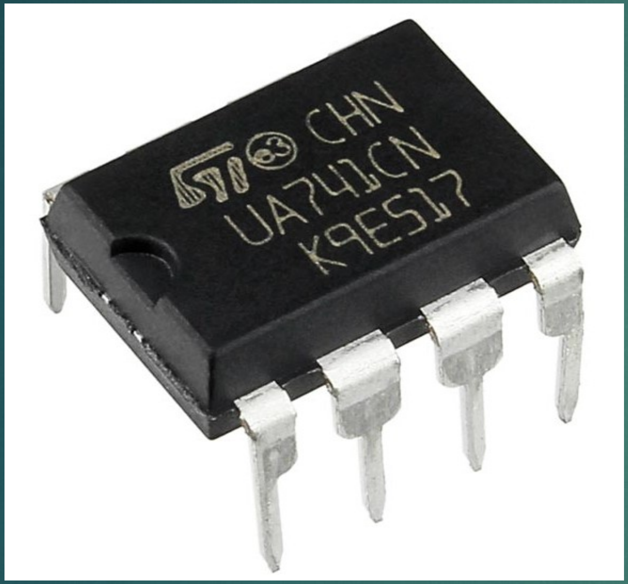
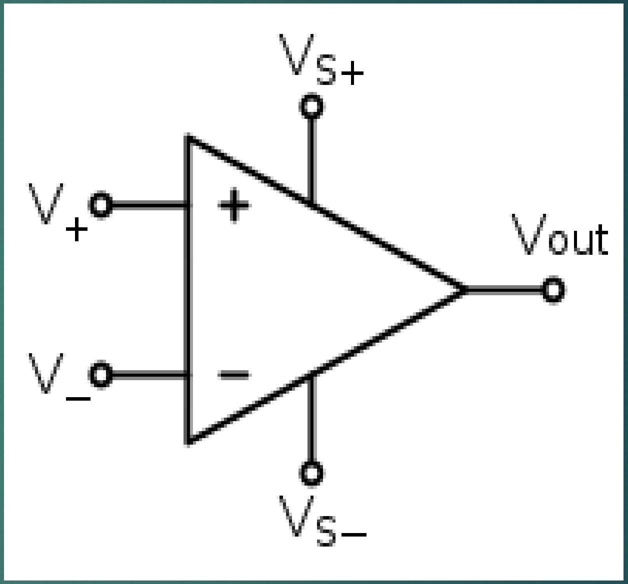
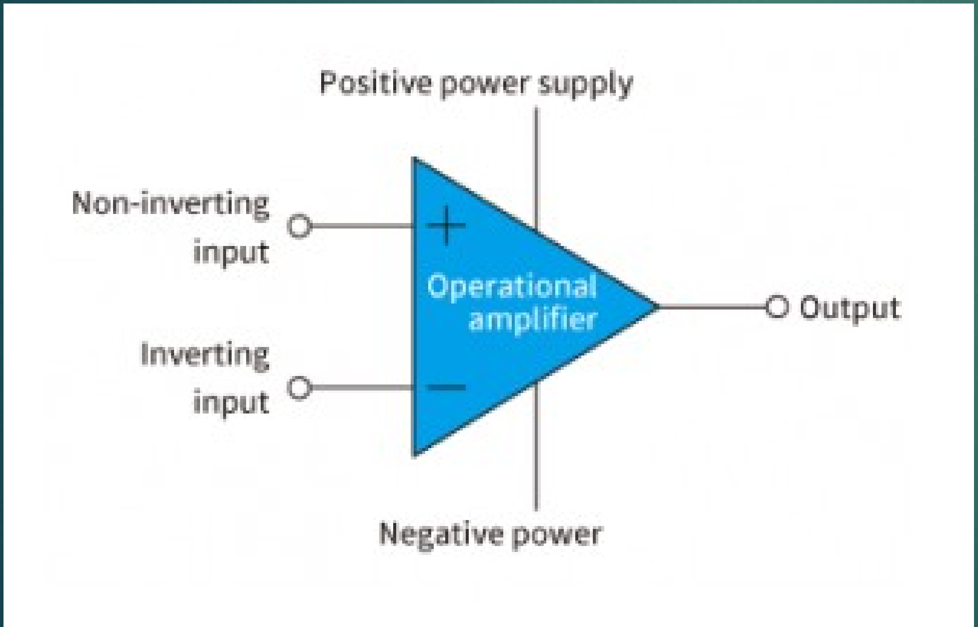
Operational Amplifier

