* Operational Amplifiers (Op-Amp)

An operational amplifier is a direct-coupled high gain amplifier that can be used to amplify dc as well as ac input signals. Along with amplification it can also perform mathematical operations on in the input signals. Hence the name operational amplifier and abbreviated as Op-Amp.

Op-amp symbol and terminals.

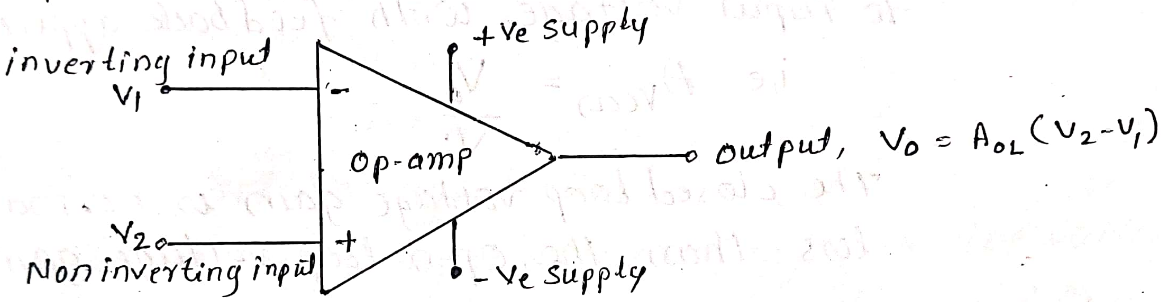


Fig.. symbol for op-amp.

The input at inverting terminal results in a opposite polarity output while the input at noninverting terminal results in the same polarity output. The op-amp works on a dual supply. i,e +ve and -ve supply with same magnitude. Ex: ±15V, ±9V, ±12V.

Basically, the op-amp is a differtial amplifier. It amplify the difference between two input voltage signals. i,e $V_0 \propto (V_2 - V_1)$.

* Operational amplifier parameters.

1) open loop gain ($A_{V(OL)}$)

The open loop voltage gain of an op-amp is defined as the ratio of output voltage to input voltage measured with no feed back applied

i.e $$A_{V(OL)} = \frac{V_0}{V_i}$$

open loop voltage gain may be thought of as the internal voltage gain of the device

The open-loop gain is often expressed in decibels (dB) rather than as a ratio. In this case

i.e. $A_{V(OL)} = 20 \log_{10}\left(\frac{V_o}{V_i}\right)$ dB.

2) Closed-loop voltage gain ($A_{V(CL)}$).

The closed-loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage with feedback applied.

i.e $A_{V(CL)} = \frac{V_o}{V_i}$

The closed loop voltage gain is normall very much less than the open-loop voltage gain.

Ex: An operational amplifier operating with -ve feedback produces an output voltage of 2V, when supplied with an input of 400 μV. Determine the value of closed loop voltage gain.

Soln: We know that

$$A_{V(CL)} = \frac{V_o}{V_i} = \frac{2}{400\times10^{-6}} = 5000$$

expressed in decibels this is,

$$A_{V(CL)} = 20 \log_{10}(5000) = 20\times3.7$$
$$= 74 \text{ dB}.$$

3) Input resistance (R_{in})

The input resistance of an op-amp is defined as the ratio of input voltage to input current expressed in ohms.

i.e. $R_{in} = \frac{V_i}{I_i}$

Where $V_i \rightarrow$ input voltage & $I_i \rightarrow$ Input current.

Ex: An op-amp has an input resistance of $2M\Omega$. Determine the input current when an input voltage of 5 mV is present

Sol: W.K.T, $R_{in} = \frac{V_i}{I_i} \Rightarrow I_i = \frac{V_i}{R_{in}} = \frac{5\times10^{-3}}{2\times10^{6}} = 2.5\times10^{-9}A$

$\therefore I_i = 2.5 nA$..

