The Operational Amplifier :-

→ An operational amplifier (op-amp) is a direct coupled high-gain amplifier usually consisting of one or more differential amplifie and followed by a level translator and an output stage.

- A direct coupled amplifier is a type of amplifier in which output of one stage of the amplifier is coupled to the input of the next stage in such a way to permit signals with zero frequency, also referred to as direct current to pass from input to output.

→ Operational amplifier is abbreviated as op-amp.

Application of Op-amp :-

→ The operational amplifier was originally designed for performing mathematical operations such as addition, subtraction, multiplication integration.

→ It can also be used for amplification of dc as well as ac input signal, active filters, oscillators, comparators, regulators and other by addition of external suitable feedback components.

Op-amp symbol :-

→ The circuit schematic of an op-amp is a triangle consists of 5 basic terminals.

→ It has 2 input terminals

→ 1 output terminal

→ 2 power supply

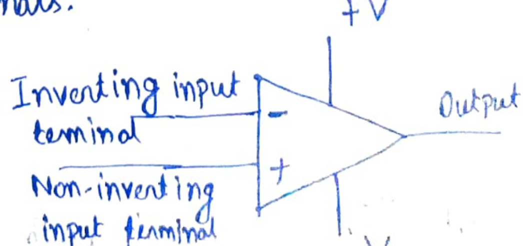


Fig. 1-

→ The terminal with a (−) sign is called inverting input terminal.

→ The terminal with (+) sign is called non-inverting input terminal.

→ Positive power supply (V+)

→ Negative power supply (V−)

→ power supply ranges from ±5V to ±22V

→ Generally ±15V is used as power supply.

Op-amp packages:

→ There are 3 popular packages available:

(i) The flat package

(ii) The metal can or transistor (TO) package

(iii) The dual-in-line package (DIP) (8, 12, 14, 16, 20 pins)

Operational Amplifier Pin Configuration

→ The IC number of 8 pin mini DIP is 741

→ The pin configuration of 8 pin mini DIP is as follows:

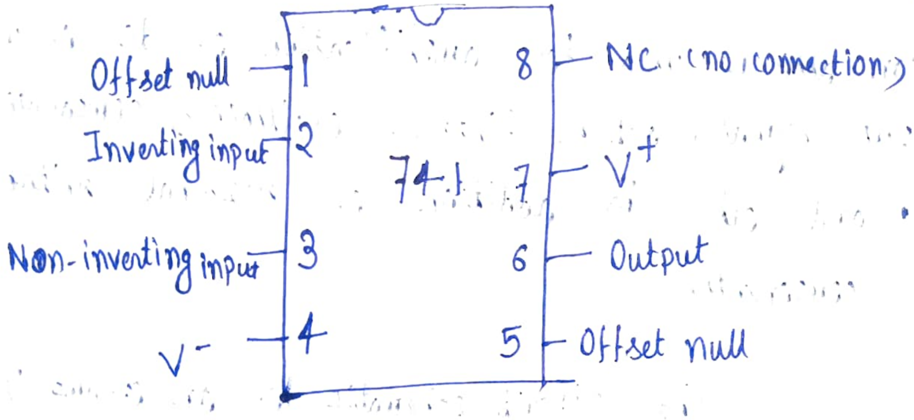


Fig. 2.

Op-amp specifications:

Temperature Ranges:

→ All ICs are manufactured fall into one of 3 basic temperature grades.

(i) Military temperature range: $-55°c$ to $+125°c$ (or $-55°c$ to $+85°c$)

(ii) Industrial temperature range: $-20°c$ to $+85°c$ (or $-45°c$ to $+85°c$)

(iii) Commercial temperature range: $0°c$ to $70°c$ (or $0°c$ to $75°c$)

→ 741 an internally compensated op-amp orginally manufactured by Fairchild.

