14/10/24

Op-Amp fundamentals:

2 input 1 output device.

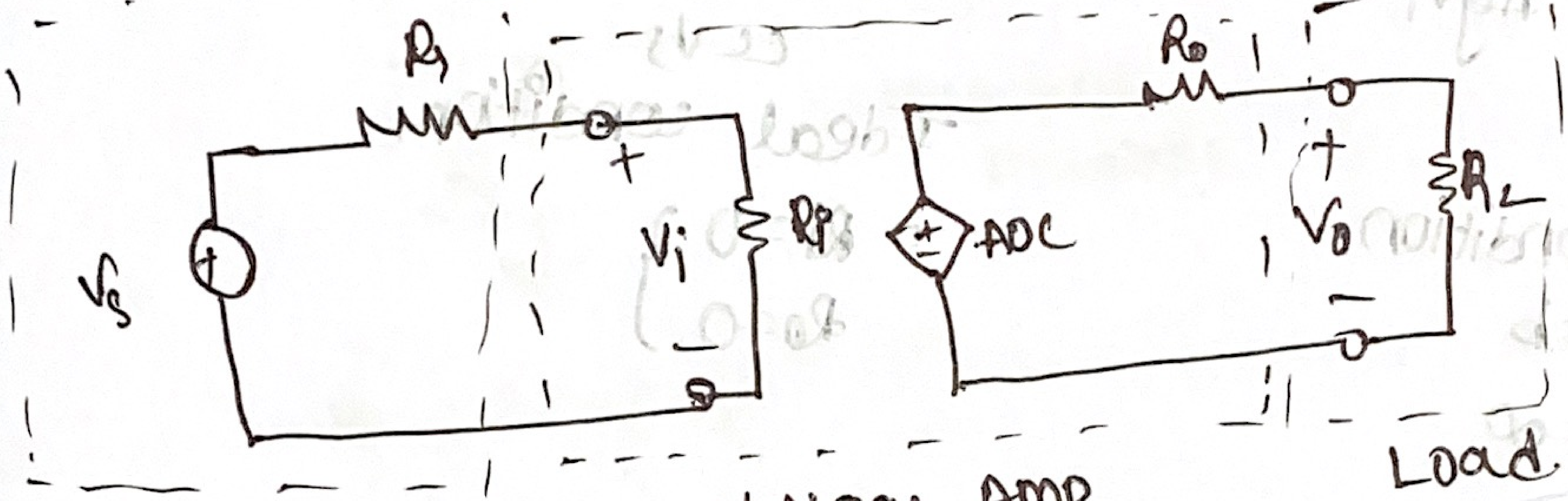
Amplifier fundamentals:

$o/p = \text{gain} \times i/p \Rightarrow$ linear Amp.

① Voltage amplifier $\rightarrow$ 1 i/p = Voltage

1 o/p = Voltage

gain = V/V (dimensionless).



$V_o/V_s = ??$

$$V_o = \frac{R_L}{R_o + R_L} \times A_{OC} V_i$$

$$V_i = \frac{R_i}{R_i + R_s} \times V_s$$

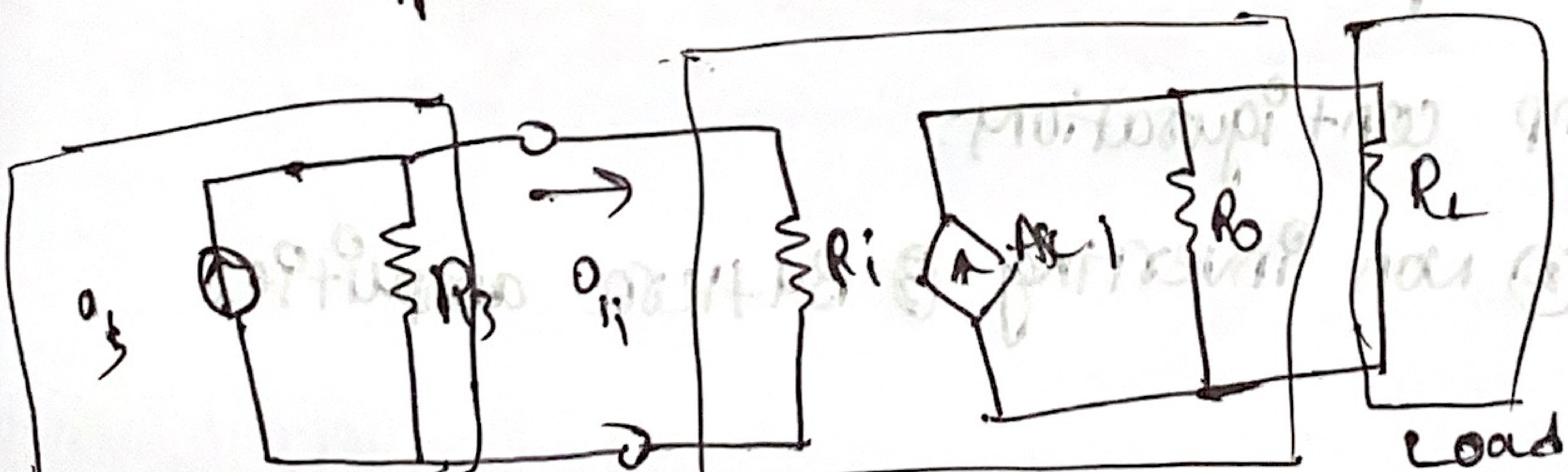
$$\boxed{\frac{V_o}{V_s} = \frac{R_i}{R_i + R_s} \times A_{OC} V_i \cdot \frac{R_L}{R_o + R_L}} \Rightarrow \begin{array}{l} R_i = \infty \\ R_o = 0. \end{array}$$

$$\Rightarrow \frac{V_o}{V_s} = A_{OC}.$$

② Current Amplifier:

i/p = current

o/p = current



$A_{SC} \rightarrow$ short ckt current gain.

$$\boxed{\frac{i_o}{i_s} = \frac{R_s}{R_s+R_i} \times A_{isc} \times \frac{R_o}{R_o+R_L}}$$

$$i_1 = \frac{R_s}{R_s+R_i} \times i_s$$

$R_s >> R_i$, $R_o >> R_L$

$$i_o = \frac{R_o}{R_o+R_L} \times A_{isc}\, i_1$$

$R_i = 0$, $R_o = \infty$

(3) Transconductance Amp:

i/p = voltage

o/p = current

gain = $A_g v_i$

VCCS

Ideal condition,

$R_i = \infty$

$R_o = \infty$

(4) Transresistance amp:

i/p = current

o/p = voltage

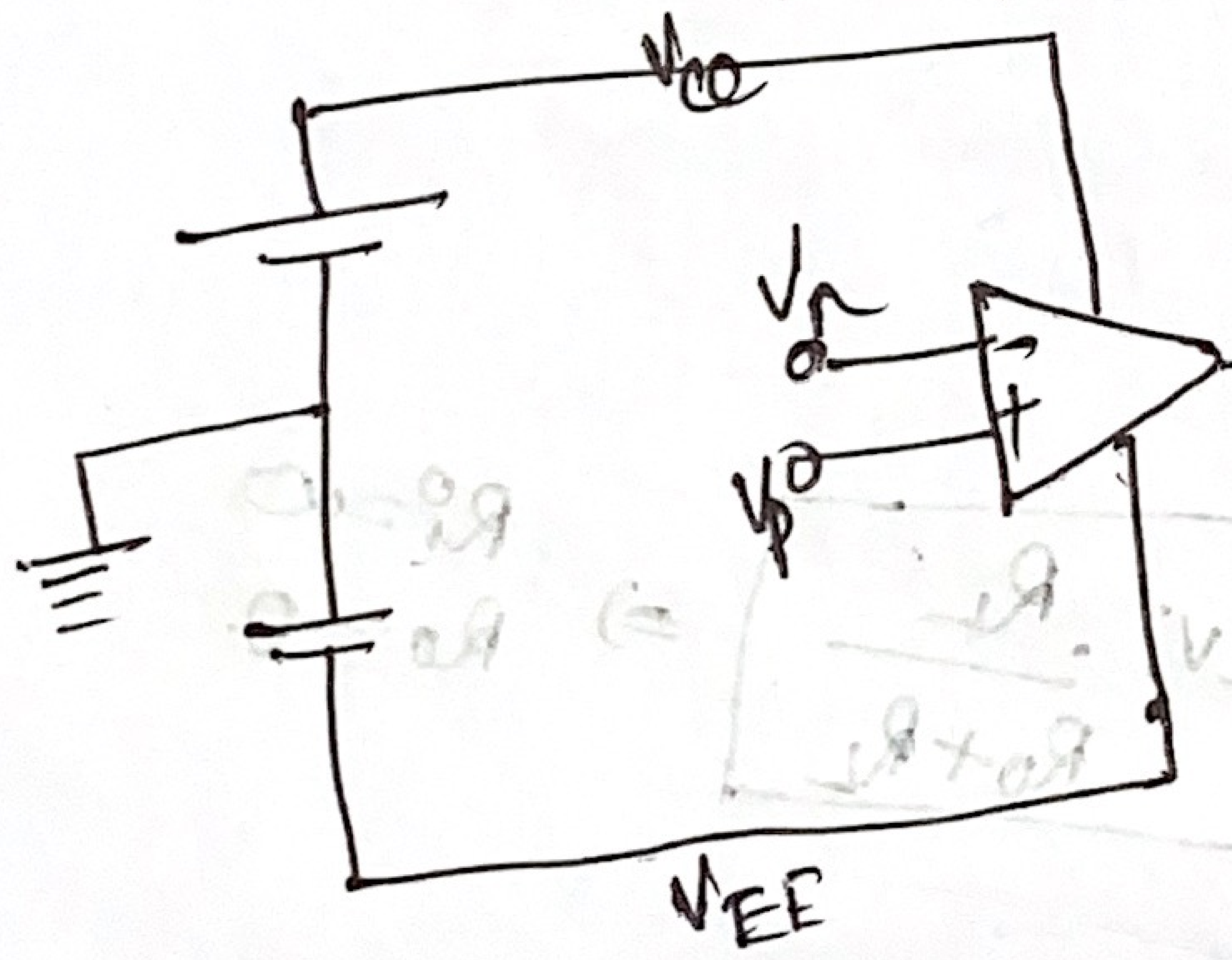
gain = $A_{ri} i_c$

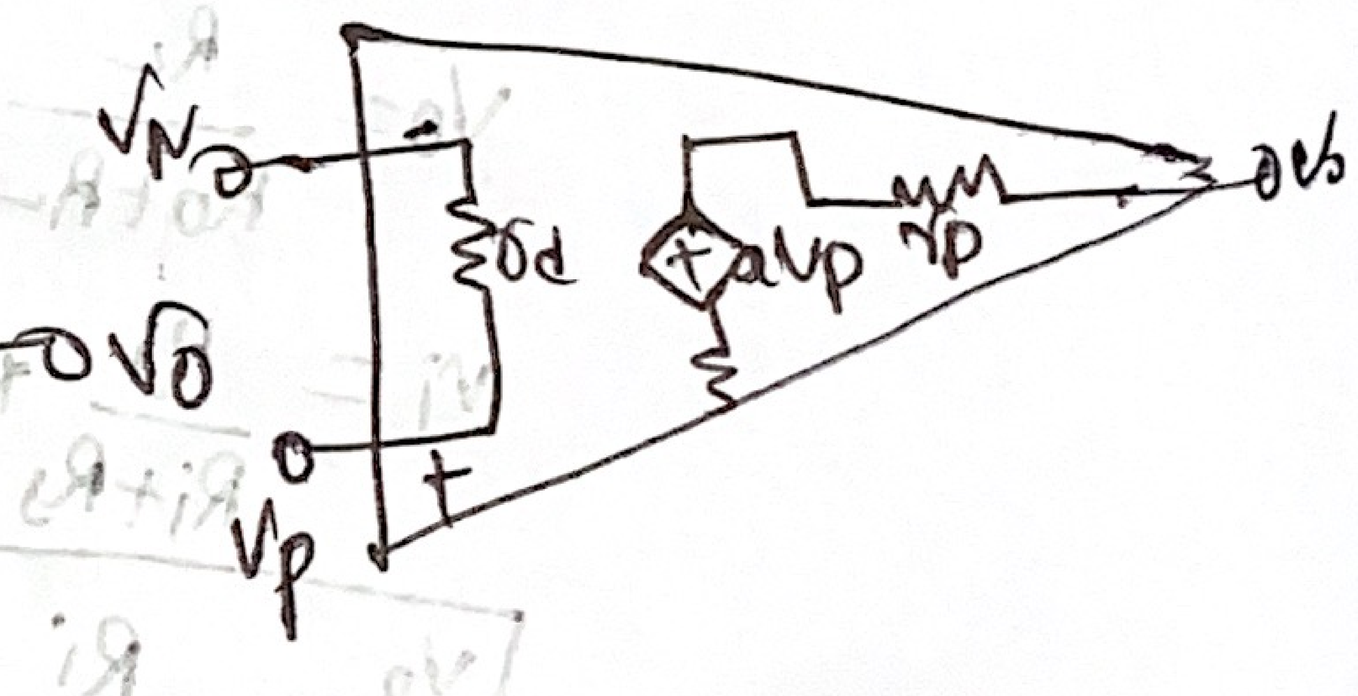
CCVS

Ideal condition

$= R_i = 0$, $R_o = 0$.

