Block Diagram Of Operational Amplifier

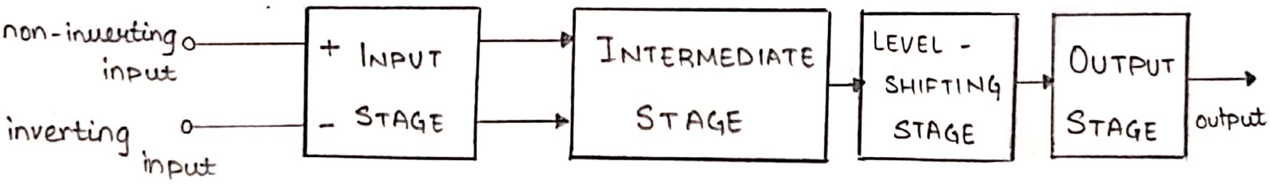
• An operational Amplifier, abbreviated as op-amp, is a very versatile electronic device which finds numerous practical applications.

• In analog computers, it is used to perform several mathematical operations like summing, integration, differentiation etc. and it gets its name from such use.

• Op-amps are used in many diverse fields like control systems, communications, instrumentation etc.

"An operation amplifier is basically a very high gain, direct-coupled amplifier with high input impedance and low output impedance."

The block diagram of a typical op-amp is as shown :-



• The input stage employs a dual-input, balanced output differential amplifier which provides a major part of the voltage gain and high input resistance.

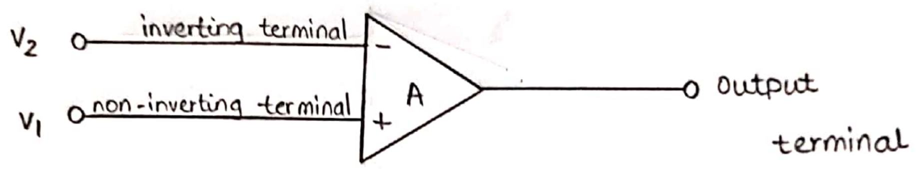
• This drives the intermediate stage, which is another dual input, unbalanced output differential amplifier.

• Since, the input stage amplifier and the intermediate stage amplifier are direct-coupled. The dc voltage at the output of the intermediate stage tends to rise above the ground, which is not desirable.

- To make the dc voltage down to zero, a level shifter (or level translator) is employed. This usually is an emitter follower which also acts as a buffer, with very high input resistance and low output resistance.
- The output stage consists of a complementary symmetry class - B amplifier, which helps to increase the output voltage swing.

SYMBOLIC REPRESENTATION OF OP-AMP :

The circuit symbol of an op-amp is as shown as :



Let, input voltages V_1 and V_2 be applied at the ~~[illegible]~~ inverting and non-inverting terminals of an op-amp.
Let, V_o denote the output.

We have: $\boxed{V_o = A(V_1 - V_2)}$ where A is the differential gain of an Op-Amp. Generally, A is very high.

(A → open loop dc gain)

EQUIVALENT CIRCUIT OF AN OP-AMP

Op-amp amplifies the difference between the two input signals applied at non-inverting and inverting input terminals.

Let, V_1 and V_2 denote the input signals.

∴ Difference input voltage : $\boxed{V_d = V_1 - V_2}$

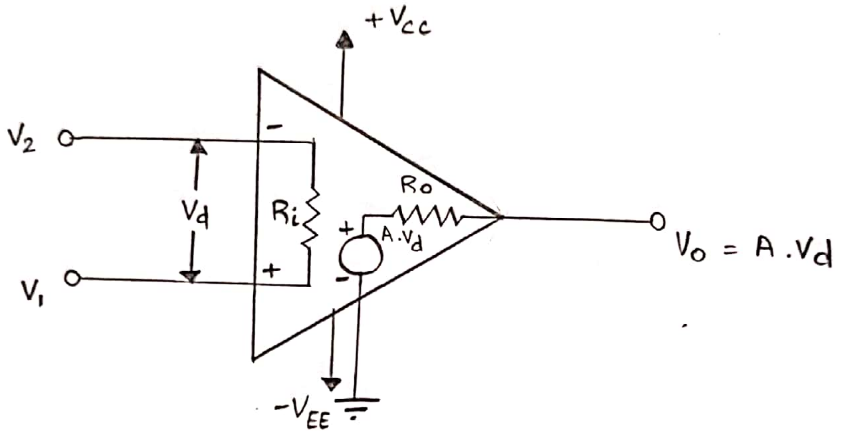
Let A = open-loop gain of Op-Amp

$\boxed{V_o = A \cdot V_d}$: Output voltage

Let R_i = Differential input resistance

R_o = Output resistance

The equivalent circuit of the Op-Amp is shown in Figure.



