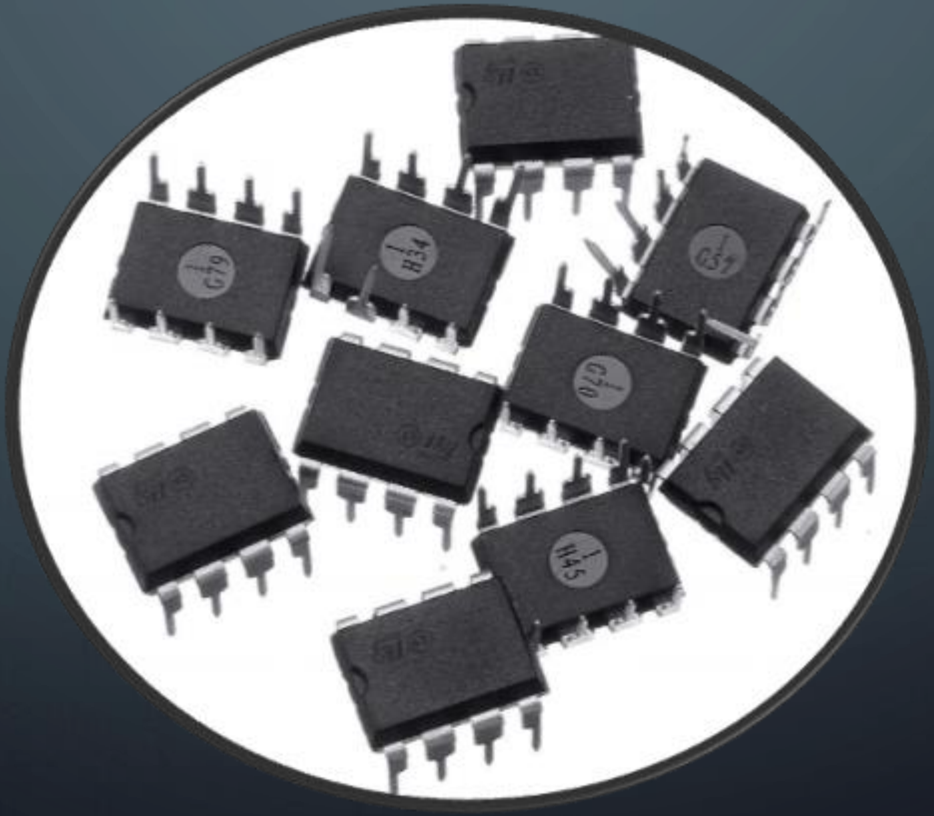
OPERATIONAL AMPLIFIER
(op-amp)



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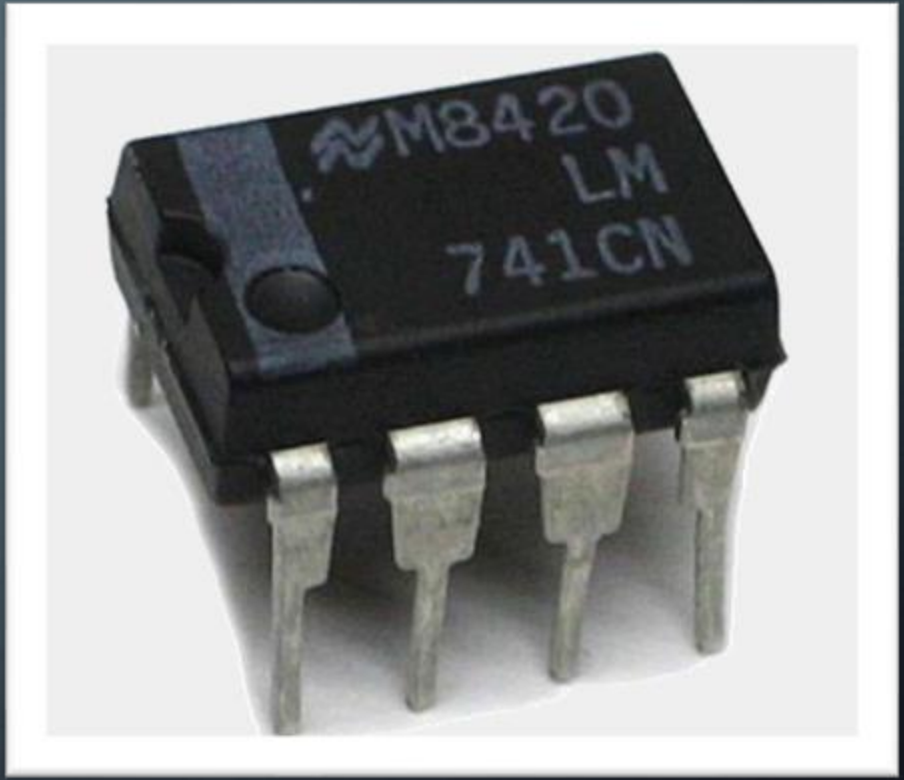
INTRODUCTION

Operational Amplifier commonly known as OP-AMP is a very high gain direct coupled differential amplifier. It is multistage voltage shunt type amplifier which can perform different types of arithmetic and logical operations.