Operational Amplifier:





r_o = o/p resistance

r_d = i/p resistance

a = voltage gain.

open loop parameter

$V_D = V_P - V_N$

$V_O = aV_D = a[V_P - V_N]$

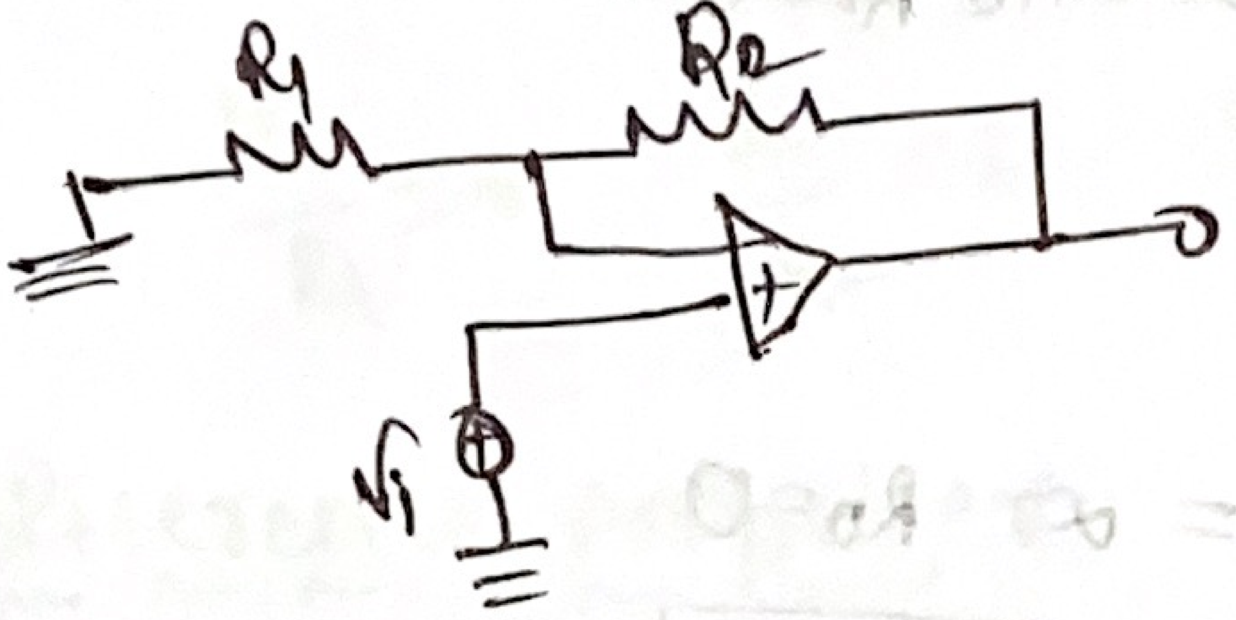
→ Ideal op-amp.

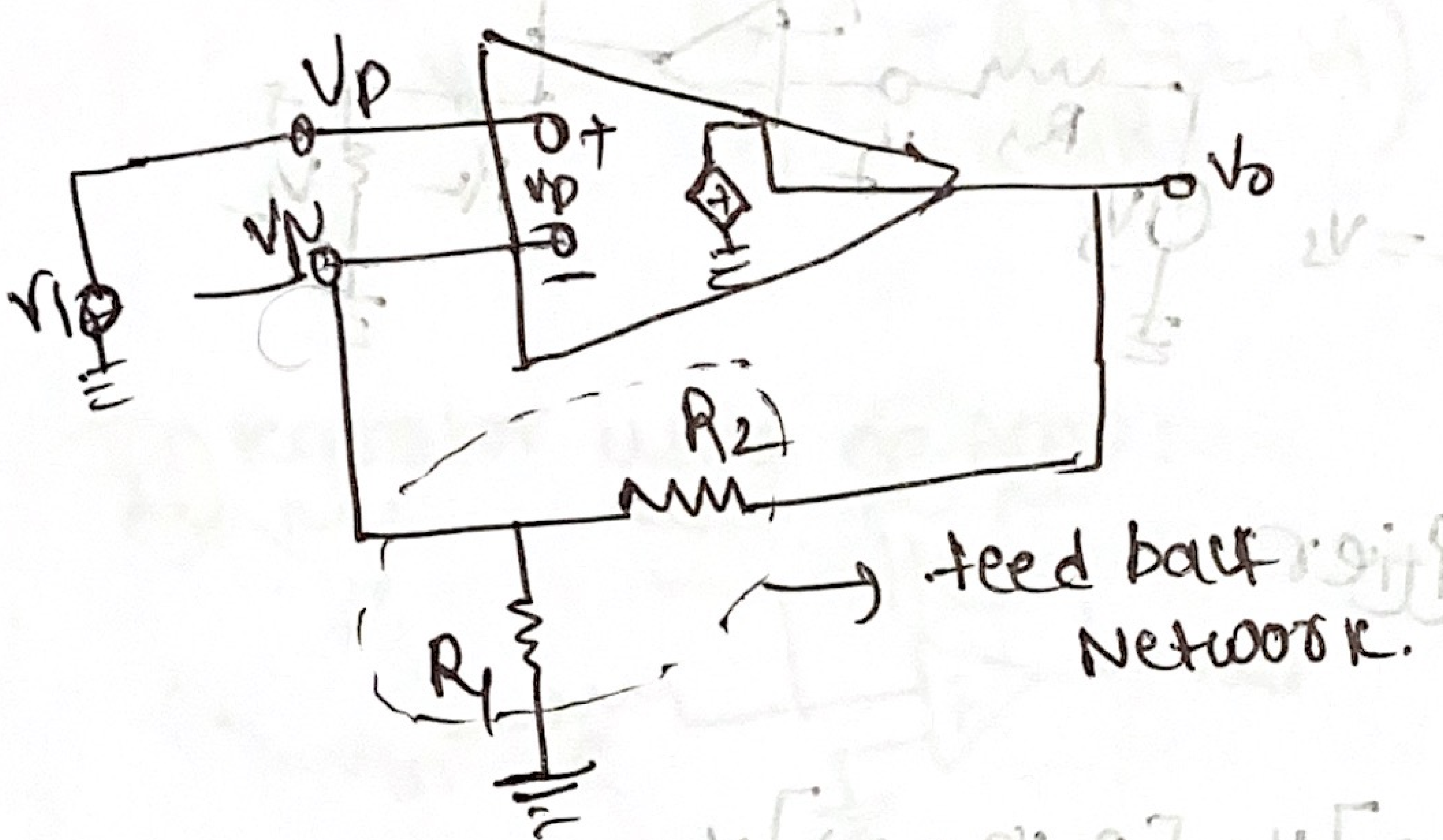
Basic of op amp configurations:

(1) Inverting (2) Non inverting (3) Buffer amplifier

Non-Inverting Amplifiers:

an op-amp + 2 external resistance





$V_o = a(V_P - V_N)$

$V_P = V_i$

$V_N = \frac{R_1}{R_1+R_2} V_o \Rightarrow V_N = \frac{1}{1+R_1/R_2} V_o$

$\Rightarrow V_o = a\left(V_i - \frac{1}{\frac{R_1+R_2}{R_1}} V_o\right)$

$$\boxed{\frac{V_o}{V_i} = A = \left(1+\frac{R_2}{R_1}\right)\left[\frac{1}{1+\left(1+\frac{R_2}{R_1}\right)/a}\right]}$$ (voltage gain)

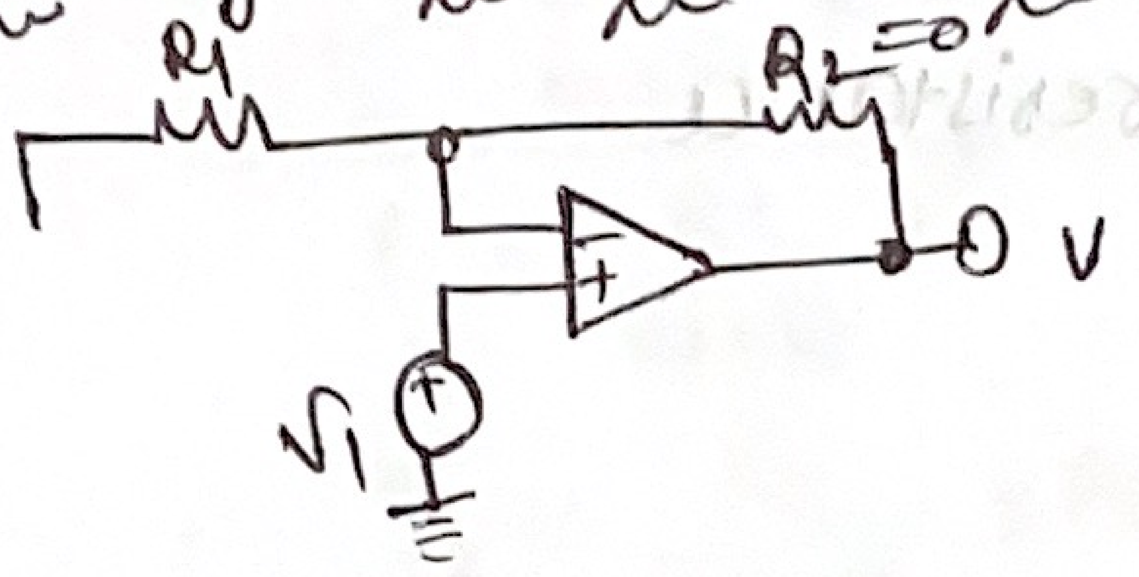
A = voltage gain for closed loop

a = voltage gain for open loop

$$\boxed{A_{ideal} = \lim_{a\to\infty} A = 1 + \frac{R_2}{R_1}}$$ letting $a \to \infty$

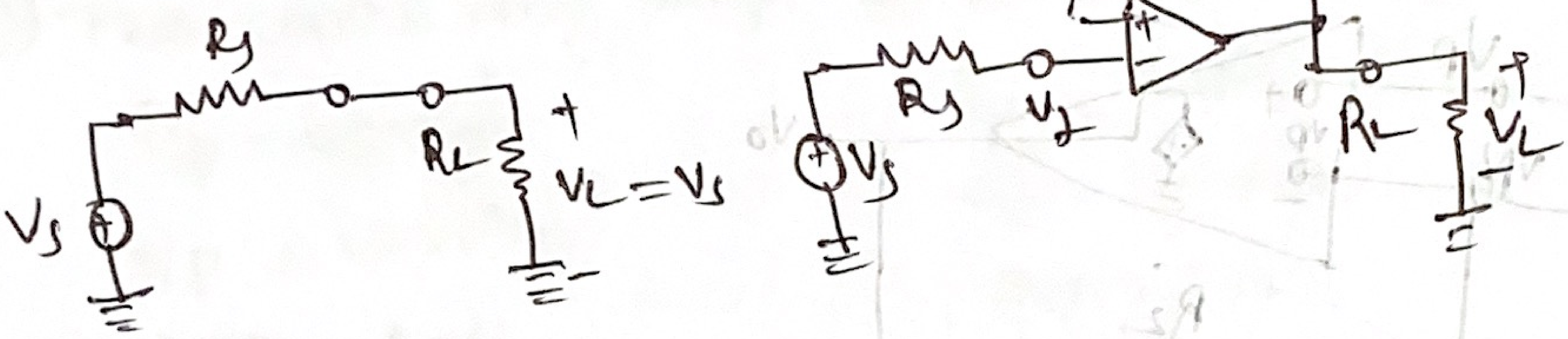
16/02/22

Voltage follower using op-Amp:



$R_1=\infty$ and $R_2=0$.

resistance transformer; $R_i=\infty$ $R_o=0$.



Inverting Amplifier:

$V_p=0$

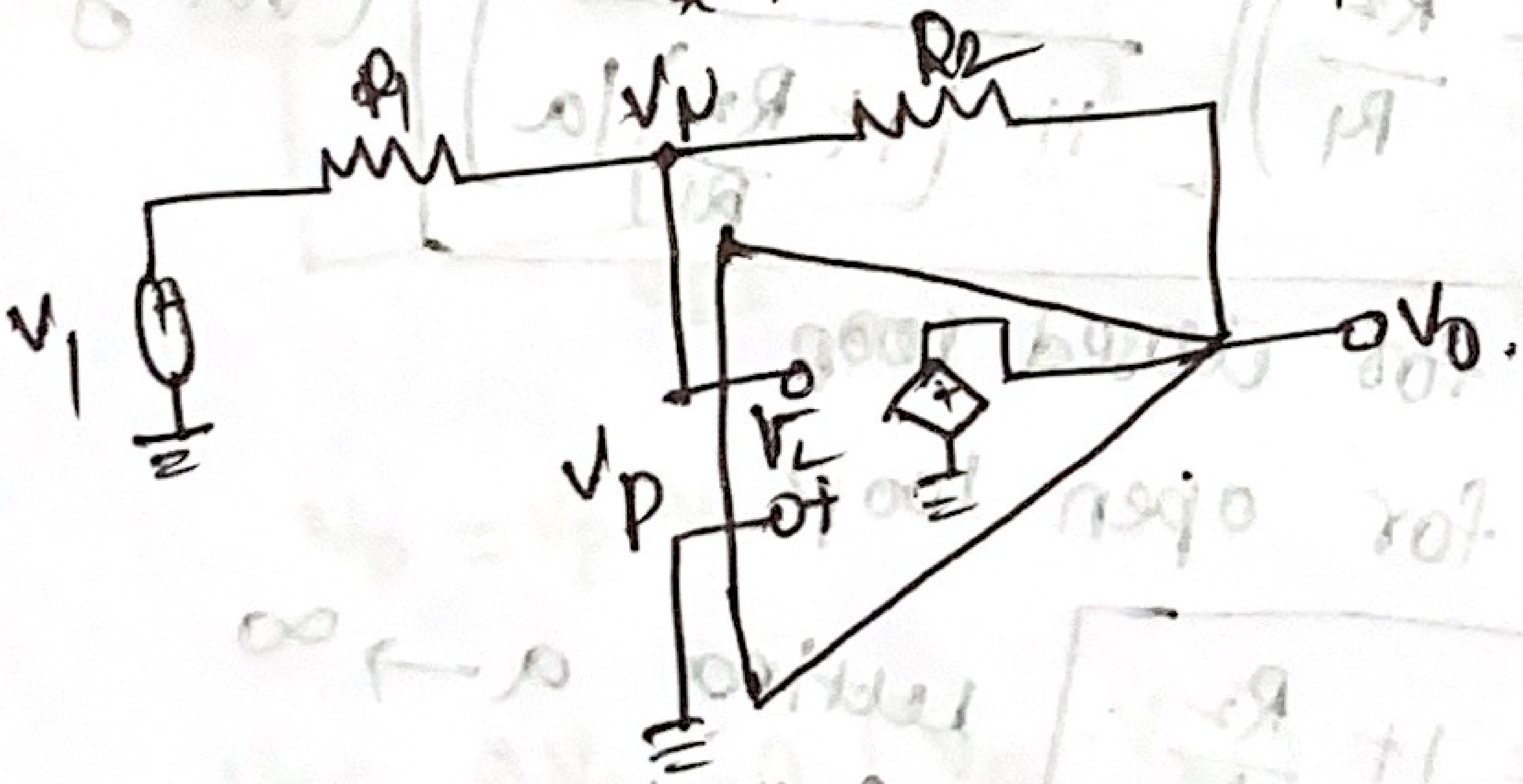
$V_N=[R_2/(R_1+R_2)]V_1+[R_1/(R_1+R_2)]V_o$

$$V_N=\frac{1}{1+R_1/R_2}V_1+\frac{1}{1+R_2/R_1}V_o$$

$$V_o=a(V_p-V_N)=a\left(-\frac{1}{1+R_1/R_2}V_1-\frac{1}{1+R_2/R_1}V_o\right)$$

$$A=\frac{V_o}{V_1}=\left(-\frac{R_2}{R_1}\right)\frac{1}{1+(1+R_2/R_1)/a}$$

$$A_{ideal}=\lim_{a\to\infty}A=-\frac{R_2}{R_1}\qquad a\to\infty$$



$$\boxed{V_d=V_p-V_N}$$

→ Application of Inverting Amp.