– Equivalent circuit of op-amp

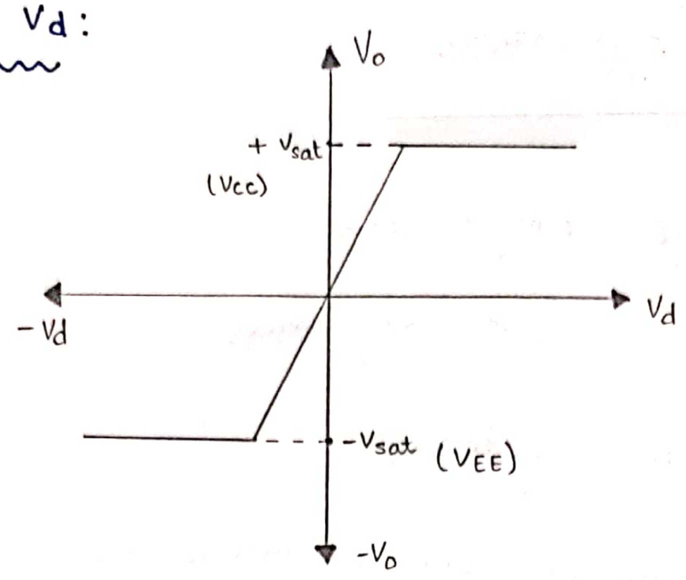
IDEAL VOLTAGE TRANSFER CHARACTERISTICS

The voltage transfer curve is the graphical plot of the output voltage V_o versus differential input voltage V_d.

The output voltage and the differential input voltage are related by the equation :

$$\boxed{V_o = A(V_1 - V_2) = A \cdot V_d}$$

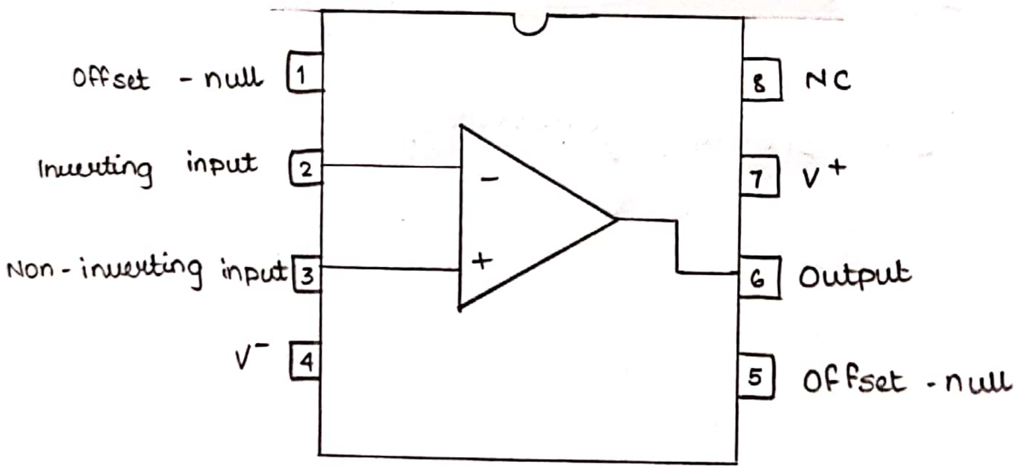
V_o versus V_d :



— Ideal voltage transfer characteristic graph

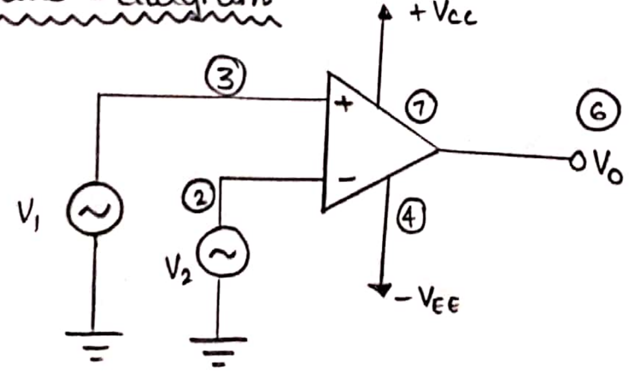
PIN DIAGRAM OF 741 IC :

The pin & schematic diagram of 741 IC operational amplifier is shown in the diagram below :



— Pin diagram of 741 IC

Schematic - diagram



Here;

② inverting input
③ non - inverting input
④ Negative supply
⑦ positive supply
⑥ Output .

Op-Amp Applications

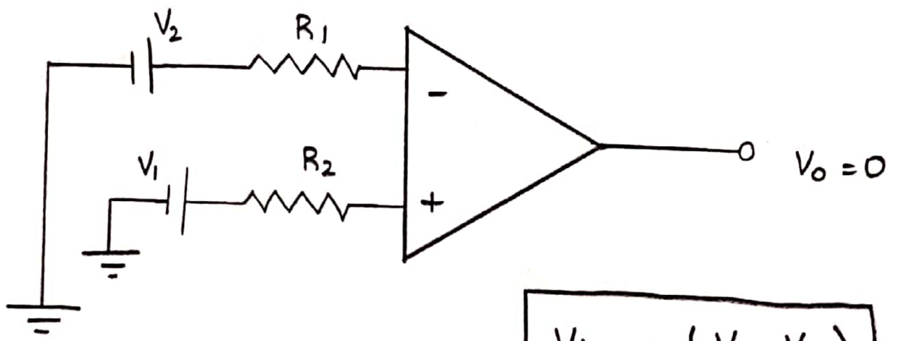
1. Audio Amplifiers
2. Low Dropout Regulators
3. Active filters
4. Medical Sensor interfaces
5. Baseband Receivers
6. Analog to Digital Converters
7. oscillators
8. Signal generators.

