Question Answer on Op-amp

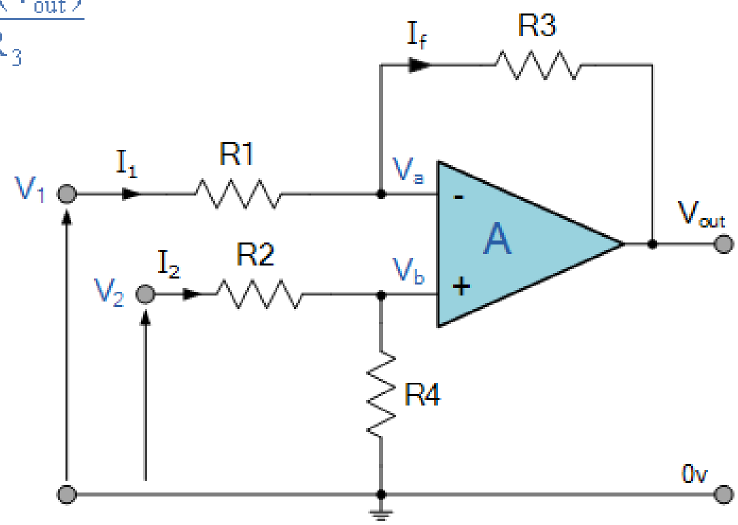
❖ What is op-amp?

The operational amplifier (OPAMP) is a direct coupled amplifier with very high voltage gain, very high input impedance and very low output impedance. It consists of two input terminals, one of which inverts the phase of the signal, the other preserves the phase, and an output terminal.

❖ What is differential amplifier?

Differential amplifier is an amplifier which amplify the difference between two input signals.

$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2}, \quad I_f = \frac{V_a - (V_{out})}{R_3}$$



$$\text{Summing point } V_a = V_b$$

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

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

$$\text{If } V_1 = 0, \text{ then: } V_{out(b)} = V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$$

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

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

When $R_2 = R_1$ and $R_4 = R_3$ then above equation become -------- $V_{OUT} = \frac{R_3}{R_1}(V_2 - V_1)$

❖ What is unity gain amplifier?

In case of closed loop gain input and output impedance of a differential amplifier become same then voltage gain of the amplifier be 1. That condition is called **unity gain**. In case of unity gain amplifier output and input signal voltage become same.

When $R_1 = R_3$ then $V_{out} = (V_2 - V_1)$.

- **What are differential gain and common-mode gain of a differential amplifier?**

When the difference of the two inputs applied to the two terminals of a differential amplifier is amplified, the resultant gain is termed as **differential gain**. But when the two input terminals are connected to the same input source then the gain established by the differential amplifier is called the **common mode gain**.

- **Define CMRR.**

CMRR is defined as the ration of differential voltage gain to common mode voltage gain and it is given as CMRR = Ad/Acm.

- **List the parameters that should be considered for ac and dc applications.**

The parameters to be considered for dc applications are:

- Input offset voltage
- Input offset current
- Input bias current
- Drift

The parameters to be considered for ac applications are:

- Gain bandwidth product (GBW)
- Rise time
- Slew rate
- Full-power response
- AC noise

- **What is characteristic of Ideal OPAMP?**

Characteristic of ideal OPAMP are

1. Infinite voltage gain
2. Zero output impedance
3. infinite input impedance
4. Infinite slew rate
5. Characteristics not drifting with temperature
6. Infinite bandwidth

- **Why OPAMP called direct coupled high differential circuit?**

OPAMP is called direct coupled because the input of one OPAMP is inserted into the input of another OPAMP. It is called high gain differential circuit because the difference of the two input is amplified.

- **Why OPAMP called operational Amplifier?**

OPAMP it is a direct coupled high gain differential input amplifier. It is called operational amplifier because it is used for performing different functions like differentiation, addition, integration, subtraction. It has infinite voltage gain, infinite slew rate, infinite input impedance, zero output impedance, infinite bandwidth.

- **Give the pin diagram of op-amp?**

Mostly we known op-amp as IC-741.

- **Pin-4&7 [Power supply pin.]**

Voltage between two pins must be in between 5-18 volt.