Summing Amplifier:

we can do sum, sub, differentiation integration by this amplifier.

$i_1+i_2+i_3=i_f$

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}=-\frac{V_o}{R_f}\qquad V_o=-\left(\frac{R_f}{R_1}V_1+\frac{R_f}{R_2}V_2+\frac{R_f}{R_3}V_3\right)$$

Ex: using standard 5% resistances, design a circuit such $V_o = -2(3V_1 + 4V_2 + 2V_3)$ if $R_f = 20k\Omega$

$\frac{R_f}{R_1} = 6$ $\quad \frac{R_f}{R_2} = 8$ $\quad \frac{R_f}{R_3} = 4$

$R_1 = 3.33k\Omega$
$R_2 = 2.50k\Omega$
$R_3 = 5.00k\Omega$

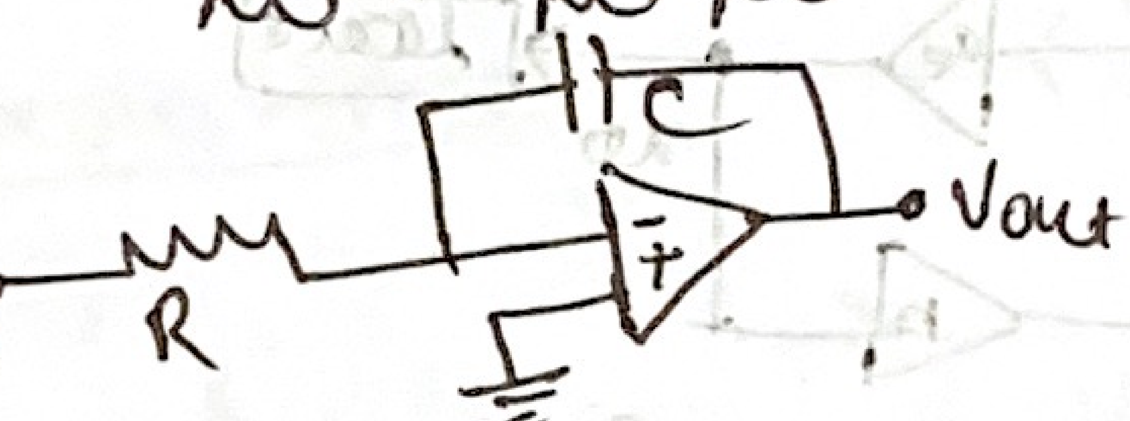
-> Difference Amplifier:

$$V_o = \frac{R_2}{R_1}\left(\frac{1+R_1/R_2}{1+R_3/R_4}V_2 - V_1\right)$$

$V_2 - V_1 = V_o$

V_2 ↓ Non inverting; V_1 → Inverting

Integrator using op-Amp:



KCL at inverting node.

$I_{in} = I_c$

$$\frac{V_{in} - 0}{R} = C_F \frac{dV_C}{dt}$$

$$V_{in}/R = C_F \frac{d[0 - V_{out}]}{dt}$$

$$\boxed{\frac{V_{in}}{R} = -C_F \frac{dV_{out}}{dt}}$$

$$\frac{dV_{out}}{dt} = \frac{-1}{RC_F}\cdot V_{in}(t)$$

$$\boxed{V_{out} = \frac{-1}{RC_F}\int V_{in}(t)\,dt}$$

If initial o/p voltage is Vout

$$\boxed{V_{out} = \frac{-1}{RC_f}\int_0^t V_{in}(t)\,dt + V_{out}(0t)}$$

Differentiator using op-Amp:

$$\boxed{V_{out} = -R_f C\,\frac{dV_{in}}{dt}}$$

Ex: In a circuit let $V_1 = 1V$, $R_1 = 2k\Omega$, $R_2 = 18k\Omega$ find V_o if (a) $a = 10^2$ V/V, (b) $a = 10^4$ V/V, (c) $a = 10^6$ V/V.

$$A = \frac{V_o}{V_1} = \left(1 + \frac{R_2}{R_1}\right)\frac{1}{1 + (1 + R_2/R_1)/a} \qquad V_o = \left(1 + \frac{R_2}{R_1}\right)\frac{1}{1 + [(1 + R_2/R_1)]/a}$$

(a) $V_o = 10/(1 + 10/10^2) = 9.091V$.

(b) $V_o = 9.990V$

(c) $V_o = 9.999V$

Higher the gain a, the closer Vo is to 10.0V.

21/02/20

Differentiator:

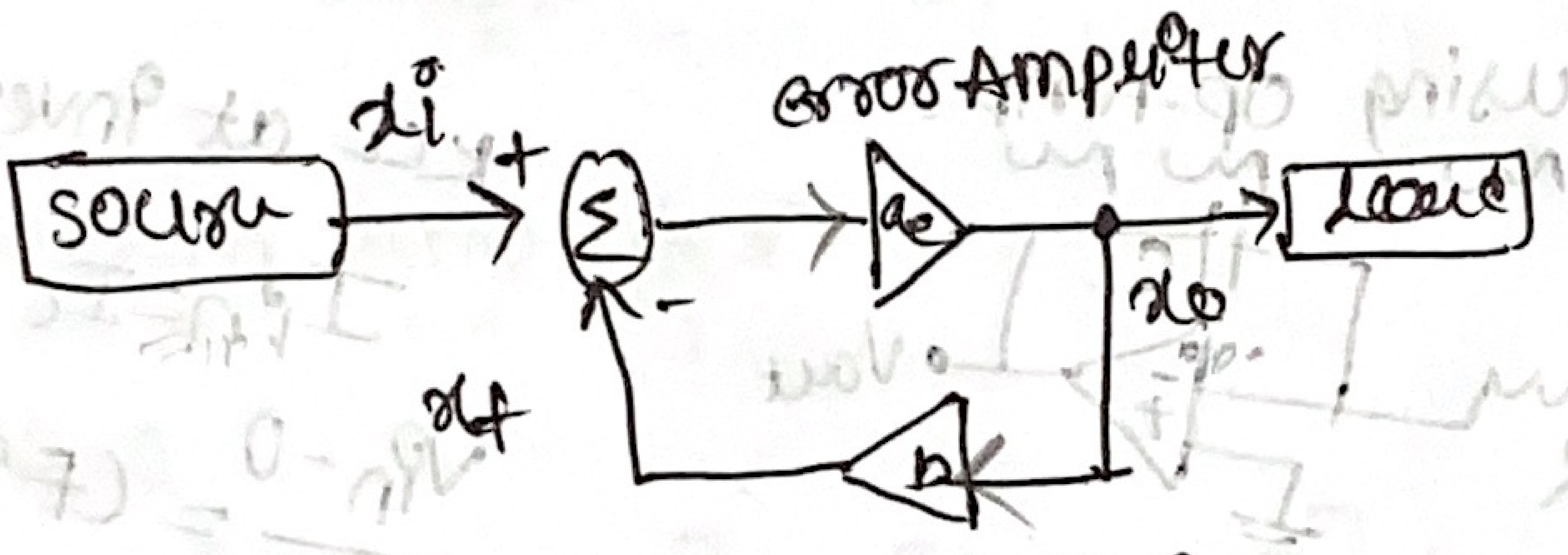
closed gain finite
open circuit

Integrator:

open feed back gain $=\infty$ $\quad A_c = V_m \sin \omega t$ $\quad$ DC signal.

$$\boxed{V_o(t) = -\frac{1}{RC}\int_0^t v_i(\varepsilon)\,d\varepsilon + V_o(0)} \quad (1.34)$$

Negative feed back:



feedback N/w

① **Error Amplifier:**

a_ε = open loop gain.

x_e = i/p

x_o = o/p

$\Big\}\ x_o = a_\varepsilon x_\varepsilon$

② **Feed back network:**

$x_o \Rightarrow$ i/p

gain $\Rightarrow b$

$x_f = b x_o$ $\quad$ b = feed back factor.

③ **Summing network: 'Σ'**

$x_e = x_i - x_f$, [∵ negative feed back]

$x_o = a_e (x_i - b x_o)$.

$$\rightarrow \boxed{A = \frac{x_o}{x_i} = \frac{a_e}{1 + a_e b}} \quad \text{closed loopgain}$$

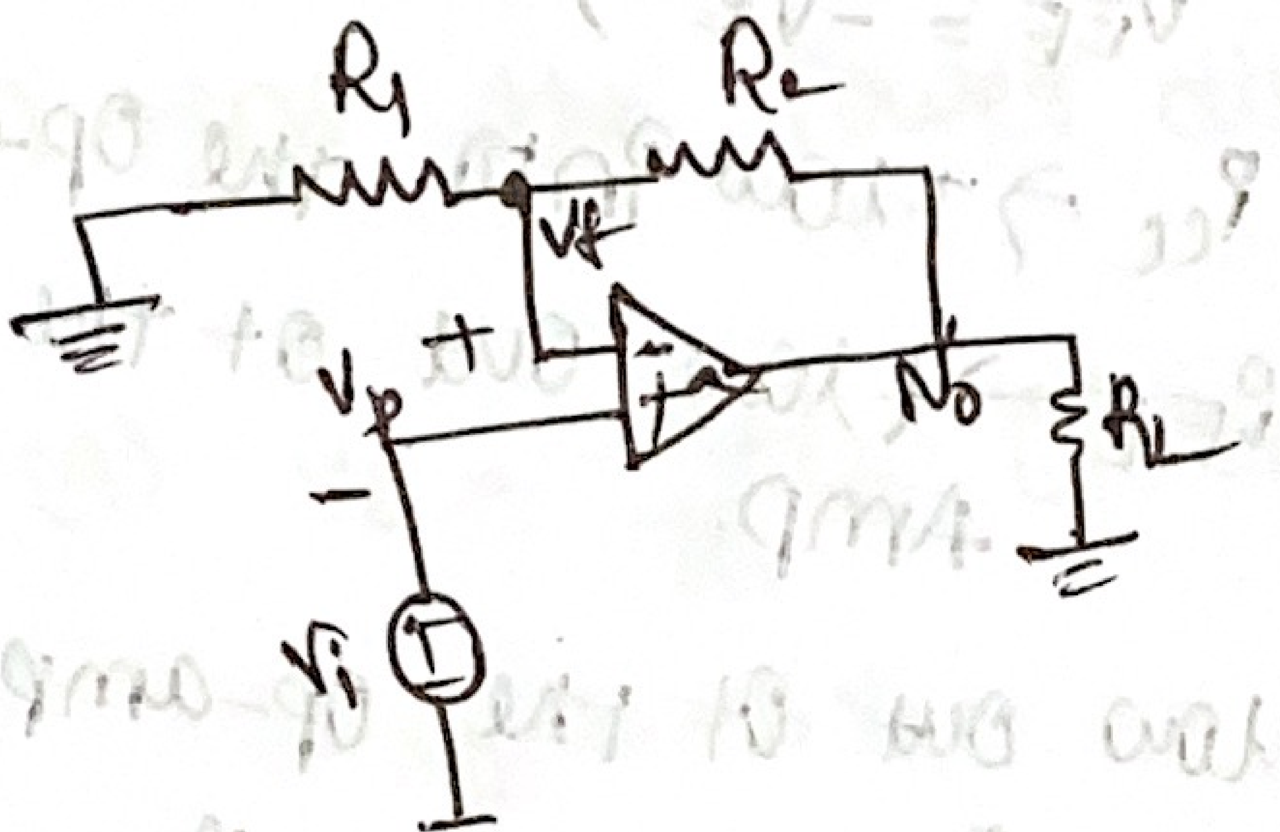
$a_e b > 0$ for feedback to be "−ve".

Feed back in op-amp circuits:

$x_o = a_\varepsilon(x_i - b x_o) \Rightarrow a_\varepsilon \Rightarrow$ open loop gain

$b \rightarrow$ feed back factor.