4) Output resistance. (R_{out}):

The output resistance of an operational amplifier is defined as the ratio of open-circuit voltage at output to short circuit output current expressed in ohm.

i.e $R_{out} = \frac{V_{o(oc)}}{I_{o(sc)}}$

5) Input offset voltage. (V_{io})

Input voltage (input offset voltage) is the voltage that must be applied between the two input terminals such that output voltage becomes zero

Typical value of V_{io} is between 1mv to 15mv.

6) Bandwidth.

It the range of frequencies overwhich the amplifier provides uniform gain with-out any distortion. It is given by.

Bandwidth $= f_2 - f_1$

Where $f_2 \rightarrow$ upper cutoff frequency

$f_1 \rightarrow$ Lower cutoff frequency.

7) Slew rate

Slew rate is the rate of change of output voltage with time.

$\therefore$ slew rate $= \frac{\Delta V_{out}}{\Delta t}$

* Operational amplifier Characteristics.

Desirable characteristics for ideal operational amplifier

1) The open-loop voltage gain should be very high (for ideal op-amp, it will be infinite, i.e ∞).

2) The input resistance should be very high (ideally infinite, i.e ∞)

3) The output resistance should be very low (ideally zero). i.e 0

4) Bandwidth (full power bandwidth) should be as wide as possible (ideally infinite. i.e ∞).

5) slew rate should be as large as possible (ideal value is infinite, i.e ∞).

6) Input offset voltage should be as small as possible (ideal value should be zero. i.e 0).

Comparison of op-amp parameters for "ideal" and "real" devices.

parameter	Ideal	Real
voltage gain	infinite.	100,000
Input resistance	Infinite.	100 MΩ
output resistance.	Zero	20 Ω
Bandwidth	Infinite	2 MHz.
slew rate	Infinite	10 V/μs.
Input offset voltage	Zero	Less than 5mV

Ex: A perfect rectangular pulse is applied to the input of op-amp. It takes 4 μs for the output voltage to change from −5V to +5V. Determine the slew rate of the device.

Soln:

$$\text{slew rate} = \frac{\Delta V_{out}}{\Delta t} = \frac{5-(-5)}{4\times10^{-6}} = \frac{10}{4\times10^{-6}} = 2.5\,V/\mu s$$

Ex: A wideband operational amplifier has a slew rate of 15 V/μs. If an amplifier is used in a circuit with a voltage gain of 20 and a perfect step input of 100 mV is applied to its input. Determine the time taken for the output to change level.

Soln: The output voltage change $= 20\times100\,mV = 2000\,mV$

$= 2V$

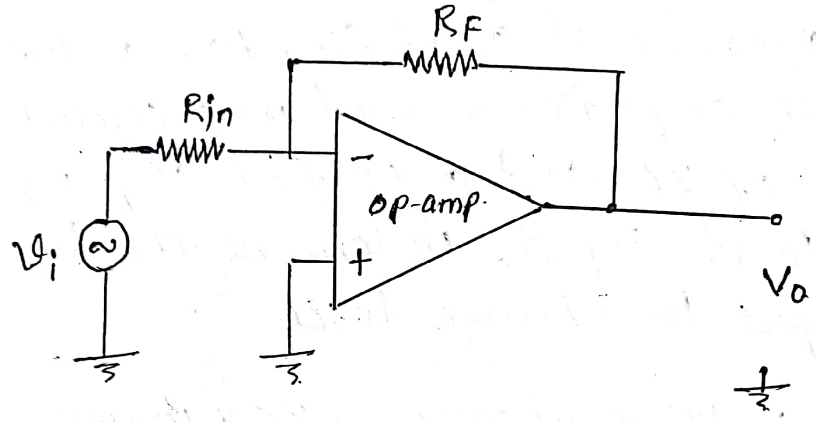
$$\therefore \text{slew rate} = \frac{\Delta V_{out}}{\Delta t}$$

$$\Rightarrow \Delta t = \frac{\Delta V_{out}}{\text{slew rate}} = \frac{2V}{15\,V/\mu s} = 0.133\,\mu s.$$

Operational amplifier Configurations.

