4.11 OPERATIONAL AMPLIFIER

Operational amplifier is a basic analog device used for constructing merly mathematical circuit (operation). The mathematical operations are addition, differentiation, integration etc.

At starting stage, operational amplifiers were constructed with vacuum tubes and worked with high voltages. The main disadvantages of this device were large size, more expensive and consume more power. Todays operational amplifier are linear integrated circuits, that use relatively low dc power supply and reliable and inexpensive.

Basically, the internal architecture of OP-AMP consists of many resistor and capacitors (RC) with a active device (Transistor) and it is properly interconected in compact form integrated circuit (IC).

The first op-amp integrated circuit was developed by Robert J. Widlar at Fairchild semiconductor company in early 1960's.

4.11.1 Ideal Operational Amplifier

An operational amplifier (op-amp) is a very high gain differential amplifier with high input impedance and low output impedance. Operational amplifiers are mainly used in oscillators, electronic filter circuits, instrumentation circuits, to provide voltage amplitude change (amplitude and polarity) and to perform mathematical operations such as addition, differentiation, multiplication, comparison and integration etc.

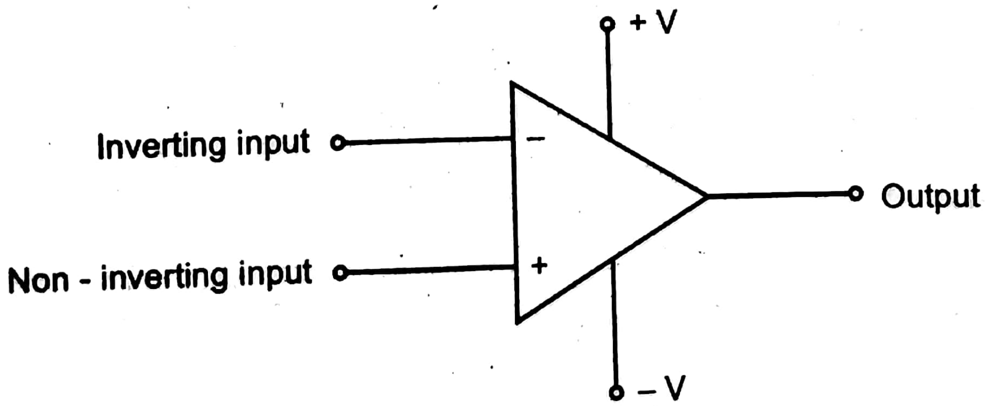

Figure 4.41

Figure 4.41 shows the symbol of operational amplifier. It has two input terminals and one output terminal. The negative terminal is called as inverting input terminal. The positive terminal is called as non inverting input terminal.

4.11.2 Equivalent Circuit of OP-Amp

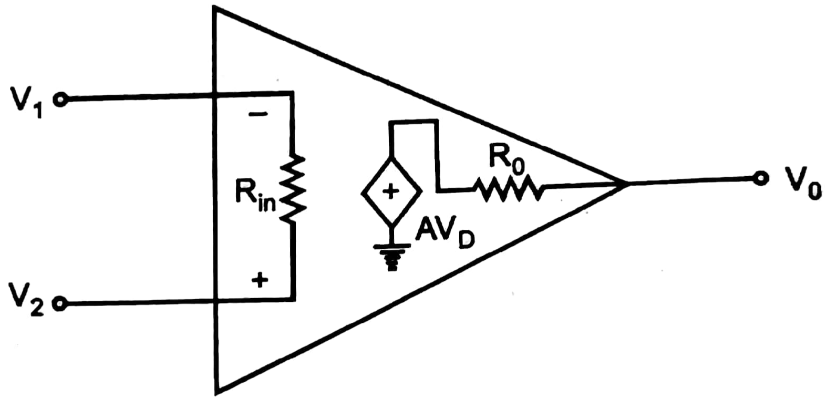

Figure 4.42

Figure 4.42 shows the equivalent circuit of OP-amp.

V_1 and V_2 are the input voltages

R_{in} is the input resistance

R_0 is the output resistance

V_0 is the differential voltage $(V_2 - V_1)$

A is the internal differential voltage gain of the OP-amp

V_0 is the output voltage of the OP-amp

The input voltage V_1 is applied to inverting input terminal and V_2 applied to non-inverting input terminal. The output voltage of the OP-amp is $V_0 = A(V_2 - V_1) = AV_D$

4.11.3 Characteristics of Ideal OP-Amp

1. Very high input resistance (R_{in}) (impedance) i.e., R_{in} is infinite.
2. Very low output resistance (impedance) i.e., R_0 = Zero
3. Very high open loop gain (A) i.e., $A = \infty$.
4. Input bias current (I_{in}) is equal to zero.
5. When the input voltages $V_1 = V_2$ and the output voltage $V_0 = 0$, that the input offset voltage $V_{in(off)}$ and input offset current $I_{in(off)}$ are equal to zero.
6. The bandwidth is equal to zero for all frequencies.
7. Infinite common mode rejection ratio (CMRR).
8. Infinite unity gain frequency.
9. Infinite slew rate.

