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Department of Electrical and
Computer Engineering

EXPERIMENT No. 5
DIFFERENTIAL AMPLIFIERS

I. INTRODUCTION

Differential amplifiers are an important part of modern integrated circuit operational amplifiers. In this experiment you will study the differential amplifier with a resistor and then a transistor current source as the biasing element. A second stage will then be cascaded to the basic amplifier. You will measure parameters such as gain, common mode rejection ratio (CMRR), input offset voltage (V_{OS}), and input bias current (I_{BIAS}).

II. BACKGROUND

A differential amplifier consists of an emitter-coupled pair of transistors, as shown in figure 1.

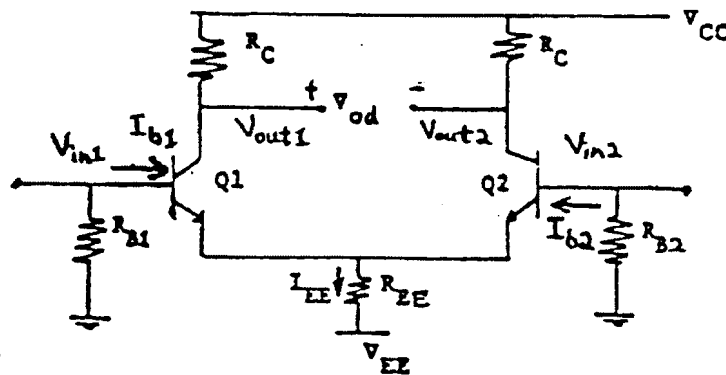


Figure 1
Differential Amplifier with resistor biasing

Ideally, the differential amplifier only amplifies the difference of its two input voltages:

$$v_{od} = A_{dm} v_{id};$$

where A_{dm} = differential mode gain, $v_{id} = v_{in1} - v_{in2}$, and $v_{od} = v_{out1} - v_{out2}$.

However, any real differential amplifier will also amplify some of its common-mode input (the average of the two inputs):

$$v_{oc} = A_{cm} v_{ic};$$

where A_{cm} = common mode gain, $v_{ic} = (v_{in1} + v_{in2})/2$, and $v_{oc} = (v_{out1} + v_{out2})/2$.

A figure of merit is the common mode rejection ratio (CMRR), where $CMRR = A_{dm}/A_{cm}$. The larger the CMRR, the better the differential amplifier. A_{dm} , A_{cm} , and CMRR can be expressed in decibels (dB). For example: A_{dm} (in dB) = $20 \log_{10} |A_{dm}|$.

To understand the operation of the differential amplifier, note that for a pure differential input ($v_{id} \neq 0$, $v_{ic} = 0$), the emitters' voltage of the transistor pair does not fluctuate (due to the symmetry of the circuit) and is therefore an A.C. ground. For a pure common-mode input ($v_{id} = 0$, $v_{ic} \neq 0$), exactly twice the emitter current of each transistor flows through R_{EE} , thus effectively doubling this resistor value when viewed from only one side of the emitter-coupled pair.

We thus obtain the following two small signal half-circuits for pure differential and common-mode inputs:

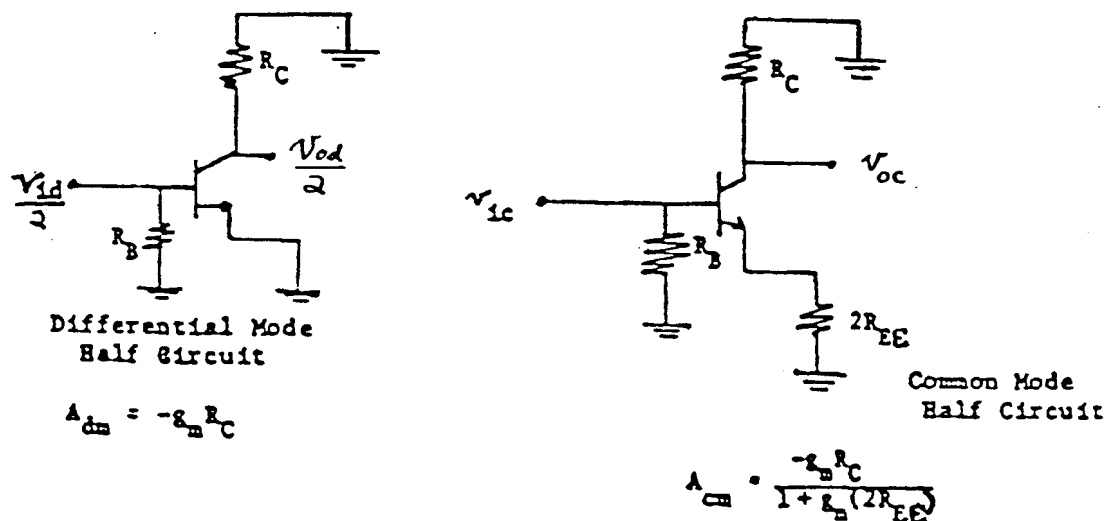


Figure 2.

Note in Fig. 2 that the differential amplifier becomes a common-emitter amplifier for differential mode inputs and a C-E amplifier with resistor degeneration of $2R_{EE}$ for common-mode inputs (for further discussion, see text, sec. 3.5).

Mismatch effects on differential amplifiers

Ideally, if the emitter-coupled pair is completely balanced, the differential output of a differential amplifier would be zero for a differential input of zero. However, due to transistor and load resistor (R_C) mismatches, an actual differential amplifier's D.C. transfer characteristic would appear as follows:

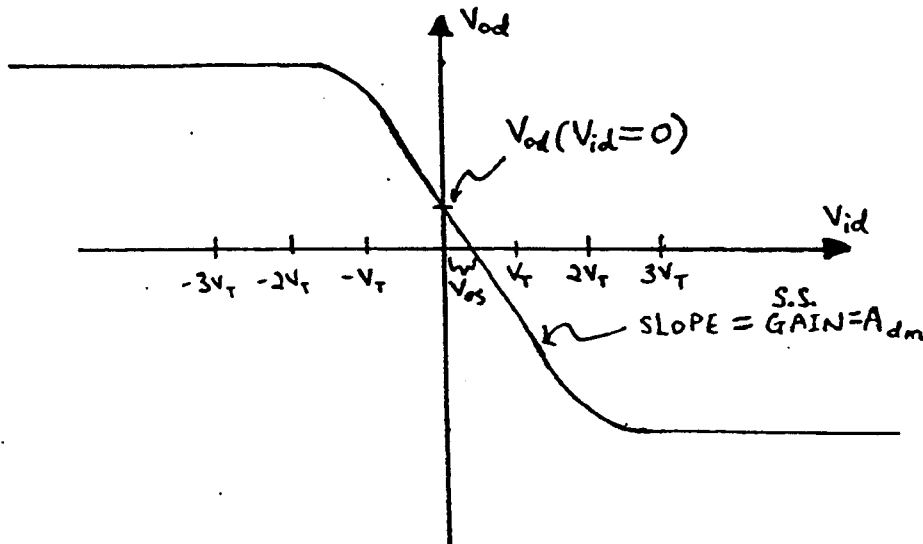


Figure 3. An actual diff.-amp. transfer characteristic.

Figure 3 shows that an offset input of V_{OS} is needed to obtain an output V_{OD} of zero. From figure 3:

$$V_{OD} = A_{dm}(V_{ID} - V_{OS}) \quad (1)$$

This D.C. voltage offset parameter is important in real differential amplifier design.

D.C. base currents are required to bias the input transistors forward active. Again, due to transistor and load resistor mismatches, the two input base currents are not identical. I_{OS} is thus defined as the difference of the two input base currents, and I_{BIAS} is defined as the average of the two input currents. (i.e. $I_{OS} = I_{B1} - I_{B2}$; $I_{BIAS} = (I_{B1} + I_{B2})/2$). For a further discussion of mismatch effects refer to the text, Sec. 3.5.6.

