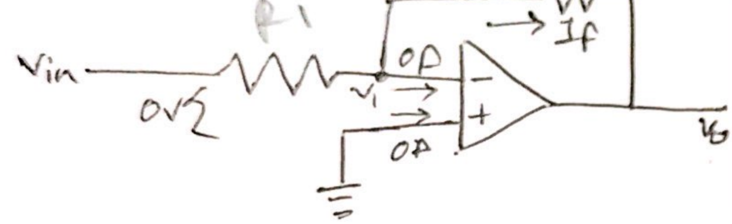
Inverting Amplifier



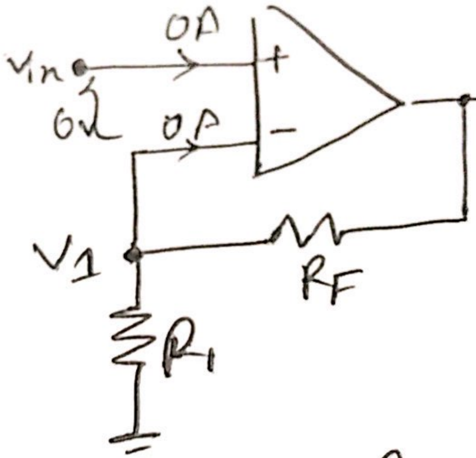
$$V_0 = \left(-\frac{R_F}{R_1}\right) \times V_{in}$$

$$A = \left(-\frac{R_F}{R_1}\right)$$

$V_1 = 0$

$$\frac{V_1 - V_{in}}{R_1} + \frac{V_1 - V_0}{R_F} + 0A = 0$$

Non-Inverting Amplifier



$\boxed{V_1 = V_{in}}$

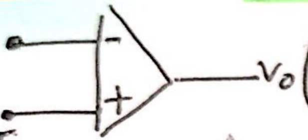
$$V_0 = V_{in}\left(1 + \frac{R_F}{R_1}\right)$$

$$A = \left(1 + \frac{R_F}{R_1}\right)$$

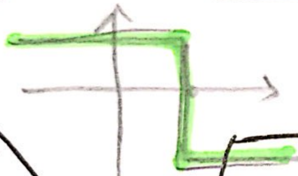
Open Loop

$V_1 = V_{Ref}$

$V_2 = V_I$

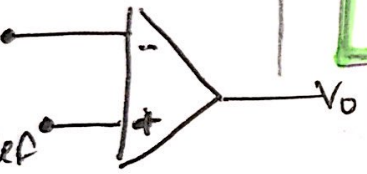


$\boxed{V_0 = A(V_1 - V_{Ref})}$



$V_1 = V_I$

$V_2 = V_{Ref}$



$\boxed{V_0 = A(V_{Ref} - V_I)}$

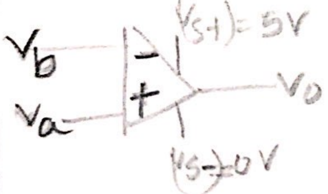
comparatore

5V

$V_d > 0 \Rightarrow V_a > V_b \Rightarrow (V_{S+}) \Rightarrow V_0 = A\,V_d$

$V_d < 0 \Rightarrow V_a < V_b \Rightarrow (V_{S-}) \Rightarrow V_0 = A\,V_d$

0V

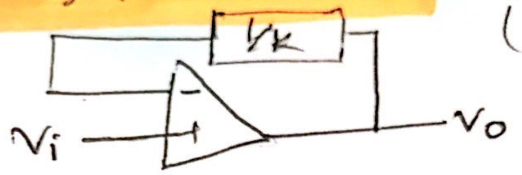


$V_d = V_2 - V_1$

Negative feedback

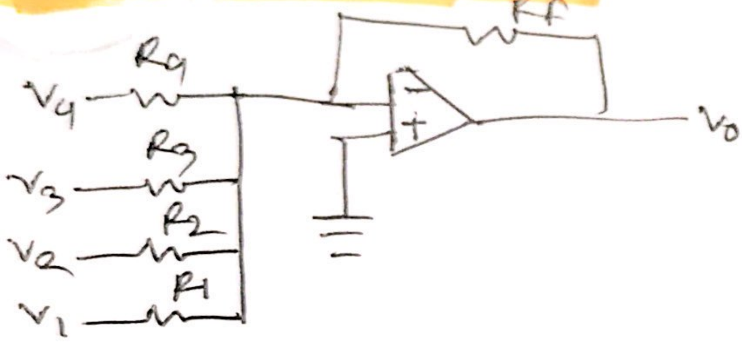
$K = 10$ and 1.0

(1/10)th of output is feedback to (-) input



$V_0 = A V_d$ | $V_0 = K V_i$ | $A = 3$ | $V_i = 5V$ | $K = 10$

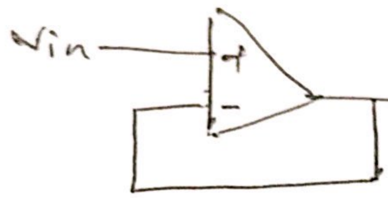
$V_0 = 0V$	$V_0 = 15$	$V_0 = 10.5$
$V_- = \frac{V_0}{10} = 0$	$V_- = \frac{15}{10} = 1.5V$	$V_- = \frac{10.5}{10} = 1.05$
$V_d = V_+ - V_-$ $= 5 - 0$	$V_d = V_+ - V_-$ $= 5 - 1.5$ $= 3.5$	$V_d = V_+ - V_-$ $= 5 - 1.05$ $= 3.95$
$V_0 = A V_d$ $= 5 \times 3$ $= 15$	$V_0 = A V_d$ $= 3.5 \times 3$ $= 10.5$	$V_0 = A V_d$ $= 3 \times 3.95$ $= 11.85$

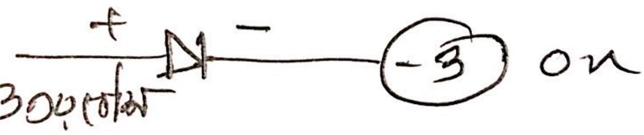


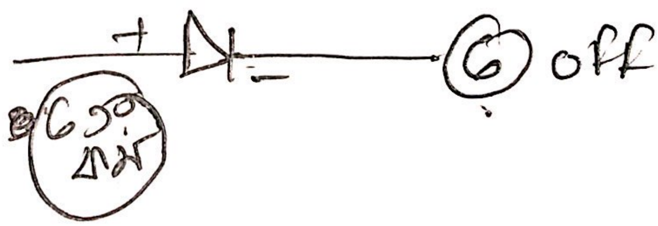
$$V_o = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}V_3 - \frac{R_f}{R_4}V_4$$

Buffer

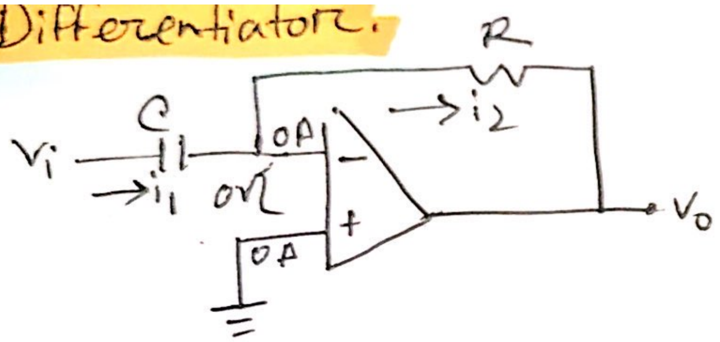
$V_o = V_{in}$
Gain(A) = 1







Differentiator.



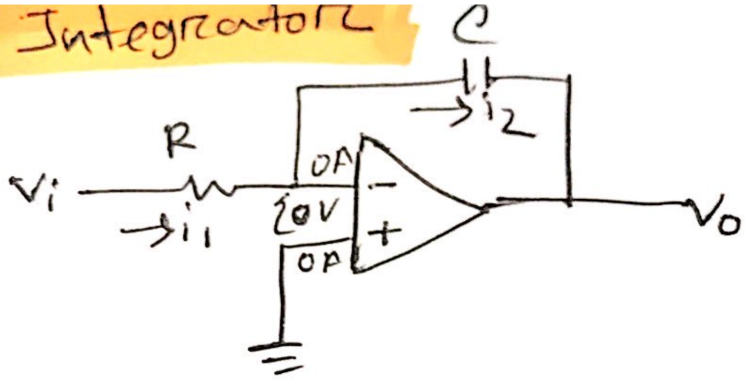
C: $i_1 = \left(C \cdot \frac{dv_c}{dt}\right) = \boxed{C\frac{d(v_i-0)}{dt}} = C\frac{dv_i}{dt}$

R: $i_2 = \left(\frac{0-v_o}{R}\right) = -\frac{v_o}{R}$

$\boxed{i_1 = i_2}$

$$v_o = -RC \cdot \frac{dv_i}{dt}$$

Integrator



R: $i_1 = \left(\frac{v_i-0}{R_F}\right) = \frac{v_i}{R}$

R: $i_2 = C \cdot \frac{dv_c}{dt} = C\frac{d(0-v_o)}{dt} = \left(-C\frac{dv_o}{dt}\right)$

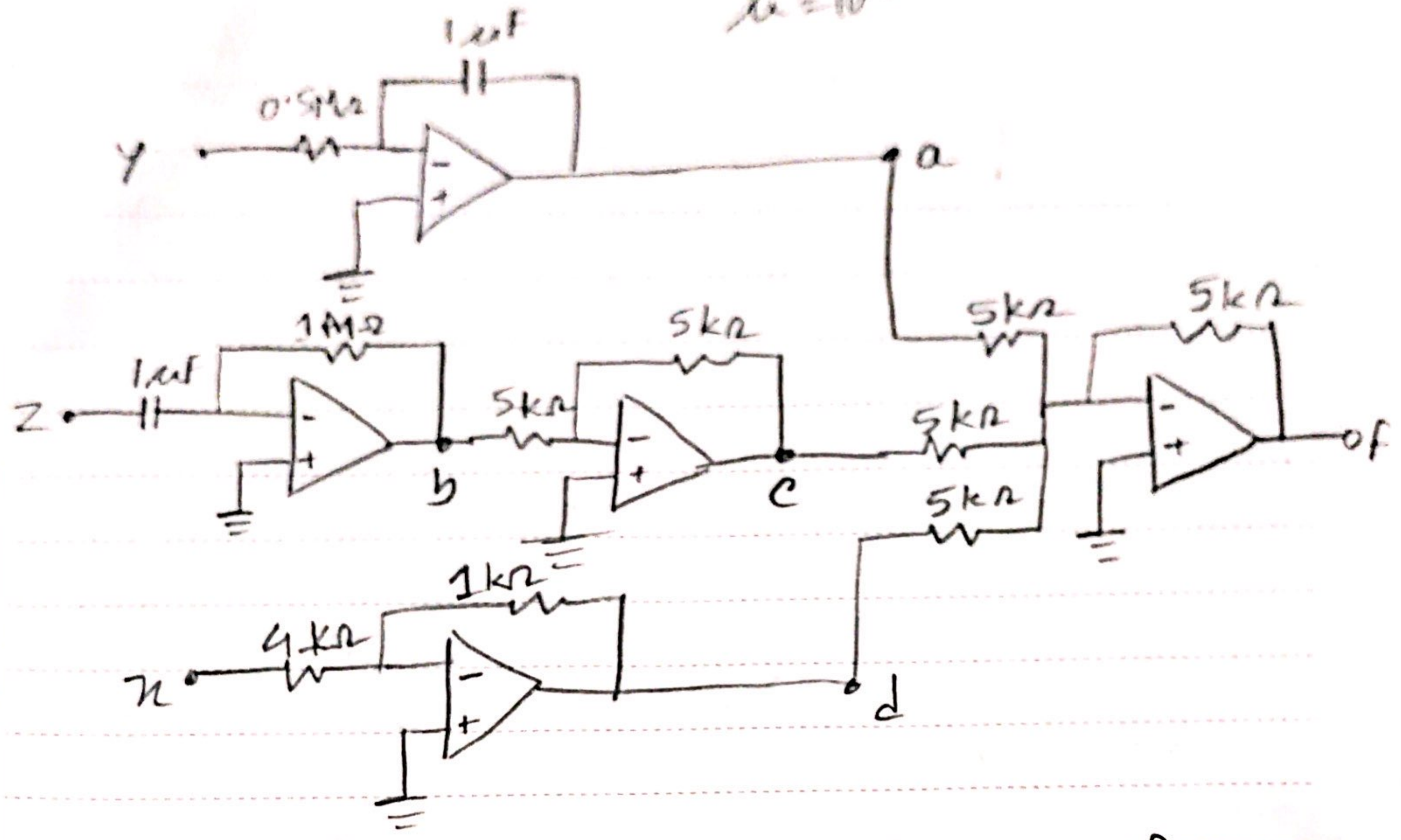
$\boxed{i_1 = i_2}$ $\frac{dv_o}{dt} = -\frac{v_i}{RC}$