→ Some of the well-known manufactures of linear ICs are:

1. Fairchild ---------- μA, μAF
2. National semiconductor ------ LM, LH, LF, TBA
3. Motorola ---------- MC, FC
4. RCA ---------- CA, CD
5. Texas Instruments ------- SN
6. Signetics ---------- N/S, NE/SE
7. Burn-Brown ---------- BB

National semiconductor --- LM741

→ Some linear ICs are available in different classes such as A, C, E, S, and SC.

741 ------ Military graded op-amp

741C ------ Commercial grade op-amp

741A ------ Improved version of 741

741E ------ Improved version of 741C.

741S ------ Military graded op-amp with higher slew rate.

741SC ------ Commercial grade op-amp with higher slew rate.

Block diagram representation of Op-amp

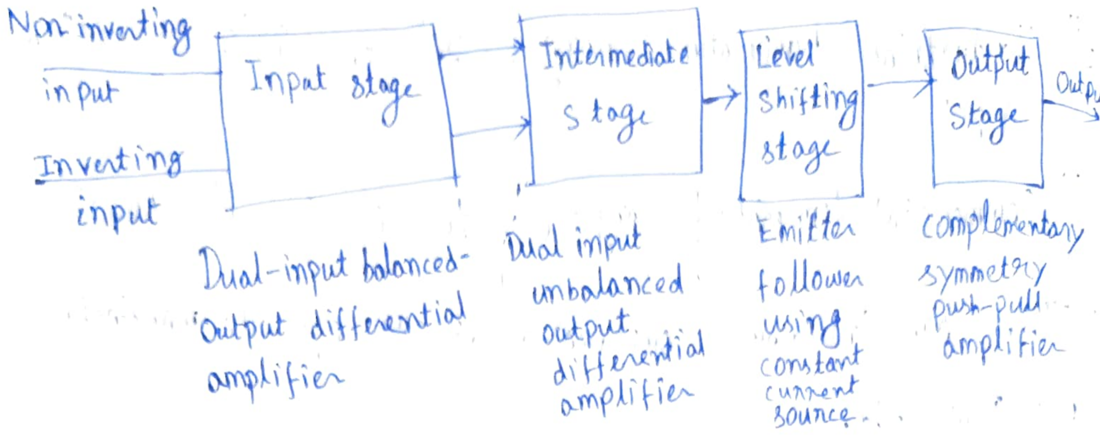


Fig.3. Block diagram of an op-amp

→ The op-amp consists of 4 stages namely input stage, intermediate stage, level shifting stage, output stage.

→ The input stage is the dual-input balanced output differential amplifier. The main purpose of the differential amplifier is to provide high gain and establish the input resistance of op-amp.

→ The intermediate stage is driven by input stage. In most amplifiers the intermediate stage is dual input, unbalanced (single ended) output. Because direct coupling is used, the dc voltage at the output of the intermediate stage is well above ground potential.

→ Generally the level translator (shifting) circuit is used after intermediate stage to shift the dc level at the output of the intermediate stage downward to zero volt with respect to ground. Here emitter follower using constant current source is used.

→ The final stage of op-amp is output stage, it consist of complementary symmetry push-pull amplifier, the output voltage swing increases, and current supplying capability of the op-amp raises. A well designed output stage also provides low output resistance.

