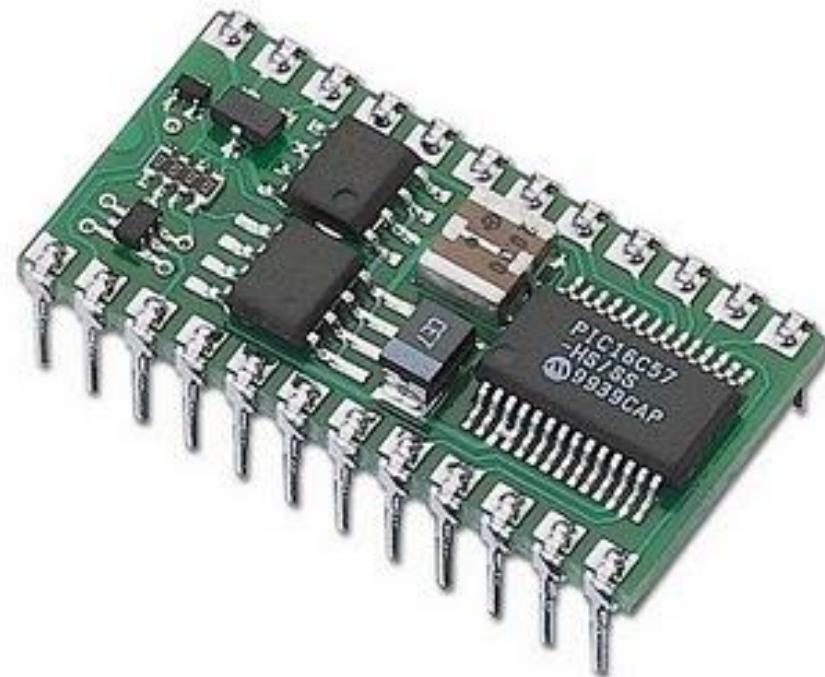


Operational Amplifiers

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INTEGRATED CIRCUITS:



An integrated circuit is a combination of components like resistors, capacitors, diodes, transistors, etc. and their interconnections, fabricated into an extremely tiny single chip of silicon.

Integrated circuits are classified into linear and digital circuits according to their mode of operation.

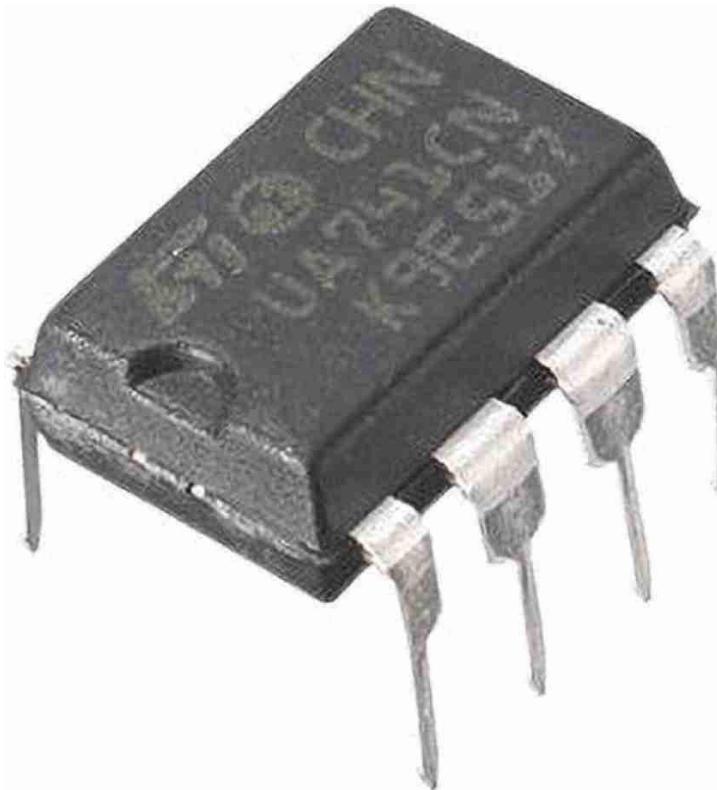
A general-purpose linear IC is found in operational amplifiers (op-amps).

With some suitable external components like resistors and capacitors, op-amps are used in amplifiers, integrators, differentiators, in filters and other such applications.

A general-purpose op-amp is numbered IC 741.

Digital ICs find applications in switching circuits, flip-flops, counters, registers, microprocessors, clock chips, calculator chips, memory chips, etc.

OPERATIONAL AMPLIFIER:



An operational amplifier is abbreviated as op-amp.

It is called as operational amplifier because originally these were used in analog computers for performing operations like integration, subtraction, differentiation, etc.