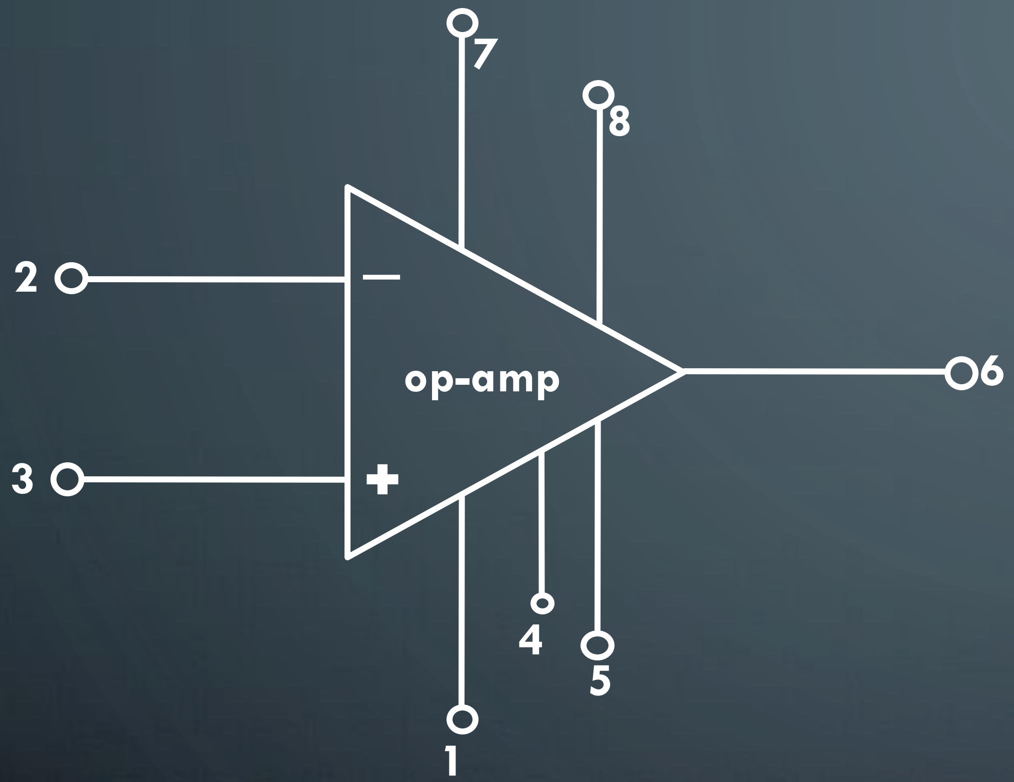
LM741 OP-AMP

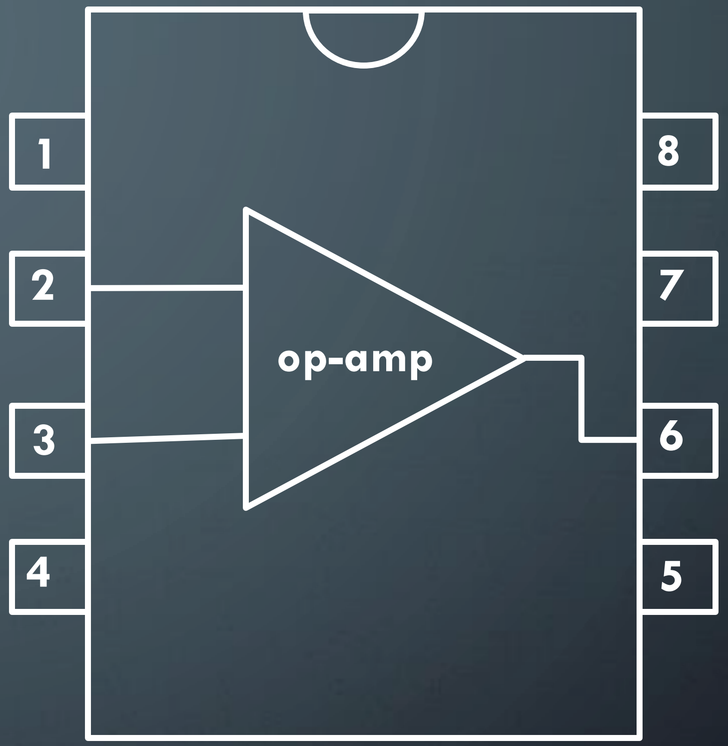
APPLICATIONS

- It can do arithmetic operations like Addition, Subtraction, Integration and Differentiation.
- It can do logical operations like Log, Antilog and also can be used as Comparator.
- It can be used as Waveform generator, Wave shaper.
- Another uses are Precision Rectifier, Instrumental Amplifier.

