Analog & Digital Electronics

Course No: PH-218

Lec-21: Differential Amplifiers

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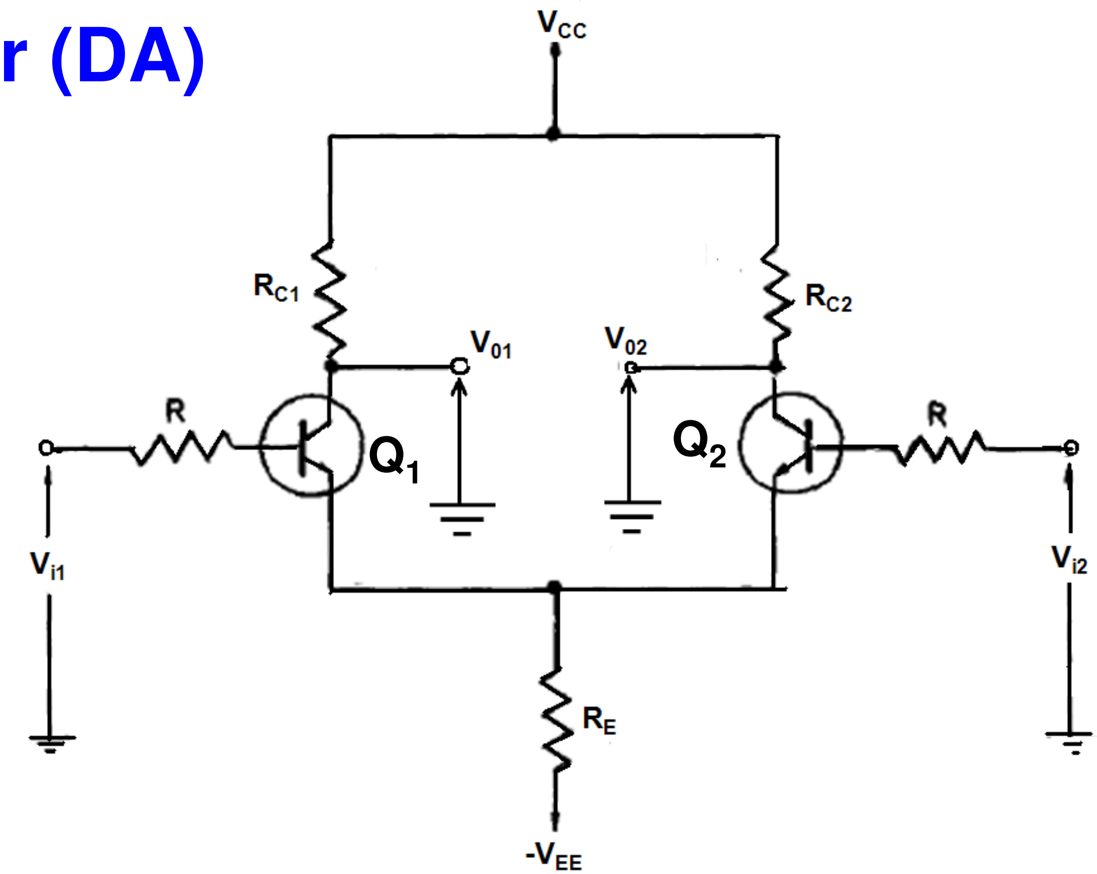
Differential amplifier (DA)

- A differential amplifier is a circuit that can accept two input signals and amplify the difference between these two input signals.

- Differential amplifier is a basic building block of an op-amp



The differential amplifier is a small signal amplifier. It is generally used as a voltage amplifier and not as current or power amplifier

Differential amplifier is a two input terminal device using at least two transistors. There are also two outputs terminals V_{o1} and V_{o2}.

Two transistor are matched so that they have identical characteristics. The collector resistance are also equal Rc1 = Rc2.