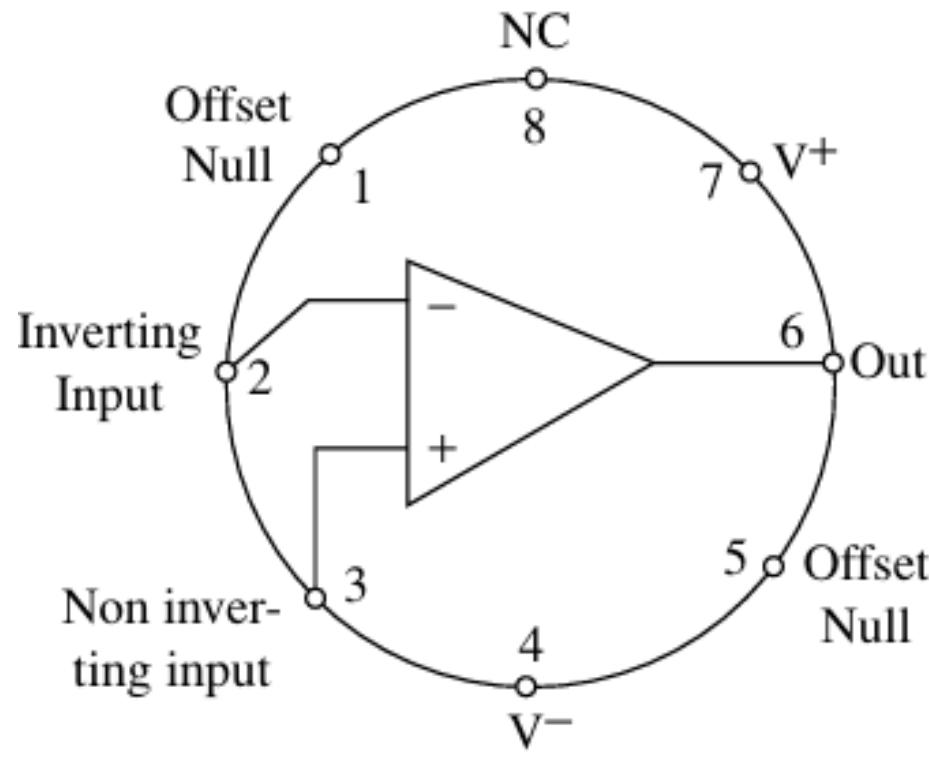
However, op-amps can also be used in signal amplification, filters, oscillators, voltage regulators, analog to digital (A to D) and digital to analog (D to A) converters, etc.

An op-amp is a high-gain directly coupled linear differential amplifier.

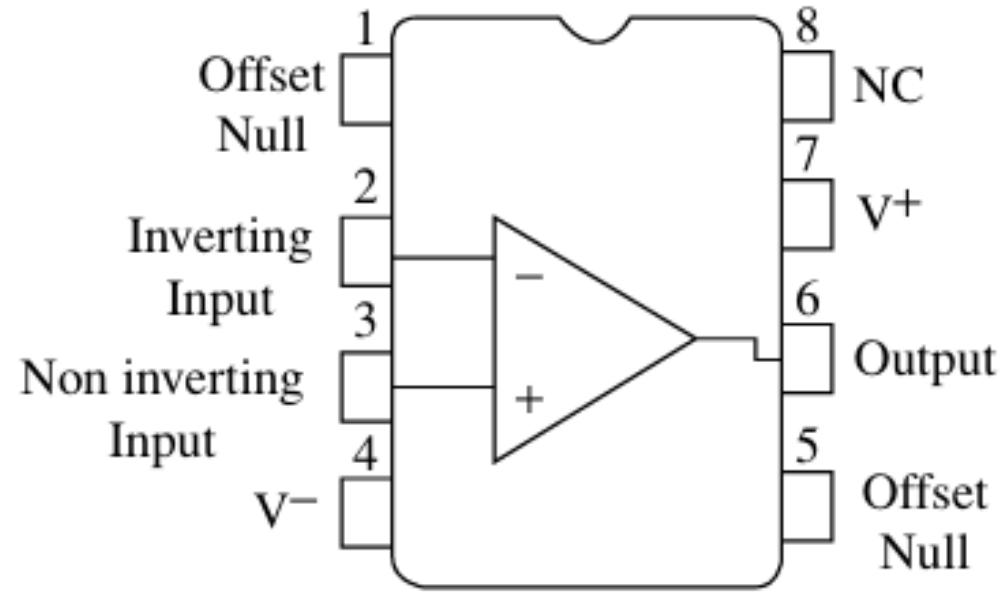
It is called a differential amplifier because it amplifies the difference between the two input signals.