① series-shunt and shunt-shunt topologies:



$V_o = aV_D$

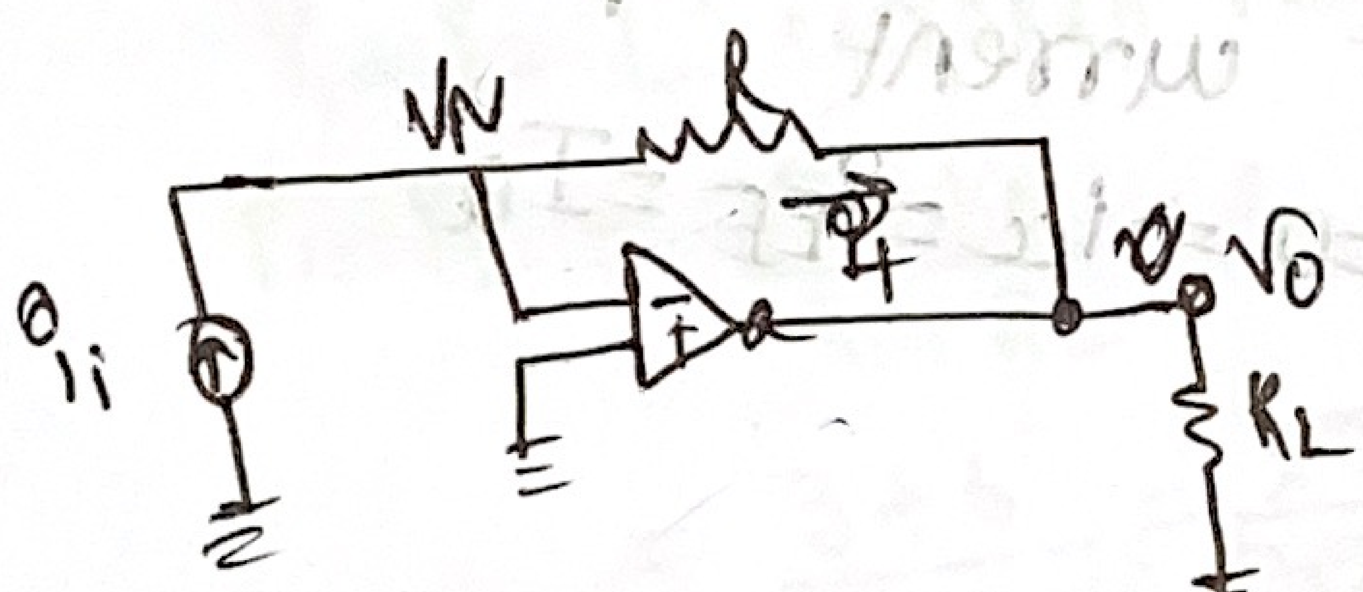
$= a(V_i - V_f)$

$V_o = a\left(V_i - \frac{R_1}{R_1+R_2} V_o\right)$.

$a_\varepsilon = a$

$b = \frac{R_1}{R_1+R_2}$

series-shunt:



$V_o = -aV_N$

$V_o = -aR\left[i_i - \left(\frac{-1}{R}\right)V_o\right]$.

shunt-shunt.

② series-series and shunt-series topologies.

series-series: $V_o = (R + R_L)\, i_o$

$V_o = a(V_i - V_f)$

$V_f = i_o R_L$

shunt series: current amplifier.

op-amp powering:

current flow & power dissipation:

i_{cc} $i_o \to$ O/p current V_{cc} = +ve

i_{EE} V_{EE} = -ve

$i_{cc} \to$ Flow into the op-amp

$i_{EE} \to$ flow out of the op amp.

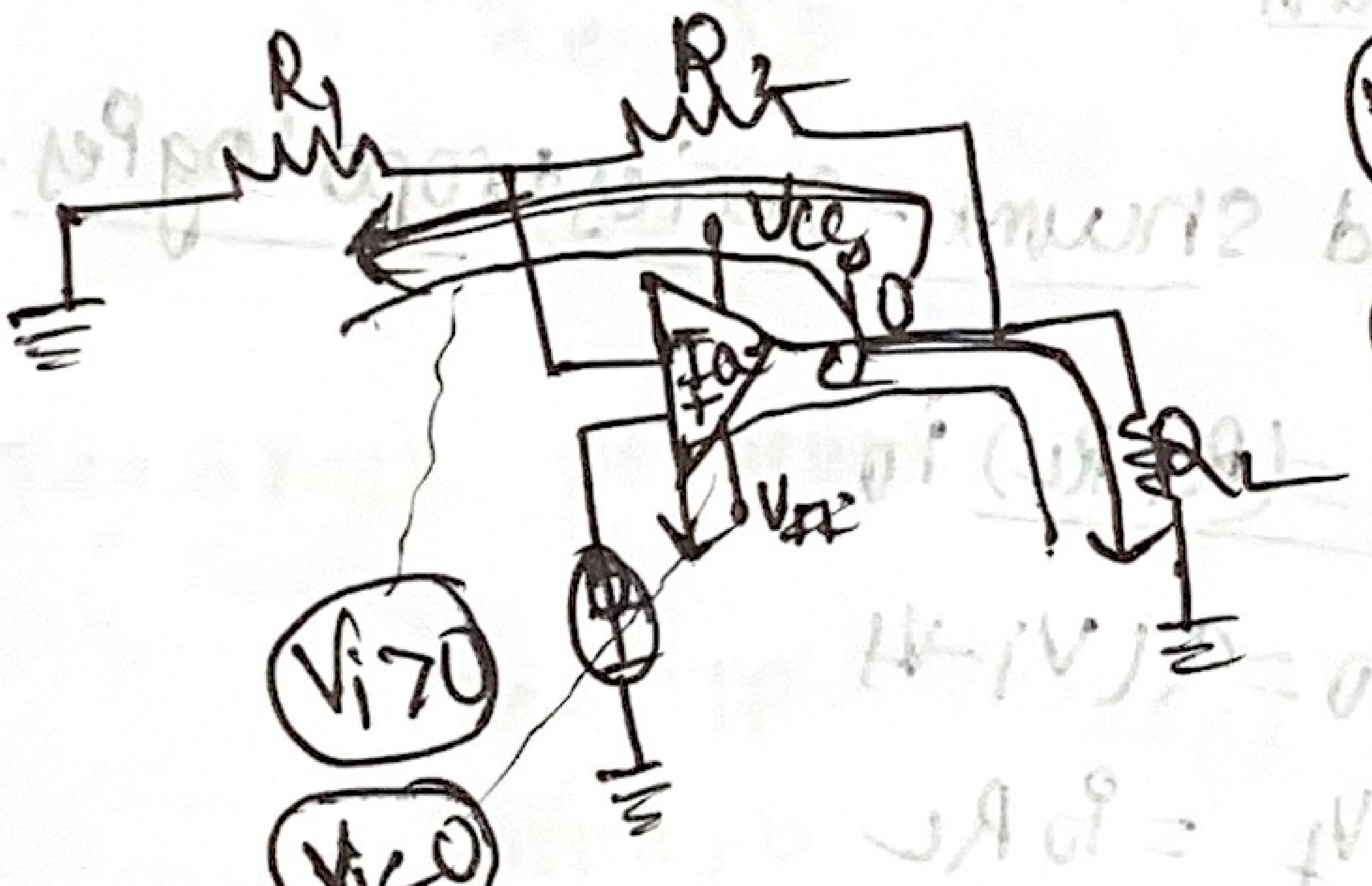
sourcing current $\to$ i_o flow out of the op-amp

sinking current $\to$ " " into " "

$\to i_{cc} = i_{EE} + i_o$ I_Q = Quiescent supply current

$\to i_{EE} = i_{cc} + i_o$ $i_o = 0 \Rightarrow i_{cc} = i_{EE} = I_Q$

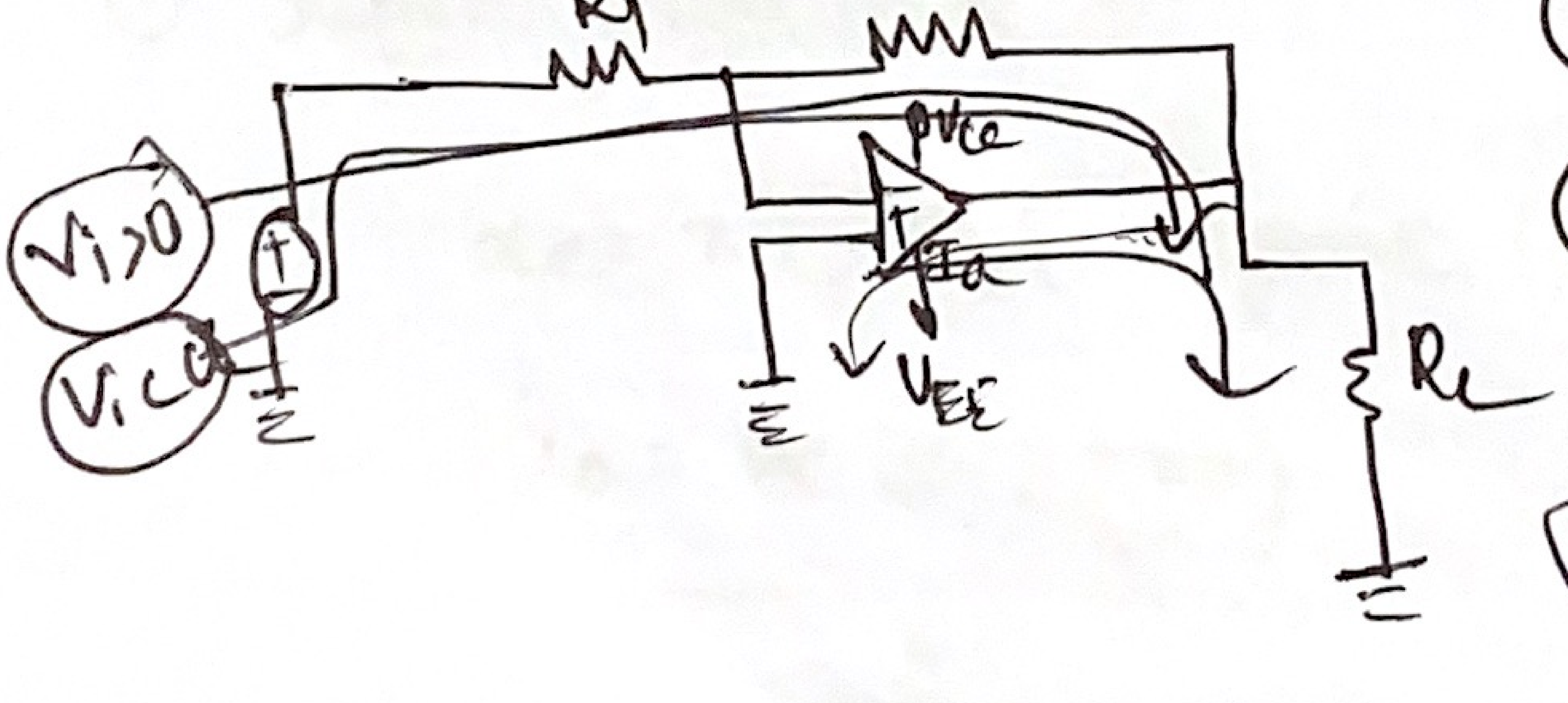
① Non-inverting Amp:



Vi>0

Vi<0

② Inverting Amp:



Vi>0

Vi<0

V_{cc} = 7 pin

V_{EE} = 4 pin

inv i/p = 2 pin

non inv i/p = 3 pin

O/p = pin 6

Q1) An inverting amplifier with $R_1 = 10\,k\Omega$, $R_2 = 20\,k\Omega$ and $v_i = 3V$ derives a $2\,k\Omega$ load.

(a) Assuming $\pm 15V$ supplies and $I_Q = 0.5mA$, find I_{CC}, I_{EE} & i_0.

(b) find the power disiipation inside the op-Amp (use above circuit).

Ans)

(a) $V_0 = -\frac{R_2}{R_1} V_i$ [inverting Amp]

$V_0 = -6V$.

$i_L = \frac{V_0}{R_L} = \frac{-6}{2000} = 0.003 = 3mA$

$i_1 = i_2$ [∵ current flow's in the same direction of i].

$i_1 = i_2 = \frac{V_i - V_0}{R_1 + R_2}$

$= \frac{3+6}{30} = \frac{9}{30} = 0.3mA$

i_0 = KCL. $i_0 = i_2 + i_L$

$= 0.3 + 3$

$= 3.3\ mA$.

Assume $i_{cc} = i_Q = 0.5mA$

$i_{EE} = i_{cc} + i_0 = 3.8mA$

(b) Power dissipation $= V \times i$

$= (V_{cc} - V_{EE})\, i_Q - (V_0 - V_{EE})\, i_0$

$P_0 =$

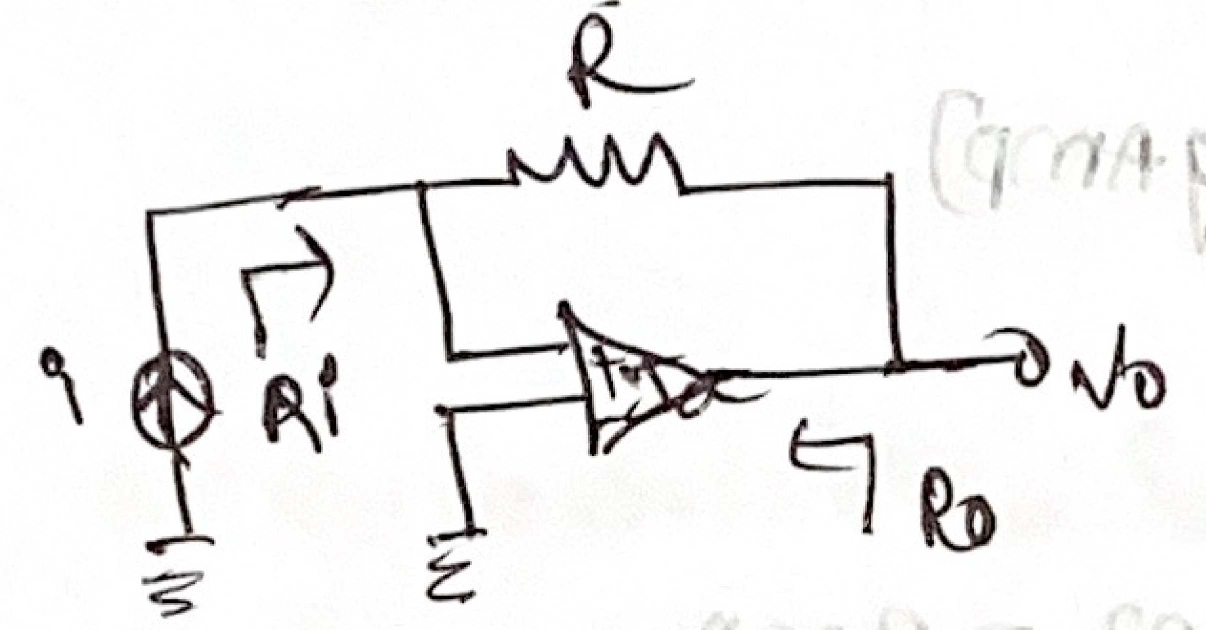
23/02/22

Circuits with Resistive Feed back:

Current to Voltage (I-V) converter:

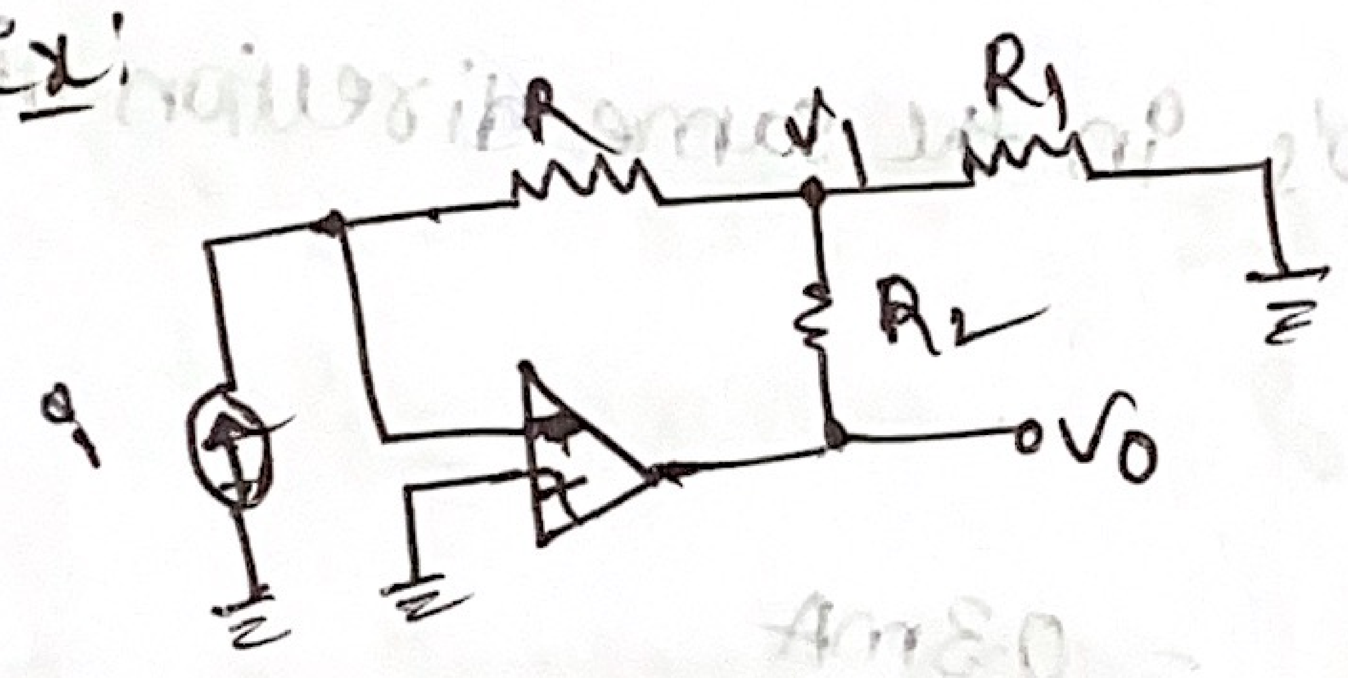
I - I/P
V - O/P

$$\text{gain} = \frac{O/P}{I/P} = \frac{V}{I}$$



$v_o = -i_0 R$

Ex:



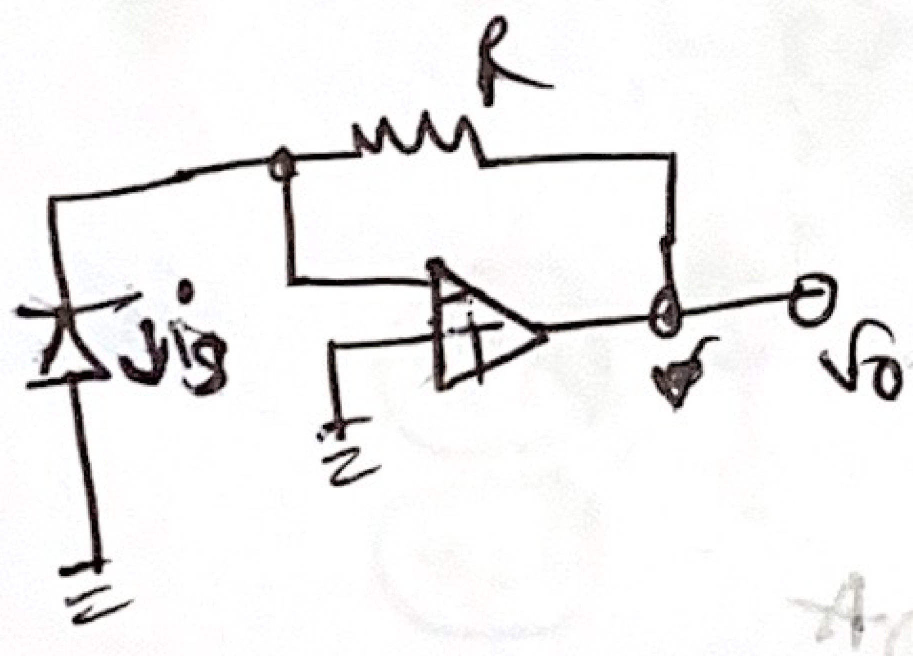
Design the circuit for a sensitivity 0.1 V/nA sensitivity

0.1 V/nA → KR = 100MΩ

if R = 1MΩ.

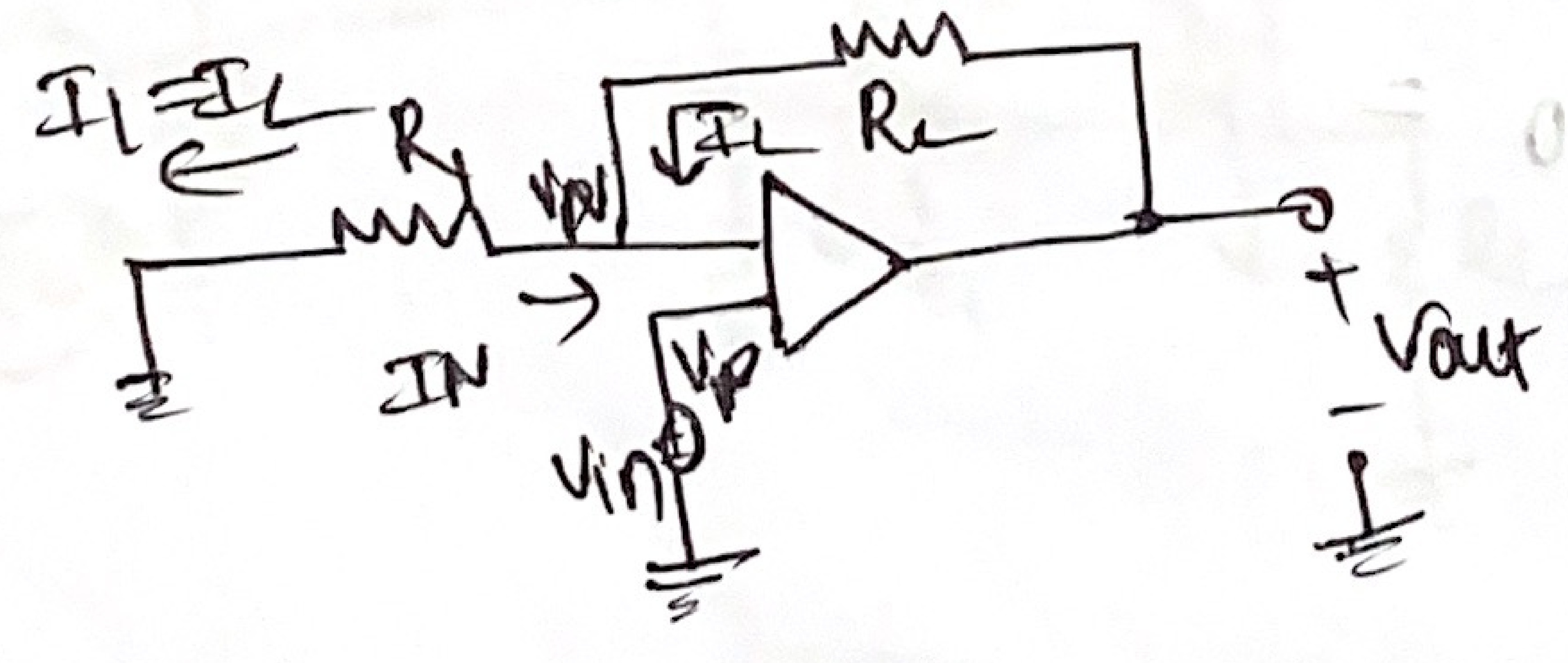
$$k = 1 + \frac{R_2}{R_1} + \frac{R_2}{R} = 100$$

if $R_1 = 1k\Omega$ we get $R_2 \simeq 99k\Omega$



Voltage to current converter:

Floating Load:



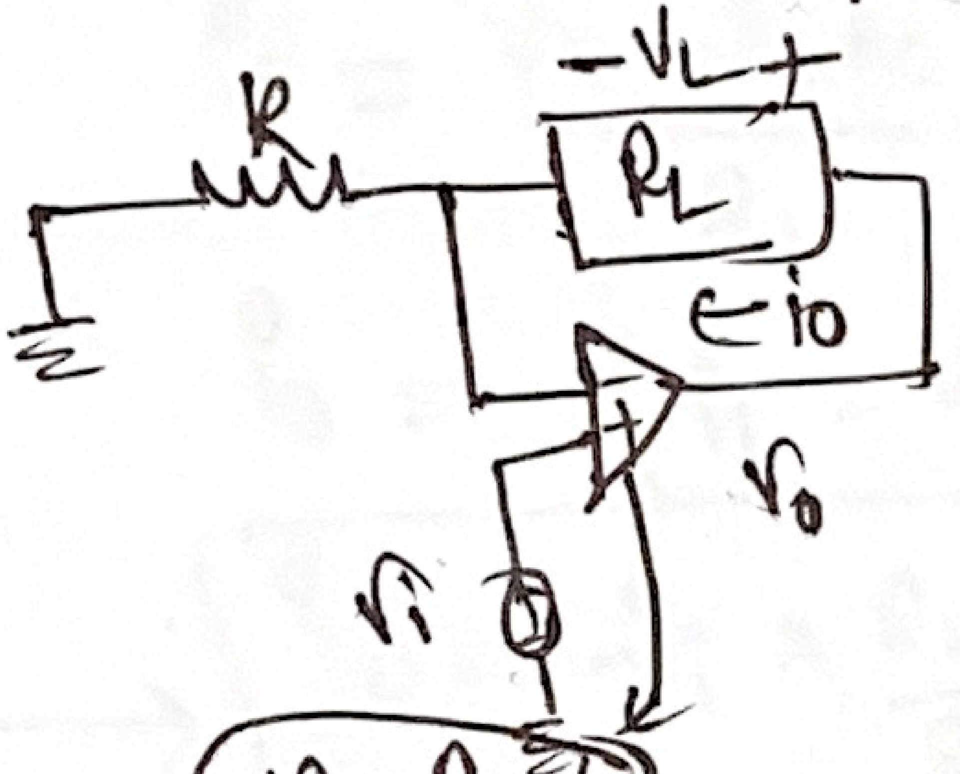
KCL at Node V_N:

$I_L = I_1 + I_N$

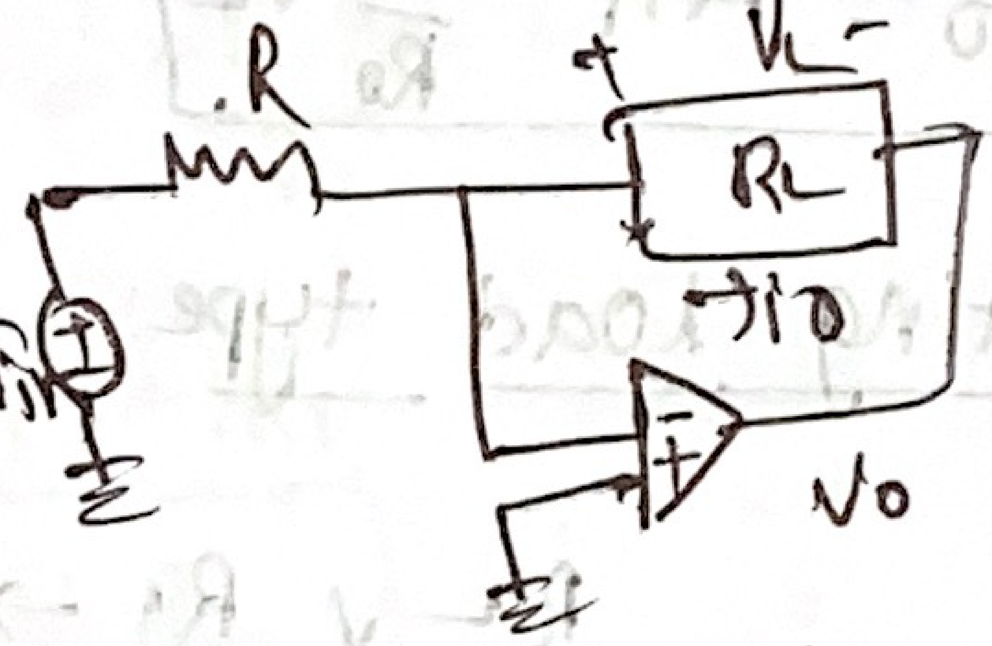
$\boxed{I_L = I_1}$ $\boxed{I_1 = \frac{V_{in}}{R_1}}$ $\boxed{V_p = V_N = V_{in}}$ $\boxed{I_L \propto V_{in}}$ $\boxed{I_L = \frac{V_{in}}{R_1}}$

ex:

In the circuit $V_i = 5V$, $R = 10k\Omega$, $\pm V_{sat} = \pm 13V$ The Resistive load R_L calculate I_o, voltage compliance and maximum permissible value of R_L.