OP-AMP CHARACTERISTICS:

INPUT OFFSET VOLTAGE (V_{io})

If no external input signal is applied to the op-amp at the inverting and non-inverting input terminals, the output must be zero. But due to variation of transistors Q_1 and Q_2 in differential amplifier. The output of the op-amp will not be zero. This is known as offset.

" It is the voltage that must be applied between the two input terminals of an op-Amp to nullify output. "



$$\boxed{V_{io} = (V_1 - V_2)}$$

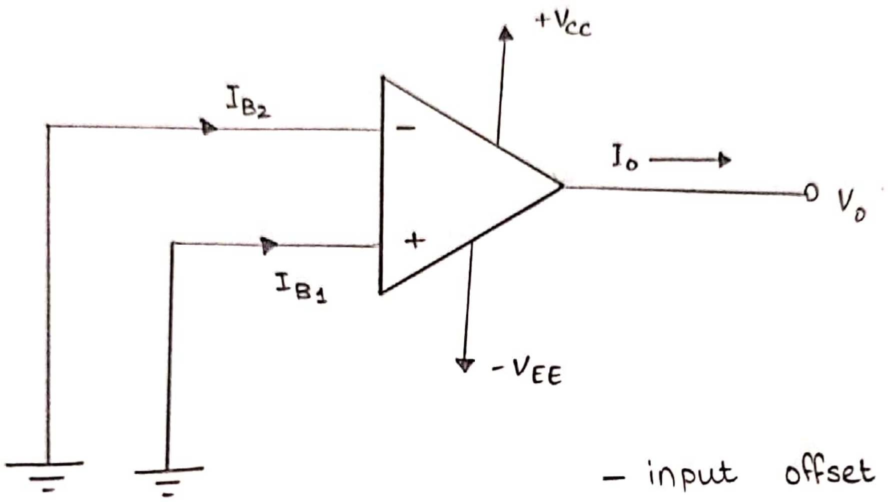
The value for ideal op-amp is $V_{io} = 0$ practical value is around $100\,\mu V$ (typical).

INPUT OFFSET CURRENT (I_{io})

Through for an ideal op-amp, the input impedance is infinite, it is not so practically, so the output

output current I_o draws from the source, however small it may be.

" The algebraic difference between the currents into the inverting and non-inverting terminals is referred to as input offset current I_{io}. "

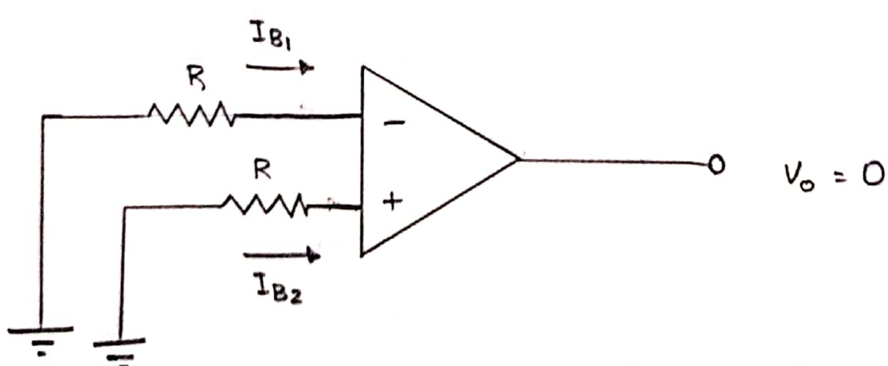


– input offset current (I_{io})

$$\boxed{I_{io} = |I_{B1} - I_{B2}|}$$

For ideal op-amp, $I_{io} = 0$, the typical value for a practical op-amp is around 100nA.

INPUT BIAS CURRENT



–input bias current

" The average value of the two currents flowing into the op-amp input terminals is called as input bias current is denoted as I_B. "

$$\boxed{I_B = \frac{|I_{B1} + I_{B2}|}{2}}$$

Common-Mode Rejection Ratio (CMRR)

Here the important point is that noise signals are not the signals that are designed to be amplified in the differential amplifier. Their distinguishing feature is that the noise signal appears equally at both inputs of the circuit. It means that any undesired (noise) signals that appear in polarity, or common to both input terminals, will be largely rejected, or cancelled out at the differential amplifier output.