An op-amp amplifies both ac and dc input signals.

OPERATIONAL AMPLIFIER:



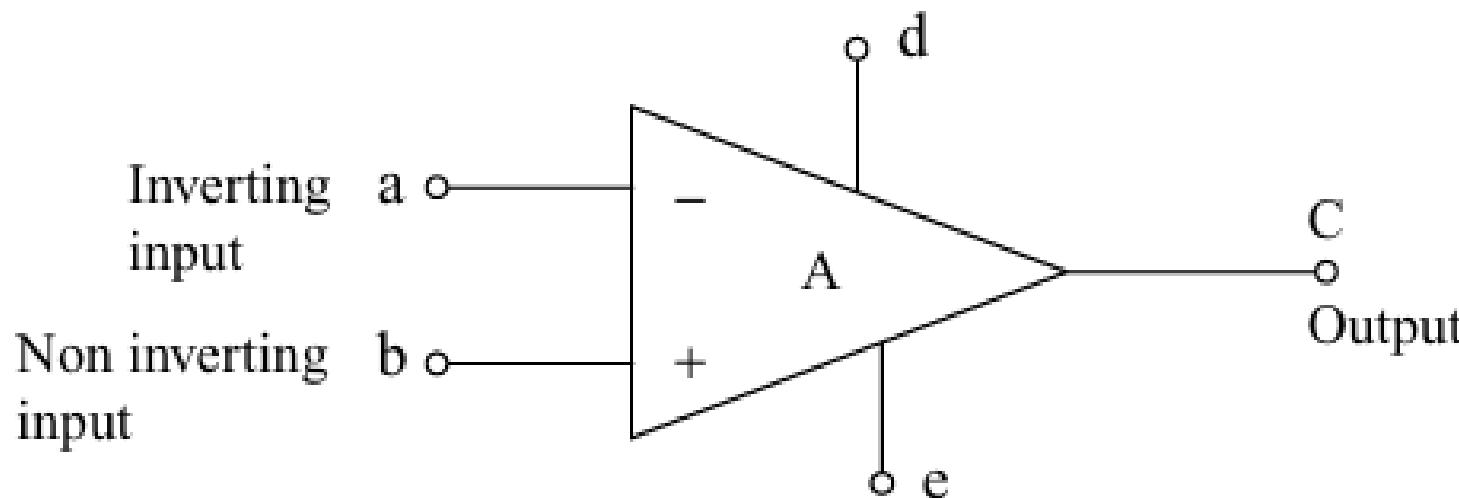
(a)



(b)

Pin diagrams of IC op-amp 741 (a) 8-pin metal can package (b) 8-pin mini dip package

OPERATIONAL AMPLIFIER:



Symbolic representation of a basic op-amp

The input terminals are marked a and b (terminals 2 and 3 respectively).

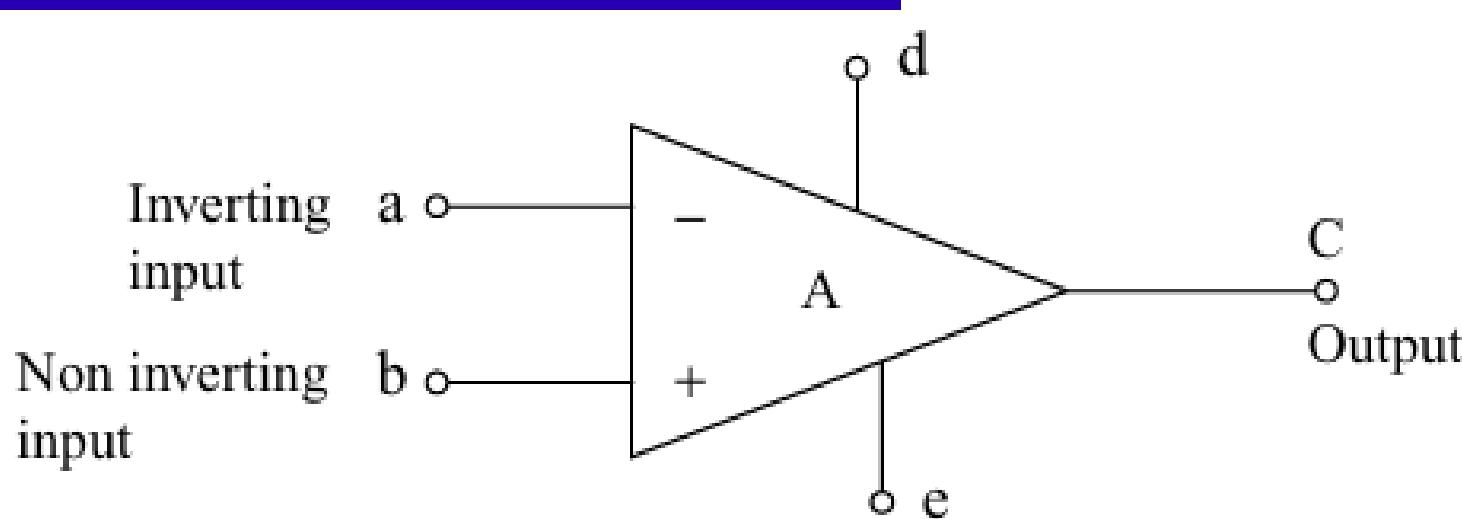
Terminal a is marked negative while terminal b is marked positive.