TO5 OP-AMP

SYMBOL AND CHIP CONFIGURATION

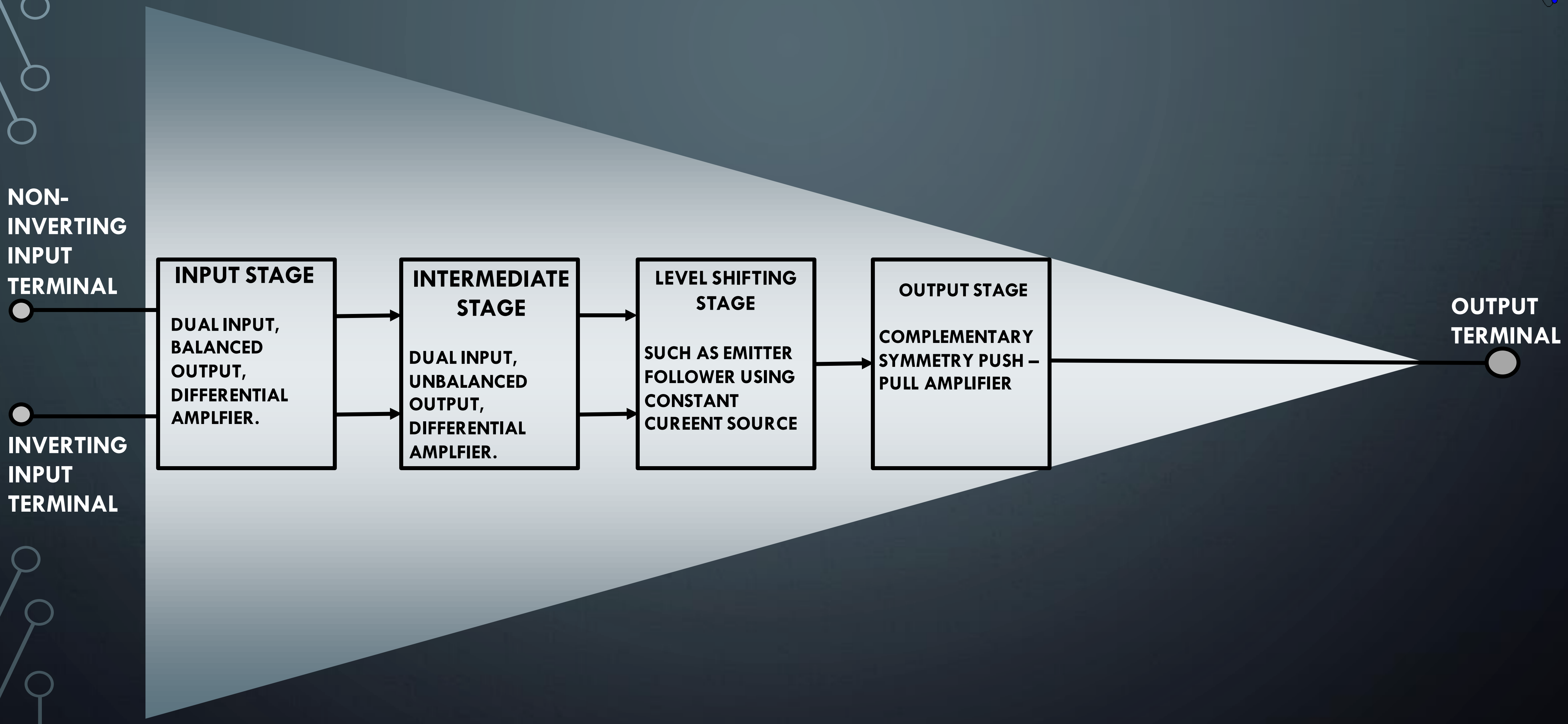




- 1- OFFSET NULL
- 2- INVERTING INPUT TERMINAL
- 3- NON- INVERTING INPUT TERMINAL
- 4- NEGATIVE VOLTAGE SUPPLY TERMINAL

- 5- OFFEST NULL
- 6- OUTPUT TERMINAL
- 7-POSITIVE VOLTAGE SUPPLY TERMINAL
- 8- NO CONNECTION

BLOCK DIAGRAM OF OP-AMP



CHARACTERISTICS OF IDEAL OP-AMP

- ❖Infinite input impedance.
- ❖Zero output impedance
- ❖Zero common-mode gain, or, infinite common-mode rejection.
- ❖Infinite open-loop gain.
- ❖Infinite bandwidth.

DIFFERENCE BETWEEN IDEAL AND PRACTICAL OP-AMP

IDEAL OP-AMP	PRACTICAL OP-AMP
Infinite input impedance. (zero output current)	Very high but finite input impedance.
Zero output impedance.	On the order of several tens of ohms.
Zero input offset voltage.	Several millivolts.
Infinite Common Mode Rejection Ratio (CMRR).	High but finite Common Mode Rejection Ratio (CMRR).
Infinite open loop gain (AV).	On the order of 4^{th} to 10^{th} to 5^{th} power of 10
Infinite frequency bandwidth.	Several hundreds oh kHz to several tens of MHz .

PARAMETERS OF OP-AMP

- **Input Offset Current:** The algebraic difference between the currents into the non-inverting and inverting terminals is referred to as input offset current. It can be written as,

$$I_{io} = | I_1 - I_2 |$$

- **Input Bias Current:** Input bias current is the average of the currents that flow into the inverting and non-inverting input terminals of an op-amp. In the equation form it can be written as,

$$I_{ib} = (I_1 + I_2)/2$$

PARAMETERS OF OP-AMP

- **Large-Signal Voltage Gain:** Since the op-amp amplifies difference voltage between two input terminals, the voltage gain of the amplifier is defined as ratio of output voltage to differential input voltage.

  Voltage gain = (output voltage) / (Differential input voltage)

- **Input Capacitance** The Input capacitance, C_i is the equivalent capacitance that is measured at either the inverting or non-inverting terminal with the other terminal connected to ground.

PARAMETERS OF OP-AMP

- **Common-Mode Rejection Ratio (CMRR):** The common-mode rejection ratio (CMRR) is defined as the ratio of differential voltage gain A_d to the common-mode voltage gain A_{CM}.