The three basic configurations for operational voltage amplifiers with the expressions for their voltage gain are as follows.

1) Inverting amplifier.



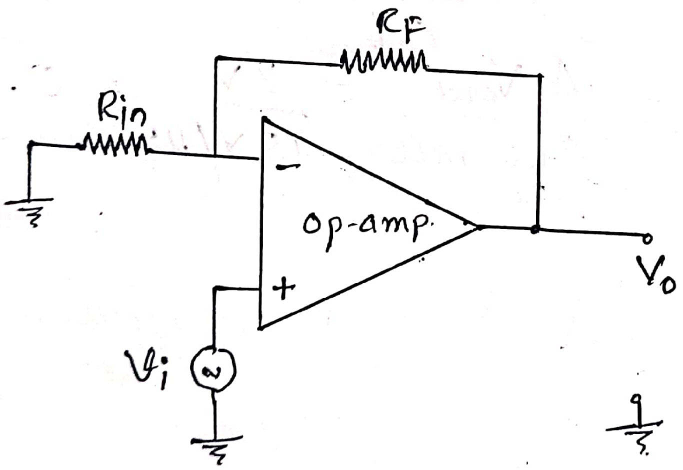
$V_o = -A_F V_i$

where

$A_F = \frac{R_F}{R_{in}}$

Voltage gain.

2) Non-Inverting amplifier



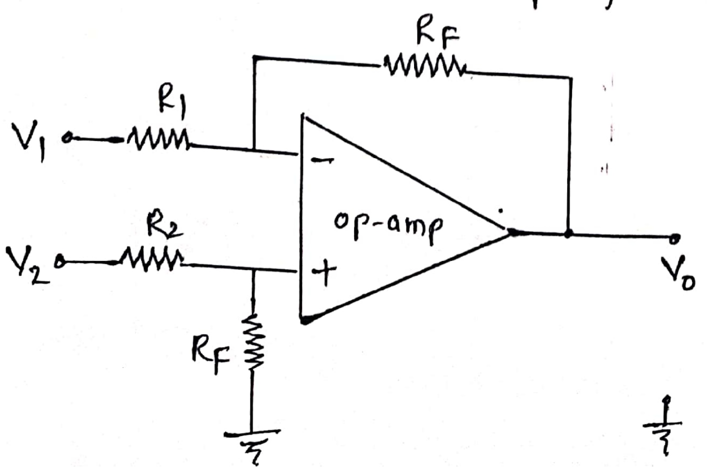
$V_o = A_F V_i$

where

$A_F = \left(1 + \frac{R_F}{R_{in}}\right)$

Voltage gain

3) Differential amplifier.



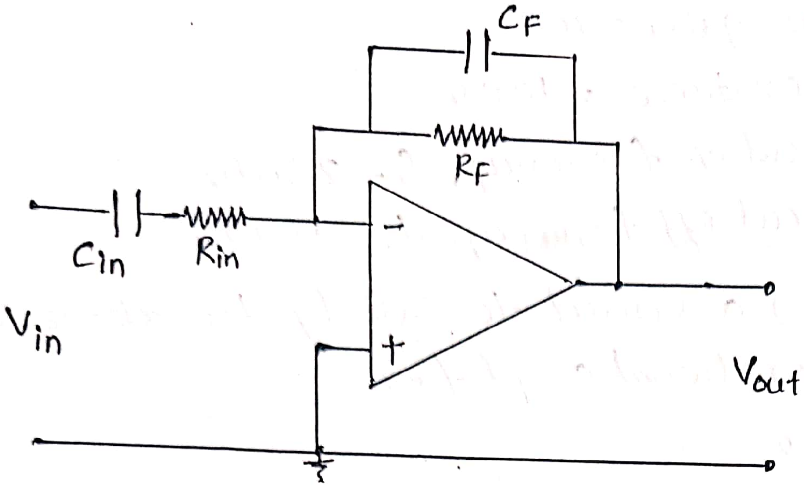
$V_o = A_F (V_2 - V_1)$

where

$A_F = \frac{R_F}{R_1}$

Voltage gain

To have smooth frequency roll-off capacitors included in the circuit of inverting amplifier as shown in fig.