" A measure of rejection of noise signals common to both inputs is referred to as the common-mode rejection of the amplifier. "

CMRR is defined as the ratio of differential voltage gain to common-mode voltage gain and is given as :-

$$\boxed{CMRR = \frac{A_d}{A_{cm}}}$$

The ideal characteristics of an Op-Amp :-

S.No.	Characteristic	Ideal
1.	CMRR	∞
2.	Slew Rate	∞
3.	Input Resistance	∞
4.	Output Resistance	0
5.	Voltage gain (Av)	∞
6.	Bandwith	∞
7.	Offset voltage	0
8.	Offset current	0

Importance Of Negative Feedback In Op-Amp

- If gain in op-amp will be more than stability will be less, so to reduce the gain, we can apply negative feedback.
- Open loop gain of op-amp is very large and therefore the stability is less. To increase the stability a small amount of negative feedback is applied so that gain is reduced and frequency stability is increased.
- Closed loop gain : A_{CL} is always less than open loop gain (A_{OL}).
- Op-amp is an analog IC that it can amplify a DC signal along with a wide band of ac signals such

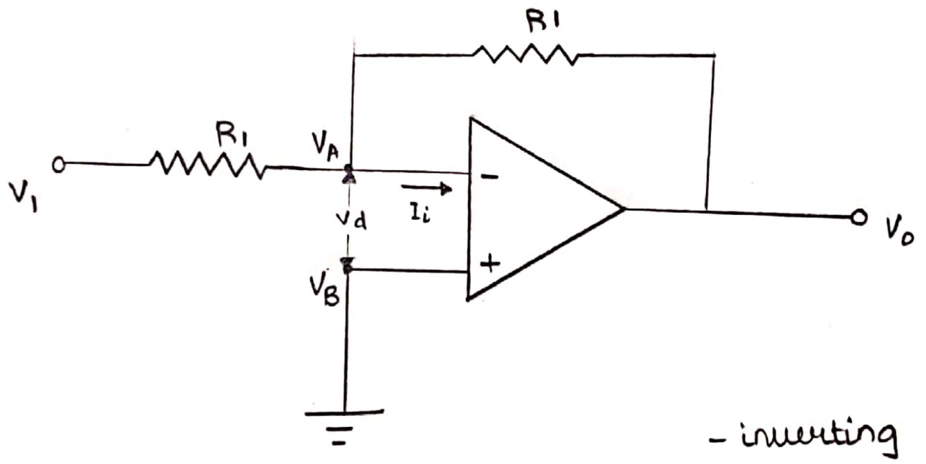
as sine, square and triangular waves.

- Op-amp is basically linear analog IC linear means we can apply super-posistion principle.

VIRTUAL GROUND :

This is an important concept for an op-amp, as it plays a vital role in deriving the expression for output voltage V_o.

Consider, the op-amp circuit show in figure.



- inverting amplifier

→ V_B is a potential defined at non-inverting input.

V_A is a potential defined at inverting input (feedback point).

V_d is difference between V_B and V_A.

i.e., $\boxed{V_d = V_B - V_A}$

According to ideal characteristics of op-amp.

Input resistance R_i is infinite, therefore the current entering into op-amp I_i will be zero. That means differential voltage : V_d will be zero.

i.e., $0 = V_B - V_A$

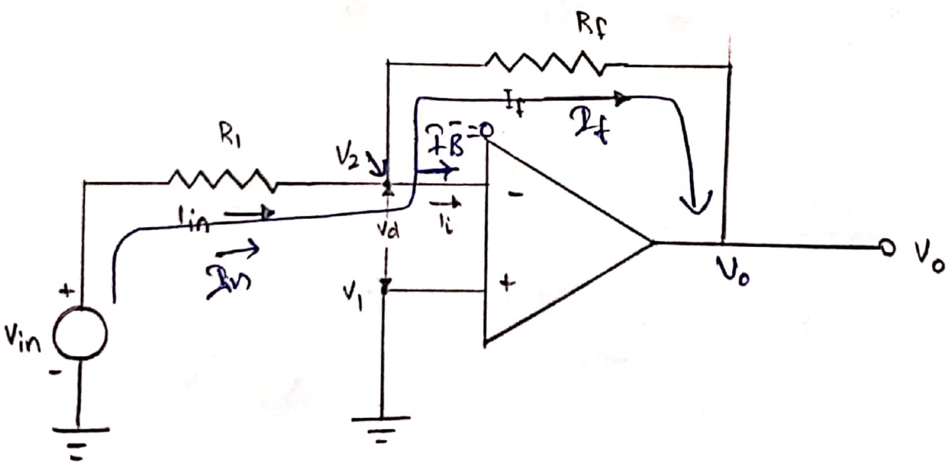
$\Rightarrow \boxed{V_A = V_B}$

The node voltage V_B at terminal positive is same as negative feedback node point V_A. This concept is called as virtual ground concept.

Practical Applications Of Op-Amp

Inverting Amplifier

The figure shows the inverting amplifier. Its non-inverting input terminal is grounded where as the external input signal V_{in} is applied to the inverting input terminal through resistance R_1. A feedback resistor R_f is connected from the output to the inverting input terminal of op-amp.