III. DIFFERENTIAL AMPLIFIER WITH RESISTOR BIASING

- 1) Build the circuit shown in figure 4 using the matched pair. Measure V_{ID} and V_{OD} (with no A.C. input). Note that you will be measuring very small voltage differences. From the voltage drop across R_{B1} and R_{B2} , compute I_{B1} and I_{B2} . Now compute I_{OS} and I_{BIAS} .
- 2) Measure the differential-mode gain A_{dm} by applying a small 1 KHz sine wave at Point X, grounding Point Y, and measuring the A.C. input at v_{in1} , and then the output, v_{od} . Note that v_{in2} is at A.C. ground and therefore $v_{id} = v_{in1}$. (Make sure the output is a clean sine wave. An input $> 50mV$ will distort the output). Compare A_{dm} with hand calculated value. Compute V_{OS} using equation (1) and the values measured in 1).
- 3) Now disconnect Point Y from ground and connect Point X to Point Y. (so $V_{in1} = V_{in2}$) Input a small sine wave at Point X and measure v_{out1} and v_{out2} . The average of these two voltages is v_{oc} . What is A_{cm} ? Compute the CMRR for your circuit. Compare A_{cm} and CMRR with hand calculations.

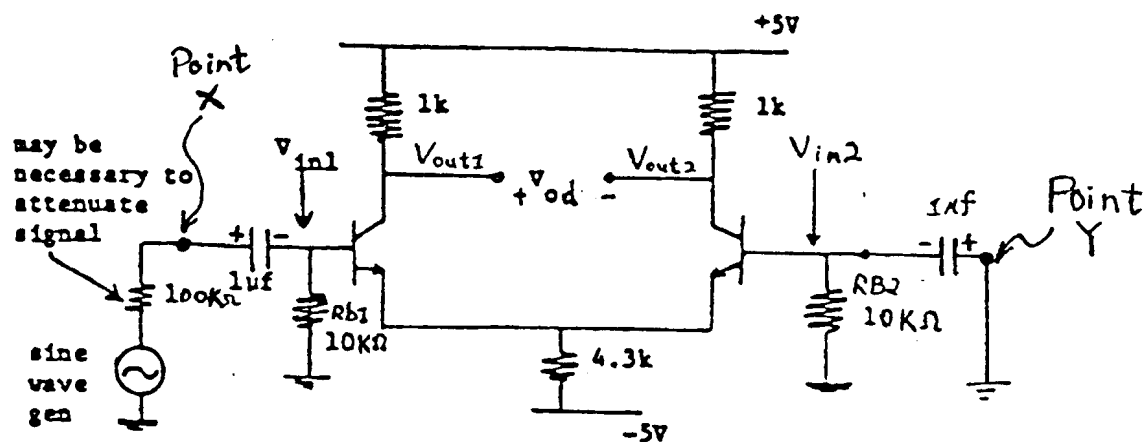


Figure 4. Differential amp. with resistor biasing.

IV. DIFFERENTIAL AMPLIFIER WITH CURRENT SOURCE

Build the circuit in Figure 5, which has a transistor current source instead of R_{EE} (Note change in V_{CC} and V_{EE}). As you did previously, measure A_{dm} and A_{cm} and compute CMRR. What are the measured differences between this circuit and the previous one? Why?

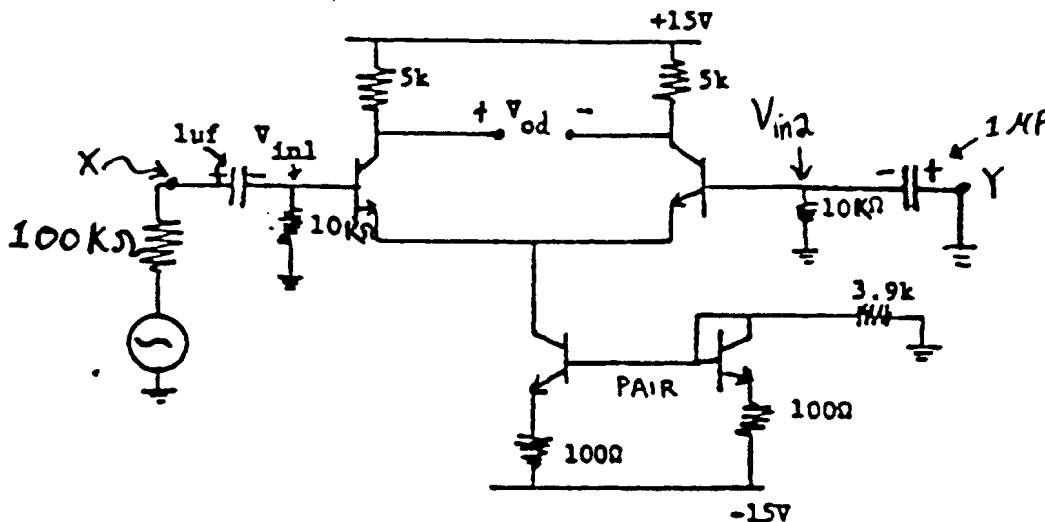


Figure 5. Differential amplifier with current source.

