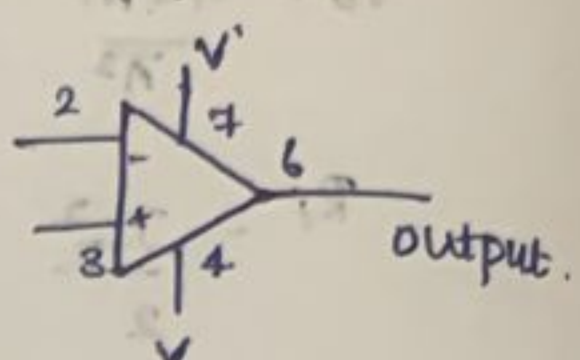
Op-Amp Indroduction.

- Op-amps (amplifiers / buffers in general) are drawn as a triangle in a circuit schematic. - They are nearly ideal.
- Two inputs :
  Inverting and Non-Inverting.
- One output.
- Also power connections. [no explicit ground).

2 -> inverting terminal (input)
3 -> non-inverting (positive) terminal.(input)



- There will be divot on pin-1. end.

The ideal op-amp.

characteristics.

- It has a infinite voltage gain.
  - means diff. b/w the positive terminal and negative terminal is amplified by 200,000.

-[which transistor used as op-amp].

- Infinite input impedance.
  - no current flow into input -> $10^{12}\Omega$ for FET Input op-amp.
- It has a zero output impedance.
  current max. (usually 5-25 mA).
- infinitely fast (infinite bandwidth).
  - in truth - limited to few MHz range.
  - Slew rate limited to 0.5 - 20 V/μs.

op-amp without feedback.

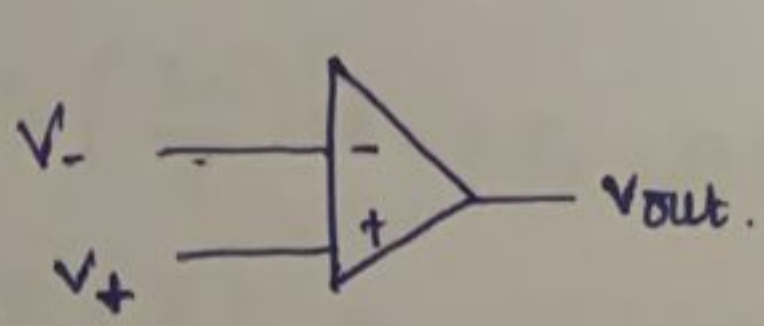
The internal op-amp formula:
symbol => A.

$V_{out} = \text{gain} \times (V_+ - V_-)$. => $V_{out} = A \times (V_+ - V_-)$.

∴ V_+ is greater than V_- so, output -> +ve.

if, V_- greater than V_+, the output -> '-'ve.

Max & Min. voltage is fixed (+15 & -15 resp.).



A ~~gio~~ gain of 200,000, device is useless. Practically.

OP-AMP Charalteristics.

Slew Rate: Maximum rate of change of output voltage vs time.

Let the signal be a sine wave $v(t) = k \sin 2\pi ft$.

The rate of change of signal w.r.t time is $\frac{dv}{dt} = 2\pi f k \cos 2\pi ft$

Max. rate of change $\frac{dv}{dt} = 2\pi f k$

slew rate required = $\boxed{2\pi f_{max} V_p}$

f_{max} is the highest signal frequency and V_p is the maximum output voltage required to be supported by the op-amp.

Ex:1. An op-amp having a slew rate of $SR = 2\ V/s$, what is the maximum closed-loop voltage gain that can be used when the input signal varies by 0.5 V in 10s?

