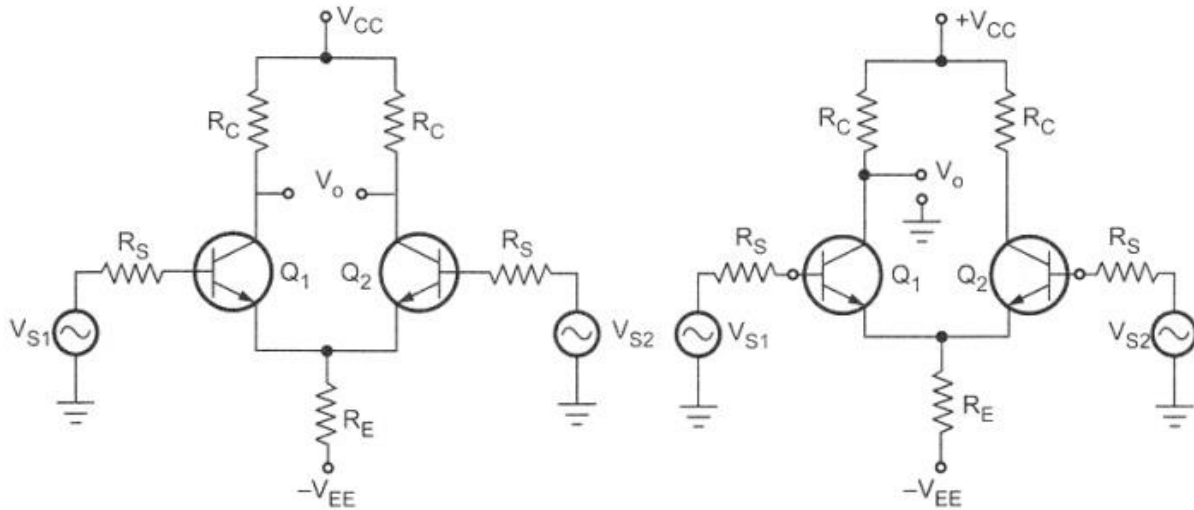


Configurations of Differential Amplifier

The differential amplifier, in the difference amplifier stage in the op-amp, can be used in four configurations :

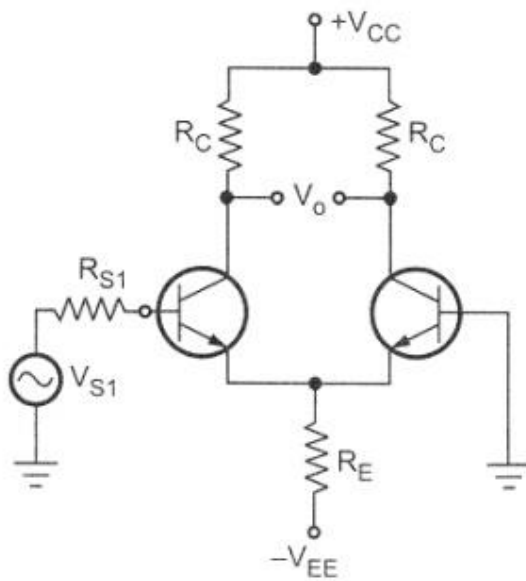
- Dual input balanced output differential amplifier.
- Dual input, unbalanced output differential amplifier.
- Single input, balanced output differential amplifier.
- Single input, unbalanced output differential amplifier.

The differential amplifier uses two transistors in common emitter configuration. If output is taken between the two collectors it is called balanced output or double ended output. While if the output is taken between one collector with respect to ground it is called unbalanced output or single ended output. If the signal is given to both the input terminals it is called dual input, while if the signal is given to only one input terminal and other terminal is grounded it is called single input or single ended input. Out of these four configurations the dual input, balanced output is the basic differential amplifier configuration. This is shown in the Figure 2.11.1. (a). The dual input, unbalanced output differential amplifier is shown in the Figure 2.11.1.(b). The single input, balanced output differential amplifier is shown in the Figure 2.11.1 (c) and the single input, unbalanced output differential amplifier is shown in the Figure 2.11.1. (d).