- **Pin-2&3 [Input Pin.]**

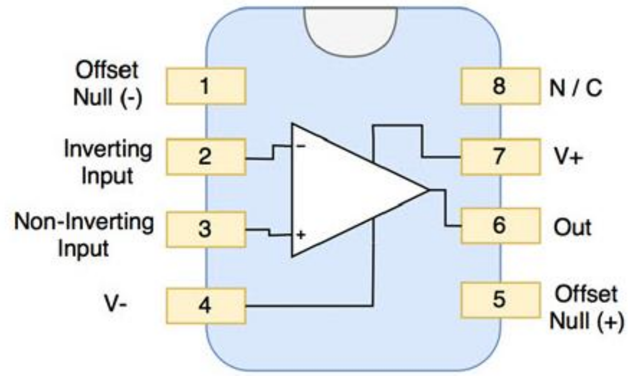
Pin-2 is called inverting pin and Pin-3 is non-inverting pin.

- **Pin-6 [Output Pin.]**
- **Pin-1&5 [Offset Null.]**

Nullify the effect on output terminal due to slight voltage difference in input terminals.

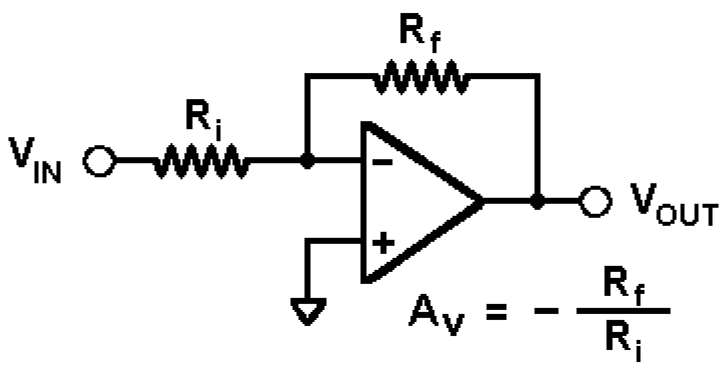
- **Pin-8 {Null}**

This pin is not connected to any circuit inside 741 IC. It's just a dummy lead.



❖ What is inverting amplifier?

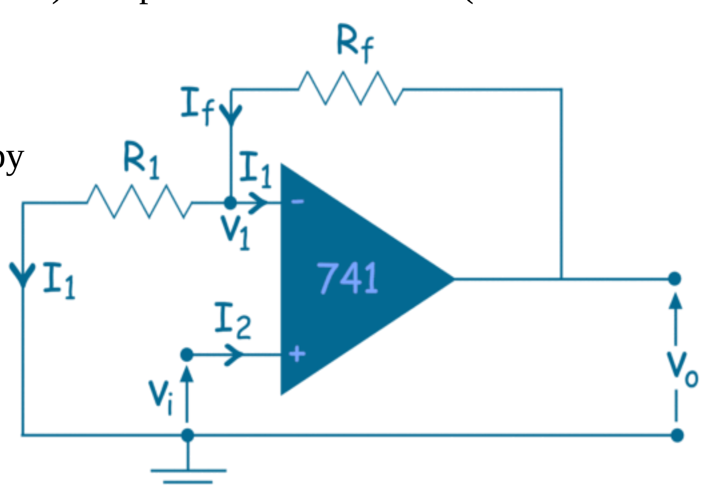
Inverting amplifier is one in which the output is exactly 180^0 out of phase with respect to input (if input is a positive voltage, output will be negative). Output is an inverted (in terms of phase) amplified version of input.



Voltage gain $A_v = V_o / V_i = -R_f/R_i$.

❖ What is non-inverting amplifier?

Non Inverting amplifier is one in which the output is in phase with respect to input (i.e. if you apply a positive voltage, output will be positive). Output is a Non inverted (in terms of phase) amplified version of input.



Here, we connect an external resistance R_1 and feedback resistance R_f at inverting input. Now, by applying Kirchhoff Current Law, we get,

$$\frac{v_1}{R_1} = \frac{v_o - v_1}{R_f} \quad \ldots\ldots\ldots\ldots \quad (i)$$

Let us assume the input voltage applied to the non-inverting terminal is v_i.