Terminal a is the inverting terminal, the input provided at this terminal appears inverted at the output with amplification.

Terminal b is non-inverting, the output for input at b appears non-inverted but amplified.

When signals are provided at both a and b terminals, the output at terminal c (terminal 6) is proportional to the difference of the two signals.

OPERATIONAL AMPLIFIER:

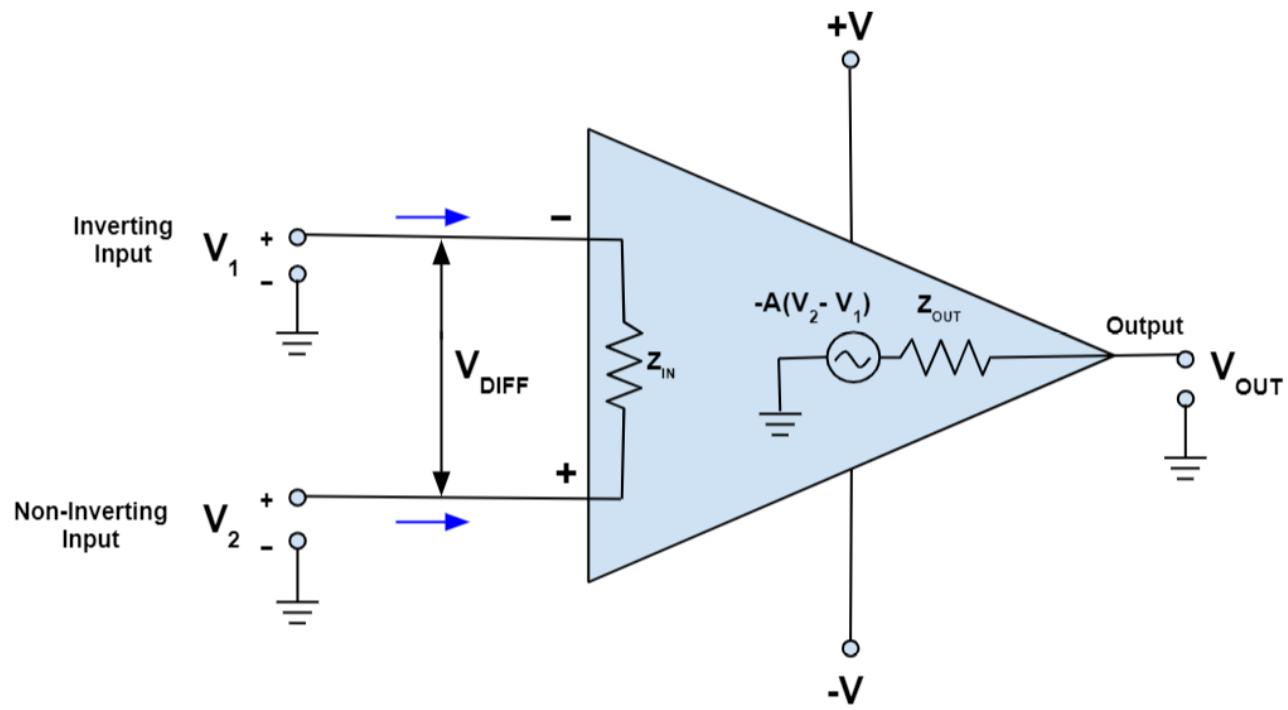


Symbolic representation of a basic op-amp

The power supply voltages which are usually balanced with respect to the ground are applied to terminals d and e (terminals 7 and 4).

Terminals d and e are often not shown in the circuit diagrams using op-amps.

