

N.I.O. Amplifier (DA)

Operational Amplifier (Op-Amp):

- An operational Amplifier (Op-Amp) is a circuit that can perform such mathematical operations as addition, subtraction, integration and differentiation.
- It's key electronic circuit is ~~an opamp~~ if the differential amplifier where the input stage is a differential amplifier and the output stage is typically a class B push-pull emitter follower.
- Differential amplifier is a circuit that can accept two input signals and amplify the difference b/w these two input signals.

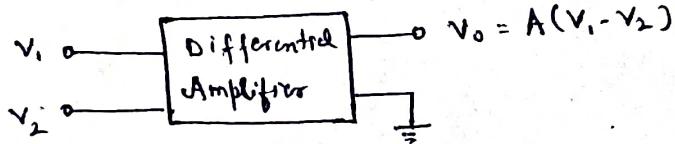


Fig. Block diagram of a Differential Amplifier.

Fig. Shows the block diagram of a Differential Amplifier.

This amplifier amplifies the difference b/w the two input voltages (V_1 & V_2)
∴ the output voltage is

$$V_0 = A(V_1 - V_2)$$

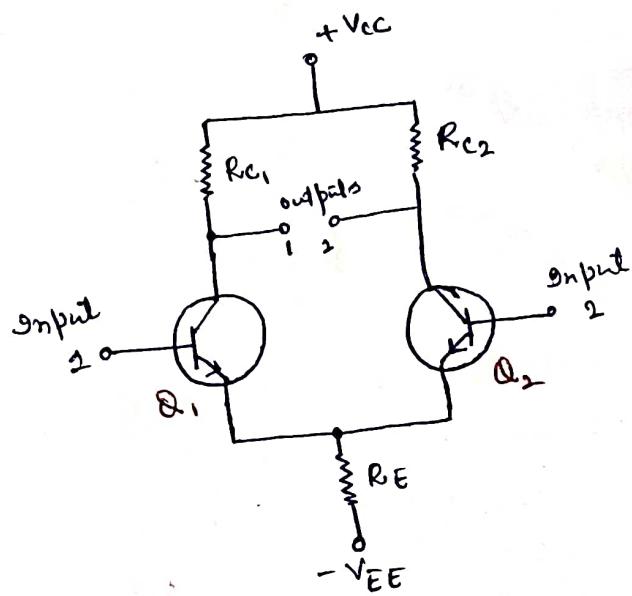
Where,
 $A \rightarrow$ Gain of the Amplifier.

Difference b/w conventional and differential Amplifiers:

In a conventional amplifier, the signal (i.e. input) is applied at the input terminals and amplified output is obtained at the output terminal.

Differential Amplifier accepts two input signals and amplifies the difference b/w these two input signals.

Basic Circuit of Differential Amplifier (DA)



Symbol of DA:

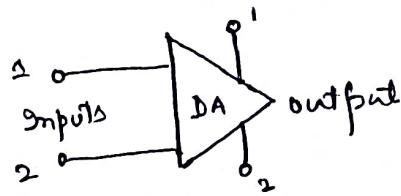
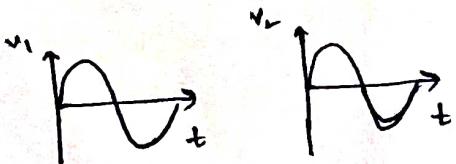


fig. Differential Amplifier.

Fig. shows the basic circuit of a differential amplifier. It consists of two transistors (Q_1 and Q_2) that have identical characteristics. They share a common positive supply V_{CC} , R_E and negative supply $-V_{EE}$. Circuit is Symmetrical.
 → Input Signals to a DA are defined as:-
Common-mode Signals.

When the input signals to a DA are in phase and exactly equal in Amplitude, they are called Common-mode signals. i.e. the difference b/w the two input signals is zero. as $V_1 = V_2$.

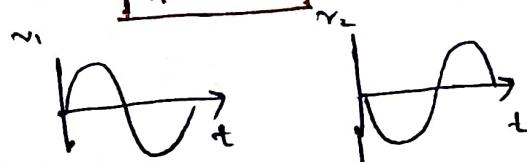


Common-mode signals.

Differential-mode Signals

When the input signals to a DA are 180° out of phase and exactly equal in amplitude, they are called Differential-mode signals. i.e. DA amplifies the Differential mode signals and Rejects the Common-mode signals.
 For differential mode signal,

$$V_1 = -V_2$$



Differential-mode signals.

