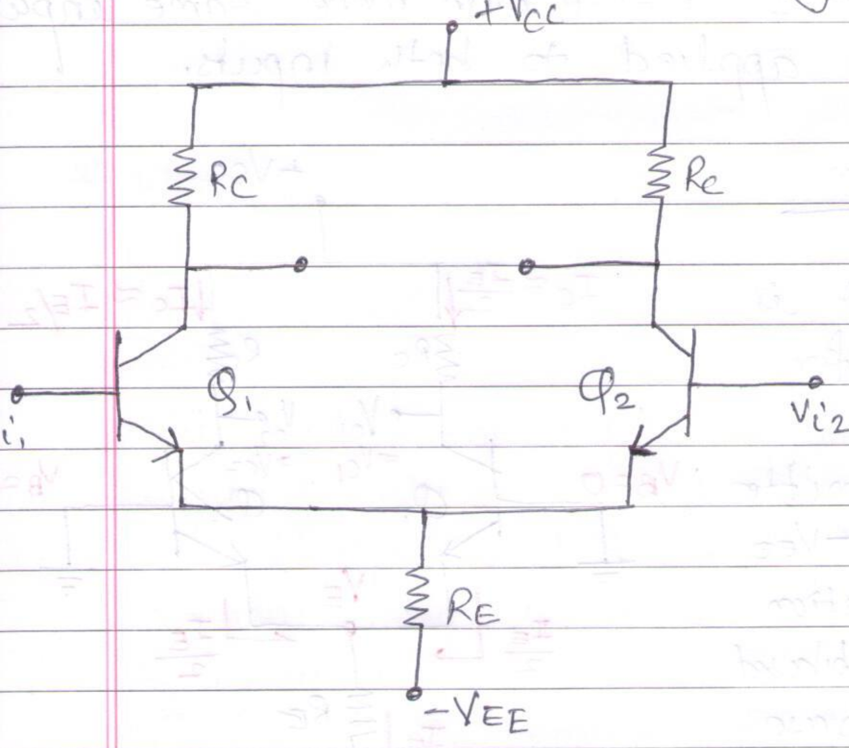
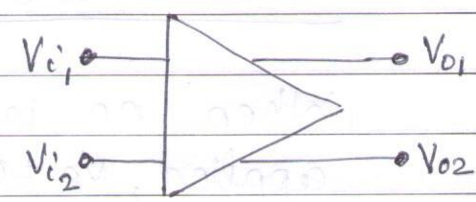
Differential Amplifier

The differential amplifier circuit is an extremely popular connection used in IC units. A basic differential amplifier circuit and its symbol is shown below.





It consists of two transistors Q_1 and Q_2 well matched (ie. $\beta_1 = \beta_2 = \beta$) connected in common emitter configuration with emitters connected together. Notice that the circuit has two seperate inputs and two seperate outputs. Typically it has two seperate supply voltages, however, the circuit can also operate with single supply.

* Types of input signal combinations:-

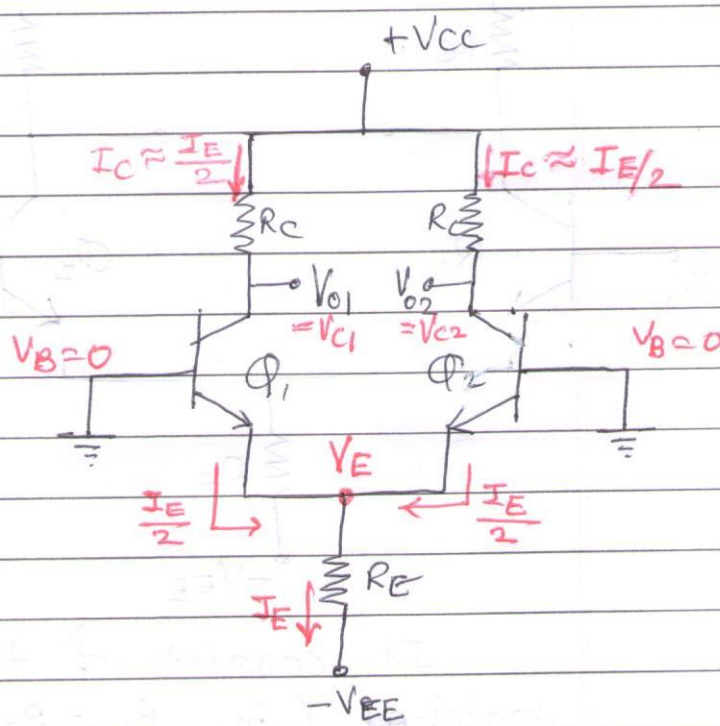
A number of input signal combinations are possible for a differential amplifier.