Soln: For voltage gain A, $V_0 = AV_i \Rightarrow \frac{\Delta V_0}{\Delta t} = A \frac{\Delta V_i}{\Delta t}$

$$\Rightarrow A = \frac{\frac{\Delta V_0}{\Delta t}}{\frac{\Delta V_i}{\Delta t}} = \frac{SR}{\frac{\Delta V_i}{\Delta t}} = \frac{2}{0.5/10} = 40.$$

common mode rejection

- The common signal is rejected while the difference of the singal is amplified.
- Noice is common to both inputs, and hence is attenuated via the differential connections.
- This feature is known as common mode rejection ratio (CMRR)

  - Ideally CMRR should be infinite.

$$CMRR = A_d / A_c$$

$$CMRR\,(dB) = 20\log_{10}(A_d / A_c)$$

It is a measure of how well the op-amp suppresses the ideal signals.

Problem 1: An op-amp with a differential gain of $A_d = 4000$ is supplied with input voltages of $v_1 = 150\,\mu V$ and $v_2 = 140\,\mu V$.

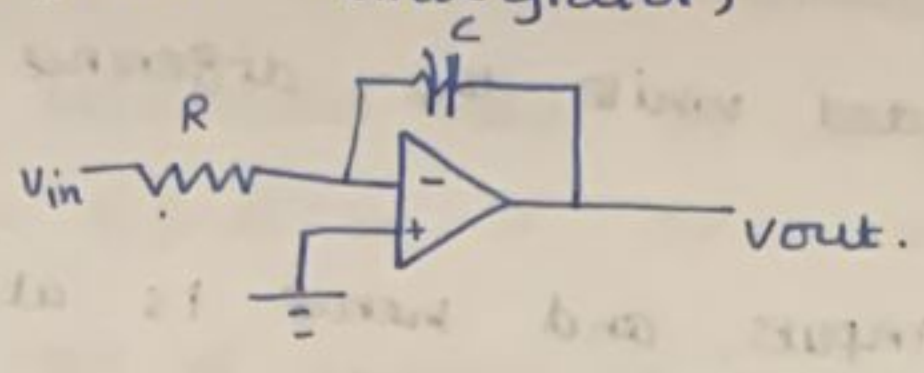
The output voltage is given by

$$V_o = A_d V_d + A_c V_c = A_d V_d\left(1 + \frac{A_c V_c}{A_d V_d}\right) \Rightarrow V_o\ A_d V_d\left(1 + \frac{1}{CMRR}\frac{V_c}{V_d}\right)$$

a. CMRR = 100

$$V_o = A_d v_d\left(1 + \frac{1}{CMRR}\frac{V_c}{v_d}\right) = 4000 \times 10$$

Low pass filter (integrator)



$I_f = V_{in}/R$, so $C \cdot dV_{cap}/dt = V_{in}/R$.

$i = \frac{V_{in}}{R}$ $\quad i = \frac{dQ}{dt} = \frac{C\,dV_0}{dt}$ $\quad Q = CV_0$

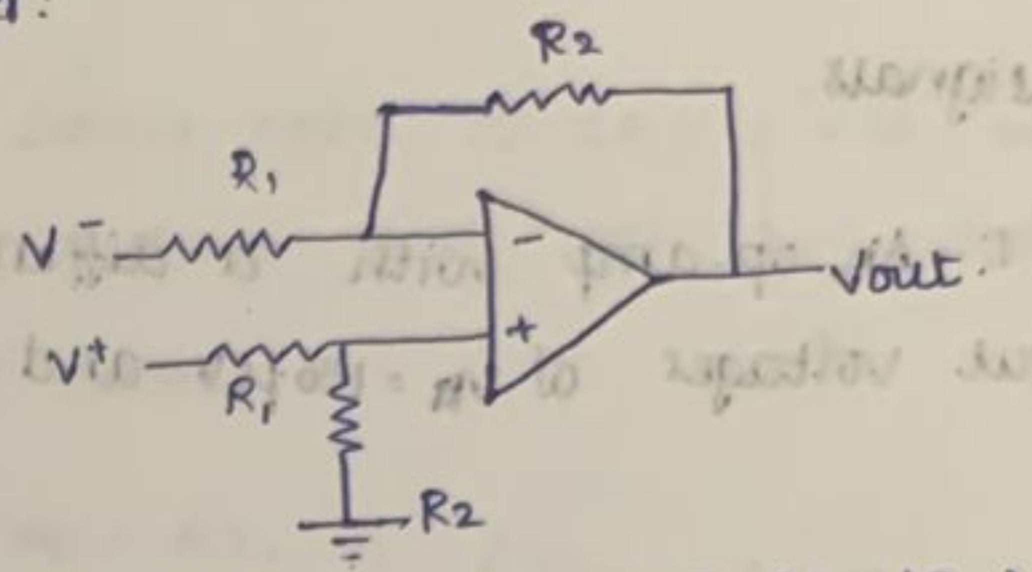
$dV_0 = \frac{V_{in}}{CR}\,dt$.