$$\Rightarrow v_o = -\frac{1}{RC}\int v_i \, dt$$

Op-Amp

$M = 10^{-6}$

$\mu = 10^{-6}$



$$a = -\frac{1}{RC}\int V_d\,dt = -\frac{1}{0.5\times 1}\int y\,dt = -2\int y\,dt$$

$$b = -RC \cdot \frac{dv_i}{dt} = -1 \cdot \frac{dz}{dt} = -\frac{dz}{dt}$$

$$c = \left(-\frac{5}{5}\right)\times\left(-\frac{dz}{dt}\right) = \frac{dz}{dt}$$

$$d = -\frac{1}{4}x = \frac{-x}{4} = -0.25x$$

$\boxed{R_f = R_1}$

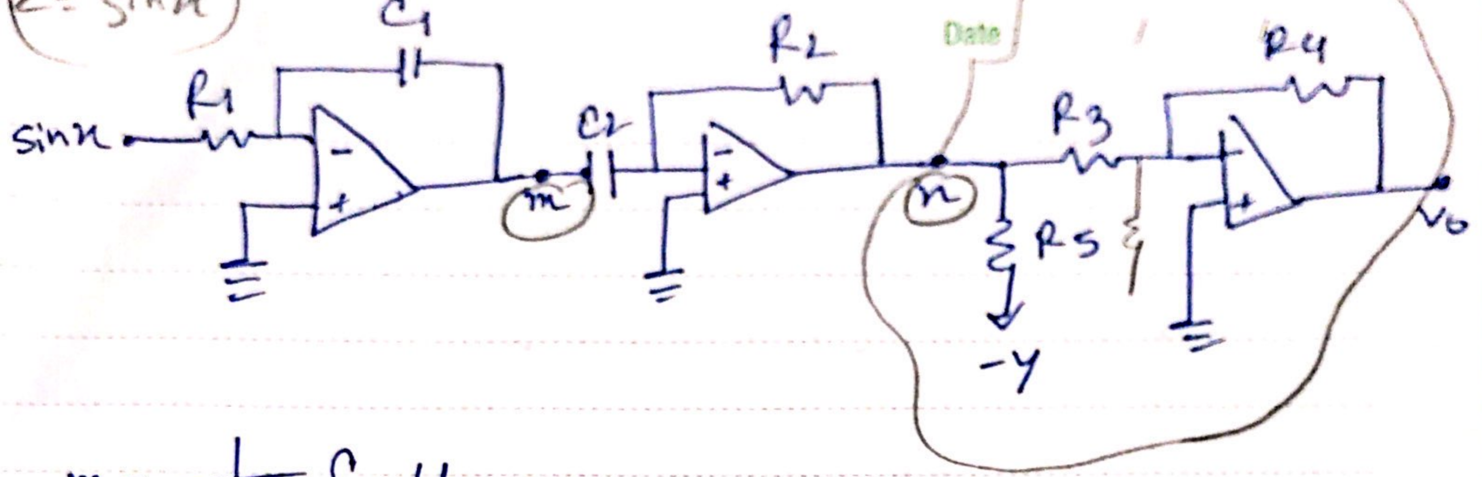
$\boxed{5 = 5}$

$$f = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_1}V_2 - \frac{R_f}{R_1}V_3$$

$$= -V_1 - V_2 - V_3$$

$$= -\left(-2\int y\,dt\right) - \left(\frac{dz}{dt}\right) - \left(-0.5x\right)$$

(z = sin x)

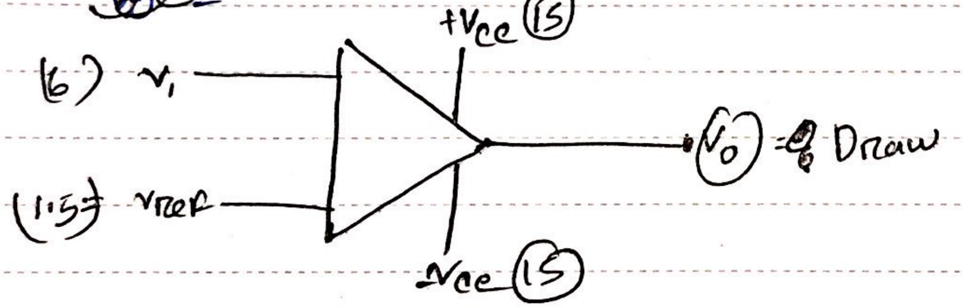


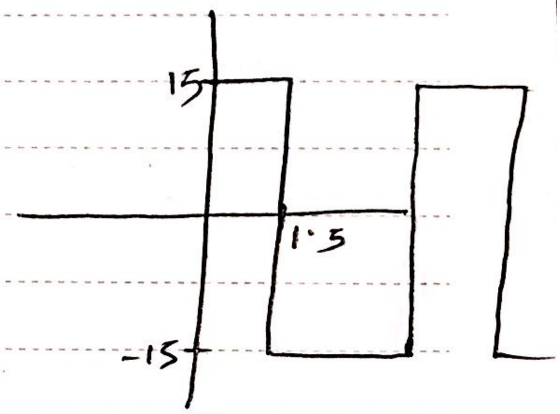
$$m = -\frac{1}{R_1C_1}\int z\,dt$$

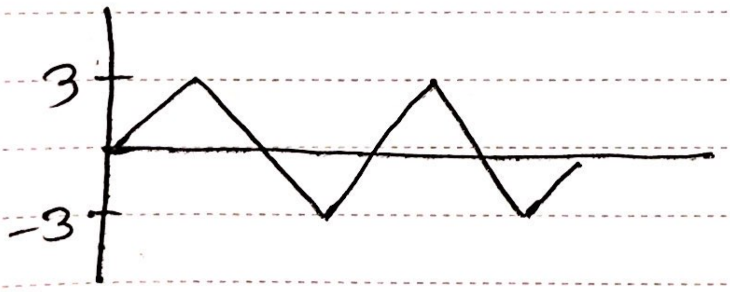
$$n = -R_2C_2\frac{dm}{dt} = -R_2C_2 \cdot \frac{d}{dt}\left(-\frac{1}{R_1C_1}\int z\,dt\right)$$

$$= \frac{R_2C_2}{R_1C_1}\cdot(z)$$

~~Vo =~~







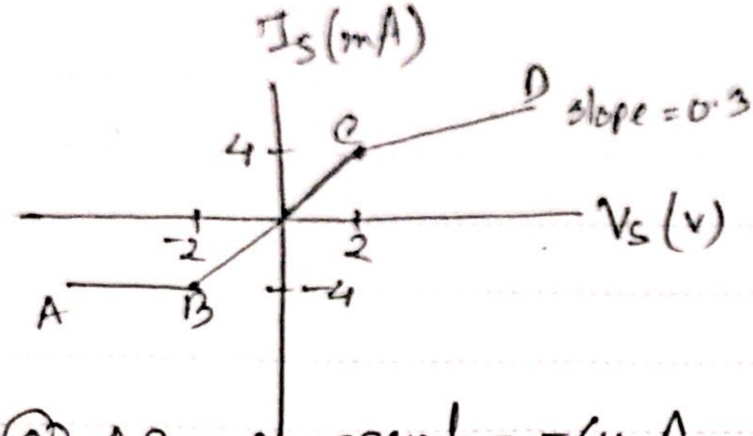
$$v_o = \left(-\frac{6}{3}\right)v_a = (-2\,v_a)$$

$$v_o = (-2\times 3) = (-6V)$$

$$v_o = (-3 \times -2) = 6V$$

I - V

Date / /



mA = 10^3

ⓐ AB = Current = $-4mA$

$BC = \text{Resistor} = \frac{1}{m} = \frac{1}{\frac{y-y_1}{x-x_1}} = \frac{1(x-x_1)}{y-y_1} = \frac{2-(-2)}{4-(-4)} \times 10^3$

$= 500\,\Omega$

$CD = (y = mx + c)$

point $(2, 4)$ $\quad m = 0 \cdot 3$

$R = \frac{1}{m} = \frac{1}{0 \cdot 3} = 3 \cdot 33\,\Omega$

$\therefore 4 \times 10^{-3} = 0 \cdot 3 \times 2 + c$

$\Rightarrow c = 0 \cdot 596$

$\frac{-V_0}{R} = c$

$\Rightarrow V_0 = -1 \cdot 98\ V$

ⓑ $V_s = 3V$

$CD = y = mx + c$

$\Rightarrow I_s = mV_s + c$

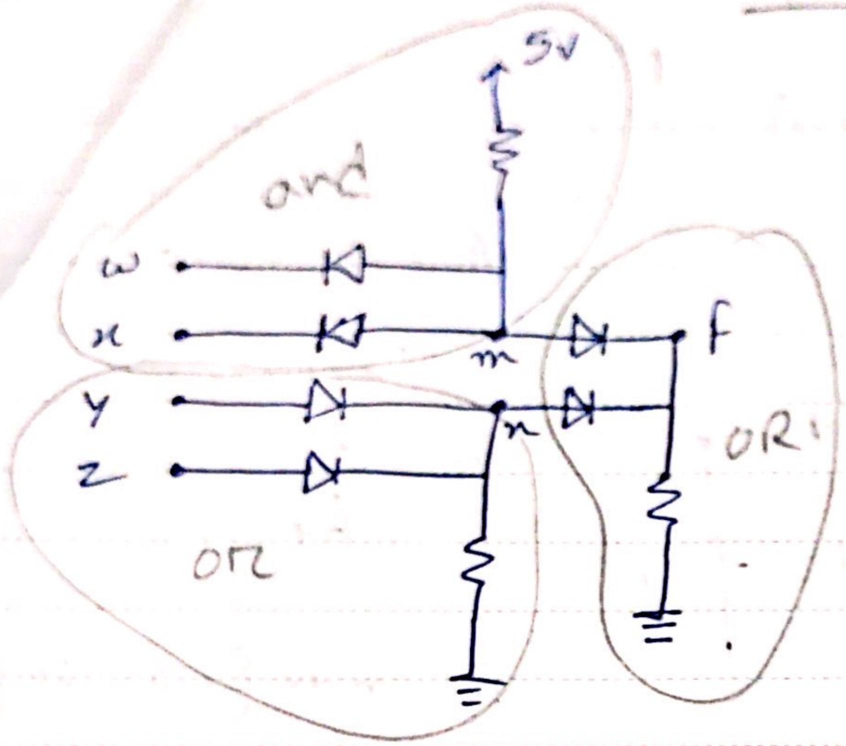
$\Rightarrow I_s = 0 \cdot 3 \times 3 + 0 \cdot 596$

$= 1 \cdot 496\ A$

Goodbac-3S Fibosyl

Diode

Diode logic



AND = (+5V)
OR = GND (0V)