1) Single ended – An input signal is applied to either input with ~~..~~ the other input connected to ground.

2) Double ended - If two opposite polarity signals are applied, the operation is referred as double ended.

3) Common Mode - It is the case were same input is applied to both inputs.

* DC Bias Condition



When no input is applied, $V_B = 0$ for both transistors. However, since emitter is connected to $-V_{EE}$, emitter-base junction will be forward biased and collector-base junction is reverse biased.

$$\Rightarrow V_E = 0V - V_{BE}$$
$$= -0.7V \longrightarrow (1)$$

$\therefore$ Emitter d' bias current is

$$I_E = \frac{V_E - (-V_{EE})}{R_E} = \frac{-0.7 + V_{EE}}{R_E}$$
$$= \frac{V_{EE} - 0.7}{R_E} \longrightarrow (2)$$

since, the transistors are well mached, we have

$$\beta_1 = \beta_2 = \beta$$

$$\Longrightarrow I_{C_1} = I_{C2} = \frac{I_E}{2} \longrightarrow (3)$$

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∴ Collector voltage is

$$V_{C1} = V_{C2} = V_{CC} - I_C R_C$$

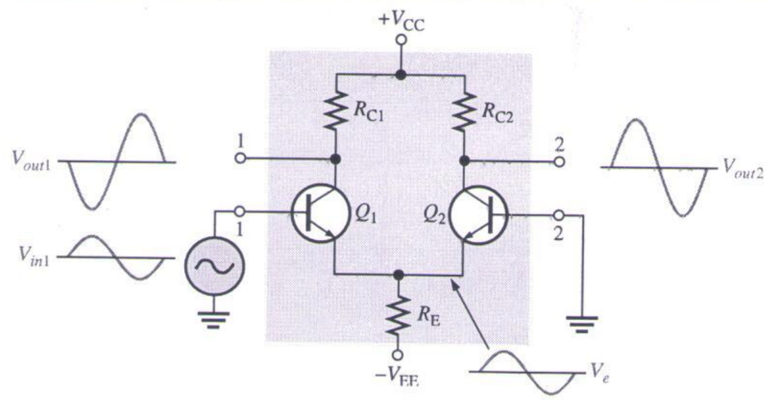
$$= V_{CC} - \frac{I_E R_C}{2} \longrightarrow (4)$$

* Working

① Single ended input -

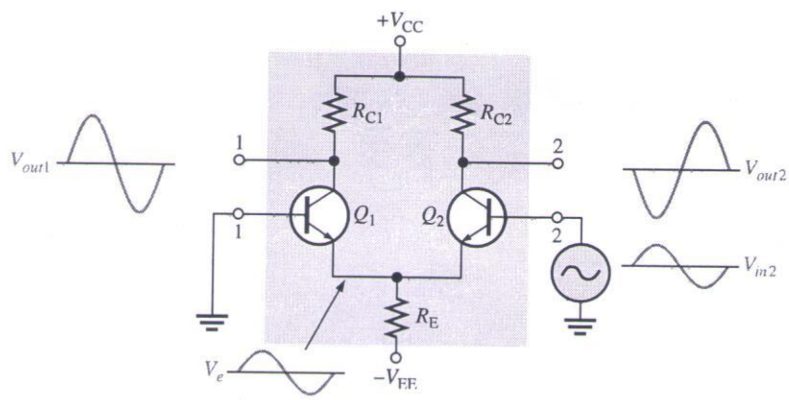
When a diff-amp is operated in this mode, one input is grounded and the signal is applied only to the other input.

