UNIT IV OPERATIONAL AMPLIFIER

Syllabus

Ideal OPAMP characteristics, DC performance characteristics, Basic applications of OPAMP- Sign Changer, Scale Changer, Phase Shift Circuits, Voltage Follower, adder, subtractor, Integrator, Differentiator

Op-Amp-Applications

A circuit is said to be **linear**, if there exists a linear relationship between its input and the output. Similarly, a circuit is said to be **non-linear**, if there exists a non-linear relationship between its input and output.

Op-amps can be used in both linear and non-linear applications. The following are the basic applications of op-amp −

- Scale changer
- Inverting Amplifier
- Non-inverting Amplifier
- Voltage follower
- Sign Changer
- Phase Shifter

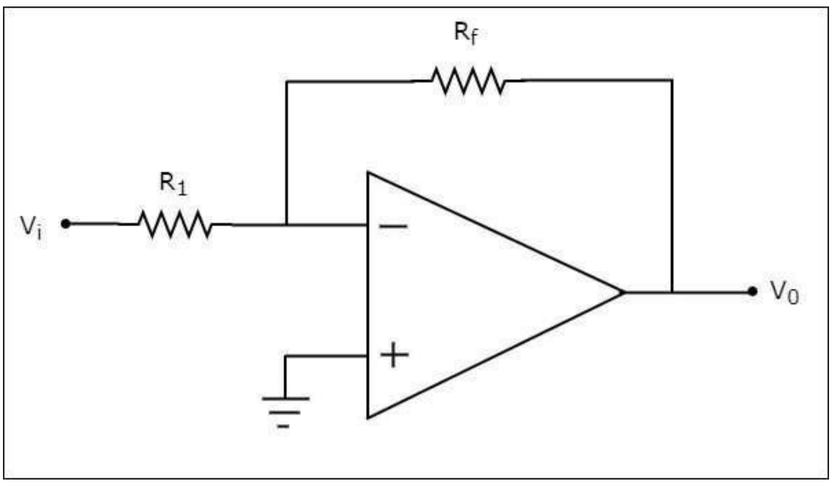
This chapter discusses these basic applications in detail.

Scale Changer and 180 degree Phase shifter

Inverting Amplifier

An inverting amplifier takes the input through its inverting terminal through a resistor R1$R1$, and produces its amplified version as the output. This amplifier not only amplifies the input but also inverts it (changes its sign).

The **circuit diagram** of an inverting amplifier is shown in the following figure −



Note that for an op-amp, the voltage at the inverting input terminal is equal to the voltage at its non-inverting input terminal. Physically, there is no short between those two terminals but **virtually**, they are in **short** with each other.

In the circuit shown above, the non-inverting input terminal is connected to ground. That means zero volts is applied at the non-inverting input terminal of the op-amp.

According to the **virtual short concept**, the voltage at the inverting input terminal of an op-amp will be zero volts.

