

OPERATIONAL AMPLIFIER

Definition: it is a direct-coupled, high gain, negative feedback amplifier.

Uses:- it is a versatile device that can be used to amplify dc as well as ac input signals and was designed for performing mathematical operations such as addition, subtraction, multiplication, integration etc.

Now a day, the OP-AMPS are put to a variety of other uses eg. Voltage regulators, phase shifters, oscillator's circuits, analog to digital and digital to analog convertors, scale changer and in many others.

Advantages:-

1. Small size
2. Reduced cost
3. High reliability
4. Less power consumption
5. Temperature tracking
6. Less offset voltage

Examples:- μ A 709, LM108, CA 741 etc.

Differential Amplifier and its transfer characteristics:-

Let us consider the emitter-biased circuit. Take two identical emitter-biased circuits in that transistor Q_1 has the same characteristics as transistor Q_2 , $R_{C1}=R_{C2}$, $R_{E1}=R_{E2}$, and the magnitude of $-V_{EE}$ is equal to the magnitude of $+V_{CC}$.

ELEMENTS OF ELECTRONICS

Now to obtain a single circuit, reconnect these two circuits as follows:-

- i. Reconnect the emitter of transistor Q_1 to the emitter of transistor Q_2 .
- ii. Reconnect the $+V_{CC}$ supply voltages of two circuits as the voltages are of same polarity and amplitude. Similarly, reconnect $-V_{EE}$ supply voltages.
- iii. Show the input signal V_1 applied to the base B_1 of transistor Q_1 and V_2 applied to the base B_2 of the transistor Q_2 .
- iv. Label the voltage between the collectors C_1 and C_2 as V_O . V_O is the output voltage.

OP-AMPS available today are of differential type with two input terminals and one output terminal.

The input terminals are marked with minus and plus signs. Terminal with $-ve$ sign is called inverting input terminal. The $-ve$ sign indicates that a signal applied on this terminal will appear amplified but with inverted phase (180° out of phase).

Similarly, terminal with $+ve$ sign is non-inverting input terminal. The $+ve$ sign indicates that a signal will amplify and in phase.

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The output voltage is directly proportional to the input voltage which is difference of V_1 and V_2

i.e.
$$V_i = V_2 - V_1$$

$$V_o \propto V_i$$

$$V_o = A V_i$$

$$A = \frac{\text{Output}}{\text{Difference between two input signals}}$$

$$= \frac{V_o}{V_2 - V_1} = \frac{V_o}{V_{id}}$$

$$V_o = A V_{id}$$

This is the basic OP-AMP equation, which is useful in studying the OP-AMPs characteristics.

The output voltage cannot exceed the positive and negative saturation voltages. These saturation voltages are specified by an OP-AMP output voltage swing ratings. This means that the output voltage is directly proportional to the input difference voltage only until it reaches the saturation voltages and thereafter output voltage remains constant as shown in graph.

IC OP-AMP (Pin description of 741 IC)

Pin 1 (offset null):- An offset null adjustment is used to compensate for offset voltage. It is also used to compensate for the irregularities in the OP-AMP manufacturing process.

Pin 2 (Inverted input):- all input signals at this pin will be inverted at output pin 6

Pin 3 (non-inverted input):- all input signals at this pin will be processed normally without inversion and result will be same at output pin 6

Pin 4 (-V):- the V- pin is the negative supply voltage terminal. Supply negative voltage operating range for 741 is -4.5 volts to -18 volts.

Pin 5 (Offset null):- An offset null adjustment is used to compensate for offset voltage. It is also used to compensate for the irregularities in the OP-AMP manufacturing process.

Pin 6(output):- output's signal polarity will be the opposite of the input signal if input is applied at the inverting terminal while it will be same if the signal is applied at the non-inverting terminal.

Pin 7 (+V):- the V+ pin is the positive supply voltage terminal. Supply positive voltage operating range for 741 is +4.5 volts to +18 volts.

Pin 8 (N/C):- The N/C stands for not connected. There is nothing connected to this pin, it is just there to make it a standard 8-pin package.