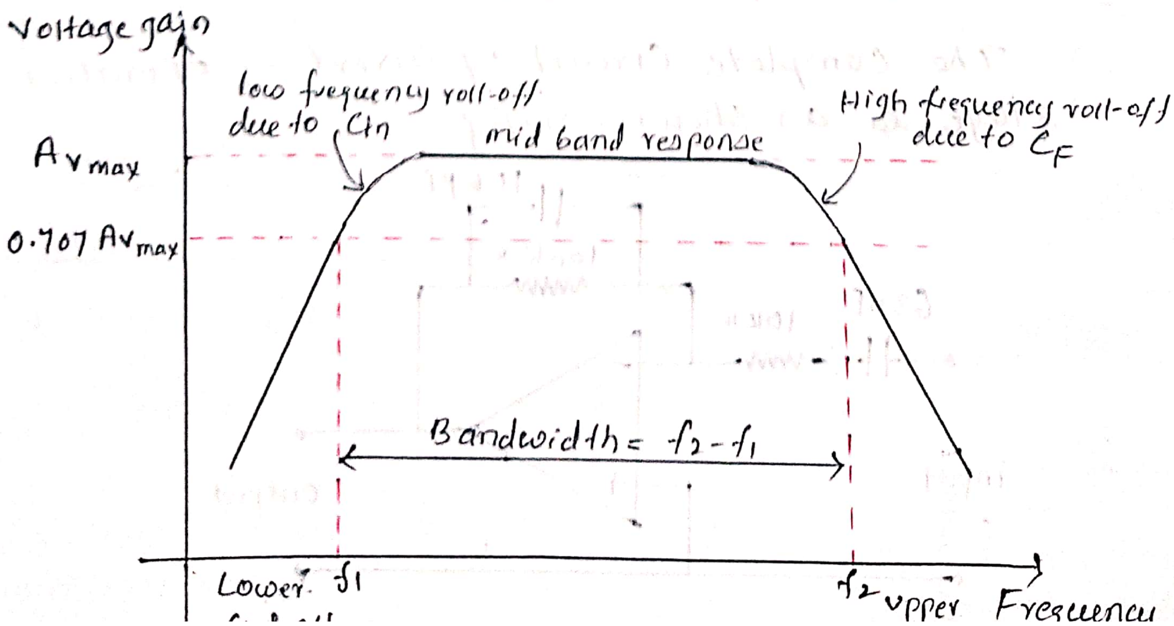
By selecting appropriate values of capacitors, the frequency response of inverting amplifier may be very easily tailored to suit the requirements. In frequency response lower cut-off frequency f_1 is determined by C_{in} and R_{in}

$$\therefore f_1 = \frac{1}{2\pi C_{in} R_{in}} = \frac{0.159}{C_{in} R_{in}}$$

and upper cut-off frequency f_2 is determined by C_F and R_F.

$$\therefore f_2 = \frac{1}{2\pi C_F R_F} = \frac{0.159}{C_F R_F}$$

The effect of these two capacitors on an op-amp frequency response is shown in fig. below.



Ex: An inverting op-amp is to operate according to the following specification.

Voltage gain = 100

input resistance = $10 k\Omega$

Lower cut-off frequency, $f_1 = 250 Hz$

Upper cut-off frequency, $f_2 = 15 KHz$

Devise (design) a circuit to satisfy the above specification using an operational amplifier.

Sol^n:

$R_{in} = 10 k\Omega$.

$A_V = A_F = \frac{R_F}{R_{in}} \Rightarrow R_F = R_{in} \times A_V = 10 \times 100 = 100 k\Omega$.

$\therefore R_F = 100 k\Omega$.