$$\text{i.e. } CMRR = A_d / A_{CM}$$

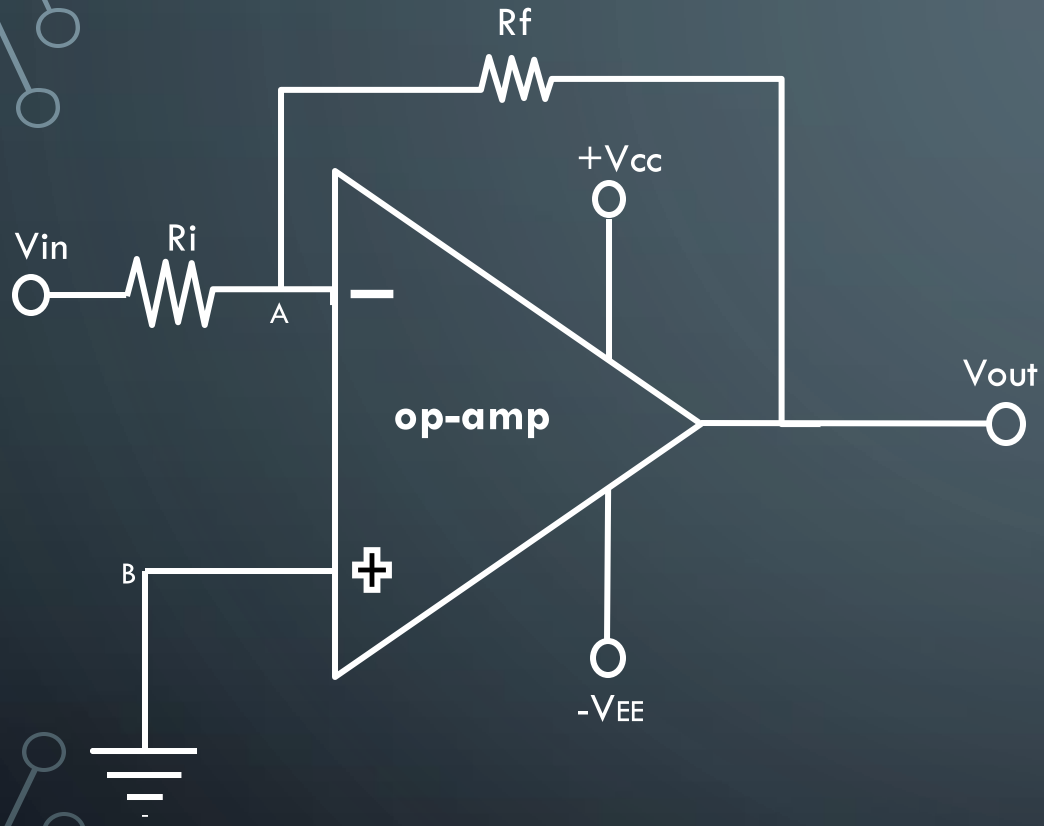
- **Supply Voltage Rejection Ratio (SVRR):** The change in op-amp's input offset voltage V_{io} caused by variations in supply voltages is called the supply voltage rejection ratio (SVRR). It is also called Power Supply Rejection Ratio(PSRR) and Power Supply Sensitivity(PSS).

If we denote the change in supply voltages by Δv and the corresponding change in input offset voltage by ΔV_{io} .

Then, SVRR is defined as,

$$SVRR = \Delta V_{io} / \Delta V .$$

VIRTUAL GROUND



Virtual Ground circuit

A **Virtual Ground** is a node of a circuit that is at a steady reference potential, without being directly connected to the reference. Here the OP-AMP is connected in inverting mode.

Differential Input Voltage(Vin)=V_A-V_B ,

Now Vin=0 as the input impedance is infinite, so

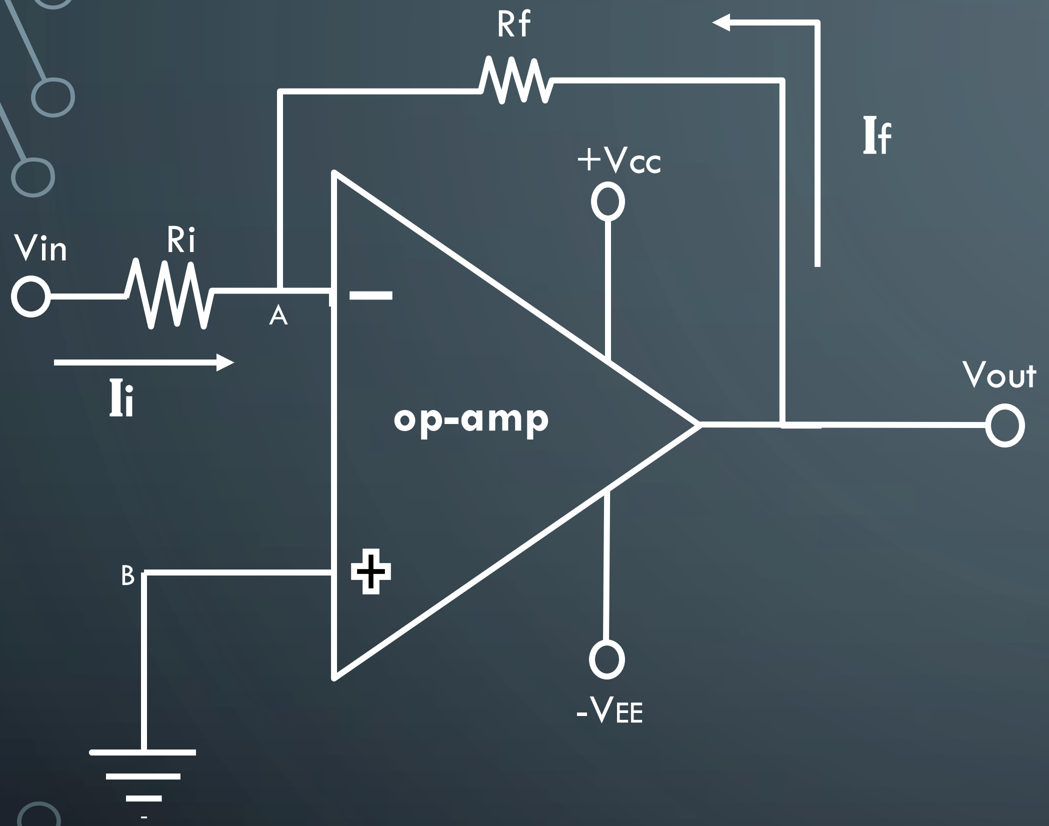
$$V_A - V_B = 0$$

$$\text{or, } V_A = V_B$$

As B is grounded, so V_B=0, therefore V_A also becomes 0. So it is called **Virtual Ground.**

DIFFERENT OPERATIONS USING OP-AMP

INVERTING AMPLIFIER



OP-AMP as Inverting Amplifier circuit

An inverting op-amp is an operational amplifier circuit which produces output voltage in opposite phase. Here the voltage source is connected with the inverting terminal of the OP-AMP and VA and VB are the voltages at A and B respectively.