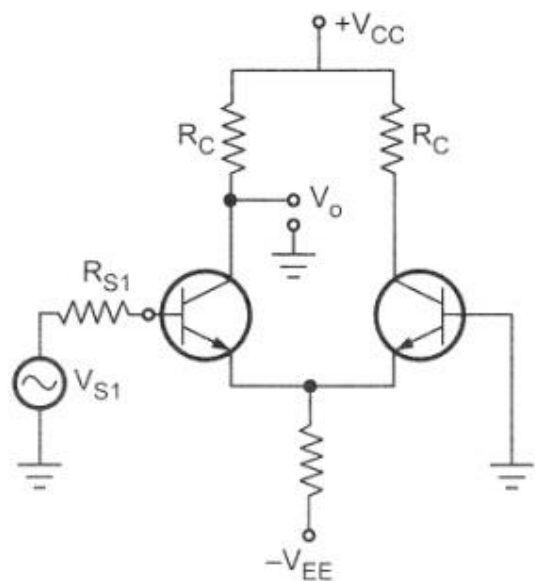


(a) Dual input balanced output

(b) Dual input unbalanced output



(c) Single input balanced output



(d) Single input unbalanced output

Figure 2.11.1 The dual input, unbalanced output differential amplifier is shown in the Fig.(b). The single input, balanced output differential amplifier is shown in the Fig (c) and the single input, unbalanced output differential amplifier is shown in the Fig. (d).

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A.C. Analysis of Differential Amplifier using h-Parameters

In the a.c. analysis, we will calculate the differential gain A_d , common mode gain A_c , input resistance R_i and the output resistance R_o of the differential amplifier circuit, using the h-parameters.

1. Differential Gain (A_d)

For the differential gain calculation, the two input signals must be different from each other. Let the two a.c. input signals be equal in magnitude but having 180° phase difference in between them. The magnitude of each a.c. input voltage V_{s1} and V_{s2} be $V_s/2$. The two a.c. emitter currents I_{e1} and I_{e2} are equal in magnitude and 180° out of phase. Hence they cancel each other to get resultant a.c. current through the emitter as zero. For the a.c. purposes emitter terminal can be grounded.

The a.c. small signal differential amplifier circuit with grounded emitter terminal is shown in the Figure 2.11.2 As the two transistors are matched, the a.c. equivalent circuit for the other transistor is identical to the one shown in the Fig..1. Thus the circuit can be analyzed by considering only one transistor. This is called as half circuit concept of analysis. The approximate hybrid model for the above circuit can be shown as in the Fig.2, neglecting h_{oe} ,