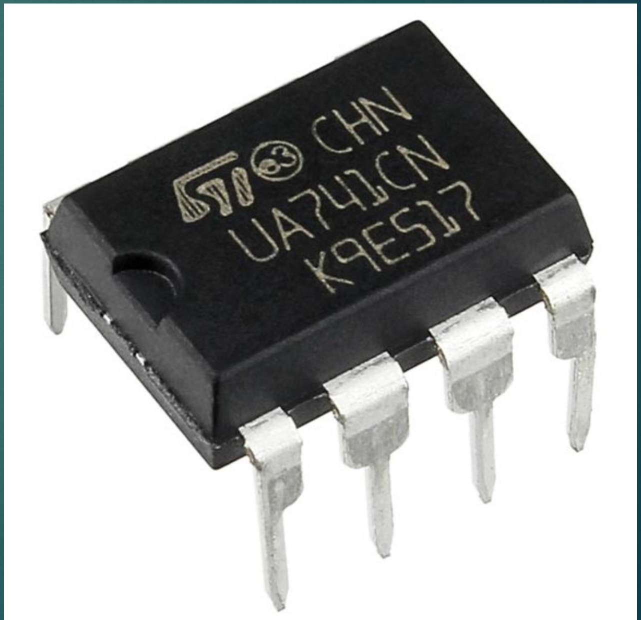




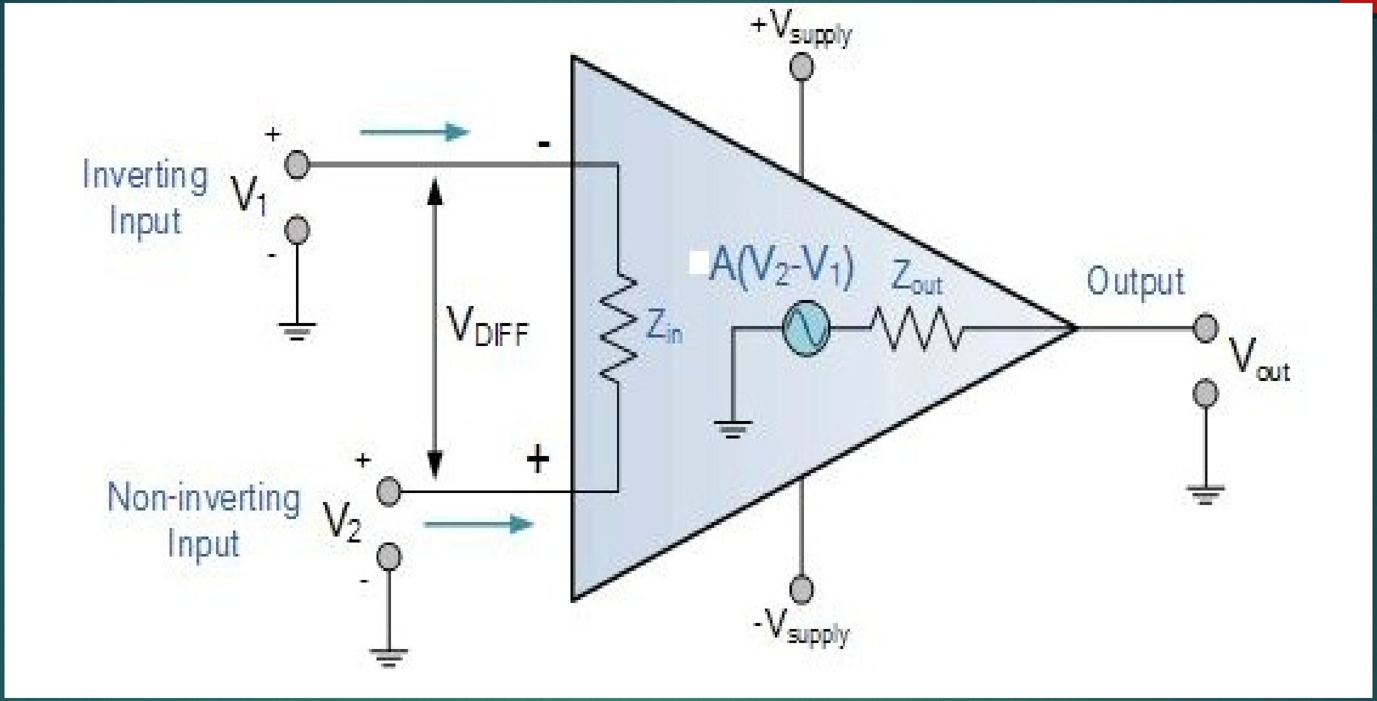
Operational Amplifier

An operational amplifier is an integrated circuit that can be used to amplify weak electrical signals. It has two input pins and one output pin. Its basic role is to amplify and output the voltage difference between the two input pins.





