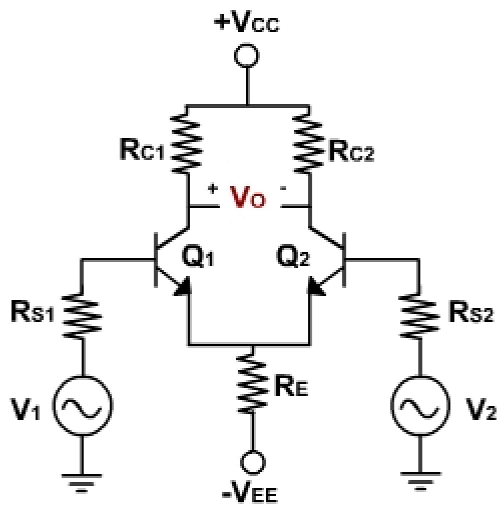
DC and AC analysis - Differential amplifier

The circuit is shown in figure, v_1 and v_2 are the two inputs, applied to the bases of Q_1 and Q_2 transistors. The output voltage is measured between the two collectors C_1 and C_2, which are at same dc potentials.



DC

Figure 1.6

A.C. Analysis: In previous lecture dc analysis has been done to obtain the operating point of the two transistors. To find the voltage gain A_d and the input resistance R_i of the differential amplifier, the ac equivalent circuit is drawn using r-parameters as shown in fig. 2. The dc voltages are reduced to zero and the ac equivalent of CE configuration is used.

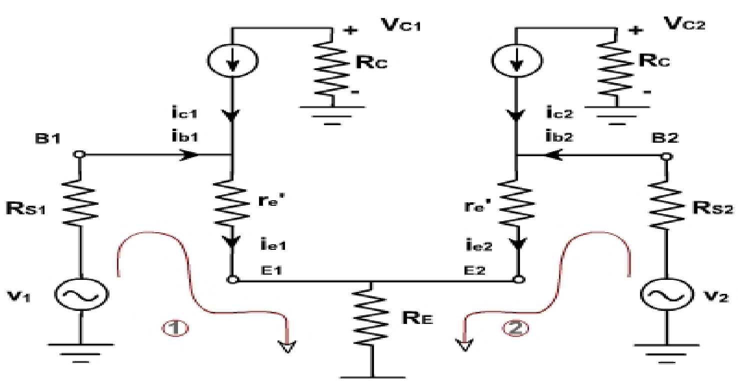


Figure 1.7

Since the two dc emitter currents are equal. Therefore, resistance r'_{e1} and r'_{e2} are also equal and designated by r'_e . This voltage across each collector resistance is shown 180° out of phase with respect to the input voltages v_1 and v_2. This is same as in CE configuration. The polarity of the output voltage is shown in Figure. The collector C_2 is assumed to be more positive with respect to collector C_1 even though both are negative with respect to to ground.

Applying KVL in two loops 1 & 2.

$$v_1 = R_{S1}\, i_{b1} + i_{e1}\, r'_e + (i_{e1} + i_{e2})\, R_E$$
$$v_2 = R_{S2}\, i_{b2} + i_{e2}\, r'_e + (i_{e1} + i_{e2})\, R_E$$

Substituting current relations,

$$i_{b1} = \frac{i_{e1}}{\beta},\quad i_{b2} = \frac{i_{e2}}{\beta}$$
$$V_1 = \frac{R_{S1}}{\beta}\, i_{e1} + r'_e\, i_{e1} + R_E\,(i_{e1} + i_{e2})$$
$$V_2 = \frac{R_{S2}}{\beta}\, i_{e2} + r'_e\, i_{e2} + R_E\,(i_{e1} + i_{e2})$$

Again, assuming $R_{S1}/\square$ and $R_{S2}/\square$ are very small in comparison with R_E and r_e' and therefore neglecting these terms,

$$(r'_e + R_E)\, i_{e1} + R_E\, i_{e2} = v_1$$
$$R_E\, i_{e1} + (r'_e + R_E)\, i_{e2} = v_2$$

Solving these two equations, i_{e1} and i_{e2} can be calculated.

$$i_{e1} = \frac{(r_e + R_E)\, v_1 - R_E\, v_2}{(r'_e + R_E)^2 - R_E^2}$$
$$i_{e2} = \frac{(r'_e + R_E)\, v_2 - R_E\, v_1}{(r'_e + R_E)^2 - R_E^2}$$

The output voltage V_O is given by

$$V_O = V_{C2} - V_{C1}$$

$$= -R_C\, i_{C2} - (-R_C\, i_{C1})$$

$$= R_C\, (i_{C1} - i_{C2})$$

$$= R_C\, (i_{e1} - i_{e2})$$

Substituting i_{e1}, & i_{e2} in the above expression

$$v_o = R_C \left\{ \frac{(r_e + R_E)V_1 - R_E V_2}{(r'_e + R_E)^2 - R_E^2} - \frac{(r_e + R_E)V_2 - R_E V_1}{(r'_e + R_E)^2 - R_E^2} \right\}$$

$$= \frac{R_C (v_1 - v_2)(r'_e - 2R_E)}{r'_e (r'_e + 2R_E)}$$

$$\text{Therefore}, v_o = \frac{R_C}{r'_e}(v_1 - v_2) \qquad (E\text{-}1)$$

Thus a differential amplifier amplifies the difference between two input signals. Defining the difference of input signals as $v_d = v_1 - v_2$ the voltage gain of the dual input balanced output differential amplifier can be given by

$$A_d = \frac{v_c}{v_d} = \frac{R_C}{r'_e}$$

Differential Input Resistance:

Differential input resistance is defined as the equivalent resistance that would be measured at either input terminal with the other terminal grounded. This means that the input resistance R_{i1} seen from the input signal source v_1 is determined with the signal source v_2 set at zero. Similarly, the input signal v_1 is set at zero to determine the input resistance R_{i2} seen from the input signal source v_2. Resistance R_{S1} and R_{S2} are ignored because they are very small.

$$R_{i1} = \left.\frac{v_1}{i_{b1}}\right|_{v_2 = 0}$$

$$= \left.\frac{v_1}{i_{e1}/\beta}\right|_{v_2 = 0}$$

Substituting i_{e1},

$$R_{i1} = \frac{\beta r'_e (r'_e + 2R_E)}{r'_e + R_E}$$

$$\text{Since } R_E >> r'_e$$

$$\therefore \quad r'_e + 2R_E >> 2R_E$$

$$\text{or} \quad r'_e + R_E >> R_E$$

$$\therefore R_{i1} = 2\beta r_e' \qquad (E-3)$$

Similarly,

$$R_{i2} = \left.\frac{V_2}{i_{b2}}\right|_{V_1=0}$$

$$= \left.\frac{V_2}{i_{e2}/\beta}\right|_{V_1=0}$$

$$R_{i2} = 2\beta r'_e \qquad (E-4)$$

The factor of 2 arises because the re' of each transistor is in series. To get very high input impedance with differential amplifier is to use Darlington transistors. Another ways is to use FET.

Output Resistance:

Output resistance is defined as the equivalent resistance that would be measured at output terminal with respect to ground. Therefore, the output resistance R_{O1} measured between collector C_1 and ground is equal to that of the collector resistance R_C. Similarly the output resistance R_{O2} measured at C_2 with respect to ground is equal to that of the collector resistor R_C.

$R_{O1} = R_{O2} = R_C$ (E-5)

The current gain of the differential amplifier is undefined. Like CE amplifier the differential amplifier is a small signal amplifier. It is generally used as a voltage amplifier and not as current or power amplifier.