

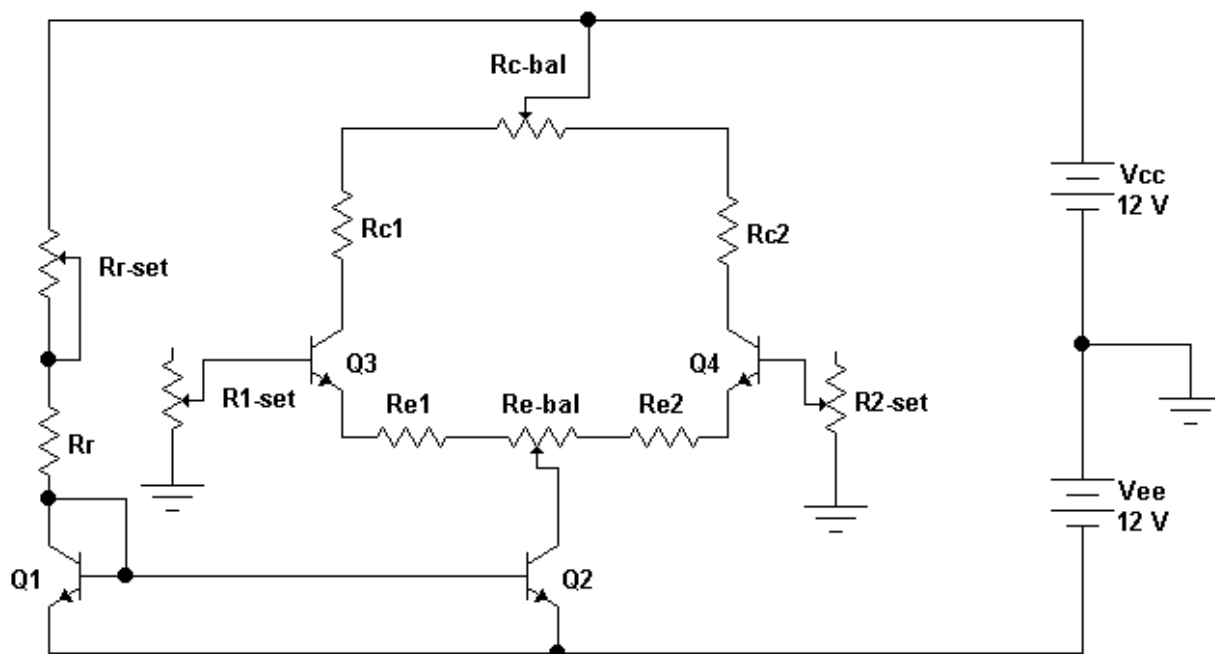
University of Pennsylvania  
Department of Electrical and Systems Engineering  
ESE319

**Laboratory Experiment - Differential Amplifier**

**1. Introduction.**

This lab is designed to demonstrate the properties of a bipolar junction transistor differential amplifier.

The bias-level schematic of a bipolar junction transistor differential amplifier is shown below. The collector and emitter resistors will be selected from standard value resistors and the variable resistors will be used to balance the circuit experimentally. A current mirror is used to set the collector current and to offer a very high common mode resistance to the input signals. The transistors on the CA3046 integrated circuit are used for Q1 – Q4.



The design constraints that your nominal design must meet are as follows.

The source voltage supplies will have magnitude:  $|V_{CC}| = |V_{EE}| = 12 \text{ V}$

The ratio of collector to emitter resistances is to be about

$$\frac{R_C}{R_E} = 10$$

The dc (bias) value of the collector voltage to ground on each amplifier transistor is to be about

$$V_C = 6 \text{ V.}$$

The nominal value for the current mirror reference current is to be about

$$I_{REF} = 1 \text{ mA.}$$

Select the base resistors on your own and give reasons for your choice.

## 2. Preliminary discussion.

The performance of a differential amplifier is critically dependent on circuit balance. Hence, we will use resistors with adjustable taps (potentiometers) to balance precisely the collector, base, and emitter resistances in the amplifier.