Equivalent Circuit



The amplifier's differential inputs consist of a non-inverting input with voltage (V+) and an inverting input with voltage (V−). Ideally, an op-amp amplifies only the difference in voltage between the two, also called differential input voltage. The output voltage of the op-amp V_{out} is given by the equation:

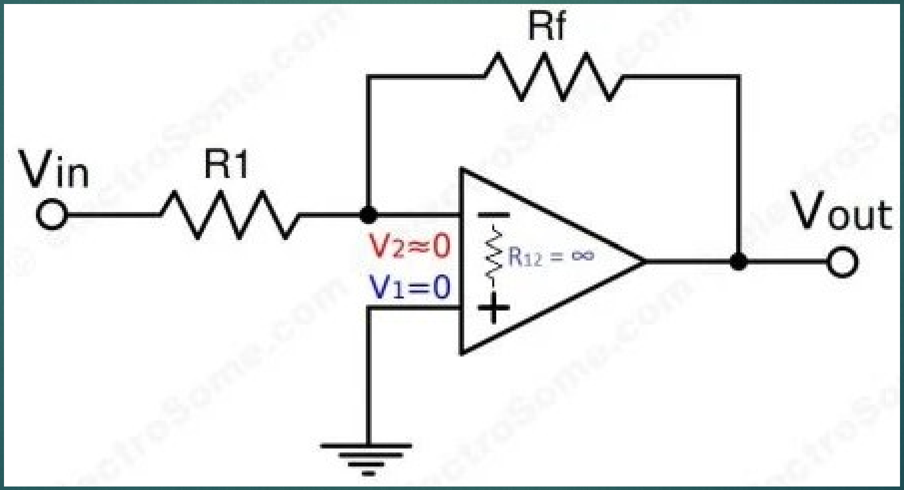
$$V_{out} = A_{OL} (V_+ - V_-)$$

CHARACTERISTICS OF AN IDEAL OP- AMP

- Infinite voltage gain A
- Infinite input resistance Z_{in}
- Zero output resistance Z_{out}
- Zero output voltage when input voltage is zero
- Infinite bandwidth
- Infinite common mode rejection ratio so that the output common mode noise voltage is zero

Virtual Ground Concept

- In Op-Amps **the term virtual ground means that the voltage at that particular node is almost equal to ground voltage** (0V). It is **not** physically connected to ground.
- This concept is very useful in analysis of Op-Amp circuits and it will make a lot of calculations very simple.

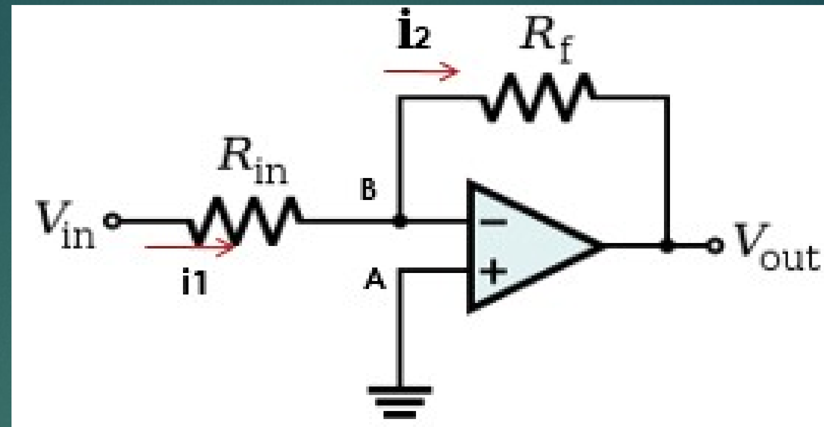


Virtual Ground Concept

- **Virtual Ground concept is very useful in analysis of an Op-Amp when negative feedback is employed. It will simply a lot of calculations and derivations.**
- **An ideal Op-Amp will provide infinite voltage gain. For real Op-Amps also the gain will be very high.**
- **Gain = Vo/Vin**
- **As gain is infinite, Vin = 0**
- **Vin = V2 – V1**
- **In the previous circuit V1 is connected to ground, so V1 = 0. Thus V2 also will be at ground potential.**

V2 = 0

Inverting Operational Amplifier



To solve OP-Amp circuits we have to apply virtual ground concept i.e. Whatever is the potential at point A the same potential will be at point B.