Differential amplifier

➢ Input signal can be applied by two ways –

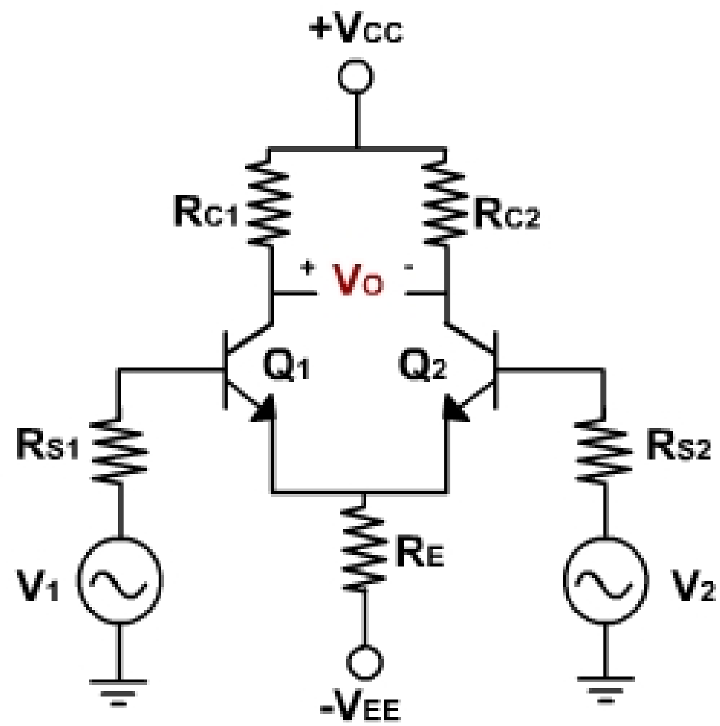
(a) Signal is applied to any one of the transistor and other input is grounded – single ended input arrangement

(b) Signals are applied to both the inputs of DA – double ended input arrangement

➢ Output signal can be taken from DA by two ways –

(a) Output signal is taken from any one of the output terminals and other output is groundec – single ended output arrangement

(b) Output signal is taken between two output terminals (between the collectors of Q1 and Q2) – double ended input arrangement



Generally Op-Amp is double ended input and single ended output device.

Operation of differential amplifier

➢ Suppose signal is applied to input 1 (the base of transistor Q1) and input 2 is grounded.

➢ Output of Q1 can be taken either at collector C (Q1 will act as a CE configuration) or emitter E (Q1 will work as a CC configuration).

➢ Output signal will be inverted and amplified at collector C of Q1

➢ Output signal will be non-inverted and of same magnitude as input signal at emitter E of Q1.

➢ If the output of Q1 is taken at emitter E – then this output will act as a input signal for transistor Q2 and Q2 will work as a CB configuration. Output of Q2 (CB configuration) is obtained at collector of Q2 (this will also be output of DA) and output signal will be non-inverted amplified signal.

Input at Q1
- **Inverted and amplified output at output 1 (Q1)**
- **Non-inverted and amplified output at output 2 (Q2)**

Input at Q2
- **Inverted and amplified output at output 2 (Q2)**
- **Non-inverted amplified output at output 1 (Q1)**

Operation of differential amplifier (DA)

- Since DA and Op-Amp both have single ended output and double ended input so we discuss operation of single ended output and double ended input device.