To determine C_{in}, we know that

$f_1 = \frac{0.159}{C_{in} R_{in}} \Rightarrow C_{in} = \frac{0.159}{f_1 R_{in}} = \frac{0.159}{250 \times 10 \times 10^3}$

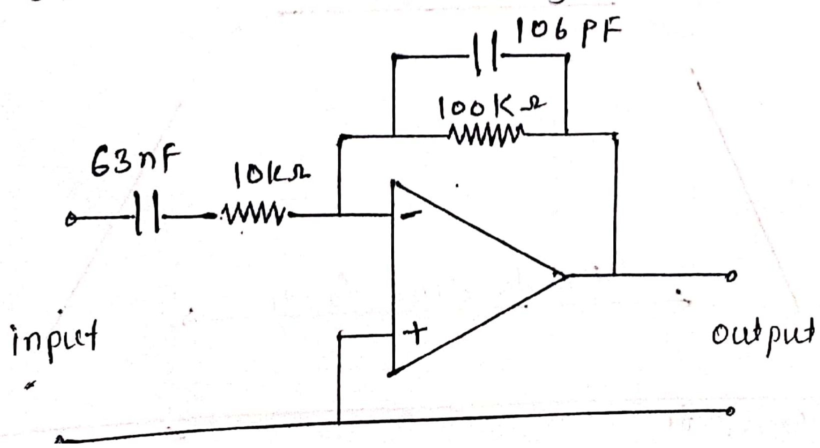
$\therefore C_{in} = 63 \times 10^{-9} F = 63 nF$.

To determine C_F, WKT.

$f_2 = \frac{0.159}{C_F R_F} \Rightarrow C_F = \frac{0.159}{f_2 R_F} = \frac{0.159}{15 \times 10^3 \times 100 \times 10^3}$

$\therefore C_F = 0.106 \times 10^{-9} F = 106 pF$.

The complete circuit of inverting operational amplifier stage is as shown in fig.



Operational amplifier Circuits.

Operational amplifiers (op-amp) have a number of uses (applications), including voltage followers, differentiators, integrators, Comparators and summing amplifiers.

1) Voltage follower.

A voltage follower using an op-amp is shown in fig.

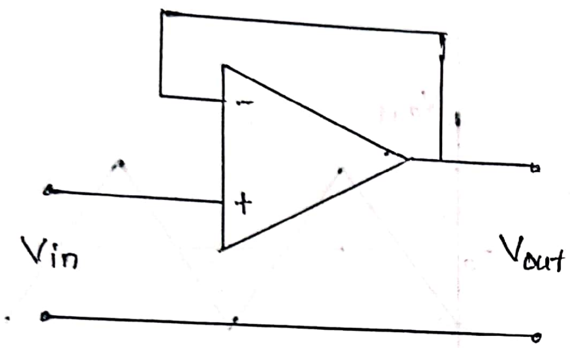


Fig. Voltage follower.

$$V_{out} = V_{in}$$

Output voltage follows input

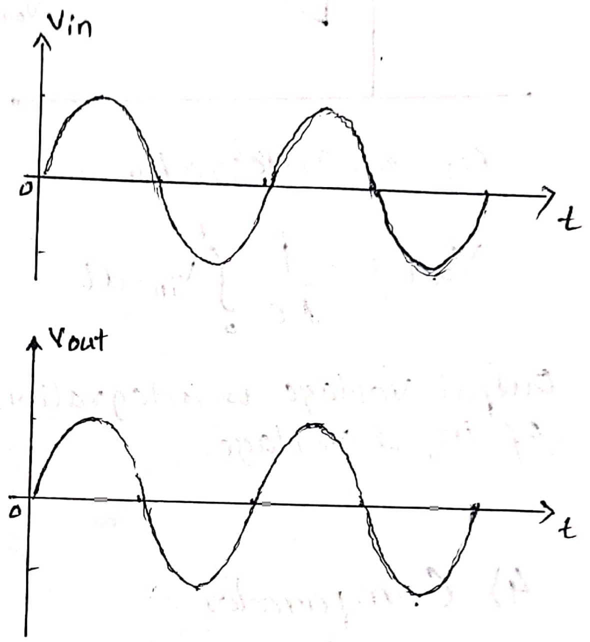


Fig. Input and output waveforms.