Say the potential at point A is V_a and the potential at point B is V_b

Then $V_a = V_b = 0V$

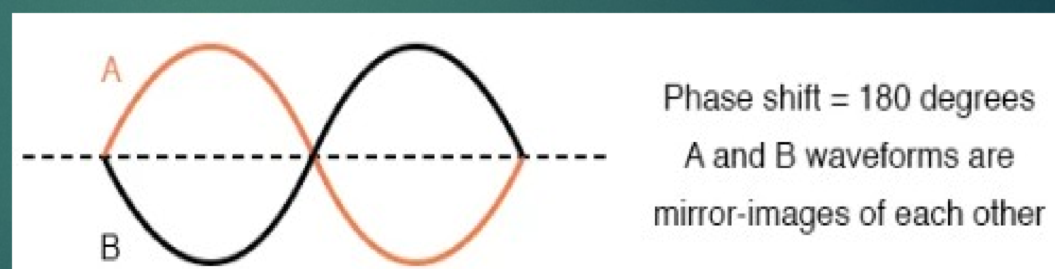
Applying KCL at point B

$i_1 = i_2$

$$\frac{V_{in} - 0}{R_{in}} = \frac{0 - V_{Out}}{R_f}$$

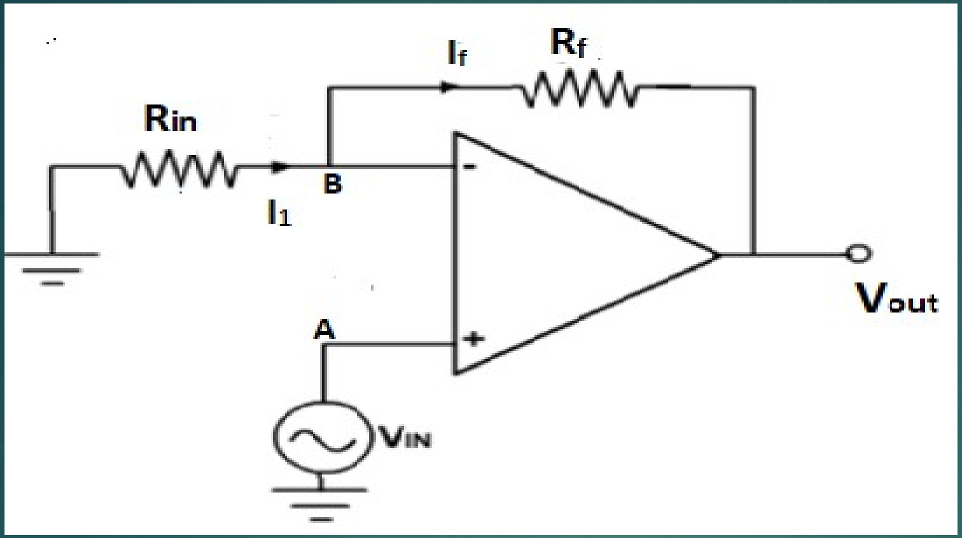
Solving we get

$$V_{Out} = -\frac{R_f}{R_{in}} V_{in}$$



As there is a negative sign at the output which means that the output is 180 degrees phase shifted from that of input i.e why the name inverting Op-Amp.

Non-Inverting Operational Amplifier



In this case the signal is applied to the positive i.e. non inverting terminal of the Op-Amp.