Basic op-amp internal schematic

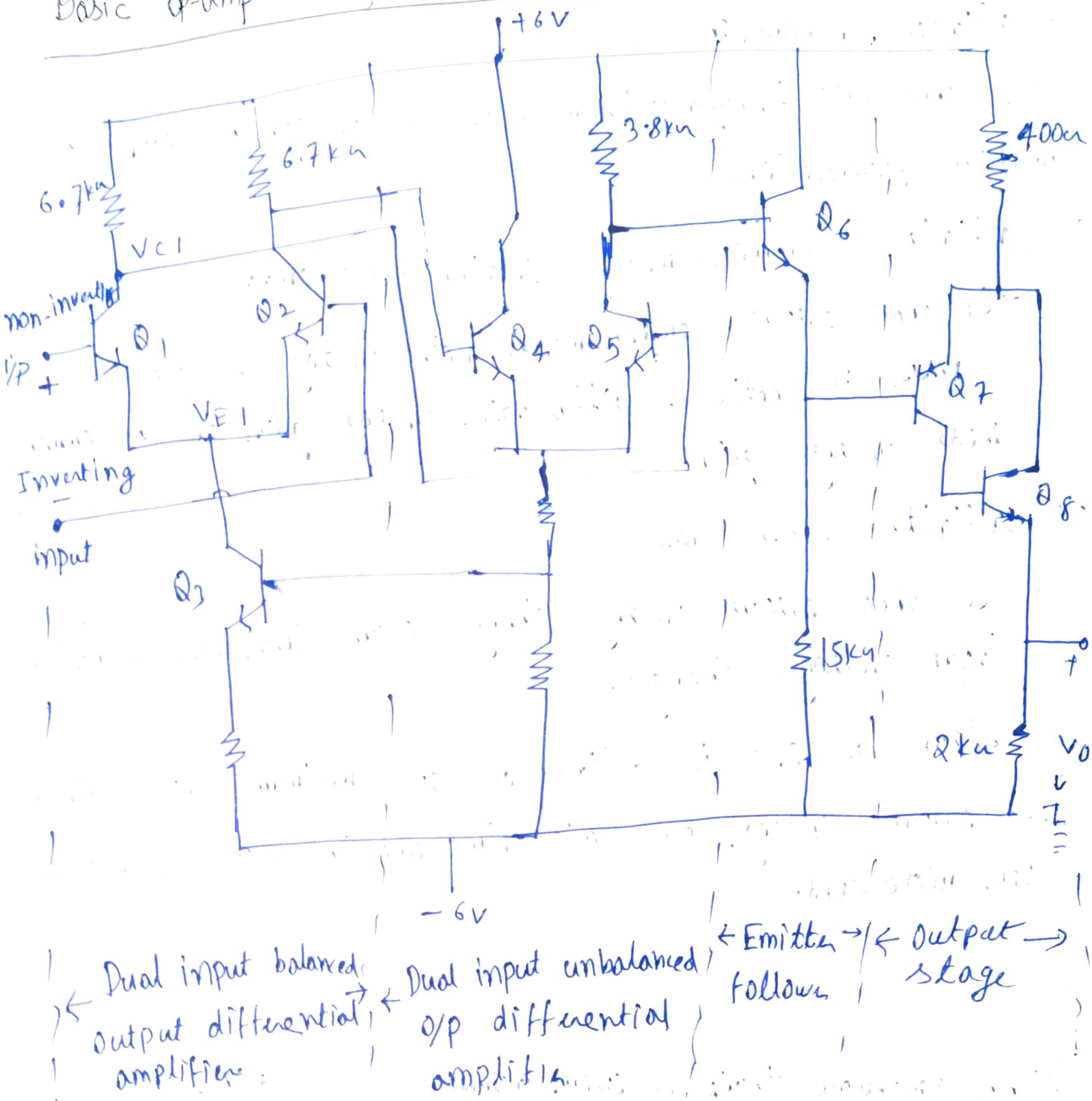


Fig.4. Internal schematic of op-amp (MC-1435 op-amp)

The ideal op-amp :

1. Infinite voltage gain A
   - for finite output voltage.
2. Infinite input resistance R_i
   - So that almost any signal source can drive it and there is no loading of preceding stage.

3. Zero output resistance, R_o

- So that output can drive infinite number of other devices.

4. Zero output voltage when input voltage is zero

5. Infinite bandwidth

- So that any frequency from 0 to ∞ Hz can be amplified without attenuation.

6. Infinite common-mode rejection ratio (CMRR)

- So that output common-mode noise voltage is zero.
- CMRR is ratio of differential voltage gain to the common mode voltage gain.