4.11.4 Block Diagram of Operational Amplifier

The operational amplifier is a direct coupled high gain device. This device perform a large number of linear and non-linear amplifications and signal processing functions. Figure 4.43 shows the block diagram of an operational amplifier.

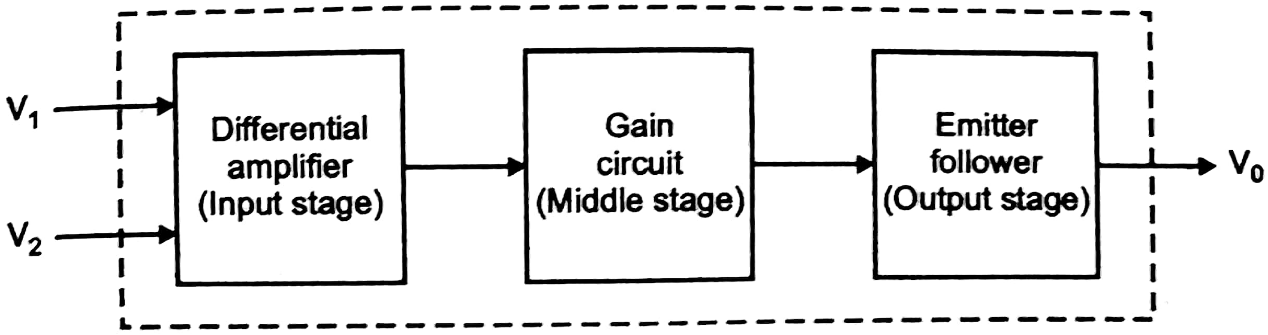

Figure 4.43

This block diagram consists of three stage of OP-amp. The input stage is a differential amplifier, the second or middle stage is a gain circuit, and the third or output stage is a emmiter follower output circuit.

Input Stage

A differential amplifier is an input stage of OP-amp. It has two inputs and provide amplification to the difference in voltage between the inputs. The basic requirements of input state is given below.

1. High input impedance (typically ≥ 10 KΩ)
2. Low input bias current (typically < 0.5 μA)
3. Low input offset voltage (typically < 10 mV)
4. Low input offset current (typically < 0.2 mA)
5. High common mode rejection ratio (typically ≥ 70 dB)

This stage is able to suppress any undesired noise which is common to both of the input terminals.

The second stage is gain circuit. It is used to provide some excessive voltage gain for the output stage. Generally, feedback capacitor is used in the middle stage to provide frequency compensation.

The third stage or output stage is emitter follower. The high gain output from the gain circuit is fed to the input of output stage. This stage is mainly used to avoid the excessive loading effect of the input stage. The output stage is to produce substantial amount of power into the low impedance load. Some basic requirements of the output stage is given below.

1. High output current and voltage swing capability
2. Low output impedance
3. Short circuit protection
4. Less standby power

4.11.5 Operational Amplifier IC 741

IC 741 is a bipolar operational amplifier. It is a popular general purpose OP-amp. The features of OP-amp IC 741 are given below.

1. Low power consumption
2. Short circuit protection
3. High input voltage range
4. No external frequency compensation required
5. Offset null capacity
6. Large common and differential mode voltage ranges
7. No batch problem
8. Overload protection on the input and output
9. Excellent temperature stability

4.11.6 Inverting Amplifier

Inverting amplifier is one of the applications of OP-amp. Figure 4.44 shows the circuit diagram of inverting amplifier.

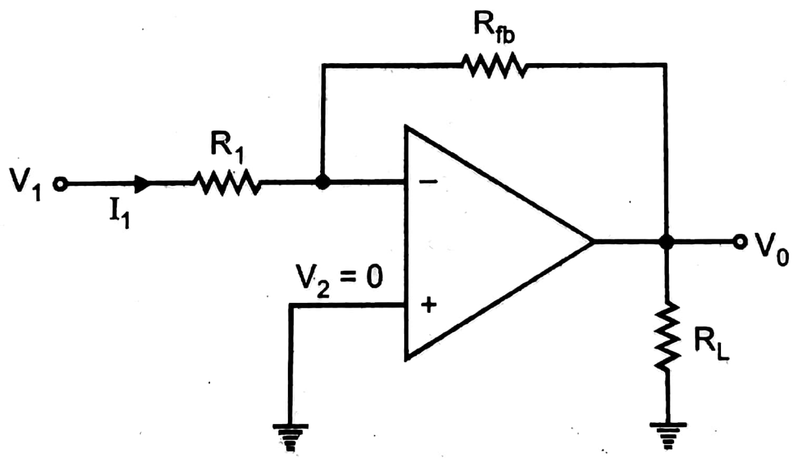

Figure 4.44

The output voltage V_0 is fedback to the inverting input terminal through the R_{fb} and R_1 network where R_{fb} is the feedback resistor. Input signal is applied to the inverting input terminal through R_1. The non-inverting terminal of OP-amp is grounded.