Potential at point A=potential at point B=V_{IN}

Applying KCL at point B and solving the circuit we get: $I_1=I_f$

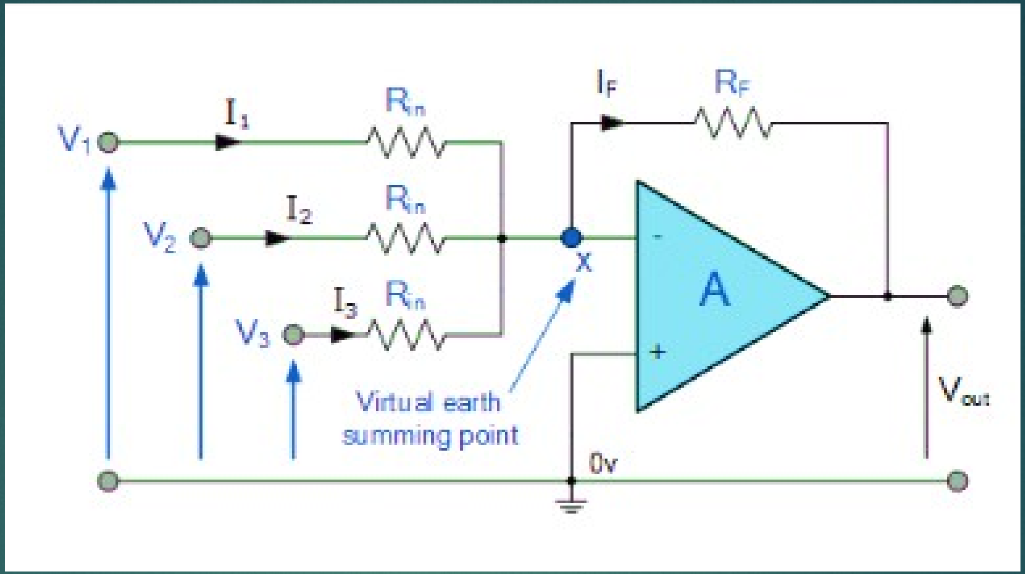
$$\frac{0-V_{IN}}{R_{in}}=\frac{V_{IN}-V_{Out}}{R_f}$$

Solving we get

$$V_{Out}=\left(1+\frac{R_f}{R_{in}}\right)V_{IN}$$

Since there is no change in sign in the output hence the output is in same phase to that of input i.e. why the name non- inverting

Summing Amplifier



In this simple summing amplifier circuit, the output voltage, (V_{out}) becomes proportional to the sum of the input voltages, V_1, V_2, V_3, etc.

$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin}\right]$$

$$\text{Inverting Equation: } Vout = -\frac{Rf}{Rin} \times Vin$$

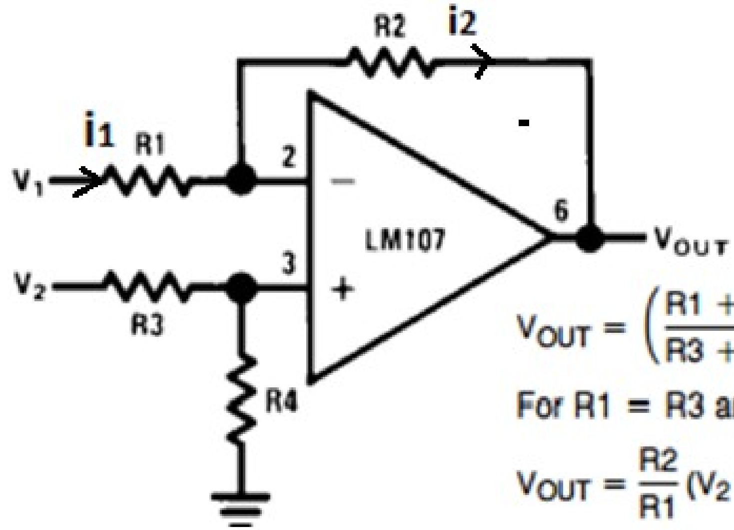
$$\text{then, } \quad Vout = -\left[\frac{R_F}{Rin}V1 + \frac{R_F}{Rin}V2 + \frac{R_F}{Rin}V3\right]$$

$$R_F = R_{in}$$

$$V_{out} = -(V_1 + V_2 + V_3)$$

Difference Amplifier

In a difference amplifier we will get output as the difference of the two inputs multiplied by the gain of the Op-Amp.