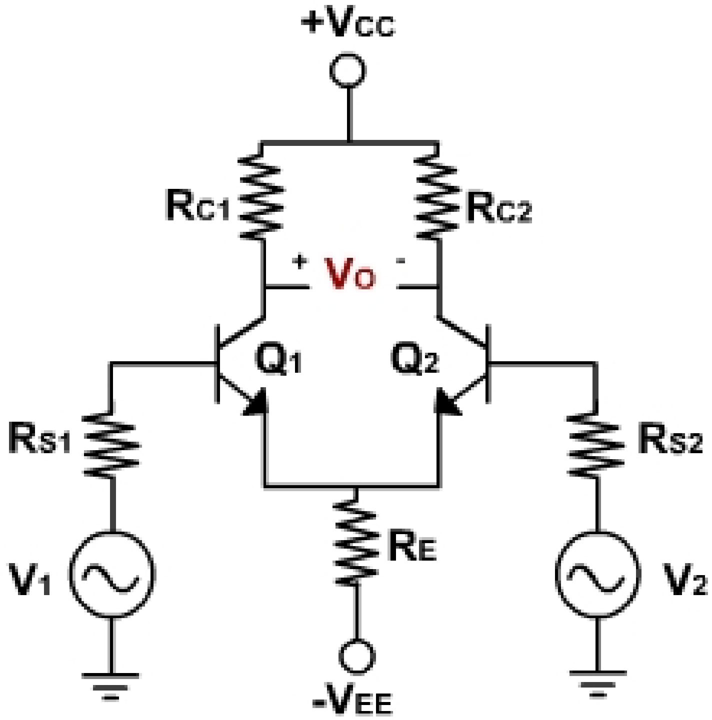
- Suppose output 2 is grounded and output of DA is taken at output 1. The input signal is applied either to input 1 or input 2 terminal.

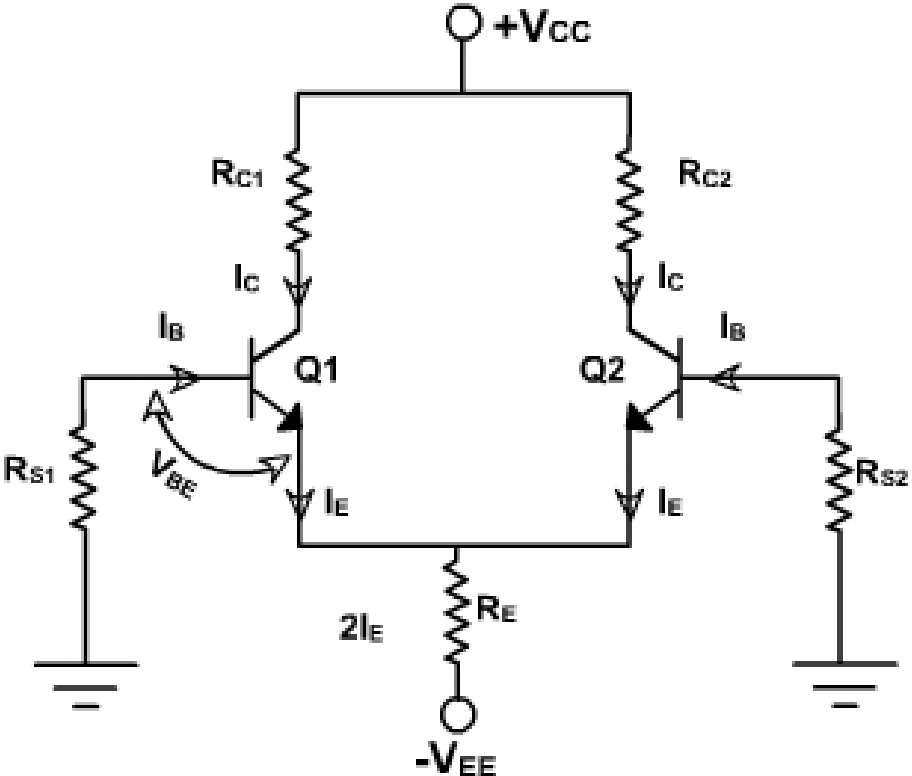
Input applied at	Output signal	Output taken at
Q1	Inverted amplified	Q1
Q2	Non-inverted amplified	Q1

- **If the signal applied to the input terminal results in opposite polarity output then input terminal is called inverting input, and if output is of same polarity as input then it is called non-inverting input.**

DC analysis of differential amplifier (DA)

Since both emitter biased sections of the DA are symmetrical in all respects, therefore, the operating point for only one section need to be determined.