(Non inv)



(INV) $-V_{sat} < V_L < V_{sat}$

$I_o = \frac{5}{10} = 0.5\ mA$

Voltage compliance

$(-13-5)V \leq V_L \leq (13-5)V$

$R_L \leq 8/0.5 = 16k\Omega$

$I_0 = 0.5\ mA$

Voltage compliance

$-13V < V_L < 13V$

$R_L < 13/0.5 = 26k\Omega$.

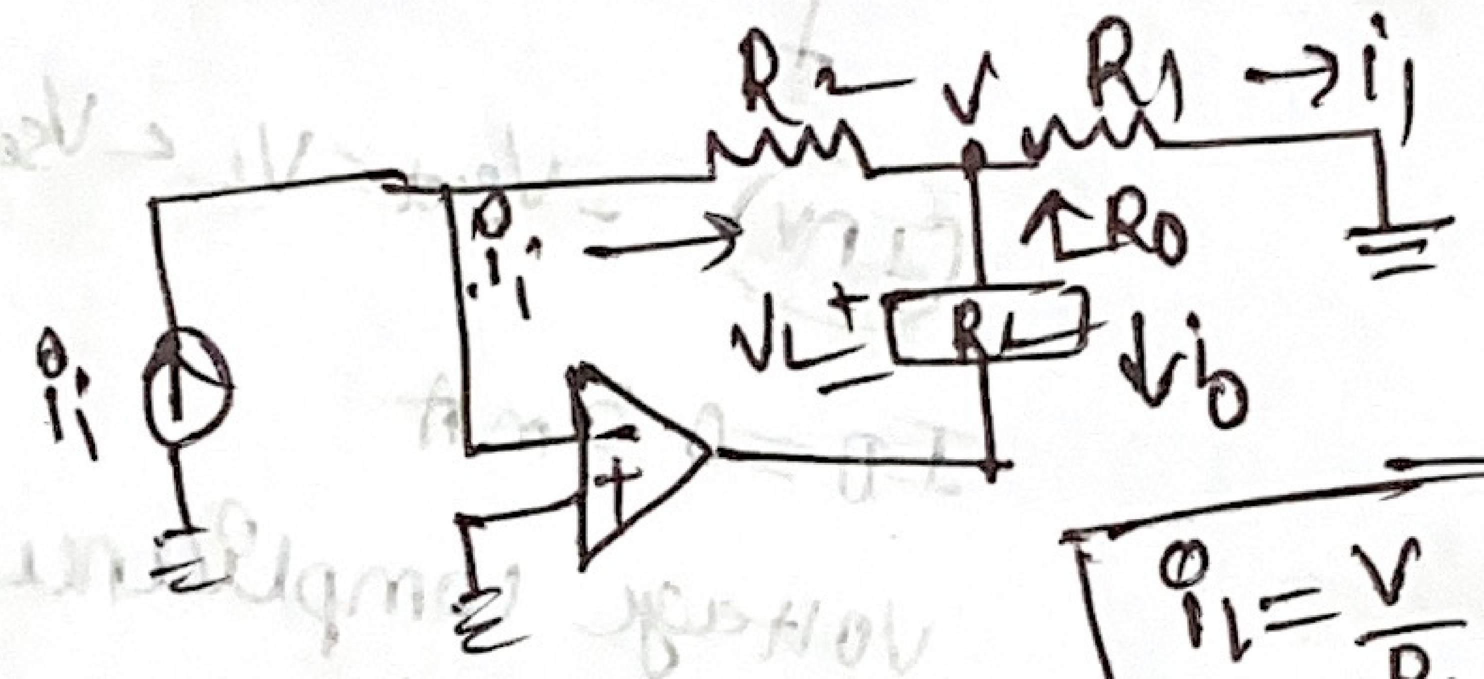
28/02/22

Current Amplifier:

$\boxed{i_0 = A i_i}$ $R_0 = \infty$

$\rightarrow$ $\boxed{i_0 = A i_i - \frac{1}{R_0} V_L}$

① Floating load type:



$\boxed{i_L = \frac{V}{R_1}}$ $V = -i_1 R_2$

Apply KCL

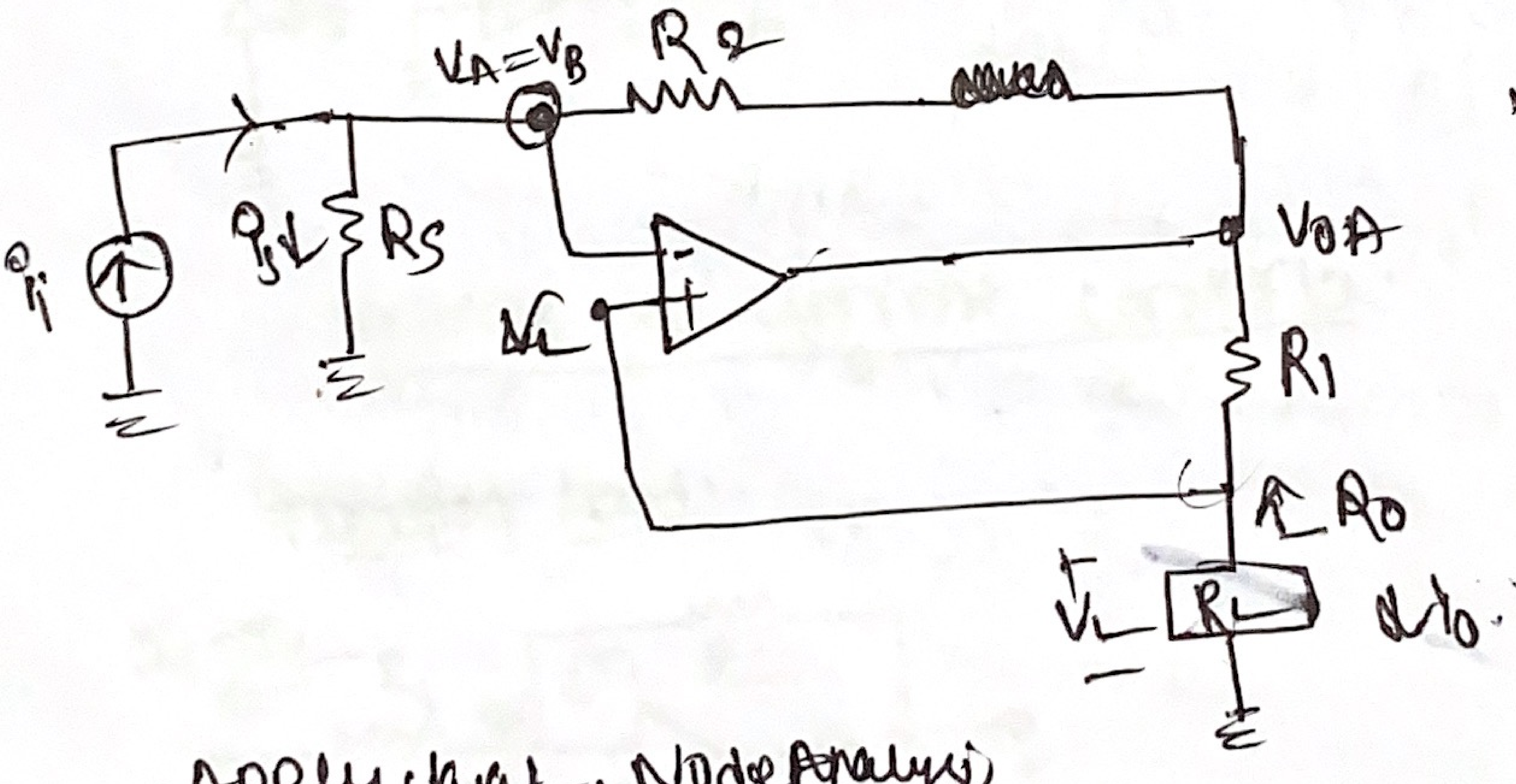
$i_0 = i_i + (-i_1)$

$i_0 = i_i + \frac{R_2}{R_1} \times i_i$

$\rightarrow$ $i_0 = i_i\left(1 + \frac{R_2}{R_1}\right) \Rightarrow \boxed{i_0 / i_i = \cancel{A} = \left(\frac{R_1 + R_2}{R_1}\right)}$

current gain

② Grounded-load current Amp:



$V_d = V_B - V_{OA} = 0$

$V_A = V_B$

Apply ~~KCL~~, Node Analysis

$i_0 = \frac{V_{OA} - V_L}{R_1}$, $i_2 = \frac{V_L - V_{OA}}{R_2}$

$\Rightarrow V_{OA} = V_L - i_2 R_2$

$i_1 = i_s + i_2$

$i_2 = i_1 - i_s$ } current through R_s.

$$\boxed{i_2 = i_1 - V_s / R_s}$$

$$i_0 = \frac{V_L - i_2 R_2 - V_L}{R_1} = \frac{-i_2 R_2}{R_1}$$

$$i_0 = -(i_1 - V_s / R_s)\, R_2 / R_1$$

$$\boxed{i_0 = -i_1 \times \frac{R_2}{R_1} + \frac{V_L R_2}{R_s R_1}}$$

$A = \frac{-R_2}{R_1}$ & $R_0 = -\frac{R_s R_1}{R_2}$ ⇒ current mirror.

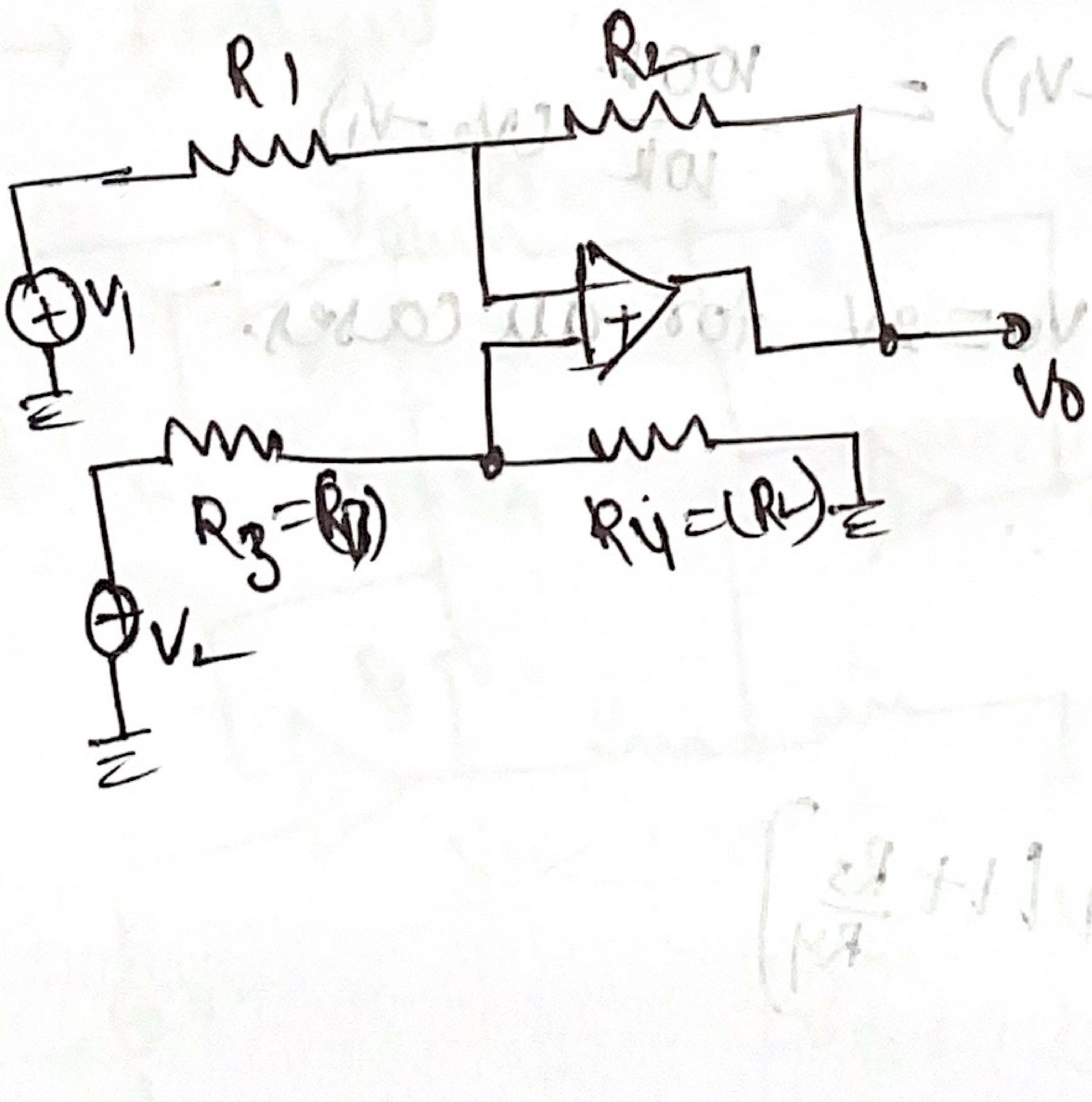
Difference Amplifier:

$$V_0 = \frac{R_2}{R_1}(V_2 - V_1)$$

$\frac{R_4}{R_3} = \frac{R_2}{R_1}$ ⇒ Bridge is balanced.

Difference mode } i/p components
common mode

V_{cm}, V_{DM}



$V_{DM} = V_2 - V_1$

$V_{cm} = \frac{V_1 + V_2}{2}$

$V_1 = V_{cm} - \frac{V_{DM}}{2}$

$V_2 = V_{cm} + \frac{V_{DM}}{2}$

⇒ Imbalance factor:

$$V_0 = \frac{R_2}{R_1}(V_2 - V_1)$$

$$\boxed{V_0 = \frac{R_2}{R_1} \cdot V_{DM}}$$

$$\boxed{V_0 = A_{dm} V_{DM}}$$

⟶ $V_0 = A_{dm} V_{DM} + A_{cm} V_{cm}$

A_{dm} = differential mode gain

V_{cm} = common mode gain

$$A_{dm} = \frac{R_2}{R_1}\left(1 - \frac{R_1 + 2R_2}{(R_1 + R_2)} \times \frac{\epsilon}{2}\right)$$

$$A_{cm} = \frac{R_2}{R_1 + R_2} \times \epsilon$$

Q) In the difference amplifier ckt, let $R_1 = R_3 = 10k\Omega$, $R_2 = R_4 = 100\ k\Omega$.