$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1}V_2 - \frac{R2}{R1}V_1$$

For R1 = R3 and R2 = R4

$$V_{OUT} = \frac{R2}{R1}(V_2 - V_1)$$

First find out the potential across R4

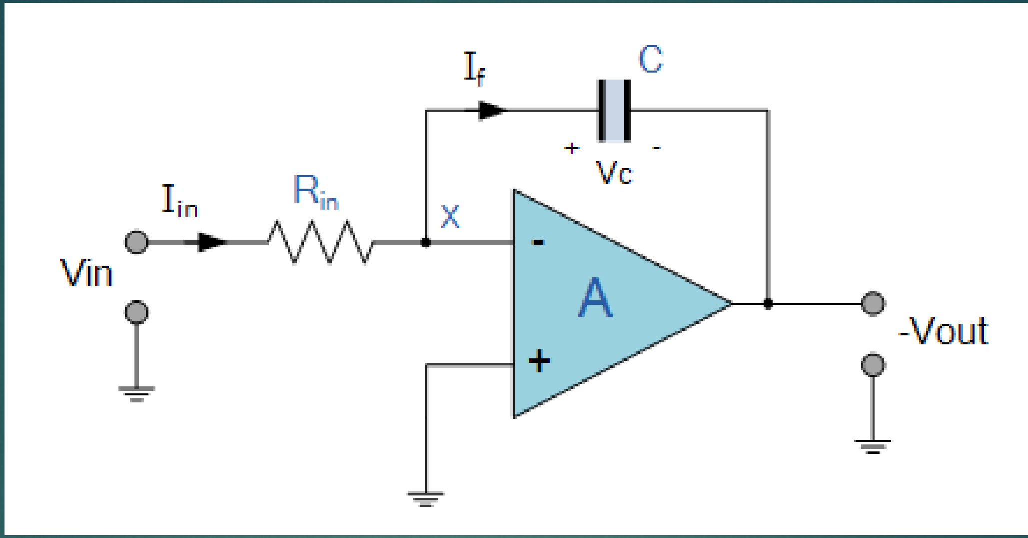
$$V_4 = \frac{R_4}{R_3 + R_4}V_2$$

According to virtual ground concept the same potential will be at point 2 .

Thereafter solve the problem by applying KCL at point 2.

$$V_1 - \frac{R_4}{R_3 + R_4}V_2 = \frac{R_4}{R_3 + R_4}V_2 - V_{out}$$

Integrator



An **Integrator** is a circuit that performs the mathematical operation of **Integration**, that is we can cause the output to respond to changes in the input voltage over time as the op-amp integrator produces an *output voltage which is proportional to the integral of the input voltage*.

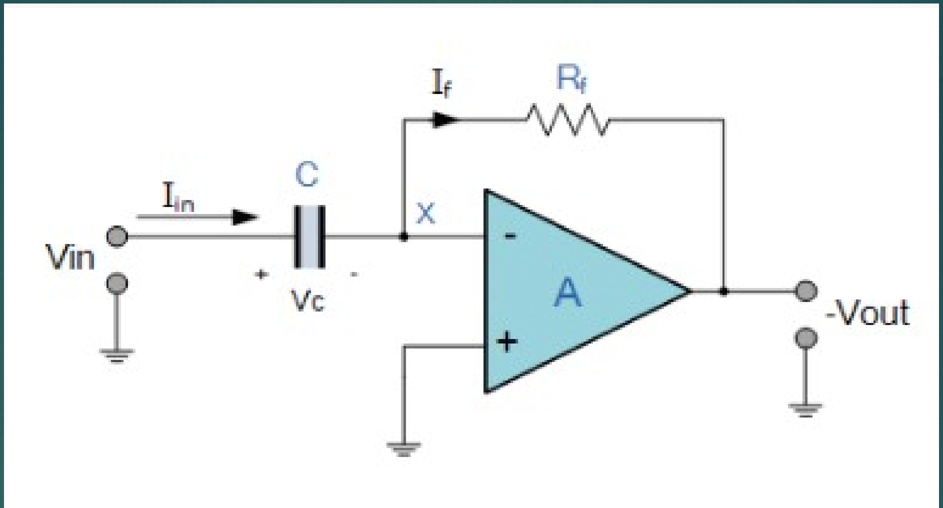
$$I_{IN} = I_F$$

$$I_{in} = \frac{V_{in} - 0}{R_{in}} = \frac{V_{in}}{R_{in}}$$

$$I_f = - C\frac{dV_{out}}{dt}$$

$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\,dt$$

Differentiator



This operational amplifier circuit performs the mathematical operation of **Differentiation**, that is it "*produces a voltage output which is directly proportional to the input voltage's rate-of-change with respect to time*".