If the signal is applied to input 1, an inverted, amplified signal voltage appears at output 1. Also, a signal voltage appears in phase at the emitter of Q_1. Since the emitters of Q_1 and Q_2 are common, the emitter signal becomes an input to Q_2, which functions as a common-base amplifier. The signal is amplified by Q_2 and appears non-inverted at output 2. This action is illustrated in part (a).



(a)

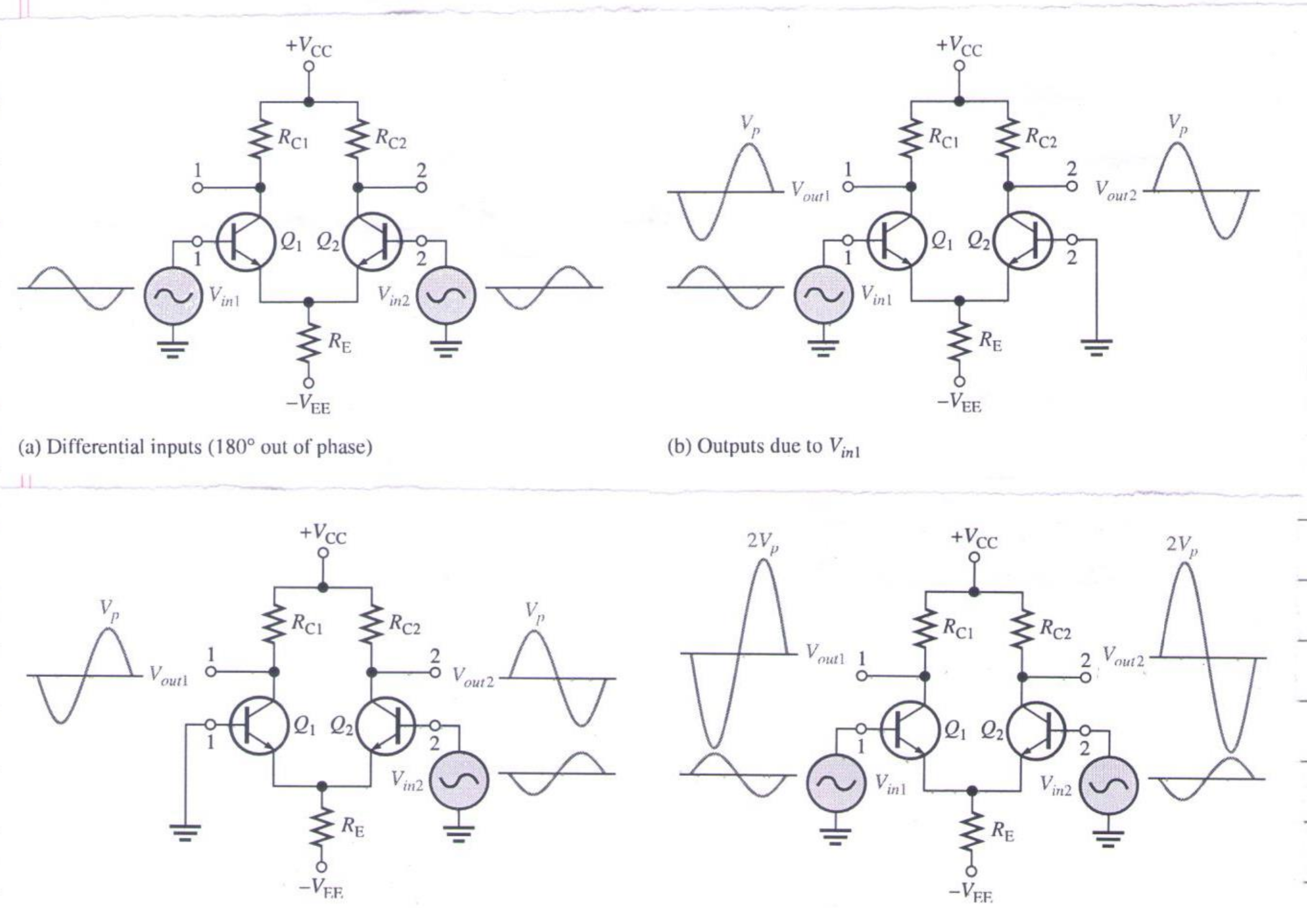
In the case where the input is applied to input 2, with input 1 grounded, an inverted, amplified



(b)

signal voltage appears at output 2. In this situation Q_1 acts as a common-base amplifier and a non-inverted amplified signal appears at output 1. This action is illustrated in part (b) of the figure.