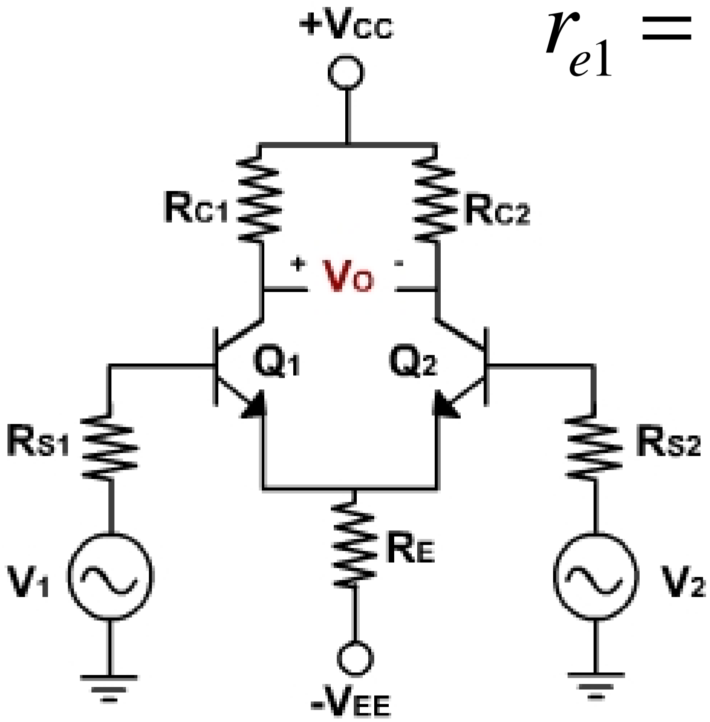


$$V_{BE} = V_B - V_E = 0.7; V_E = -0.7$$

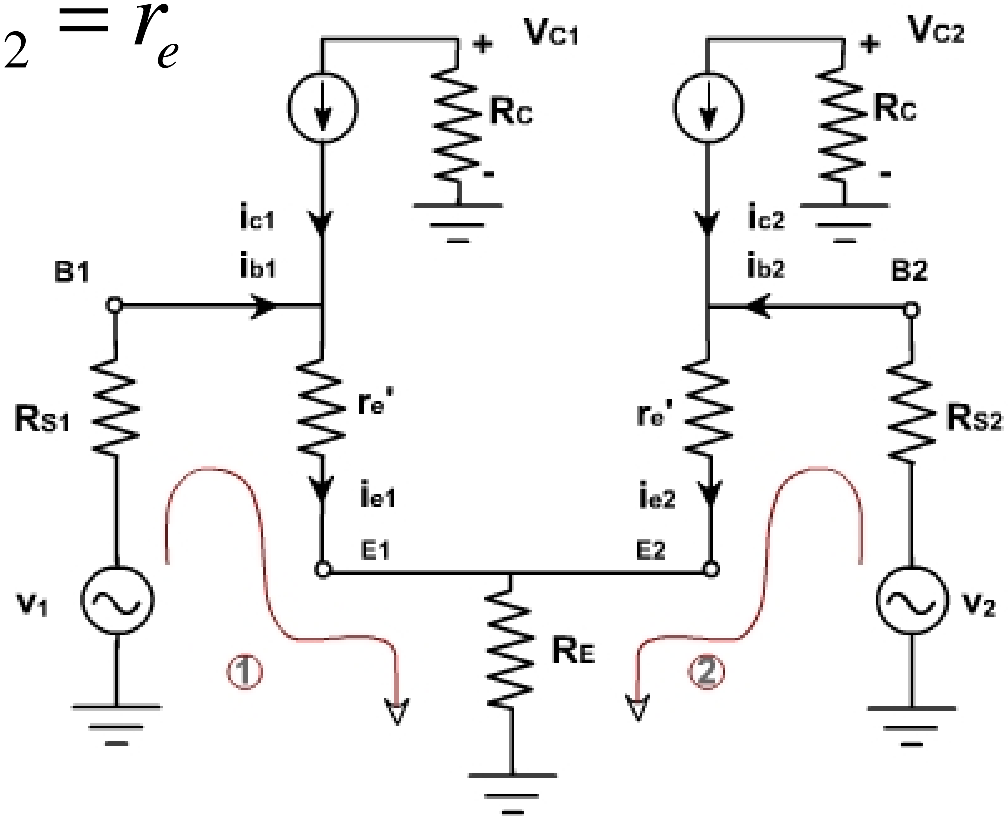
$$I_E = \frac{V_E - (-V_{EE})}{2R_E}$$

$$\boxed{I_E = \frac{V_{EE} - 0.7}{2R_E}} \qquad I_{C1} = I_{C2} = I_E \qquad \boxed{V_{C1} = V_{CC} - I_{C1}R_{c1}}$$

AC analysis of differential amplifier (DA)



$$r_{e1} = r_{e2} = r_e$$



Applying KVL in two loops 1 & 2.

$$v_1 = R_{s1} i_{b1} + r_e i_{e1} + R_E (i_{e1} + i_{e2}) \qquad i_{b1} = i_{e1} / \beta$$

$$v_2 = R_{s2} i_{b2} + r_e i_{e2} + R_E (i_{e1} + i_{e2}) \qquad i_{b2} = i_{e2} / \beta$$

AC analysis of differential amplifier (DA)

Putting value of i_{b1} and i_{b2} and assuming R_{S1} / β and R_{S2} / β are very small in comparison with R_E and r_e' and therefore neglecting these terms,

$$v_1 = (r_e + R_E)i_{e1} + R_E i_{e2} \qquad v_2 = (r_e + R_E)i_{e2} + R_E i_{e1}$$

$$i_{e1} = \frac{(r_e + R_E)v_1 - R_E v_2}{(r_e + R_E)^2 - R_E^2} \qquad i_{e2} = \frac{(r_e + R_E)v_2 - R_E v_1}{(r_e + R_E)^2 - R_E^2}$$

The output voltage V_O is given by: **Vo = V_{c2}-V_{c1} = $R_c(i_{c1}-i_{c2})$**

$$v_o = R_C(i_{e1} - i_{e2}) = \frac{R_C}{r_e}(v_1 - v_2)$$

For Single ended input: v_2 = 0; therefore $i_{e1} = v_1 / 2r_e$

$$v_o = \frac{R_C}{2r_e}(v_1)$$

Input & Output Resistance of DA

