Theory
(75%)

- Attendance (10%)
- Assignment (10%) [n-1] (5 16)
- Quiz (15%) [~~3~~ 4] (n-1)
- mid & Final (20% + 20%)

Lab
(25%)

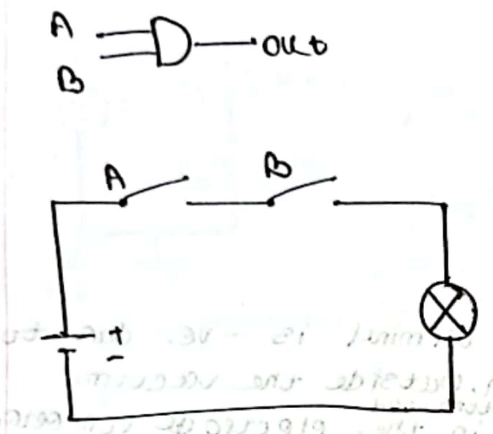
- Attendance (4%)
- Report (4%)
- Lab Test (7%)
- Project (10%)
  [water level indicator]

LECTURE 1

MONDAY

DATE: 23/01/23

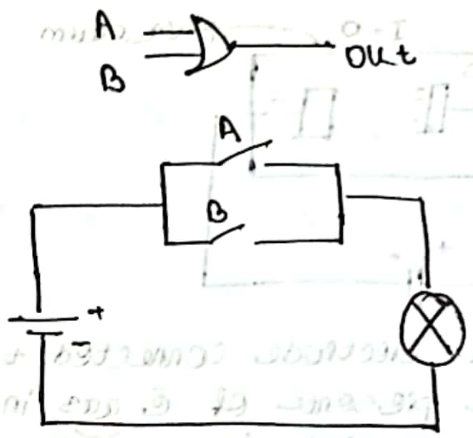
AND Gate



A	B	Out
0	0	0
0	1	0
1	0	0
1	1	1

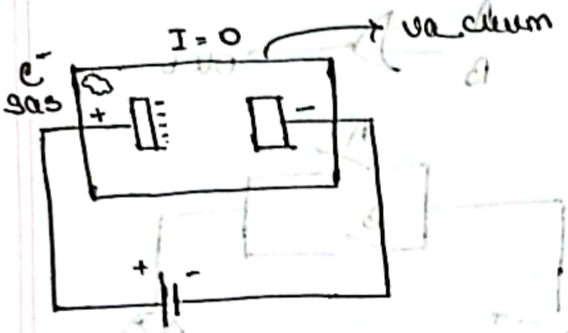
* If either A or B is open/off, there is no flow and thus there will be no outflow.

OR Gate

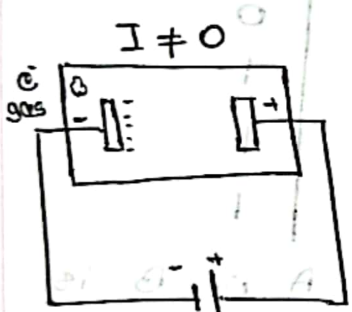


A	B	Out
0	0	0
0	1	1
1	0	1
1	1	1

* If either A or B is open/off, there is still a flow along the path which is closed/ON and thus there will an outflow.



* The electrode connected to the +ve terminal is -ve due to the presence of $\bar{e}$ gas in the vaccum. Outside the vaccum, the electrode is +ve. Thus, $\bar{e}$ remains attracted in the electrode connected to +ve terminal. Thus, there is no flow of $\bar{e}$. $\therefore$ $I = 0$



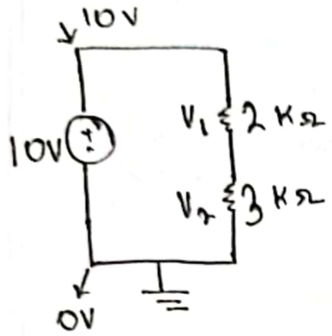
*

LECTURE 2

WEDNESDAY DATE: 25/01/23

*ALTERNATE CIRCUIT REPRESENTATION

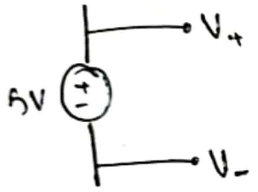
Ex-1



$V_1 = \frac{2}{2+3} \times 10 = 4V$

$V_2 = 10 - 4 = 6V$

Loop representation



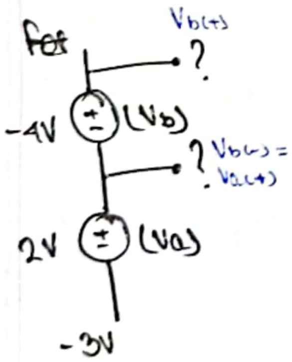
$5 = V_+ - V_-$

For ex-1, $10 = V_+ - V_-$

$\Rightarrow 10 = V_+ - 0$

$\Rightarrow V_+ = 10V$

For



Here, $V_a = V_{a(+)} - V_{a(-)}$

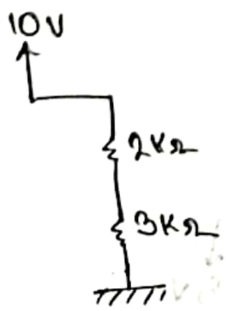
$\cancel{V_a} 2 = V_{a(+)} - (-3)$

$\therefore V_{a(+)} = -1V = V_{b(-)}$

again, $V_b = V_{b(+)} - V_{b(-)}$

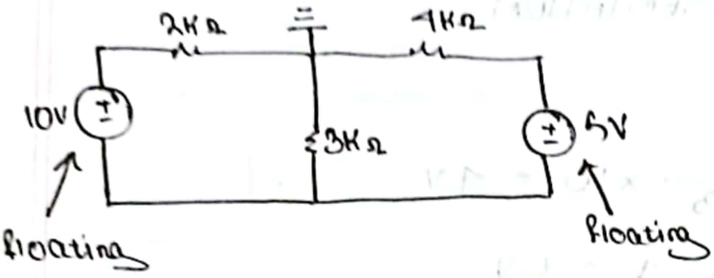
$-4 = V_{b(+)} - (-1)$

$\therefore V_{b(+)} = -5V$

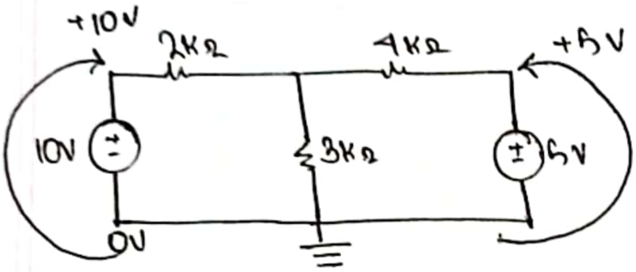


* 10V source is connected to ground. That's why we use an arrow to represent it.
* We represent ~~the~~ voltage source with arrow as we use voltage source as the supply.

Ex - 2

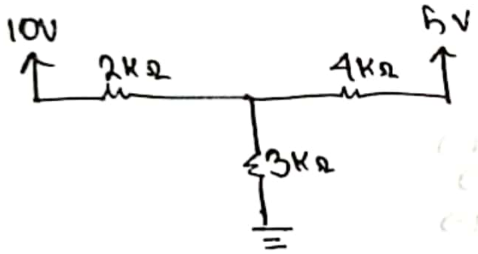


* floating – the source does not have any reference point.
* Both the supply must have same ground to avoid floating

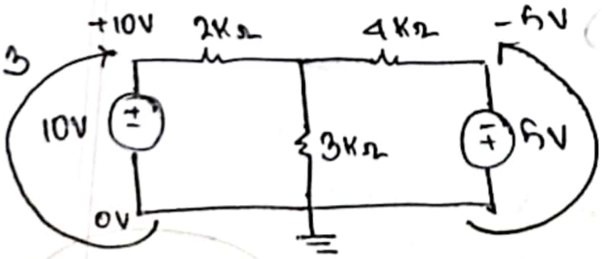


We have to design the circuit in such a way that the number of floating sources is minimized

Alternate representation



Ex - 3

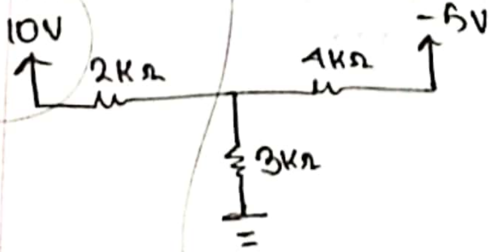


$V = V_+ - V_-$

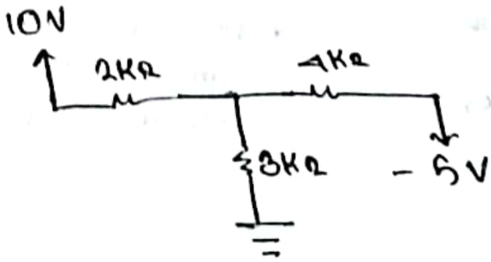
$5 = 0 - V_-$

$\therefore V_- = -5V$

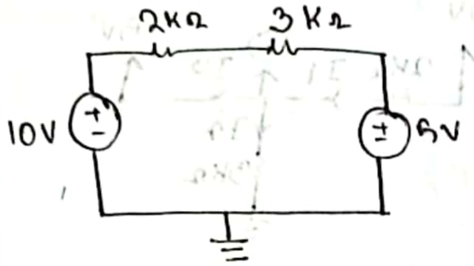
Alternate representation



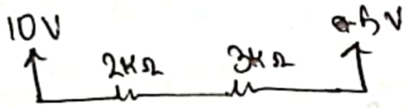
OR



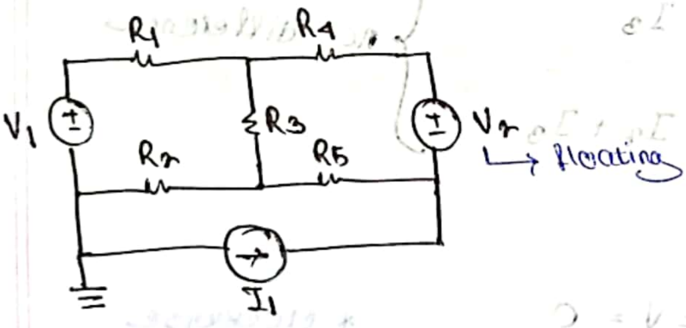
Ex - 4



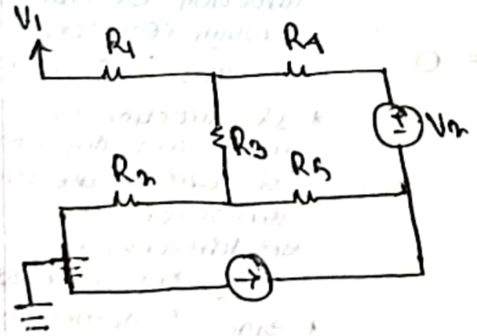
Alternate representation



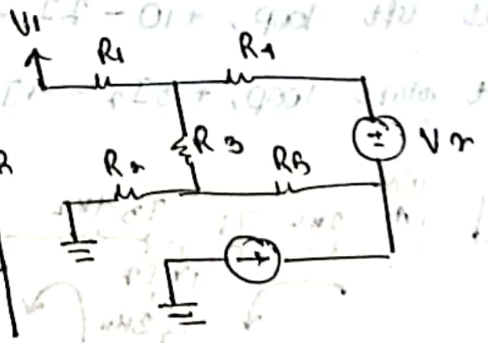
Ex - 5

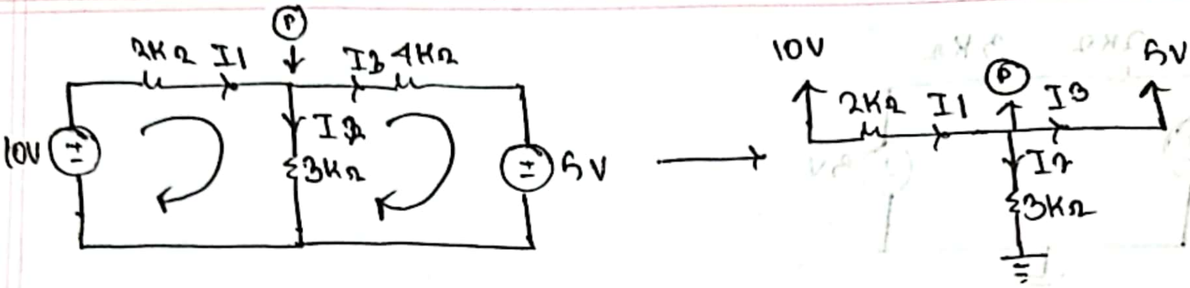


Alternate representation



OR





* KCL : at a node, $\Sigma I = 0$

~~Icominutng~~

$I_{incoming} = I_{outgoing}$

$\boxed{\text{Loop}}$ at p node, $I_1 = I_2 + I_3$

$\boxed{\text{Alternative}}$ at p node, $I_1 = I_2 + I_3$.

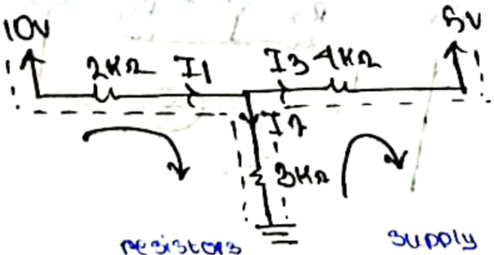
no difference

* KVL : at a closed loop, $\Sigma V = 0$

$\boxed{\text{loop}}$ at left loop, $+10 - 2I_1 - 3I_2 = 0$

at right loop, $+3I_2 - 4I_3 - 5 = 0$

$\boxed{\text{alternate}}$



at ~~the~~ left line, $\underbrace{-2I_1 - 3I_2}_{\text{resistors}} = \underbrace{V_{end} - V_{start}}_{\text{supply}} = 0 - 10$

OR

$2I_1 + 3I_2 = V_{start} - V_{end} = 10 - 0$

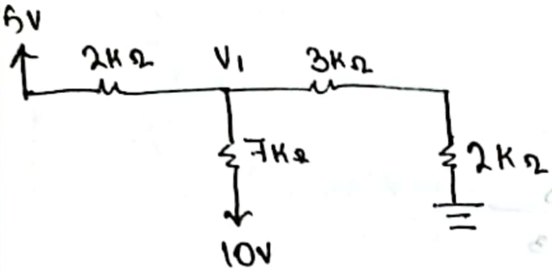
at right line, $3I_2 - 4I_3 = V_{end} - V_{start} = 5 - 0$

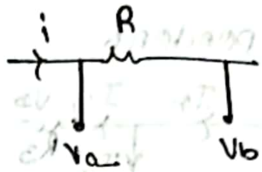
OR

$-3I_2 + 4I_3 = V_{start} - V_{end} = 0 - 5$

* clockwise
* direction of ~~arr~~ route is same as the direction of current through resistor, a $\underline{-ve}$ sign is used.
* If direction of route and direction of current ~~are~~ through ~~d~~ resistor are ~~dif~~ different, a $\underline{+ve}$ sign is used
* sign of destination is used for supply

* Nodal





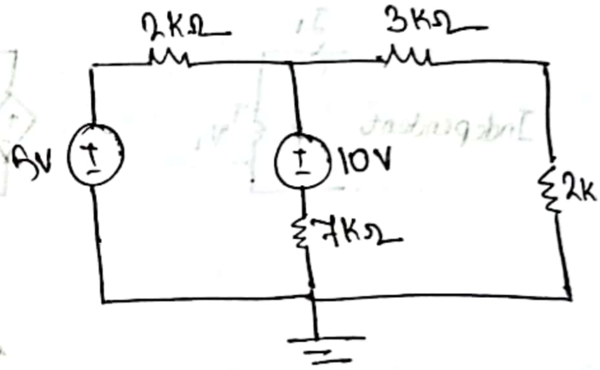
$$i = \frac{V_a - V_b}{R}$$

at V_1 node,

$$\frac{V_1-5}{2} + \frac{V_1-10}{7} + \frac{V_1-0}{3+2} = 0$$

—— OR ——

$$V_1\left(\frac{1}{2}+\frac{1}{7}+\frac{1}{5}\right) - \frac{5}{2} - \frac{10}{7} - \frac{0}{5} = 0$$



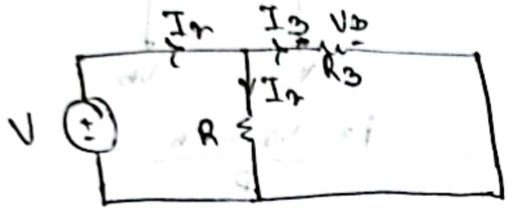
(loop representation)

LECTURE 3

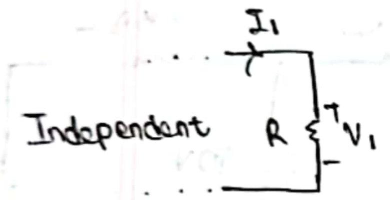
MONDAY DATE: 30/01/23

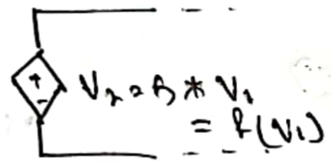
* DEPENDENT & INDEPENDENT SOURCE

* Independent

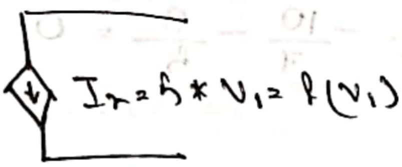


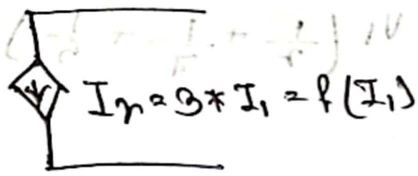
$I_3 = \frac{V_3}{R_3}$



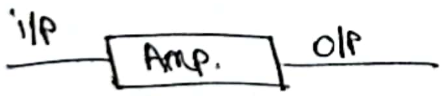


ependent



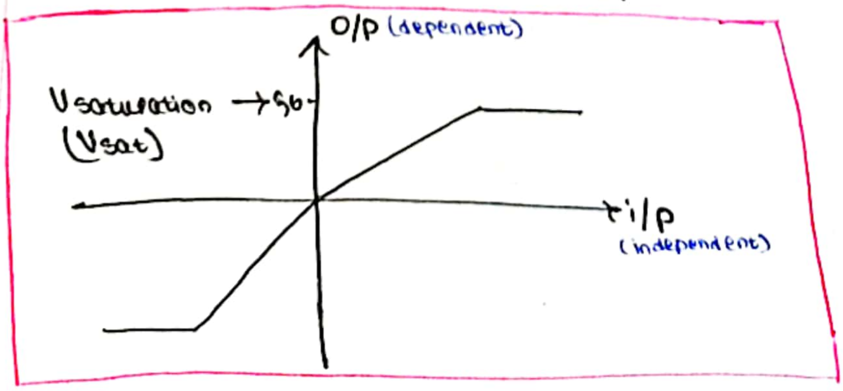


* Amplifier



0.1V ⟶ 1V (10 times amplification)

i/p ⟶ o/p = K * (i/p)

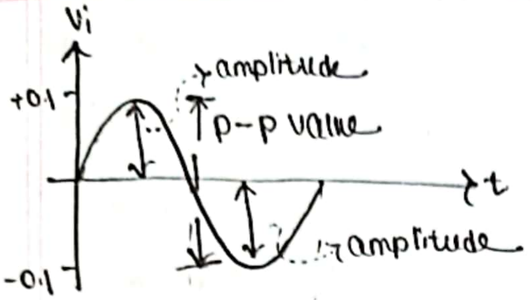


* Transfer characteristics

* Amplifier does not have infinite power supply.