Applying KCL at point A,

$I_i + I_f = 0$

or, $I_i = -I_f$

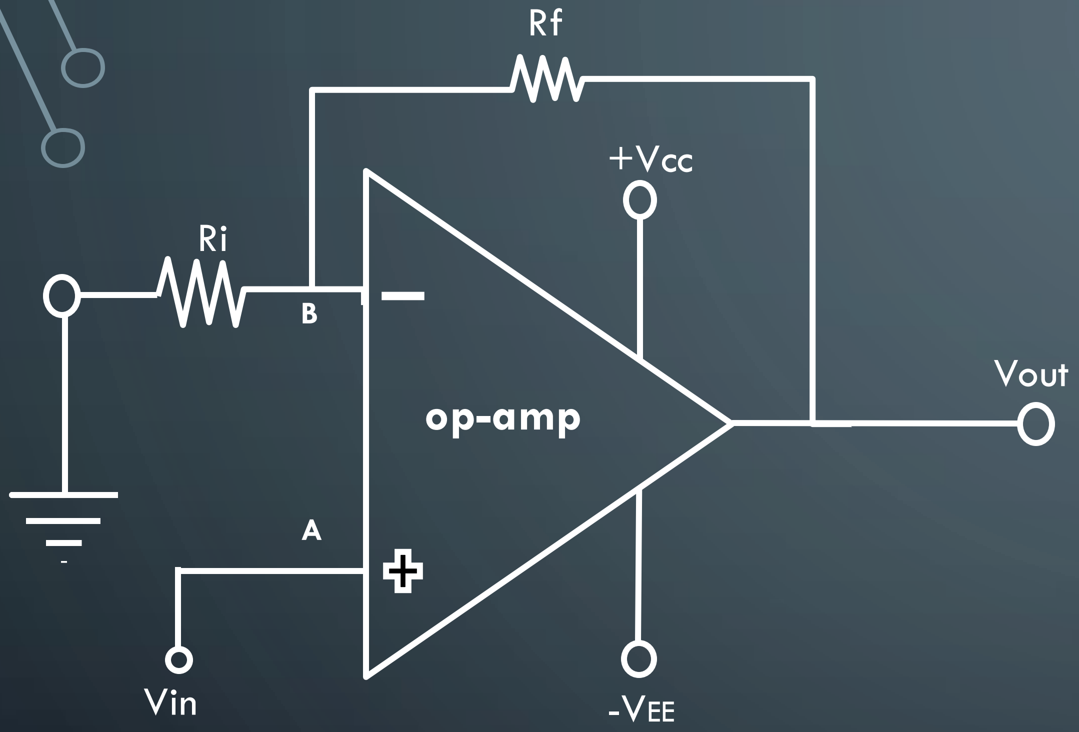
or, $\frac{V_{in} - V_A}{R_i} = \frac{V\,\text{out} - V_A}{R_f}$

or, $\frac{V_{in}}{R_i} = -\frac{Vout}{R_f}$

Therefore, $V_{\text{out}} = \left(\frac{R_f}{R_1}\right) \cdot V_{in}$

So, the Gain (A) will be $\left(\frac{V_{out}}{V_{in}}\right) = \left(\frac{Rf}{R_{in}}\right)$

NON-INVERTING AMPLIFIER



OP-AMP as Non-Inverting Amplifier circuit

A non-inverting amplifier produces an output signal that is in phase with the input signal. Here, VA and VB are the two voltages at the position A and B respectively.

According to voltage division rule at point B, we get

$$V_B = \left(\frac{R_1}{R_i+R_f}\right) \cdot V_{out}$$

As per virtual ground concept,

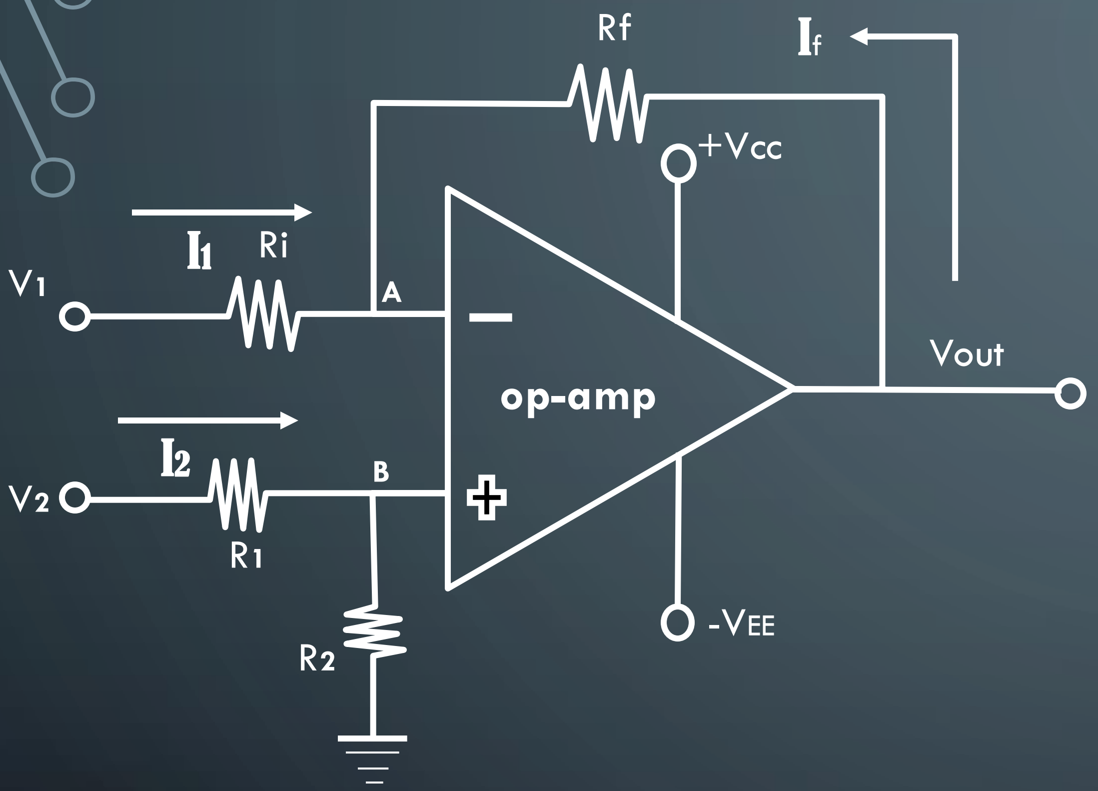
$V_A = V_B = V_{in} = Vout. \left(\frac{Ri}{Ri+Rf}\right)$