Now, if we assume that the op amp in the circuit is ideal op amp, then, $v_1 = v_i$

Therefore, equation (i) can be rewritten as,

$$\frac{v_i}{R_1} = \frac{v_o - v_i}{R_f}$$

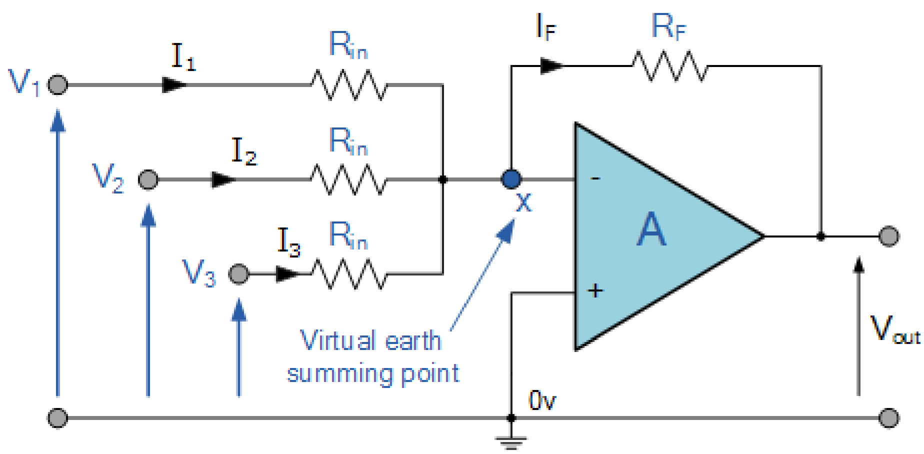
$$\Rightarrow v_i \frac{R_f}{R_1} = v_o - v_i$$

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

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

The closed loop gain of the circuit is, $A = \left(1 + \frac{R_f}{R_1}\right)$

❖ How an op-amp act as an additional operator?



Here in this circuit -----

V_1 V_2 V_3 ----- are three input voltage.

R_{in1} R_{in2} R_{in3} ----- are three input impedance.

I_1 I_2 I_3 ------ are three input current.

I_F ------ feed back current.

R_F ------- be the feedback resistance.

V_{out} ----- be the output resistance.

Voltage gain of the op-amp is

A_v = [output voltage / input voltage] = [feedback resistance / input resistance]

As the input impedance of an op-amp is very high so point X will be virtually grounded.

Due to the virtually ground condition -------

We get ----- $I_F = I_1 + I_2 + I_3$ ………………. (1.)

- $[V_0 / R_F] = [V_1 / R_1] + [V_2 / R_2] + [V_3 / R_3]$.

$V_0 = - [R_F \{(V_1 / R_1) + (V_2 / R_2) + (V_3 / R_3)\}]$

$V_0 = - [\{(R_F / R_1)V_1 \} + \{(R_F / R_2)V_2 \} + \{(R_F / R_3)V_3 \}]$

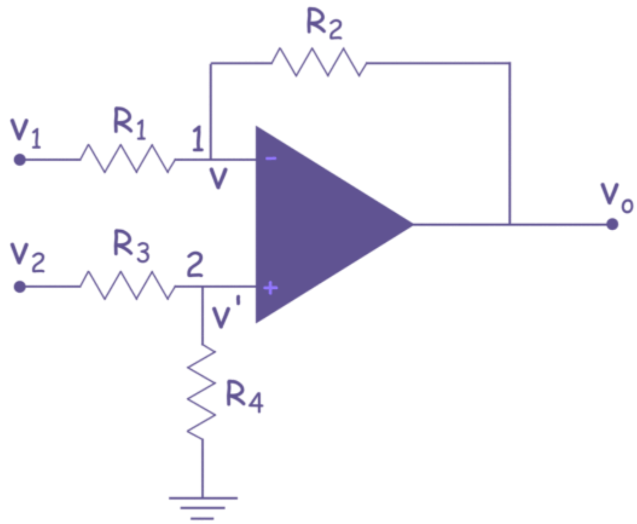
If $R_1 = R_2 = R_3$ then,

$V_0 = -(R_F / R_1) [V_1 + V_2 + V_3]$ ……………..(2.)

❖ How we use an op-amp as a subtraction operation?

