SUBJECT-BASIC ELECTRONICS ENGINEERING

TOPIC-OPERATIONAL AMPLIFIER

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OPERATIONAL AMPLIFIER

Operational Amplifier (OP-Amp)

An operational amplifier is a very high gain amplifier having very high input impedance (in mega-ohms) and low output impedance (less than 150 Ω).

The operational amplifier amplify the signal and also perform the mathematical operation like addition, subtraction, integration etc, that's why it is named as op amp.

The basic op-amp ckt is shown in fig 1.

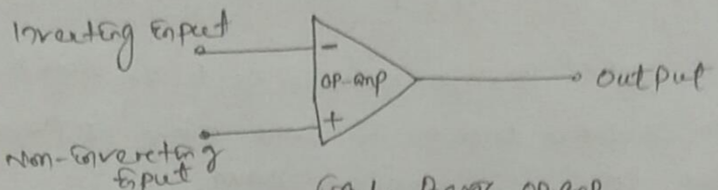

fig 1. Basic op-amp

It has two input. (i) inverting (ii) Non-inverting.

→ The (+) input produces an output that is in phase with the input signal applied, whereas an input to the (−) terminal results in an opposite-polarity output.

Ideal characteristics of op-amp :-

1) voltage gain (Av) is infinite.
2) input impedance is infinite.
3) input offset voltage is zero.
4) output voltage range is infinite.
5) Bandwidth is infinite.
6) slew rate is infinite.
7) output impedance is zero.
8) common mode rejection ratio (CMRR) is infinite.

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Basic op-Amp.

The basic ckt connection using op-amp is shown in fig 2.

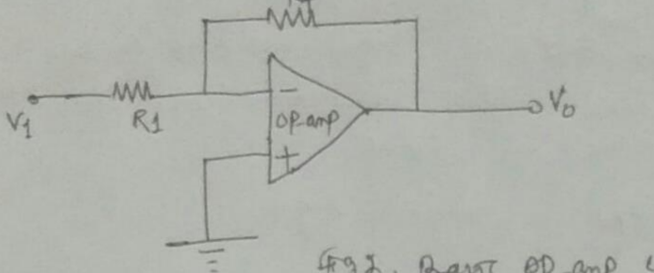
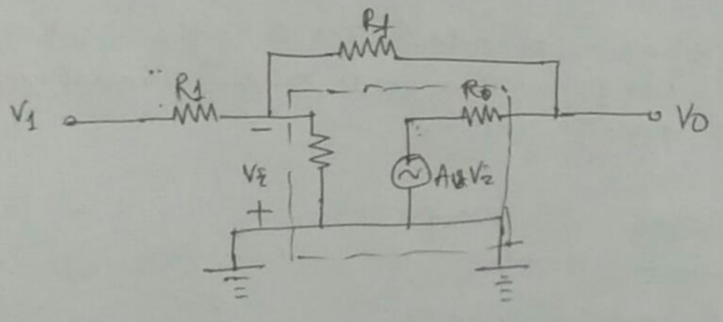


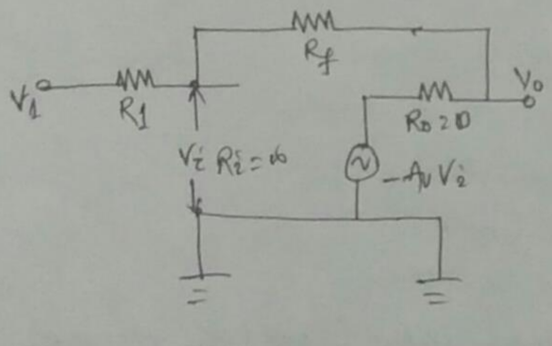
fig 2. Basic op-amp connection

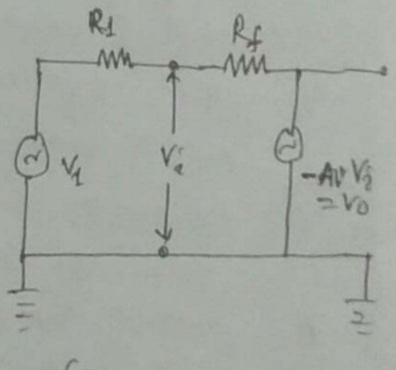
An i/p signal V_1 is applied through resistor R_1 to the minus i/p. The o/p is then connected back to the same minus i/p through resistor R_f. The plus input is connected ground.

Now draw the ac equivalent ckt. (ideal condition)



(a)





(b) (c)

fig(3). operation of op-amp as constant gain multiplier.
(a) op-amp ac equivalent ckt, (b) ideal op-amp equiv ckt
2. (c) redrawn equiv ckt.

Here, we consider the ideal op-amp equivalent ckt, therefore replace $R_i = \infty$, & $R_0 = 0\Omega$.