$I_{in} = I_f$

$\frac{V_{in} - \cancel{V_2}^{\,0}}{R_1} = \frac{V_2 - V_0}{R_f}$

according to virtual ground

$V_1 = V_2 = 0$

$\frac{V_{in}}{R_1} = -\frac{V_0}{R_f}$ — Inverting amplifier

$$\frac{V_{in}}{R_1} = \frac{-V_o}{R_f}$$

$$\boxed{V_o = -\frac{R_f}{R_1} V_{in}}$$

$$\boxed{\therefore \text{gain} = \frac{V_o}{V_{in}} = \frac{-R_f}{R_1}}$$

This arrangement provides voltage shunt negative feedback. According to the virtual ground concept.

$$\therefore \boxed{V_1 = V_2}$$

Applying kirchoff's current law at input node V_2 in figure.

$$\boxed{I_{in} = I_f + I_i}$$

and $\quad I_{in} = I_f \quad [\because I_i = 0]$

as $\quad V_1 = 0 \quad \Rightarrow \quad V_2 = 0$

$$\frac{V_{in}}{R_1} = -\frac{V_o}{R_f}$$

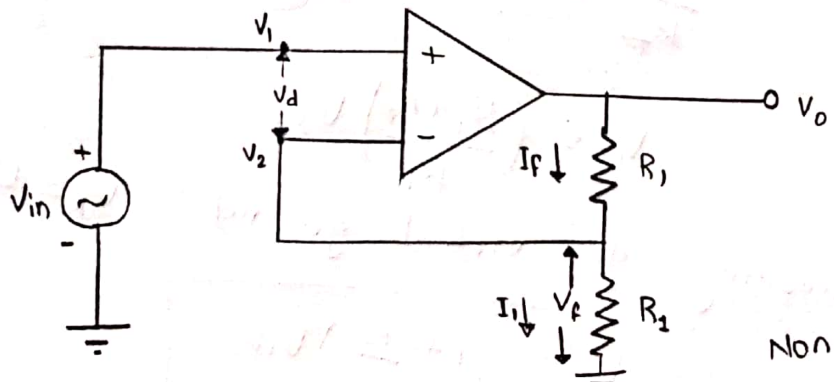
Thus:

$$\boxed{A_f = \frac{V_o}{V_{in}} = -\frac{R_f}{R_1}}$$

The negative sign in above equation indicates that the input and output voltages are out of phase by 180°. Because of this phase inversion, this configuration is commonly called as inverting amplifier.

R_1 and R_f are external resistances. Thus, it is seen that, for this type of amplifier, the closed loop gain depends only upon the feedback resistor R_f and R_1 and by properly choosing R_f and R_1, any desired gain can be obtained.

Non - Inverting Amplifier



alternative way the circuit is

Non - inverting amplifier

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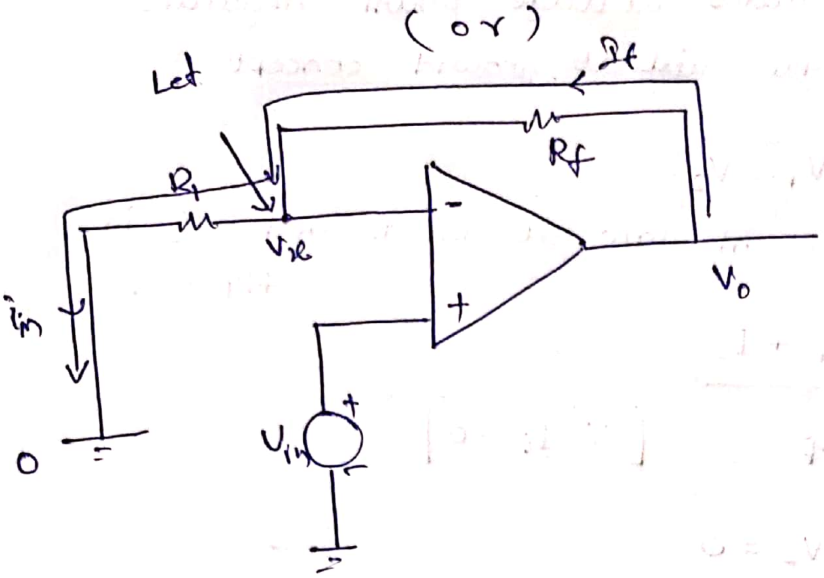
(or)

Let



~~after~~ alternative way of non-inverting circuit

Let V_x at inverting node

$$I_f = I_{in}$$

$$\frac{V_o - V_x}{R_f} = \frac{V_x - 0}{R_1}$$

$$\frac{V_o}{R_f} - \frac{V_x}{R_f} = \frac{V_x}{R_1}$$

$$\frac{V_o}{R_f} = \frac{V_x}{R_f} + \frac{V_x}{R_1} = V_x\left(\frac{1}{R_f} + \frac{1}{R_1}\right)$$

$$\frac{V_o}{\cancel{R_f}} = V_x\left(\frac{R_1 + R_f}{R_1 \cancel{R_f}}\right)$$

$$V_o = \left(\frac{R_1 + R_f}{R_1}\right) V_x$$

gain $A = \frac{V_o}{V_{in}}$

$= \left(1 + \frac{R_f}{R_1}\right)$

$\therefore$ according to virtual ground $V_x = V_{in}$

$$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right) V_{in}}$$

The circuit is commonly known as non-inverting amplifier with feedback or closed loop non-inverting amplifier because it uses a feedback and input signal is applied to the non-inverting input terminal of the op-amp.