OPERATIONAL AMPLIFIER:



An ideal op-amp has the following characteristics:

- 1) Infinite input impedance Z_{in} (practical op-amp will have finite but very high input impedance)
- 2) Zero output impedance Z_{out} (very low output impedance in case of practical op-amp.)
- 3) Infinite voltage gain A (practical op-amp will have very high voltage gain)
- 4) Infinite bandwidth (finite bandwidth in case of practical Op-amp).
- 5) Perfect balance, i.e., output is zero when both the inputs are equal. (A practical op-amp may not have perfect balance)

OPERATIONAL AMPLIFIER:

Negative feedback in op-amp:

The Open Loop Gain, (A) of an operational amplifier can be very high, as much as 1,000,000 or more.

However, this very high gain is of no real use.

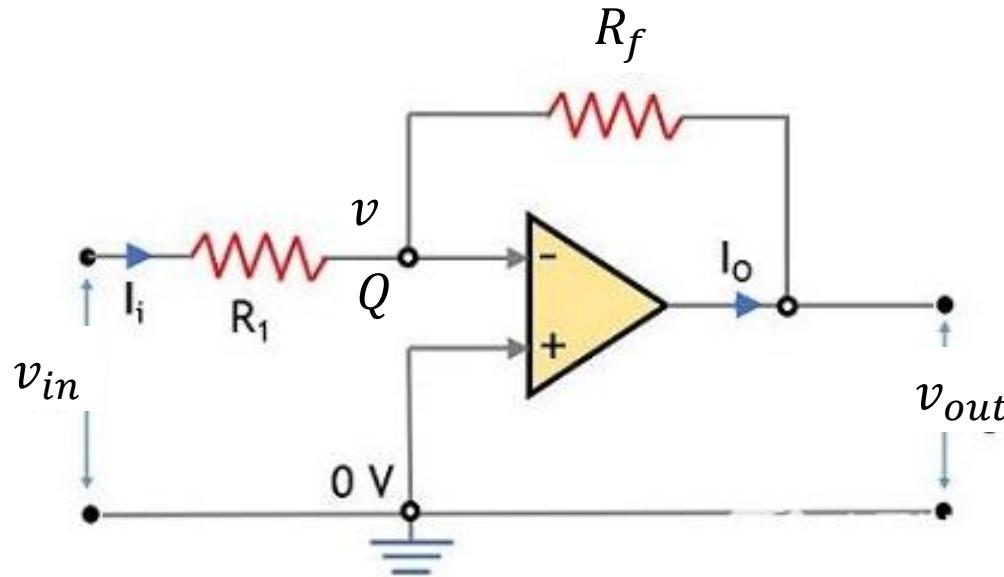
The input voltage of few μV makes the output voltage to saturate and swing towards the supply voltage, i.e., $+V$ or $-V$.

Thus the high open loop gain makes the amplifier unstable and hard to control.

To reduce and control the overall gain of the amplifier and to obtain a stable op-amp based system, a suitable resistor is connected from the output terminal back to the inverting input terminal (Negative feedback).

Negative feedback in an op amp is defined as connecting the output to the inverting input through a resistor to control the gain.

INVERTING OPERATIONAL AMPLIFIER:



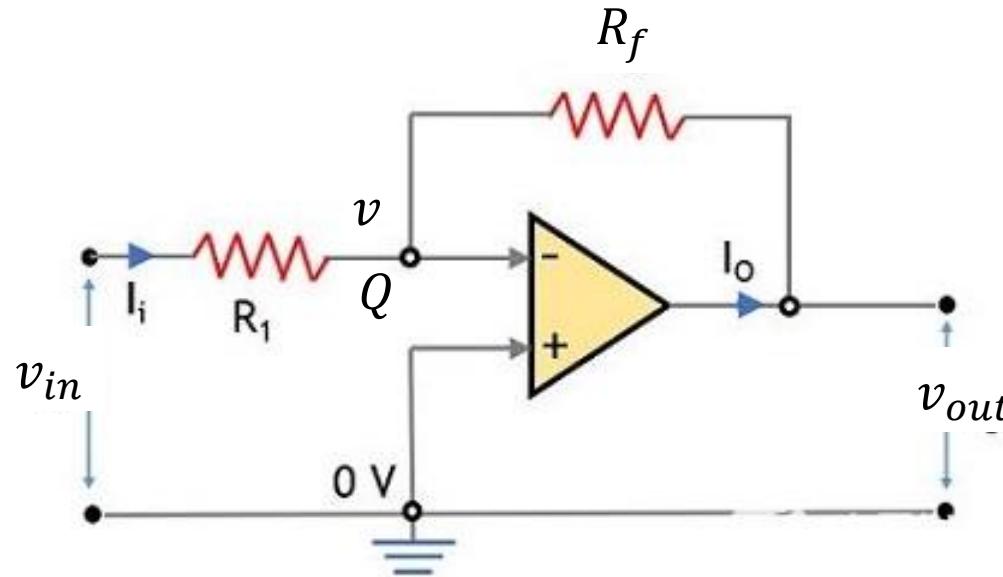
The output terminal is connected to the inverting input terminal through a feedback resistance R_f .