2) Differentiator.

A differentiator using an op-amp is shown in fig.

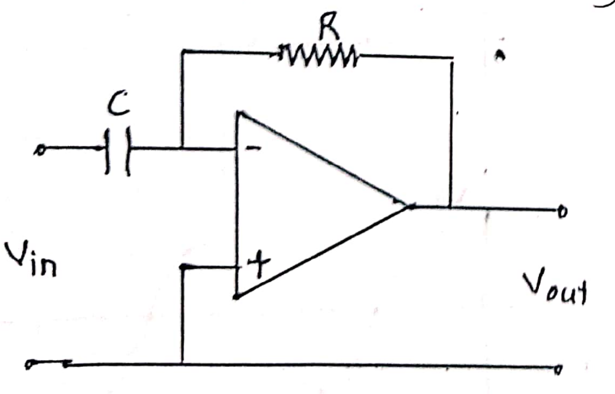


Fig. Differentiator

$$V_{out} = -CR\frac{dV_{in}}{dt}$$

output voltage is differentiation of input voltage.

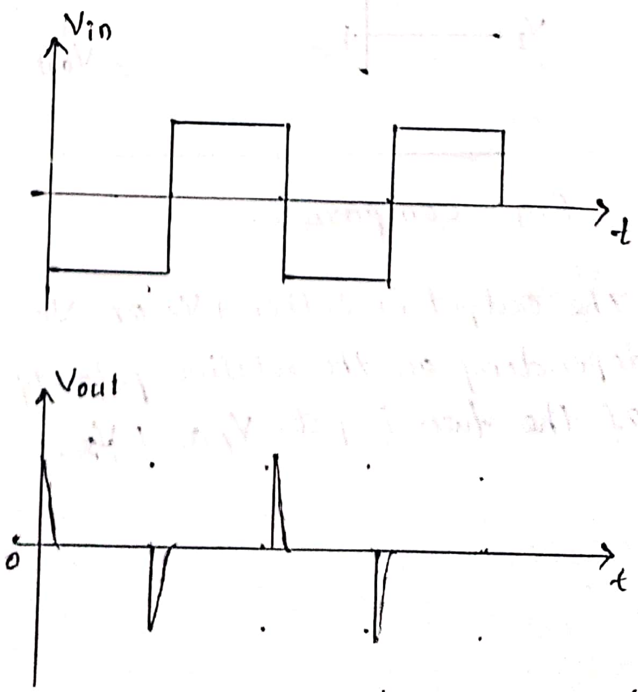


Fig. Input and output waveforms.

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3) Integrator.

An integrator using an op-amp is shown in fig.

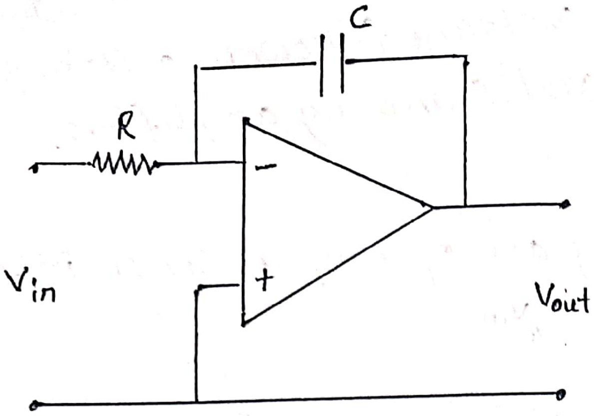


Fig. An Integrator

$$V_{out} = -\frac{1}{RC}\int_0^t V_{in} \cdot dt.$$

Output voltage is integration of input voltage.