The **nodal equation** at this terminal's node is as shown below −

$$\frac{0 - V_i}{R_1} + \frac{0 - V_0}{R_f} = 0$$

$$=> \frac{-V_i}{R_1} = \frac{V_0}{R_f}$$

$$=> V_0 = \left(\frac{-R_f}{R_1}\right) V_t$$

$$=> \frac{V_0}{V_i} = \frac{-R_f}{R_1}$$

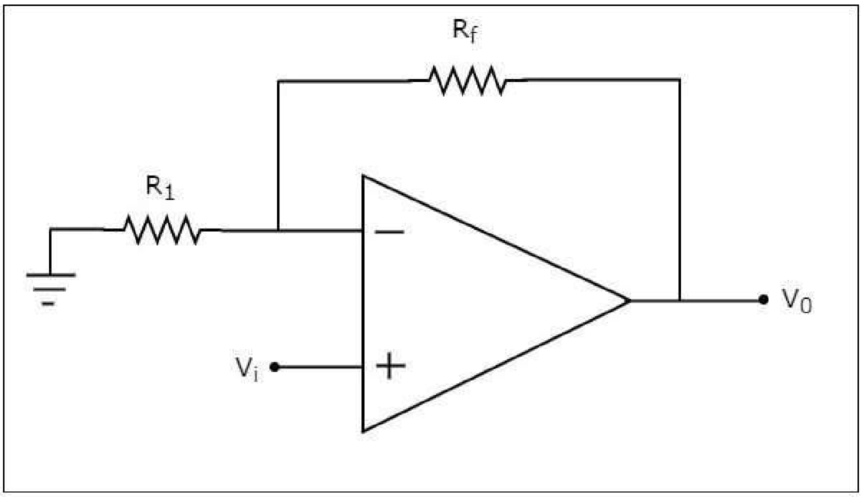
The ratio of the output voltage V0$V0$ and the input voltage ViVi is the voltage-gain or gain of the amplifier. Therefore, the **gain of inverting amplifier** is equal to $-R_f R_1$.

Note that the gain of the inverting amplifier is having a **negative sign**. It indicates that there exists a 180^0 phase difference between the input and the output.

Non-Inverting Amplifier

A non-inverting amplifier takes the input through its non-inverting terminal, and produces its amplified version as the output. As the name suggests, this amplifier just amplifies the input, without inverting or changing the sign of the output.

The **circuit diagram** of a non-inverting amplifier is shown in the following figure −



In the above circuit, the input voltage ViVi is directly applied to the non-inverting input terminal of op-amp. So, the voltage at the non-inverting input terminal of the op-amp will be Vi.

By using **voltage division principle**, we can calculate the voltage at the inverting input terminal of the op-amp as shown below −

$$=> V_1 = V_0 \left(\frac{R_1}{R_1 + R_f} \right)$$

According to the **virtual short concept**, the voltage at the inverting input terminal of an op-amp is same as that of the voltage at its non-inverting input terminal.

$$=> V_1 = V_i$$

$$=> V_0 \left(\frac{R_1}{R_1 + R_f} \right) = V_i$$

$$=> \frac{V_0}{V_i} = \frac{R_1 + R_f}{R_1}$$

$$=> \frac{V_0}{V_i} = 1 + \frac{R_f}{R_1}$$

Now, the ratio of output voltage V_0 and input voltage V_i or the voltage-gain or **gain of the non-inverting amplifier** is equal to $1 + \frac{R_f}{R_1}$.

Note that the gain of the non-inverting amplifier is having a **positive sign**. It indicates that there is no phase difference between the input and the output.

Summer

Summing Amplifier

Op-amp may be used to design a circuit whose output is the sum of several input signals. Such a circuit is called a summing amplifier or a summer. An inverting summer or a non-inverting summer may be obtained as discussed now.

Inverting Summing Amplifier

A typical summing amplifier with three input voltages V_1, V_2 and V_3, three input resistors R_1, R_2, R_3 and a feedback resistor R_f is shown in Fig. 4.2 (a). The following analysis is carried out assuming that the op-amp is an ideal one, that is, $A_{OL} = \infty$ and $R_i = \infty$. Since the input bias current is assumed to be zero, there is no voltage drop across the resistor R_{comp} and hence the non-inverting input terminal is at ground potential.

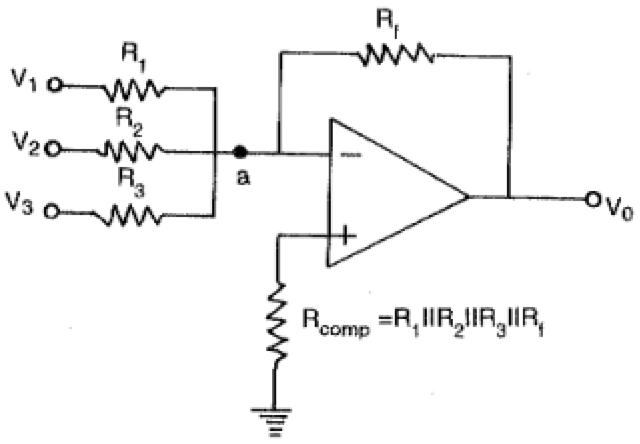


Fig. 4.2 (a) Inverting summing amplifier

The voltage at node 'a' is zero as the non-inverting input terminal is grounded. The nodal equation by KCL at node 'a' is