Applying Kirchhoff Current Law at node 1, we get,

$$\frac{v_1 - v}{R_1} = \frac{v - v_0}{R_2}$$



We have written this equation by assuming that there is no current entering in the inverting terminal of the op amp.

Now, by simplifying the above equation, we get,

$$\frac{v_1}{R_1} + \frac{v_0}{R_2} = \frac{v}{R_1} + \frac{v}{R_2}$$

$$\Rightarrow \frac{v_0}{R_2} = \frac{v}{R_1} + \frac{v}{R_2} - \frac{v_1}{R_1}$$

$$\Rightarrow v_0 = \left(\frac{R_2}{R_1} + 1\right) v - \frac{R_2}{R_1} v_1$$

$$\Rightarrow v_0 = \left(1 + \frac{R_2}{R_1}\right) v - \frac{R_2}{R_1} v_1 \quad \ldots\ldots (i)$$

Now, by applying Kirchhoff Current Law, at node 2, we get,

$$\frac{v_2 - v'}{R_3} = \frac{v' - 0}{R_4}$$

$$\Rightarrow \frac{v_2}{R_3} = \frac{v'}{R_4} + \frac{v'}{R_3}$$

$$\Rightarrow v_2 = v'\left(1 + \frac{R_3}{R_4}\right)$$

$$\Rightarrow v' = v_2 \left(\frac{R_4}{R_3 + R_4}\right) \quad \ldots\ldots (ii)$$

We know that, in ideal op amp, voltage at inverting input is same as the voltage at non inverting input. Hence,

$$v = v'$$

So, now from equation (i) and (ii), we get,

$$v_0 = \left(1 + \frac{R_2}{R_1}\right) \frac{R_4}{R_3 + R_4} v_2 - \frac{R_2}{R_1} v_1$$

$$\Rightarrow v_0 = \frac{\left(1 + \frac{R_2}{R_1}\right)}{\left(1 + \frac{R_3}{R_4}\right)} v_2 - \frac{R_2}{R_1} v_1$$

$$v_0 = \frac{R_2}{R_1} \cdot \frac{1 + \frac{R_1}{R_2}}{1 + \frac{R_3}{R_4}} v_2 - \frac{R_2}{R_1} v_1 \cdots\cdots\cdots (iii)$$

The **difference amplifier** must reject any signal common to both inputs. That means, if polarity and magnitude of both input signals are same, the output must be zero.

$\because\ when,\ v_1 = v_2,\ then,\ v_0 = 0$

This condition must be satisfied only when,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \Leftrightarrow R_1 : R_2 = R_3 : R_4$$

In that case, equation (iii) becomes,

$$v_0 = \frac{R_2}{R_1} v_2 - \frac{R_2}{R_1} v_1$$

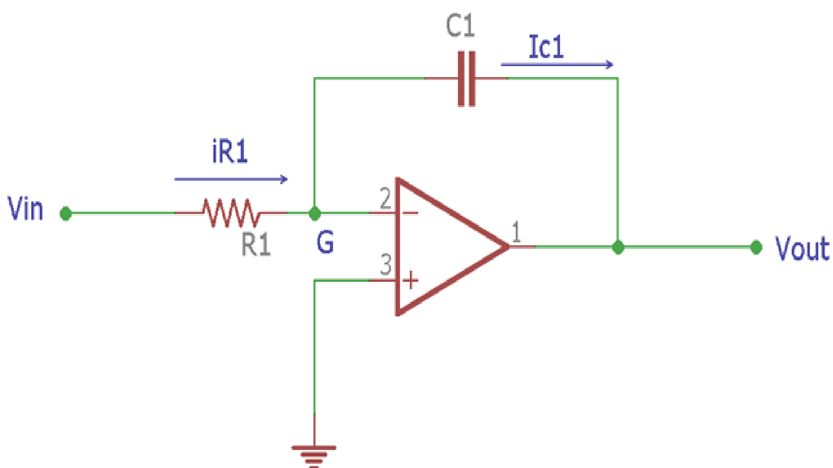
$$\Rightarrow\ v_0 = \frac{R_2}{R_1}(v_2 - v_1)\ \ \ldots\ldots(iv)$$

Again, if we make, $R_1 = R_2$, then equation (iv) becomes,

$$v_0 = v_2 - v_1$$

So, if $R_1 = R_2$ and also $R_3 = R_4$ then the difference amplifier becomes a perfect subtractor, which subtracts directly the input signals.