② Differential mode –



(a) Differential inputs (180° out of phase)

(b) Outputs due to V_{in1}

(c) Outputs due to V_{in2}

(d) Total outputs

In this mode, two opposite-polarity (out of phase) signals are applied to the inputs, as shown in figure (a). This type of operation is also referred as **double-ended**. Each input affects the outputs as follows:

i) Figure (b) shows the output signals due to the signal on input 1 acting alone as a single-ended input

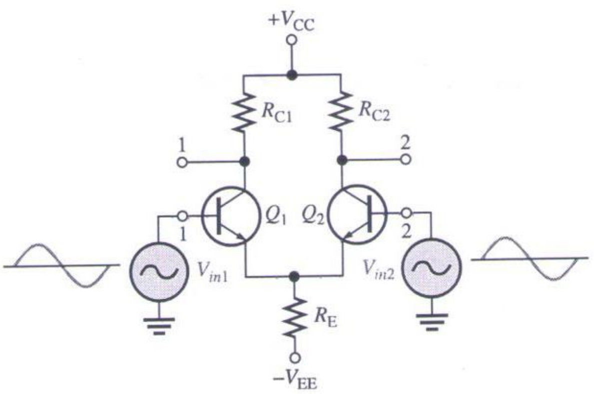
ii) Figure (c) shows the output signals due to the

~~single~~ signal on Input 2 acting alone as a single-ended input.

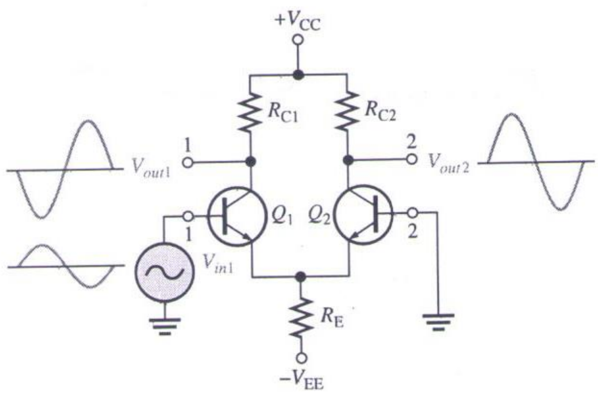
iii) Notice that in parts (b) and (c), the signals on output 1 are of the same polarity. The same is true for output 2.

iv) By superpositioning both outputs 1 signals and both output 2 signals, we get the differential operation, as pictured in Figure (d).

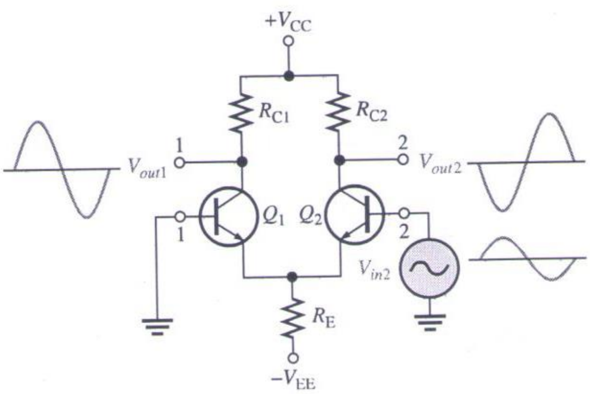
③ **Common - Mode :-**



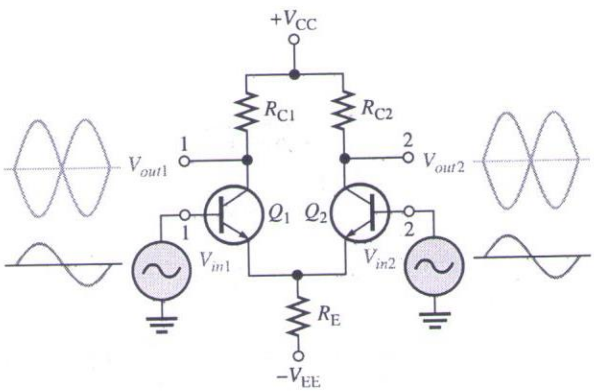
(a) Common-mode inputs (in phase)