Current through the input resistor R_1 is given by

$$I_1 = \frac{V_1 - V_2}{R_1} \quad [V_2 = 0]$$

$$= \frac{V_1}{R_1}$$

Since OP-amp draws no current, all the current flowing through R_1 must flow through R_{fb}. Therefore, the output voltage is given by,

$$V_0 = -I_1 R_{fb} = \frac{V_1}{R_1} R_{fb}$$

$$= -\frac{V_1}{R_1} R_{fb}$$

The gain of the inverting amplifier is given by

$$A_c = \frac{V_0}{V_I} = \frac{\text{Output Voltage}}{\text{Input Voltage}}$$

$$A_c = -V_1 \frac{R_{fb}/R_1}{V_1}$$

$$\boxed{A_C = -\frac{R_{fb}}{R_1}}$$

Thus, the closed loop gain of inverting amplifier is proportional to the ratio of the feedback resistance (R_{fb}) and input resistance (R_1). The gain of this amplifer can be varied by selecting the resistance values. The negative sign denotes the output voltage is out of phase with respect to input voltage by 180° or of opposite polarity. The output voltage of this amplifier is controlled by varing the input voltage. Therefore, this type of amplifier is also called voltage controlled voltage source.

4.11.7 Non-inverting Amplifier

The another application of OP-amp is non-inverting amplifier. Figure 4.45 shows the circuit diagram of non-inverting amplifier.

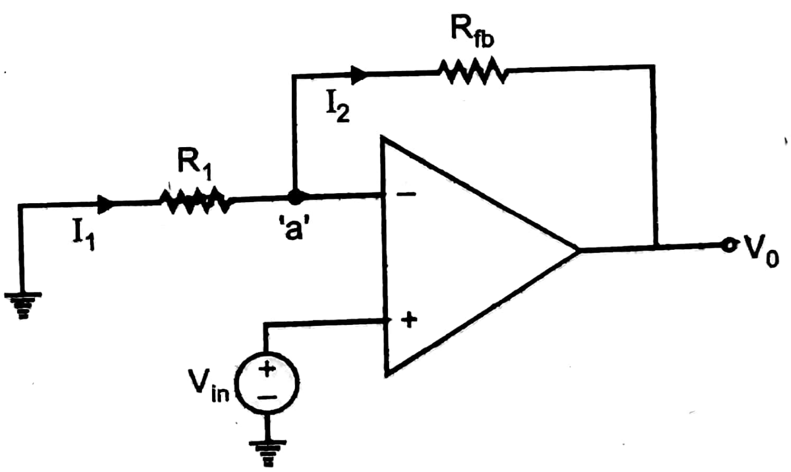

Figure 4.45

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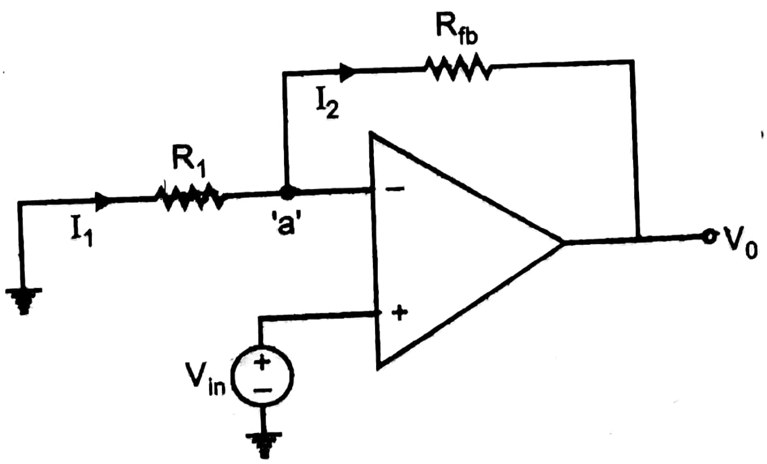

Figure 4.45

The input signal (ac or dc) is applied to the non-inverting terminal and feedback is given as shown in figure 4.45. This circuit amplifies without inverting the input voltage. That is why, this arrangement is called non-inverting amplifier.

It also uses negative feedback system i.e., output voltage is fedback to the inverting input terminal.

To analyze this configuration by appling the same linear negative feedback principle, we can write that $V_1 = V_2 = V_{in}$. This means that the negative feedback forces the inverting input V_1 to be equal to non-inverting input V_2.

This condition is referred as virtual short and it provides the differential voltage V_d as equal to zero. Now R_{fb} and R forms a potential divider.

Hence,

$$V_{in} = \frac{V_0}{R_1 + R_{fb}} R_1$$

No current flows into the op-amp

$$\frac{V_0}{V_{in}} = \frac{R_1}{R_1 + R_{fb}}$$

$$= 1 + \frac{R_1}{R_{fb}}$$

The voltage gain of non-inverting amplifier is

$$AC = \frac{V_0}{V_{in}} = 1 + \frac{R_f}{R_1}$$

Thus, the output voltage is obtained in a same phase or polarity with the input voltage. Here, the gain is always greater than unity. The voltage gain can be adjusted to unity or more, by proper selection of resistors R_1 and R_{fb}.

The output voltage of the non-inverting amplifier is also directly proportional to the input voltage. Therefore, this configuration is also called as voltage controlled voltage source.