100V ⟶ 10,000V

(~~may~~ may not be possible if the amplifier does not permits due to the limitation)

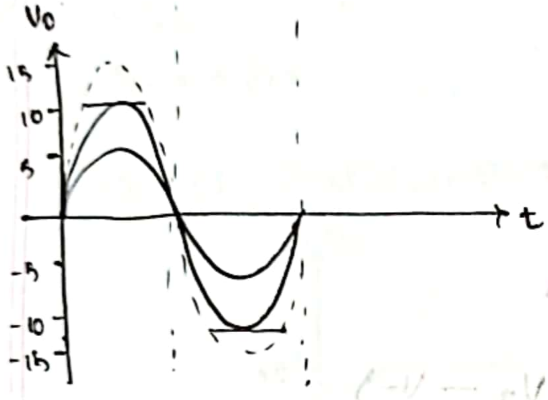


amplitude = 0.1 V

p-p value = 0.2 V

$V_i = 0.1 \underbrace{\sin \omega t}_{max^m = 1}$

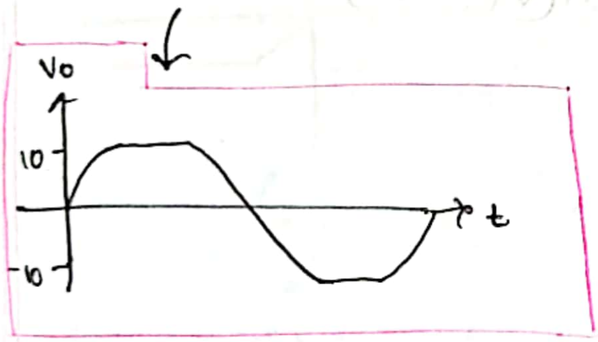
$(V_i)_{max} = 0.1 V$



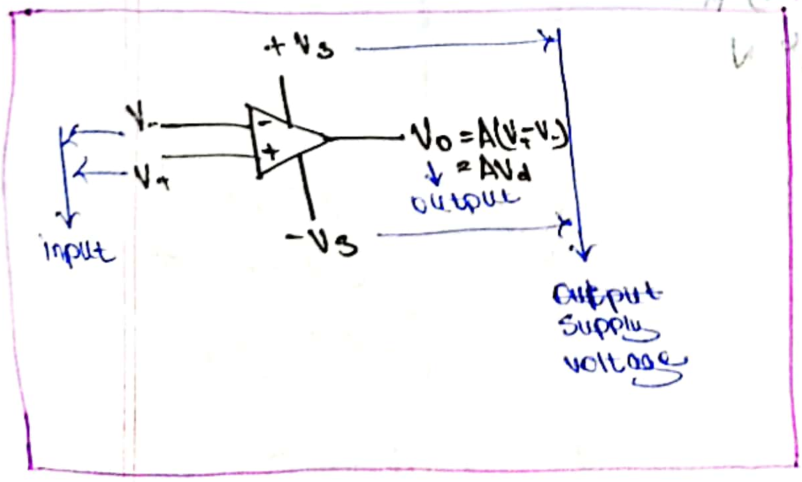
$V_{sat} = 10 V$

↳ amplitude

* when o/p reaches Vsat, for any i/p which gives value > Vsat, the graph will be cut at the Vsat.



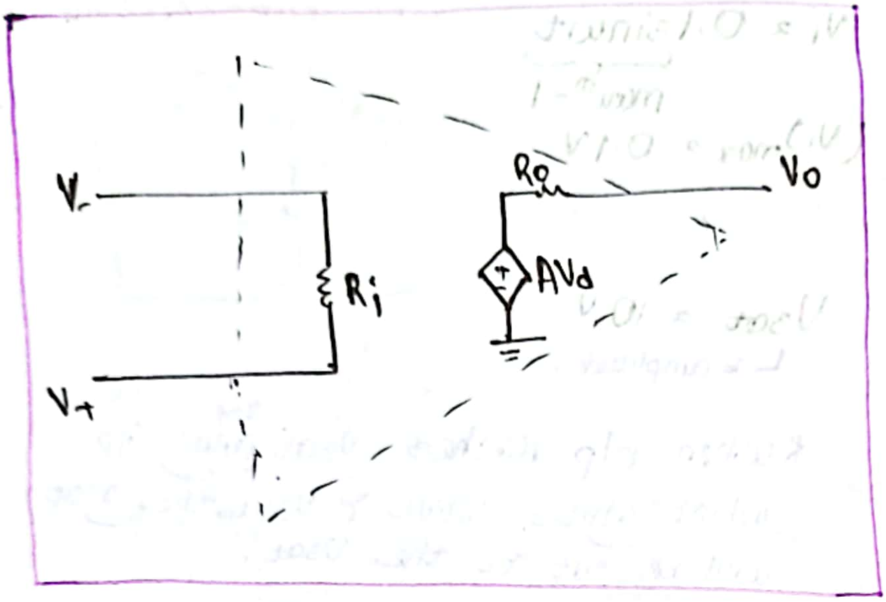
* OPERATIONAL AMPLIFIER : (Op-Amp)



* o/p cannot be greater than Vsat. Vsat is the +Vs and
↳ upper limit

−Vs (supply voltage)
↳ lower limit

equivalent circuit of op-amp:



~~* Characteristics:-~~ $V_0 = AV_d \Rightarrow V_0 = A(V_+ - V_-)$

*ex 1 : $V_+ = 1\mu V$

$V_- = 0.8\mu V$

$A = 2\times10^5$

$V_0 = ?$

sol : $V_0 = A(V_+ - V_-)$

$= 2\times10^5 \times \cancel{0.8}(1-0.8)\mu V$

$= 2\times10^5 \times 0.2\times10^{-6}\ V$

$= 0.1\ V$

*ex 2 : $V_+ = 1mV$

$V_- = 0.2mV$

$A = 2\times10^5$

$V_0 = ?$

$V_0 = A(V_+ - V_-)$

$= 2\times10^5(1-0.2)$

$= 2\times10^5\times0.8\times10^{-3}$

$= 160V$

in an op-amp,

$V_{0,max} = +V_S$

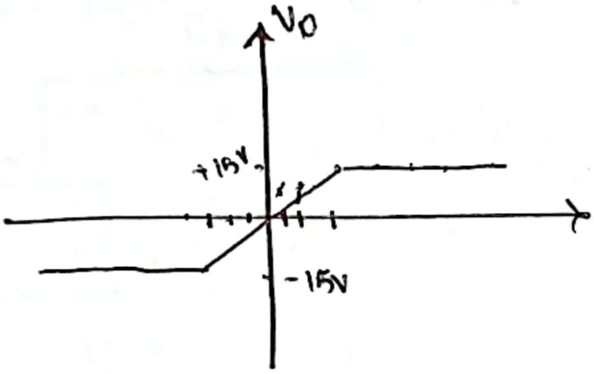
$V_{0,min} = -V_S$

if $+V_S = 15V$,

$-V_S = -15V$

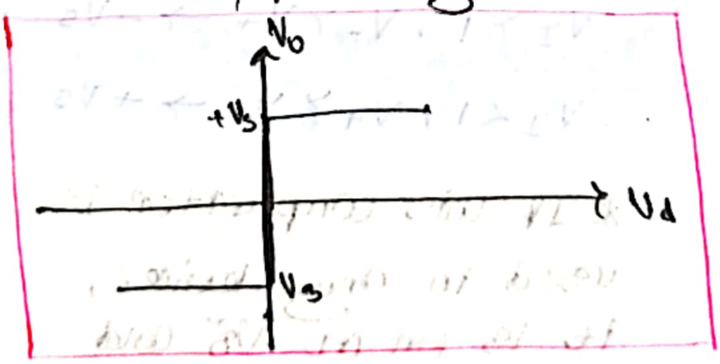
$\therefore V_0 = +15V$

* Transfer characteristics



$V_d = (V_+ - V_-)$

practically



if $V_d > 0$, $V_0 = +V_S$

$\Rightarrow (V_+ - V_-) > 0$

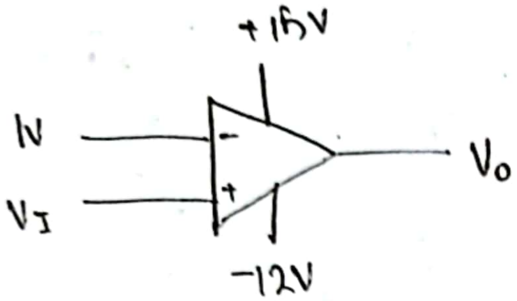
$\therefore \boxed{V_+ > V_-}$

if $V_d < 0$, $V_0 = -V_S$

$\Rightarrow V_+ - V_- < 0$

$\therefore \boxed{V_+ < V_-}$

* Comparator

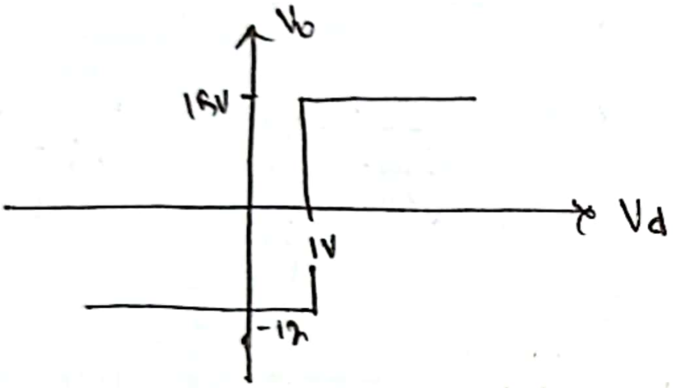


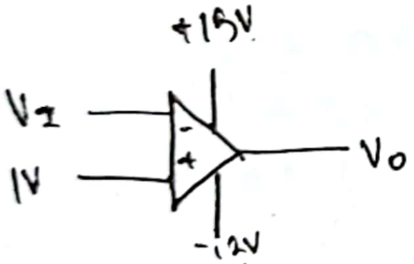
* If this comparator is used in any ~~op~~ device, it is on at V_s^+ and off at V_s^-.
[ON for higher voltage]

$V_- = 1V$, $V_+ = V_I$

$V_I > 1$, $V_+ > V_- \rightarrow +V_s$

$V_I < 1$, $V_+ < V_- \rightarrow -V_s$

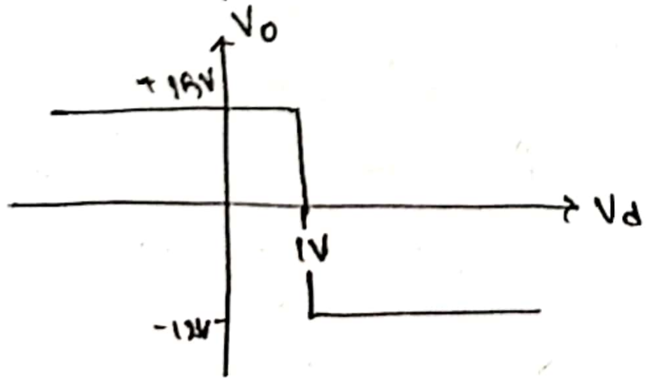




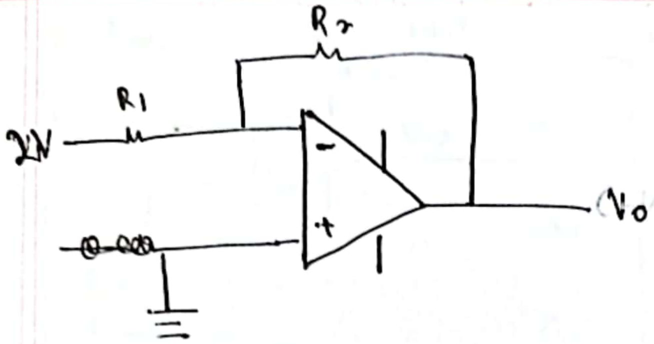
$V_- = V_I$, $V_+ = 1V$

$V_I > 1$, $V_- > V_+ \rightarrow -V_s$

$V_I < 1$; $V_+ > V_- \rightarrow +V_s$



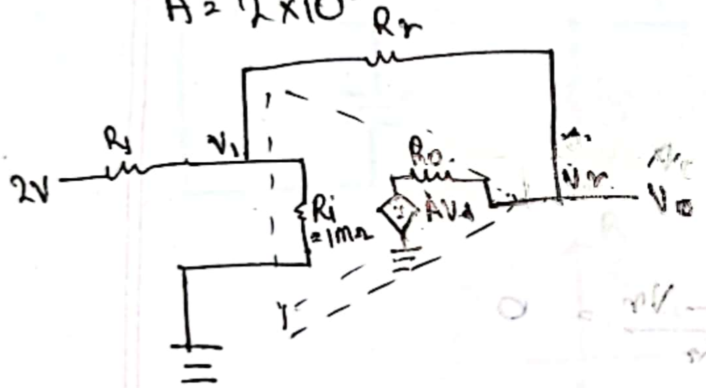
* If this comparator is used in any device, it is on at V_s^- and off at V_s^+.
[ON for lower voltage]



$R_i = 1\,M\Omega$

$R_o = 0.1\,K\Omega$

$A = 2 \times 10^5$



$$\frac{V_1 - 2}{R_1} + \frac{V_1 - V_2}{R_2} + \frac{V_1 - 0}{R_i} = 0$$

$$V_1\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{1\times10^6}\right) - V_2\left(\frac{1}{R_2}\right) = \frac{2}{R_1} \quad \text{—— (1)}$$

$$\frac{V_2 - V_1}{R_2} + \frac{V_2 - AV_d}{R_o} = 0$$

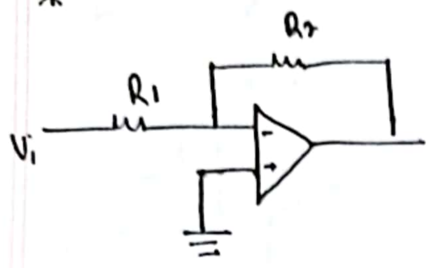
$$-V_1\left(\frac{1}{R_2}\right) + V_2\left(\frac{1}{R_2} - \frac{AV_d}{R_o}\right) = 0 \quad \text{—— (2)}$$

LECTURE 4

WEDNESDAY

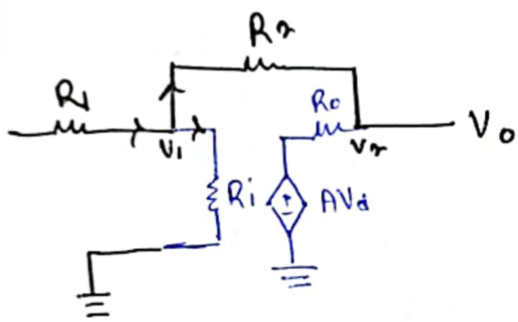
DATE: 01/02/23

*



$V_o = A(V_+ - V_-)$
$= AV_d$

↓

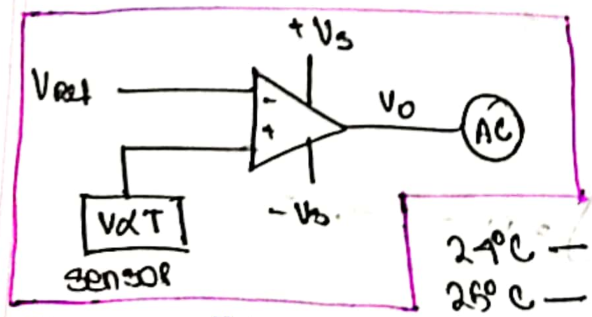


at V_1 node, $\dfrac{V_1 - V_{oi}}{R_1} + \dfrac{V_1 - 0}{R_p} + \dfrac{V_1 - V_2}{R_2} = 0$

at V_2 node, $\dfrac{V_2 - AV_d}{R_o} + \dfrac{V_2 - V_1}{R_2} = 0$

* Application

Automatic AC → Air conditioning



$T\uparrow, V\uparrow$ or $T\downarrow, V\downarrow$

24°C — 2V
25°C — 2.5V
30°C — 3V

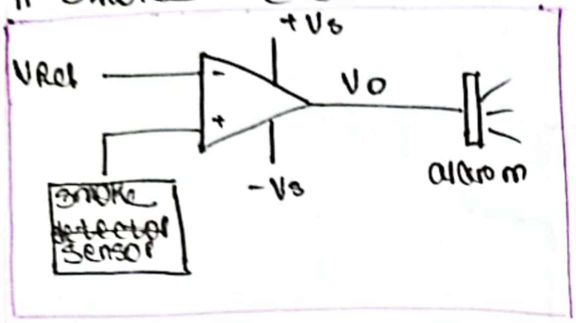
$V_{ref} = 2.5V$

If $V \alpha T$ gives 3V, $\underset{V_+}{3V} > \underset{V_-}{2.5V}$, V_o = +ve, so AC turns on.

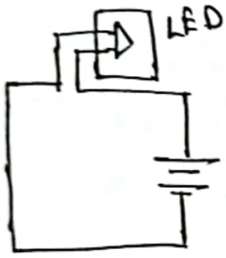
If $V\alpha T$ gives 2V, 3V < 2V, V_o = −ve, so AC turns off.

If $V\alpha T$ gives 2.5V, 2.5V = 2.5V, V_o = 0, so AC turns off.

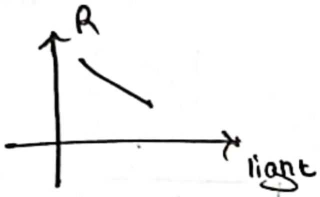
Smoke Detector



smoke sensor:



LDR
(Light - dependant resistor)



Light ↑ , R ↓

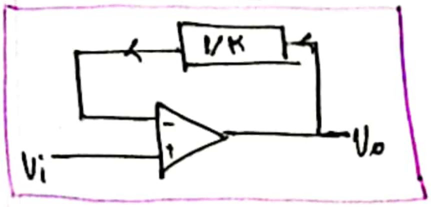
$V \propto R$

no smoke : Rp small , V small → 1V

smoke : Rp large , V large → 3V

$V_{Ref} = 2.9V$

* Introducing feedback : We get a controlled gain (A)



$V_o = A(V_+ - V_-)$

Here, $V_- = \frac{1}{K} V_o$

$V_+ = V_i$

$V_o = A\left(V_i - \frac{1}{K} V_o\right)$

$\Rightarrow V_o = AV_i - \frac{A}{K} V_o$

$\Rightarrow V_o\left(1 + \frac{A}{K}\right) = AV_i$ ~~$\Rightarrow V_o =$~~

$V_o = \frac{AV_i}{1 + \frac{A}{K}}$

$V_o = \frac{V_i}{\frac{1}{A} + \frac{1}{K}}$

A → extremely large

$\frac{1}{A} \to 0$

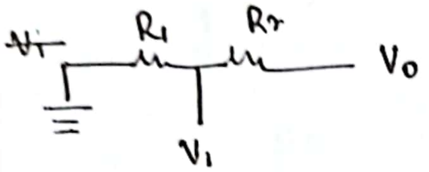
$\therefore V_o = \cancel{V_{in}}\ KV_i$

if $K = 10$, $V_o = 1V$

$V_o = KV_i$

$= 10 * 1$

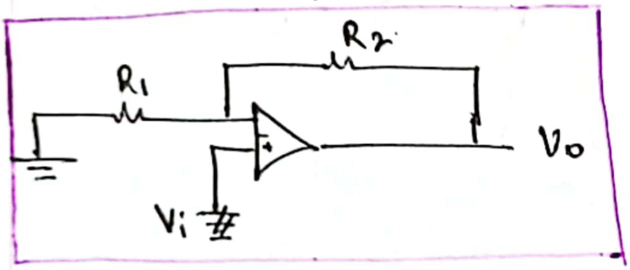
$= 10V$



$$V_1 = \frac{R_1}{R_1 + R_2} \times V_o$$

$\boxed{R_1 = 1\,K\Omega,\ R_2 = 9\,K\Omega}$

$$V_1 = \frac{1}{1+9} V_o = \frac{1}{10} V_o$$



non-inverting amplifier

$$V_- = \frac{R_1}{R_1 + R_2} V_o$$

$V_+ = V_i$

$$V_- = \frac{1}{10} V_o$$

$V_+ = V_i$

$\therefore V_o = KV_i = 10V_i$

$= (1+9)V_i$

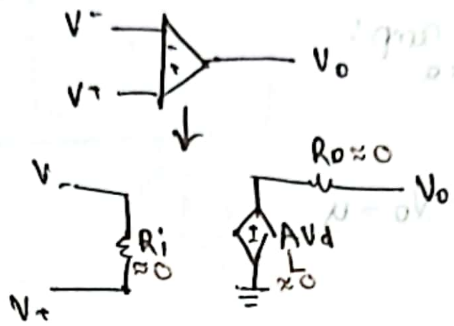
$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_i$$

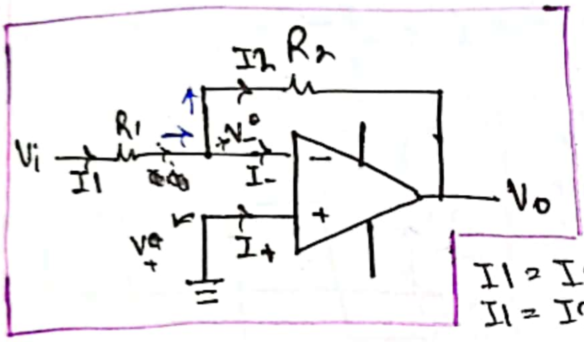
* Characteristics of an ideal op-amp

i) $A \rightarrow \infty$

ii) $R_i \rightarrow \infty$

iii) $R_o \rightarrow 0$





-ive

$\boxed{\text{inverting amplifier}}$

$I1 = I2 + I-$

$I1 = I2 + 0$

Here, $I_- = \frac{V_-}{R} = \frac{\infty}{R} = 0$

$I_+ = \frac{V_+}{R} = \frac{0}{R} = 0$

$A(V_+ - V_-) = V_o$

$\Rightarrow V_+ - V_- = \frac{V_o}{A} = \frac{V_o}{\infty}$

$= 0$

$\Rightarrow \boxed{V_+ = V_-}$ → Because there is a feedback.