7. Infinite slew rate

- So that output voltage changes occur simultaneously with input voltage changes.

→ Slew rate (SR) is defined as the maximum rate of change of output voltage per unit time and is expressed in volt per microsecond.

Equivalent circuit of an op-amp:

→ The equivalent circuit of op-amp includes voltage gain (open loop voltage gain) (A), differential voltage (V_d), output resistance (R_o), input resistance (R_i)

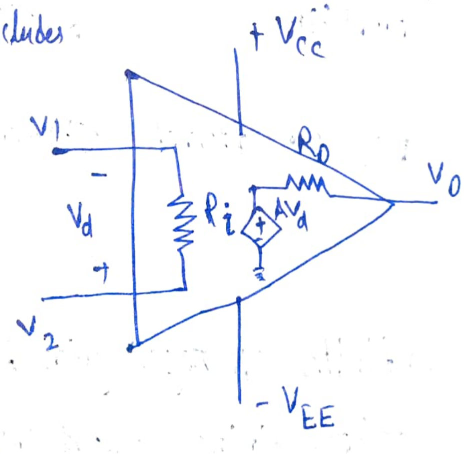


Fig.5. Equivalent circuit of an op-amp

V_1 = input at inverting terminal

V_2 = input at non-inverting terminal

V_o = Output voltage.

Output voltage $= V_o = A V_d = A(V_2 - V_1)$

→ The output can not exceed positive and negative saturation voltage.

→ Positive saturation voltage $(+V_{sat}) < +V_{CC}$

→ Negative saturation voltage $(-V_{sat}) < -V_{EE}$

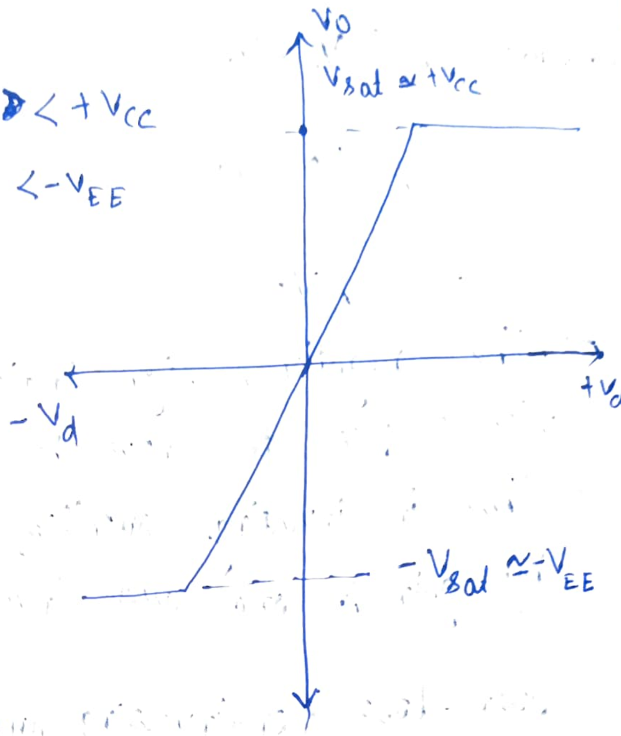


Fig. 6. Ideal voltage transfer curve

Open-loop configuration :

→ In open loop op-amp configuration, no connection either direct or via another network exists between the output and input terminals. (output signal is not feedback to input).

→ There are 3 open-loop op-amp configurations.

(i) Differential amplifier.

(ii) Inverting amplifier

(iii) Non-inverting amplifier

Open-loop differential amplifier

$$V_o = A V_d = A(V_1 - V_2)$$

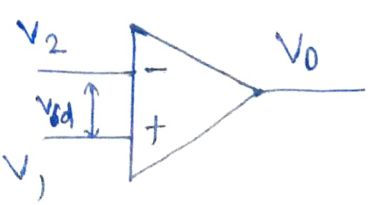


Fig. 7.

