

UNIVERSITY OF UTAH
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

ECE 3110

LABORATORY EXPERIMENT NO. 1

CURRENT MIRRORS AND DIFFERENTIAL AMPLIFIERS

Introduction

This lab covers basic bipolar transistor current mirrors and bipolar transistor differential amplifiers, both basic building blocks for analog integrated circuits. We will use 2N3904 NPN transistors during this lab. The pinout diagrams of discrete transistors are shown below.

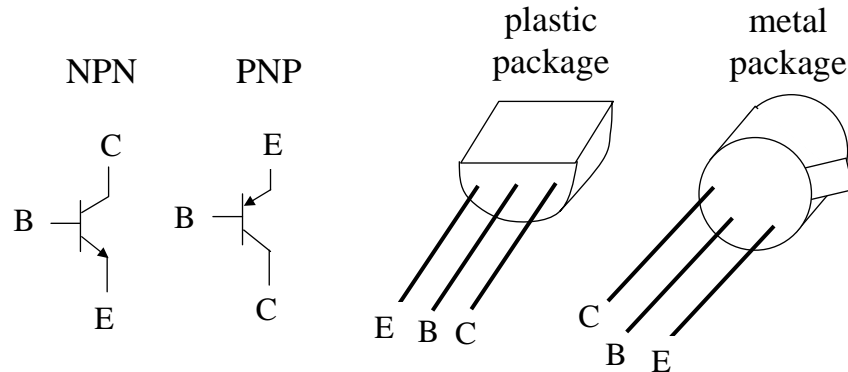


Figure 1. Pin-out diagram of discrete bipolar transistors

In this experiment, you will construct and characterize the following circuits:

1. A simple BJT current mirror (text, pp. 567-569).
2. A "Widlar" current source (text, pp. 653-655).
3. A simple differential amplifier (text, section 7.3).
4. An improved differential amplifier which uses a current mirror to provide the bias current.

Experiment

I. Current Mirror

Build the circuit shown in Figure 2 using two NPN transistors. The 50k resistor is a potentiometer and the voltage source on the output is a variable DC source.

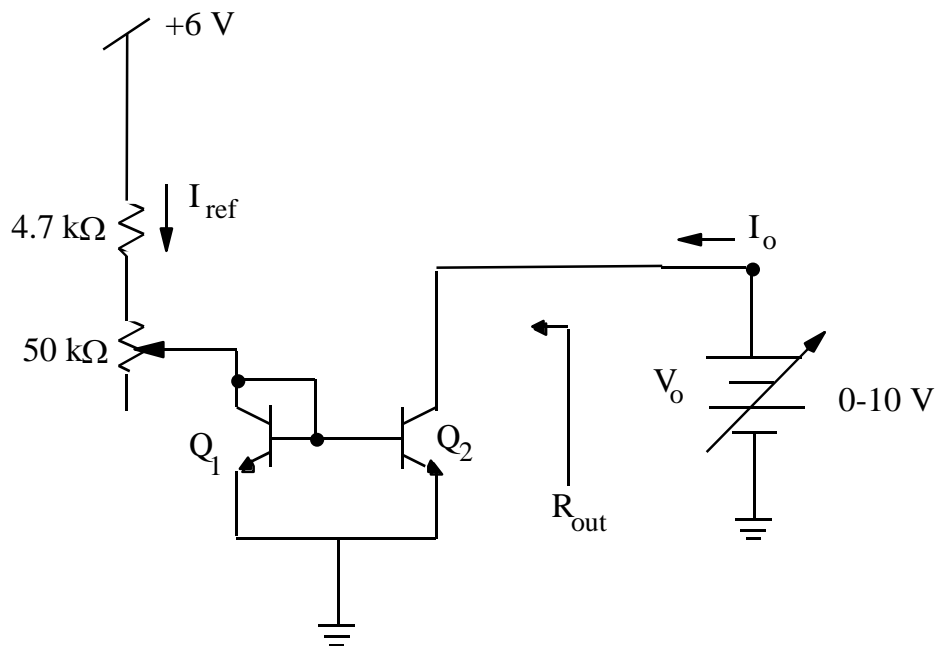


Figure 2.

For the settings: 5kΩ, 25kΩ, and 50kΩ of the 50-kΩ potentiometer, do the following:

- Measure I_{ref} and V_{be1} . V_{be1} is the base-emitter voltage of Q_1 .
- Measure I_o while varying V_o from 0 to 10 volts, in 500mV increments. **Don't forget to check the multi-meter mode before you measure a current or voltage, if it is set incorrectly you will blow a fuse.** How does the mismatch between the two transistors affect the current mirror's gain (I_o / I_{ref})? "Mismatch" just refers to the fact that two discrete transistors often have slightly different

values of I_S . You may wish to try different combinations of various transistors here to find a well-matched pair. Use MATLAB to plot the data.

