Part : B

Operational amplifier

Question-1: What is operational amplifier?

Answer: An operational amplifier is an circuit that can perform ~~such~~ mathmetical operation such as addition, substraction integrator and differentiator.

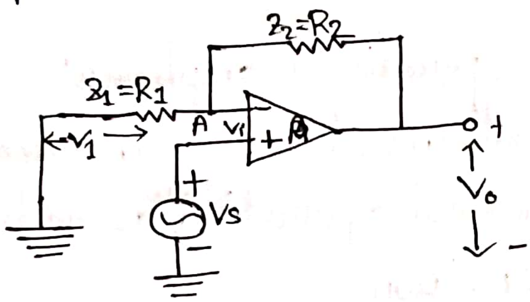
Question-2: Write down the application of ~~an~~ op-amp.

Answer: Operational amplifier has many different applica

They are:

(I) As inverting amplifier
(II) As non-inverting amplifier
(III) As differentiator
(IV) As integrator
(V) As phase shifter
(VI) As scale changer
(VII) As adder or summing amplifier
(VIII) As voltage or current converter.

⇒ Voltage gain of non-inverting amplifier:



If we assume that we are not at saturation, the potential at point A is the same as Vin. Since the input impedence of op-amp is high. All of the current that flows through R_2 also flows through R_1. We have

Voltage across $R_1 = V_{in} - 0$

" " $R_2 = V_{out} - V_{in}$

Now,

$$A = \frac{V_o}{V_1 - V_s}$$

$$\Rightarrow V_1 - V_s = \frac{V_o}{A}$$

$$\Rightarrow V_1 - V_s = 0$$

$$\Rightarrow V_1 = V_s$$

$$V_1 = \frac{V_o}{R_1 + R_2} \cdot R_1$$

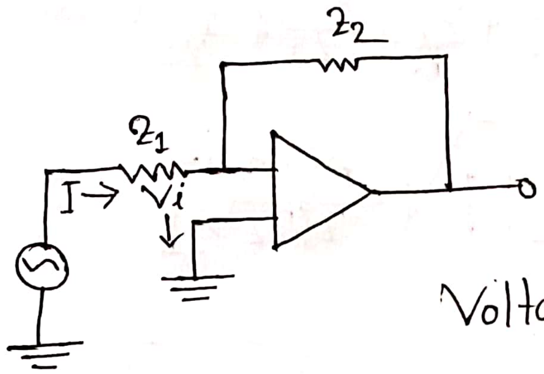
$$V_1 = V_S = \frac{V_o}{R_1 + R_2} \times R_1$$

$$\therefore V_S = \frac{V_o \cdot R_1}{R_1 + R_2}$$

$$\Rightarrow \frac{V_S}{V_o} = \frac{R_1}{R_1 + R_2}$$

$\therefore A = 1 + \frac{R_1}{R_2}$ which is the gain of a non-inverting operational amplifier.

⇒ Voltage gain of an inverting op-amp:



$$\text{Voltage gain } |A| = \frac{V_o}{V_i}$$

Current I flowing through Z_1 will also flow through Z_2

Thus current through Z_1 is $I = \frac{V_S - V_i}{Z_1}$

Current through Z_2 is $I = \frac{V_i - V_o}{Z_2}$

$$\therefore \frac{V_S - V_i}{Z_1} = \frac{V_i - V_o}{Z_2}$$

$$\Rightarrow \frac{V_S}{Z_1} - \frac{V_i}{Z_1} = \frac{V_i}{Z_2} - \frac{V_o}{Z_2}$$

$$\Rightarrow \frac{V_o}{Z_2} = \frac{V_i}{Z_2} + \frac{V_i}{Z_1} - \frac{V_s}{Z_1}$$

$$\Rightarrow \frac{V_o}{Z_2} = V_i\left(\frac{1}{Z_2} + \frac{1}{Z_1}\right) - \frac{V_s}{Z_1}$$

$$\Rightarrow \frac{V_o}{Z_2} = \frac{-V_o}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right) - \frac{V_s}{Z_1}$$

[since $A = \frac{-V_o}{V_i}$ so $V_i = -\frac{V_o}{A}$]

$$\Rightarrow \frac{V_o}{Z_2} + \frac{V_o}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right) = \frac{-V_s}{Z_1}$$

$$\Rightarrow V_o\left\{\frac{1}{Z_2} + \frac{1}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)\right\} = \frac{-V_s}{Z_1}$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{-1}{Z_1\left[\frac{1}{Z_2} + \frac{1}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)\right]}$$

$$= \frac{-1}{Z_1 \cdot \frac{1}{Z_2} + \frac{Z_1}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)}$$

$$\cancel{= \frac{-1}{\frac{Z_1}{Z_2}\left[1 + \frac{1}{A}\left(\frac{Z_2 + Z_1}{Z_1 Z_2}\right)\right]}}$$