[Virtual short circuit]

Here, $V_+ = V_-$

$V_+ = 0V = V_-$

[Virtual ground]

$I1 = I2$ → no current flow through –

$\frac{V_i - \cancel{V_-}^{0}}{R_1} = \frac{\cancel{V_-}^{0} - V_o}{R_2}$

$\therefore V_o = \frac{-R_2}{R_1} V_i$

For non-inverting amplifier,

Here, $V_+ = V_-$

$V_+ = V_i = V_-$

$I_1 = I_2$

$\frac{0 - V_-}{R_1} = \frac{V_- - V_o}{R_2}$

$\frac{0 - V_i}{R_1} = \frac{V_i - V_o}{R_2}$

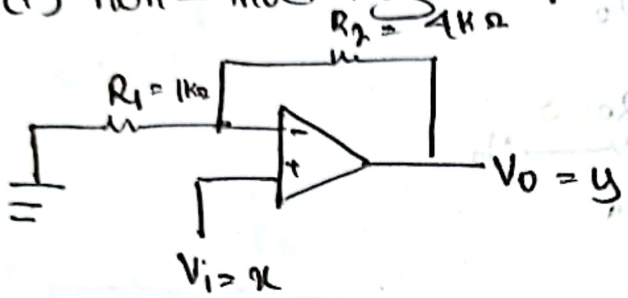
$\frac{V_o}{R_2} = \frac{V_i}{R_1} + \frac{V_i}{R_2}$

$V_o = R_2 \left[\frac{1}{R_1} + \frac{1}{R_2}\right] V_i$

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

* Ex: $y = 5x$

(1) non-inverting amp:



Here, $y = 5x$

$= (1+4)x$

$\frac{R_2}{R_1} = 4$

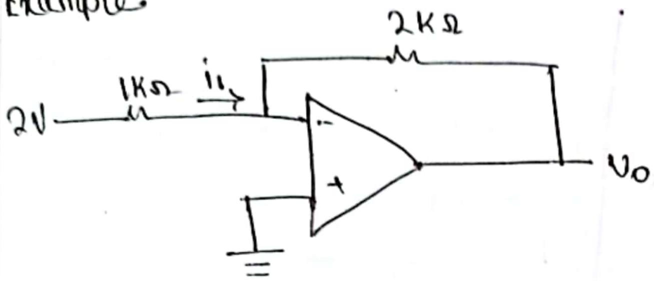
if $R_1 = 1K\Omega$, $R_2 = 4K\Omega$

~~(2) inverting~~

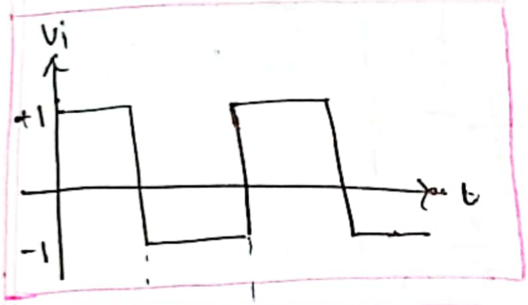
LECTURE 8

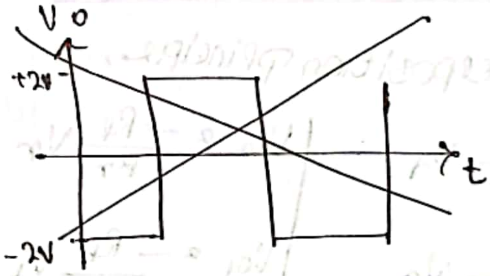
MONDAY DATE: 06/02/23

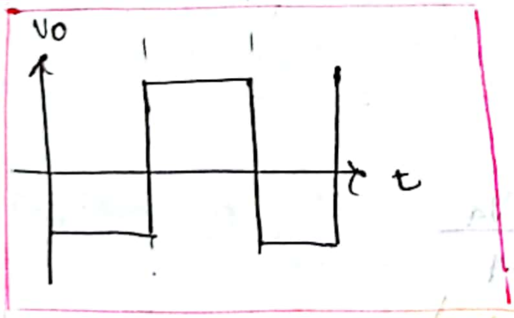
Example



$$V_o = -\frac{R_2}{R_1} V_i = \frac{-2}{1} \times 2 = -4V$$







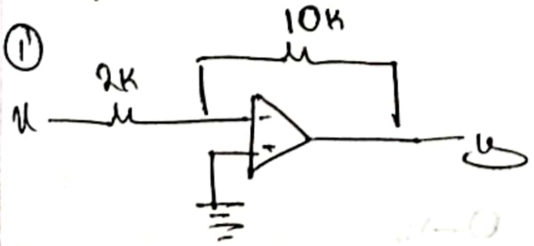
$$V_o = -\left(\frac{2}{1}\right) V_i$$

$$= -2V_i$$

if $V_i = +1V$, $V_o = -2V$

if $V_i = -1V$, $V_o = +2V$

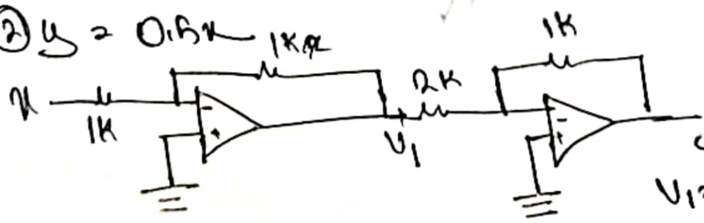
Example

① 

$$y = -\frac{10}{2} x$$

$$y = -5x$$

② $y = 0.5x$

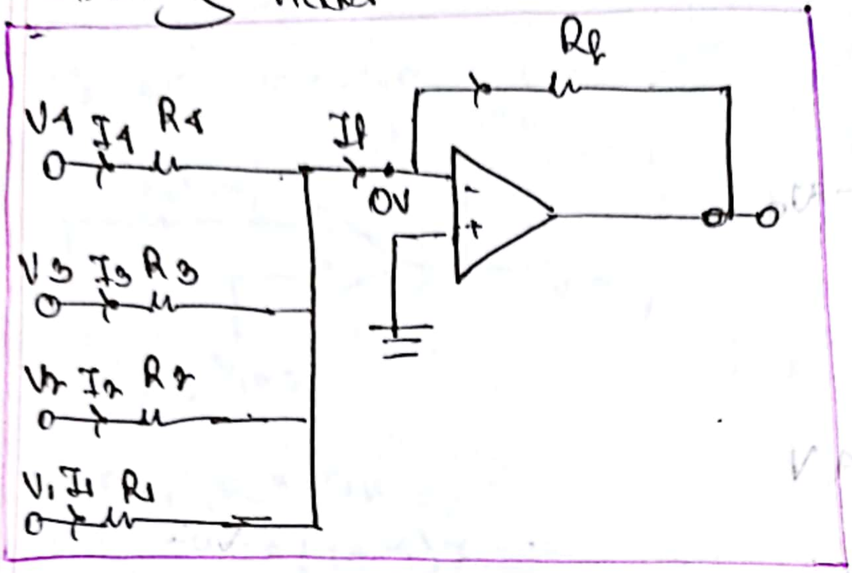


$$y = \left(-\frac{1}{2}\right)(-2) = 0.5x$$

$$V_1 = -\frac{R_2}{R_1} V_i \Rightarrow \left(-\frac{1}{1}\right)(x) = -x$$

$$y = -\frac{R_2}{R_1} V_1 \Rightarrow \left(-\frac{1}{2}\right)(-x) = 0.5x$$

Inverting Adder



Using superposition principle,

$$V_{04} = -\frac{R_f}{R_4} V_4 \qquad V_{02} = -\frac{R_f}{R_2} V_2$$

$$V_{03} = -\frac{R_f}{R_3} V_3 \qquad V_{01} = -\frac{R_f}{R_1} V_1$$

$$V_0 = V_{01} + V_{02} + V_{03} + V_{04}$$

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

$$V_0 = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3 + \frac{R_f}{R_4} V_4\right)$$

OR,

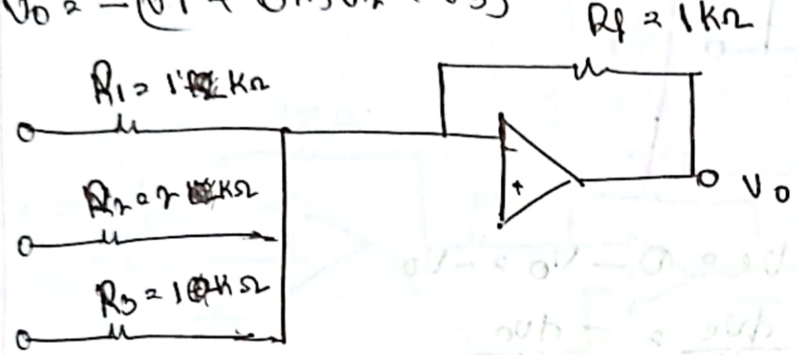
$$I_1 + I_2 + I_3 + I_4 = I_f$$

$$\frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} + \frac{V_3 - 0}{R_3} + \frac{V_4 - 0}{R_4} = \frac{0 - V_0}{R_f}$$

Example

Implement the following function using op-amps:

$V_0 = -(V_1 + 0.5V_2 + V_3)$

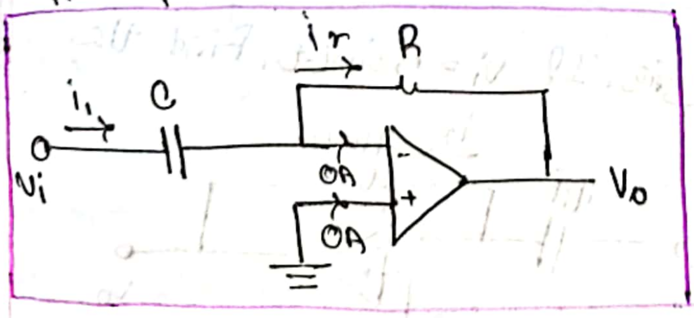


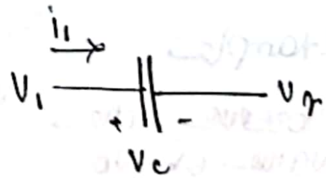
$V_{03} = -\frac{R_f}{R_3} V_3 \Rightarrow -\frac{1}{1} V_3$

$V_{02} = -\frac{R_f}{R_2} V_2 \Rightarrow -\frac{1}{2} V_2$

$V_{01} = -\frac{R_f}{R_1} V_1 \Rightarrow -\frac{1}{1} V_1$

Op Amp as Differentiator





$V_c = V_1 - V_2$

$i_1 = C\frac{dV_c}{dt} = C\frac{d(V_1 - V_2)}{dt}$

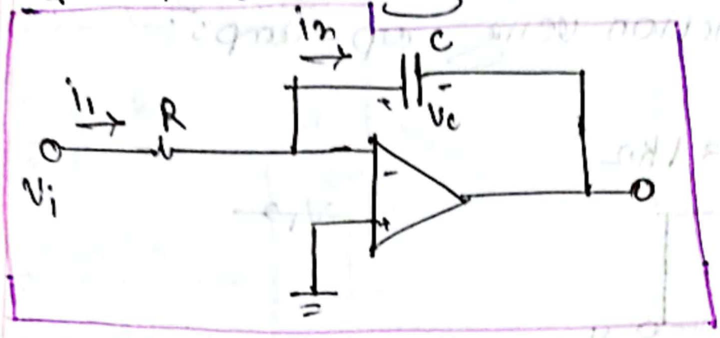
$i_1 = i_2$

$\Rightarrow C\frac{dV_c}{dt} = \frac{0 - V_0}{R}, \quad V_c = V_i - 0$

$\Rightarrow C\frac{dV_i}{dt} = \frac{-V_0}{R}$

$\Rightarrow V_0 = -RC\frac{dV_i}{dt}$

Op Amp as Integrator



$$\Rightarrow \frac{V_i - 0}{R} = C\frac{dv_c}{dt}, \quad V_c = 0 - V_0 = -V_0$$

$$\Rightarrow \frac{dv_c}{dt} = -\frac{dv_0}{dt}$$

$$\Rightarrow \frac{V_i}{R} = -C\frac{dv_0}{dt}$$

$$\Rightarrow \frac{dv_0}{dt} = \frac{-V_i}{RC}$$

$$\Rightarrow V_0 = \frac{-1}{RC}\int V_i \, dt$$

Example

Observe the following figure. If $V_i = 5\sin 6t$, Find the value of V_0

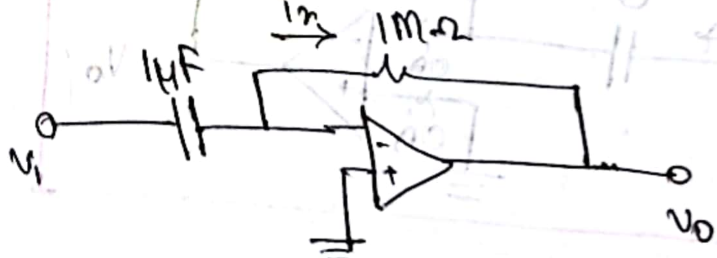
Differentiator :-

$V_0 = -(10^6 \times 10^{-6}) \frac{d}{dt}(5\sin 6t)$

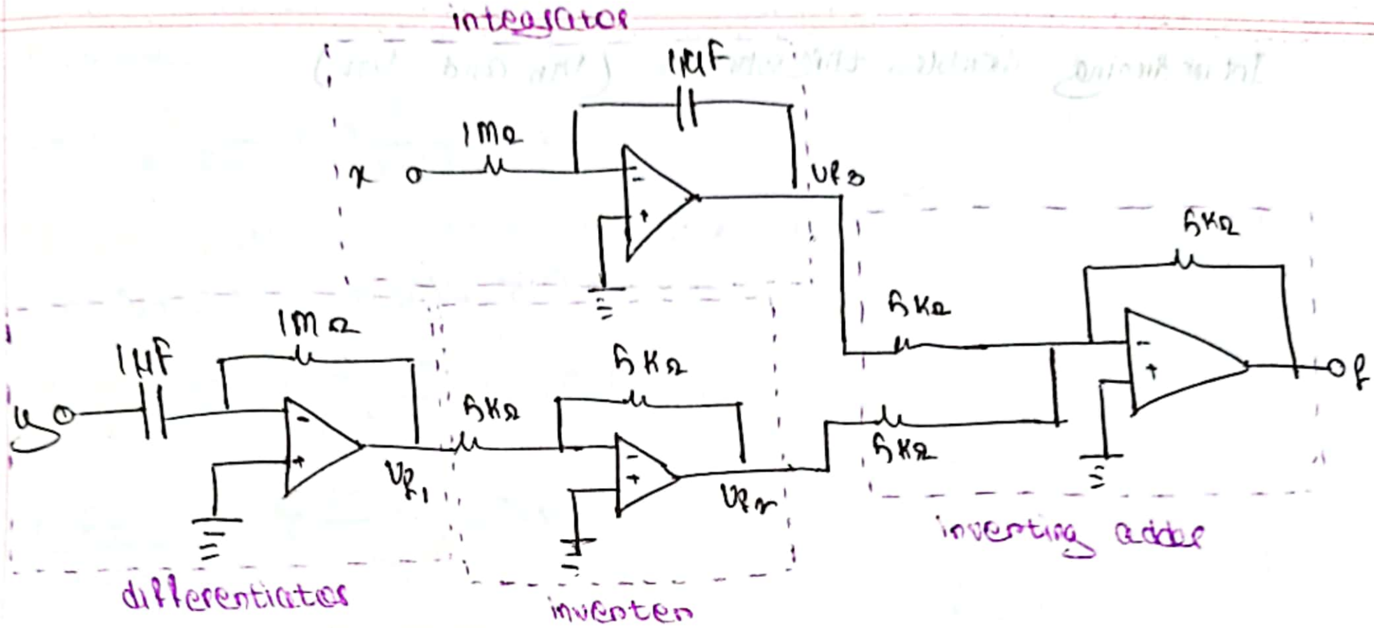
$V_0 = -(1)\frac{d}{dt}(5\sin 6t)$

$= -5(6)\cos 6t$

$\therefore V_0 = (-30\cos 6t)\,V$



$$V_0 = -RC\frac{dV_c}{dt}$$



Differentiator: $V_{f1} = -(10^{-3}\times 10^{6})\frac{d}{dt}(y)$

$V_{f1} = -\frac{d}{dt}(y)$

Integrator: $V_{f3} = \cancel{(+10^{-})} \frac{-1}{10^{6}\times 10^{-6}}\int x \frac{d}{dt}\, dt$

$V_{f3} = -\int x' \frac{d}{dt}\, dt$

$\cancel{V_{f3} = (5\times10^{3}\times 5\times 10^{3}}$

Inverting Amplifier: $V_{f2} = \left(\frac{-5\times 10^{3}}{5\times 10^{3}}\right) V_{f1}$

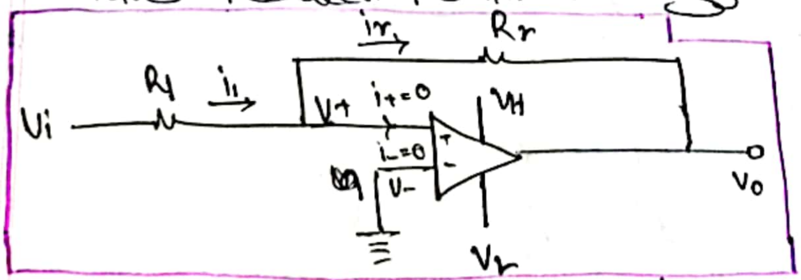
$V_{f2} = -V_{f1} = -\frac{dy}{dt}$

Inverting Adder: $f = -\left(\frac{5\times10^{3}}{5\times10^{3}}V_{f3} + \frac{5\times10^{3}}{5\times10^{3}}V_{f2}\right)$

$f = -\left(-\int x \frac{dt}{dt} + \cancel{-V_{f1})} - \frac{dy}{dt}\right)$

Introducing double thresholds (V_{TH} and V_{TL})

Positive feedback : Schmitt Trigger



* The feedback from Vo goes to ~~0~~ +ve input side — (+) feedback

$i_1 = i_2$

$$\Rightarrow \frac{V_i - V_+}{R_1} = \frac{V_+ - V_0}{R_2}$$

$$\Rightarrow \frac{V_i}{R_1} - \frac{V_+}{R_1} = \frac{V_+}{R_2} - \frac{V_0}{R_2}$$

$$\Rightarrow \frac{V_i}{R_1} + \frac{V_0}{R_2} = V_+\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$$

$$= V_+\left(\frac{R_1+R_2}{R_1R_2}\right)$$

$$V_+ = \frac{R_1R_2}{R_1+R_2}\left[\frac{V_i}{R_1}+\frac{V_0}{R_2}\right]$$

$$= \frac{R_2}{R_1+R_2}V_i + \frac{R_1}{R_1+R_2}V_0$$

Assume initially, $V_o = V_L$

$$V_+ = \frac{R_2}{R_1+R_2}V_i + \frac{R_1}{R_1+R_2}V_L$$

if we want to have $V_o = V_H$,

then $V_+ > V_-$ or $\Rightarrow V_+ > 0V$

$$\Rightarrow \frac{R_2}{R_1+R_2}V_i + \frac{R_1}{R_1+R_2}V_L > 0$$

$$\Rightarrow \frac{R_2}{R_1+R_2}V_i > -\frac{R_1}{R_1+R_2}V_L$$

$$\therefore V_i > -\frac{R_1}{R_2}V_L \rightarrow \text{upper threshold } (V_{TU})$$

if we want to have $V_o = V_L$,

then $\cancel{V_- > V_+}$ $\Rightarrow V_+ < 0V$

Assuming $V_o = V_H$

$$V_+ = \frac{R_2}{R_1+R_2}V_i + \frac{R_1}{R_1+R_2}V_H$$

$$\Rightarrow \frac{R_2}{R_1+R_2}V_i + \frac{R_1}{R_1+R_2}V_H < 0$$

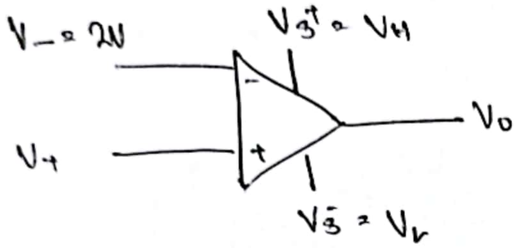
$$\Rightarrow \frac{R_2}{R_1+R_2}V_i < -\frac{R_1}{R_1+R_2}V_H$$

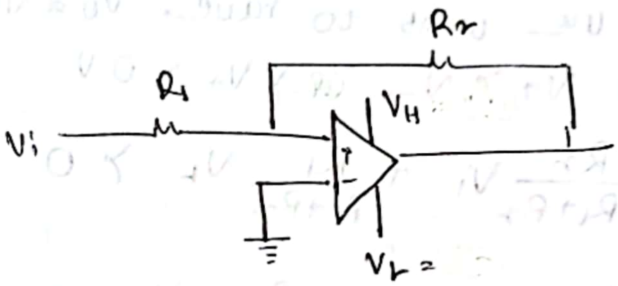
$$\Rightarrow V_i < -\frac{R_1}{R_2}V_H \rightarrow \text{lower threshold } (V_{TL})$$

LECTURE 6

WEDNESDAY DATE: 08/02/23

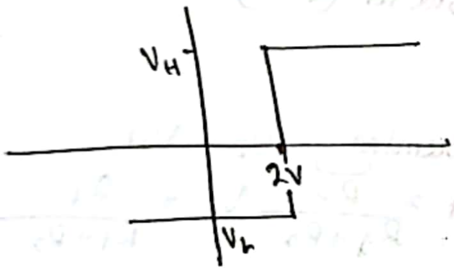
Schmitt Trigger





$V_+ > V_-$, $V_o = V_H$

$V_+ > V_-$, $V_o = V_L$

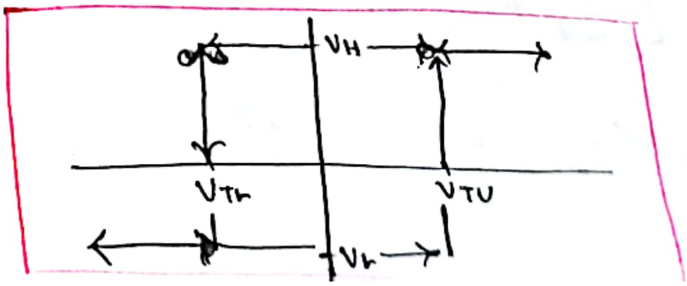


In schmitt trigger, due to introduction of feedback with V^+, we are getting two thresholds.