The ckt is redrawn as shown in fig 2c.

Using superposition, we can solve for the voltage V_1 in terms of the components due to each of the sources.

For the source V_1 set $-A_v V_2 = 0$,

$$V_{i1} = \frac{R_f}{R_1+R_f} V_1.$$

For the source $-A_v V_2$, set $V_1 = 0$,

$$V_{i2} = \frac{R_1}{R_1+R_f}(-A_v V_i)$$

The total voltage V_i is then

$$V_i = V_{i1} + V_{i2} = \frac{R_f}{R_1+R_f} \cdot V_1 + \frac{R_1}{R_1+R_f}(-A_v V_i)$$

$$V_i = \frac{R_f}{R_f + (1+A_v)R_1} V_1$$

If $A_v >> 1$ and $A_v R_1 >> R_f$, then

$$V_i = \frac{R_f}{A_v R_1} V_1$$

Solving for V_0/V_i, we get

$$\frac{V_0}{V_i} = \frac{-A_v V_i}{V_i} = \frac{-A_v}{V_i} \frac{R_f V_1}{A_v R_1} = \frac{-R_f}{R_1} \frac{V_1}{V_i}$$

So that
$$\boxed{\frac{V_0}{V_1} = -\frac{R_f}{R_1}}$$

$$\boxed{A_v = -R_f/R_1}$$

Unity gain: If $R_f = R_1$, then the voltage gain

voltage gain $= -R_f/R_1 = -1$

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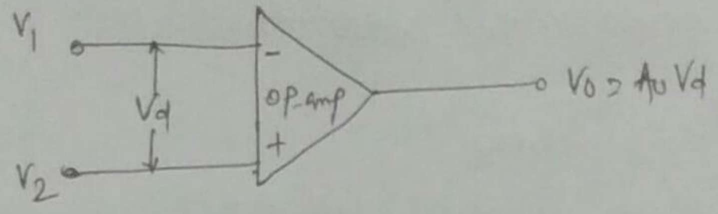
Virtual ground :-

In ideal condition, if one input is at zero potential, then the other terminal is also considered as at zero potential.



$V_1, V_2 \rightarrow$ input voltages

$V_d \rightarrow$ difference voltage

$V_d = V_1 - V_2$, $A_v \rightarrow$ voltage gain

The o/p voltage $(V_0) = A_v V_d$

Now $A_v = V_0 / V_d$

$$= \frac{V_0}{V_1 - V_2}$$

We know that the voltage gain of the ideal op-amp is ∞.

$$\text{So, } \infty = \frac{V_0}{V_1 - V_2} = \frac{V_0}{0V}$$

$\therefore \Rightarrow V_1 - V_2 = 0V$

and $\boxed{V_1 = V_2}$

Inverting Amplifier

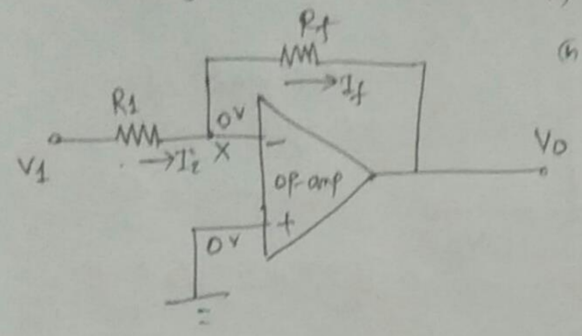


fig. Inverting op-amp configuration

In inverting amplifier, the input signal is applied to the (−) terminal, and the (+) terminal is connected to ground.

I_i is the i/p current & I_f is feedback current.

Applying KCL at Node X. As per virtual ground concept the voltage at X is zero.

$$I_i = I_f$$

$$\frac{V_1 - 0V}{R_1} = \frac{0V - V_o}{R_f}$$

$$\Rightarrow \frac{V_1}{R_1} = \frac{-V_o}{R_f}$$

$$\Rightarrow \boxed{\frac{V_o}{V_1} = -R_f/R_1}$$

Non Inverting Amplifier :-

In Non-Inverting amplifier, the input signal is applied to (+) terminal and (−) terminal is connected to ground.

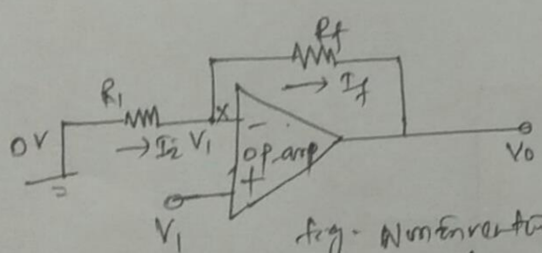


fig. Non-inverting Amplifier

Applying KCL at X, we get.

$$I_i = I_f$$

$$\Rightarrow \frac{0V - V_1}{R_1} = \frac{V_1 - V_o}{R_f}$$

$$\Rightarrow \frac{-V_1}{R_1} = \frac{V_1 - V_o}{R_f}$$

$$\Rightarrow \boxed{\frac{V_o}{V_1} = 1 + \frac{R_f}{R_1}}$$

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Summing Amplifier :- It produces the sum of the input signals.