Voltage Gain of DA:

A_{DM} → Differential-mode voltage gain of DA operating in differential mode.

A_{CM} → Common-mode voltage gain of DA operating in common-mode.

Ideally,

DA provides a very high voltage gain for differential-mode signals and zero gain for common-mode signals.

Practically, DA do exhibits a very small common-mode gain (< 1)

while providing a high differential voltage gain.
The higher the differential gain w.r.t the common-mode gain, the better performance of the DA in terms of rejection of common-mode signals.

Common-mode Rejection Ratio (CMRR):-

The DA should have high A_{DM} and very low A_{CM} .

The ratio of A_{DM}/A_{CM} is called CMRR.

i.e

$$\boxed{CMRR = \frac{A_{DM}}{A_{CM}}}$$

It is ~~meas~~ expressed in decibels (dB). As

$$CMRR_{dB} = 20 \log_{10} \frac{A_{DM}}{A_{CM}}$$

$$\boxed{CMRR_{dB} = 20 \log_{10} CMRR.}$$

The CMRR is the ability of a DA to reject the common-mode signals. The larger the CMRR, the better the DA is at eliminating common-mode signals.

Parameters of an OP-Amp due to mismatch of Transistors.

DA has been based on the assumption that the transistors are perfectly matched i.e. they have the same electrical characteristics. In practical, this can't happen. There will always be some difference between the characteristics of the two transistors. Which results in following two parameters of op-amp.

① Output offset voltage: ($V_{out\text{offset}}$)

Even though the transistors in the DA are very closely matched, there are some differences in their electrical characteristics. One of these differences is found in the values of V_{BE} for the two transistors.

When $V_{BE1} \neq V_{BE2}$, an imbalance is created in the DA (op-Amp). In such situation - op-Amp may show some voltage at the output even when the voltage applied b/w two input terminals is zero. This is called output offset voltage.

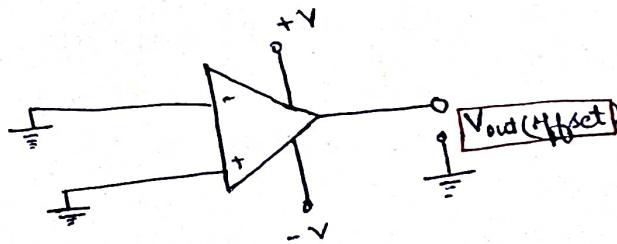


Fig:

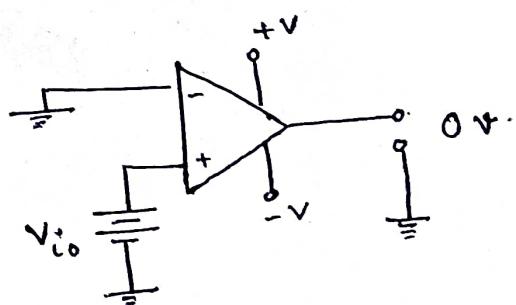
Method to eliminate $V_{out\text{offset}}$:

One way to eliminate $V_{out\text{offset}}$ is to apply an input offset voltage b/w the input terminals of op-amp, so to make the output 0V.

The input offset voltage (V_{io}) is required to eliminate the output offset voltage and is given by:

$$V_{io} = \frac{V_{out\text{offset}}}{A}$$

where A is the gain.



2. Input offset Current:

When the output offset voltage of a op-amp is eliminated, there will be a slight difference b/w the input currents to the noninverting and inverting inputs of the device. This slight difference in input currents is called input offset current, which is caused by a mismatch (β) b/w the transistors.

e.g. $I_{B1} = 75 \mu A$ and $I_{B2} = 65 \mu A$.

Then $I_{in(offset)} = 75 - 65 = 10 \mu A$.

If the transistors are identical, then input offset current is zero as both currents will be equal. But practically, the two transistors are different and the base currents are not equal.

3. Input Bias Current:

The inputs to an op-amp require some amount of d.c biasing current for the transistors in the differential Amplifier.