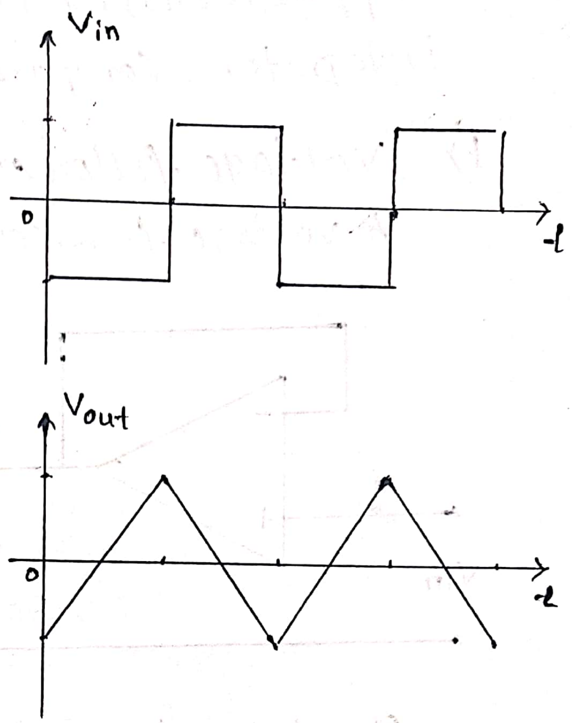


Fig. Input and output voltage waves

4) Comparator.

A Comparator using an op-amp is shown in fig.

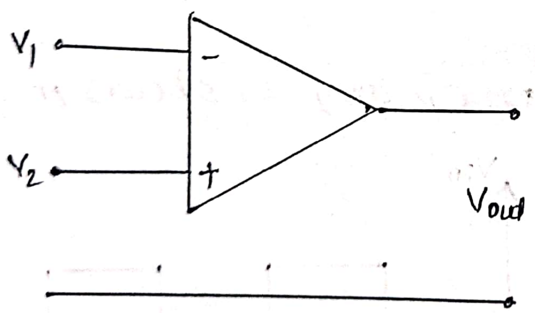
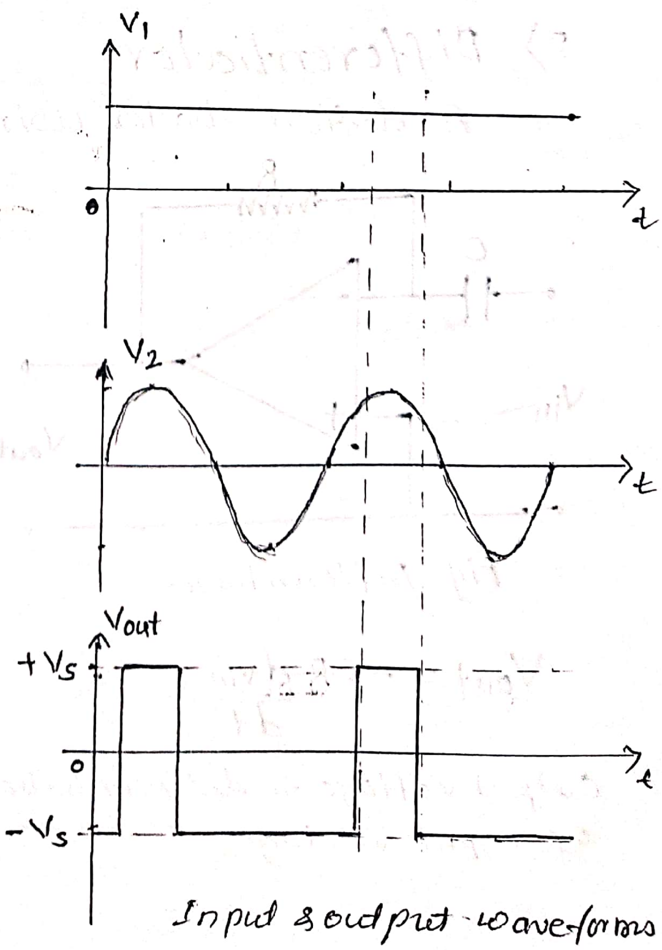


Fig. Comparator

The output is either $+V_s$ or $-V_s$ depending on the relative polarity of the two inputs V_1 and V_2.



