UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE
Department of Electrical and Computer Engineering

EXPERIMENT 1 – BJT DIFFERENTIAL PAIR AMPLIFIER WITH BJT CURRENT MIRROR

OBJECTIVES

In this experiment the students will be familiarize with the biasing and operation of a BJT differential pair amplifier.

INTRODUCTION

The typical BJT differential pair amplifier consists of a pair of transistors coupled at the emitters to a current source, having equal resistances in each collector and equal but opposite, signal sources in each base. The amplifier has several variations on this basic configuration. The basic configuration (Figure 1-1) will be studied in this experiment.

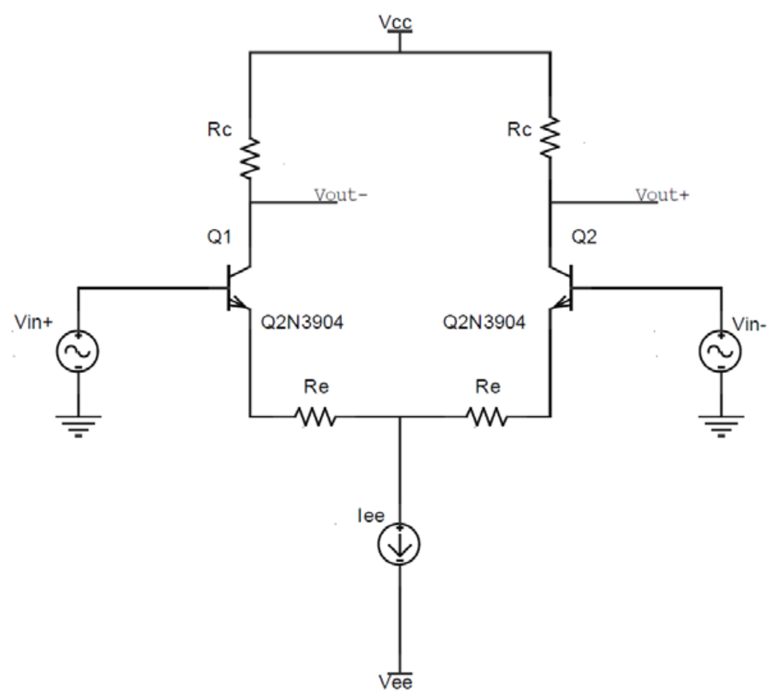

Figure 1-1 Basic BJT differential pair amplifier

The important characteristics for the differential pair amplifier to be studied in this experiment are: differential voltage gain (A_{Vd}), common mode gain (A_{Vcm}), common-mode rejection ration CMRR, and single-ended voltage gain (A_{Vse}).

Assuming that $r_{o1,2} >> R_C$ and $r_{e1} = r_{e2}$, the following information can be found for the differential pair BJT amplifier:

$$V_{in} = V_{in}(+) + V_{in}(-)$$

$$V_{out}(-) = -i_{c1}R_c = -\alpha i_{e1}R_c \quad \text{and} \quad V_{out}(+) = -i_{c2}R_c = -\alpha i_{e2}R_c$$

$$i_{e1} = \frac{V_{in}}{2r_{e1} + 2R_e} \quad \text{and} \quad i_{e2} = \frac{V_{in}}{2r_{e2} + 2R_e}$$

$$A_{vd} = \frac{V_{out}(+) - V_{out}(-)}{V_{in}(+) - V_{in}(-)} = \frac{\alpha\left(\left(\frac{V_{in}}{2}\right)\frac{R_c}{r_e + R_e} - \left(-\left(\frac{V_{in}}{2}\right)\frac{R_c}{r_e + R_e}\right)\right)}{V_{in}} = \frac{\alpha R_c}{r_e + R_e}$$

Note: $V_{in}(+)$ and $V_{in}(-)$ are equal and opposite – and add together to make V_{in}.