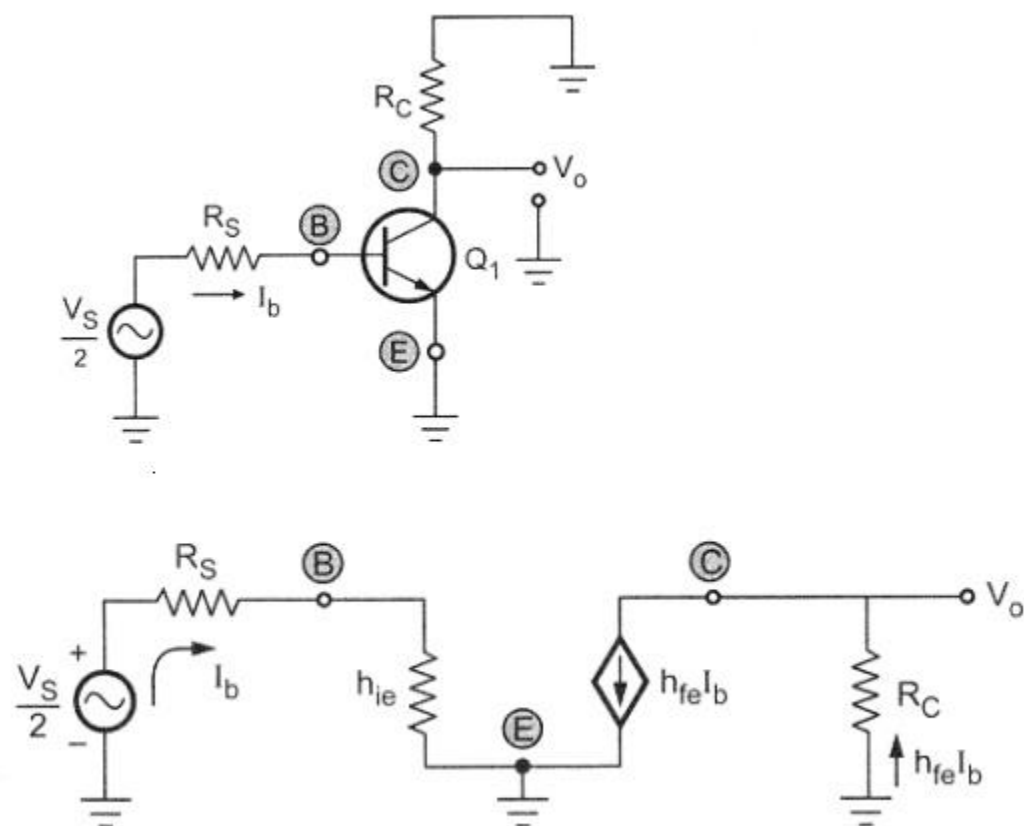


Figure 2.11.2 AC Equivalent for differential Operation and its hybrid model

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Applying KVL to the input loop,

$$-I_b R_S - I_b h_{ie} + \frac{V_S}{2} = 0 \quad \dots(1)$$

$$-I_b (R_S + h_{ie}) = -\frac{V_S}{2}$$

$$I_b = \frac{V_S}{2(R_S + h_{ie})} \quad \dots(2)$$

Applying KVL to the output loop,

$$V_o = -h_{fe} I_b R_C \quad \dots(3)$$

Substituting equation (2) in equation (3),

$$V_o = -h_{fe} R_C \frac{V_S}{2(R_S + h_{ie})}$$

$$\boxed{\frac{V_o}{V_S} = \frac{-h_{fe} R_C}{2(R_S + h_{ie})}} \quad \dots(4)$$

The negative sign indicates the phase difference between input and output. Now two input signal magnitudes are $V_S/2$ but they are opposite in polarity, as 180° out of phase.

$$V_d = V_1 - V_2 = \frac{V_S}{2} - \left(-\frac{V_S}{2}\right) = V_S$$

The **magnitude** of the differential gain A_d is

$$\boxed{A_d = \frac{V_o}{V_S} = \frac{h_{fe} R_C}{2(R_S + h_{ie})}} \quad \text{(For unbalanced output)} \quad \dots(5)$$

where

$V_S =$ Differential input

the expression for A_d with balanced output changes as

$$A_d = 2 \times \frac{h_{fe} R_C}{2(R_S + h_{ie})}$$

$$A_d = \frac{h_{fe} R_C}{(R_S + h_{ie})} \text{ (magnitude)} \quad \dots(6)$$

This is the differential gain for balanced output dual input differential amplifier circuit.

2. Common Mode Gain (A_c)

Let the magnitude of both the a.c. input signals be V_S and are in phase with each other. Hence the differential input $V_d = 0$ while the common mode input V_c is the average value of the two.

$$V_c = \frac{V_1 + V_2}{2} = \frac{V_S + V_S}{2} \quad \dots(7)$$

$$= V_S$$

the output can be expressed as

$$V_o = A_c V_S \quad \dots (8)$$

$$A_c = \frac{V_o}{V_S} \quad \dots(8 (a))$$

But now both the emitter currents flows through R_E in the Same direction. Hence the total current flowing through R_E is $2I_e$. considering only one transistor, as in the figure 2.11.3