From your data, determine the small-signal output resistance, R_{out} , using the measured data in the linear range.

Note: $R_{out} = \Delta V_o / \Delta I_o$

II. Widlar Current Source (text, pp. 653-655)

The Widlar current source shown in Figure 3 is used when a small current is needed.

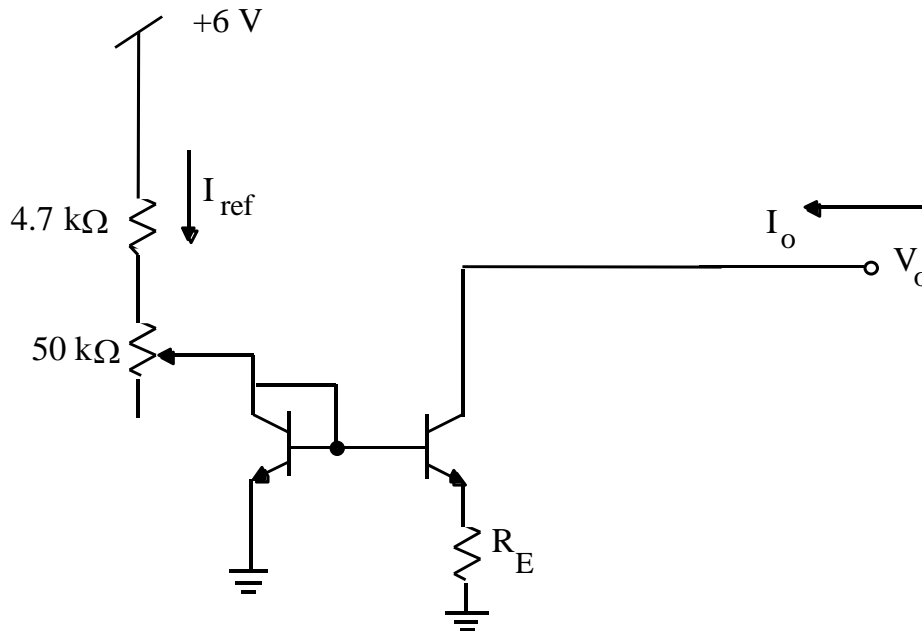


Figure 3.

I_o can be made very small compared to I_{ref} as shown on pages 653-655 of the text. The design equation is:

$$I_o R_E = V_t \ln \left(\frac{I_{REF}}{I_o} \right)$$

As seen from this equation, R_E can be chosen to give the desired I_O so long as $I_O < I_{ref}$.

Assume $I_{ref} = 1$ mA and calculate the value of R_E required to give $I_O = 50$ microamps (note that a closed form solution doesn't exist, try some values and iterate until the both sides are approximately equal).

Construct the circuit in Figure 3 using a value of R_E close enough to the calculated R_E that $I_O = 50$ microamps $\pm 5\%$. What value of R_E did you choose? Plug the value back into the equation and report the expected I_O .

Set $I_{ref} = 1.0$ mA by adjusting the 50-k Ω potentiometer. Vary V_O from 0 to +10 Volts in 500mV increments and record I_O . Use the highest sensitivity meter and setting available because the current won't change very much and will make the output resistance calculation inaccurate or impossible. Using MATLAB, plot I_O vs. V_O . From the measured data, calculate the small-signal output resistance, R_O , at I_O about equal to 50 μ A. Is the output resistance of the Widlar current mirror higher or lower than a standard current mirror? Is this expected?

III. Differential Amplifiers

Build the differential amplifier circuit shown in Figure 4.