The single-ended gain (output taken at either $V_{out}(+)$ or $V_{out}(-)$, is then:

$$A_{vse} = \frac{V_{out}(+)}{V_{in}(-)} = \frac{V_{out}(-)}{V_{in}(+)} = \frac{1}{2}A_{vd} = \frac{\alpha R_c}{2r_e + 2R_e}$$

These results are derived by looking at the output current i_c flowing through the resistors R_c, its relation to i_e, and finding the resultant voltage at the output terminals (in small signal terms).

The common mode gain is found by applying the input signal to both the (+) and (-) inputs to the differential pair as shown in Figure 1-2. The differential output voltage with a common mode input is zero since:

$$V_{out}(+) = V_{out}(-) = -V_{cm}\left(\frac{\alpha R_c}{r_e + R_e + 2r_{ee}}\right)$$

and

$$A_{vcmd} = V_{out}(+) - V_{out}(-) = 0$$

However, the single-ended common-mode voltage gain is not zero and is given by:

$$A_{vcmse} = \frac{V_{out}(+)}{V_{cm}} = \frac{V_{out}(-)}{V_{cm}} = \frac{-\alpha R_c}{r_e + R_e + 2r_{ee}}$$

***Note:** The term $2r_{ee}$ is derived from the resistance of the current source i_{ee} which is ideally infinity, but in practical circuits is not infinitely high.

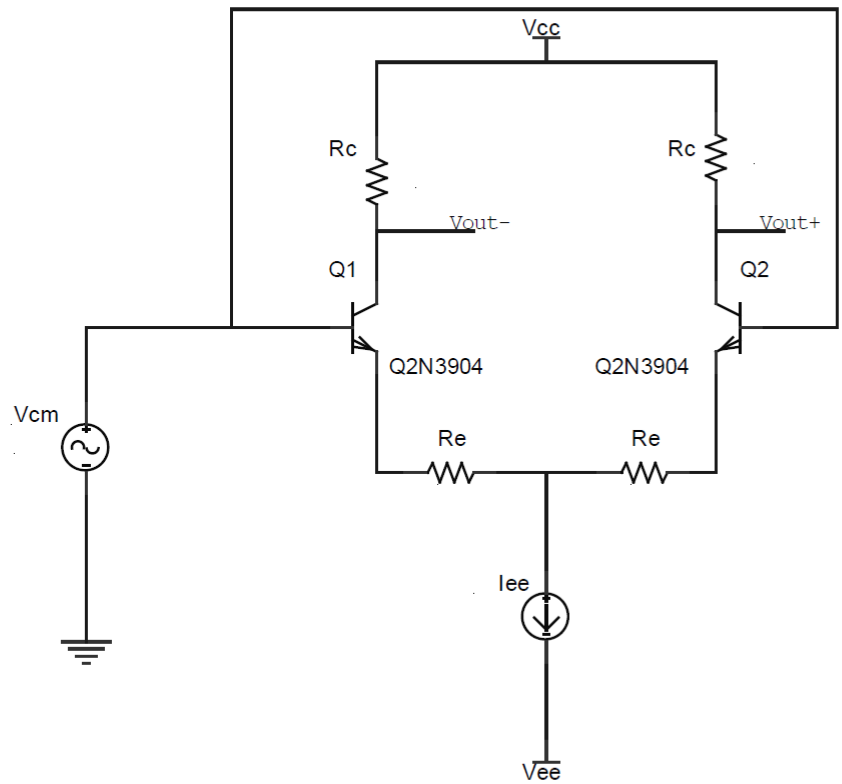

Figure 1-2 Common mode circuit for differential pair

The common-mode rejection ratio is defined by the division of the single-ended differential circuit gain by the single-ended common-mode gain as follows:

$$CMRR = \frac{A_{Vdse}}{A_{Vcmse}} = \frac{\dfrac{\alpha R_c}{2r_e + 2R_e}}{\dfrac{\alpha R_c}{r_e + R_e + 2r_{ee}}} = \frac{r_e + R_e + 2r_{ee}}{2r_e + 2R_e} \approx \frac{r_{ee}}{r_e + R_e} \text{ since } r_{ee} \gg r_e + R_e$$

From the above equations it can be seen that the differential amplifier enhances the difference between the inputs and suppresses the common mode component. This desirable characteristic is used to attenuate unwanted presences in the input signal such as noise from a coaxial cable or from an audio cable.