(a) Assuming perfectly matched resistors find V_0 for each of the following i/p voltage pairs, (V_1, V_2) = $(-0.1V, +0.1V)$, $(4.9V, 5.1V)$, $(9.9V, 10.1V)$.

(b) Repeat (a) with mismatched resistors, $R_1 = 10k\Omega$, $R_2 = 98k\Omega$, $R_3 = 9.9k\Omega$, $R_4 = 103\ k\Omega$.

A) (a) $V_0 = \frac{R_2}{R_1}(V_2 - V_1) = \frac{100k}{10k}(V_2 - V_1)$

⇒ $V_0 = 10(V_2 - V_1)$ ⇒ $V_0 = 2V$ for all cases.

$V_{cm} = 0, 15V, 10V$

(b) $V_0 = A_2 V_2 - A_1 V_1$

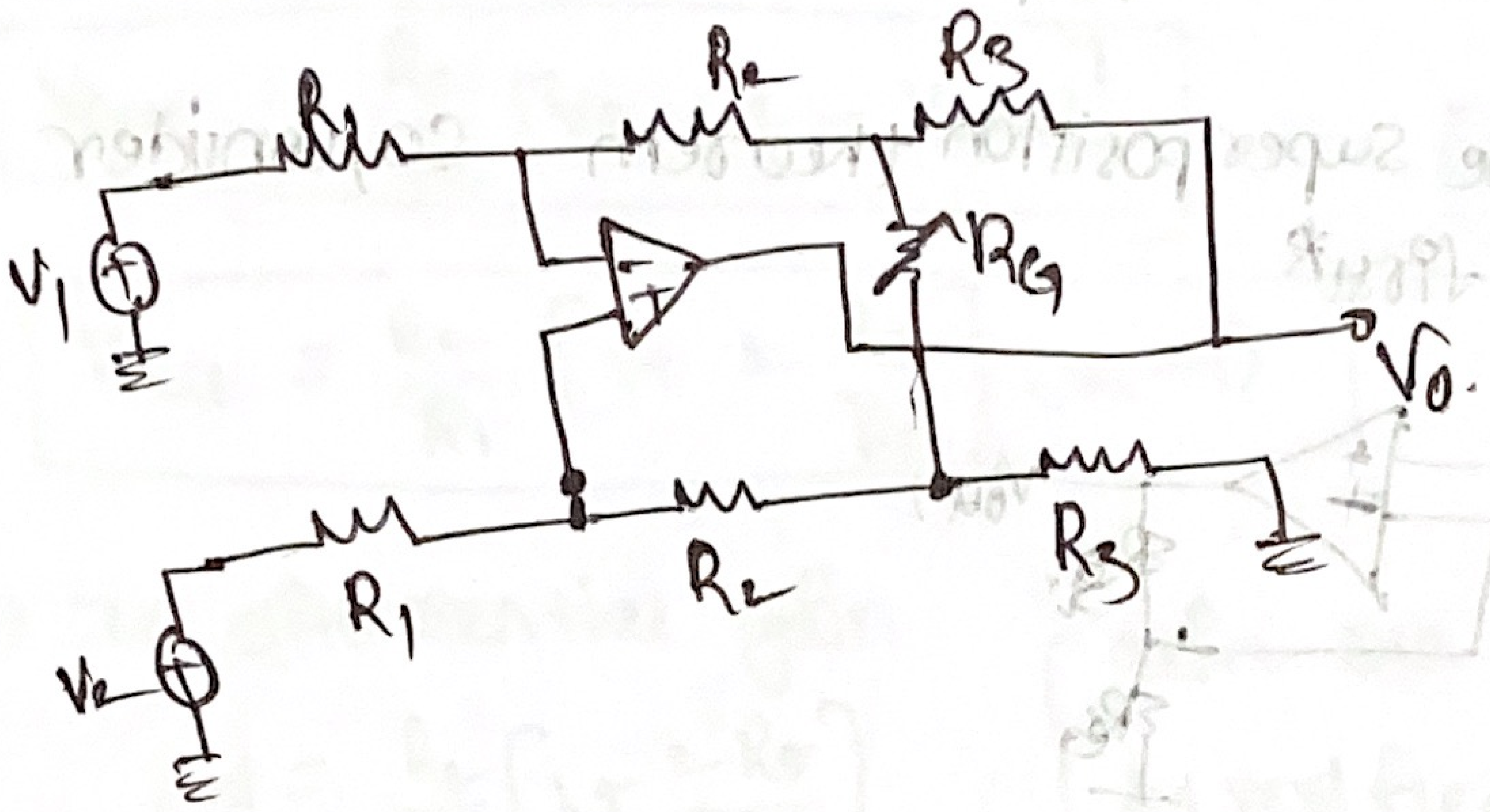
$$A_2 = \left[1 + R_2/R_1\right] \left[1 + \frac{R_3}{R_4}\right]$$

$$A_1 = \frac{R_2}{R_1}$$

$A_2 =$ $A_1 =$

$V_0 =$

Difference Amplifier with variable gain:



when, $\frac{R_4}{R_3} = \frac{R_2}{R_1}$, $V_o = \frac{R_2}{R_1}(V_2 - V_1)$

$$V_o = \frac{2R_2}{R_1}\left(1 + \frac{R_2}{R_G}\right)(V_2 - V_1).$$

. gain varies inversly with R_G.

Instrumentation Amplifier:

1- CMR.

2- High Resistance I/P.

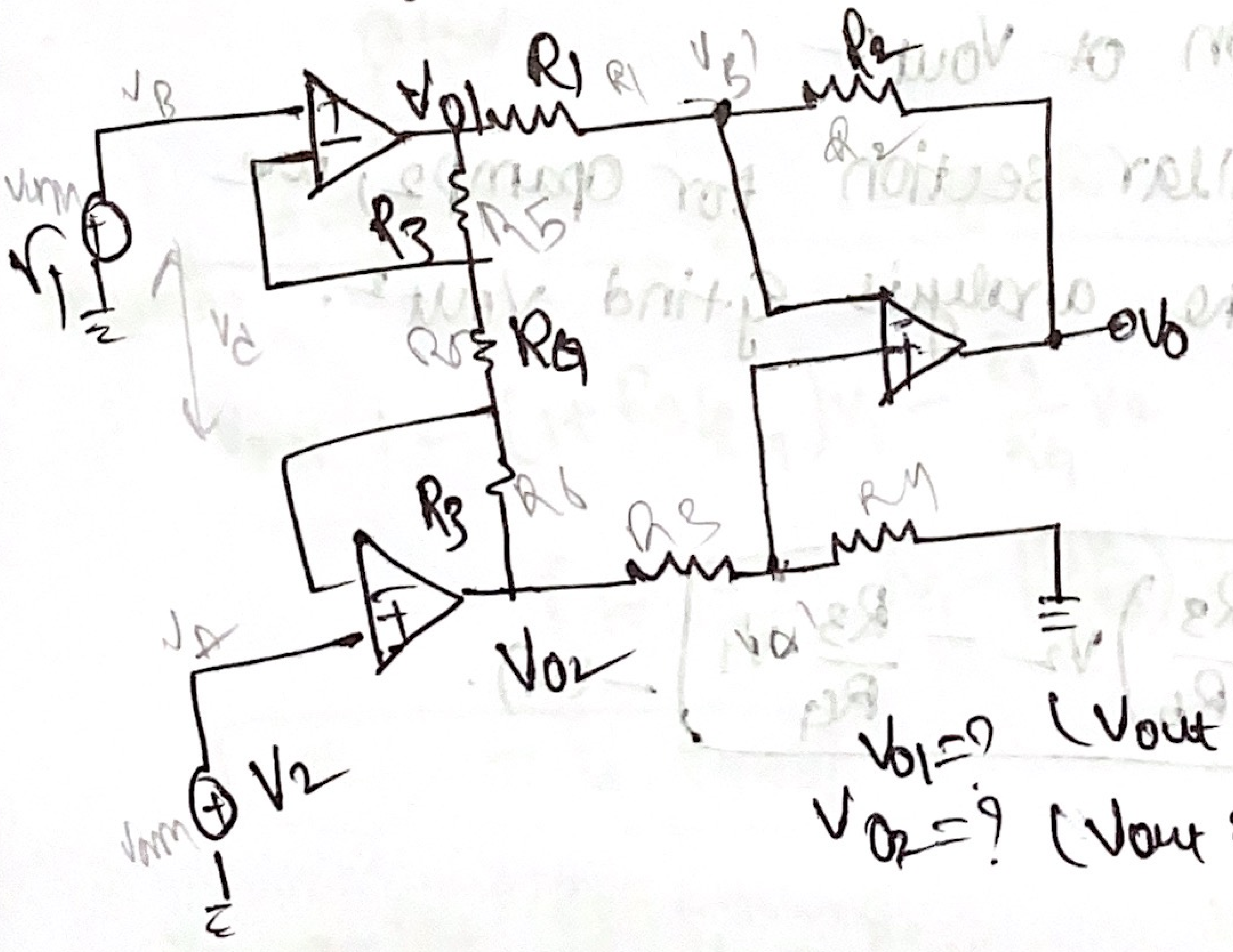
Low Resistance O/P.

3- Stable gain.

4- extremely high common-mode ratio

→ Analysis

$V_o = A_d V_d + A_c V_{cm}$



$V_o = \frac{R_4}{R_3} \times V_A \times \left[\frac{2\left(1+\frac{R_2}{R_1}\right)}{\left(1+\frac{R_4}{R_3}\right)}\right]$ because of Similar ... $\frac{R_2}{R_1} \times V_B$

$V_{o1} = ?$ (Vout 1)

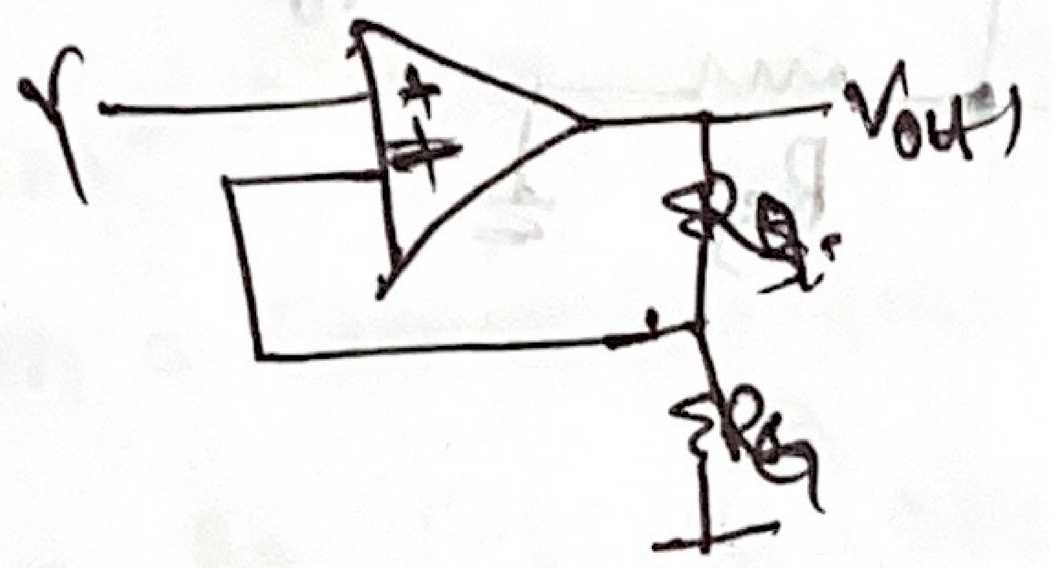
$V_{o2} = ?$ (Vout 2)

$V_o = \left(1 + \frac{2R_5}{R_G}\right)\left(\frac{R_2}{R_1}\right) \times (V_A - V_B)$

$V_{out} = \frac{R_2}{R_1}(V_A' - V_B')$

Step 1: calculation of Vout1:

We can use superposition theorem. So, consider Op-Amp-1 first*



Case 1: V_1 source active, V_2 source deactivated, so circuit becomes non inverting amp.

$$\boxed{V'_{out} = \left(1+R_3/R_4\right)(V_1)} \quad -(1)$$

Case 2: V_2 source active, V_1 source deactivated. So circuit becomes inverting amp.

$$\boxed{V''_{out1} = -\frac{R_3}{R_4} V_2} \quad -(2)$$

$$V_{out1} = V'_{out1} + V''_{out1}$$

$$\boxed{V_{out1} = \left(1+\frac{R_3}{R_4}\right)\left(V_1 - \frac{R_3}{R_4} \cdot V_2\right)} \quad -(3)$$

Step-2: calculation of Vout2

* Because of similar section for opamp2, we can perform the analysis & find Vout2.