$V_0 = \frac{1}{RC}\int V_{in}\,dt$.

Subtractor - Differencing Amplifier:

The non-inverting input:

$V_{node} = \frac{V^{+}R_2}{(R_1+R_2)}$



So $I_f = (V^{-} - V_{node})/R_1$

$V_{out} = V_{node} - I_f R_2$

$= V^{+}(1 + R_2/R_1)(R_2/(R_1+R_2)) - V^{-}(R_2/R_1)$

So, $V_{out} = \underbrace{(R_2/R_1)}_{\text{voltage gain}}(V^{+} - V^{-})$.

Differential mode operation.

$V_0 = A_d V_i$ — A_d: differential gain

$[V_0 = A_d V_i]$

A_d typically very large.

Common mode operation:

$V_0 = A_c V_i$

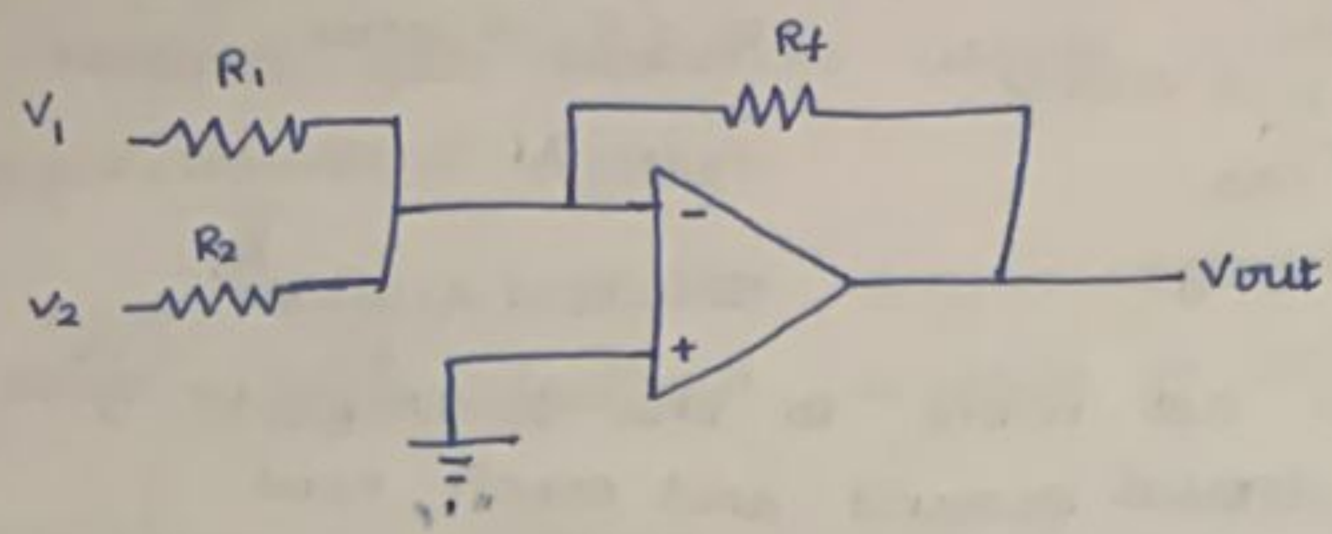
$A_c << A_d$

ouput voltage $= V_0 = A_d V_d + A_c V_c$

$V_d = (V_{i1} - V_{i2})$, $V_c = (V_{i1} + V_{i2})/2$

$A_d >> A_c$,

Summing Amplifiers:



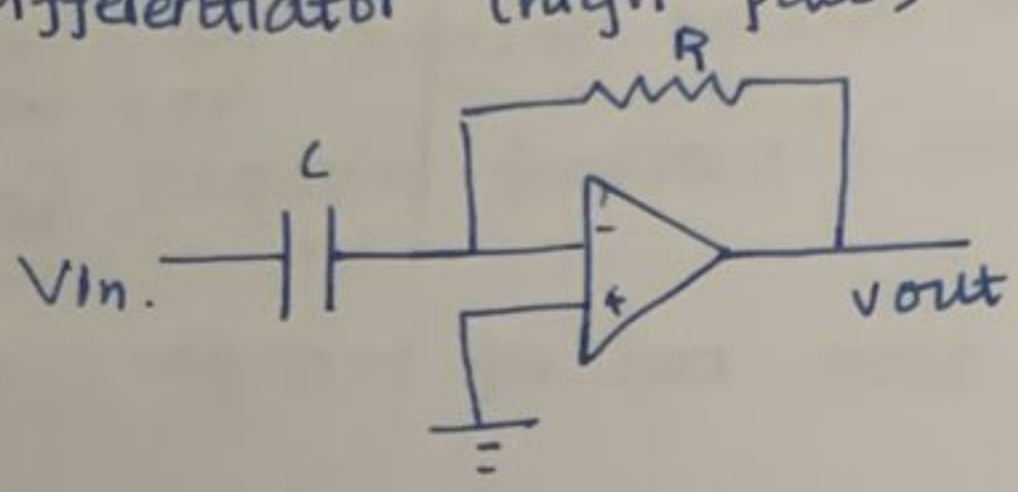
inverting input still held at virtual ground.

I_1 and I_2 are added together to run through R_f.

$V_{out} = R_f \times (V_1/R_1 + V_2/R_2)$

If $R_2 = R_1$ we get a sum proportional to (V_1+V_2).

Differentiator (high-pass)



$Q = CV$ $\quad I_{cap} = dQ/dt = C \cdot dV/dt.$

Thus, $V_{out} = -I_{cap} R = -RC \cdot dV/dt$.

- If signal is $V_0 \sin\omega t$, $V_{out} = -V_0 RC\omega \cos\omega t$
- the ω-dependence means higher frequencies amplified more.

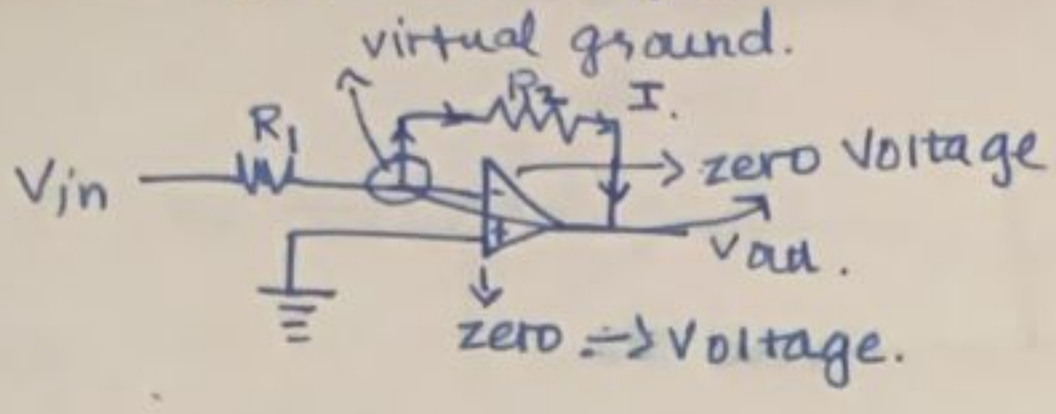
$i = \frac{dQ}{dt} = \frac{C\, dV_{in}}{dt}$

$V_{in} = \sin\omega t$

$i = \frac{V_0}{R} = C\frac{dV_{in}}{dt}$

$V_0 = -RC \cdot \frac{dV_{in}}{dt}$.