(b) Outputs due to V_{in1}



(c) Outputs due to V_{in2}



(d) Outputs due to V_{in1} and V_{in2} cancel because they are equal in amplitude but opposite in phase. The resulting outputs are 0 V ac.

One of the most important aspect of the operation of a diff-amplifier can be seen by considering the common-mode. In this case the ~~same~~ signal with same phase, frequency and amplitude is applied to the two inputs. Figure (b) shows the output signals due to the signal on only input 1. Figure (c) shows the output signals due to the signal on only input 2. Notice that the corresponding signals on output 1 are of the opposite phase of that on output 2. When both the inputs are applied, the outputs are superimposed and they cancel, resulting in the zero output voltage, as shown in figure (d). This action is called Common-Mode Rejection.

COMMON-MODE REJECTION RATIO (CMRR):-

In most of practical operations, differential amplifier is used in single-ended or in differential mode. The desired signal appears only on one input or with opposite polarities on both input lines. These desired signals are amplified and appear on the outputs. An unwanted signal (noise) appearing with the same polarity on the both inputs are essentially cancelled by differential amplifier and do not appear at the outputs is called common mode rejection.

CMRR (Common Mode Rejection Ratio) is the measure of an amplifier's ability to reject common-mode signals. Ideally, a differential amplifier provides a very high gain for desired signals (single-ended or differential) and zero gain for common-mode signals. Practically they do exhibit a very small common-mode gain (usually much less than 1), while providing a high differential voltage gain (usually several thousands). If Avd is the differential voltage gain and if Acm is the common-mode gain, the CMRR is defined as

$$CMRR = \frac{A_{vd}}{A_{cm}}$$

The higher the CMRR, the better. A very high value of CMRR means that the differential gain Avd is high and common-mode gain Acm is low.

Techniques to improve CMRR :—

① Use of Constant-Current Source :-

To achieve high CMRR, use of constant-current source is a popular choice. Figure (a) shows a differential amplifier with a constant-current source circuit to provide a large

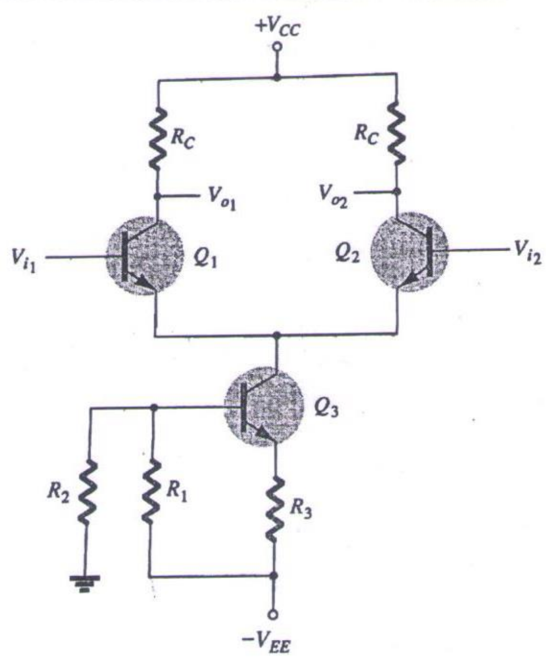


FIG. (a)
Differential amplifier with constant-current source.