The non-inverting terminal is connected to the ground.

The input voltage is v_{in} and the output voltage is v_{out} .

The voltage at point Q is v .

INVERTING OPERATIONAL AMPLIFIER:



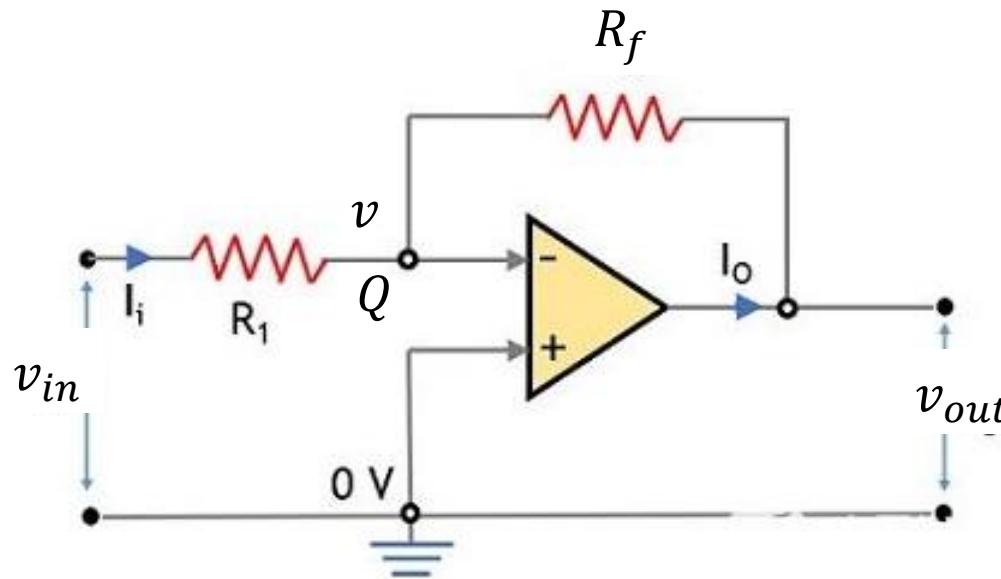
As the noninverting input is connected to the ground, the differential voltage input to the amplifier is v .

$$\therefore v_{out} = Av \quad \text{or, } v = \frac{v_{out}}{A}$$

As the open loop gain, A of the amplifier is infinite, if A tends to infinity, v will tend to zero.

Thus, the potential of point Q can be considered as zero, also referred as a virtual ground.

INVERTING OPERATIONAL AMPLIFIER:



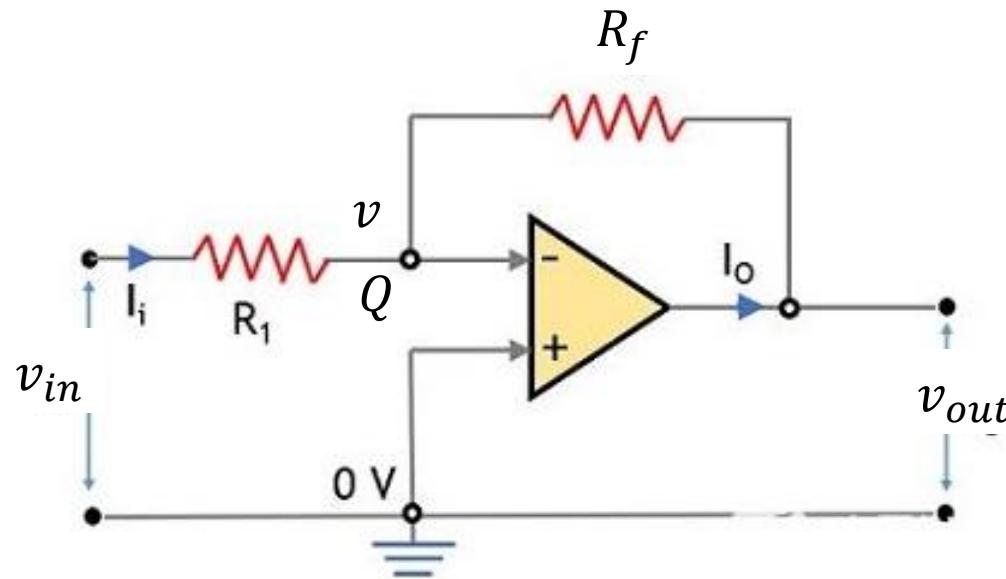
The current through resistance R_1 is $I_i = \frac{v_{in} - v}{R_1}$

As the input impedance of op-amp is infinite, op-amp will not allow any current to flow through it.