Therefore, Gain(A) $= \frac{Vout}{Vin}$

$= \frac{Ri+Rf}{Ri}$

$= 1 + \frac{Rf}{Ri}$

DIFFERENTIAL AMPLIFIER



OP-AMP as Differential Amplifier circuit

A Differential amplifier is a circuit which produces difference of the given input voltages. Here V_a and V_b are the voltages at point A and B respectively in the figure alongside.

We get from the figure, $I1 = \frac{V1-Va}{Rf}$, $I2 = \frac{V2-Vb}{R1}$ and $If = \frac{Vout-Va}{Rf}$.

According to virtual ground concept, V_a=V_b and by voltage division rule, $Vb = V2.(\frac{R1}{R1+R2})$

Considering V2=0, we get,

$Vout_a = -V1.(\frac{Rf}{Ri})$ [Acc. to inverting mode]

Considering V1=0, we get,

$Vout_b = V2.\left(\frac{R2}{R1+R2}\right).\left(1+\frac{Rf}{Ri}\right)$ [Acc. to non-inverting mode]

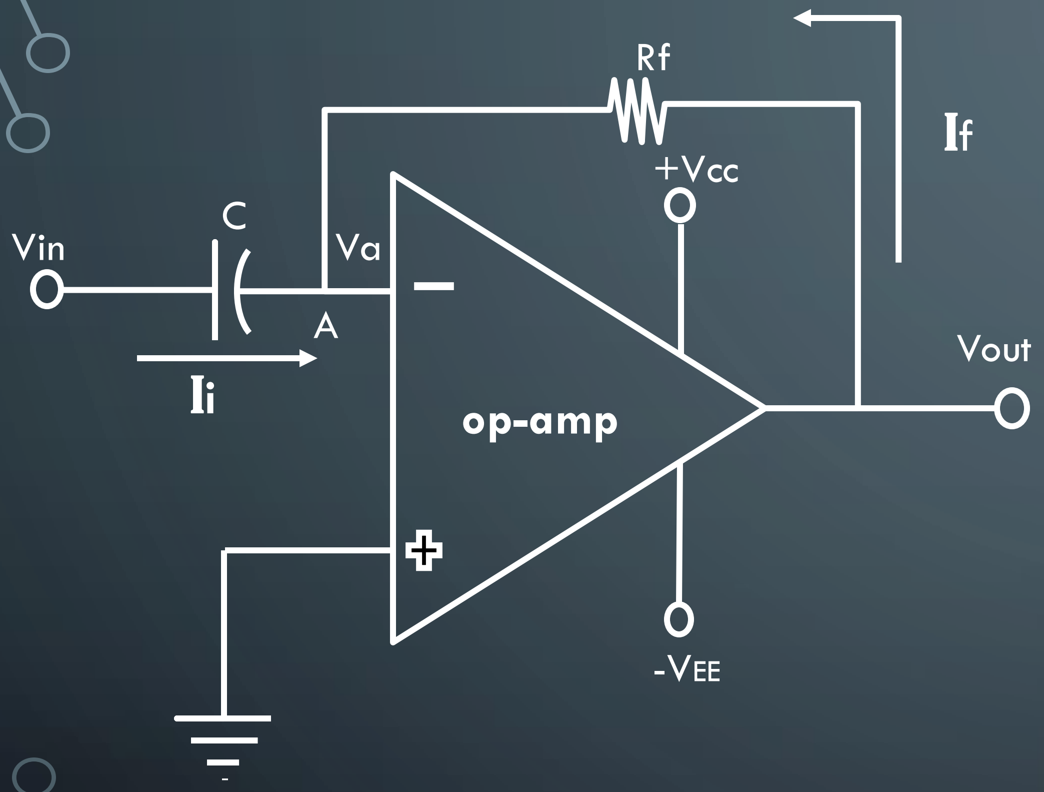
Therefore, $Vout = Vout_a + Vout_b$

$$= -V1.(\frac{Rf}{Ri}) + V2.\left(\frac{R2}{R1+R2}\right).\left(1+\frac{Rf}{Ri}\right)$$

When resistors Ri=R1 and Rf=R2,

We get, $Vout = (V2 - V1).\left(\frac{Rf}{Ri}\right)$

OP-AMP AS DIFFERENTIATOR



OP-AMP as Differentiator

Differentiator is an op-amp based circuit, whose output signal is proportional to differentiation of input signal. An op-amp differentiator is basically an inverting amplifier with a capacitor of suitable value at its input terminal.