- For the calculated fixed resistances,  $R_E$ , and  $R_C$ , choose equal value standard resistors LOWER in value than the calculated values. Then for balance adjustments, select potentiometers with full-scale resistance values that, when added to the resistors selected for  $R_C$  and  $R_E$ , come close to the theoretical values  $2R_C$  and  $2R_E$ , respectively.
- Use adjustable resistors (potentiometers) in the base circuits.
- Choose a fixed resistor lower than the calculated value for the current-reference resistor in the current mirror and connect an adjustable resistor in series. Later, you will use the variable resistor to adjust the reference current to obtain the correct bias currents in each amplifier transistor.

To obtain the best balance in the transistor characteristics, we will use transistors from a matched array, CA3046, for the BJT amplifier and current mirror transistors. The connection diagram for the CA3046 can be obtained from its data sheet.

### PRE-LAB:

- Determine values for  $R_{C1}$ ,  $R_{C2}$ ,  $R_{E1}$ ,  $R_{E2}$  and  $R_r$ , assuming no potentiometers. Choose reasonable values for base resistors  $R_{1-set}$  and  $R_{2-set}$ .
- Determine the theoretical mid-band differential-mode gains for single-ended operation. For single-ended gain choose either the Q3 or Q4 outputs.
- Using the CA3046 data sheet, estimate the value of  $r_o$  for the current source (use the value for VAF). Determine the theoretical mid-band common-mode gains for single-ended and differential operation. For single-ended gains choose either the Q3 or Q4 outputs.
- Simulate your design in *Multisim*, assuming matched resistor pairs for ( $R_{C1}$ ,  $R_{C2}$ ); ( $R_{E1}$ ,  $R_{E2}$ ) and ( $R_{1-set}$ ,  $R_{2-set}$ ). Use the transistor models for the CA3046 (determined for the *Multisim* simulation in the Current Source Bias BJT Amplifier Lab). Evaluate the differential-mode and common-mode gains vs. frequency for single-ended and differential operation over the frequency range from 10 Hz to 10 MHz.
- Compare the simulated mid-band gains with the theoretical calculations in 2 and 3.

**NOTE: DO NOT forget to connect pin 13 to -12V. Use Q3 and Q4 for the amplifier transistors.**

## 3. Assembly and biasing.

Assemble and wire your circuit on a Protoboard. Try to be as symmetric as possible in the physical layout of the circuit. Capacitive imbalance to ground and unequal lead lengths from the signal source to the transistor base input points can degrade the common mode rejection properties of a differential amplifier at higher frequencies.

Use the resistance measurement capability of your DVM to adjust the potentiometers in the emitter and collector circuits so that the resistance from one side of the resistor string to the pot tap is equal to the resistance of the other side. This adjustment balances the collector and emitter resistances. Also measure and adjust the base to ground resistors so that you have equal resistance in each base.

- Once assembled, power up the circuit and adjust the current mirror. To do this, measure the voltage across the reference resistor  $R_r$  and adjust the variable resistor  $R_{r-set}$  until the current through  $R_r$  is 1 mA, or the voltage across  $R_r$  is  $R_r$  volts, where  $R_r$  is measured in  $k\Omega$ .

- b. Then measure the voltage between transistor collector Q4 and collector Q3, i.e.  $V_{C4} - V_{C3}$ , and record the output offset,  $V_{OS}$ . Don't attempt to reduce this output offset, just record it.

**NOTE: To measure the dc voltage between two points, neither of which is ground, use either the DVM or two scope probes with the scope inputs set to dc mode and with the display set to show the difference of the two probe voltages. You can use x1 probes, or ordinary pieces of coax for the scope probes to take dc measurements.**

#### 4. Response characteristics.

There are two ways to take an output from the differential amplifier: differential, and single-ended. Explain both and plan to measure the differential and single ended-output voltages of the amplifier. For common mode gain measurements, apply a common voltage simultaneously to both inputs.