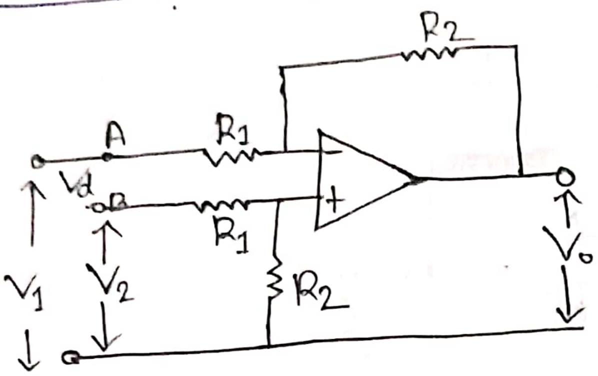
$$= \frac{-1}{Z_1 \cdot \frac{1}{Z_2} + \frac{Z_1}{A}\left(\frac{Z_1 + Z_2}{Z_1 Z_2}\right)}$$

$$= \frac{-1}{\frac{Z_1}{Z_2}\left[1 + \frac{1}{A}\left(1 + \frac{Z_2}{Z_1}\right)\right]}$$

$$\therefore \frac{V_o}{V_s} = -\frac{Z_2}{Z_1}$$

which is the gain of inverting op-amp.

⇒ Differential amplifier:



The voltage $e_2 = \left(\frac{R_2}{R_1+R_2}\right)V_2$. Here $\frac{R_2}{R_1+R_2}$ is termed as the transfer function T(s) of the network involving R_1 and R_2 at the terminal 2. Similarly by the principle of superposition, the voltage at the inverting input terminal 1, is

$$e_1 = \left(\frac{R_2}{R_1+R_2}\right)\cdot V_1 + \frac{R_1}{(R_1+R_2)}\cdot V_o$$

$$e_1 = e_2$$

$$\left(\frac{R_2}{R_1+R_2}\right)\cdot V_1 + \left(\frac{R_1}{R_1+R_2}\right)\cdot V_o = \left(\frac{R_2}{R_1+R_2}\right)V_2$$

$$\Rightarrow \frac{1}{R_1+R_2}\left(R_2 V_1 + R_1 V_o\right) = \frac{1}{R_1+R_2}\left(R_2 \cdot V_2\right)$$

$$\Rightarrow R_2 V_1 + R_1 V_o = R_2 V_2$$

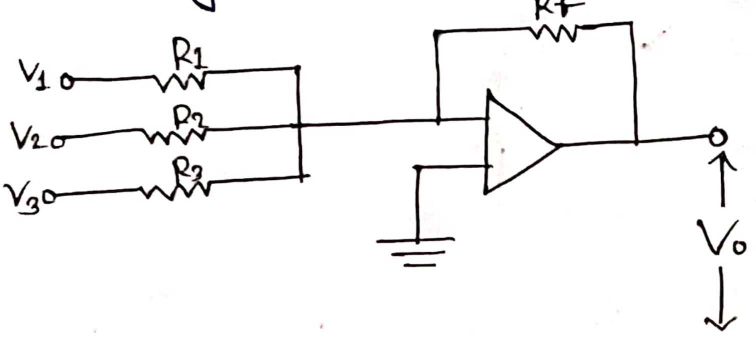
$$\Rightarrow R_1 \cdot V_o = R_2 V_2 - R_2 V_1$$

$$\Rightarrow R_1 V_o = R_2(V_2 - V_1)$$

$$\therefore V_o = \frac{R_2}{R_1}(V_2 - V_1) = \frac{R_2}{R_1}\cdot V_d \qquad \left[\text{Here, } V_2 - V_1 = V_d\right]$$

⇒ Application of operational amplifier:

① Summing amplifier/adder:



It is the same as the inverting amplifier except that it has several input terminals. Virtual ground exists at the inverting terminal due to feedback and the input current to the ideal amplifier is zero. Thus the current equation for the node at the inverting terminal is,

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_o}{R_f}$$

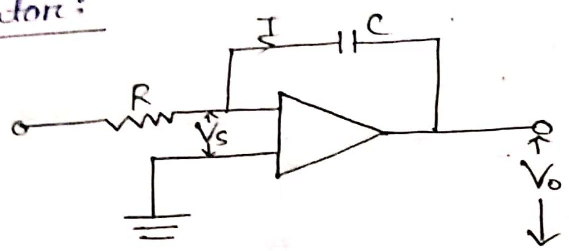
$$\Rightarrow \left\{ \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right\} R_f = -V_o$$

$$\Rightarrow \left\{ \frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} \right\} R_f = -V_o \qquad [\text{if } R_1 = R_2 = R_3 = R]$$

$$\Rightarrow \frac{R_f}{R}(V_1 + V_2 + V_3) = -V_o$$

$$\therefore V_o = \frac{-R_f}{R}(V_1 + V_2 + V_3)$$

(11) Integrator :