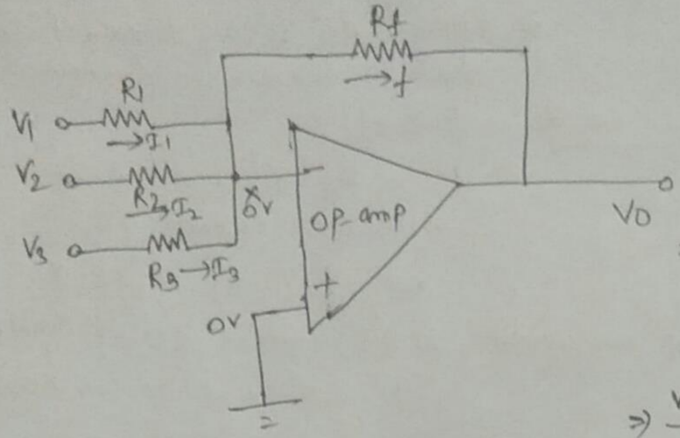


Fig. Summing amplifier

Applying KCL at X, we get

$$I_1 + I_2 + I_3 = I_f$$

$$\Rightarrow \frac{V_1 - 0V}{R_1} + \frac{V_2 - 0V}{R_2} + \frac{V_3 - 0V}{R_3} = \frac{0V - V_0}{R_f}$$

$$\Rightarrow \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_0}{R_f}$$

$$\Rightarrow \boxed{V_0 = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right)}$$

If $R_f = R_1 = R_2 = R_3$

$$V_0 = -(V_1 + V_2 + V_3)$$

The o/p of the summing amplifier is the summation of all the input signals.

Subtractor ~~amplifier~~ or Differential amplifier :

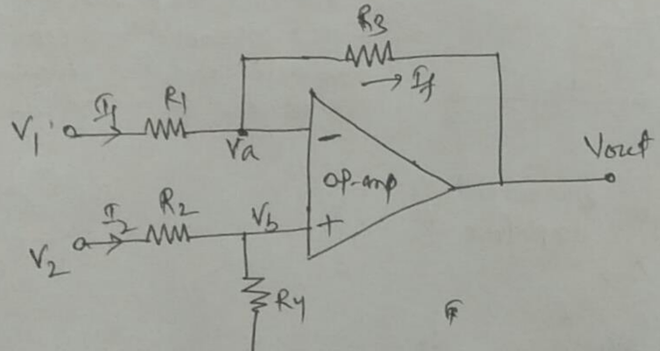


Fig. Differential amplifier

From the fig. we can find

$$I_1 = \frac{V_1 - V_a}{R_1},$$

$$I_2 = \frac{V_2 - V_b}{R_2},$$

$$I_f = \frac{V_a - V_{out}}{R_3}$$

As per the virtual ground concept, $V_a = V_b$.

and $V_b = V_2\left(\frac{R_4}{R_2+R_4}\right)$

If $V_2 = 0$; then; $V_{out(a)} = -V_1\left(\frac{R_3}{R_1}\right)$

If $V_1 = 0$, then,

$$V_{out(b)} = V_2\left(\frac{R_4}{R_2+R_4}\right)\left(\frac{R_1+R_3}{R_1}\right)$$

using voltage division

$V_{out} = -V_{out(a)} + V_{out(b)}$

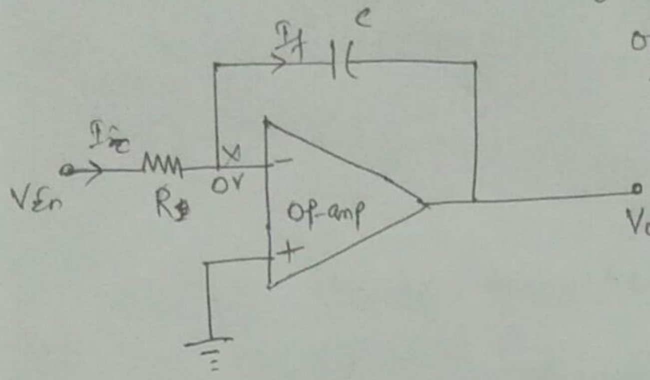
$$\therefore V_{out} = -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2+R_4}\right)\left(1+\frac{R_3}{R_1}\right)$$

If $R_1 = R_2 = R_3 = R_4$, then the

$$\boxed{V_{out} = V_2 - V_1}$$

Integrator circuit

The op-amp integrator is an operational amplifier circuit that performs the mathematical operation of integration.