We know that the capacitor charge is equal to product of the capacitance and the input voltage so,

$$Q = CV$$

Therefore the change in charge rate is

or, $\frac{dq}{dt} = C \cdot \frac{dv_{in}}{dt}$

or, $I_{in} = C \cdot \frac{dv_{in}}{dt}$

or, $I_{in}. dt = C. dv_{in}$

Now, from the circuit we can say,

$$\frac{V_{out} - V_A}{R_f} = I_f$$

or, $I_f = \frac{V_{out}}{R_f}$ [Acc. To virtual ground concept]

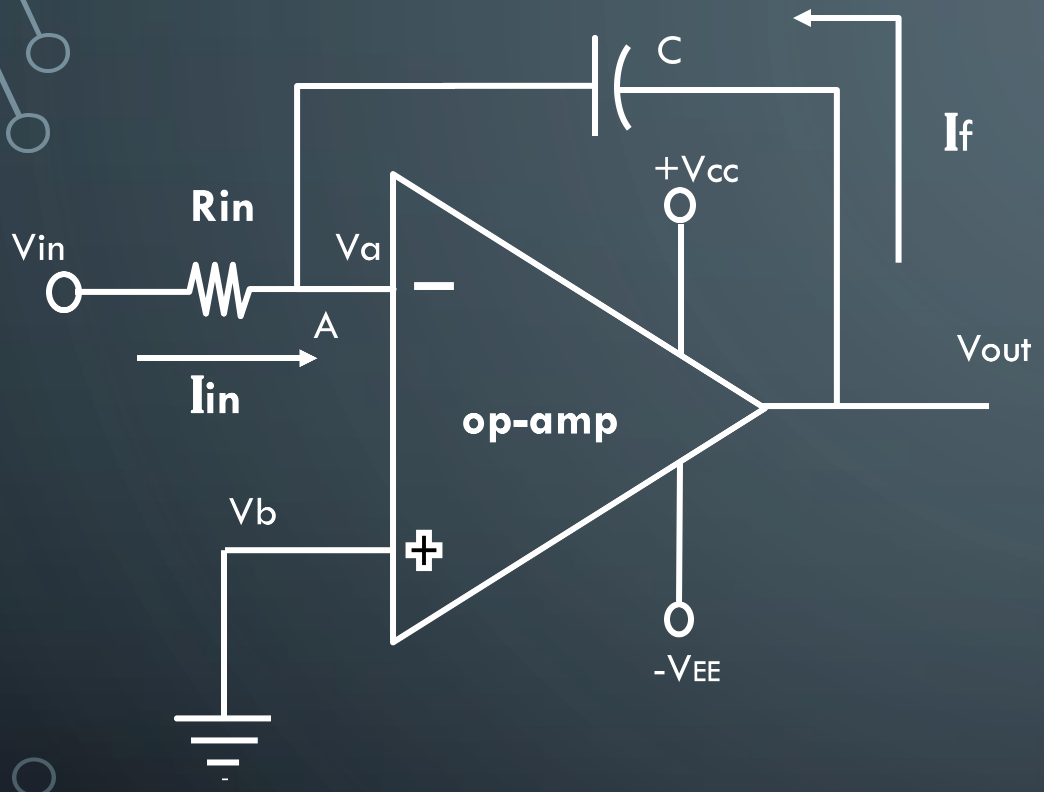
From the circuit, $I_{in} = -I_f$

so, $C \cdot \frac{dv_{in}}{dt} = - \frac{V_{out}}{R_f}$

or, $V_{out} = R_f. C \cdot \frac{dv_{in}}{dt}$

So, the output voltage, $V_{out} = R. C \cdot \frac{dv_{in}}{dt}$

OP-AMP AS INTEGRATOR



OP-AMP as Intergrator

Op-amp Integrator is an operational amplifier circuit that performs the mathematical operation of **Integration**, that produces an output voltage which is proportional to the integral of the input voltage.

From the figure along side we can say,

$$I_{in} = \frac{V_{in} - V_a}{R_{in}}$$

$$\text{or, } I_{in} = \frac{V_{in}}{R_{in}}$$

From the circuit, $I_{in} = -I_f$

We know that the capacitor charge is equal to product of the capacitance and the input voltage so,

$$Q = CV$$

Therefore the change in charge rate is

$$\text{or, } \frac{dq}{dt} = C \cdot \frac{dv_{out}}{dt} \; [V_c = \text{capacitor voltage} = V_{out}]$$

$$\text{or, } I_f . dt = C . dv_{out}$$

$$\text{or, } dv_{out} = \frac{I_f}{c} \cdot dt$$

Integrating both sides, we get

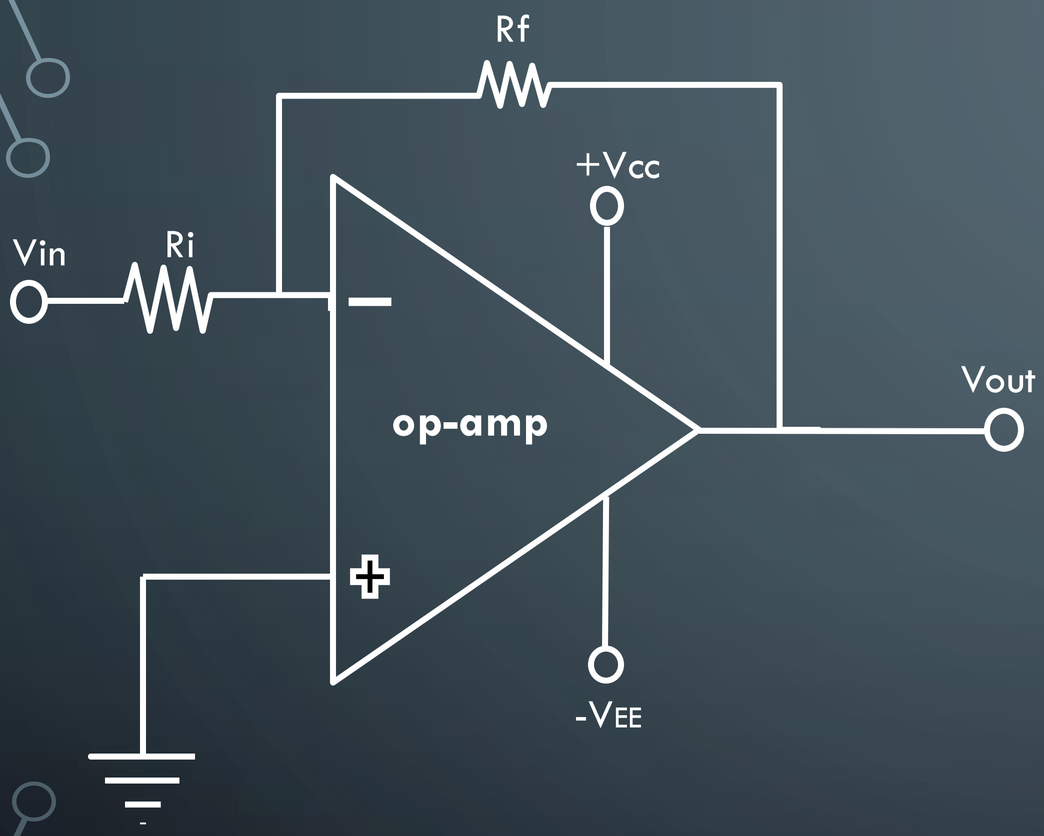
$$\text{or, } \int \boldsymbol{dv_{\text{out}}} = \int \frac{I_f}{C} \cdot \boldsymbol{dt}$$