Inverting amplifier example:



R_1 & R_2 → series.

I in R_1 → $\dfrac{0 - V_{in}}{R_1} = -\dfrac{V_{in}}{R_1}$

I in R_2 → $\dfrac{V_{out} - 0}{R_2} = \dfrac{V_{out}}{R_2}$.

current will not move to the opamp, it goes through the virtual ground and reach vout.)

Inverting → positive input.

⇓

negative output.

$V_{out} = 0 - V_{in} \times (R_2 / R_1)$

$= -V_{in} (R_2 / R_1)$

We amplify vin by factor $-R_2 / R_1$.

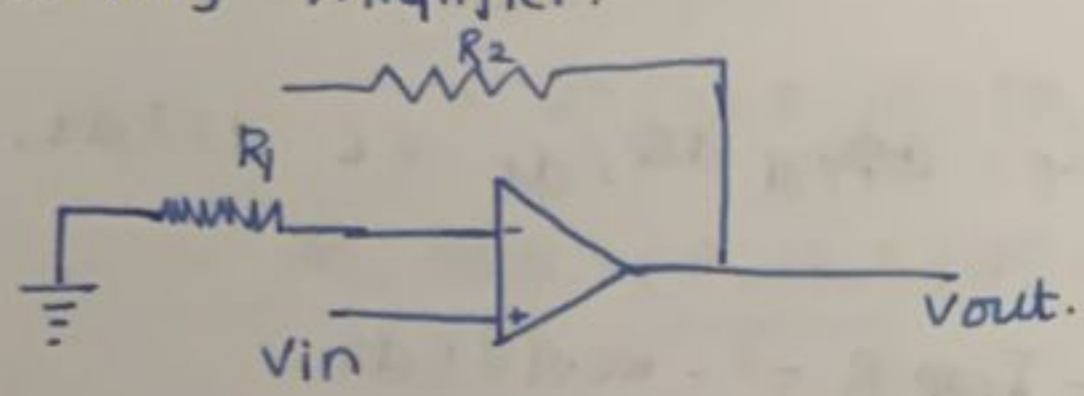
$\therefore V_0 = -\dfrac{R_2}{R_1} V_{in}$.

$V_0 =$ Gain vin.

$\therefore$ Gain $= -\dfrac{R_2}{R_1}$.

inverting.

Non-inverting Amplifier.



vin in positive terminal.

R_1 is $I = V_{in} / R_1$.

R_2 is $I_1 R_2 = V_{in} \times (R_2 / R_1)$.

$V_{out} = V_{in} + V_{in} \times (R_2 / R_1) = V_{in} \times (1 + R_2 / R_1)$

$$\left[V_{in} = V_0 \frac{R_1}{R_1 + R_2} \Rightarrow V_0 = \left(\frac{R_1 + R_2}{R_2}\right) V_{in} \quad \therefore V_0 = \left(1 + \frac{R_2}{R_1}\right) V_{in} \right]$$

