EXPERIMENT #2
DIFFERENTIAL AMPLIFIERS

OBJECTIVE

Familiarization with biasing and common mode characteristics of differential amplifiers.

THEORY

The differential amplifier is a versatile circuit, which serves as the input stage to most opamps, comparators and emitter coupled logic circuits. The basic property of a differential amplifier is that the output voltage is proportional to the difference between the two input voltages.

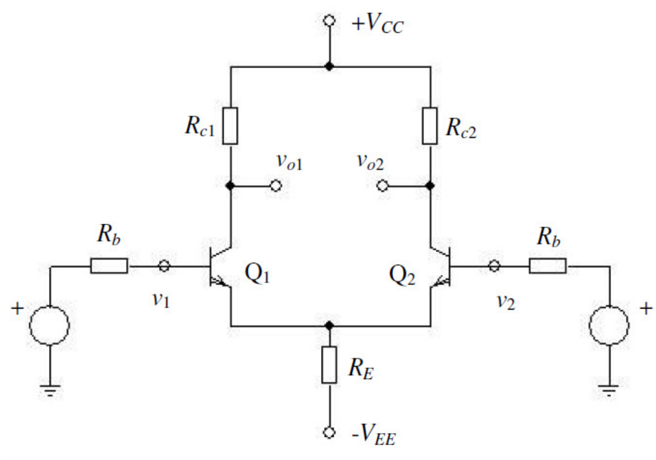


Figure 2.1 The basic differential amplifier

The basic differential amplifier circuit is given in *Figure 2-1*. The voltage difference between two inputs is called the differential-input voltage, *vd*, and the average of these two voltages is called the common-mode input voltage, *vc*.

$$v_d = v_1 - v_2$$

$$v_c = \frac{v_1 + v_2}{2}$$

Therefore two different gains can be defined for a differential amplifier. The differential mode gain, *Ad*, and the common-mode gain, *Ac*.

$$A_d \stackrel{\Delta}{=} \frac{v_{o2}}{v_d} = -\frac{v_{o1}}{v_d}$$

$$A_c \stackrel{\Delta}{=} -\frac{v_{o2}}{v_c} = -\frac{v_{o1}}{v_c}$$

For a good differential amplifier, the differential mode-gain is desired to be as high as possible and the common mode gain is desired to be as small as possible. The quality measure of a differential amplifier is therefore expressed as the ratio of these two gains and is called the Common Mode Rejection Ratio, *CMRR*.

The differential gains of the amplifier in *Figure 2.1* for *hfe* >>1 can be expressed as follows:

The differential mode gain:

$$A_d = \frac{1}{2}\frac{R_c}{r_e + R_b/h_{fe}} \quad \text{where} \quad r_e = \frac{25}{I_E(mA)}$$

The common-mode gain:

$$A_c = \frac{R_c}{2R_E + r_e + R_b/h_{fe}}$$

The Common Mode Rejection Ratio:

$$CMRR = \frac{A_d}{A_c} = \frac{2R_E + r_e + R_b/h_{fe}}{2(r_e + R_b/h_{fe})}$$

In order to increase *CMRR*, R_E should be chosen as large as possible. But it cannot be increased indefinitely because this resistor also determines the emitter current of the transistors. If the input DC voltage is zero, the total emitter current can be calculated as follows:

$$I_{E(total)} = I_{E1} + I_{E2} = (0 - 0.6 + V_{EE})/R_E$$

To overcome this problem instead of an emitter resistor, a current source is used as shown in *Figure 2-2*. This circuit is called "Long tailed circuit" and provides good *CMRR* with high differential gain at the same time.

In this case the total emitter current is calculated as follows:

$$I_{E(total)} = (V_{B3} - 0.6 + V_{EE})/R_E$$

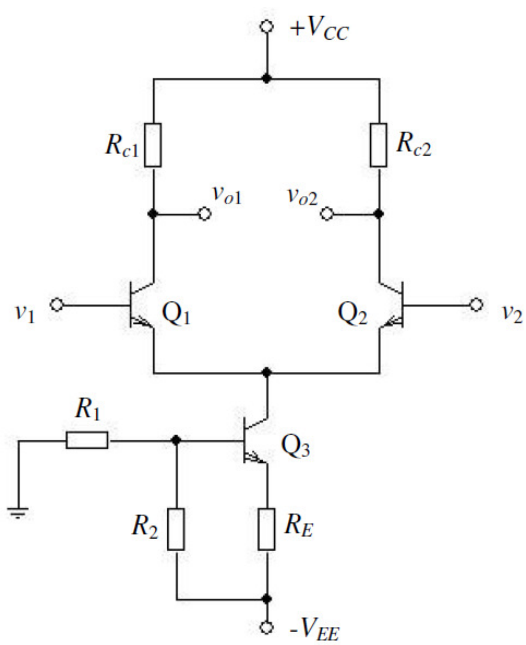


Figure 2.2 The long-tailed differential amplifier

PRELIMINARY CALCULATIONS

1. Calculate the resistor values of the circuit in *Figure 2-1* to obtain the following DC operating conditions when the input voltages are zero and the power supply voltages are ±12V; Vo = +5V; $I_{E1} = I_{E2}$ = 1mA

R_E = ... R_C = ...