PRELAB

1. For the circuit of Figure 1-3, find the values of R_{ref} and R_C's such that $I_{CQA,B}$ is approximately equal to 2 mA and $V_{CE1,2}$ = 6V. Given: $V_{CC} = -V_{EE}$ = 15V, $R_A = R_B$ = 2.2kΩ, and R_e = 250Ω. Assume: V_{BEon} = 0.7V, V_t = 25mV, V_A = 100V, β = 100, $I_{CQ1,2} = 0.5I_{CQA,B}$, and the transistors are matched and operating in the active region.
2. Using the equations in the Introduction and information from the previous part of the prelab, find the small-signal differential voltage gain A_{Vd}, the differential circuit single-ended gain A_{Vse}, the single-ended circuit common-mode voltage gain A_{Vcmse}, and the CMRR (Common-Mode Rejection Ratio) for the circuit in Figure 1-3. The value of r_{ee} is needed to calculate the CMRR . To determine r_{ee} assume that the emitter resistor on the reference side of the current mirror is zero. Although this will causes some error it will greatly simplify the calculation.

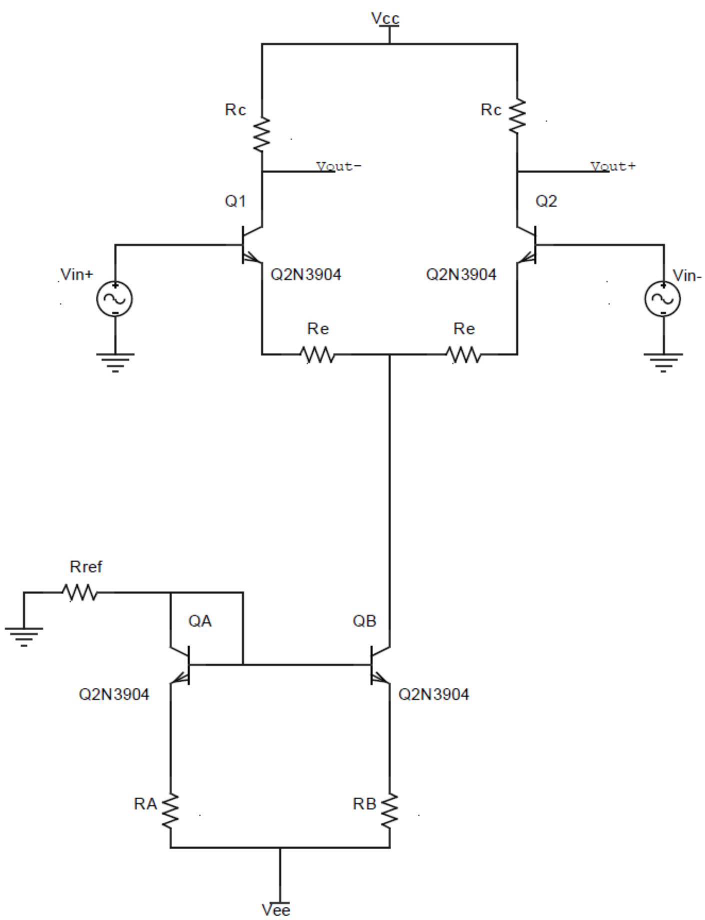

Figure 1-3 Differential pair amplifier with current mirror biasing

PROCEDURE

1. Prepare the power supplies for V_{CC} and V_{EE} to ensure the proper voltages, +15V and -15V, respectively.
2. Connect the circuit of Figure 1-4 with the resistor values calculated in the Prelab. Make sure to include the supply bypass capacitors to reduce noise.