Input & output waveforms.

5) Summing amplifier (adder).

A summing amplifier using an operational amplifier is as shown in fig.

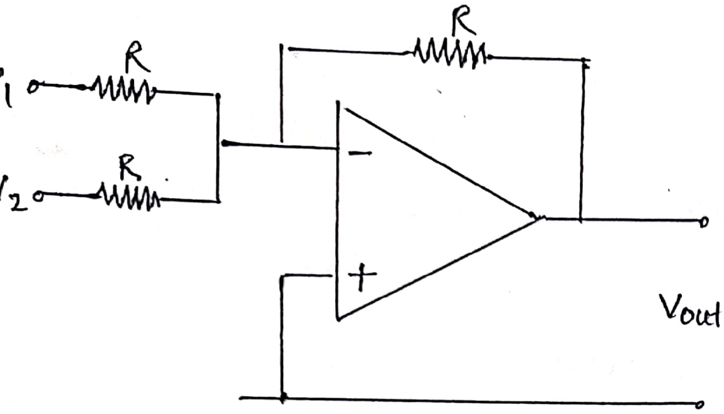


Fig. A summing amplifier

$V_{out} = -(V_1 + V_2)$

The typical application is that of 'mixing' two input signals to produce an output voltage that is the sum of the two.

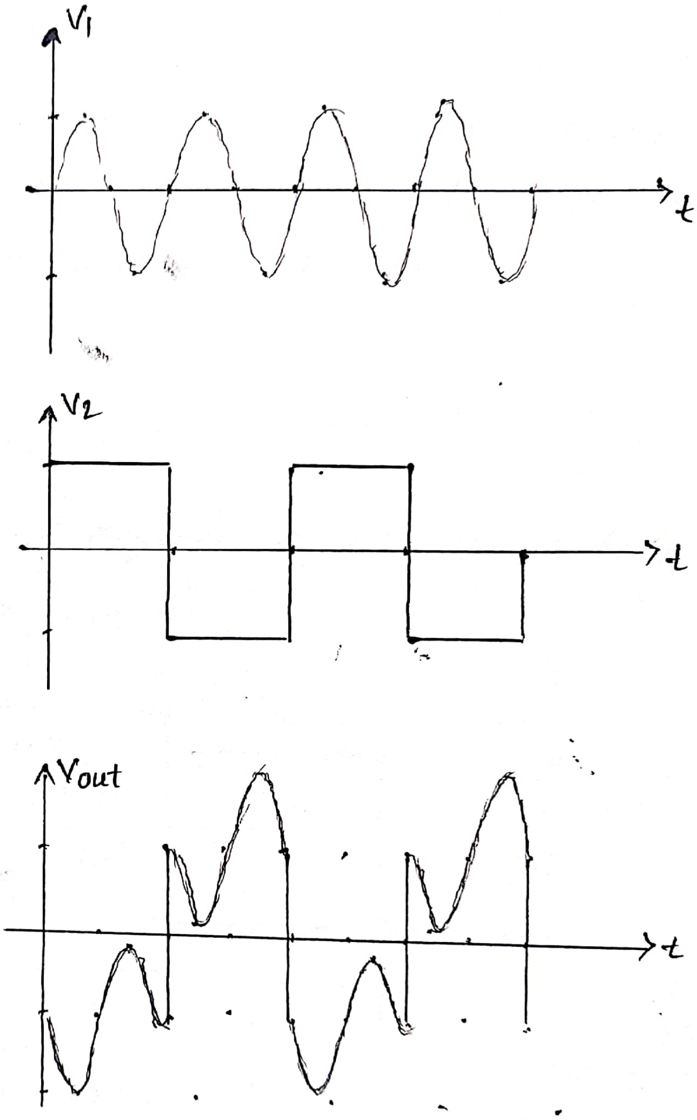


Fig. Input and output waveforms.