In this inverting amplifier feedback resistor R_2 is replaced by a capacitor C. Feedback through the capacitor forces a virtual ground to exist at the inverting input terminal. It means voltage across C is simply the output voltage V_o.
We can write,

$$V_o(t) = \frac{-q}{C}$$

$$\cancel{= -q\int}$$

$$= -\frac{1}{C}\int I\,dt$$

$$I = \frac{dq}{dt}$$

$$dq = I\,dt$$

$$q = \int I\,dt$$

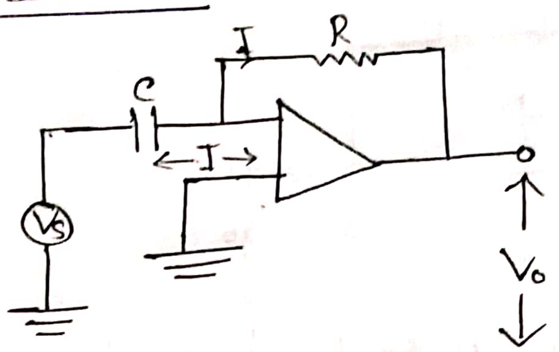
Input current to the ideal amplifier is zero

$$I = \frac{V_S(t)}{R}$$

$$\therefore V_o(t) = -\frac{1}{C}\int \frac{V_S(t)}{R}\,dt$$

$$\therefore V_o(t) = \frac{-1}{CR}\int V_S(t)\,dt$$

(iii) Differentiator:



In inverting operation amplifier, we replace the input resistance by a capacitor to design a differentiator. Because of virtual ground at the inverting terminal, we have,

$$I = \frac{dq}{dt}$$

$$= \frac{d}{dt}(CV_s)$$

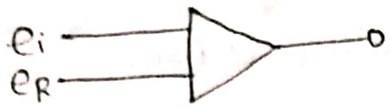
$$= C\frac{dV_s}{dt}$$

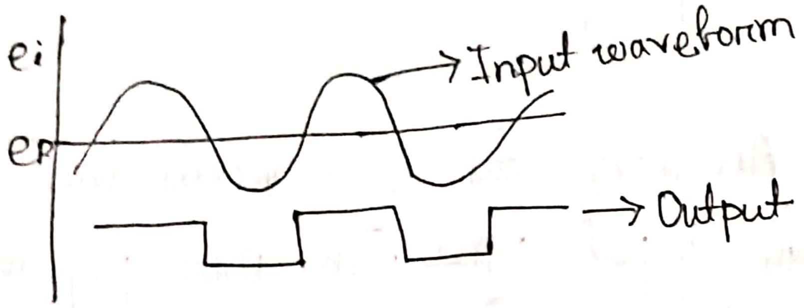
~~Vo~~ The output voltage,

$$V_o = -IR$$

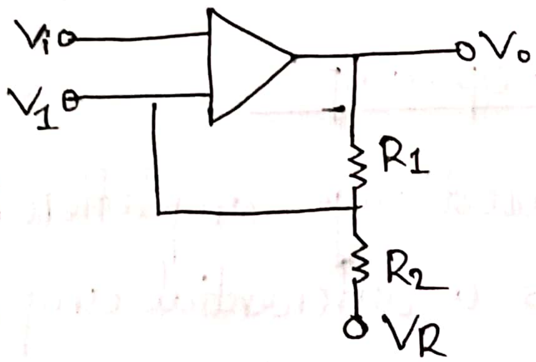
$$= -RC\frac{dV_s}{dt}$$

(iv) Comparator: The function of voltage comparator is to compare ~~function~~ the time varying voltage at one input with a fixed reference voltage on the other.





(v) Schmitt tigger:



(a) For $V_i < V_1$ and $V_o = +V_o$

$$V_1 = \left(\frac{R_1}{R_1+R_2}\right)V_R + \left(\frac{R_2}{R_1+R_2}\right)V_o$$

(b) For $V_i > V_1$

$$V_2 = \left(\frac{R_1}{R_1+R_2}\right)V_R - \left(\frac{R_2}{R_1+R_2}\right)V_o$$

(i) **Differentiator:** A differentiator is a circuit that performs differentiation of the input signals. A differentiator produces an output voltage that is proportional to the rate of change of the input voltage. It's important application is to produce a rectangular output ~~form~~ from a ramp input.

(ii) **Integrator:** An integrator is a circuit that performs integration of the input signal. The most popular application of an integrator is to produce a ramp output voltage.

⇒ **Characteristics of op-amp:**

(i) An op-amp is a multistage amplifier. The input stage of an op-amp is a differential amplifier stage.

(ii) An inverting input and non-inverting output.

(iii) A high input impedence as both input

(iv) A low output impedence ($<200\Omega$)

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(v) A large open-loop voltage gain

(vi) The voltage gain remain constant over a wide frequency range.

(vii) Very large CMRR (> 90dB).