$$I_{IN} = I_F \text{ and } I_F = -\frac{V_{OUT}}{R_F}$$

$$I_{IN} = C\frac{dV_{IN}}{dt} = I_F$$

$$\therefore -\frac{V_{OUT}}{R_F} = C\frac{dV_{IN}}{dt}$$

$$V_{OUT} = -R_F C\frac{dV_{IN}}{dt}$$

CMRR

- The op amp common-mode rejection ratio (CMRR) is the ratio of the common-mode gain to differential-mode gain.

$$CMRR = \frac{A_D}{A_{CM}}$$

- Common-mode voltage gain refers to the amplification given to signals that appear on both inputs. You will recall from a previous discussion that a differential amplifier is designed to amplify the difference between the two voltages applied to its inputs. Thus, if both inputs had +5 volts, for instance, with respect to ground, then the difference would be zero. Similarly, the output would be zero. This means the output is unaffected by voltages that are common to both inputs.
- Differential Amplifier Gain A_D is given by

  $A_D = V_{OUT} / (V_1 – V_2) = R_2 / R_1$

For an ideal Difference Amplifier, the common mode voltage gain is zero. Hence, the CMRR is infinite.

Instrumentation Amplifier

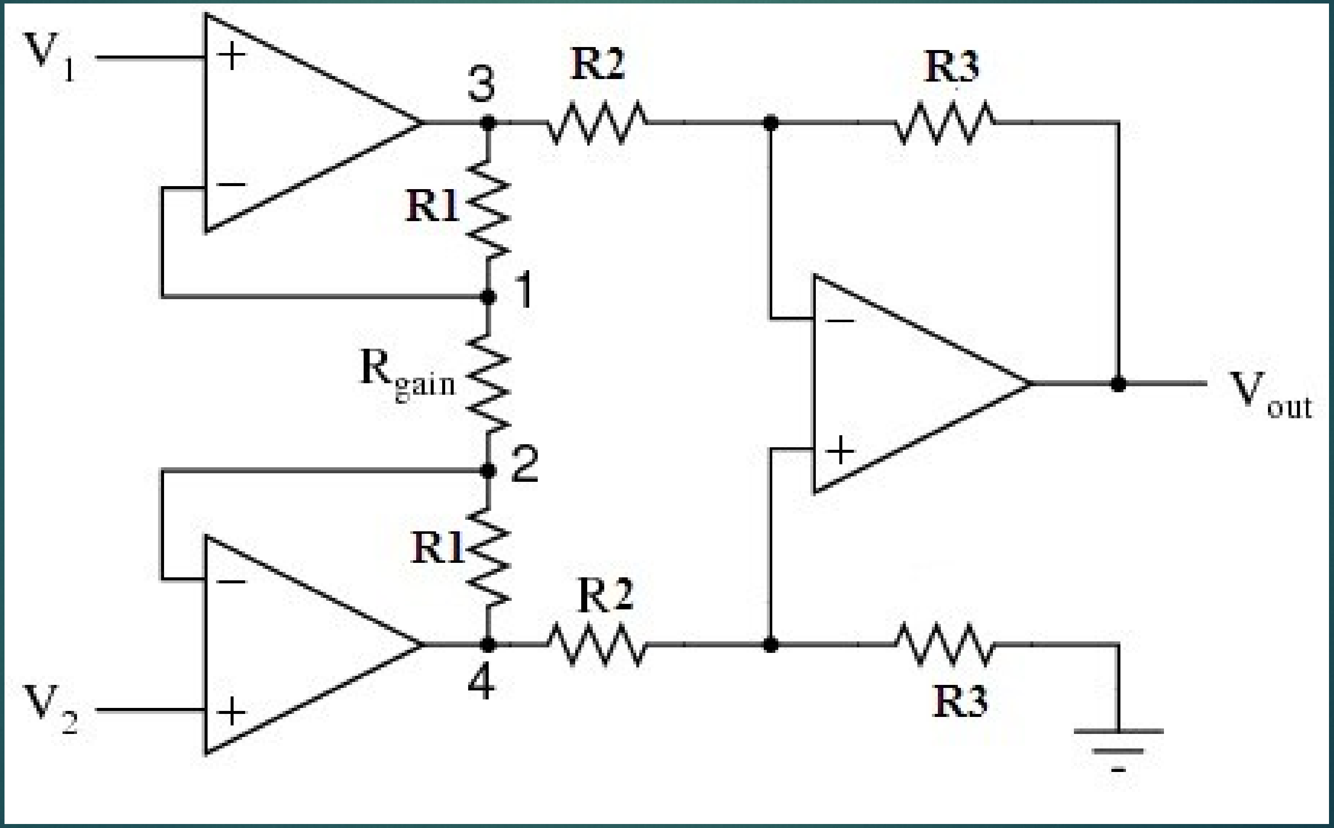
Instrumentation amplifier is a kind of differential amplifier with additional input buffer stages. The addition of input buffer stages makes it easy to match (impedance matching) the amplifier with the preceding stage. It is designed in such a way that while amplification of the signal, it eliminates the noise and the interference. Instrumentation are commonly used in industrial test and measurement application.