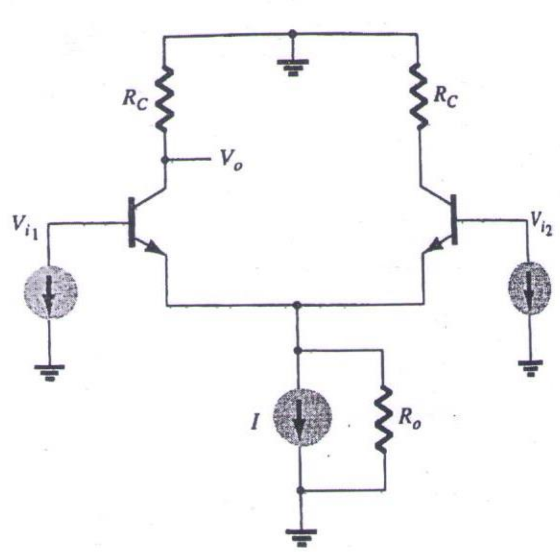
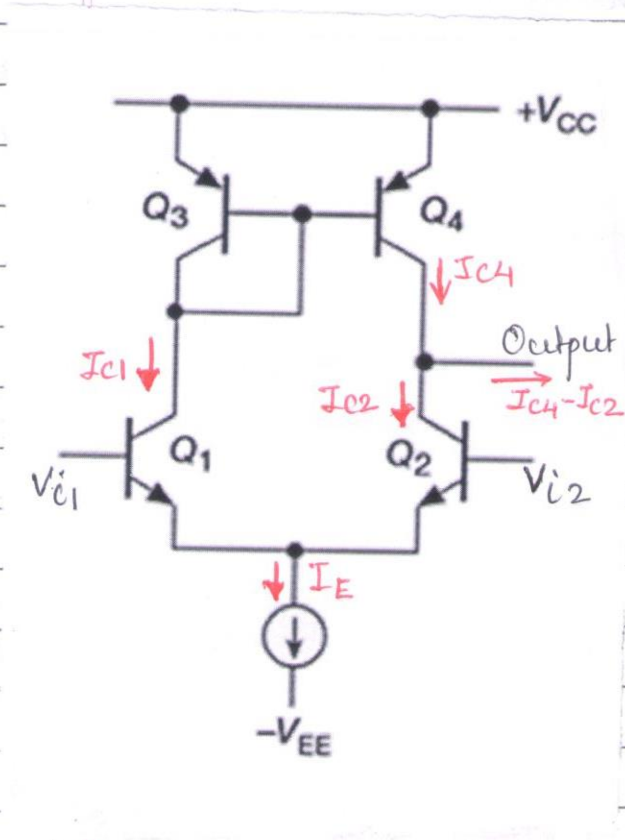


FIG. (b)
AC equivalent of the circuit of Fig. (a)

value of resistance from common emitter to ac ground. The corresponding ac equivalent is shown in figure (b). A partial constant-current source is shown as a high impedance, in parellel with constant current.

(2) Use of Current Mirror -



Though the Q_1 and Q_2 are very closely balanced, small variations in their parameters leads to increase in common-mode gain. Therefore, to improve circuit performance a self-balancing circuit using current mirror is employed.

Here Q_3 and Q_4 form a current mirror of their own. As a result, the reference current for Q_3 is exactly same to the collector current of Q_1. This current is mirrored by Q_4 and has no other connection.

When $V_{i1} = V_{i2}$, there is no differential input. This means that $I_{C1} = I_{C2}$. Q_3 uses I_{C1} as its reference current, and this current is mirrored by Q_4. Therefore $I_{C4} = I_{C2}$ and there is no current flowing into or out of output.

Now, consider V_{i1} increase, which increase I_{C1} by 0.1mA. This increases I_{C3} by 0.1mA, which inturn increases I_{C4} by 0.1mA. At the same time, increasing I_{C1} by 0.1mA also means that decreasing

I_{C2} by 0.1mA. As a result, there is now a difference of 0.2mA between I_{C2} and I_{C4}. This becomes the output current.

If we apply a differential input sufficient to increase I_{C2} by 0.1mA, the same thing happens in reverse. I_{C1} decreases by 0.1mA, thus decreasing I_{C3} by 0.1mA and I_{C4} by 0.1mA. This creates a 0.2mA difference in the other direction between I_{C2} and I_{C4}. Again that difference becomes the output current.

This increases differential gain and thus improves CMRR.