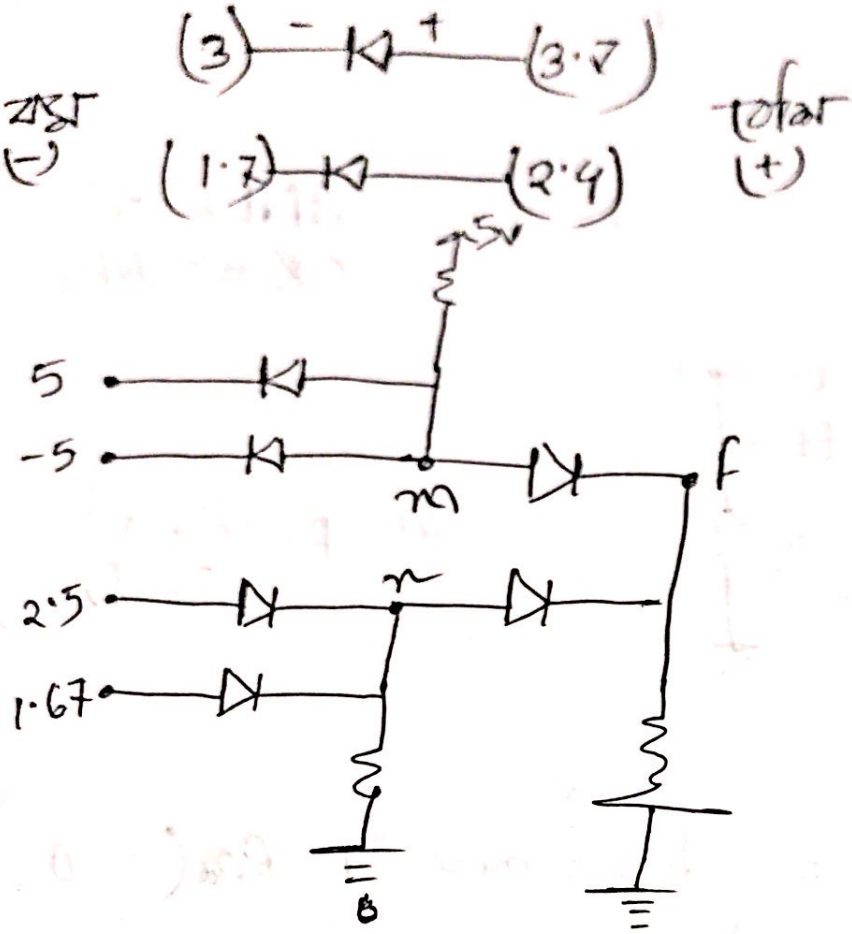
(a) $f = m + n$
$= wx + (y+z)$

(b) $w = (-x) = 2y = 3z = 5$ determine f ~~Rea~~ (CVD and ideal) ($V_d = 0.7V$)

AND = min{inputs}
OR = max{input}

$w = 5V$
$x = -5V$
$2y = 5 \Rightarrow y = 5/2 = 2.5V$
$3z = 5 \Rightarrow z = 5/3 = -\cancel{0}1.6V$

$m = \min\{5, -5\} = -5$
$n = \max\{2.5, -1.6\} = 2.5$
$f = \max\{2.5, -5\} = 2.5$ for Ideal



And = min{5, −5}

= −5

$m = (-5 + 0.7)$

$= (-4.3)$

OR = max{2.5, 1.67}

= 2.5

$n = (2.5 - 0.7)$

$= 1.8$

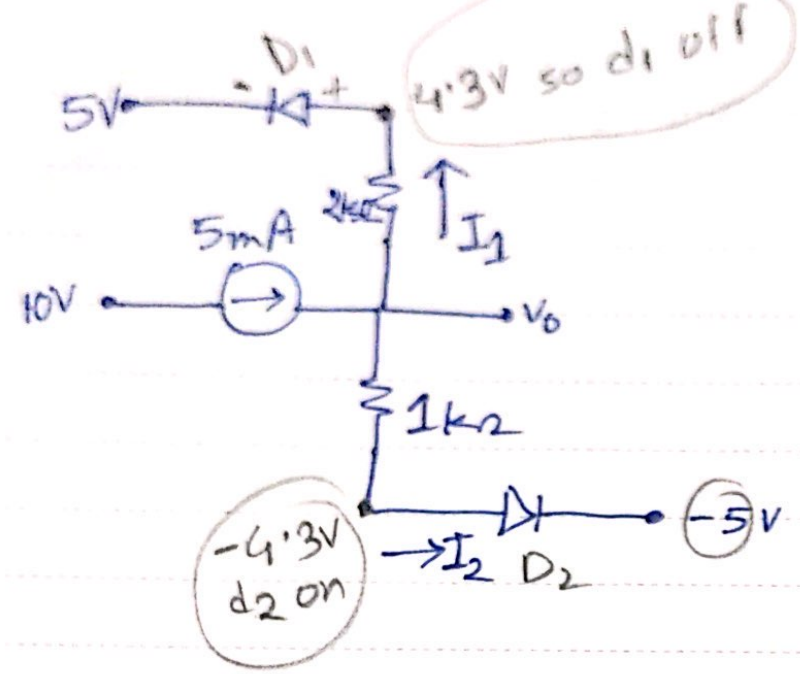
$f = \max\{-4.3, 1.8\} - 0.7$

$= 1.8 - 0.7$

$= 1.1$ V (CVD model)

Diode Assumption

Date / /



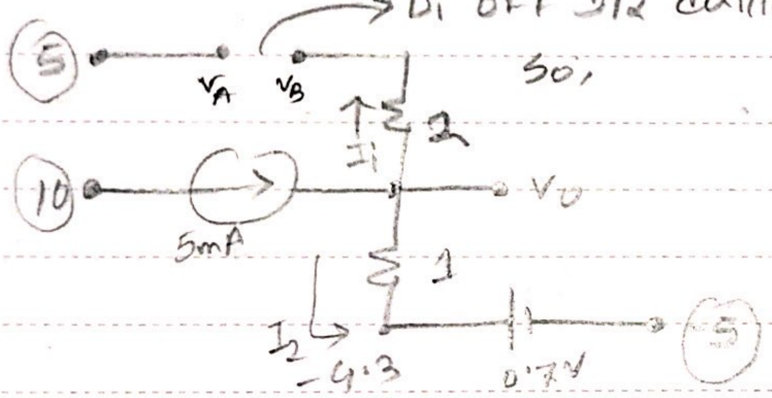
Diode এর possitive এ বেশি voltage থাকলে diode on হবে এটুকু enough

+ —▷|— − : −3 on (3 এর বেশি)

+ —▷|— − : 6 off (6 এর কম)

D_1 off and D_2 on হলে

→ D_1 off তাই current flow ও হবে না।



How to test

- Diode off → test the voltage accross the diode
- Diode on → test the current accross the diode

$$\frac{V_0 - (-4.3)}{1} = 5mA$$

$$\Rightarrow V_0 = 0.7$$

$$I_2 = \frac{V_0 - (-4.3)}{1} = \frac{0.7 + 4.3}{1} = 5mA.$$

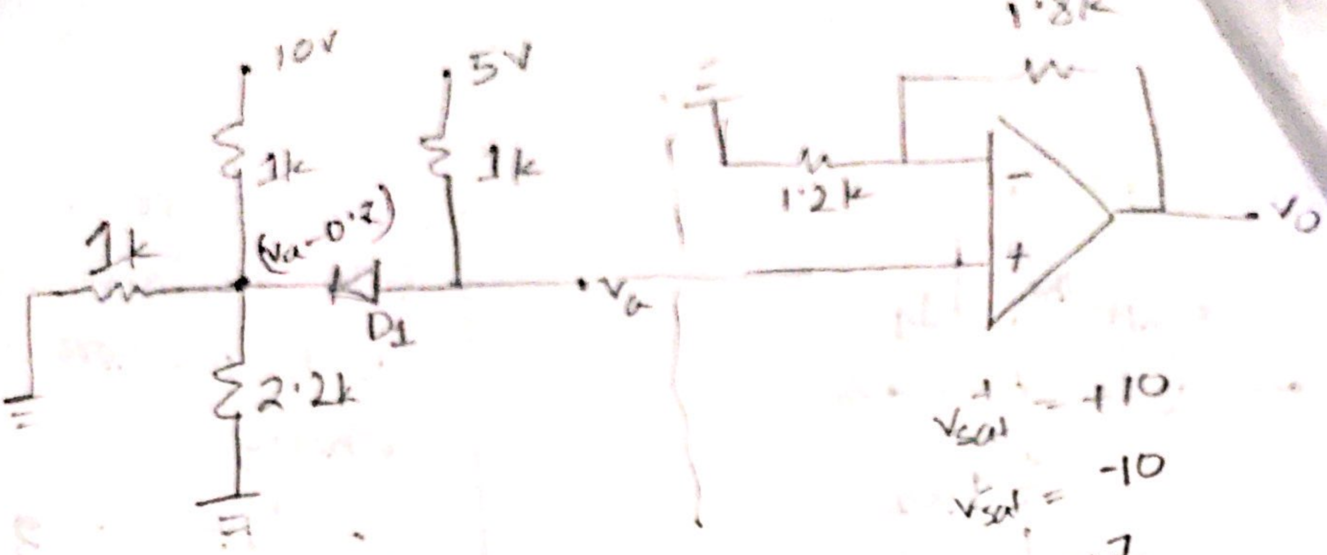
Verify

on → current (+)

off → voltage oppsite.

$V_A - V_B = 5 - 4.3$

$V_B = 10 - 0.7$



$V_a = 4{\cdot}84\ V$

$$(V_a - 0{\cdot}7)\left(1+1+\frac{1}{2{\cdot}2}\right) + V_a - 10 - 5 = 0$$

$\Rightarrow V_a = 4{\cdot}84$

$I_{D1} = 0{\cdot}16\ mA = \left(\frac{5 - V_a}{1}\right)$

no current flows into op-amp terminals.

$I_{D1} > 0$

so, assumption is true.

Non-inverting,

old ($V_d = 0{\cdot}7 / 0{\cdot}5\ V$)

ideal ($V_d = 0V$)

$$V_o = \left(1+\frac{R_F}{R_1}\right)V_a$$

$$= \left(1+\frac{1{\cdot}8}{1{\cdot}2}\right)4{\cdot}84$$

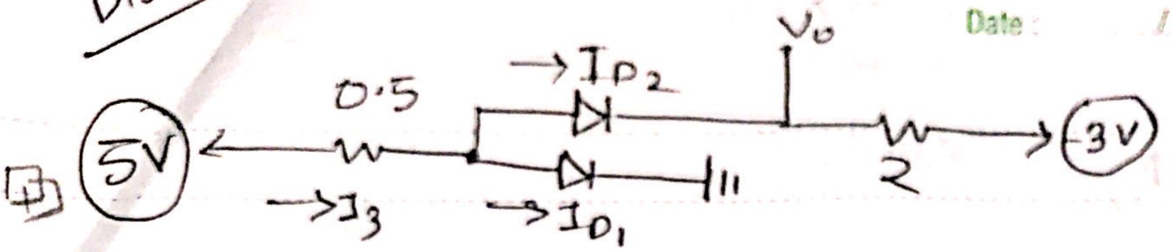
$$= 12{\cdot}1\ V$$

$V_o > V_{sat}^{+}$

so, $V_o = v_o = (+10)$

Diode.

Date: / /



$\boxed{V_d = 0.6V}$

$I_3 = I_{D_1} + I_{D_2}$

$V_a - 0 = 0.6$

$\Rightarrow V_a = 0.6$

$\frac{5 - V_a}{0.5} = I_3$

$\Rightarrow I_3 = 8.8A$

$\frac{V_o + 3}{2} = I_{D_2}$

$\Rightarrow I_{D_2} = 1.5A$

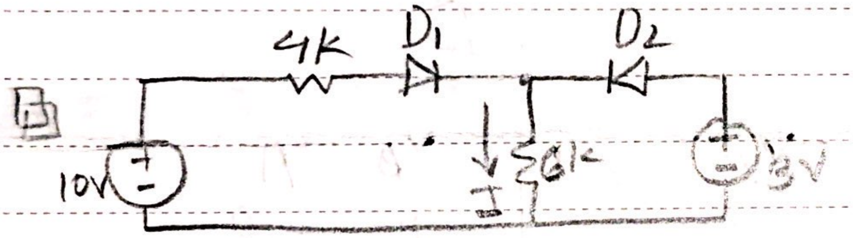
$\therefore I_{D_1} = 7.3A$

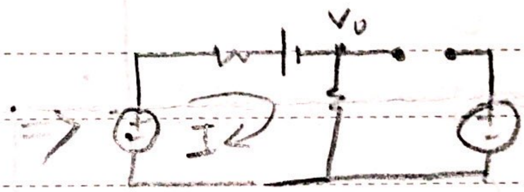
$V_o - V_a = 0.6$

$\Rightarrow V_o = 0$

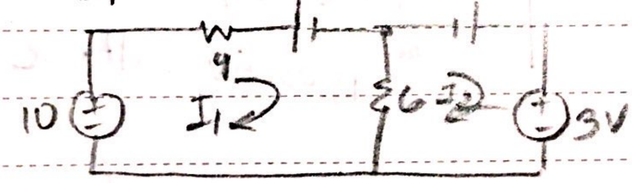
Assumption correct

D_1 and D_2 on.