V. CASCADE OF AMPLIFIERS

Design and connect a second stage common-emitter amplifier with degeneration as shown below in figure 6. (Note the use of the PNP transistor. Why is a PNP used?). Calculate R_E and R_C values for a gain of 2. (Hint: assume $g_m R_E = (I_C R_E)/V_T \gg 1$; $R_O \gg R_C$. See text, sec. 3.3.8). Apply a 1 KHz signal and measure the overall gain of the cascaded amplifier, v_{out}/v_{in1} (note that the output from the differential amplifier is taken from only one side, effectively reducing the gain of this first stage by one-half). What is the overall gain? What is the maximum output swing?

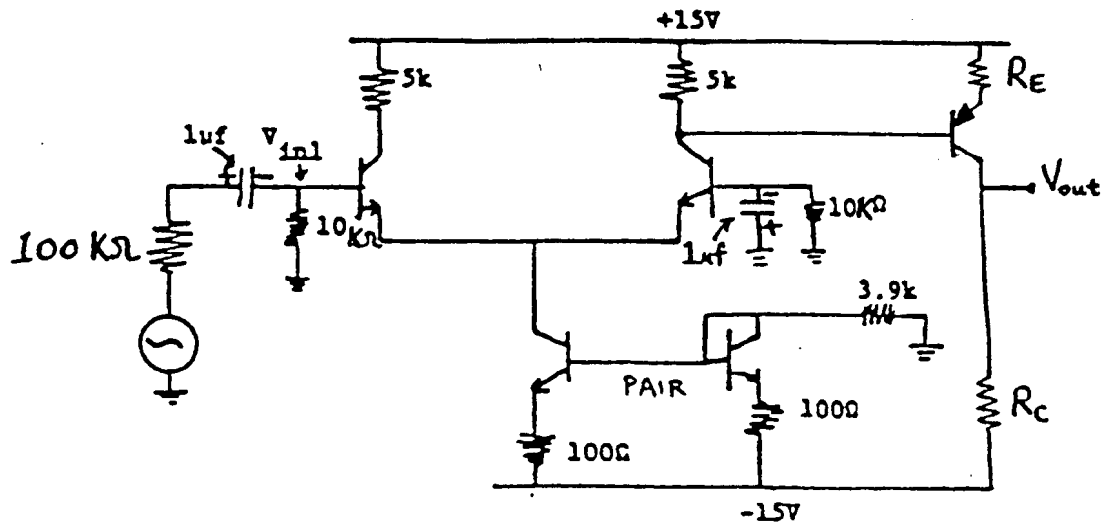


Figure 6. Cascading second stage to the differential amplifier.

Lab Results:

Experiment - DIFFERENTIAL AMPLIFIERS

III. DIFFERENTIAL AMPLIFIER WITH RESISTOR BIASING

(1) $I_{B1} = \underline{\hspace{2cm}}$ $I_{B2} = \underline{\hspace{2cm}}$

$I_{OS} = \underline{\hspace{2cm}}$ $I_{BIAS} = \underline{\hspace{2cm}}$

(2) measured $A_{dm} = \underline{\hspace{2cm}}$ calculated $A_{dm} = \underline{\hspace{2cm}}$

$V_{OS} = \underline{\hspace{2cm}}$

(3) measured CMRR = $\underline{\hspace{2cm}}$ calculated CMRR = $\underline{\hspace{2cm}}$

measured $A_{cm} = \underline{\hspace{2cm}}$ calculated $A_{cm} = \underline{\hspace{2cm}}$

IV. DIFFERENTIAL AMPLIFIER WITH CURRENT SOURCE

$A_{dm} = \underline{\hspace{2cm}}$ $A_{cm} = \underline{\hspace{2cm}}$ CMRR = $\underline{\hspace{2cm}}$

V. CASCADE OF AMPLIFIERS

$R_E = \underline{\hspace{2cm}}$ $R_C = \underline{\hspace{2cm}}$

$A_V = \underline{\hspace{2cm}}$ $V_{out(max)} = \underline{\hspace{2cm}}$ $V_{out(min)} = \underline{\hspace{2cm}}$