Differential input resistance is defined as the equivalent resistance that would be measured at either input terminal with the other terminal grounded. Resistance R_{S1} and R_{S2} are ignored because they are very small.

$$R_{i1} = \left(\frac{v_1}{i_{b1}}\right)_{v_{2=0}} = \frac{\beta v_1}{i_{e1}}$$

$$i_{e1} = \frac{(r_e + R_E)v_1}{(r_e + R_E)^2 - R_E^2}$$

$$R_{i1} = \frac{\beta r_e (r_e + 2R_E)}{(r_e + R_E)}$$

Since $R_E >> r_e$ hence

$$R_{i1} = 2\beta \times r_e$$

Output Resistance of DA

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. $R_{O1} = R_{O2} = R_C$

Common Mode Rejection Ratio (CMRR)

- **If the signals v_{i1} and v_{i2} at the input terminals are opposite, the output voltage is highly amplified and if v_{i1} and v_{i2} are same, they are only slightly amplified.**

- **Overall operation : To amplify the difference signal while rejecting the common signal at the two inputs**

- **Noise is common to both inputs so the DA attenuates this input.**

- **Two signals $v_{i1}$and v_{i2} in general have both in-phase and out-of-phase components. So the resulting output $V_0 = A_dV_d+A_cV_c$**

where A_d= Differential gain of the Amplifier
A_c = Common mode gain of the Amplifier
V_d= Difference voltage = $v_{i1} - v_{i2}$
V_c= Common voltage = = $(v_{i1} + v_{i2}) / 2$

Common Mode Rejection Ratio (CMRR)