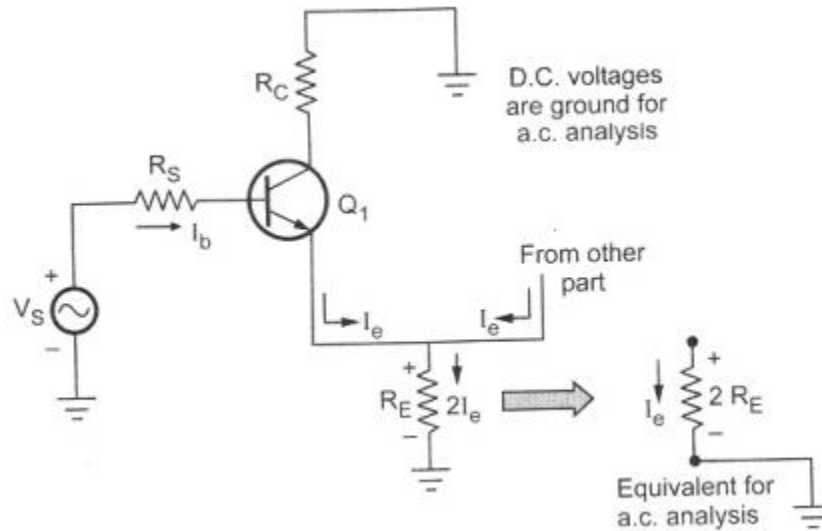


Figure 2.11.3 AC Equivalent for differential Operation and its hybrid model

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$$\begin{aligned}
 \therefore -\frac{I_L}{h_{oe}} + \frac{h_{fe}}{h_{oe}} I_b - 2R_E I_L - 2R_E I_b - I_L R_C &= 0 \\
 I_b \left[\frac{h_{fe}}{h_{oe}} - 2R_E \right] &= I_L \left[\frac{1}{h_{oe}} + 2R_E + R_C \right] \\
 I_b [h_{fe} - 2R_E h_{oe}] &= I_L [1 + h_{oe} (2R_E + R_C)] \\
 \frac{I_L}{I_b} &= \frac{[h_{fe} - 2R_E h_{oe}]}{[1 + h_{oe} (2R_E + R_C)]} \quad \dots (10)
 \end{aligned}$$

Substituting value of I_b , into the equation (8(b)), we get

$$\begin{aligned}
 V_S &= \frac{I_L [1 + h_{oe} (2R_E + R_C)] (R_S + h_{ie} + 2R_E)}{[h_{fe} - 2R_E h_{oe}]} + I_L (2R_E) \\
 \therefore \frac{V_S}{I_L} &= \frac{[1 + h_{oe} (2R_E + R_C)] (R_S + h_{ie} + 2R_E)}{[h_{fe} - 2R_E h_{oe}]} + (2R_E)
 \end{aligned}$$

Finding L.C.M. and adjusting the terms, we get

$$\therefore \frac{V_S}{I_L} = \frac{2 R_E (1 + h_{fe}) + R_S (1 + 2 R_E h_{oe}) + h_{ie} (1 + 2 R_E h_{oe}) + h_{oe} R_C [2 R_E + R_S + h_{ie}]}{[h_{fe} - 2 R_E h_{oe}]}$$

$$\therefore \frac{V_S}{I_L} = \frac{2 R_E (1 + h_{fe}) + (R_S + h_{ie}) (1 + 2 R_E h_{oe}) + h_{oe} R_C [2 R_E + R_S + h_{ie}]}{[h_{fe} - 2 R_E h_{oe}]} \quad \dots (11)$$

Neglecting the terms of $h_{oe} R_C$ as practically $h_{oe} R_C \ll 1$.

$$\therefore \frac{V_S}{I_L} = \frac{2 R_E (1 + h_{fe}) + (R_S + h_{ie}) (1 + 2 R_E h_{oe})}{[h_{fe} - 2 R_E h_{oe}]} \quad \dots (12)$$

Substituting the value of I_L , in the equation (9)

$$V_o = \frac{-V_S (h_{fe} - 2 R_E h_{oe}) R_C}{2 R_E (1 + h_{fe}) + (R_S + h_{ie}) (1 + 2 R_E h_{oe})}$$

Hence the common mode gain can be written as (absorbing negative sign),

$$A_c = \frac{V_o}{V_S} = \frac{(2 R_E h_{oe} - h_{fe}) R_C}{2 R_E (1 + h_{fe}) + (R_S + h_{ie}) (1 + 2 R_E h_{oe})} \quad \dots (13)$$

In practice h_{oe} is generally neglected hence the expression for A_c can be further modified as

$$\therefore \boxed{A_c = \frac{-h_{fe} R_C}{R_S + h_{ie} + 2 R_E (1 + h_{fe})}} \quad \dots (14)$$

Common Mode rejection Ratio (CMRR)

Once the differential and common mode gains are obtained, the expression for the CMRR can be obtained as,

$$\text{CMRR} = \left| \frac{A_d}{A_c} \right|$$

$$\therefore \text{CMRR} = \frac{R_S + h_{ie} + 2 R_E (1 + h_{fe})}{(R_S + h_{ie})} \quad \dots(15)$$

This is CMRR for ***dual input balanced output*** differential amplifier circuit.