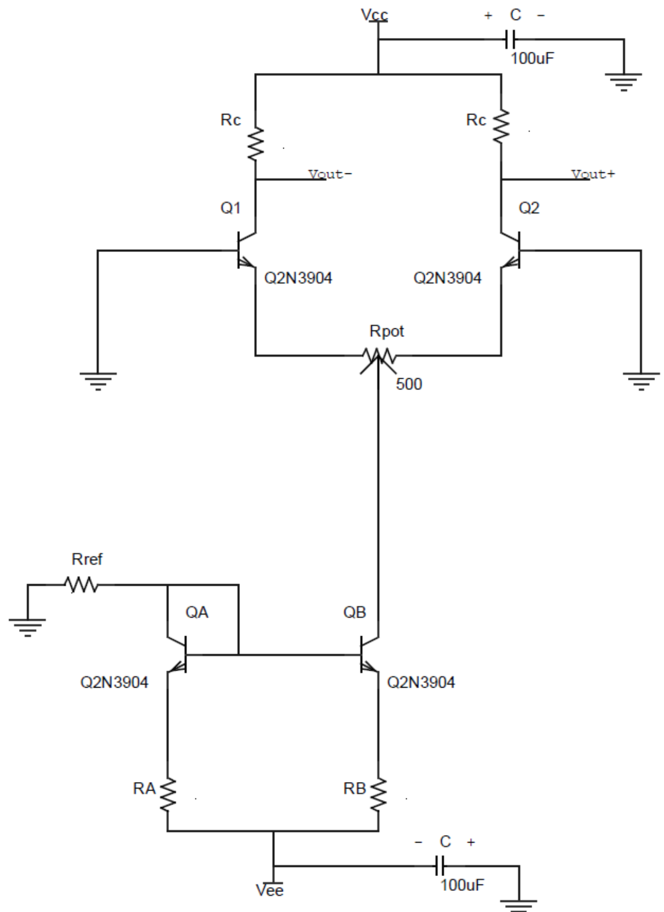

Figure 1-4 Differential pair amplifier biasing configuration

3. Measure I_{CQA}, I_{CQB}, V_{CE1}, and V_{CE2}. If $V_{CE1,2}$ is not equal to approximately 6V, but $I_{CQA,B}$ = 2mA and $V_{BE1,2}$ ~ 0.7V, adjust R_{pot} until $V_{CE1,2}$ is almost 6V. Due to the differences in resistors R_C and the differences in β, the potentiometer is necessary to balance the differential pair.
4. Record the bias voltages and currents and momentarily take out the potentiometer R_{pot} and measure the resistance on each side. Measure and record the value of $I_{CQ1,2}$ and $V_{C1,2}$.
5. Apply a small signal input of $100mV_{p-p}$ with a frequency of 1kHz at the base of Q_1 (i.e. $V_{in}(+) = 100mV_{p-p}$). Use a voltage divider as shown in Figure 1-5 below. Leave $V_{in}(-)$ grounded.
6. Measure and record the single-ended output voltages $V_{out}(+)$ and $V_{out}(-)$. Note which is in phase and which is out of phase with $V_{in}(+)$.

7. Vary the function generator frequency and record enough data to plot the voltage gain ($A_{Vse} = V_{out}/V_{in}$) versus frequency. Do this only for the V_{out}(-) output point, it is not necessary to take measurements for both as they will have the same frequency response.