#### 5. Common mode tests.

Apply a 1 kHz common mode voltage to both inputs of the amplifier. Choose a suitably large voltage so you can obtain a reasonably clean output voltage from one collector to ground. Don't forget that this circuit REJECTS common mode voltages! Record the input and single-ended output voltages, and additionally, record the collector-to-collector balanced output voltage. Always use 10x scope probes. For the balanced measurement, use the scope difference function to combine the two probe measurements.

Record the measurements as the input frequency varies from 1kHz to 1MHz. Concentrate your measurements in the 100 kHz to 1 MHz Range. Compute the common mode "gain," for both single-ended and differential outputs.

#### 6. Differential mode tests.

For differential mode gain measurements **do not attempt** to create two voltage signals of precisely equal size and opposite polarity with respect to ground. Instead, apply an input voltage signal  $v_i$  to one side of the amplifier and connect the other input to ground through a  $47 \Omega$  resistor. Show, that, in this case, the differential mode voltage applied to each transistor base is  $v_i/2$  and the applied common mode voltage is also  $v_i/2$ . Also convince yourself, by one means or another, that the output voltage of the amplifier in this case is strongly dominated by the differential component and that the common mode component has negligible effect at the amplifier output when compared to the differential component. The effect of this connection is equivalent to applying differential voltages of  $v_i/2$  to one input and  $-v_i/2$  to the other and a common mode voltage of  $v_i/2$  to both.

Apply a 1kHz voltage signal to one amplifier input. Choose a suitably small voltage - remember this circuit AMPLIFIES differential voltages! Record the input and single-ended output voltages, and additionally, record the collector-to-collector balanced output voltage. Always use 10X scope probes. For the balanced measurement, use the scope difference function.

Record the measurements at the same input frequencies that you used for the common mode measurements. Compute the differential mode "gain," for both single-ended and differential outputs.

#### 7. Common mode rejection ratio.

Finally, compute the common mode rejection ratio for the amplifier at each measurement frequency.

#### 8. In-Lab Simulation

Re-simulate your design in *Multisim* using actual component values and compare the simulation results with your experimental results. Use the ideal NPN BJT circuit model for all transistors – amplifier and current mirror - modified to reflect data sheet values for the CA3046 array. Include reasonable values for the Protoboard capacitance between

the mirror transistor collector and base and base and emitter terminals. Also include scope probe input impedance in your circuit model.

In addition to the single-ended gain (and phase) vs. frequency plots, use the *Multisim* data to compute and plot differential voltage gain using the post-processing capability within *Multisim*. The procedure is given in the Appendix.

Try to adjust the transistor saturation currents in your simulation to model the dc offset you observed experimentally. Does this help improve the agreement between simulation and experiment?

Overall, how well do your simulation results compare with experimental measurements? How might the agreement be improved?

Kenneth R. Laker 27 Oct 2009

### **APPENDIX: *Multisim* Procedure for Computing Differential Gain and Phase vs. Frequency**

The plotting of the differential voltage gain (and phase) vs. frequency cannot be done by the *Multisim* bode plotter. It necessitates the post-processing of the *Multisim* data for the specific node voltages being subtracted to form the differential signal. The procedure is as follows:

1. Enable viewing of node names. Options -> Preferences -> Enable “show node names,” Click ok
2. Run the simulation. Simulate -> Analyses -> AC Analysis -> Set start and stop frequencies, Set vertical scale to “linear,” under the “output variables” tab select the two collector nodes, and click add, then click simulate.
3. Exit out of the Analysis Graphs
4. Go to Simulate -> Postprocessor. Click the plus next to the lowest version of the circuit name and select the AC Analysis. Click “add” to add an expression and type: “ $20 \cdot \log(\text{ac.v}(\text{AA}) - \text{ac.v}(\text{BB}))$ ” where AA and BB are your node names. Under the “graph tab” select your expression and click the right arrows. Finally click “Calculate”.