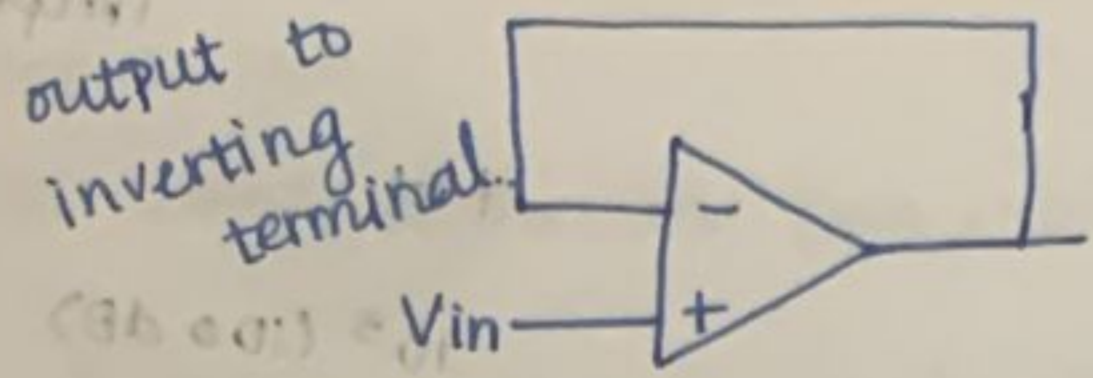
current is sourced from op-amp output. in the above example.

Infinite gain in negative feedback

- Infinite gain would be useless except in the self-regulated negative feedback regime.

positive feedback → runaway or oscillation → very bad.

negative feedback → leads to stability.

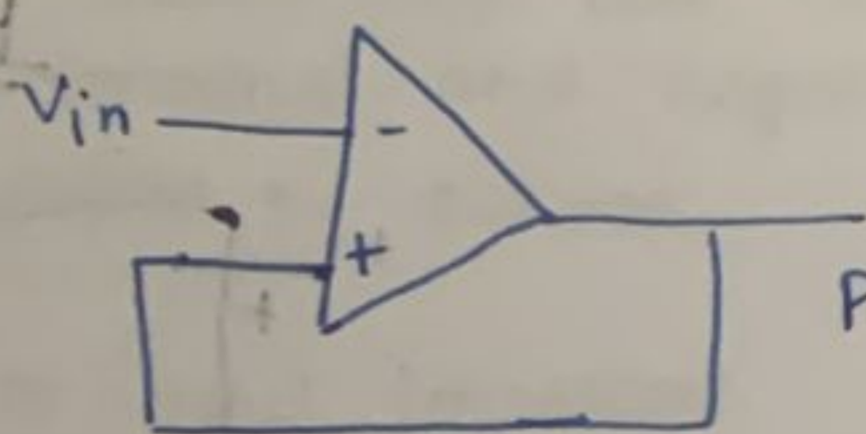


negative feedback loop

- ouput ~~negative~~ greater than Vin - negative
- output less than Vin → positive

$$V_o = A(V_{in}^{+} - V_{in}^{-})$$

- If we give to positive feedback, the output will shoot the extreme saturation value.
- negative feedback -> osillated b/w positive and negative.
- negative feedback make it self-working.



positive feedback: BAD.

Makes the positive terminal even more positive. System will immediately "rail" at the supply voltage.

Op-amp rules:

configured in any negative feedback arrangement:

- The inputs to the op-amp ~~output~~ draw or source no current.
- The op-amp output will do whatever it can to make the voltage difference b/w the two inputs zero.

[one terminal is always grounding].

- The external resistance are much larger than R_o and much smaller than R_i [Assume: $R_i \to \infty$, $R_o \to 0$]

Ideal op-amp → Input is ∞.