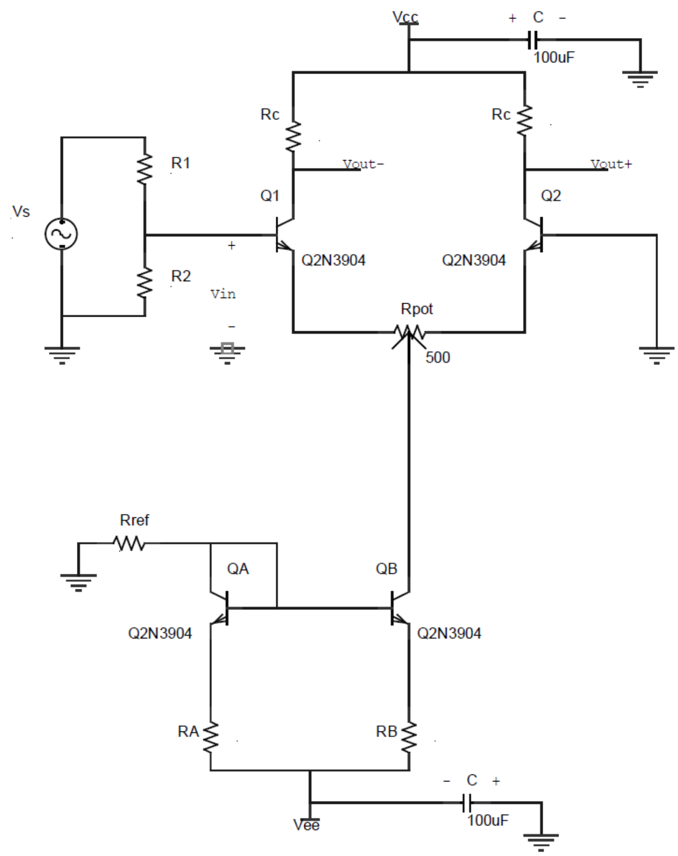

Figure 1-5 Differential amplifier with single-ended input (R_1&R_2>>r_{inQ1})

8. Now connect the small signal input to V_{in}(-) and ground V_{in}(+). Again use a voltage divider network to attain a $100mV_{p-p}$ input with a frequency of 1kHz at V_{in}(-).
9. Now measure and record the single-ended output voltages V_{out}(+) and V_{out}(-). Note which is in phase and which is out of phase with V_{in}(-).
10. Vary the fuction generator frequency and record enough data to plot the voltage gain ($A_{Vse} = V_{out}/V_{in}$) versus frequency. For the same reason as before, only do this for the Vout(+) output point.
11. Using the same circuit used in step 10, connect channel 1 of the oscilloscope to V_{out}(+) and channel 2 of the oscilloscope to V_{out}(-). Make sure that the volts/division adjustments are the same for both channels. This will allow for the calculation of the differential voltage gain:

$$A_{vd} = \frac{V_{out}(+) - V_{out}(-)}{V_{in}}$$

12. Vary the function generator frequency in order to obtain enough data to plot the differential voltage gain A_{Vd} versus frequency.

13. Now connect a sinusoidal input (4.0V_{p-p} @1kHz) to both V_{in}(+) and V_{in}(-), this connection will allow for common-mode measurements.
14. Measure and record the single-ended common-mode output voltage at either V_{out}(+) or V_{out}(-). Vary the function generator frequency and record enough data to plot the single-ended common-mode voltage gain A_{Vcmse} versus frequency.

POST-LAB

Post-Lab questions must be answered in each experiment's laboratory report.

1. Plot voltage gain vs. frequency for the data collected in Steps 7, 10 and 14 of the Procedure using Excel, Matlab or a similar software. Compare the plots and note any differences. Do the different configurations have a similar frequency response? Did the voltage gains for each circuit at 1kHz correspond to the calculated values from the Prelab?
2. Using the data obtained for the single-ended common-mode gain and the differential circuit single-ended gain (either measurement), calculate the Common Mode Rejection Ratio (CMRR) for the differential pair amplifier. Compare this with the calculated value in the Prelab.
3. Did the calculated bias currents and voltages correspond to the measured values obtained in the experiment? Note any differences and note what the different resistances were on each side of the resistor Rpot, were the resistor values drastically different (more than 100Ω apart.)?

Note: When plotting the frequency response curves make sure the x and y axes are log (i.e., 1, 10, 100, 1000, etc.).