$D_1 = ON$ and $D_2 = ON$



$-10 + 4I_1 + 0.7 + 6(I_1 - I_2) = 0$

$\Rightarrow 10I_1 - 6I_2 = 9.3$ —— (I)

$6(I_2 - I_1) - 0.7 + 3 = 0$

$\Rightarrow 6I_2 - 6I_1 = -2.3$

$\Rightarrow 6I_1 - 6I_2 = 2.3$ —— (II)

$I_1 = 1.75, I_2 = 1.36$

Goodbac-3S $I_{d_2} = -1.36$ assumption worng

$D_1 = ON$, $D_2 = OFF$

$I(4+6) - 10 + 0.7 = 0$

$\Rightarrow I = 0.93mA$

$I_{d_1} > 0$

$V_o = 6 \times 0.93 = 5.58$

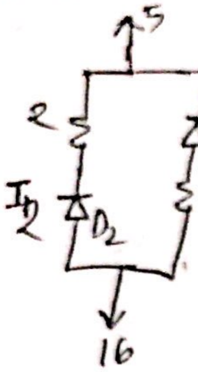
$V_{d_2} = 3 - 5.58$

$= -2.58 \leq 0.7$

Assumption right.

Fibosyl

(b) $V_0 = 0.8V$



$16-5 = 2I_2 + 0.8 + 1I_3$

$16-5 = 10I_1 + 0.8 + 1I_3$

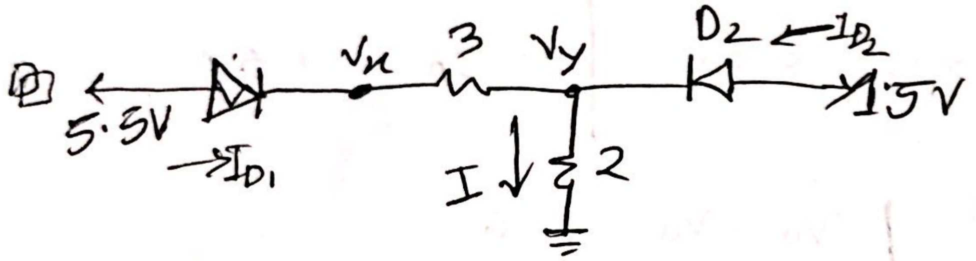
$I_3 = I_2 + I_1$

$I_1 = 0.6375 > 0$

$I_2 = 3.1875 > 0$

$I_3 = 3.825$

(b)



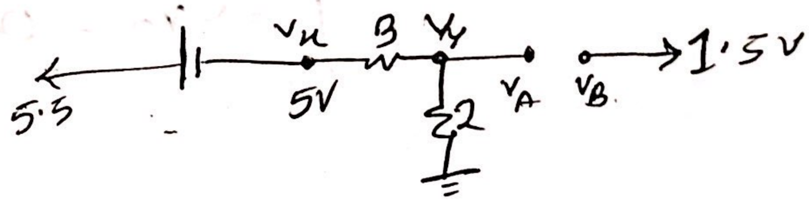
$V_x = (5.5 - 0.5) = 5V$

$I_{D_2} = 0$

$I_{D_1} = I$

$\frac{V_x - 0}{2+3} = I$

$\Rightarrow I = \frac{5}{5} = 1mA = I_{D_1}$



$\frac{V_y - 0}{2} = 1$

$\Rightarrow V_y = 2$

$V_B - V_A$

$= 1.5 - 2$

$= (-0.5)$

oppositie voltage

$\therefore I_{D_1} > 0$

current possitive — so assumption is correct.

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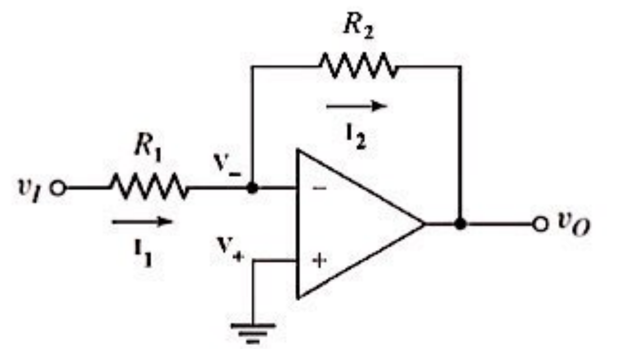
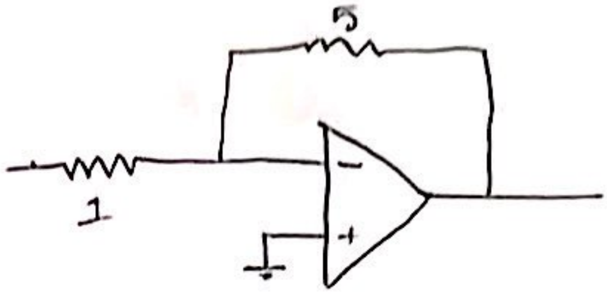


(a) **Design an inverting amplifier (i.e., find the values of R_1 and R_2 of the circuit shown in the Figure above) in such a** way that the voltage gain is −5.

(b) Consider the circuit you drew in (a) again. Assume the input $v_i = 0.1 \sin\omega t$ (V) has a maximum current rating of 5 μA. What design changes, if any, are required for this input, if the voltage gain remains the same?

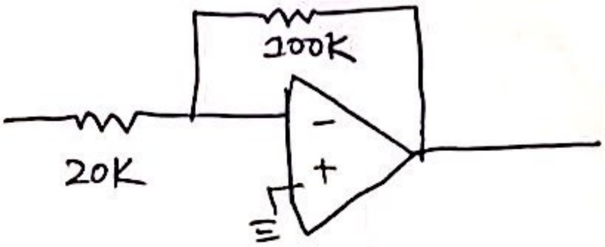
(c) **Draw** the input and output waveforms of the circuit you designed in (c).

(a)

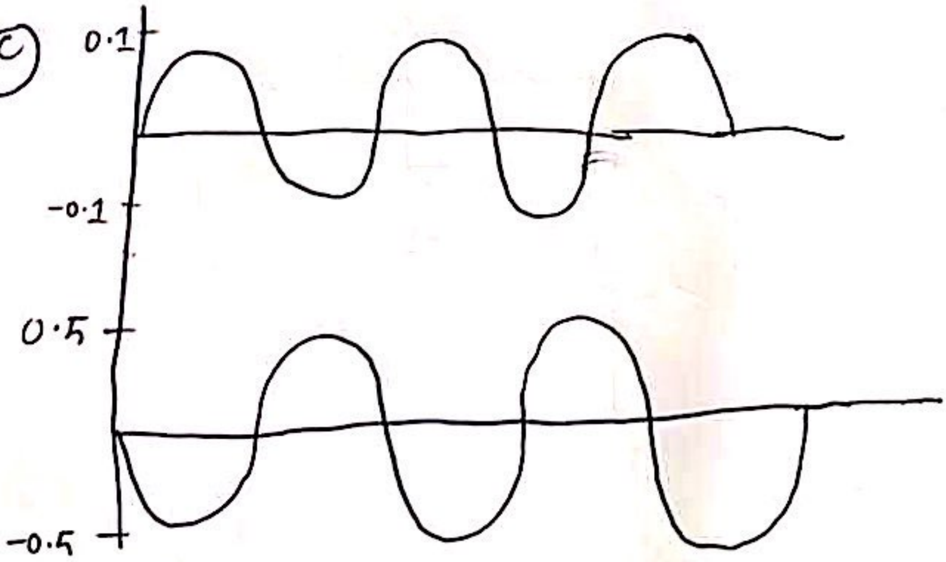


(b)

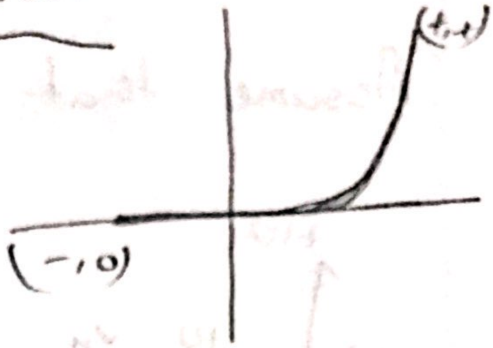
$$R_{in} = \frac{0.1}{5\times10^{-6}} = 20K\Omega$$



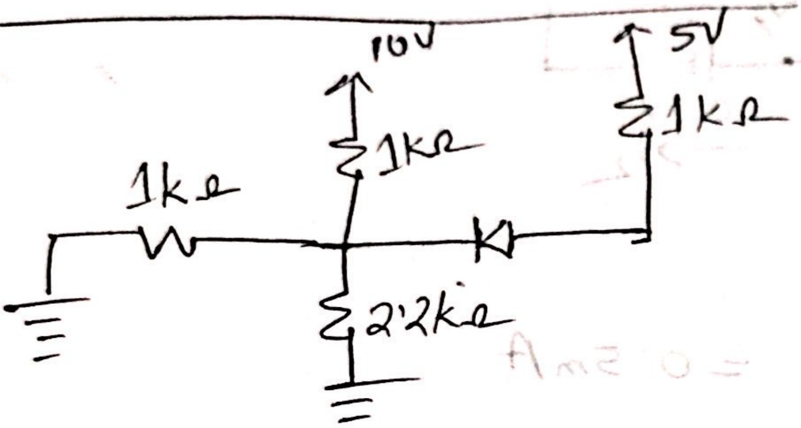
(c)

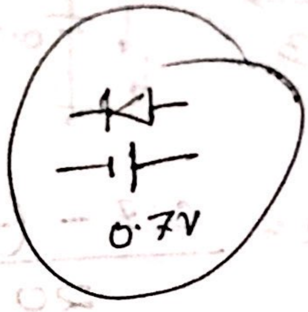


J class miss disilam seita.



Method of assumed states:



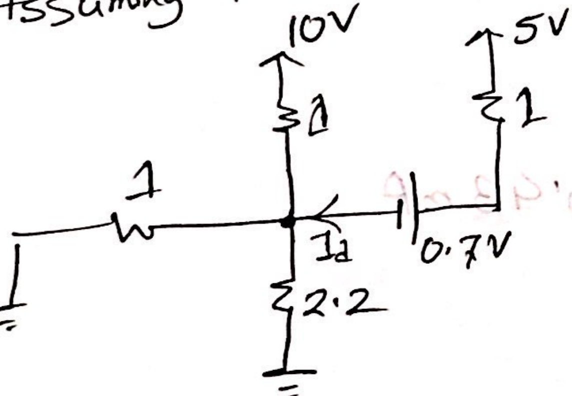


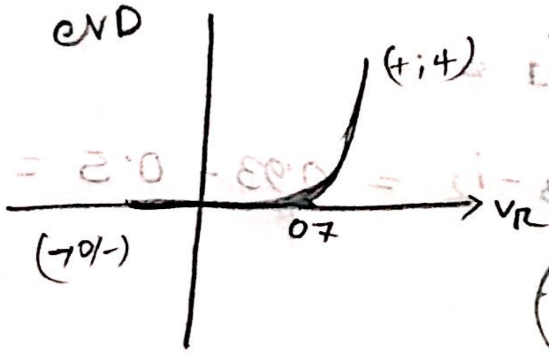
Diode

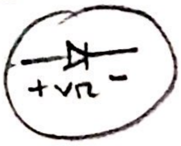
on → current direction test

off → voltage polarity test.