$V_o \rightarrow$ The integrator produces an output voltage which is proportional to the integral of the input voltage.

fig. integrator ckt

Applying KCL at X, we get

$$I_i = I_f$$

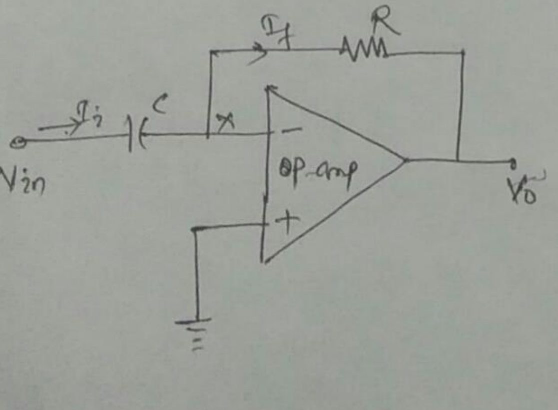
$$\Rightarrow \frac{V_{in} - 0V}{R_f} = C\frac{d(0V - V_o)}{dt}$$

$$\Rightarrow \frac{V_{in}}{R_f} = -C\frac{dV_o}{dt}$$

$$\Rightarrow \boxed{V_o = -\frac{1}{RC}\int V_{in}\,dt}$$

Differentiator amplifier :-

The op-amp differentiator is an operational amplifier ckt that perform the mathematical operation of differentiation.



The differentiator produces an output voltage which is directly proportional to the input voltage's rate-of change with respect to time.

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Applying KCL at X, we get

$$I_{in} = I_f$$

$$\Rightarrow \frac{C\,d(V_{in} - 0V)}{dt} = \frac{0V - V_0}{R}$$

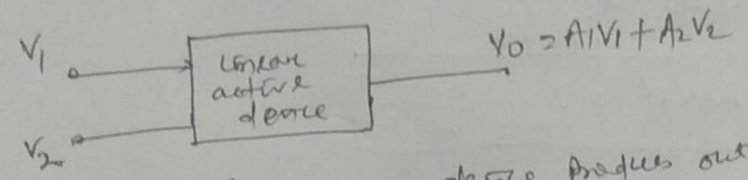
$$\Rightarrow \frac{C\,dV_{in}}{dt} = -\frac{V_0}{R}$$

$$\Rightarrow \boxed{V_0 = -RC\frac{dV_{in}}{dt}}$$

CMRR (common mode rejection ratio)

The CMRR is defined as, it is the ratio between differential gain (Ad) to common mode gain (Ac).

$$CMRR = \frac{A_d}{A_c}.$$



Let us consider a linear active device produces output V_0 is the linear combination of inputs.

The difference voltage is defined as

$$V_d = V_1 - V_2 \qquad \text{---(1)}$$

and the common mode voltage is defined as

$$V_c = \frac{V_1 + V_2}{2} \qquad \text{---(2)}$$

Subtract eqn (2) from eqn (1)

$$V_d = V_1 - V_2$$
$$2V_c = V_1 + V_2$$
$$V_d - 2V_c = -2V_2$$
$$\Rightarrow V_2 = V_c - \frac{V_d}{2}$$

Adding eqn (1) with eqn (2)

~~we get~~;

$$V_d = V_1 - V_2$$
$$2V_c = V_1 + V_2$$
$$V_d + 2V_c = 2V_1$$
$$\Rightarrow V_1 = V_c + \frac{V_d}{2}$$

Substitute the value of V_1 and V_2 in

$$V_0 = A_1V_1 + A_2V_2.$$

So,

$$V_0 = A_1\left(V_c + \frac{V_d}{2}\right) + A_2\left(V_c - \frac{V_d}{2}\right)$$
$$= A_1V_c + \frac{A_1V_d}{2} + A_2V_c - \frac{A_2V_d}{2}$$
$$= (A_1 + A_2)V_c + \left(\frac{A_1 - A_2}{2}\right)V_d$$

$$\boxed{V_0 = A_cV_c + A_dV_d}$$

where $A_1 + A_2 = A_c$

& $\frac{A_1 - A_2}{2} = A_d.$

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A_c → common mode gain of the amplifier

A_d → differential gain of the amplifier.

$$CMRR \text{ in dB} = 20\log_{10}\frac{A_d}{A_c}.$$

$$V_O = A_d V_d + A_c V_c$$

$$= A_d V_d\left(1 + \frac{A_c V_c}{A_d V_d}\right)$$

$$\boxed{V_O = A_d V_d\left(1 + \frac{1}{CMRR}\frac{V_c}{V_d}\right)}$$