* If V_{in} is greater than V_{TU} and ~~does~~ is not less than V_{TL}, then V_o will be V_H. When V_{in} crosses V_{TL}, then V_o with be V_L. [For high to low]

~~* If V_{in} is less than V_{TL} and~~

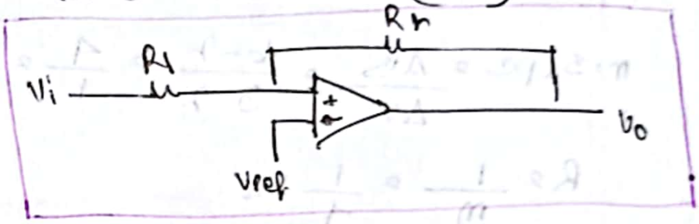
* If Vin is less than V_{TL} and is not greater than V_{TU}, then Vo will be V_L. When Vin crosses V_{TU}, then Vo will be V_H. [For low to high]



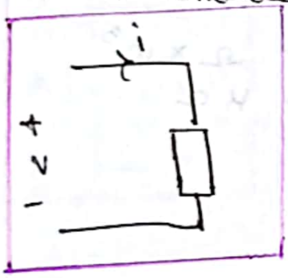
* By changing V_- from 0 to a value, we can tune the threshold voltage

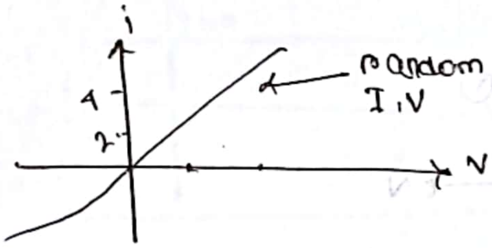
$$V_i > -\frac{R_1}{R_2} V_L + V_{ref}\frac{R_1+R_2}{R_2}$$ ← upper threshold (V_{TU})

$$V_i < -\frac{R_1}{R_2} V_H + V_{ref}\frac{R_1+R_2}{R_2}$$ ← lower threshold (V_{TL})



* I-V Characteristics:



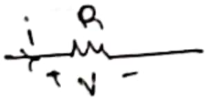


$V = 1V, i = 2mA$

$V = 2V, i = 4mA$

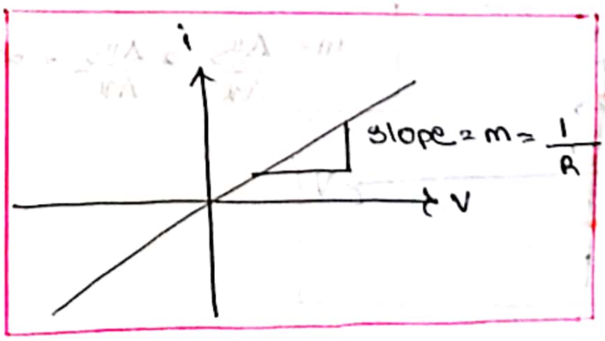
$V = \ldots, i = \ldots$

* Some linear devices is
# Simple linear device
# resistor

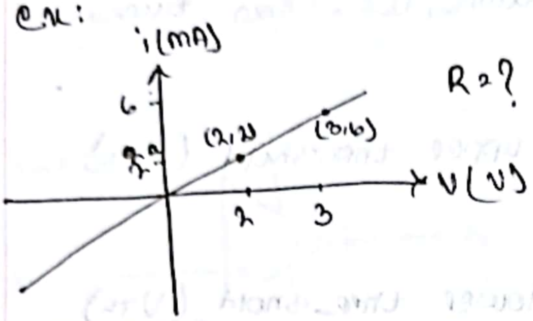


Ohm's law

$$i = \frac{V}{R}$$
$$y = m x$$



ex:

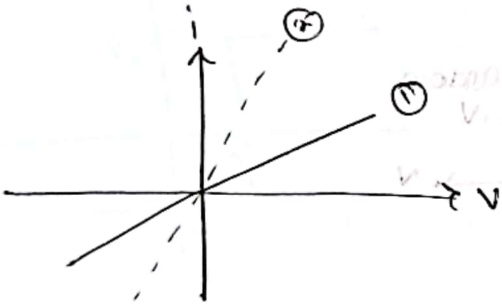


R = ?

$$m = \text{slope} = \frac{\Delta y}{\Delta x} = \frac{6-2}{3-2} = \frac{4}{1} = 4$$

$$R = \frac{1}{m} = \frac{1}{4}\ K\Omega$$

$$R = \frac{V}{I} = \frac{V}{mA} = \frac{V}{A \times 10^{-3}} = \frac{V}{A} \times 10^{3} = \Omega \times 10^{3} = K\Omega$$



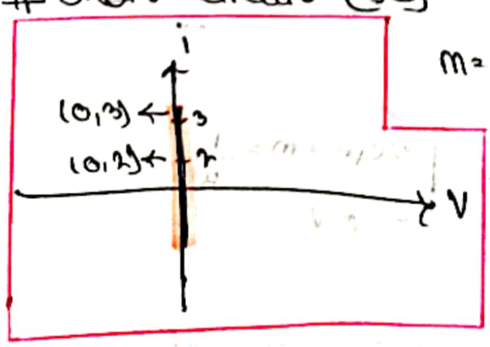
slope of 2 > slope of 1

$m_2 > m_1$

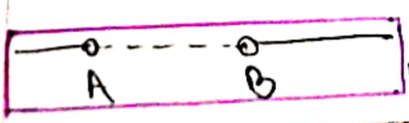
$\Rightarrow \frac{1}{R_2} > \frac{1}{R_1}$

$\Rightarrow R_1 > R_2$

Short circuit (SC)

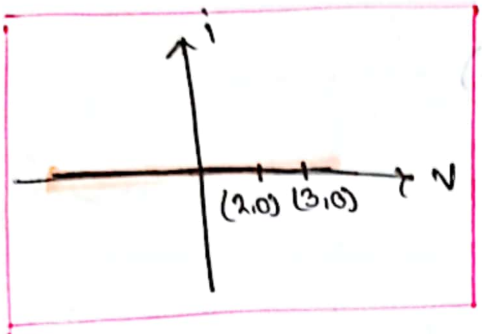


$$m = \frac{\Delta y}{\Delta x} = \frac{\Delta y}{\Delta x} = \infty, \quad R = \frac{1}{m} = \frac{1}{\infty} = 0$$



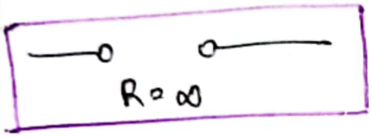
A — B shorted

Open Circuit

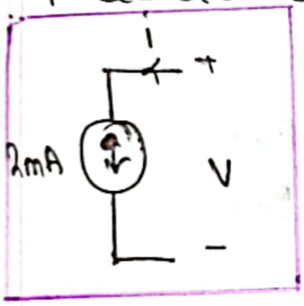


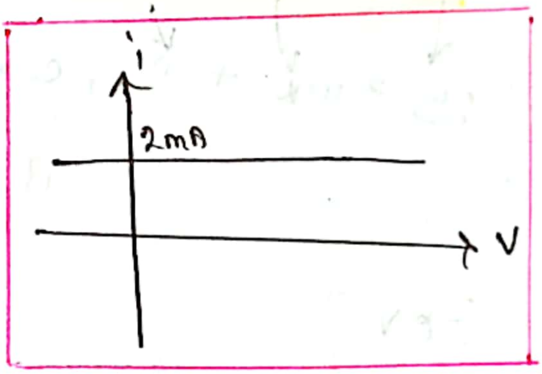
$m = \frac{\Delta y}{\Delta x} = \frac{0-0}{3-2} = 0$

$R = \frac{1}{m} \rightarrow \frac{1}{0} = \infty$

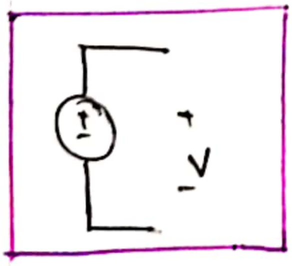


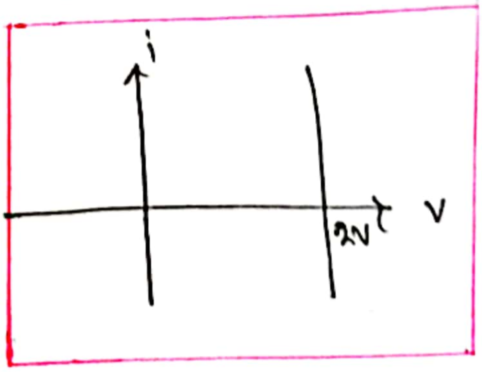
Current source :





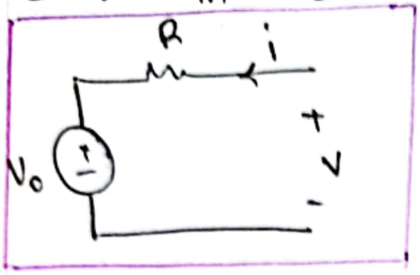
Voltage source





Compound linear device:

(1) V.S in series with a R (V.S. + RS)



$V = iR + V_0$

$i = \frac{V - V_0}{R}$

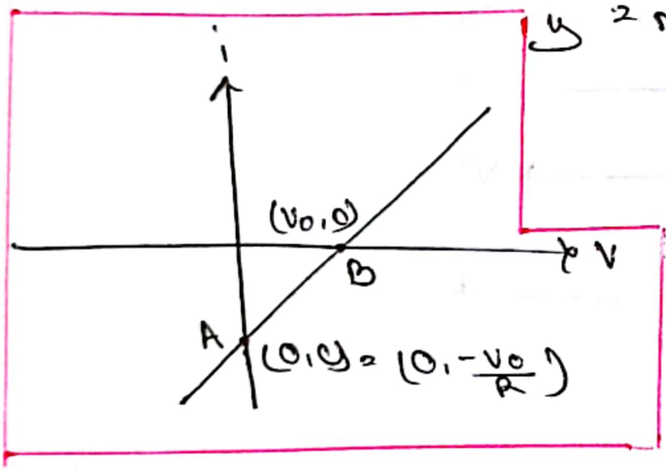
$= \frac{V}{R} - \frac{V_0}{R}$

$i = \frac{V}{R} + \left(\frac{-V_0}{R}\right)$

$y = mx + c$, $c = \frac{-V_0}{R}$

if $V_0 = +ve$,

$c \rightarrow -ve$



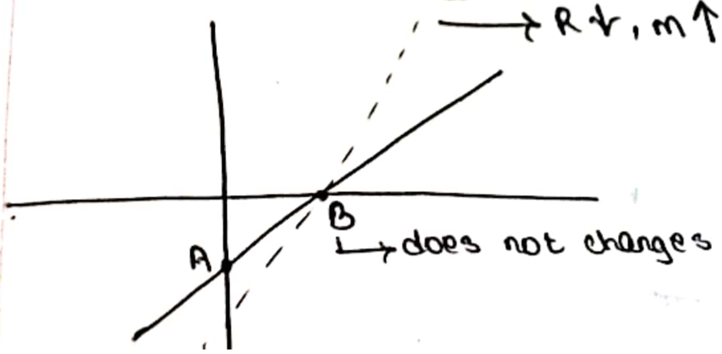
at V, i = 0

$0 = \frac{V}{R} - \frac{V_0}{R}$

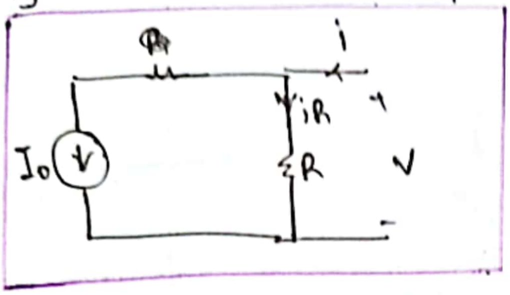
$\Rightarrow V = V_0$

if we change R?

m & c will change.



ii) Current source in parallel to R (I.S + Rp)



applying KCL,

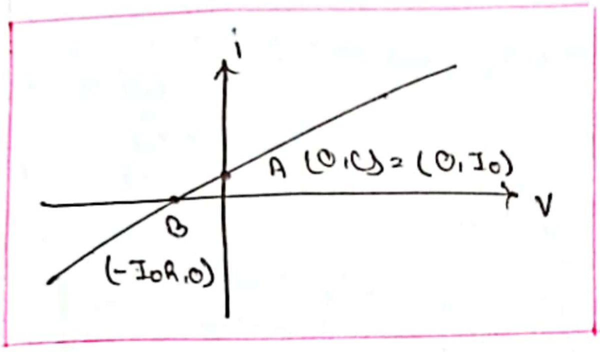
$i = i_R + I_0$

$\Rightarrow \boxed{i = \frac{V}{R} + I_0}$

$y = mx + C$, $C = I_0$

if $I_0 \rightarrow +ve$

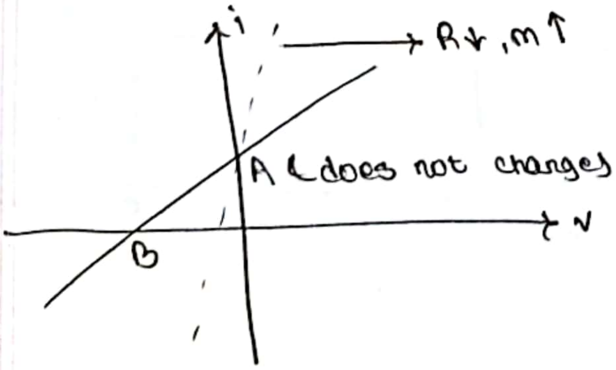
$C \rightarrow +ve$

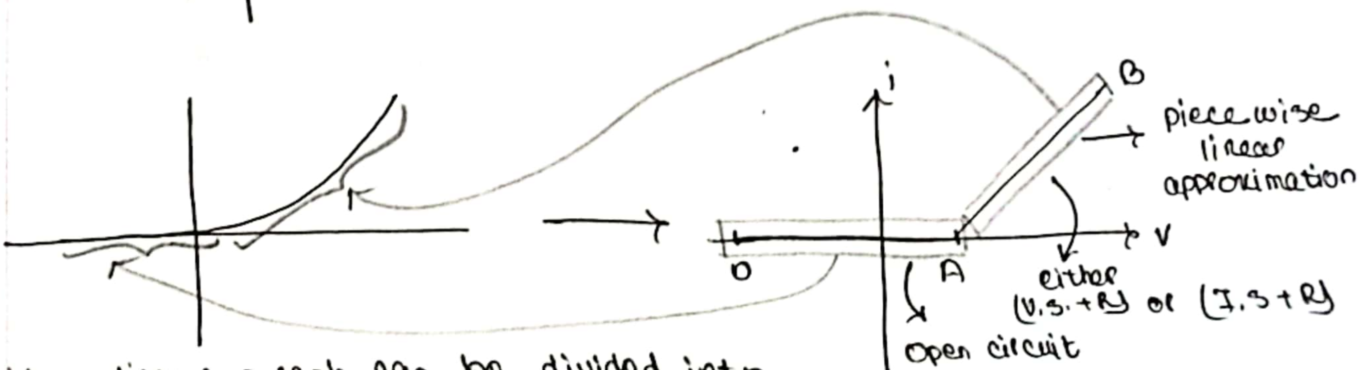


$i = 0, = \frac{V}{R} + I_0$

$\Rightarrow V = -I_0R$

if R changes, A does not change as there is no R. B changes.





Non-linear graph can be divided into linear parts and solved.