Assuming that the diode is active,







$$\frac{V_1}{2.2} + \frac{V_1-10}{1} + \frac{V_1}{1} + \frac{V_1+0.7-5}{1} = 0$$

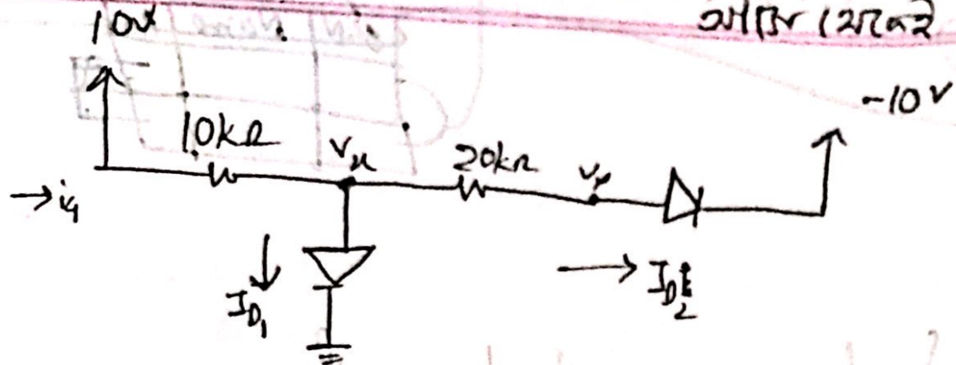
$\Rightarrow V_1 = 4.139$

$V_1 = 4.139 + 0.7 = 4.839\ V$

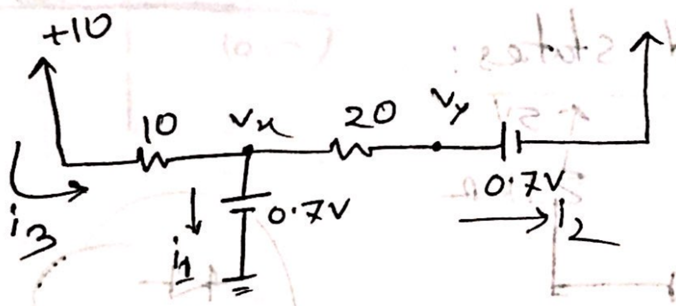
$i_d = \left(\frac{5-4.83}{1}\right) = 0.17\ mA.$

Scanned with CamScanner

দুইটা তোমার Diode থাকলে
আমরা দুটোকেই Assume করে নিতে হবে.



Assume that D_1 and D_2 both are on,



$$i_2 = \frac{0.7 - (-9.3)}{20} = 0.5\,mA$$

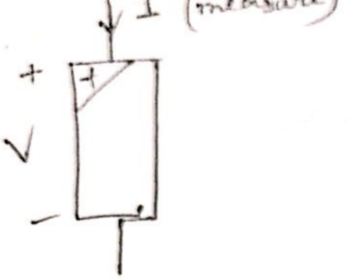
$$i_3 = \frac{10 - 0.7}{10} = 0.93\,mA$$

$$i_3 = i_2 + i_1$$

$$\Rightarrow i_1 = i_3 - i_2 = 0.93 - 0.5 = 0.43\,mA$$

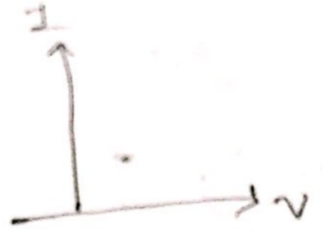
Scanned with CamScanner

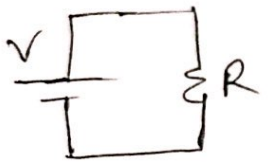
I-V Characteristics



$V = IR$

$\Rightarrow \boxed{R = \frac{V}{I}}$





$I = \frac{V}{R}$

$= \frac{1}{R} \cdot V$ [For resistor only]

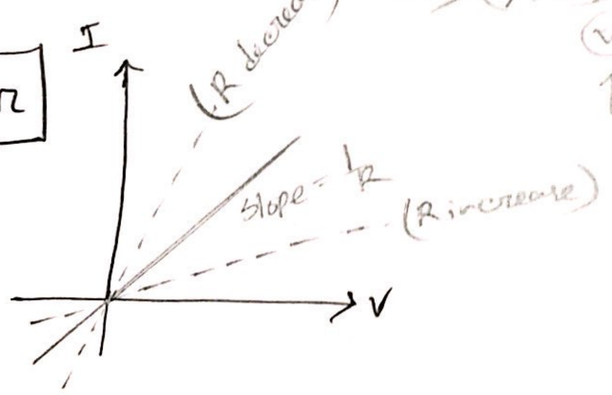
$(y = mx)$ origin

V 1 — 1 (I)

↑ 2 — 2 ↑

3 — 3

ⓐ Resistor



$I = \frac{1}{2}V$

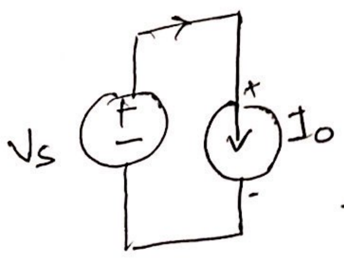
$= \frac{1}{3}V$

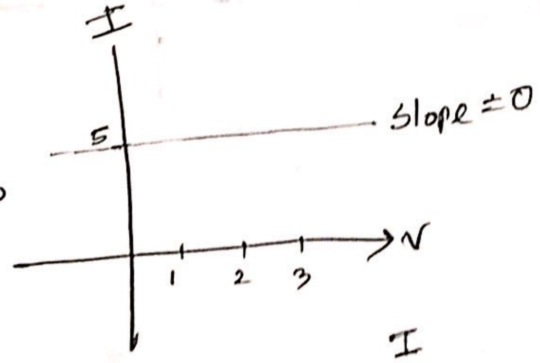
$= \frac{1}{4}V$

$= \frac{1}{5}V$

R বাড়লে আসলে slope ছোট হয়ে যাবে

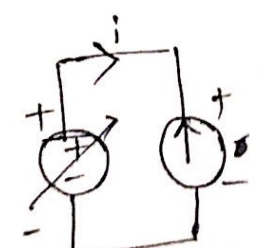
ⓑ Current Source:



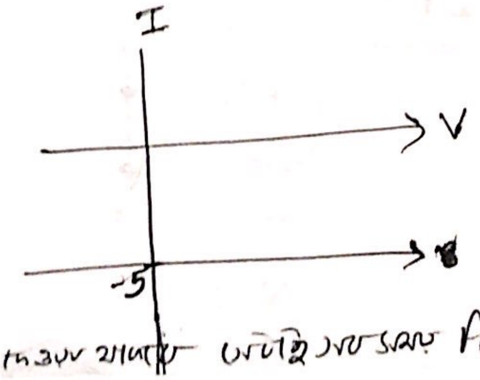


V	I
1V	5A
2V	5A
3V	5A

$(y = 5)$

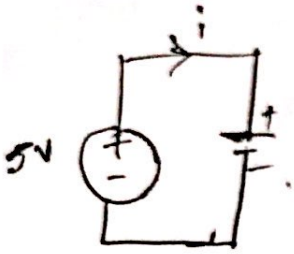


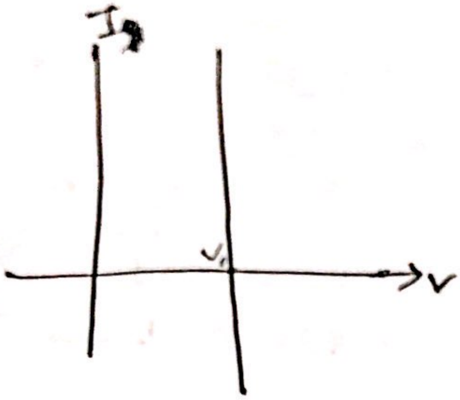
$i = -5A$



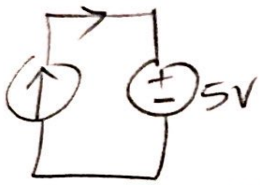
ideal current source হলে যে current fixed থাকবে সেটাই সবসময় flow করবে।

(c) Voltage source.

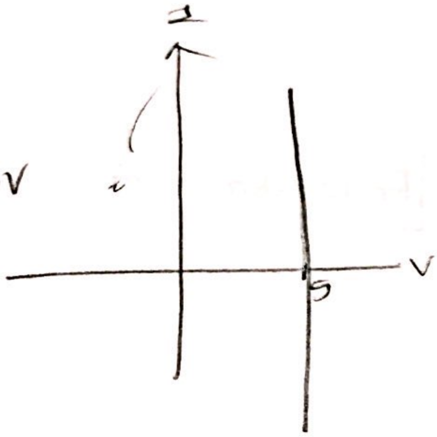




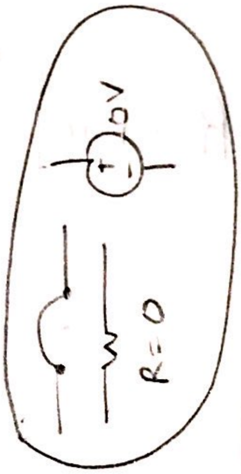
Slope → ∞



$x=5$



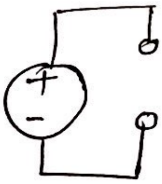
V	I
5V	1A
5V	2A
5V	3A



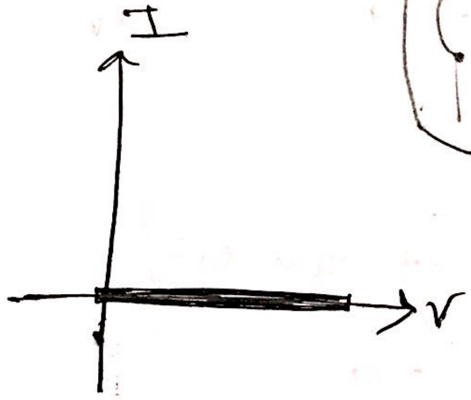
(ii) Degenarate element.

(a) open circuit :

V	I
5V	0
6V	0
7V	0

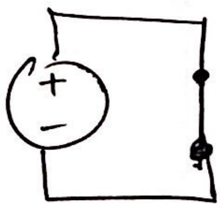


$y=0$

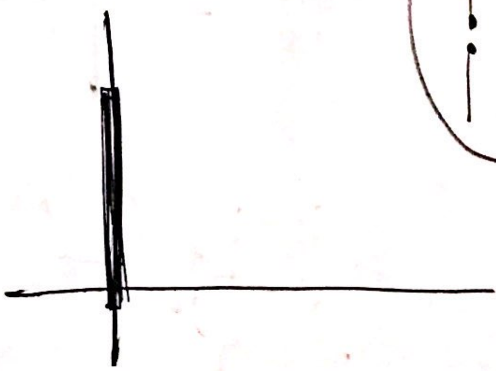


(b) short circuit :

V	I
0V	5A
0V	6A
0V	7A

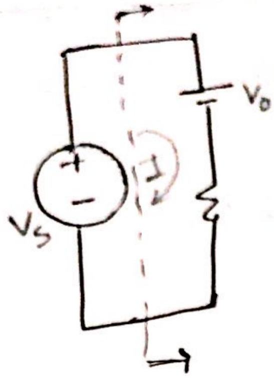


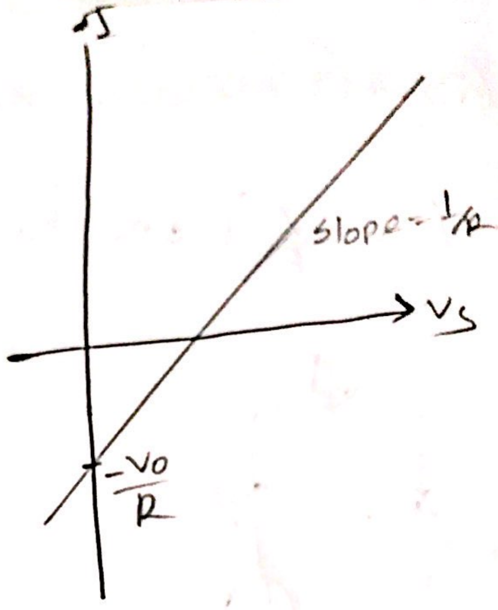
$x=0$



Linear element

(d) Voltage + resistor





$-V_s + V_0 + IR = 0$

$\Rightarrow IR = V_s - V_0$

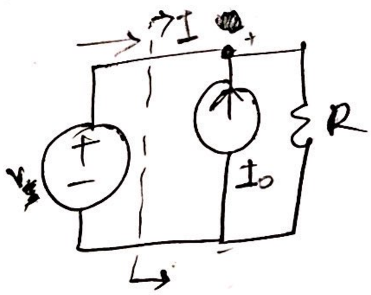
$\Rightarrow I = \frac{V_s - V_0}{R}$

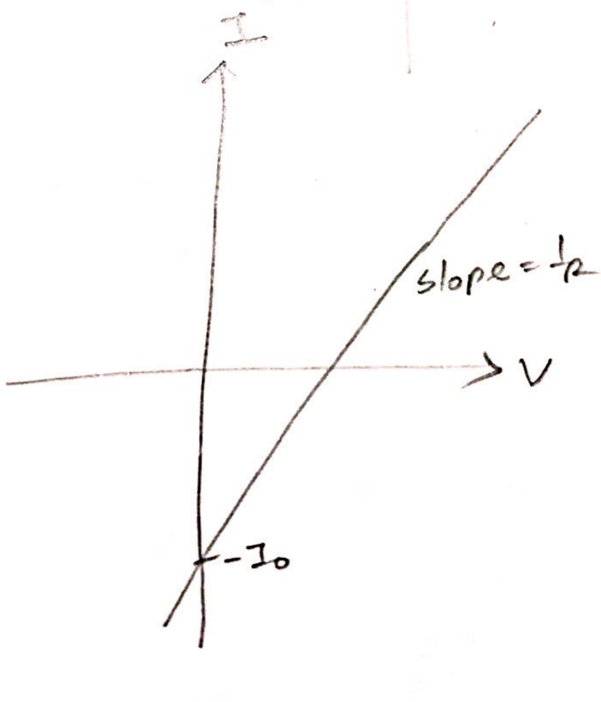
$= \frac{V_s}{R} - \frac{V_0}{R}$

$= \frac{1}{R} \cdot V_s - \frac{V_0}{R}$

$y = mx + c$

(e) Current + Resistor:





$I + I_0 = \frac{V}{R}$

$\Rightarrow I = \left(\frac{1}{R} \cdot V - I_0\right)$

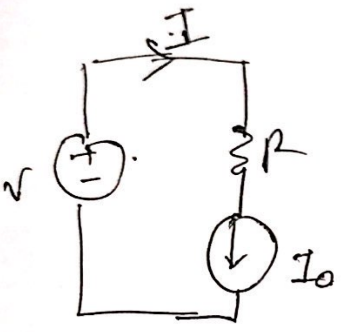
ⓒ $\boxed{\text{Voltage source.}}$

I_0

ⓓ and ⓔ এর Same ব্যবহার হবে,

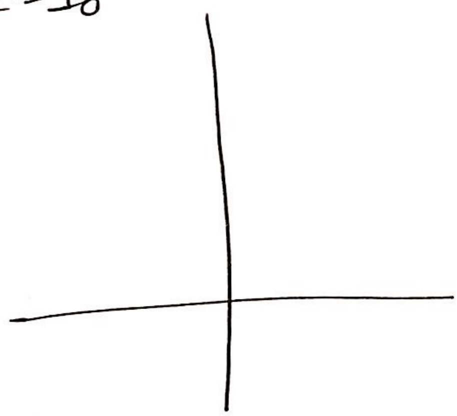
$\left(I_0 = \frac{V_0}{R}\right)$ or $V_0 = I_0 R$

Slope = 0 হবে Resistor(∞)
Slope = (−) হবে Non-exist element.



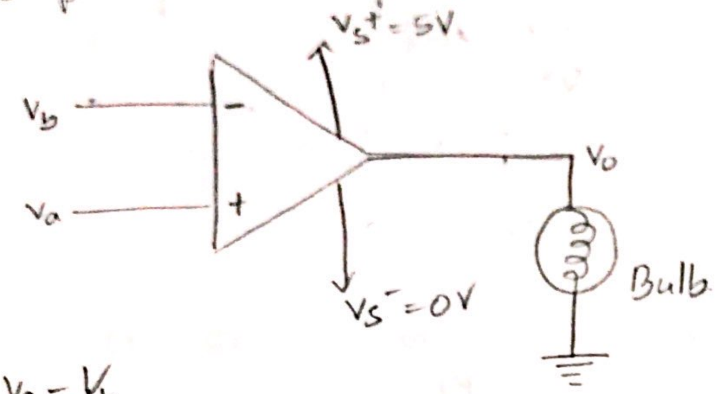
V	I
5V	I_0
6V	I_0

$I = I_0$



Open Loop

① comparator:



$V_d = V_a - V_b$

$V_d > 0 \Rightarrow V_a > V_b \longrightarrow (V_S^+) \longrightarrow V_o = 5V =$ Bulb on

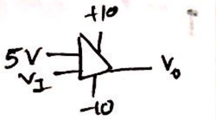
$V_d < 0 \Rightarrow V_a < V_b \longrightarrow (V_S^-) \longrightarrow V_o = 0V =$ Bulb off

Open Loop

(*) No connection between output and input in physical configaration. ~~(zero feedback)~~.

(*) feedback থাকলে controll system এ ব্যবহার হয়

$V_I (-10 < V_I < 10)$



$V_d = V_2 - V_1$

$= V_I - 5$

$\Rightarrow -10-5 \Rightarrow -15$

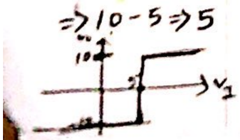
$\Rightarrow -9-5 \Rightarrow -9$

$\Rightarrow 0-5 \Rightarrow -5$

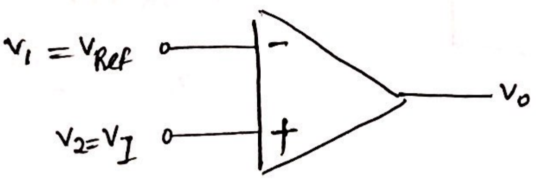
$\Rightarrow 5-5 \Rightarrow 0$

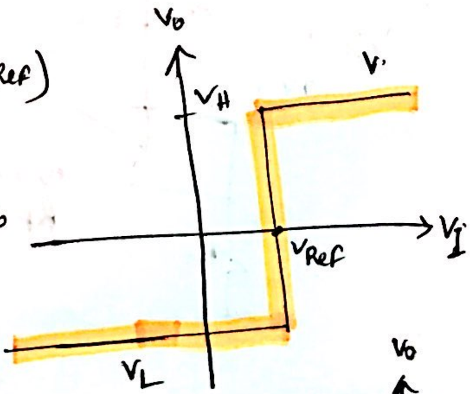
$\Rightarrow 6-5 \Rightarrow 1$

$\Rightarrow 10-5 \Rightarrow 5$

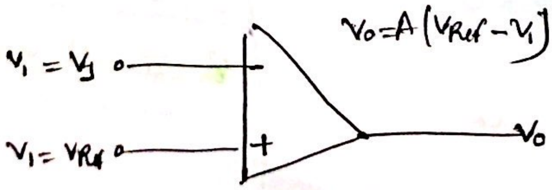


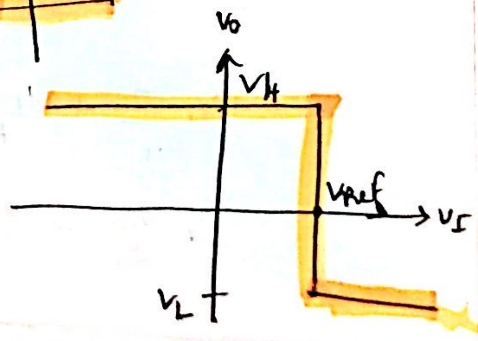
$V_o = A(V_1 - V_{Ref})$





$V_o = A(V_{Ref} - V_1)$





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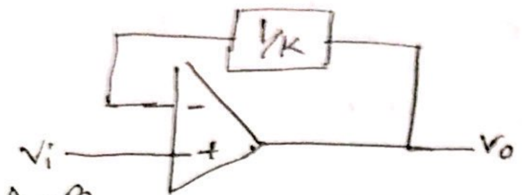
Negative feedback



K=10 ⇒ (1/10) th of output is feedback to (−) input.

A=3

and $\boxed{V_i = 5V}$ and $\boxed{k = 10}$

if no feedback.

V_d (+) হলে V_{s+} আসবে

$v_o = A v_i$

$= 15\cancel{00}\ V$

$\boxed{V_o = 0V}$ connect করার আগে

$V_- = \frac{V_o}{10} = 0$

$V_d = V_+ - V_-$
$= 5 - 0$
$= 5$

$\boxed{V_o = A V_d}$
$V_o = 5 \times 3$
$= 15$

Connection পরে:

$\boxed{V_o = 15V}$ feedback

$V_- = \frac{15}{10} = 0.5V$

$V_d = V_+ - V_-$
$= 5 - 1.5$
$= 3.5$

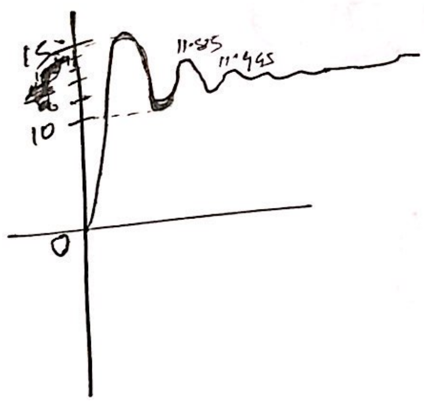
$V_o = 3.5 \times 3$
$= 10.5$

$\boxed{V_o = 10.5}$

$V_- = \frac{10.5}{10} = 1.09$

$V_d = V_+ - V_-$
$= 5 - 1.05$
$= 3.95$

$V_o = 3.95 \times 3$
$= 11.85$



graph

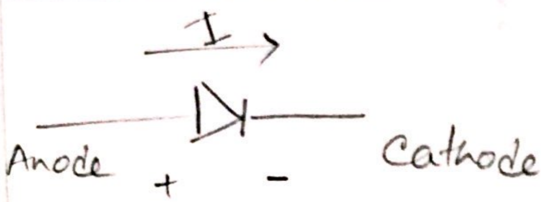
$\boxed{V_o = 11.85}$

$V_- = \frac{11.85}{10} = 1.185$

$V_d = 5 - 1.185 = 3.815$

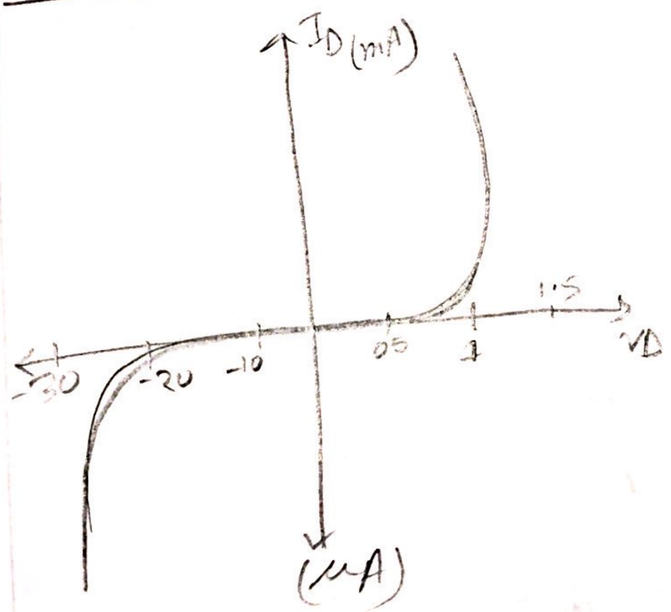
$\boxed{V_o = 11.445}$

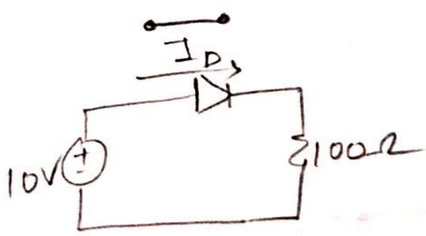
Diode



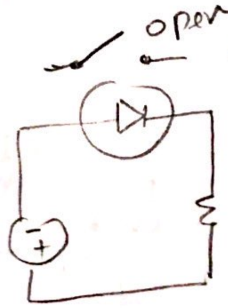
current flow হবে না

V-I characteristic of diode





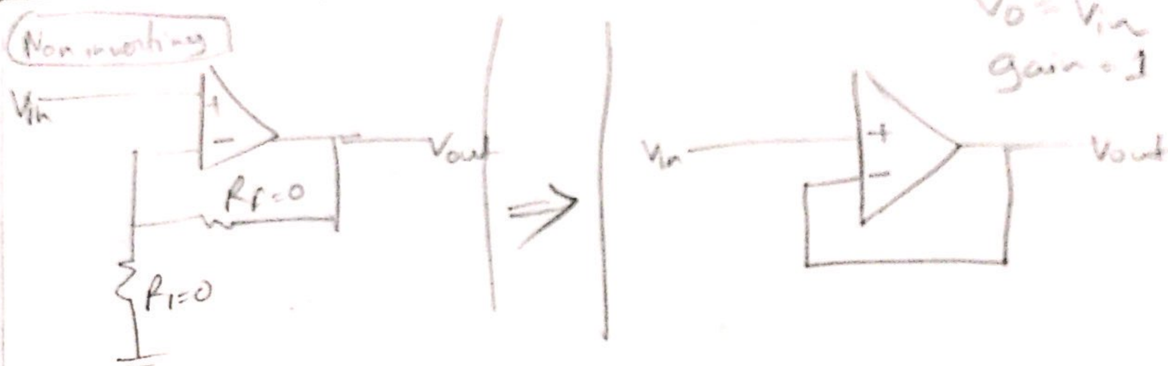
$$I_D = \frac{10}{100} A$$
$$= 0.1 A$$



open হয়ে যাবে so no current flow

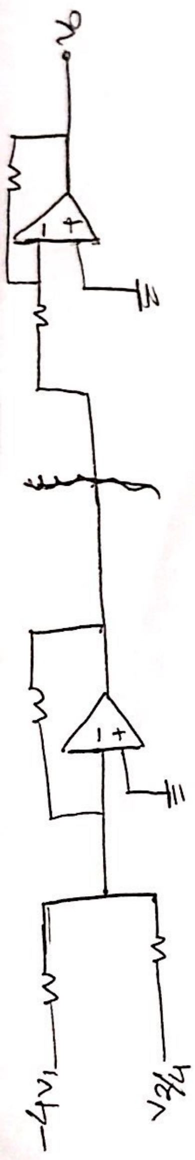
5V
V_1
V_d

Buffer configuration:



$$\text{gain} = \left(1 + \frac{R_f}{R_1}\right) = \left(1 + \frac{0}{\infty}\right) = 1$$

