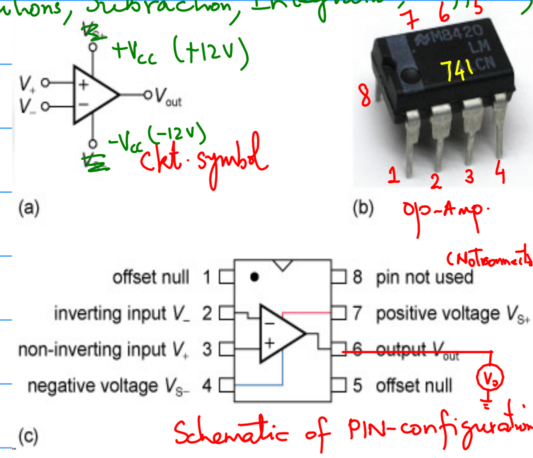
19.12.2023

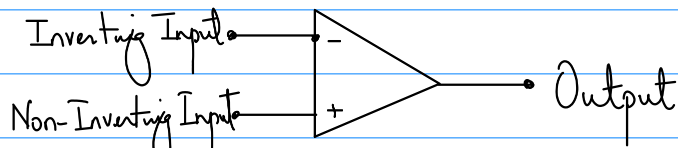
Operational Amplifiers (Op-Amps)

– To perform mathematical operations
(Additions, Subraction, Integration, Differenti)

1964, First integrated circuit Op-Amp was developed by Fairchild Semiconductor.



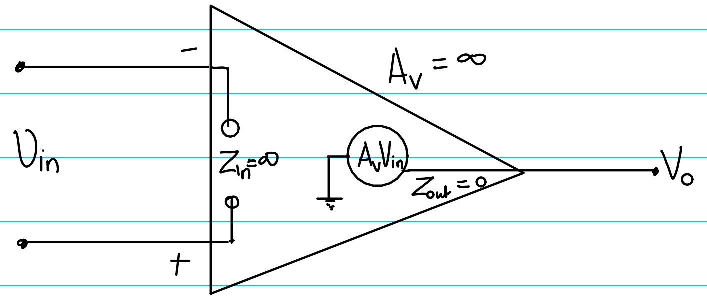
Ckt. symbol w/o bias :



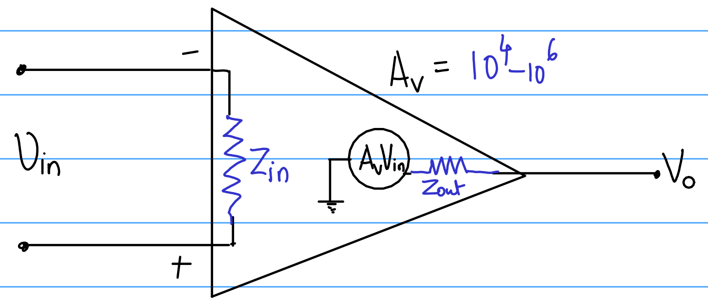
Characteristics of Op-Amps.

	Characteristics	Ideal	Practical
1.	Open-loop Voltage Gain, A_{OL}	∞	$\sim 10^4 - 10^6$
2.	Input Impedance, Z_{in}	∞	$\sim M\Omega$ $(10^6\Omega)$
3.	Output Impedance, Z_{out}	0	$\sim 100\Omega$
4.	Bandwidth	∞	$\sim 1\,Hz$
5.	Common-mode Rejection Ratio (CMRR)	∞	$\sim 80-120\,dB$
6.	Slew Rate	∞	$\sim 1V/\mu sec$

Ideal Representation of Op-Amp.



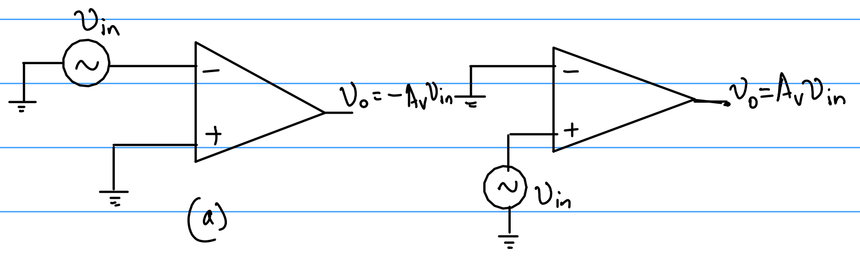
Practical Representation of Op-Amp.