Open-loop inverting amplifier

Here $V_2 = 0$, $V_1 = V_i$

O/p voltage $V_o = A(V_2 - V_1)$

$= A(0 - V_i)$

$= -AV_i$

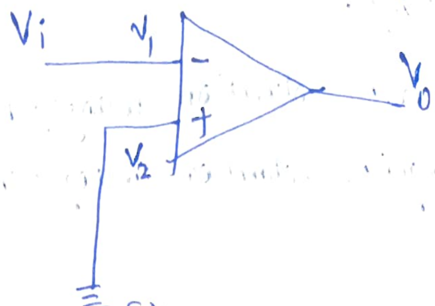


Fig. 8.

⇒ The negative sign indicates that the output of phase with respect to input by 180° or is of opposite polarity.

→ Thus in inverting amplifier, the input signal is amplified by gain A and also inverted at output

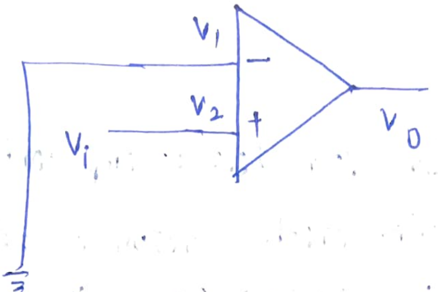
Open-loop non-inverting amplifier:

Here $V_1 = 0$, $V_2 = v_i$

$V_o = A(V_2 - V_1)$

$= A(v_i - 0) = Av_i$

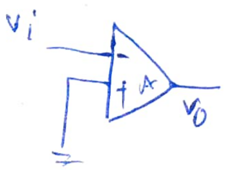
V_o = o/p voltage.



→ In non-inverting amplifier, the input signal is amplified by gain A and phase difference between input and output voltage is 0°.

Problems:

1. Q: Determine the output voltage for the open-loop inverting amplifier if:



a. Input voltage = 20 mV dc

b. Input voltage = −50 μV peak sin wave

Assume op-amp is 741 (Saturation voltage ±14V, A = 2,00,000).

Ans:- (a) $V_0 = -AV_i = -2,00,000 \times 20 \times 10^{-3} = -4000V$

As $V_0 \geq V_{sat}$ so $V_0 = -V_{sat} = -14V$

∴ O/P voltage = $V_0 = -14V$.

(b) $V_0 = -AV_i = -2,00,000 \times (-50) \times 10^{-6} = 10V$

∴ O/P voltage = $V_0 = 10V$.

~~2Q:- Determine the output voltage for the~~ ~~invert in~~ open-loop ~~inverting amplifier.~~

~~(a) V_{in} = 20 mV dc~~

~~(b) V_{in} = -50 μV peak sine wave.~~

~~Assume that~~

2Q:- Determine the output voltage in each of the following cases for the open-loop differential amplifier.

(a) Input to non-inverting ~~i/p~~ terminal = 5 μV dc

Input to inverting ~~i/p~~ terminal = -7 μV dc

(b) Input to non-inverting ~~i/p~~ terminal = 10 mV rms

Input to inverting terminal = 20 mV rms

→ The op-amp is a 741 with the following specification:
A = 2,00,000, R_i = 2 MΩ, R_o = 75Ω, $+V_{CC}$ = +15V, $-V_{EE}$ = -15V.
and output voltage swing = ±14V.