$V_o = V_{in}$



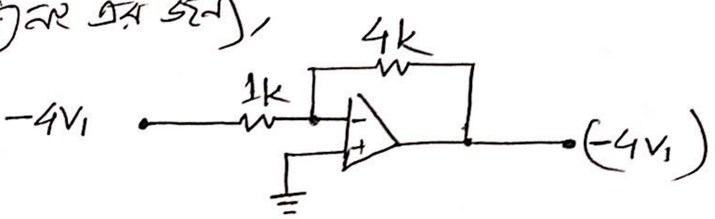
Design Problems.

① $V_o = -4V_1 + V_2/4$

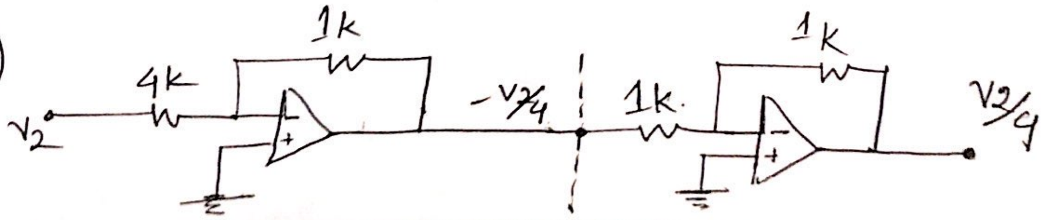
(ii) $V_o = -3V_1 + 4V_2 + 0.5V_3$

Non-inverting	Inverting	Adder.
$1 + \frac{R_f}{R_1}$	$-\frac{R_f}{R_1}$	$-\sum \frac{R_f}{R_1} \cdot V_i$

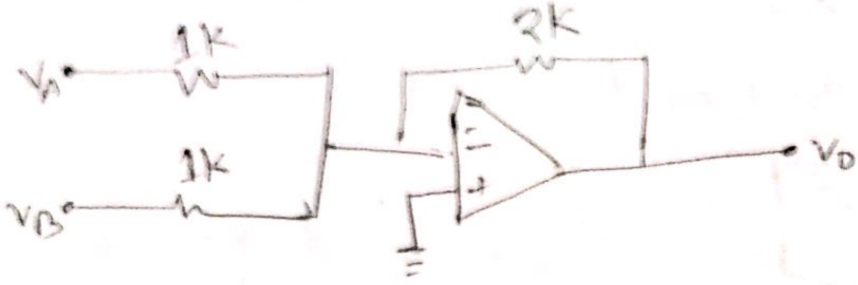
① নং এর জন্য,

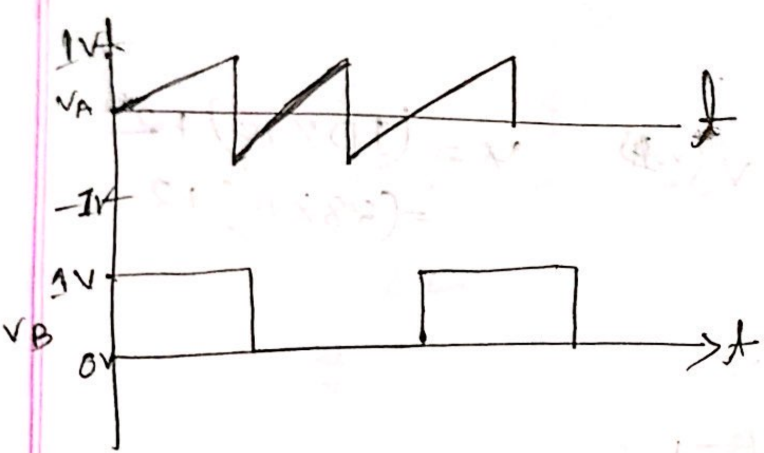


$-\left(-\frac{1}{4}V_2\right)$



Q2.

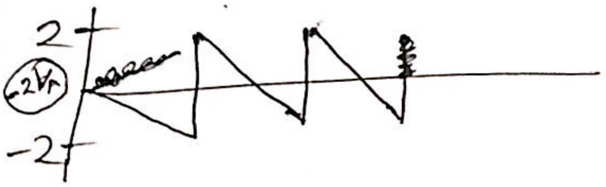


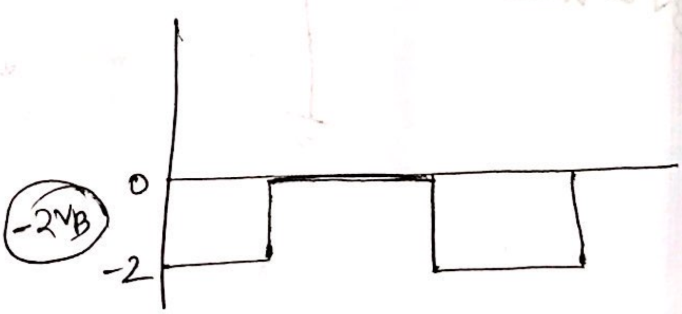


$$V_O = -\left(\frac{2}{1} V_a + \frac{2}{1} V_B\right) = -2V_A - 2V_B$$

$-2\times V_A$
$= -2\times 1$
$= -2$

$-2\times V_A$
$= -2\times -1$
$= +2$



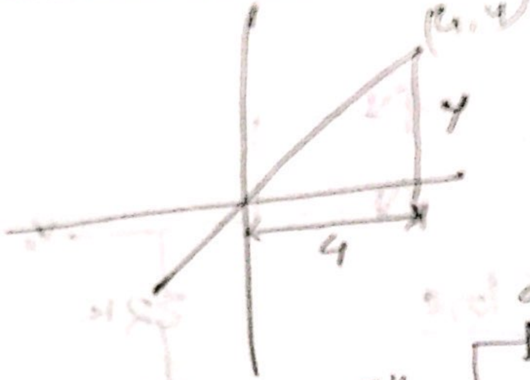


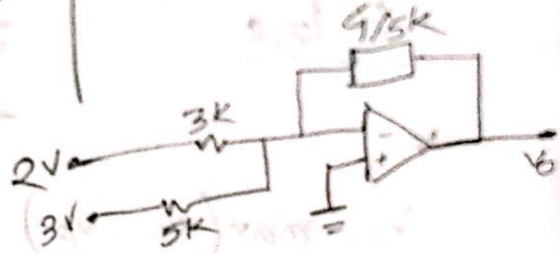
$\frac{9}{2}k\Omega \,/\, \frac{9}{12}k\Omega$

Q1. x = Resistor

$R = \frac{4}{y}$

$= \frac{4}{5}$ (let)

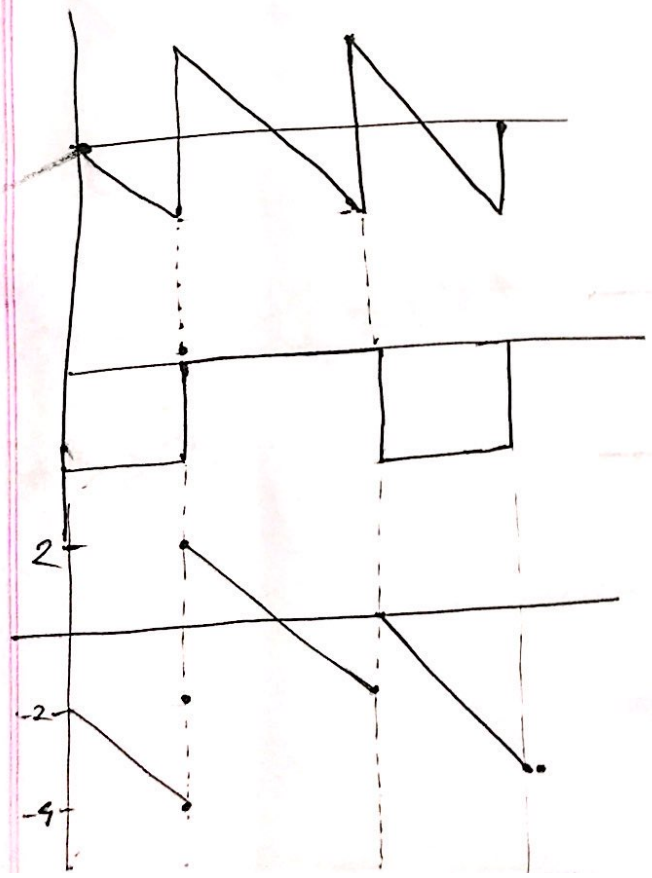




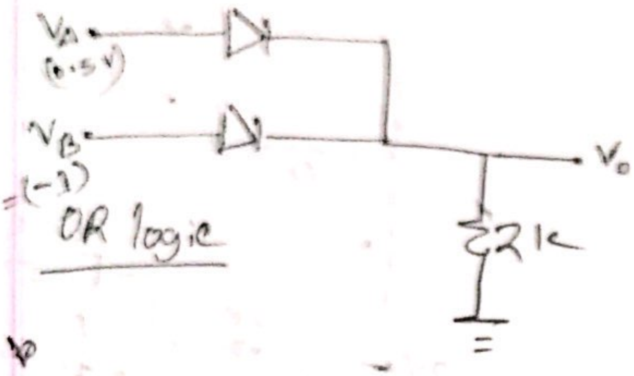
$$V_0 = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2\right)$$

$$= -\left(\frac{4}{5\times 3}\times 2 + \frac{4}{5\times 5}\times 3\right)$$

Q2.