In this case, inverting terminal is grounded through resistor R_1 and output is applied to the inverting input terminal through feedback circuit composed of two resistors R_1 and R_f.

According to the virtual ground:

$$\boxed{V_{in} = V_2}$$

$$I_f = I_1$$

$$\frac{V_o - V_{in}}{R_f} = \frac{V_{in} - 0}{R_1}$$

$$\Rightarrow \quad \boxed{A_V = \frac{V_o}{V_{in}} = \left[1 + \frac{R_f}{R_1}\right]}$$

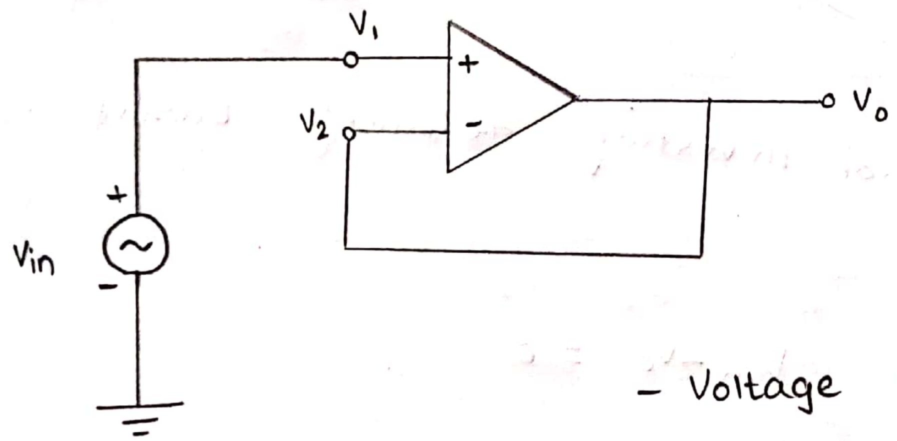
R_f and R_1 are both positive. Hence, gain is positive. Also there is no phase inversion. The expression for closed loop gain reveals, that the voltage gain is always greater than unity, whatever the values of R_1 and R_f. Also, the closed loop independent of the open loop gain, but depends only upon the external resistors R_1 and R_f.

VOLTAGE FOLLOWER

In non-inverting amplifier, when the resistor R_f is set equal to zero (or) R_1 is made ∞ by keeping it open-circuited.

The output voltage : $V_{out} = V_{in}$;

i.e., the output voltage of the op-amp exactly tracks the input voltage both in sign and magnitude. This is the reason that this circuit is called a voltage follower.



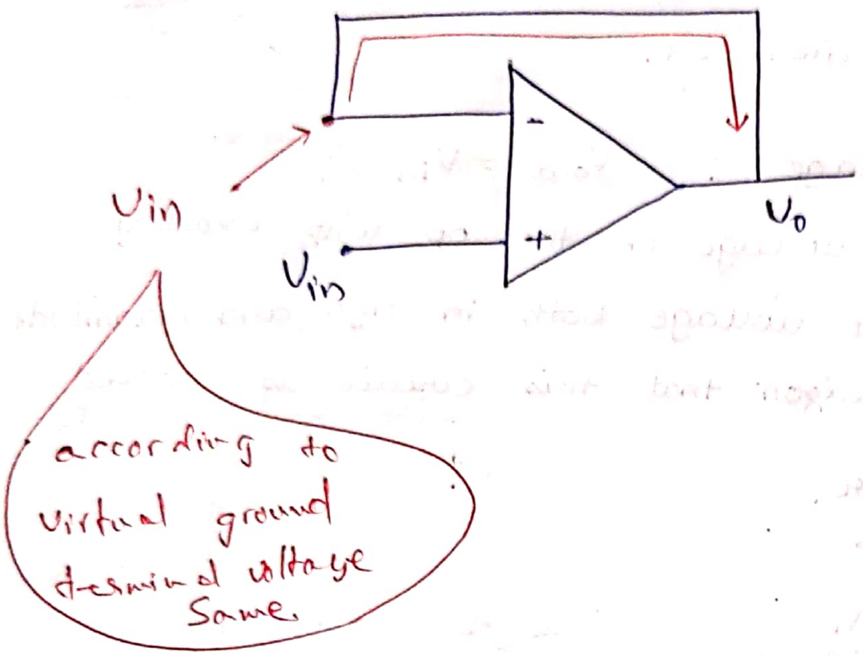
- Voltage follower

The direct connection of the output voltage to the inverting terminal of the op-amp represents the case of 100% negative feedback of the output to the input.

From figure ; V_2 is equal to V_o and $V_{in} = V_1$.