* So, similarly.

$$\boxed{V_{out2} = \left(1+\frac{R_3}{R_4}\right)V_2 - \frac{R_3}{R_4} \cdot V_1} \quad -(4).$$

Step-3: Since op-amp-3 is a differentail amplifier.

$$\boxed{V_{out} = \frac{R_2}{R_1}[V_{out2} - V_{out1}]}$$

$(V_{out} \propto (V_2 - V_1))$

$$\boxed{V_{out} = \frac{R_2}{R_1}\left[1 + 2\frac{R_3}{R_G}\right](V_2 - V_1)}$$

→ In differential gain

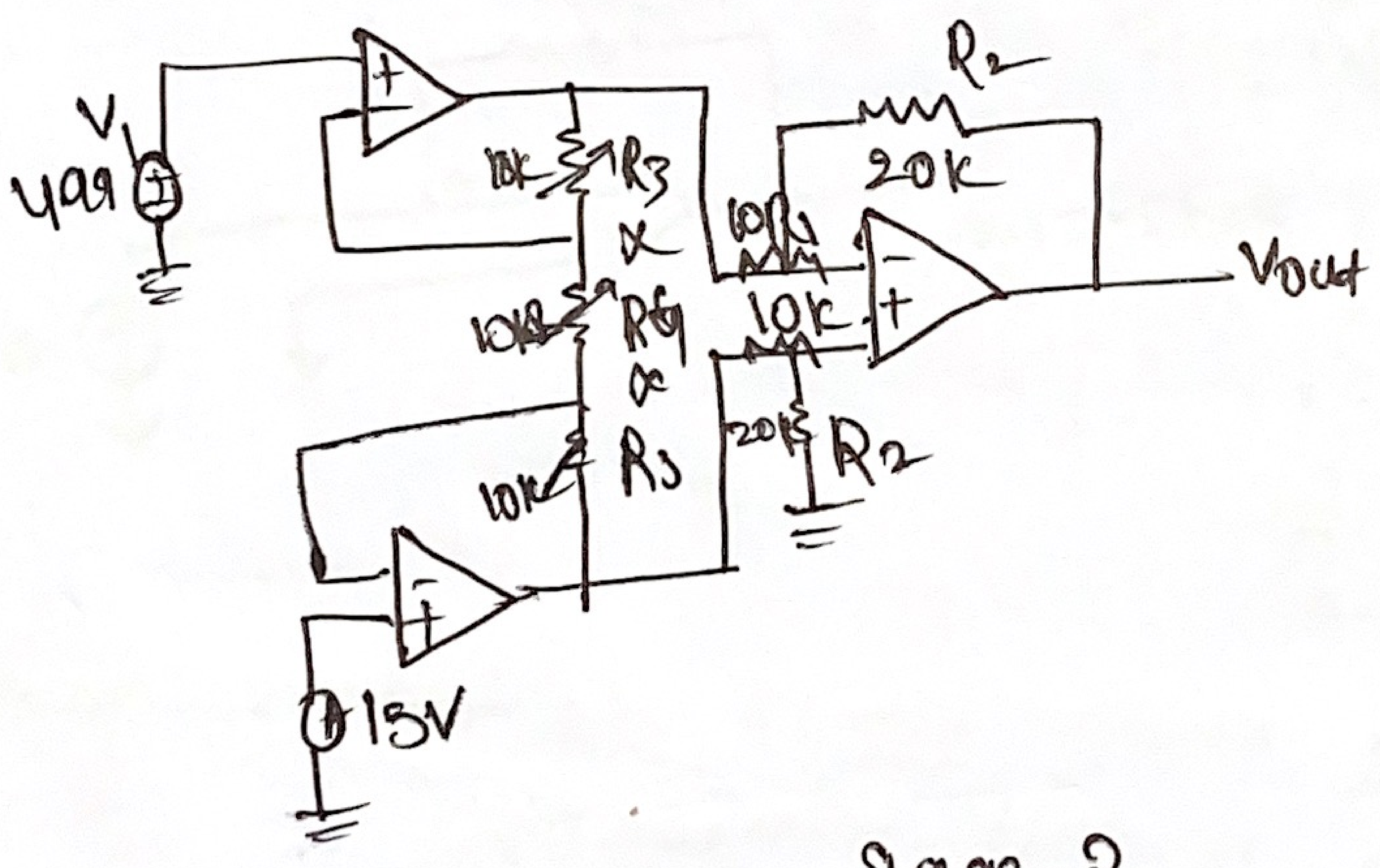
$$Ad = \underbrace{\frac{R_2}{R_1}}_{\text{Gain of 2nd stage}}\underbrace{\left[1 + \frac{2R_3}{R_G}\right]}_{\text{Gain of 1st stage}}$$

(gain can be adjusted by verified by the adjusting variable resistance.)

Q1)

for the given IA, determine the output voltage for the circuit given below. $R_3 = 10K$, $R_G = 100\Omega$, $R_1 = 10K$, $V_2 = 5V$, $V_1 = 4.995V$, $R_2 = 20K$

Ans)



Stage-1 ⟷ Stage-2

Solution:

$$V_{out1} = (1 + R_3/R_G)V_1 - \frac{R_3}{R_G}V_2$$

$$= \left(1 + \frac{10k}{100}\right)V_1 - \left(\frac{10k}{100}\right)V_2$$

$$\boxed{V_{out} = 4.495V}$$

$$V_{out2} = \left(1 + \frac{R_3}{R_G}\right)V_2 - \frac{R_3}{R_G}V_1$$

$$= \left(1 + \frac{10k}{1000}\right)V_2 - \left(\frac{10k}{100}\right)V_2$$

$V_{out2} = (100)V_2 - 100V_1$

$$\boxed{V_{o2} = 5.5V}$$

$$V_{out} = \frac{R_2}{R_1}(V_{out2} - V_{out1})$$

$$= \frac{20K}{10K}(5.5 - 4.95)$$

$$\boxed{V_{out} = 2.01V} *$$

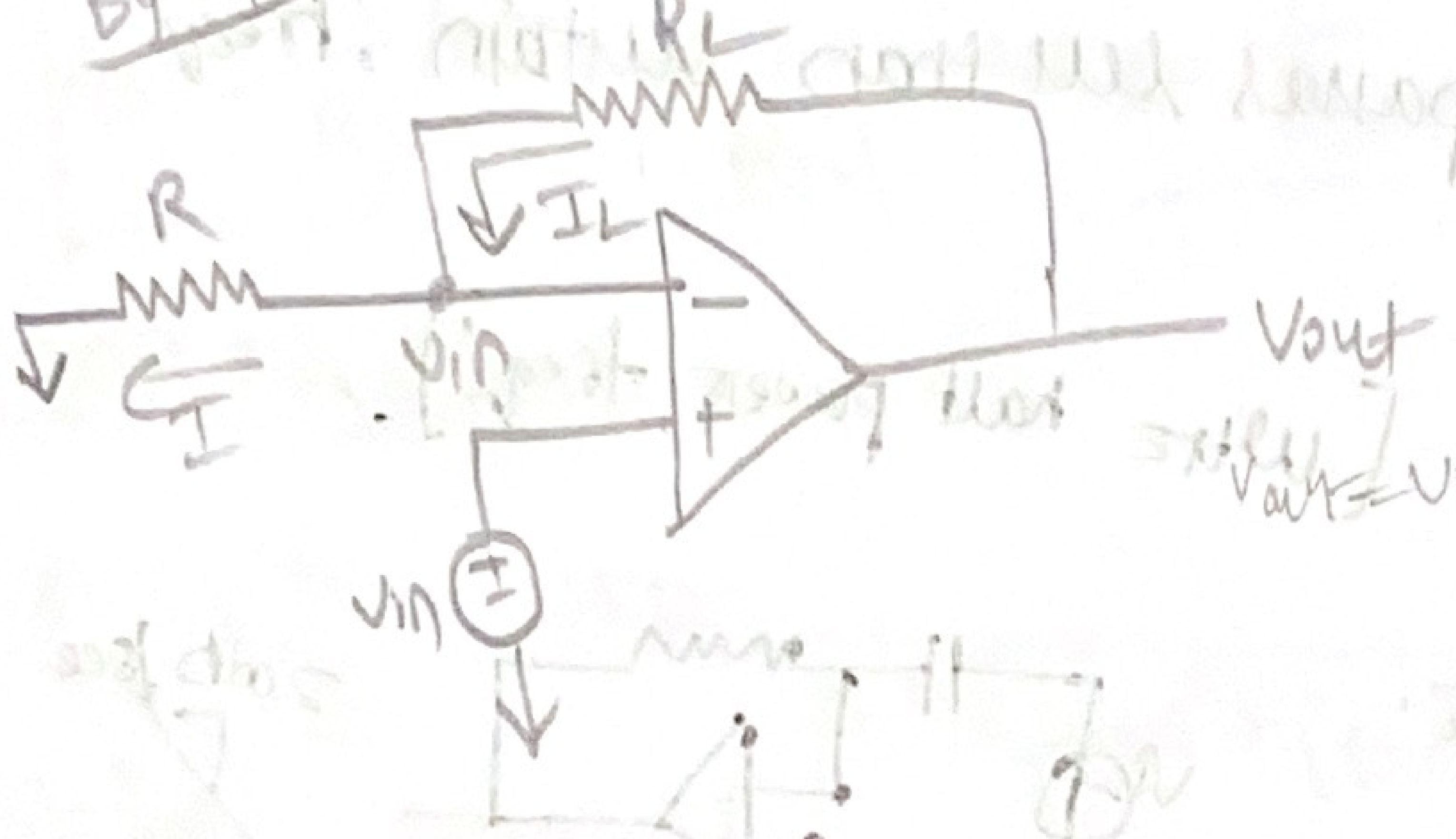
Dual op-Amp Instrumentation Amp:

$$\text{when } \left.\frac{R_4}{R_3} = \frac{R_2}{R_1}\right\} \quad V_o = \left(1 + \frac{R_2}{R_1} + \frac{2R_2}{R_G}\right)(V_2 - V_1)$$

Voltage to current conversions

$$\boxed{I_1 = \frac{V_{in}}{R+R_L}}$$

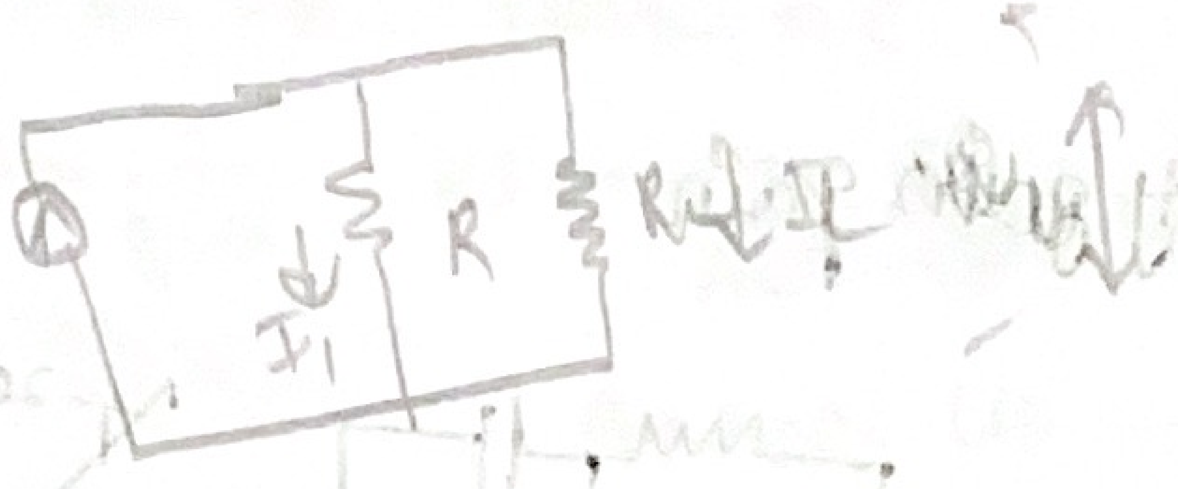
By-opamp



$$\boxed{I_L = \frac{V_{in}}{R}}$$

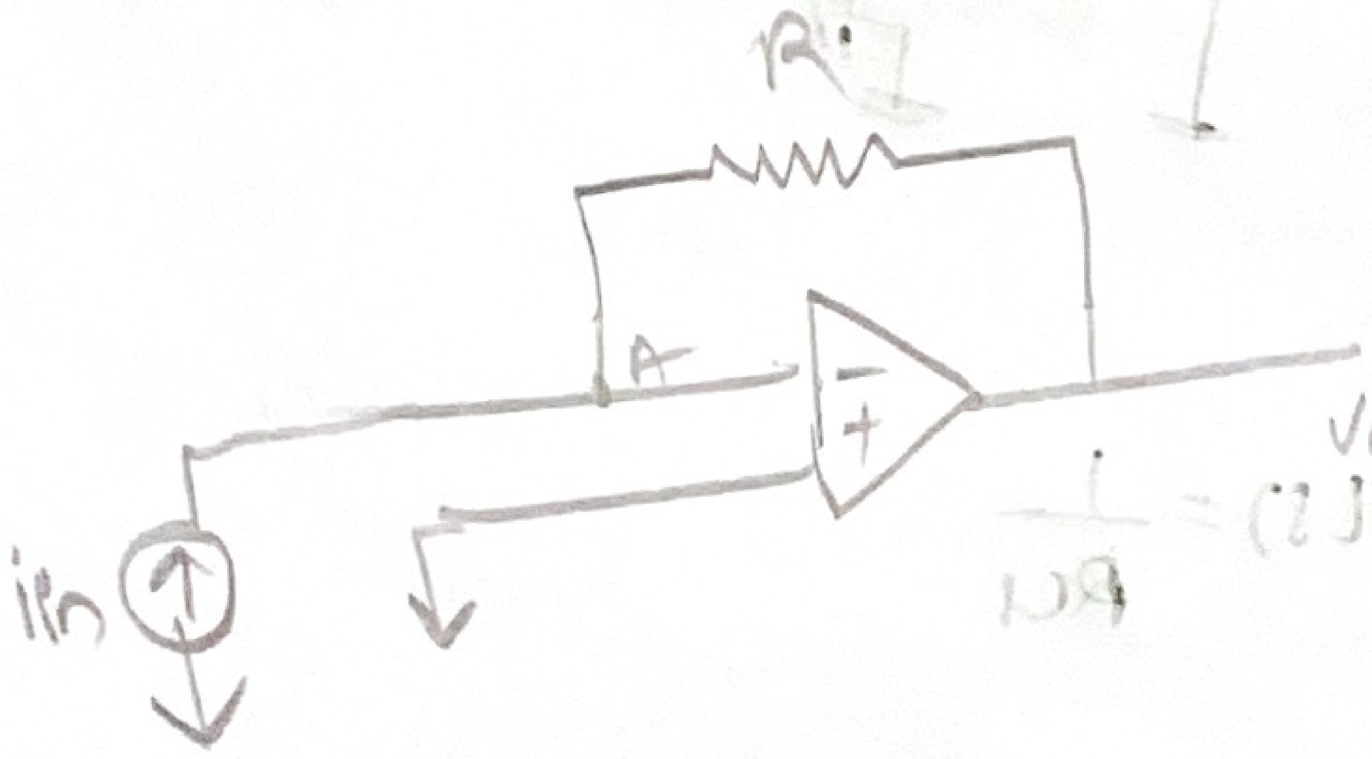
$V_{out} = V_{in} + V_D$(Diode) if Diode connected

current to voltage converter



$R_L \gg R$

$$\boxed{V_1 = I_{in} \times R}$$



$V_{out} = -I_R \times R$