The instrumentation amplifier also has some useful features like:

- low offset voltage
- high CMRR (Common mode rejection ratio)
- high input resistance
- high gain etc.

Instrumentation Amplifier Circuit

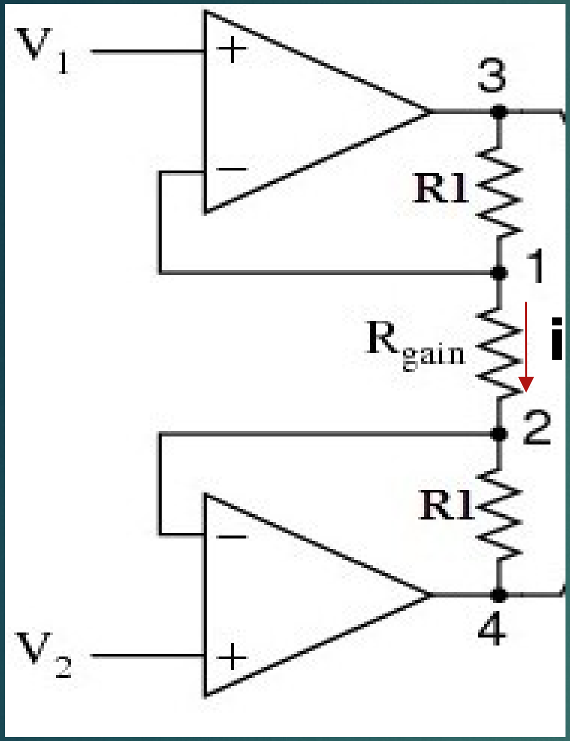
It consists of two non-inverting amplifiers along with a differential amplifier. The intention is to design an amplifier with a high CMRR value along with the maximum undistorted value of signals.



Working

- The initial amplifiers like non-inverting ones are considered as the buffers. It can be evident from the circuit that for those two buffers three resistors are connected.
- The values of the resistors connected in the circuit will be equal. Except for the resistor R_{gain}.
- At point 1 in the circuit, the voltage will be considered as V1.
- Similarly, at point 2, the voltage will be considered equal to V 2.
- The potential drop generated at the R_{gain} is the difference between the voltages V_1 and V_2.
- Because of this reason the current flow through that point that is through R_{gain}. This indicates that there is no current flow is observed through the feedback.
- Then this results in the same amount of the current flow through resistors that are connected above and below in the circuit.

Instrumentation Amplifier Derivation



input-stage-of-the-instrumentation-amplifier

From the input stage, it is clear that due to the concept of virtual nodes, the voltage at node 1 is V_1. Similarly, the voltage at the node in the above circuit is V2. Initially, the current through the op-amps considered zero. Hence no current can flow through the resistors. The current I is given by:

$$I=(V_1-V_2)/R_{gain} \qquad (1)$$

Also

$$V_3-V_4=I(R_1+R_1+R_g)$$

$$V_3-V_4=I(2R_1+R_{gain}) \qquad (2)$$

From the second stage of the Amplifier circuit

$$V_{out}=-R_3/R_2[V_3-V_4] \qquad (3)$$

Put the value of (2) in (3) and using (1) the expression for V_{out} becomes:

$$V_{out}=(V_2-V_1)[1+2(R_1/R_{gain})]xR3/R_2$$

Applications

- The instrumentation amplifier applications involve when the environment possesses high noise. The requirement of this amplifier is to achieve high gain. The applications of these amplifiers are as follows
- In the amplification of the signals with the high frequency, these amplifiers are preferred.
- In the systems where the acquisition of the data is required these amplifiers are utilized.
- Practically, in the design of the light intensity meters, temperature control systems these amplifiers are used.

THANK YOU