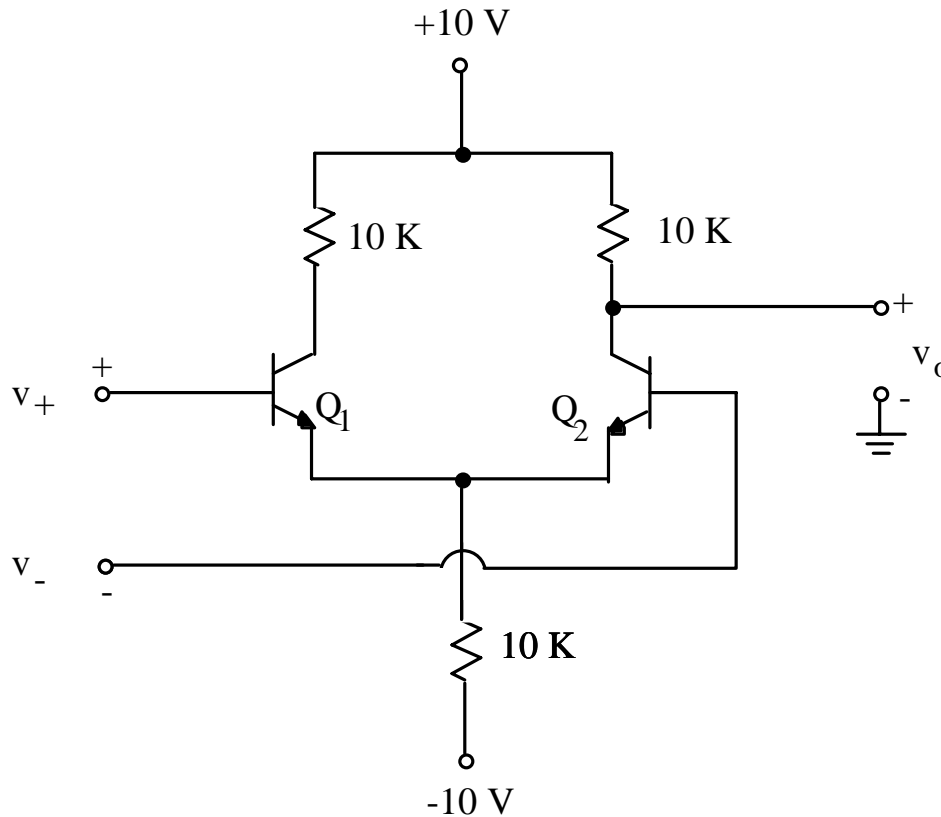


Figure 4. Basic differential amplifier.

You are to measure the common mode voltage gain, A_{CM} , and the differential mode voltage gain, A_d , of the circuit in Fig. 4. (See text, pp. 713-717.)

a. Common Mode Gain

Connect a 1-kHz sinusoidal signal of 1 Volt peak-to-peak to both inputs, as shown in Figure 5. Note that the differential amplifier itself has been represented as a block. **Remember to set the HP 33120A to high-impedance (“HI-Z”) load mode for the following experiments, or your signal amplitudes will be off by a factor of two!**

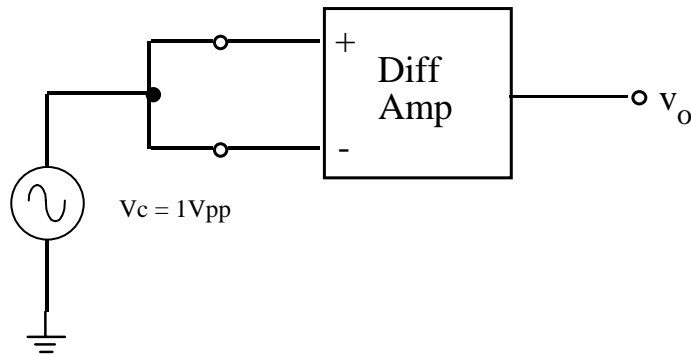


Figure 5. Measurement set-up for common mode voltage gain.

Check both v_c and v_o with your oscilloscope to insure that there is no distortion. If you observe noticeable distortion, reduce v_c until the distortion disappears. If you cannot lower the amplitude enough to get rid of the distortion completely, build a resistive voltage divider to attenuate the input signal further. If you used a voltage divider to attenuate your input signal, don't forget to factor the attenuation factor into your gain calculations. Measure and record v_o and v_c . Compute and report the common mode gain, $A_{CM} = v_o/v_c$. Is the common mode gain expected to be high or low? What differential amplifier feature does common mode gain help or hurt depending on its magnitude?

b. Differential Mode Gain

To measure the differential mode gain, you will need two equal amplitude signals which are opposite in sign. The circuit shown in Figure 6 will supply the needed signals (a 741 or similar op amp with ± 10 volt supplies will suffice).

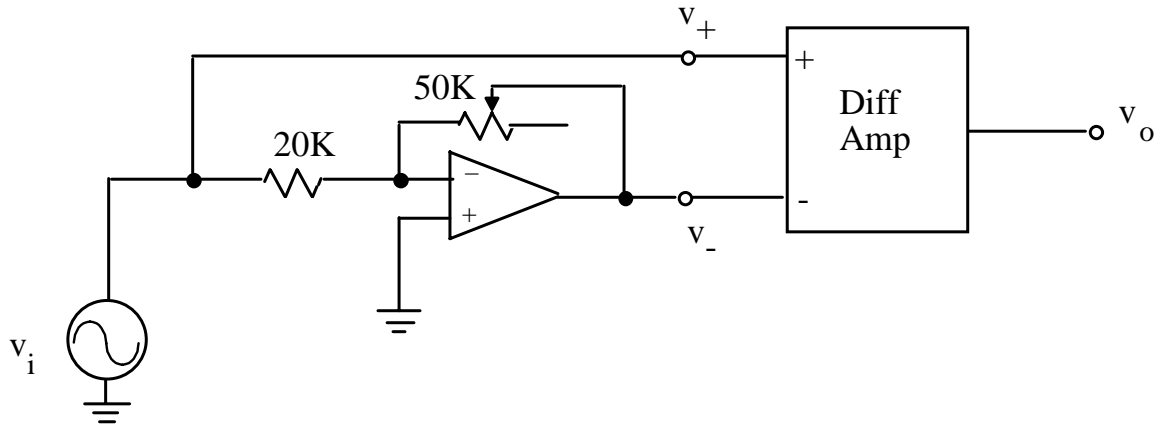


Figure 6. Measurement set-up for differential mode voltage gain.