CMRR is a measure of an amplifiers' ability to reject the common signals and defined as

$$\mathrm{CMRR} = \frac{|A_d|}{|A_c|}$$

$$\text{or,}\quad \mathrm{CMRR(log)} = 20\log_{10}\frac{|A_d|}{|A_c|}$$

$$\text{Now, } v_o = A_d v_d + A_c v_c$$

$$= A_d v_d\left(1 + \frac{A_c v_c}{A_d v_d}\right) \quad = A_d v_d\left(1 + \frac{A_c}{A_d}\frac{v_c}{v_d}\right)$$

$$= A_d v_d\left(1 + \frac{1}{\mathrm{CMRR}}\frac{v_c}{v_d}\right)$$

The higher the CMRR , the better is DA.

Operational amplifier (OP-AMP)

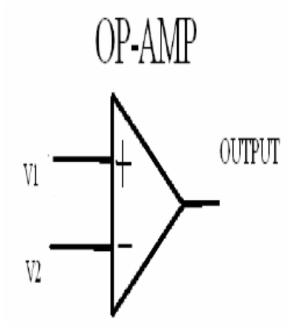
- An Op-Amp is a very high gain differential amplifier with very high input impedance (typically a few Mega ohm) and a low output impedance (less than 100Ω)

- Earlier, op-amp were used primarily to perform mathematical operation such as summation, subtraction, differentiation and integration etc. so named as op-amp.

- Typical application of op-amp includes – voltage amplitude change, oscillators, filter circuits and in instrumentation circuits.

- An Op-Amp have two inputs terminal called inverting (-ve terminal) and noninverting input (+ve terminal) and one output terminal.

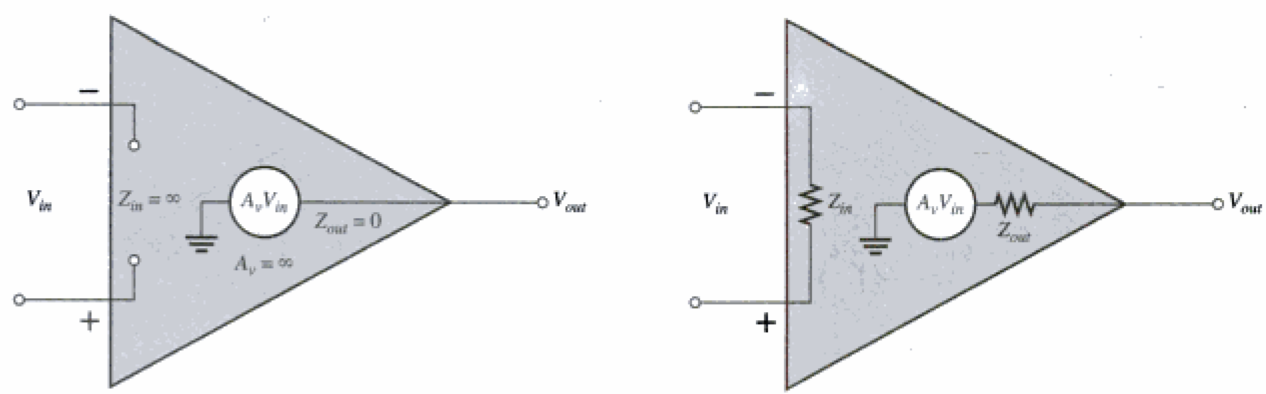
- If the signal applied to the input terminal, results in opposite polarity output then input terminal is called inverting input, and if output is of same polarity input terminal is called non-inverting input.



Characteristics of an Ideal Operational amplifier

Ideal op-amp has following characteristics -

- **Input Resistance Ri= ∞**
- **Output Resistance Ro= 0**
- **Voltage Gain A = ∞**
- **Bandwidth = ∞**
- **Perfect balance i.e vo= 0 when v1= v2**
- **Characteristics do not drift with temperature**



(a) Ideal op-amp representation (b) Practical op-amp representation