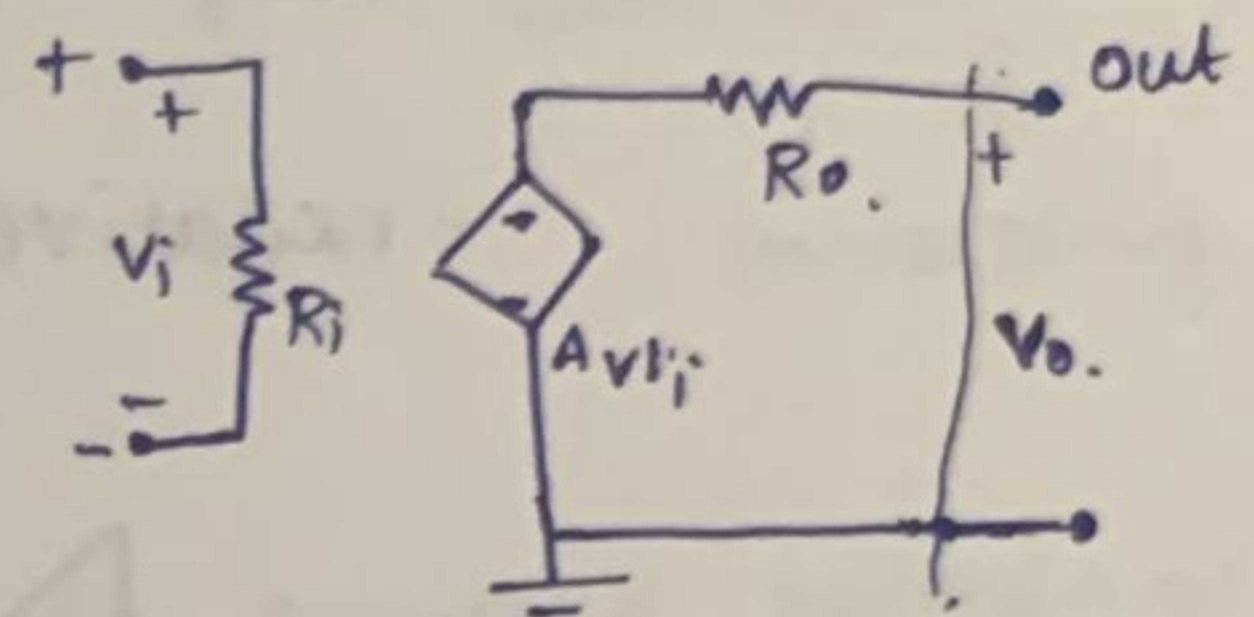
Amt. of current flow through the op-amp is zero, but it is flowing outside.

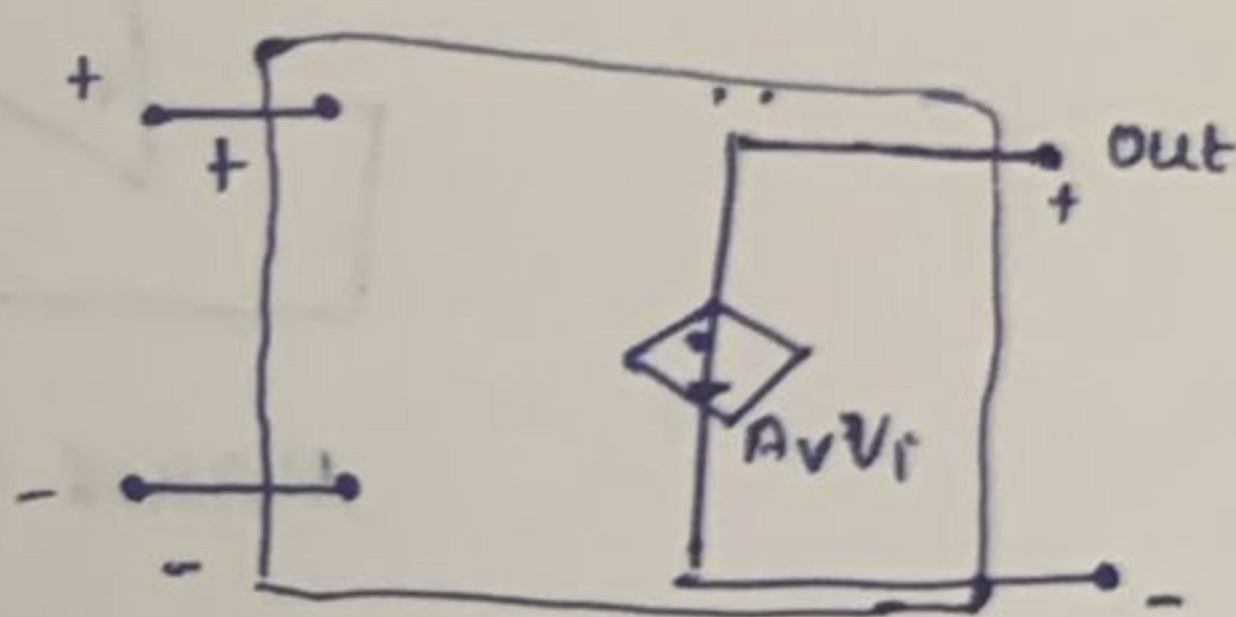
zero ↓ coz of ∞ input impedance.