Therefore, the same current I_i will flow through R_f .

$$\therefore I_i = \frac{v_{in} - v}{R_1} = \frac{v - v_{out}}{R_f} = \frac{v_{in}}{R_1} = \frac{-v_{out}}{R_f}$$

INVERTING OPERATIONAL AMPLIFIER:

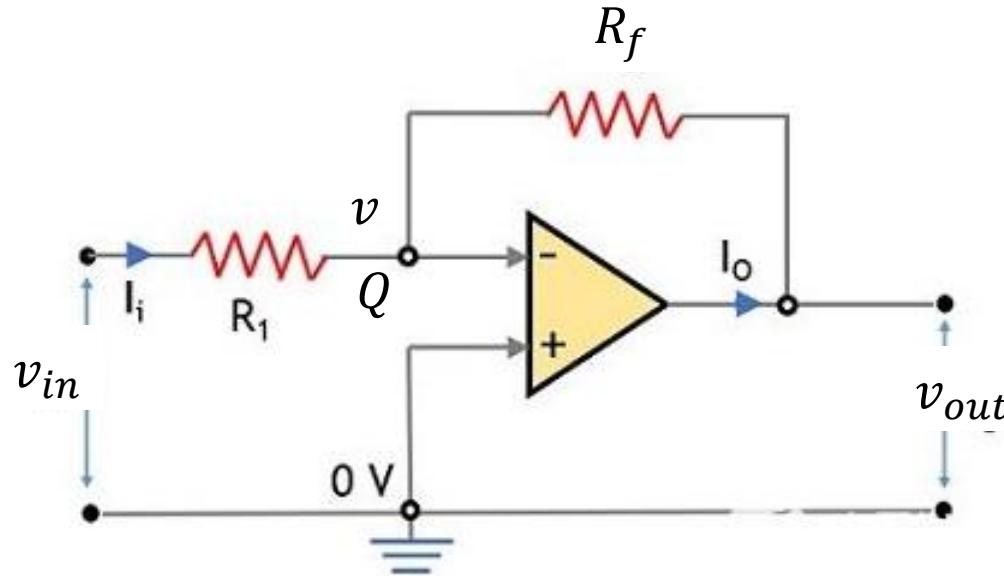


$$\therefore v_{out} = - \left(\frac{R_f}{R_1} \right) v_{in}$$

Therefore, the closed loop voltage gain of the inverting operational amplifier circuit is $- \left(\frac{R_f}{R_1} \right)$.

The negative sign indicates that the output voltage is inverted.

EXAMPLE:



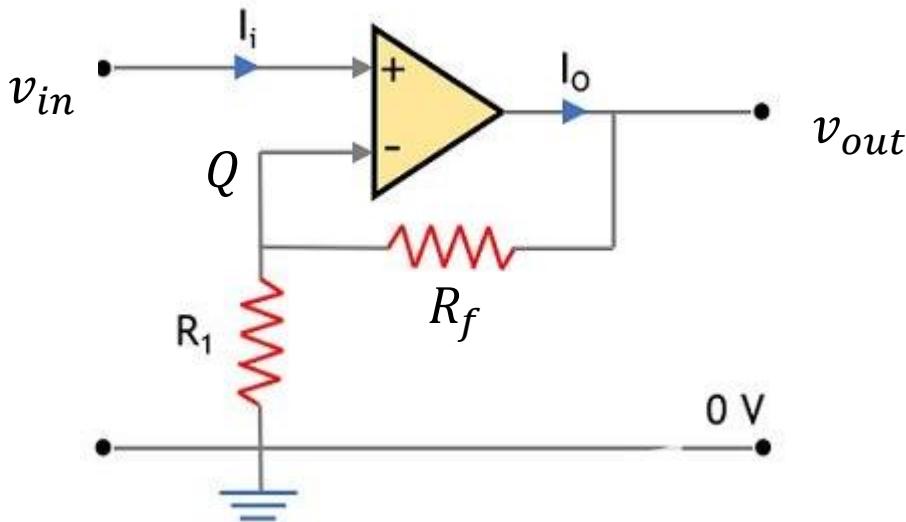
If $R_1 = 10 \text{ k}\Omega$ and $R_f = 47 \text{ k}\Omega$, determine the voltage gain of the op-amp circuit.

The configuration is inverting amplifier; therefore, the voltage gain is $-\left(\frac{R_f}{R_1}\right)$

$$Gain = \frac{v_{out}}{v_{in}} = -\left(\frac{R_f}{R_1}\right) = -\frac{47 \times 10^3}{10 \times 10^3} = -4.7$$

The negative sign indicates that the output voltage is inverted.

