (W1) and Channel 2 (W2). Set their Type = Sine, Frequency = 100 Hz, Amplitude = 1 mV, Offset = 0 V, Symmetry =

50%. Set the Channel 1 (W1) Phase = 0° and Channel 2 (W2) Phase = 180°.

2.8 Display the measurement results using the Scope function in WaveForms. In Scope 1, set Channel 1 with Offset = 0 V and Range = 1 mV/div in order to see the input waveform. For Channel 2, set Offset = -V_{oQ2} V and Range = 1 mV/div, where V_{oQ2} is obtained from Step 2.6. Use Y Cursors to set their upper and lower peak values, and use the Ref function to calculate the difference. **Note:** If you notice the mismatch in Step 2.6, gradually increase the Offset value of Channel 2 (W2) until the amplitude of the output voltage reaches its maximum. Enter the measured amplitude of Scope Ch. 1 Positive (1+) and Scope Ch. 2 Positive (2+) in the sheet "Step 2.8" of the Excel file "Lab 3 – DC Amplifier.xlsx" to calculate the differential-mode voltage gain in dB.

C. Questions for Part 2:

For the differential amplifier designed, answer the following questions with simulated and measured data, and discuss any discrepancy between the simulation and measurement results.

Q3. (1) Based on the simulation data obtained in Step 2.2, what is the voltage gain A_d in dB for the differential-mode signal? (2) Compare your simulated result with the measured result obtained in Step 2.8. Did you observe any mismatch in Step 2.8? If yes, how much offset voltage did you applied at V_2?

Q4. Estimate its upper 3-dB frequency f_H (i.e., the frequency at which the amplitude becomes $1/\sqrt{2}$ = 0.707 of its low-frequency value or the phase changes 45°).

Q5. Compare the upper 3-dB frequency f_{3dB} of this differential amplifier with a current mirror load with that of the differential amplifier using resistive loads obtained in Q10 of Lab 2. Why the differential amplifier with the current mirror load has smaller f_{3dB}?

Q6. What is the gain-bandwidth product of the two differential amplifiers with the current mirror load and the resistive load, respectively?