A — B = $m = 5, R_1 = \frac{1}{5}$ K-Ω

B — C → $R_2 = \infty$ KΩ

C — D → $R_3 = \frac{2-2}{3-0} = \frac{0}{3} = 0$ KΩ ~~(fixed~~ (voltage source with B: 2V)

D — E → $m = 0.2, R_4 = \frac{1}{0.2} = 5$ KΩ

at DE, $R = \frac{1}{slope} = \frac{1}{0.2} = 5$ KΩ

C.S + Rp = $i = \frac{V}{R} + I_0$

$i = \frac{V}{5} + I_0$

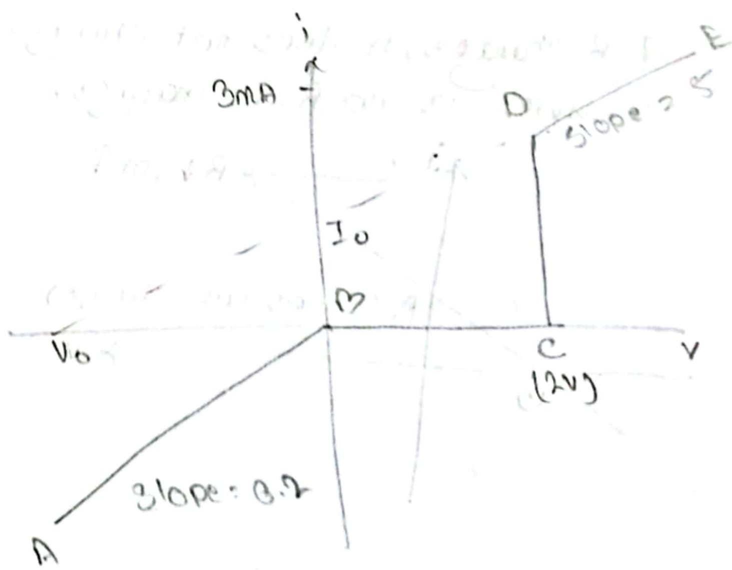
at D (2,3)

$3 = \frac{2}{5} + I_0$

$I_0 = 3 - \frac{2}{5}$

$I_0 = 2.6$ mA

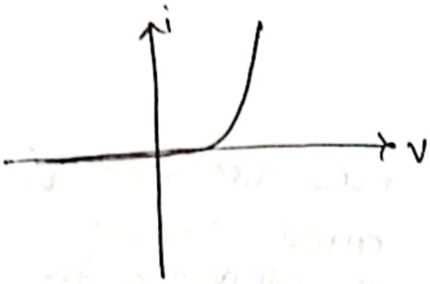
$i = \frac{V}{5} + 2.6$

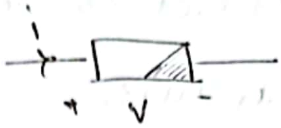


LECTURE 7

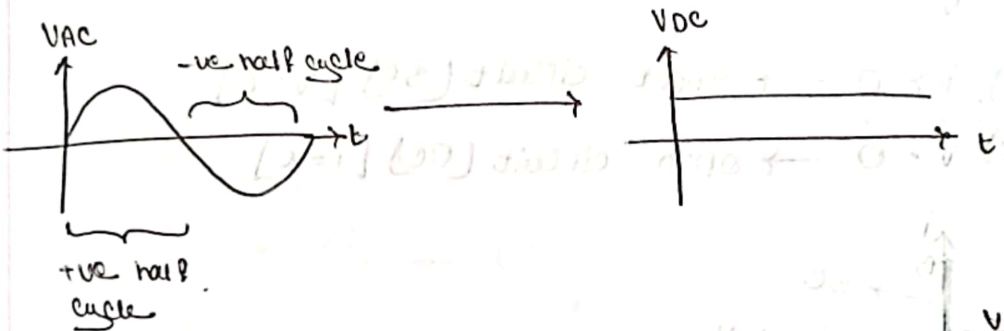
MONDAY DATE: 13/02/23

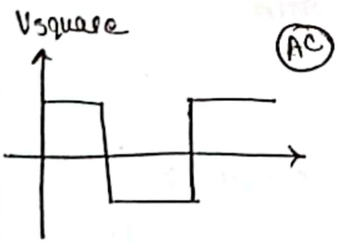
* Non-linear devices:

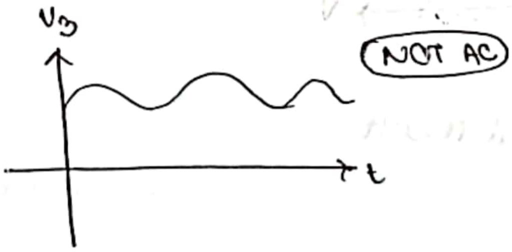


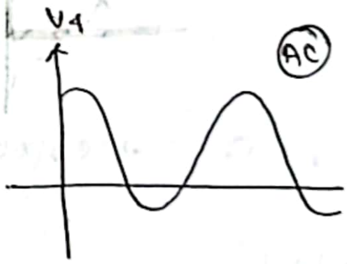


* AC to DC conversion:

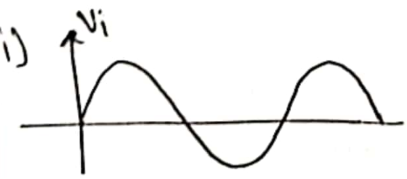








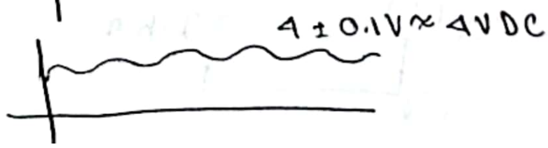
* AC to DC

i) 

Rectification →
only one side appears (+ve|-ve)

ii) Filtering

iii) Regulation

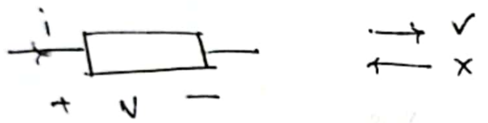


* Rectification & regulations require non-linear device.

* Filtering requires capacitor.

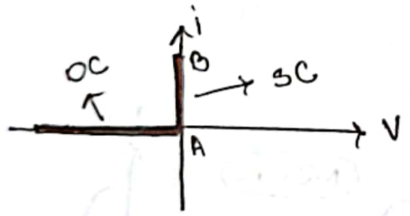
* Rectification allows current flow in +ve direction to get the +ve curve. It does not allow current flow in -ve direction and no -ve curve is produced, in -ve.

* Non-linear device: we want to have a valve.



we want: i) $i > 0 \rightarrow$ short circuit (SC) $[v = 0]$

ii) $v < 0 \rightarrow$ open circuit (OC) $[i = 0]$



expected result

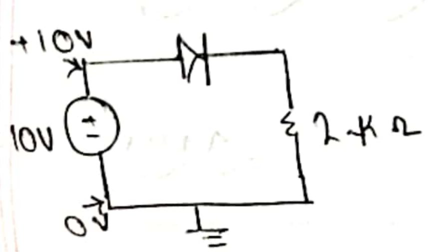
* Diode

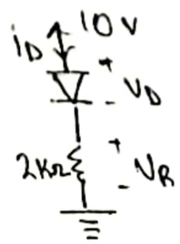
Anode $\xrightarrow{i_D}$ (+ V_D -) Cathode

i) $i_D > 0 \rightarrow$ ON $(V_D = 0)$ [short circuit]

ii) $V_D < 0 \rightarrow$ OFF $(i_D = 0)$ [open circuit].

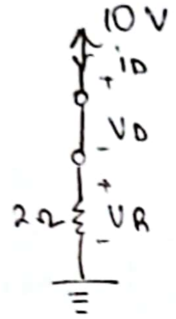
* Diode in DC:





* we have solve twice.
(i) considering diode to be ON, find the variables.
(ii) considering diode to be OFF, find the variables.
(i) or (ii) must have both the assumptions

Let the diode be is ON. → SC



$\therefore V_D = 10\,V$

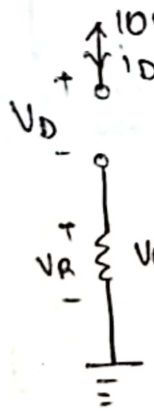
$i_D = \dfrac{10-0}{2} = 5\,mA > 0$ (assumption verified)

$V_R = i_D * R$

$= 5 * 2$

$V_R = 10\,V$

Say, diode is Off → OC



$i_D = 0\,mA$

$V_R = i_D R = 0 * R = 0\,V$

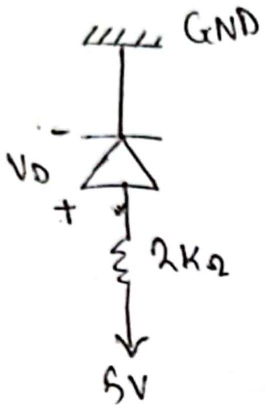
Here, $V_D = V_A - V_C$

$= 10 - 0$

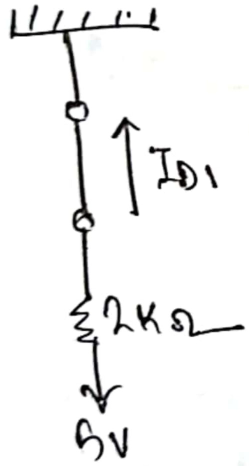
$V_D = 10\,V \not< 0$

(assumption wrong)

(b)



Let the diode be ON → SC



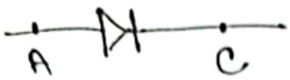
$I_{D1} = \frac{5-0}{2} \Rightarrow I_{D1} = 2.5\,mA > 0\,mA$

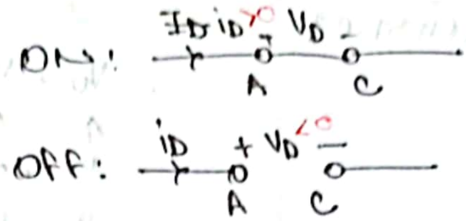
∴ Assumption is correct.

LECTURE 8

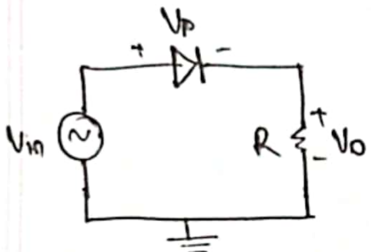
WEDNESDAY DATE: 15/02/23

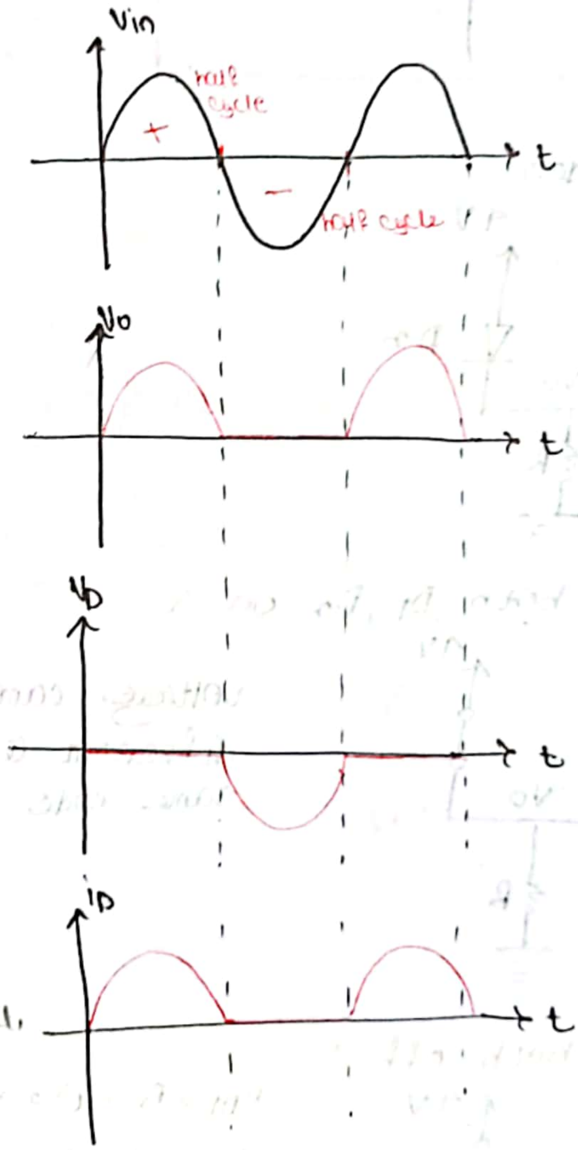
* Ideal diode



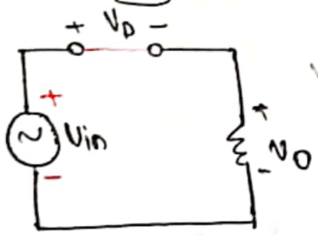


* Application as Half – wave rectifier:





(+) half cycle:



$V_{in} = V_o$

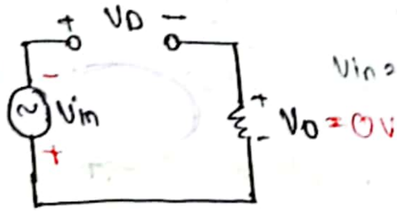
* when +ve part of diode is connected to higher potential, diode is generally ON.

(–) half cycle:

$V_{in} + V_D + V_o = 0$

$V_{in} + V_D + 0 = 0$

$V_D = -V_{in}$

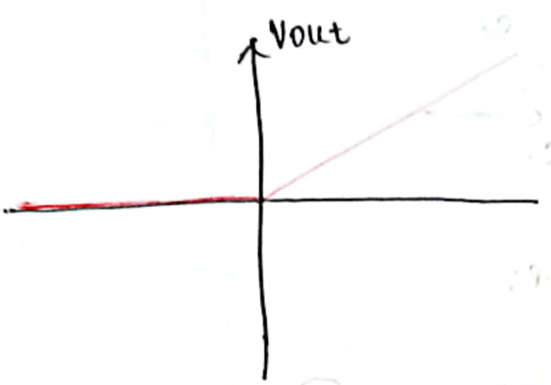


$V_{in} = V_D$

* when +ve part of diode is not connected to higher potential, diode is generally OFF.

$i_D = \frac{V_o}{R}$

* Transfer characteristics: [of ideal diode]



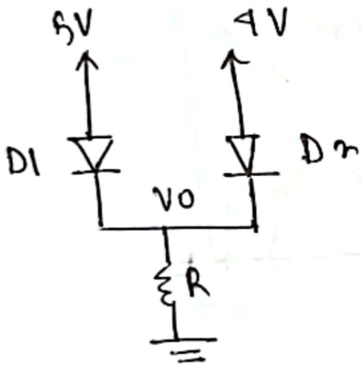
$V_o = V_{in}$

$\uparrow \quad \uparrow$

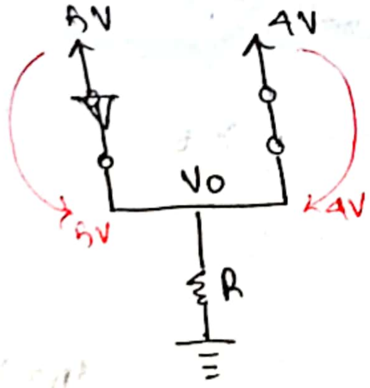
$y = x$

$y = mx \quad [m = 1]$

* 2 diodes

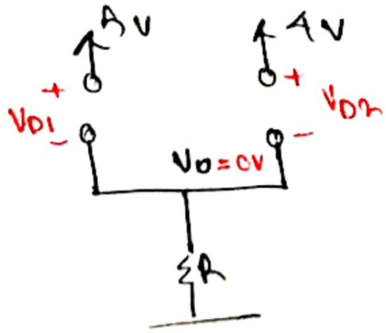


Case 1: both D_1, D_2 on ✗



voltage cannot be different at the same node

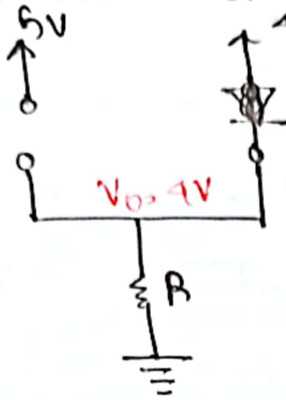
Case 2: both off ✗



$V_{D1} = 5 - 0 = 5V \nless 0$

$V_{D2} = 4 - 0 = 4V \nless 0$

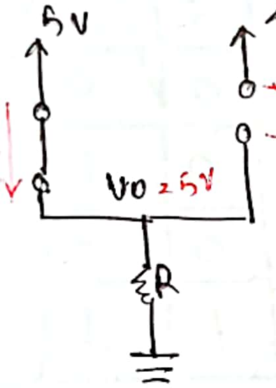
Case 3: D2 ON, D1 OFF ×



$\downarrow i_{D2} = \frac{4-0}{R} > 0$ ✓

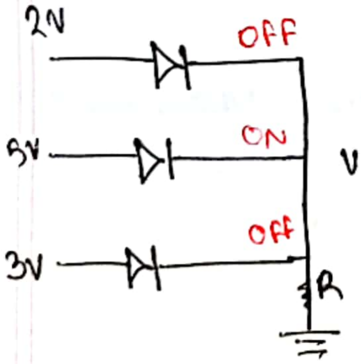
$V_{D1} = 5 - 4 > 0$

Case 4: D1 ON, D2 OFF



✓ $i_D = \frac{5}{R} > 0$

$V_{D2} = 4 - 5 = -1 < 0$ ✓

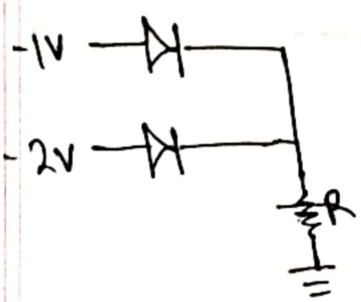


$V_O = 5V$

* The diode connected with ~~a~~ the highest potential is ON and the rest is OFF. (for parallel)

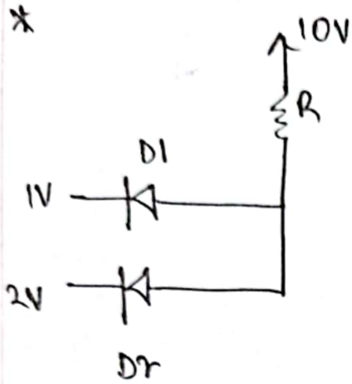
$V_O = MAX(V_1, V_2, V_3, \ldots \ldots V_n)$

* exception



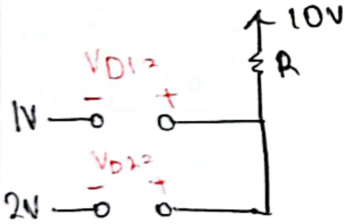
both off

*



Case 1 : Both ON
(same reasons → x)

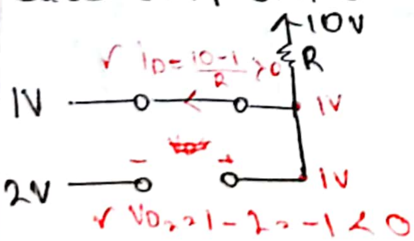
Case 2 : Both Off x



$V_{D1} = 10 - 1 \nless 0$

$V_{D2} = 10 - 2 \nless 0$

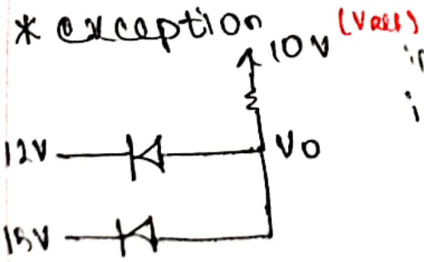
Case 3 : D1 ON, D2 Off



* The diode connected to the lowest potential is ON and the rest is off (for series)

$V_0 = MIN(V_1, V_2, V_3 \ldots\ldots V_n)$

* exception



input > 10V (Vref)
i/p's must be Vref

* Logic gate using ideal diode.

Representing Boolean in circuit

Voltage   5V → 1, 0V → 0

$\boxed{3.3-5V} \to 1$, $\boxed{0-2.7V} \to 0$

AND:

x	y	f
0	0	0
0	1	0
1	0	0
1	1	1

x	y	f
0V	0V	0V
0V	5V	0V
5V	0V	0V
5V	5V	5V

MIN

OR:

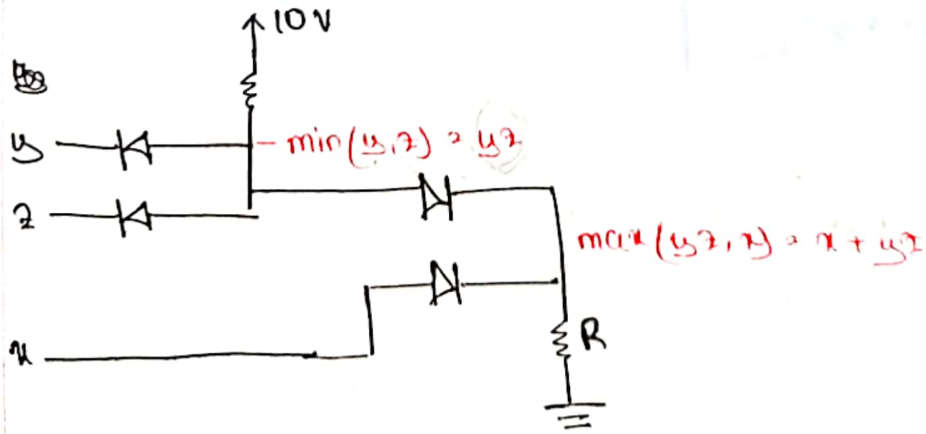
x	y	z
0	0	0
0	1	1
1	0	1
1	1	1

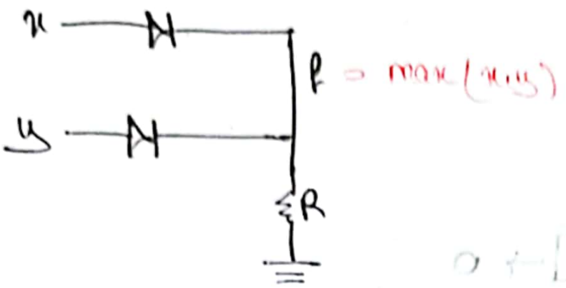
x	y	f
0V	0V	0V
0V	5V	5V
5V	0V	5V
5V	5V	5V

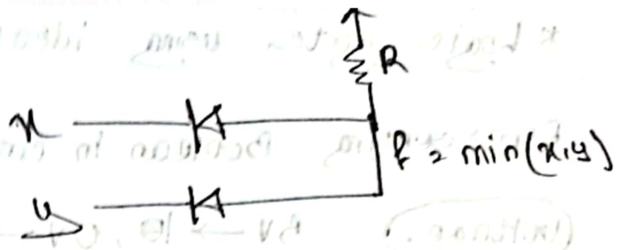
MAX

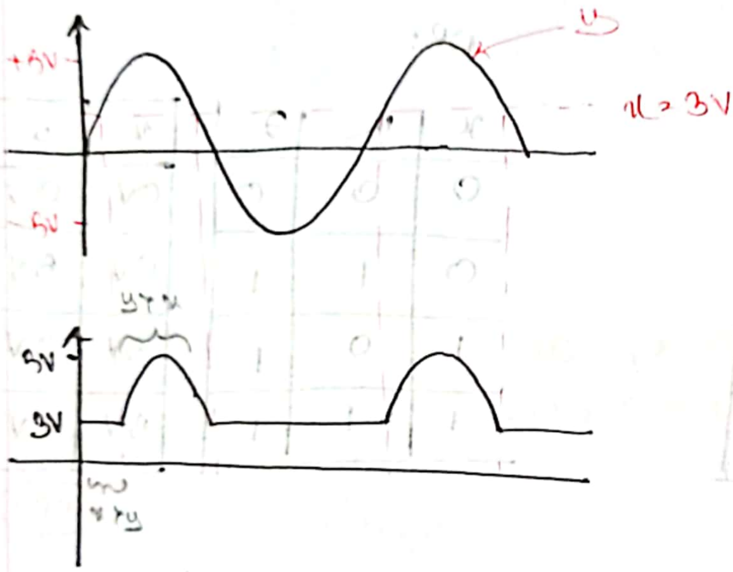
* Implement using ideal diode:

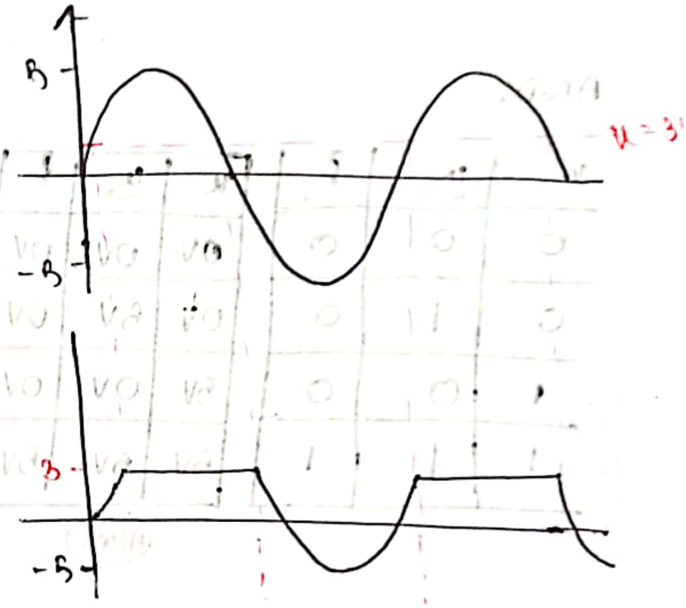
$f = x + yz$




x
y
R
f = max(x,y)


x
y
R
f = min(x,y)


+5V
-5V
y
x = 3V
y > x
5V
3V
x > y

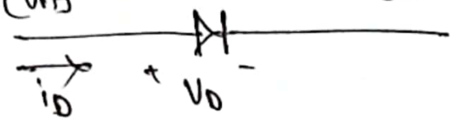

5
-5
x = 3
3
-5

LECTURE 9

MONDAY DATE: 20/02/23

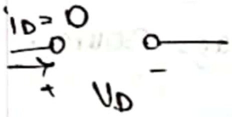
Ideal Diode model

Anode (V_A) Cathode (V_C)



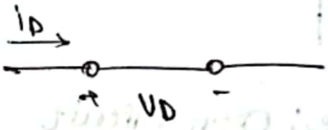
OFF state : Open Circuit

$i_D = 0$

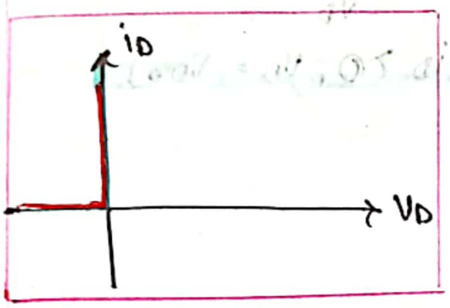


[$V_D < 0$, $i_D = 0$]

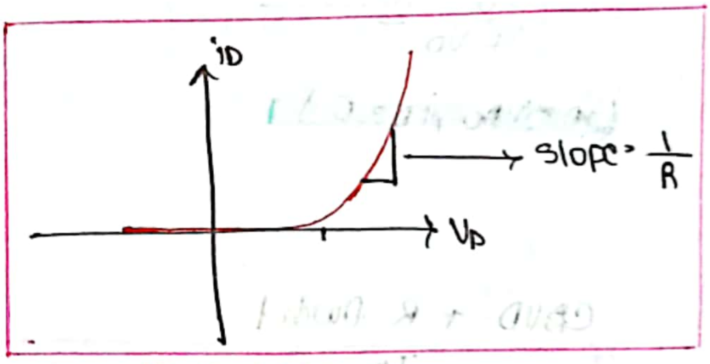
ON state : Short Circuit



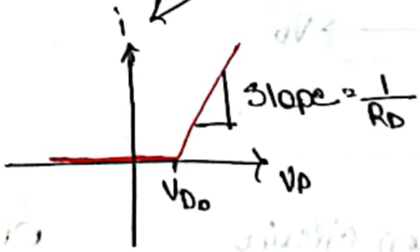
[$i_D > 0$, $V_D = 0$]



ideal diode



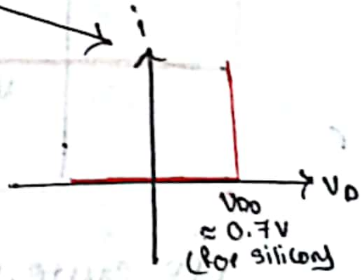
Real diode



if slope ↑↑, R_D ↓↓

~~if slope → ∞, R_D → 0~~

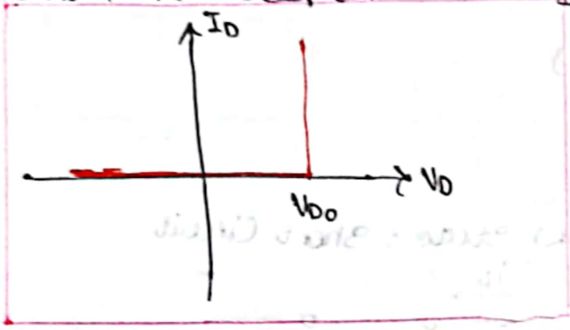
[CVD + R model]



if slope → ∞, R_D → 0

[Constant voltage drop [CVD] model]

~~CVD + R Model~~ Constant voltage drop (CVD) model



OFF state: Open Circuit

$i_D = 0$, V_D

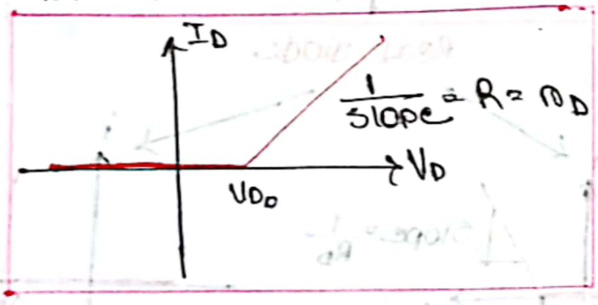
($V_D < V_{D0}, i_D = 0$)

ON state: Voltage source

i_D, V_{D0}, V_D

($i_D > 0$, $V_D = V_{D0}$)

CVD + R model



OFF state: Open circuit

$i_D = 0$, V_D

($V_D < V_{D0}, i_D = 0$)

ON state:

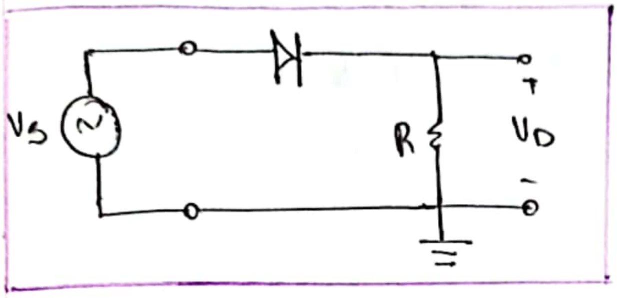
I_D, V_{D0}, r_D, V_D

($V_D = V_{D0} + I_D r_D$, $I_D > 0$) negligible

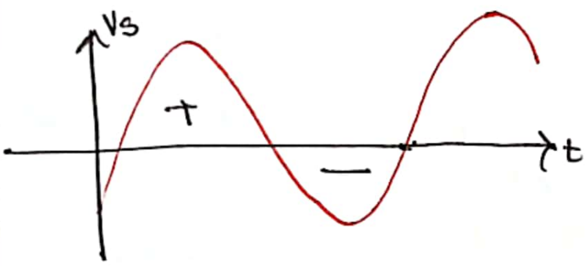
if r_D small, $V_D \approx \boxed{i_D r_D \text{ small}} + V_{D0}$

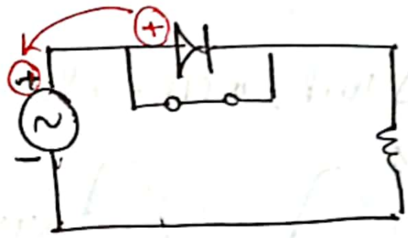
$V_D = V_{D0}$

Half-wave rectifier (ideal diode model)

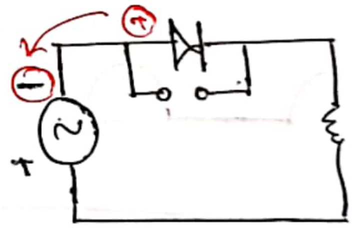


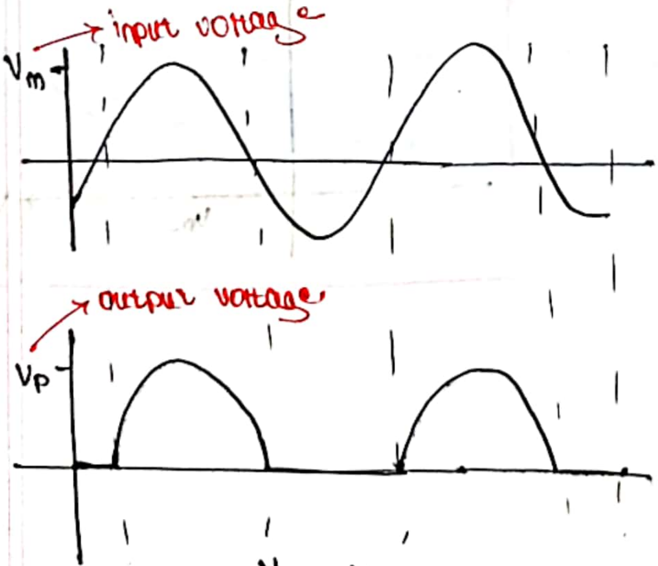
(+) half cycle of Vs





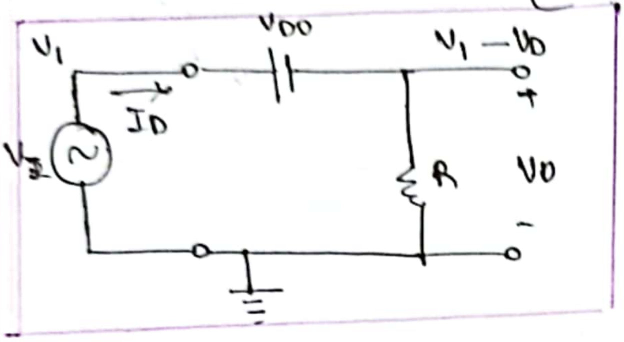
(-) half cycle of Vs



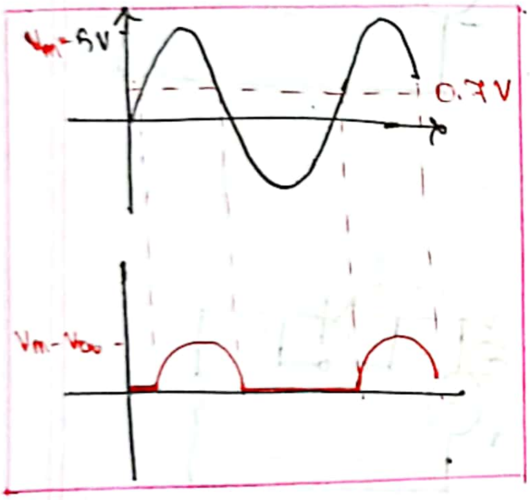


Vp = Vm

Half-wave rectifier (CVD model)

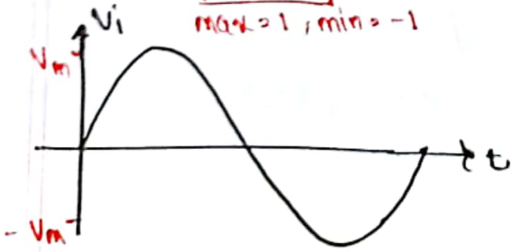


(+) half cycle, $V_0 = V_i - V_{D0}$

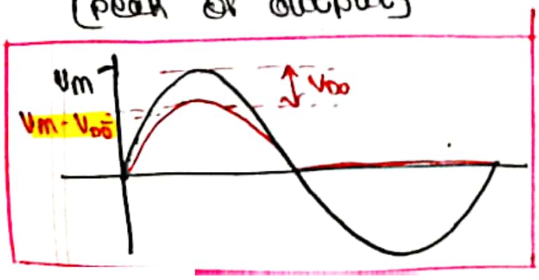


$V_i = V_m \boxed{\sin\omega t}$

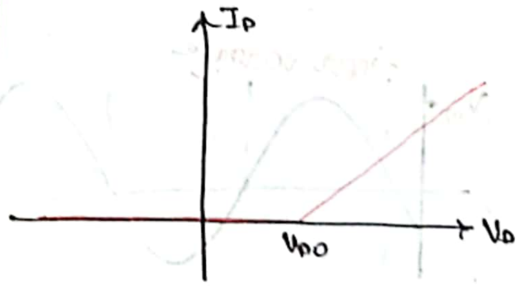
max = 1, min = -1



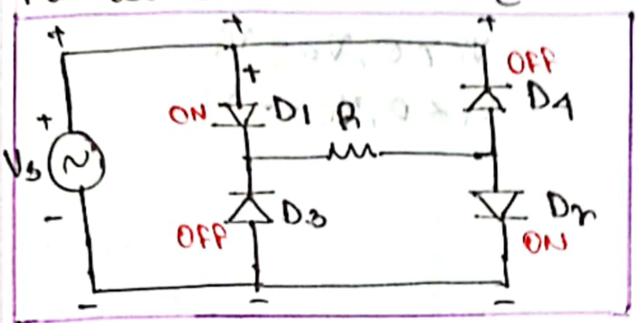
max^m value of output = $V_m - V_{D0}$
(peak of output)



Transfer characteristics

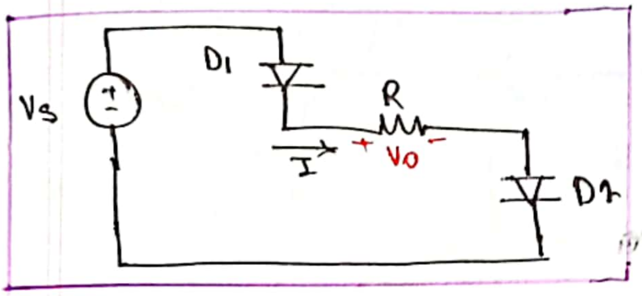


Full wave rectifier (ideal diode & CVD model)



~~For +ve~~

(+) half cycle

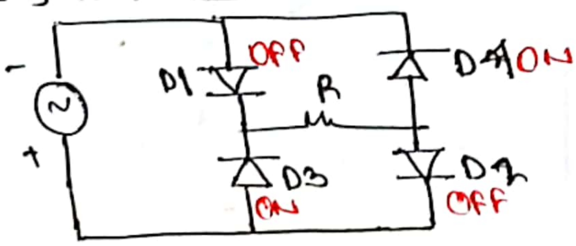


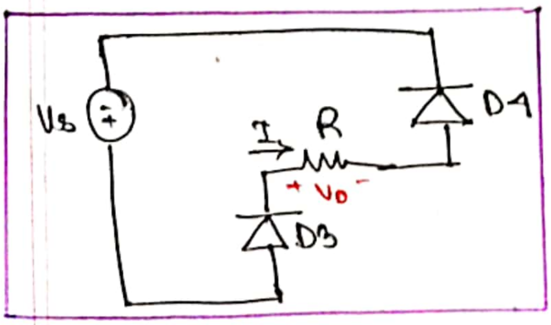
If the (+ve) end of diode and (+ve) terminal of source are on the same node, then that diode is ON.

Also, if the (-ve) end of the diode and (-ve) terminal of source are on the same node, then that diode is ON.

Other than these conditions, all the diodes are OFF.

(-) half cycle

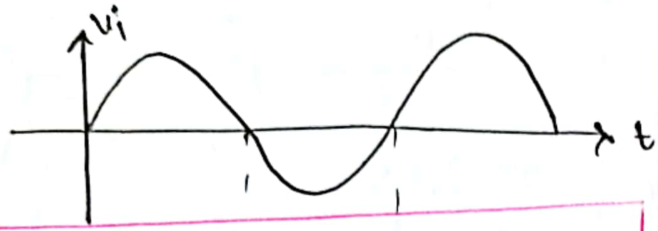


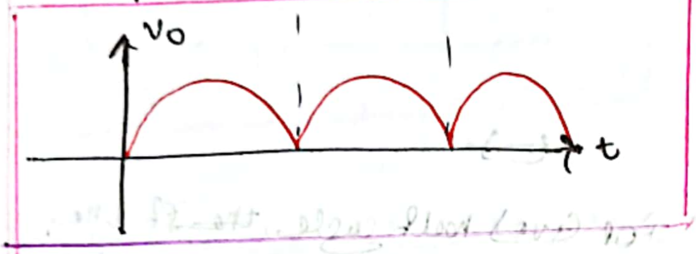


1) Ideal:

$V_i > 0, V_o = V_i$

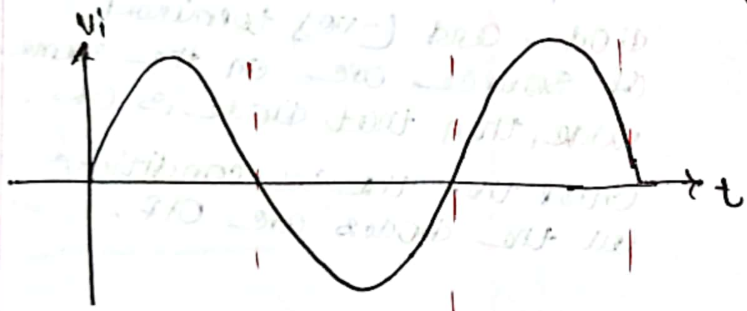
$V_i < 0, V_o = -V_i$

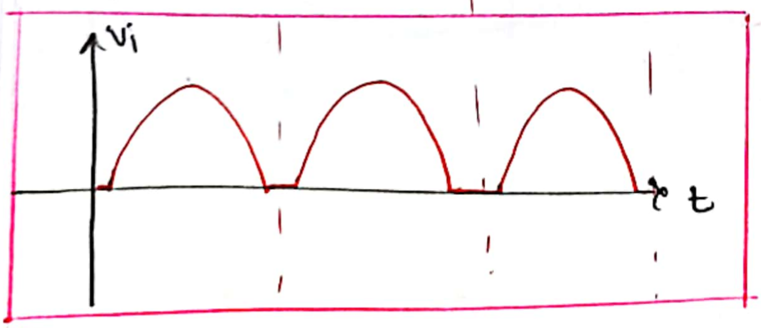


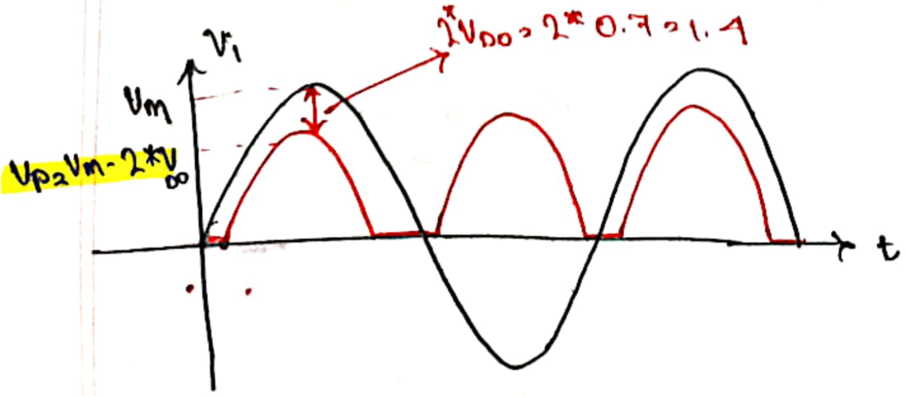


2) CVD Model

$V_o = V_i - 2 * V_{DO}$

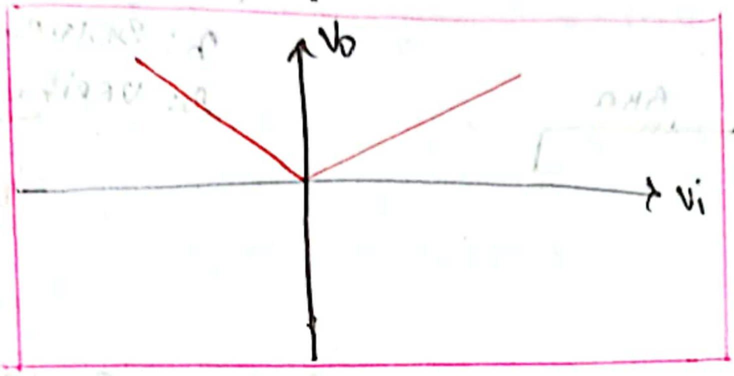




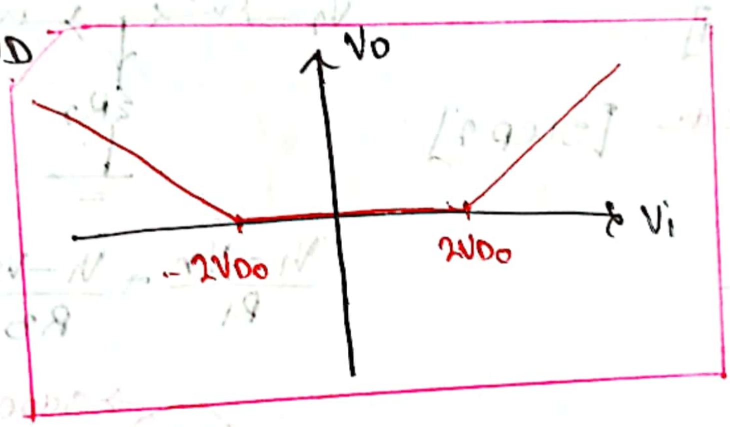


* Transfer Characteristics

ideal diode model



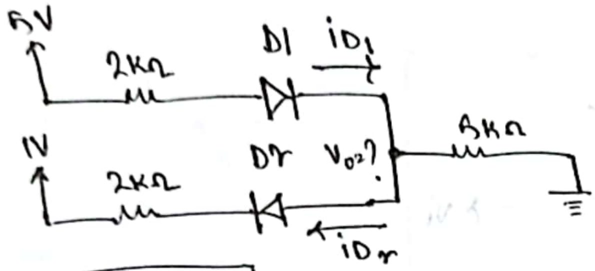
CVD



LECTURE 10

WEDNESDAY DATE: 22/02/23

* Method of Assumed State

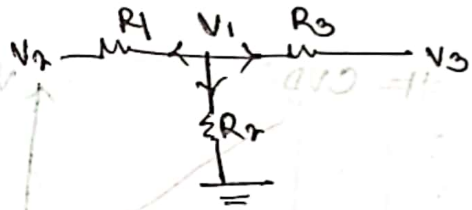


$\boxed{V_{D0} = 0.7V}$

Step 1 : Assume (ON/OFF)
2: Solve (ON/OFF)
3: Verify (ON/OFF)