Adjust the 50-k Ω potentiometer until v_+ and v_- are exactly equal in magnitude. To do this, connect a 1-kHz, 1-volt sinusoidal signal to v_i and feed v_+ into one input of your oscilloscope and v_- into the other. Set the scope to sum the two channels (note that v_+ and v_- have opposite signs, so the difference of the two voltages is actually being displayed). Adjust the range of the scope to insure that the difference signal is as close to zero as possible.

Now reduce v_i until v_o is sinusoidal (for no distortion, again you may need to build the voltage divider to attenuate the input signal). The adjusted v_i will be in the range of 50 millivolts or so. Measure v_i and v_o . The measurement of v_i requires some care, for noise can contaminate such a small signal. Compute the differential mode gain (v_o/v_i).

Use the differential gain and your previously computed common mode gain to calculate CMRR_{dB} (see pg. 716 in text).

Build the circuit shown in Figure 7, using a current source in the common emitter lead to improve the CMRR.

Compute the value of R which will result in the same emitter bias currents for Q_1 and Q_2 as those used in the circuit of Fig. 4 (with $v_+ = v_- = 0$). Assume β and r_o are infinite for this calculation. Use this value of R in your circuit. Measure the values of common and differential mode voltage gains using the same techniques as above. Calculate and report the common mode rejection ratio. Is it higher? If so, why?

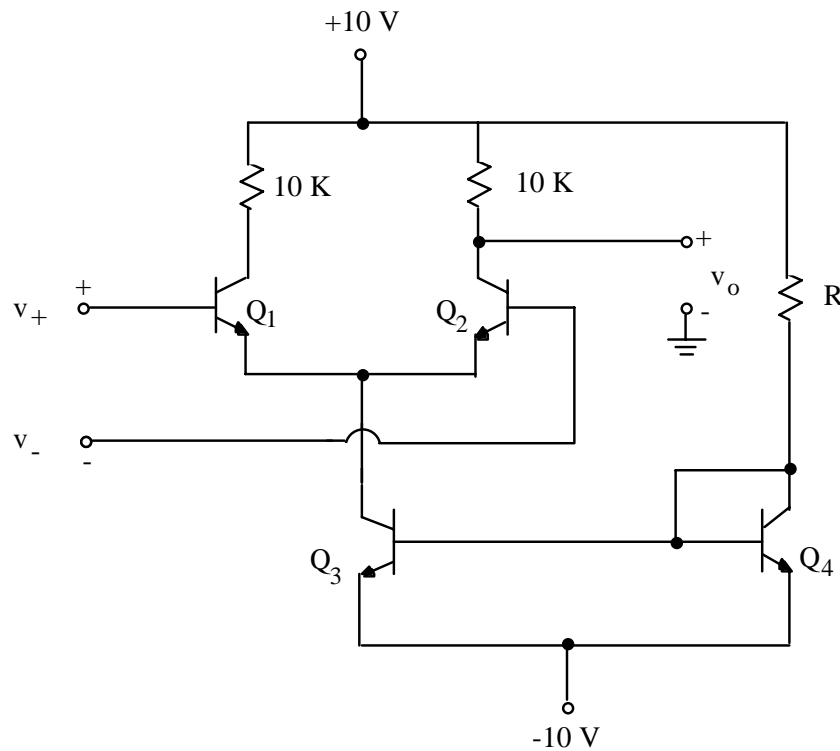


Figure 7. Improved differential amplifier.

Report: Answer these questions in your lab notebook.

1. Using your measured value of the output resistance R_o , of the simple current mirror of Figure 2, part 1, calculate the Early voltage V_A of the 2N3904. What significance does R_o have in the design of differential amplifiers?
2. a. Compare the measured values of A_{CM} , A_d , and $CMRR_{dB}$ for both of the differential amplifiers you built (resistor tail current and current mirror tail current). What are the major differences and why do they occur? Which one is more stable?

- b. Compare your measured values of A_{CM} , A_d , and $CMRR_{dB}$ for both of the differential amplifiers with those predicted theoretically by equations derived in class and/or the textbook. (Assume $V_A = \infty$ for Q_1 and Q_2 . For Q_3 use the value of V_A measured in part 1.) Discuss any significant differences between your data and calculations.