A:- (a) Given V_1 = 5 μV dc, V_2 = -7 μV dc

A = 2,00,000

∴ Output of differential amplifier = $V_0 = A(V_1 - V_2)$

$= 2,00,000 (5 \times 10^{-6} + 7 \times 10^{-6})$

$= 2 \times 10^5 \times 12 \times 10^{-6} = 24 \times 10^{-1} = 2.4$ V dc

∴ $\boxed{V_0 = 2.4V\ dc}$

(b) Given $V_1 = 10\,mV$ rms $= \sqrt{2} \times 10\,mV = 14.14\,mV$ peak

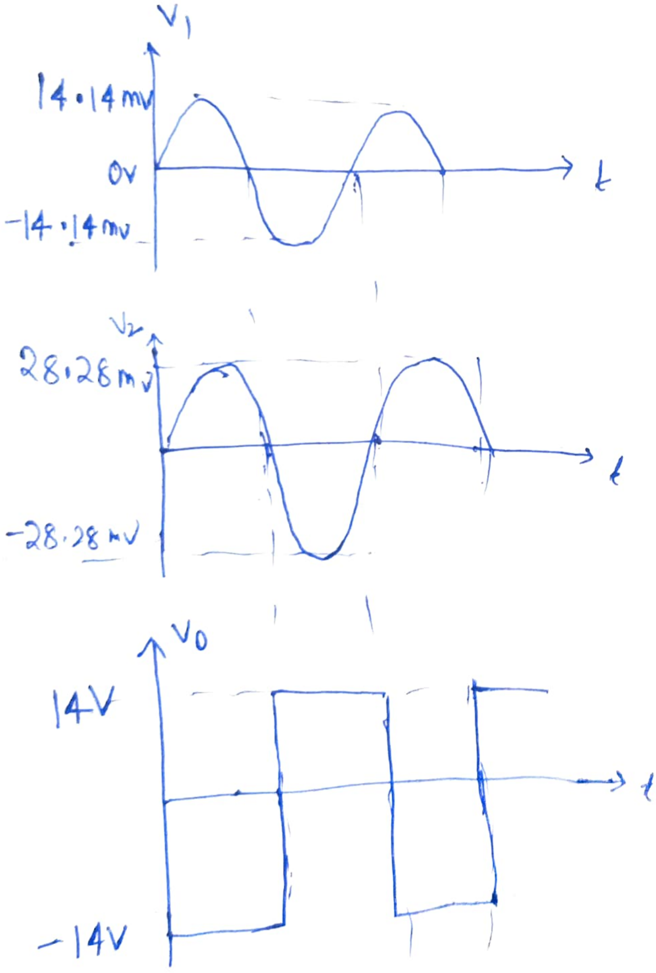
$V_2 = 20\,mV$ rms $= \sqrt{2} \times 10\,mV = 28.28\,mV$ peak

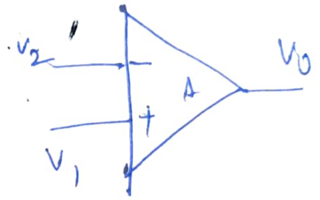
∴ Output voltage $= V_0 = A(V_1 - V_2)$

$= 2 \times 10^5 \times (10 \times 10^{-3} - 20 \times 10^{-3})$

$= -2000\ V$ rms

However, the values are more than $\pm 14V$ it clips.





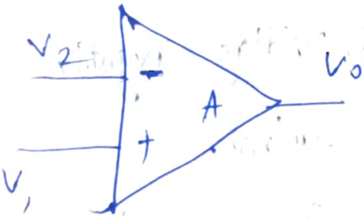
waveform of Q.2.(b)

3Q:- In the open-loop differential amplifier, input to the non-inverting terminal is 2.1 V_{dc} and input to the inverting terminal is 2.0 V_{dc}. Determine the output voltage V_o, Assume the op-amp is 741 with supply voltag = $\pm 15V$.

Ans:-

Given = $V_1 = 2.1 \, V \, d$

$V_2 = 2.0 \, V \, dc$



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

$$= 2\times10^5 \, (2.1 - 2.0)$$

$$= 2\times10^5 \, (0.1)$$

$$= 2\times10^4 \, V \, dc$$

$$V_0 = 2\times10^4 \, V \, dc$$

$= 14 \, V$ (as can not exceed saturation)