$\therefore$ $\boxed{V_o = V_{in}}$

alternative way of voltage follower



$\therefore$ at Inverting terminal current $= \infty$

$$V_{in} - V_o = 0$$

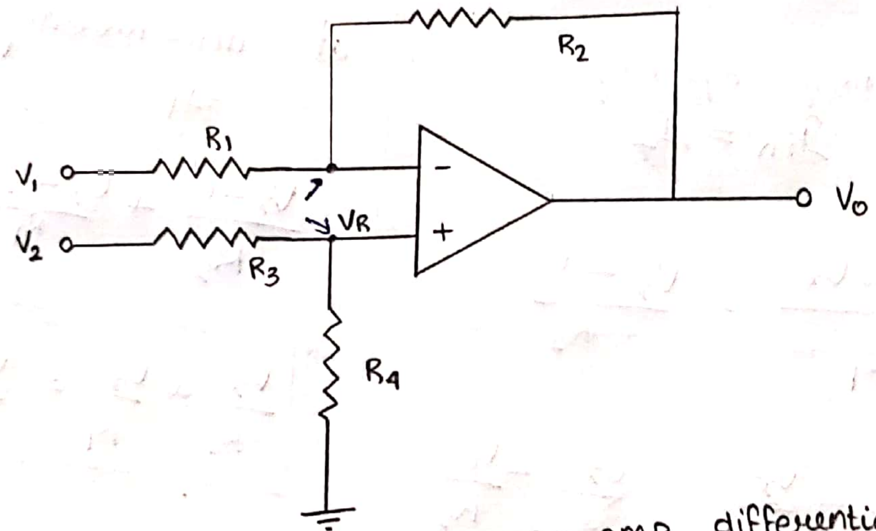
$$V_{in} = V_o$$

$$\boxed{V_o = V_{in}}$$

DIFFERENTIAL AMPLIFIER

Sometimes it is necessary to amplify the voltage difference between two input lines neither of which is grounded. In this case, the amplifier is called a differential amplifier.

The circuit of an op-amp differential amplifier is shown in the figure.



— op-amp differential amplifier

Since, the circuit has two inputs V_1 and V_2 super-posistion theorem will be used for the determination of voltage gain of the amplifier.

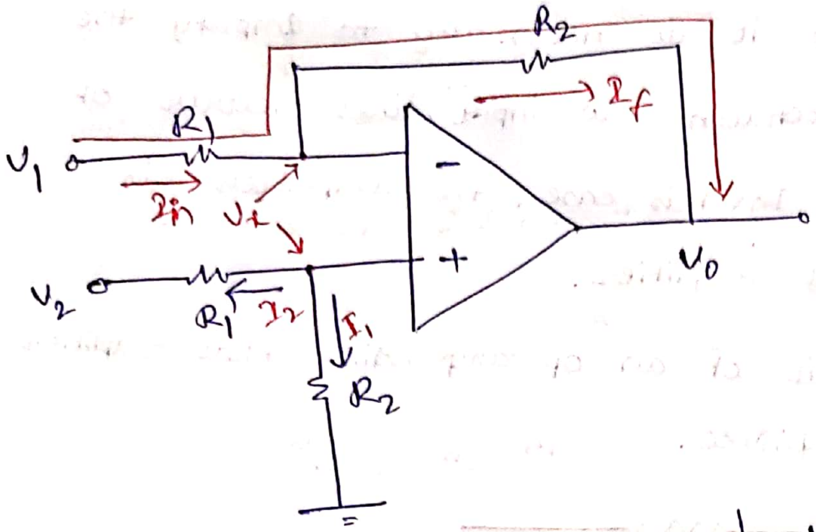
When ; $V_2 = 0$; it behaves like a inverting mode

$$\therefore \boxed{V_{01} = -\frac{R_2}{R_1} V_1}$$

When $V_1 = 0$; it behaves like a non-inverting mode.

$$\boxed{V_{02} = \left(1 + \frac{R_2}{R_1}\right) \cdot V_R}$$

Difference Amplifier



at inverting op-Amp

$$I_{in} = I_f$$

$$\frac{V_1 - V_x}{R_1} = \frac{V_x - V_0}{R_2}$$

$$\frac{V_1}{R_1} - \frac{V_x}{R_1} = \frac{V_x}{R_2} - \frac{V_0}{R_2}$$

$$\frac{V_1}{R_1} = \frac{V_x}{R_1} + \frac{V_x}{R_2} - \frac{V_0}{R_2}$$

$$\boxed{\frac{V_1}{R_1} + \frac{V_0}{R_2} = \left(\frac{V_x}{R_1} + \frac{V_x}{R_2}\right)} \rightarrow (1)$$

at non-inverting terminal

$$\underbrace{\frac{V_x - 0}{R_2}}_{I_1} + \underbrace{\frac{V_x - V_2}{R_1}}_{I_2} = 0$$

$$\boxed{\frac{V_x}{R_2} + \frac{V_x}{R_1} = \frac{V_2}{R_1}} \rightarrow (2)$$

from eq (1) & eq (2)

$$\frac{V_1}{R_1} + \frac{V_0}{R_2} = \frac{V_2}{R_1} \Rightarrow \boxed{V_0 = V_2 - V_1} \text{ * here } R_1 = R_2 = R$$

$$\therefore R_1 = R_2 = R$$

$$\boxed{V_0 = \frac{R_2}{R_1}(V_2 - V_1)}$$

where ;