Characteristics of An Ideal OP-AMP:-

1. An **infinite voltage gain** i.e. open- loop voltage gain is infinite
2. An **infinite Bandwidth** i.e. any frequency signal ranging from 0 to ∞ Hz may be amplified without distortion.
3. An **infinite input resistance:** - the resistance measured between inverting and non-inverting terminals is called input resistance.
4. **Zero output resistance:** - output resistance is like the internal resistance of the battery and hence should be very small.
5. **Perfect balance:** - the output is zero when equal voltages are applied at the two input terminals.
6. **Zero offset voltage:** - when input signal voltage is zero, the output signal will also be zero.
7. **Infinite CMRR:**- Common Mode Rejection Ratio is infinite.
8. **Infinite Slew rate:** - changes in output voltages occur simultaneously with the input voltage changes.
9. **Zero drift:** - the characteristic does not change with the temperature changes.

Operational Amplifier Practical Specifications:-

1. **Input offset voltage:** - when the input is 0V, the output of OP-AMP should be zero. But in actual operation, there is some offset voltage at the output. The input offset voltage is defined as the voltage that must be applied between the two input terminals to nullify the output. Typically, it lies in the range 1mV to 5mV.
2. **Input offset current:** - the two input transistors are never exactly matched. Each has a slightly different current. The input offset current is the difference between the two input current. Typically it lies in the range 20nA to 60nA.
3. **Input bias current:** - it is the average of the currents that flow into the inverting and non-inverting input terminals of an OP-AMP.

$$= \frac{i_1 + i_2}{2}$$

4. **Input offset voltage drift:** - it is the ratio of the change of input offset voltage to the change in temperature.

$$= \frac{dv_{io}}{dt}$$

5. **Input offset current drift:** - it is the ratio of the change of input offset current to the change in temperature.

$$= \frac{di_{io}}{dt}$$

6. **Input resistance:** - this is the differential input resistance that can be measured at either of the input terminal with the other terminal connected to ground. It is of the range of $100\text{k}\Omega$ to $1\text{M}\Omega$.
7. **Output resistance:** - it is the resistance measured between the output terminal of the OP-AMP and the ground. It is of the range of 40Ω to 100Ω .
8. **Common Mode Rejection Ratio (CMRR):** -It is defined as the ratio of differential voltage gain (A_d) to the common mode voltage gain(A_{CM}) i.e.

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

Where A_{CM} is common mode voltage gain and is given by

$$A_{CM} = \frac{V_{OCM}}{V_{CM}}$$

Where V_{OCM} = output common mode voltage

V_{CM} = input common mode voltage

CMRR is often expressed in desibel's (dBs)

In practical case, A_{CM} is very small, A_d is very large therefore CMRR is very large, but not exactly infinite.

9. **Slew Rate:-** is the maximum rate of change of output voltage with respect to time i.e.

$$SR = \left. \frac{dv_o}{dt} \right|_{max}$$

The unit of slew rate is V/μs (volts per microsecond).

10. **Power Supply Rejection Ratio (PSRR) or Supply Voltage Rejection Ratio (SVRR):-** It is defined as the change in an OP-AMP input offset voltage (V_{io}) caused by variation in supply voltage.

$$PSRR \text{ or } SVRR = \frac{dV_{io}}{dV}$$

OPEN LOOP OP-AMP CONFIGURATIONS:-

There are three open loop OP-AMP configurations:-

- a. Inverting amplifier
- b. Non-inverting amplifier
- c. Differential amplifier

Inverting amplifier:-

The input signal is applied to the inverting input terminal. The non-inverting terminal is grounded i.e. $V_2=0V$.

The output voltage is given by:-

$$\begin{aligned} V_o &= AV_{id} \\ &= A(V_2 - V_1) \\ &= A(0 - V_1) \\ &= A(-V_1) \\ &= -AV_1 \end{aligned}$$

The –ve sign indicates that the output voltage is out of phase wrt input. Thus in inverting amplifier, the input is amplified by gain A with change in polarity.

Non-Inverting amplifier:-

The input signal is applied to the non-inverting input terminal. The non-inverting terminal is grounded i.e. $V_1=0V$.

The output voltage is given by:-

$$\begin{aligned}V_O &= AV_{id} \\&= A(V_2 - V_1) \\&= A(V_2 - 0) \\&= A(V_2) \\&= AV_2\end{aligned}$$

Thus in non-inverting amplifier, the output voltage is gain A times the input voltage and in phase with the input.

Non-Inverting amplifier:-

The input signal is applied to the both inverting and non-inverting input terminals. As the OP-AMP amplifies the difference between two input signals and hence this configuration is called as differential amplifier.