$i_D > 0$ $\quad V_D < V_{D0}$

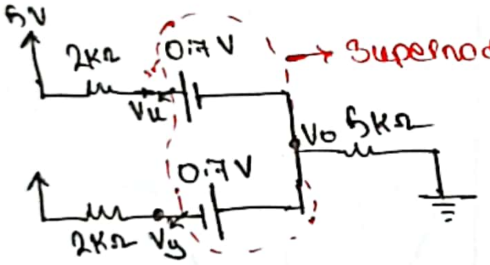
Review Supernode:



$$\frac{V_1 - V_2}{R_1} + \frac{V_1 - V_3}{R_3} + \frac{V_1 - 0}{R_2} = 0$$

* Soln:

both D1, D2 ON [Step 1]



[Step 2]

At the supernode,

$$\frac{V_0 - 0}{5} + \frac{V_x - 5}{2} + \frac{V_y - 1}{2} = 0$$

Here,

$V_x - V_0 = 0.7 \Rightarrow V_x = V_0 + 0.7$

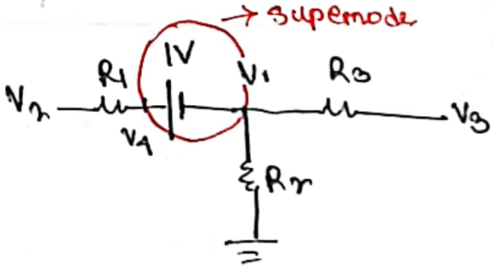
$V_0 - V_y = 0.7 \Rightarrow V_y = V_0 - 0.7$

~~$V_y - V_0$~~

$$\Rightarrow \frac{V_0}{5} + \frac{V_0 + 0.7 - 5}{2} + \frac{V_0 - 0.7 - 1}{2} = 0$$

$$\Rightarrow V_0\left(\frac{1}{5} + \frac{1}{2} + \frac{1}{2}\right) + \frac{-4.3}{2} + \frac{-1.7}{2} = 0$$

$$\Rightarrow V_0 = \frac{\frac{4.3}{2} + \frac{1.7}{2}}{\frac{1}{5} + \frac{1}{2} + \frac{1}{2}} \Rightarrow V_0 = 2.5\,V$$



At the supernode,

$$\frac{V_1 - V_3}{R_3} + \frac{V_1 - 0}{R_2} + \frac{V_4 - V_2}{R_1} = 0$$

Here, $V_4 - V_1 = 1$

$\Rightarrow V_4 = V_1 + 1$

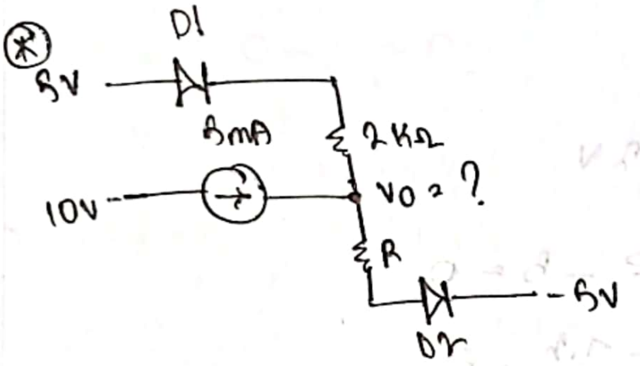
[Step 3]

$$i_{D1} = \frac{5 - V_x}{2} = \frac{5 - (V_0 + 0.7)}{2} = 0.9\,mA > 0$$

$$i_{D2} = \frac{V_y - 1}{2} = \frac{(V_0 - 0.7) - 1}{2} = 0.4\,mA > 0$$

∴ the assumption is correct.

(*)



$V_{D0} = 0.8\,V$
[cut-in voltage/threshold]

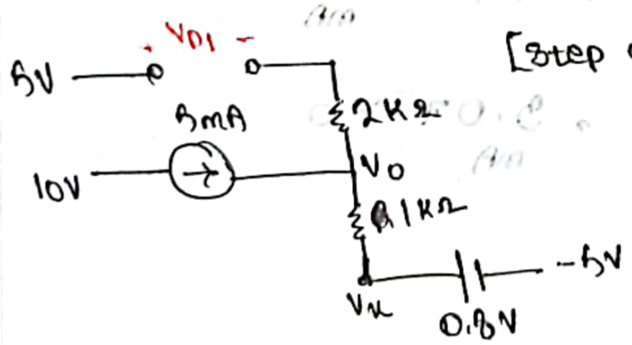
(i) $R = 1K\Omega$

$\boxed{\text{(ii) } R = 5K\Omega}$ → HW

(i) Soln: Let D2 ON, D1 Off [Step 1]

~~Rule of Thump:~~
~~* If any of of the two~~

[Step 2]



Here,

$V_x - (-5) = 0.8 \Rightarrow V_x = -4.2\,V$

at Vo node,

$$\frac{V_0 - V_x}{1} - 5 = 0$$

$$\frac{V_0 - (-4.2)}{1} - 5 = 0 \Rightarrow V_0 = 0.8\,V$$

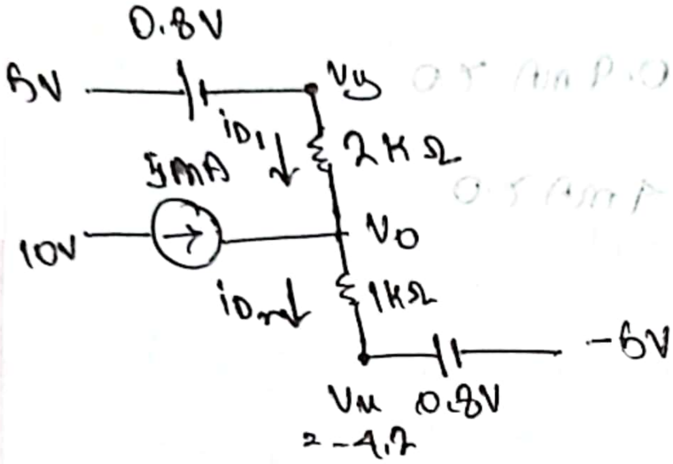
[Step 3]

$$i_{D2} = \frac{V_0 - V_x}{1} = \frac{5}{1} = 5\,mA > 0 \checkmark$$

$$V_{D1} = V_A - V_C = 5 - 0.8 = 4.2 \ngtr 0.8 \times$$

[By considering D2 - ON, condition is fulfilled. So, for the next assumption, keep D2 - ON and change D1 only → Rule of Thump]

* Let D_1 ON, D_2 ON



Here, $V_x = -4.2$ V

and, $5 - V_y = 0.8 \Rightarrow V_y = 4.2$ V

at V_o node, $\frac{V_o - V_x}{1} + \frac{V_o - V_y}{2} - 5 = 0$

$$\Rightarrow \frac{V_o - (-4.2)}{1} + \frac{V_o - 4.2}{2} = 5$$

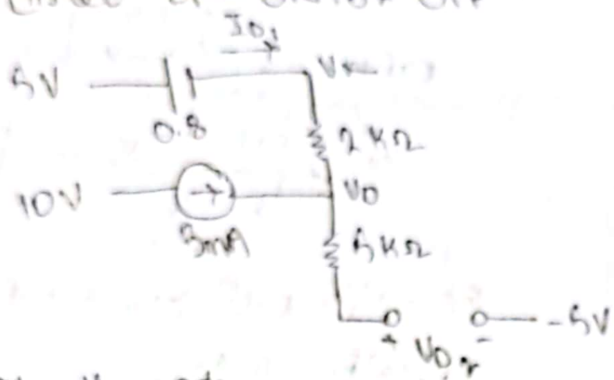
$$\Rightarrow V_o = 1.93 \text{ V}$$

$i_{D1} = \frac{V_y - V_o}{2} = \frac{4.2 - 1.93}{2} = \cancel{1.7 \text{ mA} > 0}\ 1.14 \text{ mA} > 0$

$i_{D2} = \frac{V_o - V_x}{2} = \frac{1.93 - (-4.2)}{2} = 3.07 \text{ mA} > 0$

The assumption is correct.

(ii) let D1 – ON, D2 – OFF



at V_0 node,

$$\frac{V_0 - 4.2}{2} + V_0 0 - 5 = 0$$

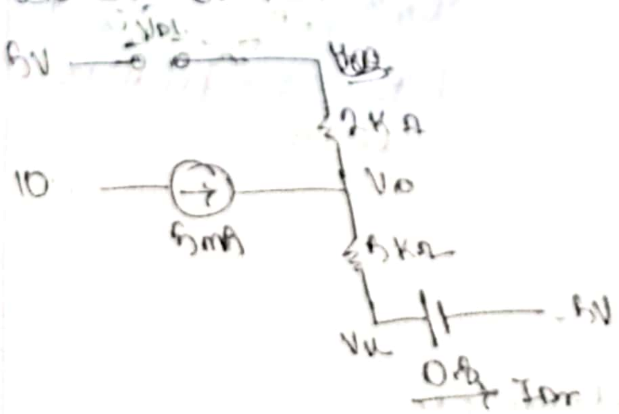
$V_0 = 14.2V$

$5 - V_u = 0.8 \Rightarrow V_u = 4.2$

$I_{D_1} = \frac{4.2 - 14.2}{2} = -5mA \ngtr 0 mA$

$V_{D_2} = 14.2 - 5 = 19.2 \nless 0.8V$

let D1 – OFF, D2 – ON



$V_u - (-5) = 0.8 \Rightarrow V_u = -4.2 V$

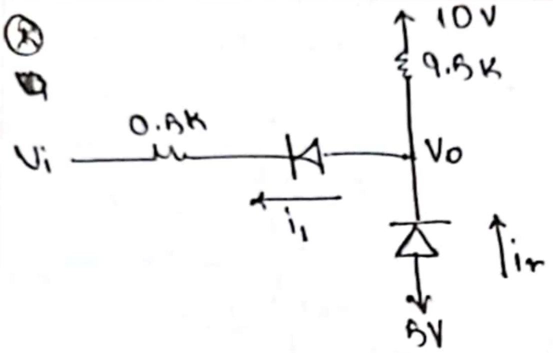
$\frac{V_0 - (-4.2)}{5} - 10 = 0 \Rightarrow V_0 = 5.8 V$

$I_{D_2} = \frac{V_0 - V_u}{5} \Rightarrow I_{D_2} = 2mA > 0 mA$ ✓

$V_{D1} = 5 - 5.8 V_0 \Rightarrow 5 - 5.8 \Rightarrow -0.8 < 0.8$ ✓

(The assumption is correct)

2

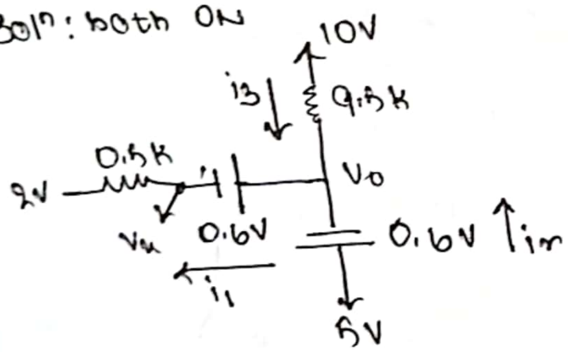


$i_1 = ?$ $i_2 = ?$ $V_o = ?$

Use CVD model with $V_{D0} = 0.6V$

(i) $V_i = 2V$ (ii) $V_i = 4V$

(i) Soln: both ON



Here, $5 - V_o = 0.6$

$V_o = 4.4$ V

and, $V_o - V_x = 0.6$

$\Rightarrow V_x = V_o - 0.6 \Rightarrow 3.8V$

$i_1 = \frac{V_x - V_i}{0.5} \Rightarrow i_1 = \frac{3.8-2}{0.5} = 3.6 \text{ mA} > 0$

$i_3 = \frac{10 - V_o}{9.5} \Rightarrow i_3 = \frac{10-4.4}{9.5} = 0.589 \text{ mA}$

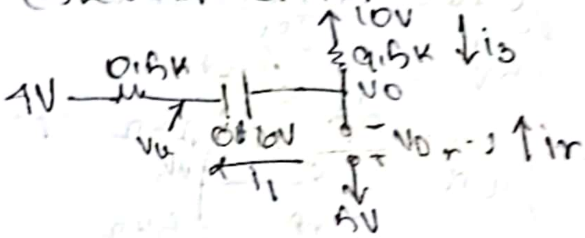
at V_o node, $i_3 + i_2 = i_1$

$i_2 = i_1 - i_3 = 3.6 - 0.589$

$\Rightarrow i_2 = 3.01 \text{ mA} > 0$

The assumption is correct.

(ii) Let D1 — ON, D2 — OFF



$V_o - V_x = 0.6$

$V_x = V_o - 0.6$

$\frac{V_o - 10}{9.5} + \frac{V_x - 4}{0.5} = 0$

$\frac{V_o - 10}{9.5} + \frac{V_o - 0.6 - 4}{0.5} = 0$

$V_o = 4.87$ V

$V_x = 4.87 - 0.6 \Rightarrow V_x = 4.27$ V

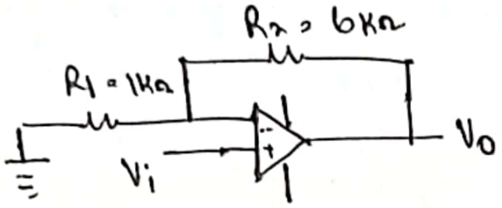
$I_{D1} = \frac{4.37 - 4}{0.5} = 1.74 > 0 \text{ mA}$ ✓

$V_{D2} = 5 - 4.87 = 0.13 \text{ V} < 0.6 \text{ V}$ ✓

(The assumption is correct)

Quiz — 01 (Solution)

(a) Non-inverting amplifier (7 times amplification)



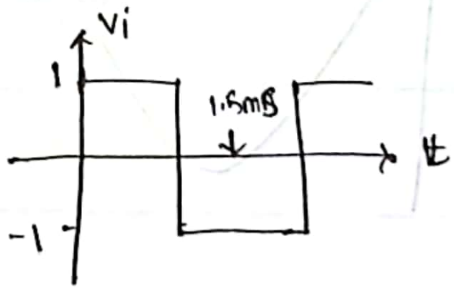
We know, $V_o = \left(1 + \frac{R_2}{R_1}\right) V_i$