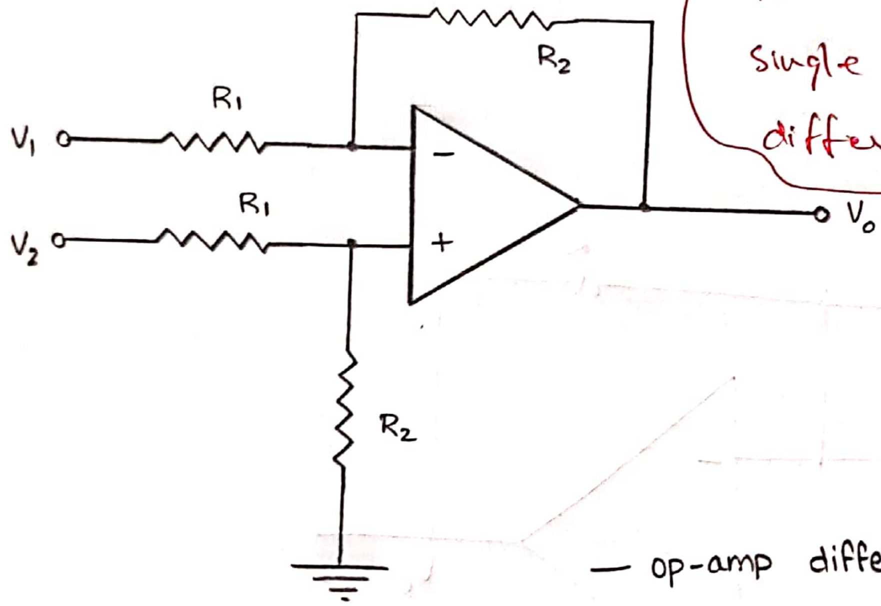
$$V_R = \frac{V_2 \times R_4}{R_3 + R_4}$$

$$\therefore \; V_o = V_{o1} + V_{o2}$$

$$\boxed{V_o = -\frac{R_2}{R_1} V_1 + \left(1 + \frac{R_2}{R_1}\right) \frac{V_2 \times R_4}{R_3 + R_4}}$$

If suppose the differential amplifier with $R_3 = R_1$ and $R_4 = R_2$.

Then :



alternative name
single op-amp
difference op-amp

— op-amp differential amplifier

$$V_o = -\frac{R_2}{R_1} \cdot V_1 + \left(1 + \frac{R_2}{R_1}\right) V_2 \times \frac{R_4}{R_3 + R_4}$$

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

$$= \frac{R_2}{R_1} (V_2 - V_1)$$

$$\boxed{\therefore \; V_o = \frac{R_2}{R_1} (V_2 - V_1)}$$

Note i) Difference op-Amp, (or) Differential op-amp

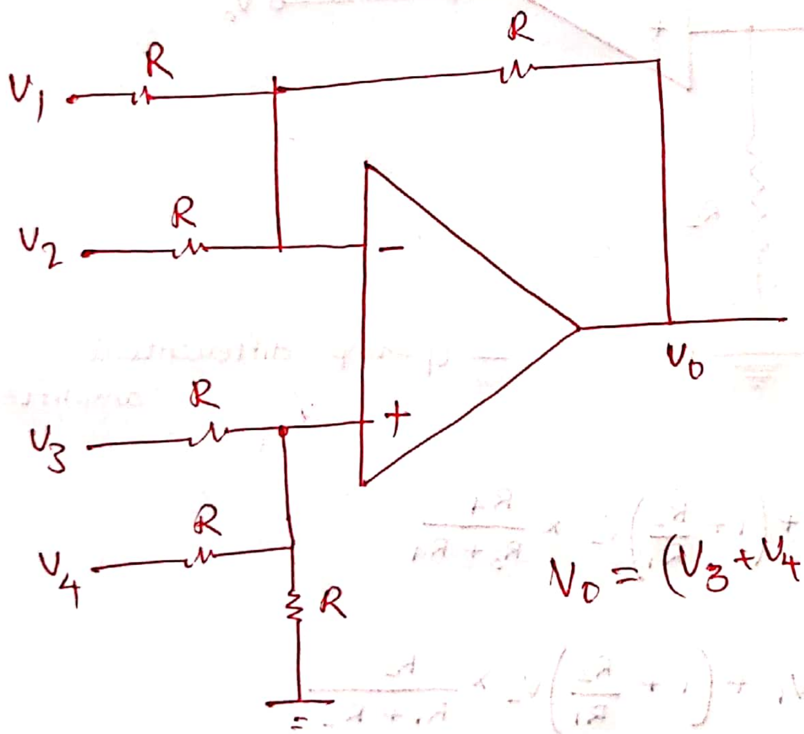
$$V_0 = \frac{R_2}{R_1}(V_2 - V_1)$$

ii) above difference op-amp

$$R_1 = R_2 = R$$

$$\boxed{V_0 = V_2 - V_1}$$ i.e Subtract op-amp.

iii)



$$V_0 = (V_3 + V_4) - (V_1 + V_2)$$