❖ How we use an op-amp as an integrator operation?



I_{R1} is the current flowing through the resistor.
G is the virtual ground.
I_{C1} is the current flowing through the capacitor.

If Kirchhoff's current law is applied across the junction G, which is a virtual ground, the **I_{R1}** will be the sum of current entering in the Inverting terminal (Op-amp pin 2) and the current passing through the Capacitor C1.

$$I_{R1} = I_{\text{Inverting terminal}} + I_{C1}$$

Since the op-amp is an ideal op-amp and the G node is a virtual ground, no current is flowing through the op-amp's inverting terminal. Therefore, **$I_{\text{Inverting terminal}} = 0$**

$$I_{R1} = I_{C1}$$

As the G node is a virtual ground point and the op-amp is an ideal op-amp, the voltage across this node is 0.

Therefore,

$$\frac{Vin - 0}{R1} = C1\frac{d(0 - V_{out})}{dt}$$

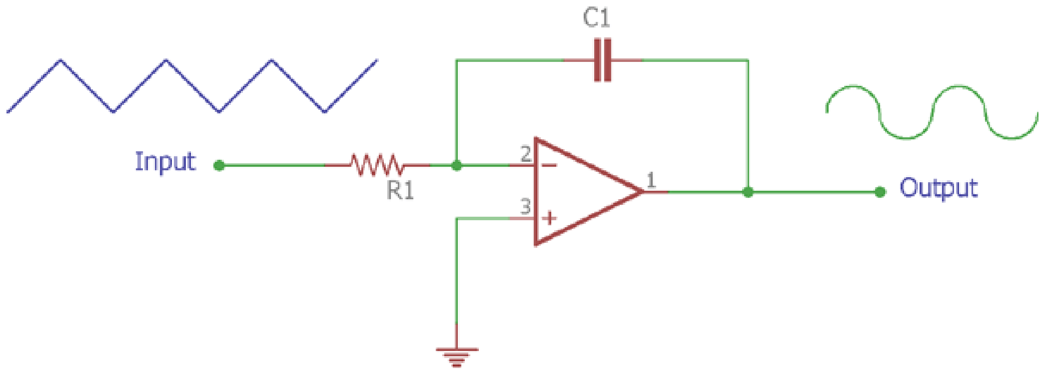
$$=> \frac{Vin}{R1} = -C1\frac{dV_{out}}{dt}$$

Now, integrating both sides,

$$=> \int_0^t \frac{Vin}{R1} = -\int_0^t C1\frac{dV_{out}}{dt}$$

Or the **ideal output voltage of op-amp integrator is**

$$V_{out} = -\frac{1}{R1C1}\int_0^t Vin\,dt = -\int_0^t Vin\,\frac{dt}{R1\,C1}$$



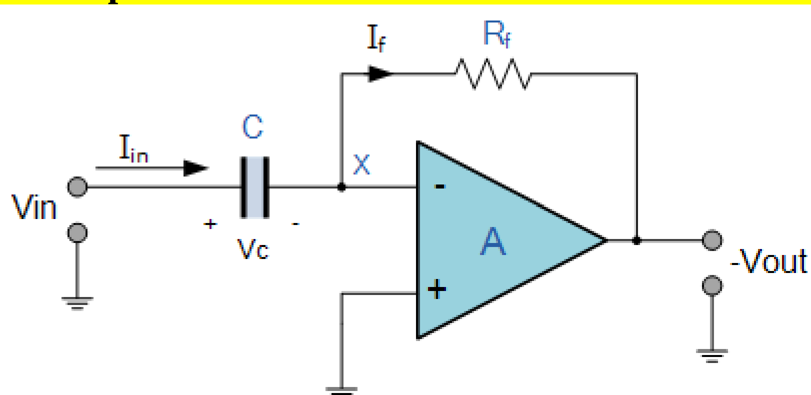
❖ Application an op-amp as an integrator operation?