The input bias current is defined as the average of the two d.c base current

i.e

$$I_{in(bias)} = \frac{I_{B1} + I_{B2}}{2}$$

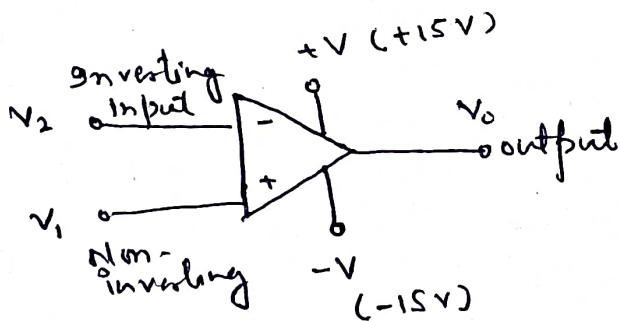
Op-Amp:

Properties of op-Amp:

i) An op-amp is a multistage amplifier. The input stage of an op-amp is a differential amplifier stage.

- ii) An inverting input and a non-inverting input.
- iii) High input impedance (usually ∞).
- iv) Low output impedance ($< 200\Omega$).
- v) A large open-loop voltage gain.
- vi) Voltage gain remains constant over a wide frequency range.
- vii) Large CMRR ($> 90 \text{ dB}$).

Schematic Symbol:



Summary:

Practical op-amp

$$Z_{in} = 2 \text{ M}\Omega$$

$$A_v = 1 \times 10^5$$

$$Z_{out} = 100\Omega$$

Ideal op-amp.

$$Z_{in} \rightarrow \infty$$

$$A_v \rightarrow \infty$$

$$Z_{out} \rightarrow 0 \Omega$$

Bandwidth of an op-amp :-

The electronic devices work only over a limited range of frequencies. This range of frequencies is called Bandwidth. i.e. Every op-amp has a bandwidth, over which it will work properly. Bandwidth of an op-amp depends upon the ^{open} loop gain of the op-amp circuit.

Moreover, The Gen-Bandwidth product (GBW) is defined as

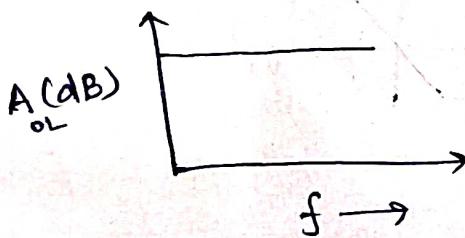
$$GBW = f_{unity} = A_{OL} \times f_{\infty}$$

Where, A_{OL} is the ^{open} loop gain at frequency f_{∞}

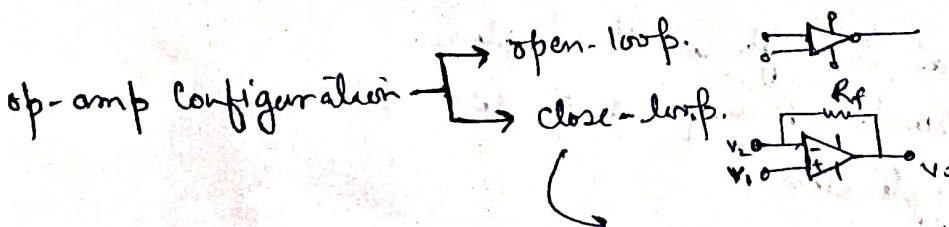
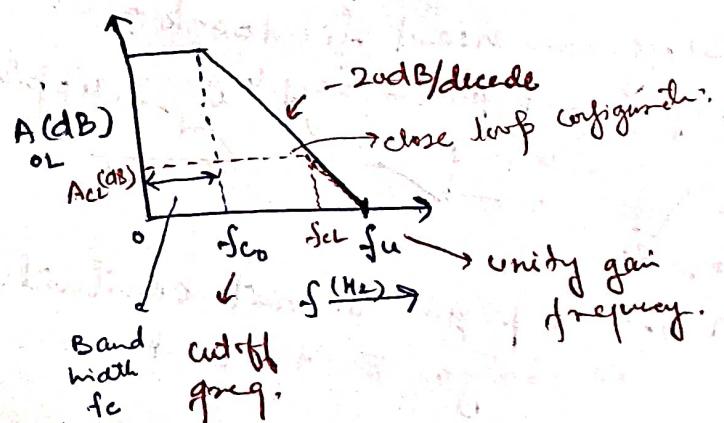
f_{unity} is the frequency at which the closed-loop gain is unity

Variation of gain w.r.t freq.