NON-INVERTING OPERATIONAL AMPLIFIER:



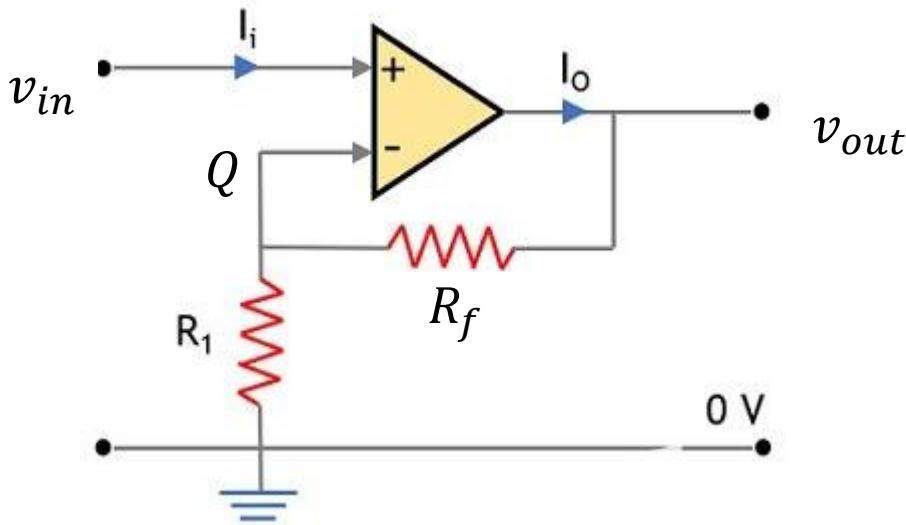
In noninverting operational amplifier, the input signal is applied at the non-inverting terminal of the amplifier.

Thus, the output is in phase with the input.

The negative feedback is provided by applying a small part of the output voltage signal back to the inverting (-) input terminal through a potential divider circuit formed by R_f and R_1 .

The output voltage can be calculated as $v_{out} = \left(1 + \frac{R_f}{R_1}\right) v_{in}$

EXAMPLE:



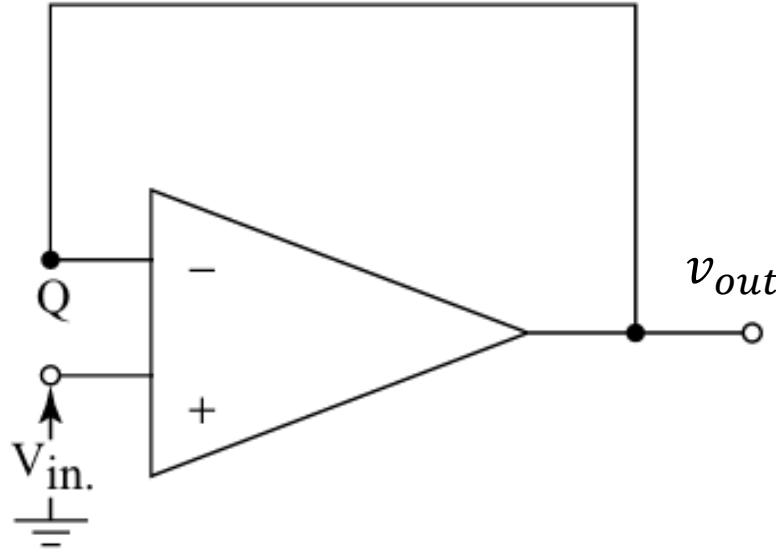
For the op-amp configuration shown, if $R_1 = 1 \text{ k}\Omega$ and the required gain is 61. Determine the appropriate value of feedback resistance R_f .

$$Gain = \frac{v_{out}}{v_{in}} = \left(1 + \frac{R_f}{R_1}\right)$$

$$\therefore 61 = \left(1 + \frac{R_f}{1 \times 10^3}\right)$$

$$\therefore R_f = 60 \times 1 \times 10^3 = 60 \text{ k}\Omega$$

VOLTAGE FOLLOWER (UNITY GAIN BUFFER):



In voltage follower, the feedback resistance R_f has been made zero.

As it is a noninverting amplifier circuit, the output voltage is, $v_{out} = \left(1 + \frac{R_f}{R_1}\right) v_{in}$

$$\therefore v_{out} = (1 + 0)v_{in} = v_{in}$$

Thus, this circuit is called a unity gain voltage follower.

Such a circuit is used for impedance matching in electronic devices and circuits.

Thank You