- Integrator is an important part of the instrumentation and is used in Ramp generation.
- In function generator, the integrator circuit is used to produce the triangular wave.
- Integrator is used in wave shaping circuit such as a different kind of charge amplifier.
- It is used in analog computers, where integration is needed to be done using the analog circuit.
- Integrator circuit is also widely used in analog to the digital converter.
- Different sensors also use an integrator to reproduce useful outputs.

❖ How we use an op-amp as a differentiator operation?

The node voltage of the operational amplifier at its inverting input terminal is zero, the current, i flowing through the capacitor will be given as:

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



The charge on the capacitor equals Capacitance times Voltage across the capacitor

$$Q = C \times V_{IN}$$

Thus the rate of change of this charge is:

$$\frac{dQ}{dt} = C\frac{dV_{IN}}{dt}$$

but dQ/dt is the capacitor current, *i*

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

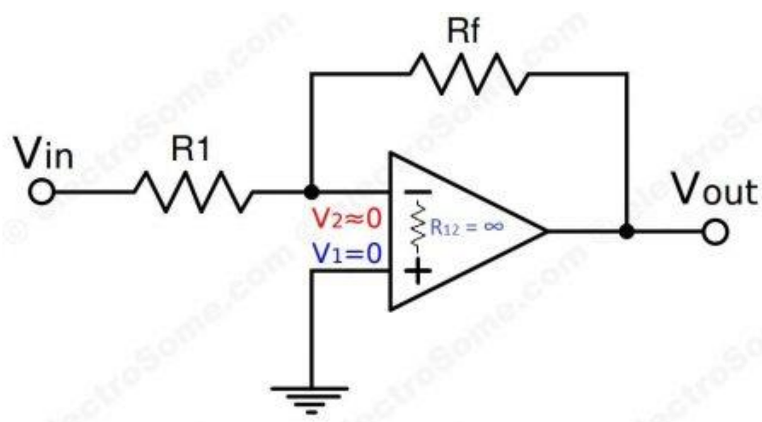
$$\therefore\ -\frac{V_{OUT}}{R_F} = C\frac{dV_{IN}}{dt}$$

From which we have an ideal voltage output for the op-amp differentiator is given as:

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

❖ What is Virtual ground for Op-amp?

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 and make calculation very simple.

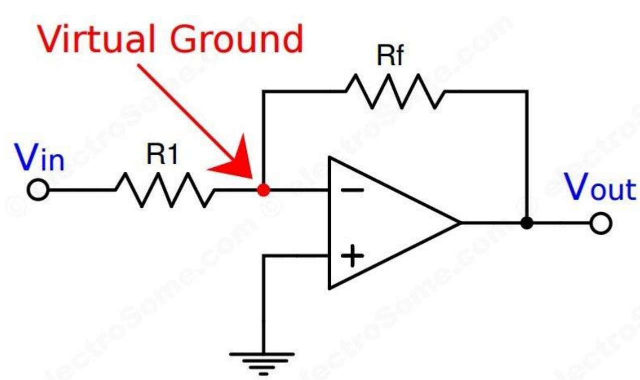


For real op-amps also the gain will be very high such that we can consider it as infinite.

Gain, $(A_V) = (V_{Out} / V_{in})$

As Gain (A_V) ------- infinite. V_{in} ------ 0

$V_{in} = (V_2 – V_1) = 0$



Non-inverting terminal of an op-amp is physically grounded. So $V_1 = 0$

Thus, $V_1 = V_2$

As the input impedance of the op-amp is very high so that there is no voltage drop between two input terminals. $V_2 = 0$.

Virtual Ground	**Real Ground**
Virtual Ground is a concept that made for easy explanation and calculation purposes.	Real Ground is a terminal which is physically connected to ground or earth which acts as the reference point for the entire circuit.
Voltage is **approximately** Zero	Voltage is Zero
Not able to sink infinite current	It is an infinite current sink
Not electrically connected to Ground	Electrically connected to Ground

Operational Amplifier (OPAMP):

Introduction to differential amplifier,
Characteristics of ideal and real OPAMP,
Concept of virtual ground,
Applications of OPAMP as inverting amplifier, non-inverting amplifier,
Mathematical operation - addition,
Subtraction,
Integration and
Differentiation,
Solution of differential equations and linear algebraic equations.