$$\text{or, } V_{out} = -\int \frac{v_{in}}{R_{in}} . \frac{1}{C} dt$$

$$\text{or, } V_{out} = -\frac{1}{R_{in} \cdot C} \int V_{in} \cdot dt$$

So, the output voltage, $V_{out} = -\frac{1}{\mathrm{R} \cdot C} \int V_{in} \cdot dt$

OP-AMP AS SCALE CHANGER



OP-AMP as Scale Changer

A **Scale Changer** circuit is a circuit which produces output voltage in opposite phase of the given input. This circuit is just like an inverting mode circuit where the inverting input is connected to a voltage source and the non-inverting end is grounded.

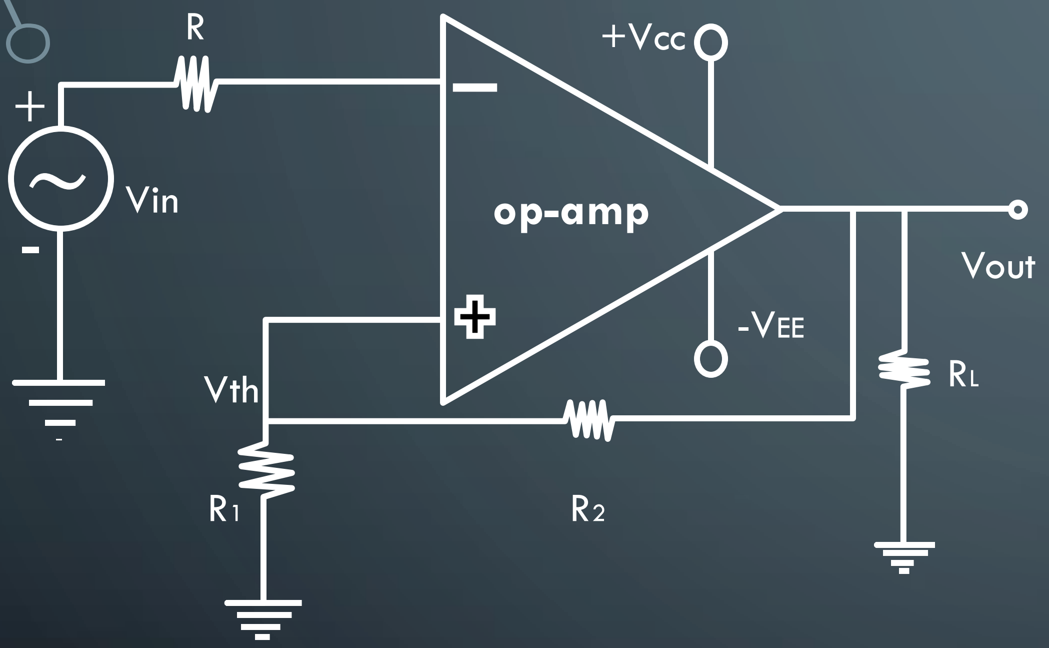
Now, we can say that for this circuit

$$V_{\text{out}} = -V_{in} \cdot \left(\frac{R_f}{R_i}\right)$$

Here, if Rf=Ri=r, then we can say, V_{out}=-V_{in}

As said above this circuit should produce an output in the opposite phased of the input. This is why it is called **Scale Changer**, also known as **Voltage Follower Circuit.**

OP-AMP AS SCHMITT TRIGGER



OP-AMP as Schmitt Trigger

Schmitt trigger is a positive feedback circuit. Therefore, it is called regenerative comparator which compares the supply voltage applied at the inverting terminal with respect to a threshold voltage (V_{th}) where ,

$$V_{\text{th}} = \left(\frac{R_2}{R_1+R_2}\right) \cdot Vout$$

This V_{th} is used as a reference voltage, 'Vref',

When $V_{out} = +V_{sat}$, $V_{\text{ref}} = \left(\frac{R_2}{R_1+R_2}\right) \cdot Vsat = Vut$ [Upper threshold Voltage]

for $V_{out} = -V_{sat}$, $V_{\text{ref}} = -\left(\frac{R_2}{R_1+R_2}\right) \cdot Vsat = Vlt$ [Lower threshold Voltage]

As the input of the op-amp changes from Vut to Vlt the output changes from $+V_{sat}$ to $-V_{sat}$