Op-Amp Input Modes :

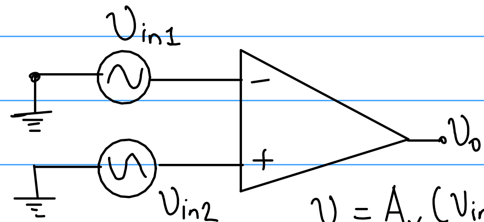
1) Differential mode :

- One signal is applied to an input and the other input is grounded.



Single-ended differential mode.

- Two opposite-polarity signals are applied to the inputs.



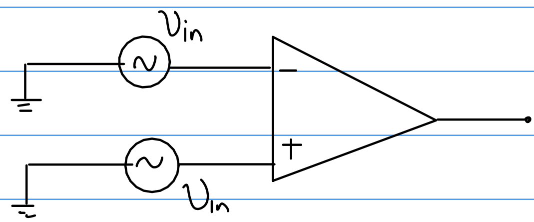
Double-ended differential mode.

$$V_0 = A_v(V_{in1} - V_{in2})$$

V_{in1} and V_{in2} has to be 180° out of phase.

2) <u>Common Mode</u> :

In this mode, two signal voltages of same phase, frequency and amplitude are applied to the two inputs.



$V_0 = 0V$ (ideally)

This action is known as Common-Mode rejection.

Rejection of unwanted signal (noise) appearing commonly to both the inputs of the op-amp.

<u>Example</u> :

Differential Mode : $V_{in} = V_{in1} - V_{in2}$

Common Mode : $V_{in} = \dfrac{V_{in1} + V_{in2}}{2}$

Differential Mode : Gain (A_v) is very high (ideally ∞, 10^4-10^6)

Common Mode : Gain (A_v) is very low (ideally 0, $10^{-3} - 10^{-5}$)

$$\boxed{\begin{aligned} A_{v,DM} &\sim 10^{4} - 10^{6} \\ A_{v,CM} &\sim 10^{-3} - 10^{-5} \end{aligned}}$$

$$v_{in1} = 5V$$

$$v_{in2} = 5V + 0.001 \sin\omega t$$

$$v_{in,DM} = v_{in1} - v_{in2} = -0.001 \sin\omega t$$

$$v_{in,CM} = \frac{v_{in1} + v_{in2}}{2} = 5V + 0.0005 \sin\omega t$$

$$v_{o,DM} = A_{v,DM} \cdot v_{in,DM} = 10^{5} \cdot (-0.001 \sin\omega t)$$

$$v_{o,DM} = -10^{2} \sin\omega t = -100V \sin\omega t$$

$$v_{o,CM} = A_{v,CM} \cdot v_{in,CM} = 10^{-5} (5V + 0.0001 \sin\omega t)$$

$$= 5\times10^{-5} V + 10^{-9} \sin\omega t)$$

$\Rightarrow$ Output voltage corresponding to DM input is very high whereas it is negligible for CM input.

The performance of Op-Amps is measured on the basis of it rejection of signal in common mode.

We define a parameter called 'Common-Mode Rejection Ratio'

ie $$\text{CMRR} = \frac{A_{OL}}{A_{CM}} \sim \frac{10^5}{10^{-3}} \sim 10^8$$

Higher the CMRR, better is the Op-Amp.

$$\text{CMRR (in dB)} = 20 \log_{10}\left(\frac{A_{OL}}{A_{CM}}\right)$$

if $\frac{A_{OL}}{A_{CM}} = 10^8$, then CMRR (in dB) = 160 dB

Maximum Output Voltage Swing ($V_{O(p-p)}$) :

In the above example, we have seen that for differential input voltage,

$$V_{O,DM} = -100V \sin\omega t.$$

However, we never get $\pm$ 100V in one cycle of oscillation.

That is, the output voltage is clipped above $\pm V_{cc}$.