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_o}{R_f} = 0$$

or,

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right) \tag{4.1}$$

Thus the output is an inverted, weighted sum of the inputs. In the special case, when $R_1 = R_2 = R_3 = R_f$, we have

$$V_o = -(V_1 + V_2 + V_3) \tag{4.2}$$

in which case the output V_o is the inverted sum of the input signals. We may also set

$$R_1 = R_2 = R_3 = 3R_f$$

in which case

$$V_o = -\left(\frac{V_1 + V_2 + V_3}{3}\right) \tag{4.3}$$

Thus the output is the average of the input signals (inverted). In a practical circuit, input bias current compensating resistor R_{comp} should be provided as discussed in Sec. 3.2.1. To find R_{comp}, make all inputs $V_1 = V_2 = V_3 = 0$. So the effective input resistance $R_i = R_1 \| R_2 \| R_3$. Therefore, $R_{comp} = R_i \| R_f = R_1 \| R_2 \| R_3 \| R_f$.

Example 4.1

Design an adder circuit using an op-amp to get the output expression as

$$V_o = -(0.1\ V_1 + V_2 + 10\ V_3)$$

where V_1, V_2, and V_3 are the inputs.

Solution

The output in Fig. 4.2 (a) is

$$V_o = -[(R_f/R_1)\ V_1 + (R_f/R_2)V_2 + (R_f/R_3)V_3]$$

say $\quad R_f = 10\text{ k}\Omega,\ R_1 = 100\text{ k}\Omega,\ R_2 = 10\text{ k}\Omega,\ R_3 = 1\text{ k}\Omega$

Then the desired output expression is obtained.

Non-inverting Summing Amplifier

A summer that gives a non-inverted sum is the non-inverting summing amplifier of Fig. 4.2 (b). Let the voltage at the (–) input terminal be V_a. The voltage at (+) input terminal will also be V_a. The nodal equation at node 'a' is given by

$$\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = 0$$

from which we have,

$$V_a = \frac{\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}} \tag{4.4}$$

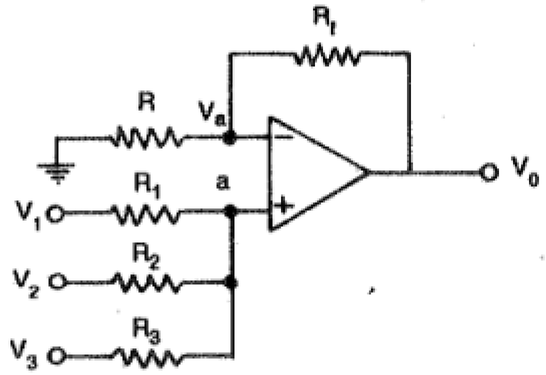


Fig. 4.2 (b) Noninverting summing amplifier

The op-amp and two resistors R_f and R constitute a non-inverting amplifier with

$$V_o = \left(1 + \frac{R_f}{R}\right) V_a \tag{4.5}$$

Therefore, the output voltage is,

$$V_o = \left(1 + \frac{R_f}{R}\right) \frac{\left(\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}\right)}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}} \tag{4.6}$$

which is a non-inverted weighted sum of inputs.