* frequency response of ideal op-amp :-



* frequency response of Practical op-amp:



mostly -ve feedback. { \therefore bandwidth res distortion res. stability res. gain res. }

open loop Configuration

$$GBP = f_u \times AOL$$

$$GBP = f_u \quad (\because \text{at } f_u \rightarrow AOL \rightarrow 1)$$

For f_c

$$GBP = f_c \times AOL$$

$$f_u = f_c \times AOL$$

$$f_c = \frac{f_u}{AOL}$$

cut off frequency in open loop.

used in oscillators, square wave generator

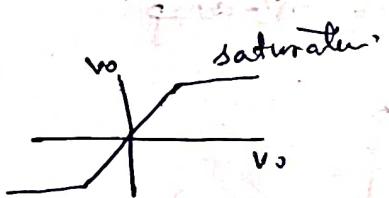
→ Feedback $\begin{cases} +ve \\ -ve \end{cases}$ (Amplifiers, adder, subtractor, Integrator, Diff. equation)

Why we need feedback?

i) open loop gain is very high. → clipping



large signal



ii) open loop gain is not constant.

It changes w.r.t temp. & power supply.

iii) Bandwidth.

For open loop gain is high which implies BW is small. Such op-amp can't be used for ac application.

close loop Configuration

$$f_c' \times AOL = GBP$$

$$\text{again } GBP = f_u$$

$$\Rightarrow f_c' = \frac{f_u}{AOL}$$

cut off frequency in closed loop

Slew Rate :-

The slew rate of an op-amp is a measure of how fast the output voltage can change and is measured in volts per microsecond (V/μs). e.g. if slew rate of an op-amp is 0.5 V/μs, it means the output from the amplifier can change by 0.5 V every μs.

$$\text{Slew rate} = \frac{dV_o}{dt}_{\text{max}}$$

As frequency is a function of time, the slew rate can be used to determine the maximum operating frequency of the op-amps as

$$\text{Maximum operating frequency} \cdot f_{\text{max}} = \frac{\text{Slew rate}}{2\pi V_{\text{pk}}}$$



Where,

V_{pk} → Peak output voltage.

i.e. peak output voltage limits the maximum operating frequency!

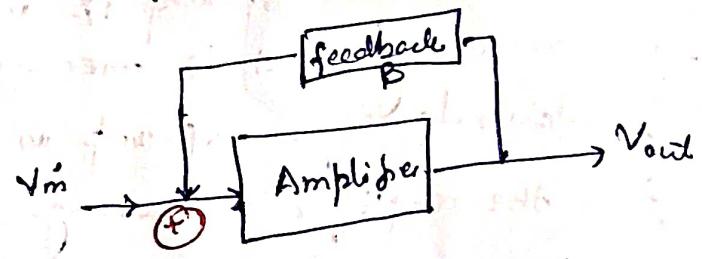
Closed loop gain of op-amp: (A_{CL})

Gain

$$V_{out} = A \times V_{in}$$

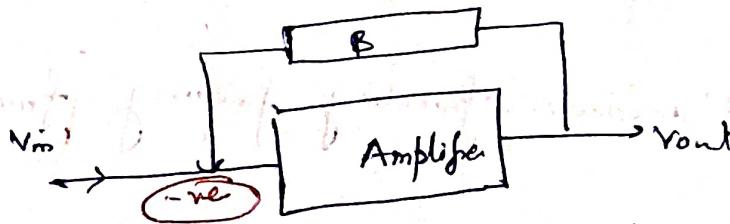
$$= A (V_{in} + \beta V_{out})$$

$$V_{out} (1 - A\beta) = A V_{in}$$



Positive feedback.

$$A_{CL} = \frac{V_{out}}{V_{in}} = \frac{A}{1 - A\beta}$$



Negative feedback.

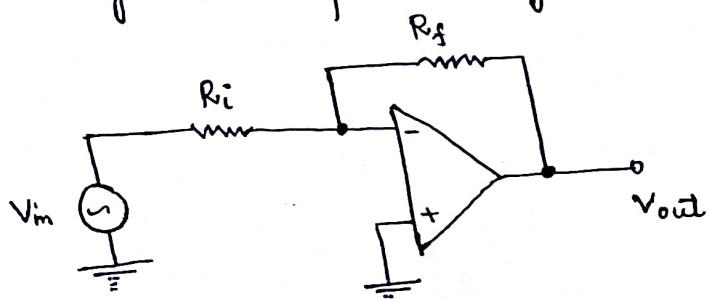
$$A_{CL} = \frac{A}{1 + A\beta}$$

Applications of op-amp:-

1) Inverting Amplifiers :-

An op-amp can be operated as an inverting amplifier as in fig. 1. An input signal v_{in} is applied through input resistance R_i to the inverting input (-ve). The output is fed back to the same (-ve) input thru' feedback resistor R_f .