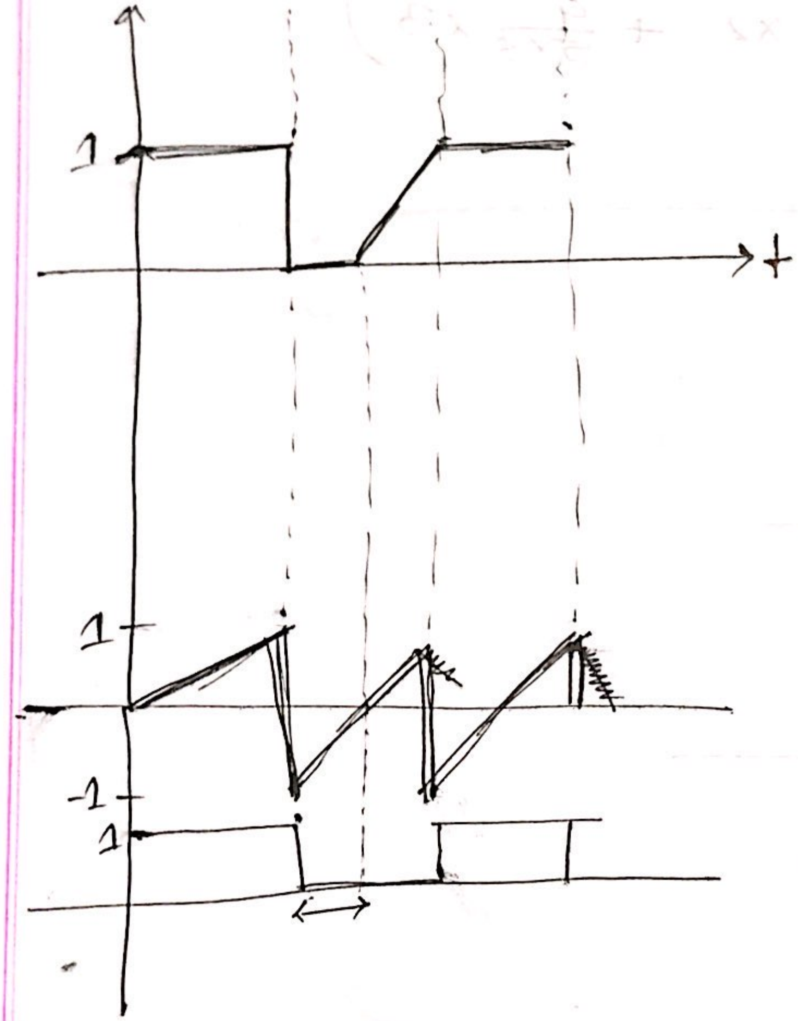
(a)



OR logic

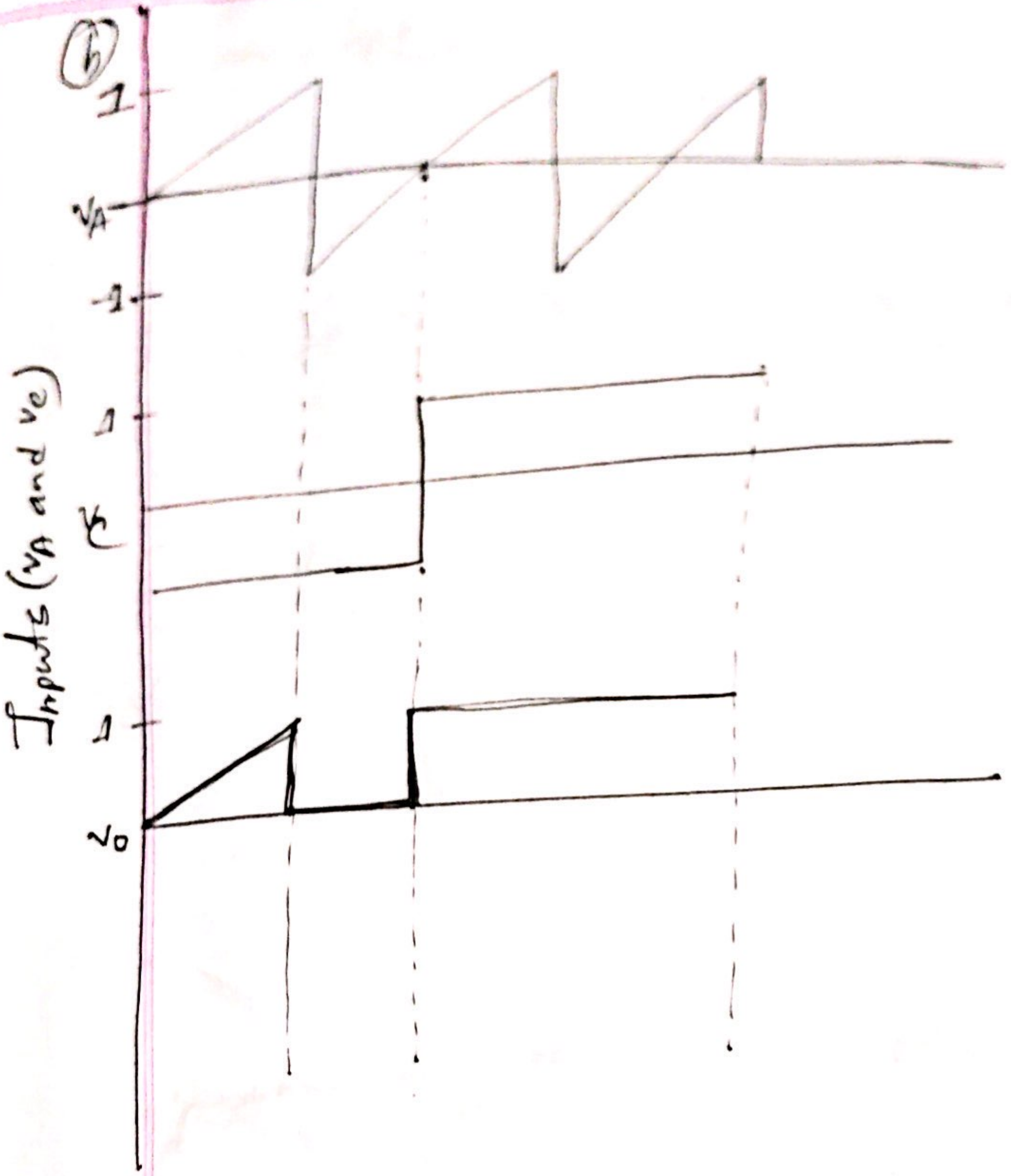
$V_0 = max(V_A, V_B)$

কিছু বলা না থাকলে Diode = Ideal ($V_d > 0$, $V_d < 0$)



divider voltage with (·) ... Diode on ... non-linear circuit

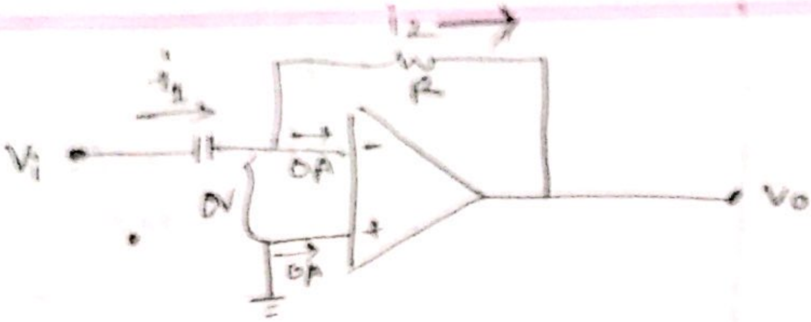
(b)



$v_O = \max\{v_A, v_C\}$

$\Rightarrow v_O \geqslant 0$

(a)



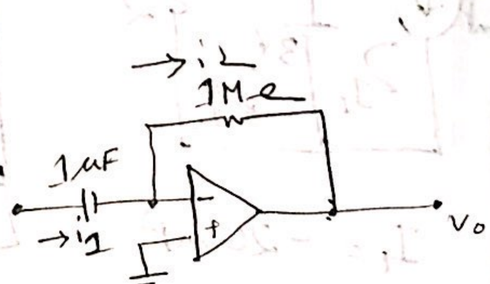
$$i_1 = \left(\frac{V_i - 0}{R}\right) = \frac{V_i}{R}$$

$$i_2 = C\frac{dv_i}{dt} = C\frac{d(0-v_o)}{dt}$$

$$= -C\frac{dv_o}{dt}$$

$$\therefore i_1 = i_2 \Rightarrow \frac{dv_o}{dt} = -\frac{V_o}{RC}$$

$$\Rightarrow \boxed{V_o = -\frac{1}{RC}\int V_i\, dt}$$



(b)

$$v_o = -RC\cdot\frac{dv_i}{dt}$$

$R = 1\,M\Omega$

$C = 1\,\mu F$

$RC = 1\,sec$

$$\frac{d}{dt}\left(0.25\sin(20t)\right)$$

$$= 0.25\cos 20t \times 20$$

$$= 5\cos 20t$$

$$v_o = -1\times 5\cos(20t)$$

$$= -5\cos(20t)$$

$\underline{i_1 = i_2}$

$$i_2 = \frac{0 - (-5\cos 20t)}{1\,M\Omega} = 5\times10^{-6}\cos 20t \text{ A}$$

$$= 5\cos 20t\ \mu A$$

$$= i_1$$

B

integr

add.

diff

invert

$$V_{I_1} = -\frac{dy}{dt}$$

$$V_{I_2} = -\frac{5}{5}(V_{I_1}) = \frac{dy}{dt}$$

$$V_{I_3} = -\int \cancel{x}\,dt$$

$$f = -\frac{R_F}{R_1}V_{I_2} - \frac{R_F}{R_1}V_{I_3}$$

$R_F=5$
$R_1=5$

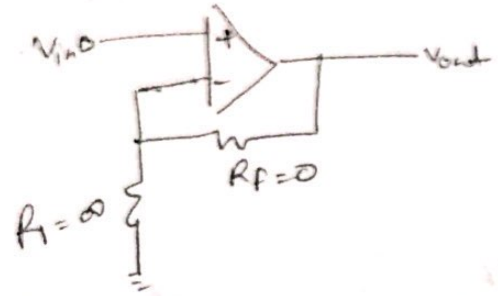
$$= -V_{I_2} - V_{I_3}$$

$$= -\frac{dy}{dt} + \int x\,dt$$

$$\boxed{\begin{array}{l} x = 2\sin 50t \\ y = 5\cos 2t - 7\sin 3t \\ \text{at } t = 5 \text{ sec,} \\ f = ? \end{array}}$$

$$\boxed{\begin{array}{l} x = 2\sin 25t \\ y = \sin 2t - \cos 3t \\ t = 5 \text{ sec} \\ f = ? \end{array}}$$

[4] Buffer configuration (config 2.1)



$$gain = 1+\frac{R_f}{R_1} = \left(1+\frac{0}{\infty}\right) = 1$$

$v_o = V_{in}$

[5] Design problems. (exam এ আসবে?)

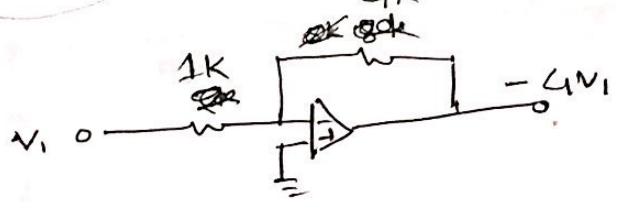
(i) $V_o = -4V_1 + V_2/4$

(ii) $V_o = -3V_1 + 4V_2 + 0.5V_3$

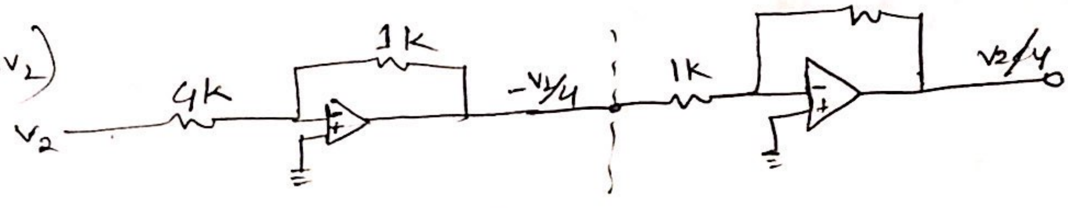
Non-inverting	Inverting	Adder
$1+\frac{R_f}{R_1}$	$-R_f/R$	$-\sum \frac{R_f}{R_i} \cdot v_i$

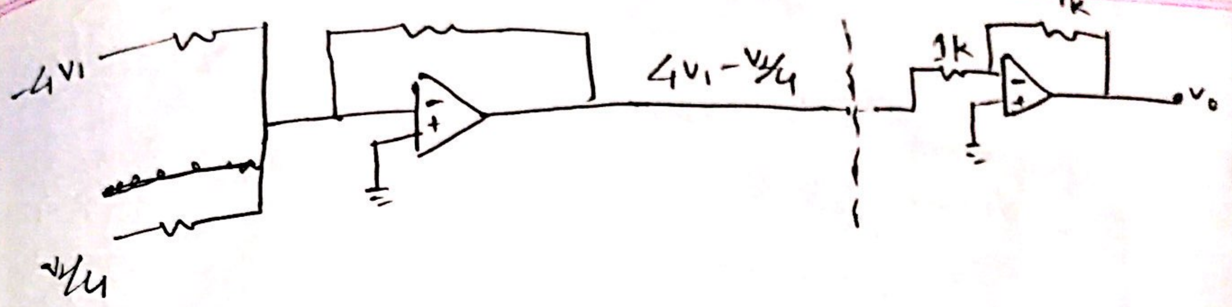
(i) $V_o = -4V_1 + V_2/4$

$-4V_1$



$-(0.25V_2)$





(17) $V_0 = \left(-3V_1 + 4V_2 + 0.5V_3\right)$

$= -\left(3V_1 - 4V_2 - 0.5V_3\right)$