The output voltage is given by:-

$$V_O = AV_{id}$$

$$= A(V_2 - V_1)$$

LIMITATIONS OF OPEN LOOP OP-AMP CONFIGURATIONS:-

- a. Open loop gain of OP-AMP is very high. So input signal of slightly greater than zero drives the output to the saturation level.
- b. Open loop gain of OP-AMP is not constant. It varies with change in temperature and power supply.

That's why OP-AMP is unsuitable for many linear applications.

CLOSED LOOP OP-AMP CONFIGURATIONS:-

There are three open loop OP-AMP configurations:-

- a. Inverting amplifier
 - b. Non-inverting amplifier
 - c. Differential amplifier
- a. **Inverting amplifier:-**

Inverting amplifier consists of an input resistance R_1 and a feedback resistor R_F .

In this mode of operation, the non-inverting input terminal of the amplifier is grounded and the input signal is applied to the negative input terminal.

V_1 is the dc or ac voltage signal within the bandwidth of the amplifier. The output signal is fed back to the inverting input of OP-AMP through feedback resistor R_F .

When input voltage v_i is applied at the input terminal, the point G attains some positive potential. Now there exists output voltage v_o . Due to negative feedback, a fraction of the output voltage with phase inverted is fed back to point G. The algebraic sum of the two voltages at point G is almost zero. Thus the point G, although not connected to ground, but is held virtually at ground.

GAIN:-

$$i_1 = \frac{V_1 - v_i}{R_1}$$

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

$$i_2 = \frac{v_i - V_O}{R_F}$$

$$= \frac{-V_O}{R_F}$$

At point G,

$$i_1 = i_2$$

$$\frac{V_1}{R_1} = \frac{-V_O}{R_F}$$

$$\frac{V_O}{V_1} = \frac{-R_F}{R_1}$$

The ratio of output voltage V_O and input voltage V_1 is known as the closed loop gain of the inverting amplifier.

So gain is $A_v = \frac{-R_F}{R_1}$

Input resistance:-

$$R_{in} = \frac{V_1}{(V_1 - v_i)/R_1} = \frac{V_1 R_1}{V_1} \approx R_1$$

Negative scalar:-

OP-AMP works as a negative scalar.

Denote $\frac{R_F}{R_1}$ by k, a real constant

$$V_O = -KV_1$$

Unity gain amplifier:-

If $R_F = R_1$ then

$$A_V = -1$$

So, the circuit provides a unity voltage gain with 180° phase inversion.

b. Non-inverting amplifier:-

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Here the input voltage is applied to the non-inverting input terminal and hence the name non-inverting amplifier. The potential of point G is also V_2 since the gain of OP-AMP is infinite.

The voltage across $R_1 = V_2$

Across $R_F = V_o - V_2$

GAIN:-

$$i_1 = \frac{V_2}{R_1}$$

$$i_2 = \frac{V_o - V_2}{R_F}$$

At point G,

$$i_1 = i_2$$

$$\frac{V_2}{R_1} = \frac{V_o - V_2}{R_F}$$

$$\frac{R_F}{R_1} = \frac{V_o - V_2}{V_2}$$

$$\frac{R_F}{R_1} = \frac{V_o}{V_2} - \frac{V_2}{V_2}$$

$$\frac{R_F}{R_1} = \frac{V_o}{V_2} - 1$$

$$\frac{V_o}{V_2} = 1 + \frac{R_F}{R_1}$$

So gain is one plus the ratio of two resistances R_F and R_1 .

Positive Scalar:-

$$\text{Here } \frac{V_O}{V_2} = 1 + \frac{R_F}{R_1} = K$$

$$V_O = KV_1$$

So the amplifier acts as a positive scalar.

Voltage Follower/Buffer Amplifier:-

$$\text{If } R_1 = \infty \text{ and } R_F = 0$$

Then the circuit is known as voltage follower or buffer amplifier or source follower or unity-gain amplifier or isolation amplifier.

$$\text{Then } A_V = 1 \text{ i.e. } V_O = V_2 = V_i$$

Thus the output voltage is equal and in phase with the input i.e. OP-AMP circuit acts as a voltage follower. This is required when a signal from high-impedance source is to be applied and no signal current is to be drawn.