The non-inverting (+ve) input is grounded.

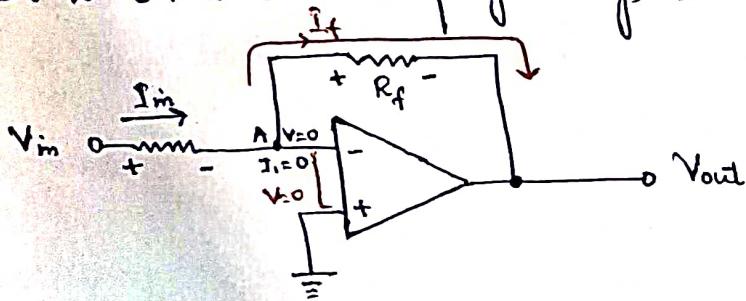


$R_f \rightarrow$ provides the negative feedback.

Since, the input signal is applied to the inverting input, the output will be inverted (i.e. 180° out of phase) as compared to input. Hence the name inverting amplifier.

Voltage gain:

An op-amp has an infinite impedance, that means there is zero current at the inverting input. If there is zero current through the input, then there must be no voltage drop b/w the inverting & non-inverting inputs. which means the voltage at the inverting input is zero. The OV at the inverting input terminal (A) is referred as Virtual Ground. (It is OV but not physically connected to the ground).



In fig. 1, the current I_i to the inverting input is zero. ($I_i = 0$)
 \therefore current I_m flowing through R_i entirely flows through
 feedback resistor R_f .

i.e. $I_f = I_m$.

as

$$I_{in} = \frac{\text{Voltage across } R_i}{R_i}$$

$$= \frac{V_m - V_A}{R_i}$$

$$I_{in} = \frac{V_m}{R_i} \quad (\text{as } V_A = 0). \rightarrow ①$$

and

$$I_f = \frac{\text{Voltage across } R_f}{R_f}$$

$$= \frac{V_A - V_{out}}{R_f}$$

$$I_f = -\frac{V_{out}}{R_f} \quad (\text{as } V_A = 0) \rightarrow ②$$

We know, $I_{in} = I_f$.

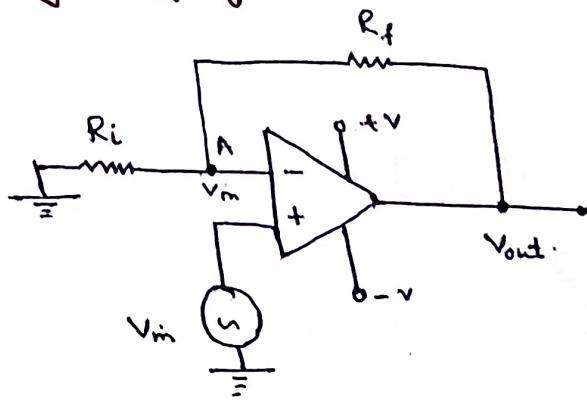
$$-\frac{V_{out}}{R_f} = \frac{V_m}{R_i}$$

$$\therefore \boxed{\text{Voltage gain (Acl)} = \frac{V_{out}}{V_m} = -\frac{R_f}{R_i}}$$

-ve sign indicates that the output signal is inverted as compared to input signal.

- Note:
- i) The closed-loop gain (A_{cl}) is independent of op-amp internal open-loop voltage gain. The -ve feedback stabilizes the voltage gain.
 - ii) If $R_f = R_i$, then A_{cl} is unity with 180° phase inversion.
 - iii) If R_f is some multiple of R_i , the amplifier gain is constant. Thus, the amplifier provides constant voltage gain.

Non-Inverting Amplifier



Voltage gain:

$$\text{Voltage across } R_i = V_m - 0$$

$$\dots \quad \dots \quad R_f = V_{out} - V_m$$

$$\text{as } I_m = I_f$$

$$\frac{V_m - 0}{R_i} = \frac{V_{out} - V_m}{R_f}$$

$$V_m R_f = V_{out} R_i - V_m R_i$$

$$V_m (R_f + R_i) = V_{out} R_i$$

$$\frac{V_{out}}{V_m} = \frac{R_f + R_i}{R_i}$$

$$= 1 + \frac{R_f}{R_i}$$

\therefore closed-loop voltage gain, $A_{CL} = \frac{V_{out}}{V_m} = 1 + \frac{R_f}{R_i}$