2. Calculate the resistor values of the circuit in *Figure 2-2* to obtain the same DC operating conditions and V_{E3} = -11V.

R_1 = ... R_2 = ... R_E = ...

3. Calculate the differential and common mode gains of *Figure 2-1* and find the *CMRR* of the circuit when the signal generator source impedance, R_b is 600W.

Ad = ... Ac = ... *CMMR* = ...

PROCEDURE

1. Build the circuit in *Figure 2-1* with the calculated resistor values. Connect both inputs to ground and measure DC voltages and calculate the emitter currents.

2. Apply an AC voltage source (sine wave signal generator) of 1kHz frequency and 100mV amplitude at one of the inputs. Adjust the input voltage until a perceptible distortion occurs on the output voltage. Measure this input voltage. Halve the input voltage and measure the amplitude and phase of AC output voltages, v_{o1} and v_{o2}. Calculate the differential gain of the circuit.

$Ø_{o1}$ = ... $Ø_{o2}$ = ...

3. Connect both inputs to the same sine wave signal generator. Increase the input voltage until a measurable, distortionless output voltage is obtained from one of the outputs. Measure the input-output voltages and calculate the common mode gain.

4. Double the value of the common emitter resistor, R_E, and repeat steps 1,2,3.

$Ø_{o1}$ = ... $Ø_{o2}$ = ...

5. Repeat steps 1, 2, 3 for *Figure 2-2*.

$Ø_{o1}$ = ... $Ø_{o2}$ = ...

DC Operating Conditions

Procedure#	V_{C1} (V)	V_{C2} (V)	V_E (V)	I_{E1} (mA)	I_{E2} (mA)
1					
4					
5					

Differential-mode Gains

Procedure#	v_i (V)	v_{o1} (V)	v_{o2} (V)	A_d
2				
4				
5				

Common-mode Gains and CMRR

Procedure#	v_i (V)	v_{o1} (V)	v_{o2} (V)	A_c	*CMRR*
3					
4					
5					

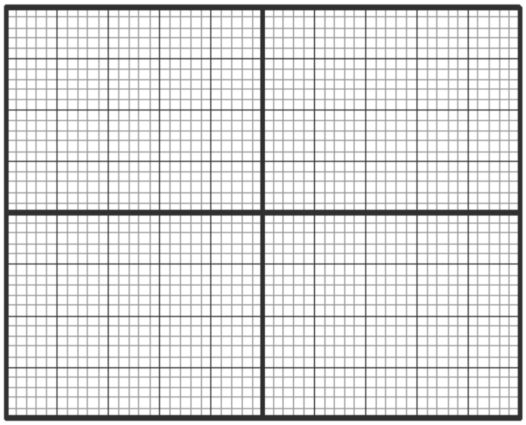
EQUIPMENT

1. CRT oscilloscope
2. DC power supply (+12V,-12V)
3. Sine wave generator
4. AC and DC voltmeters
5. Breadboard

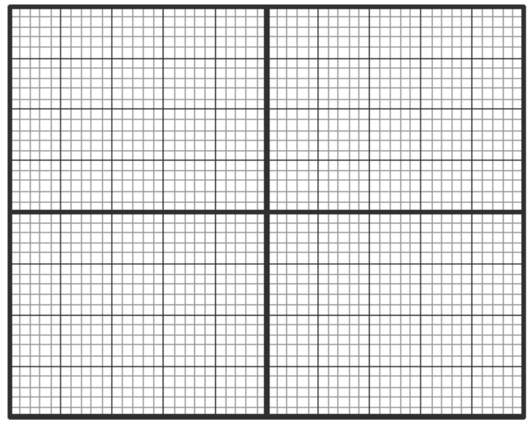
COMPONENTS

1. BC238B Transistors (3)
2. Resistors (to be calculated)

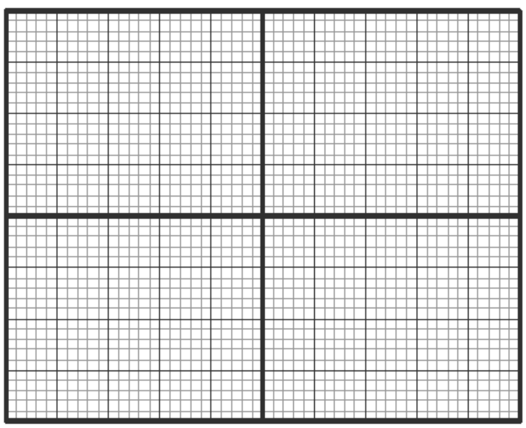
Input



Outputs



Input



Outputs