Let $R_1 = R_2 = R_3 = R = R_f/2$, then $V_o = V_1 + V_2 + V_3$

Subtractor

A basic differential amplifier can be used as a subtractor as shown in Fig. 4.3 (a). If all resistors are equal in value, then the output voltage can be derived by using superposition principle. To find the output V_{o1} due to V_1 alone, make $V_2 = 0$. Then the circuit of Fig. 4.3 (a) becomes a non-inverting amplifier having input voltage $V_1/2$ at the non-inverting input terminal and the output becomes

$$V_{o1} = \frac{V_1}{2}\left(1+\frac{R}{R}\right) = V_1 \tag{4.7}$$

Similarly the output V_{o2} due to V_2 alone (with V_1 grounded) can be written simply for an inverting amplifier as

$$V_{o2} = -V_2 \tag{4.8}$$

Thus the output voltage V_o due to both the inputs can be written as

$$V_o = V_{o1} + V_{o2} = V_1 - V_2 \tag{4.9}$$

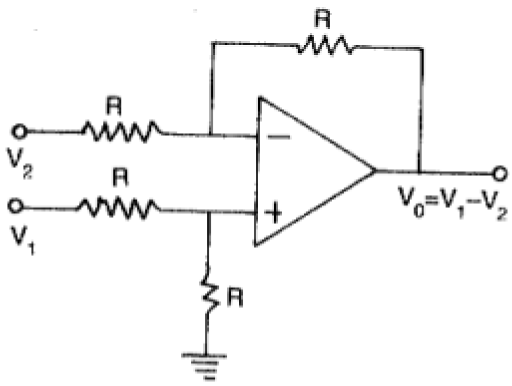
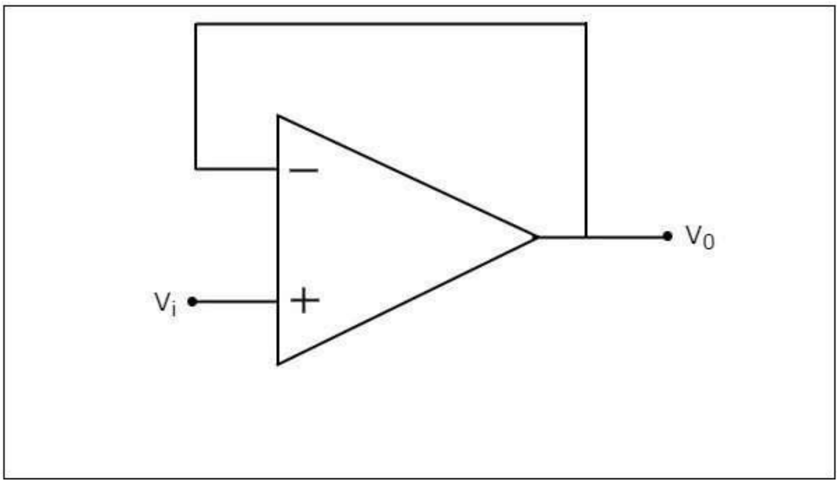


Fig. 4.3 (a) Op-amp as subtractor

VOLTAGE FOLLOWER

A **voltage follower** is an electronic circuit, which produces an output that follows the input voltage. It is a special case of non-inverting amplifier.

If we consider the value of feedback resistor, RfRf as zero ohms and (or) the value of resistor, 1 as infinity ohms, then a non-inverting amplifier becomes a voltage follower. The **circuit diagram** of a voltage follower is shown in the following figure −



In the above circuit, the input voltage Vi is directly applied to the non-inverting input terminal of the op-amp. So, the voltage at the non-inverting input terminal of op-amp is equal to Vi. Here, the output is directly connected to the inverting input terminal of opamp. Hence, the voltage at the inverting input terminal of op-amp is equal to $V0$.

$$=> V_0 = V_i$$

The output voltage is equal to input voltage, both magnitude and phase. In other words, we can also say that the output voltage follows the input voltage exactly. Hence, the circuit is called a voltage follower. The use of the unity gain circuit lies in the fact that its input impedance is very high (i.e. MΩ order) and output impedance is zero. Therefore, it draws negligible current from the source. Thus a voltage follower may be used as buffer for impedance matching, that is, to connect a high impedance source to a low impedance load.