Parameter	Ideal OP-amp	741
Av	∞	10^5 (100 dB)
Ri	∞	2MΩ
Ro	0	75Ω.

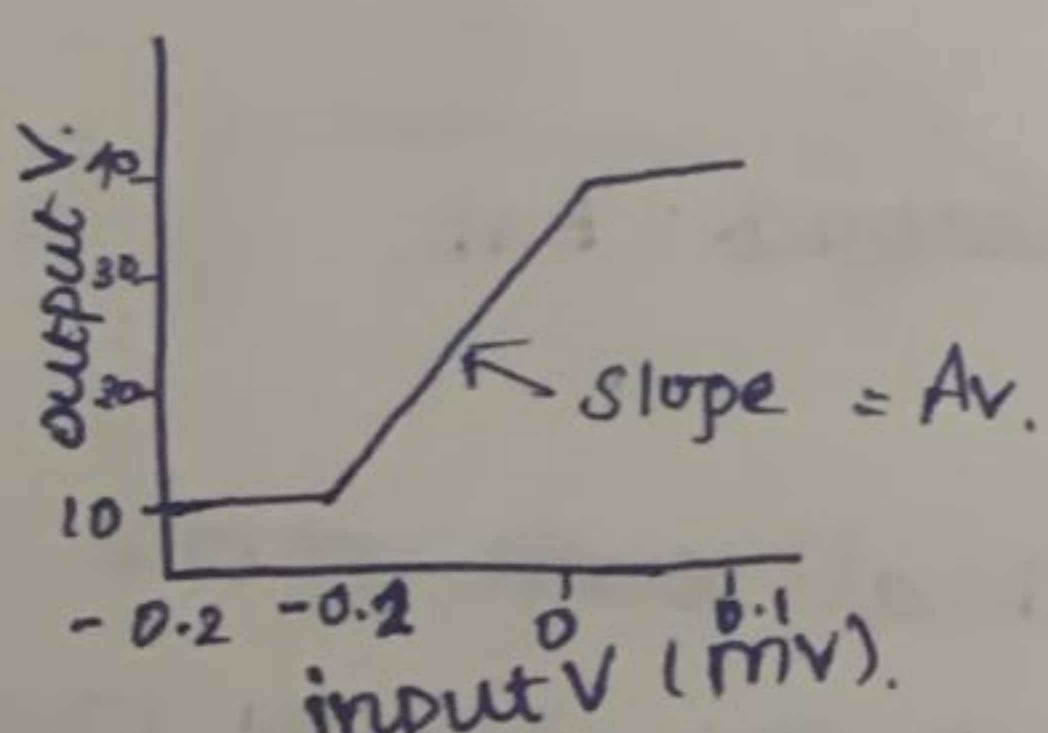
$\left.\begin{array}{cc} V_{CC} \text{ and } & V_{EE} \\ \downarrow & \downarrow \\ 4\text{pin} & 7\text{pin} \end{array}\right\} \to$ supply voltage.

block diagrams.





Graph:



i.e, V_+ as 1

V_- as 0.0001.

$\left.\begin{array}{l} V_+ \text{ is } 1.0001 \\ V_- \text{ is } 1. \end{array}\right\} \to 10V.$