Here, $1 + \frac{R_2}{R_1} = 7$

$\Rightarrow \frac{R_2}{R_1} = 6$

if $R_1 = 1K\Omega$, $R_2 = 6K\Omega$

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

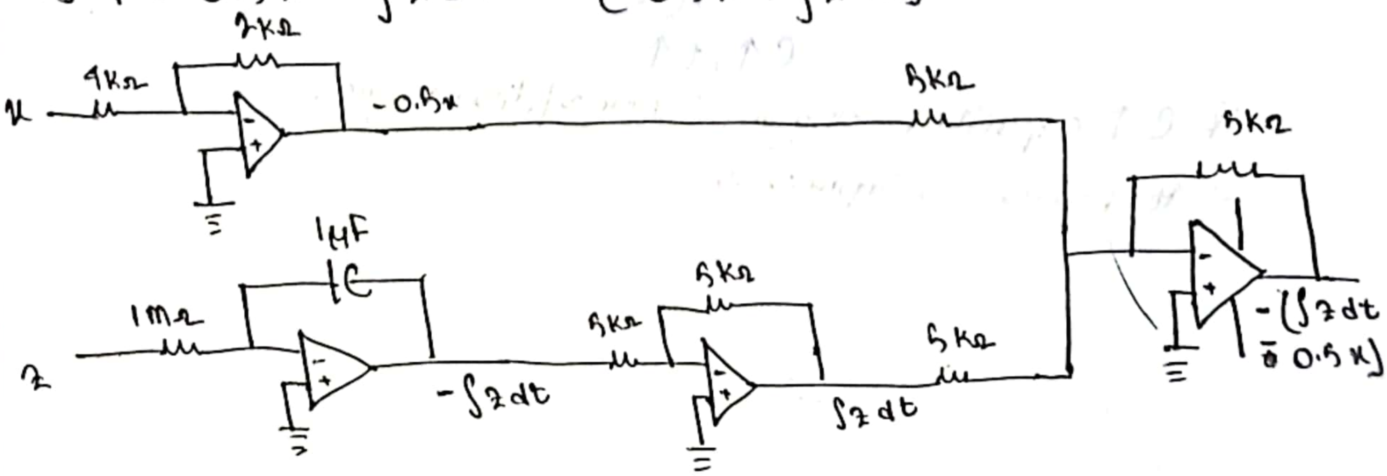


~~(a)~~ at $t = 1.5ms$, $V_i = -1V$

$\therefore V_o = 7V_i$

$= -7V$

(c) $f = 0.5x - \int z\,dt = -\left(-0.5x + \int z\,dt\right)$

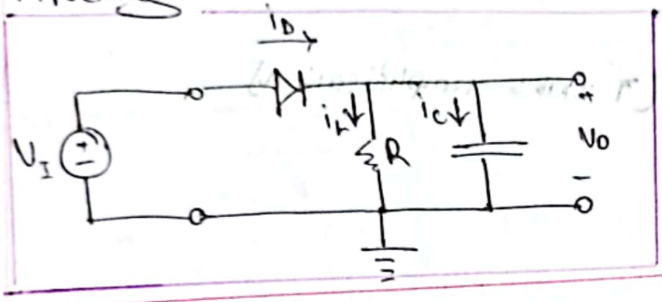


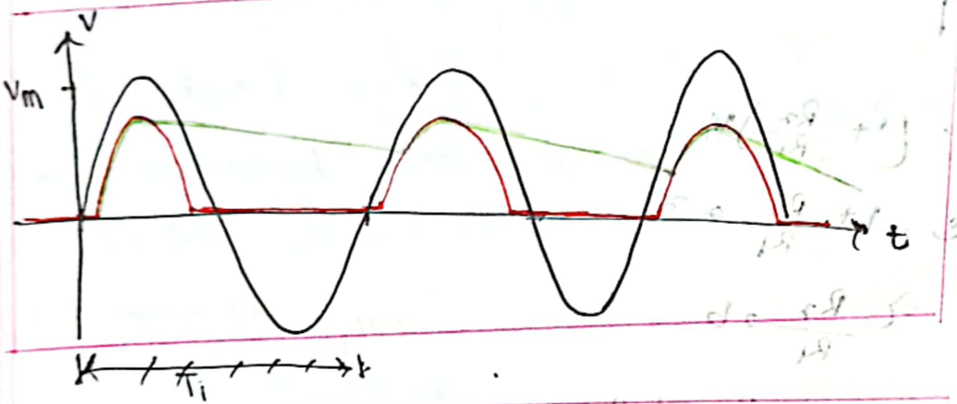
LECTURE 11

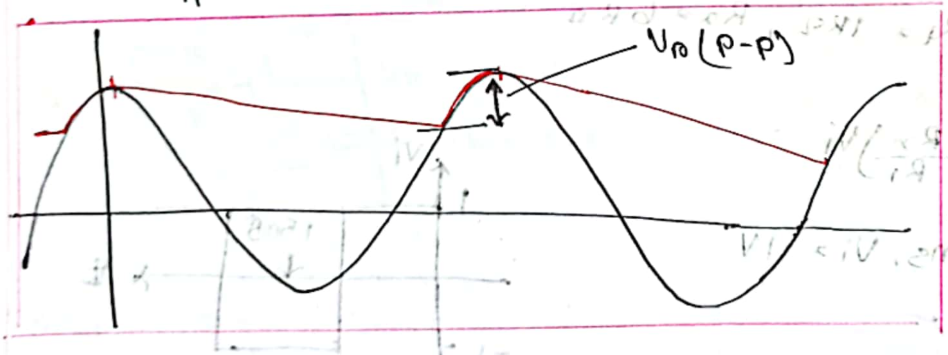
MONDAY

DATE: 27/02/23

Filtering: Half-wave rectifier







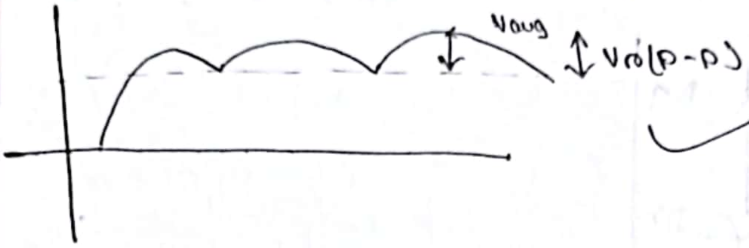
charging | discharging $t = 5\tau$

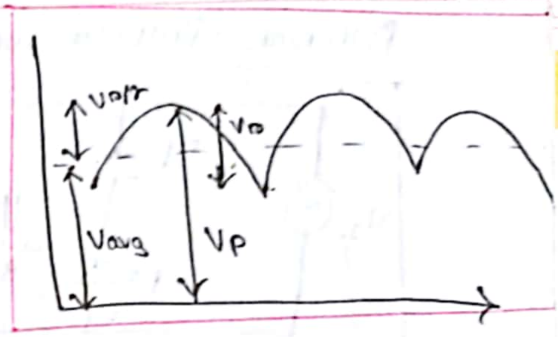
$= 5(RC)$

$C\uparrow, t\uparrow$

if $C\uparrow$ capacitor slowly charges/discharges.

∴ Performance improves





$V_{avg} = V_{DC} = V_p - \frac{V_{r(p-p)}}{2}$

$V_o = V_{avg} \pm \frac{V_r}{2}$

(2) $V_o = 5 \pm 0.2$

$\downarrow \quad \downarrow$

$V_{avg} \quad \frac{V_r}{2}$

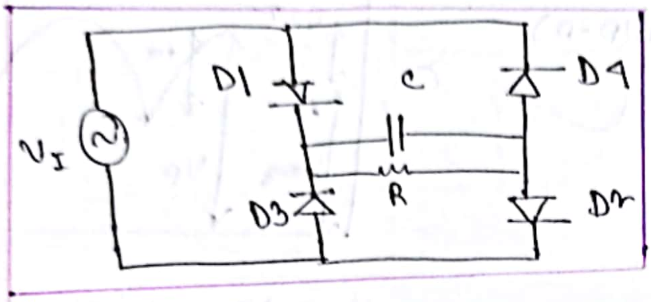
$V_{avg} = 5\,V$

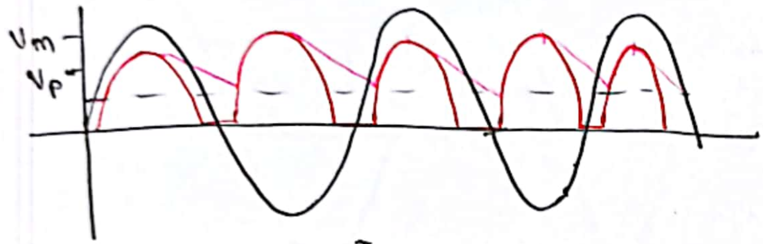
$V_r = \left(\frac{V_r}{2} \times 2\right) = (0.2 \times 2) = 0.4\,V$

$V_{o,avg} = \frac{1}{T}\int_0^T V_o(t)\,dt$

$V_{o,avg}$ [H/W, W/O capacitor] $= \frac{V_m}{\pi} - \frac{V_{DO}}{2}$

Filtering : Full-wave rectifier



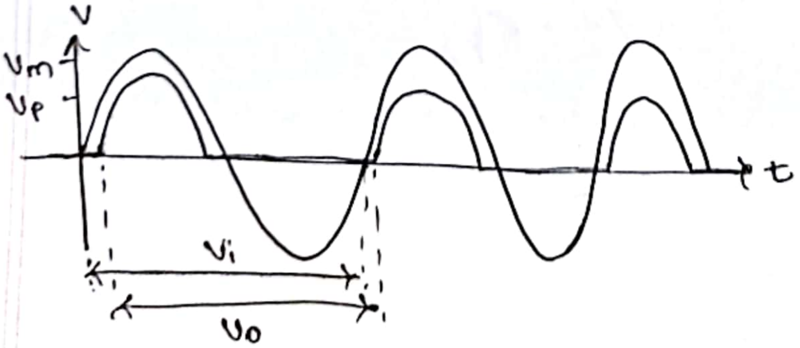


$$V_{o,avg} = \frac{1}{T}\int_0^T V_o(t)\,dt$$

$$V_{o,avg}\,[F/W, \text{ w/o capacitor}] = \frac{2V_m}{\pi} - 2V_{Do}$$

$$V_{o,avg}\,[\text{with capacitor H/W \& F/W}] = V_p - \frac{V_{o(p-p)}}{2}$$

For half-wave rectifier



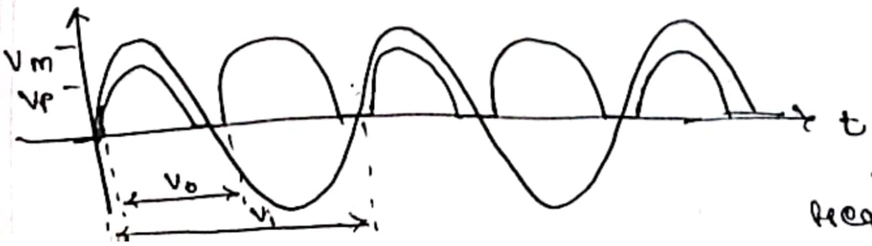
H/W

$T_o = T_i$

$\Rightarrow \frac{1}{f_o} = \frac{1}{f_i}$

$\Rightarrow f_o = f_i$

For full wave rectifier



F/W

$T_o = \frac{1}{2}T_i$

$\Rightarrow \frac{1}{f_o} = \frac{1}{2f_i}$

$\Rightarrow f_o = 2f_i$

* with/without capacitor, frequency relationship remains same.

* $V_i = 10V \sin(240\pi t)$

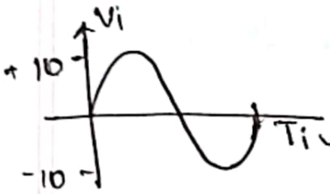
$V_i = V_m \sin(2\pi f_i t)$ → ideal formula

peak voltage of input

$V_i = V_m \sin(2\pi f_i t)$

$\therefore V_m = 10, V_i = 10 \sin(2\pi * 120 t)$

$\therefore f_i = 120$



$T_i = \frac{1}{f_i} = \frac{1}{120}$ s

$= \frac{1}{120} \times 1000$ ms

(i) $V_o = V_p \sin(240\pi t)$ → Half-wave rectifier [$f_o = f_i \Rightarrow 120 = 120$]

(ii) $V_o = V_p \sin(480\pi t)$ → Full-wave rectifier [$f_o = 240, f_i = 120, f_o = 2f_i$]

(iii) $V_o = V_p \sin(140\pi t)$ → normal wave [~~H/w~~ Not H/w or F/w]

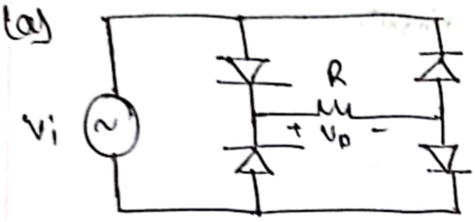
* To check whether a curve is ~~half~~ for half-wave rectifier or full-wave rectifier, we can check its f_o and f_i.

* $I_{avg} = \frac{V_{o\,avg}}{R}$

Example (from slide)

$V_i = 8\sin(2000\pi t)$

(a)



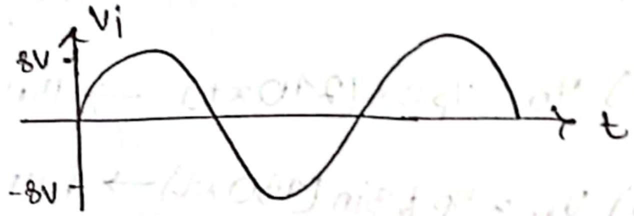
(b) $V_i = V_m \sin(2\pi f_i t)$

$\therefore V_m = 8V$

$V_p = V_m - 2V_{DO}$

$= 8 - 2(0.\cancel{8})$

$= 6.4V$



(c) $V_{o,avg} = \dfrac{2V_m}{\pi} - 2V_{DO}$

$= \dfrac{2(8)}{\pi} - 2(0.6)$

$=$

$v_i = 10\sin(240\pi t) \longrightarrow H/W \qquad V_o = V_p\sin(240\pi t)$

Since f_o and f_i are same, H/W is used.

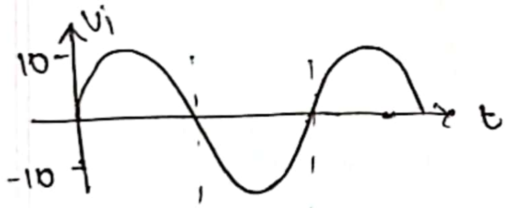
(i) peak output voltage $= V_p = V_m - V_{D0} = 10 - 0.7 = 9.3\,V$

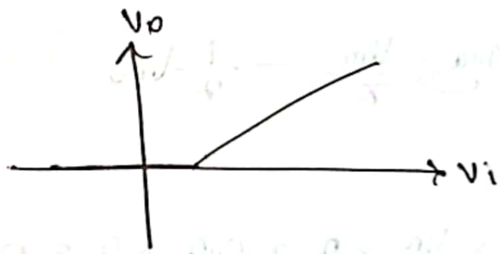
(ii) Peak diode current = peak output current $= \frac{V_P}{R} = \frac{9.3}{10} = 0.93\,mA$

(iii) Output frequency = 120 Hz

(iv) Average value of the output voltage $= \frac{V_m}{\pi} - \frac{1}{2}V_{D0}$

(v) Sketch the output and input voltage



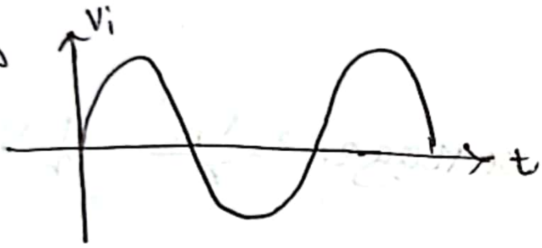


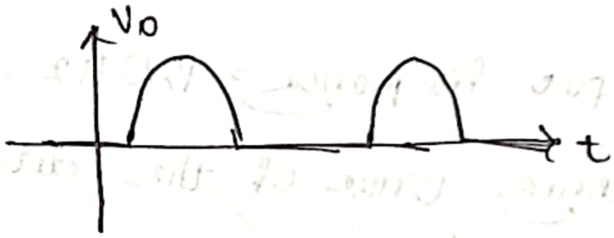
[For Transfer characteristics]

Question 4

(a) First step of converting AC to DC.
Negative half cycle of input is removed.

(b)





(c) $V_{o,avg} = \frac{V_m}{\pi} - \frac{1}{2}V_{DO}$

(d) $V_r = \frac{V_r}{2} \times 2 = 0.2 \times 2 = 0.4$

$V_r = \frac{V_p}{f_r RC}$

$\Rightarrow C = \frac{V_p}{f_r R V_r}$

$= \frac{V_m - V_{DO}}{f_r R V_r}$

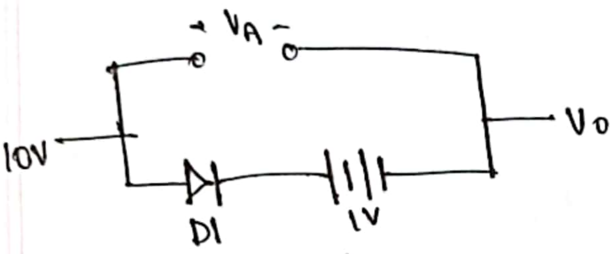
LECTURE 12

WEDNESDAY DATE: 01/03/23

Quiz 2 Solution

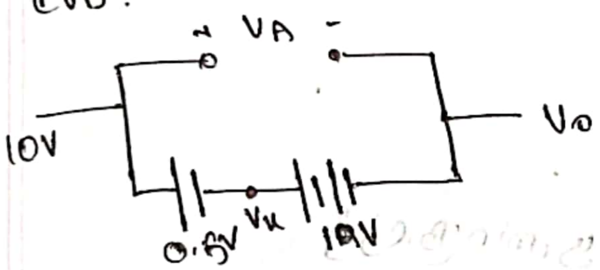
(1) $V_{D0} = 0.5\,V$

$r_D = 0.5\,k\Omega$

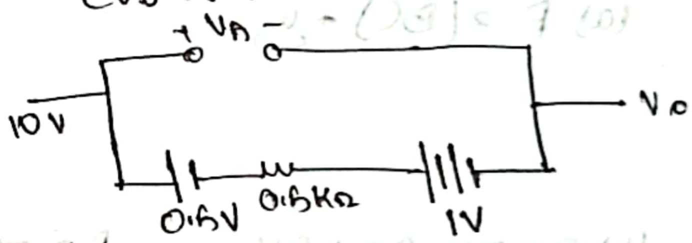


(ON → given)

CVD:



CVD + R:

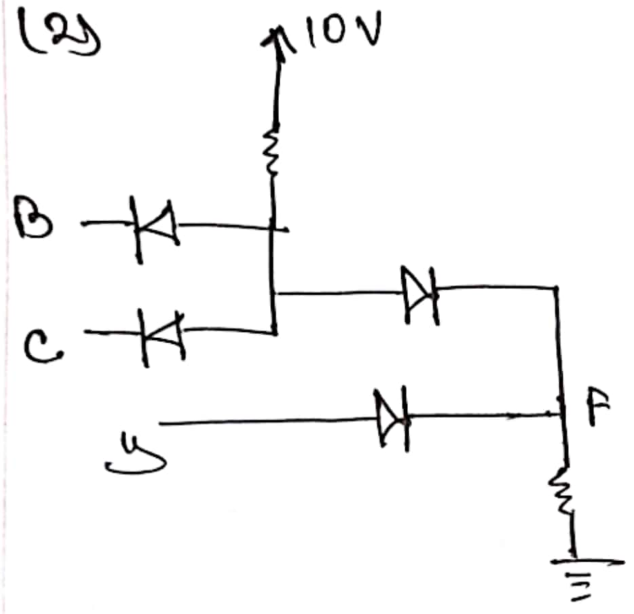


$0.5 = 10 - V_x \Rightarrow V_x = 9.5\,V$

$1 = V_x - V_o \Rightarrow V_o = 8.5\,V$

$\therefore V_A = 10 - V_o = 10 - 8.5 = 1.5\,V$

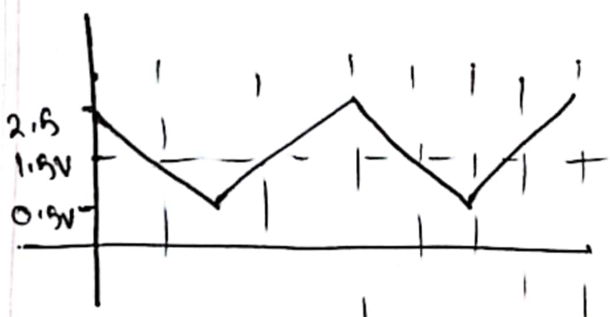
(2)



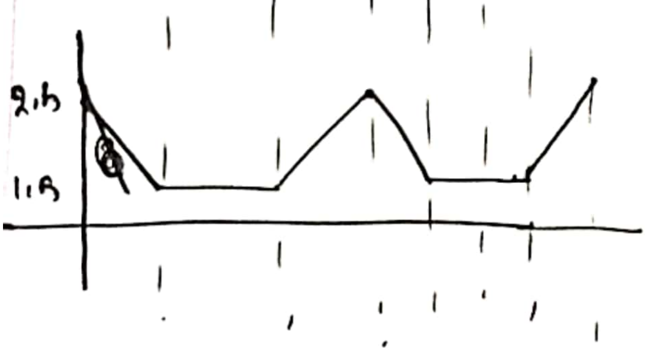
(a) $F = (BC) + y$

(b) $B = 7V, C = 1.5V$ $\quad F = \max(y, \min(B,C))$

Here, $\min(B,C) = 1.5V$



$+ \; 1.5 = \min(B,C)$

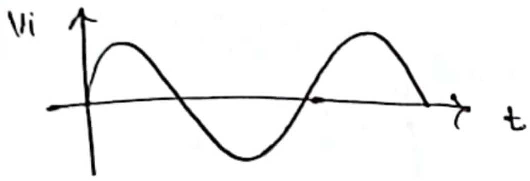


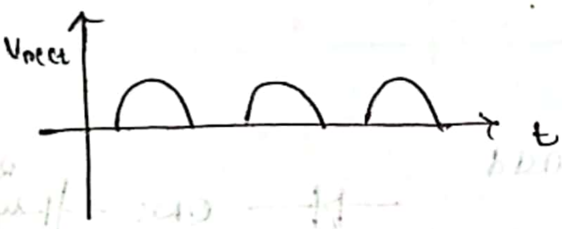
FINAL

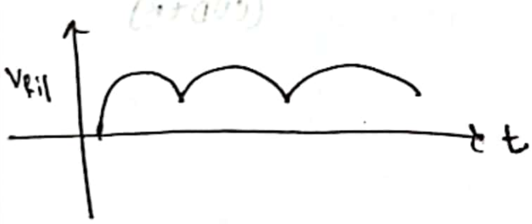
LECTURE 13

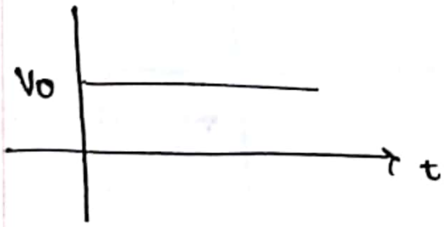
SATURDAY   DATE: 18/03/23

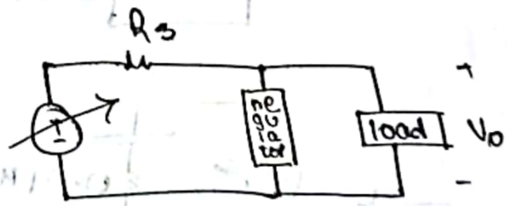
ZENER DIODE



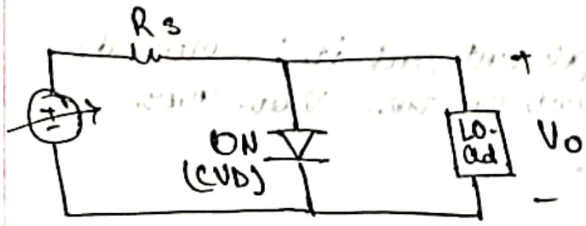


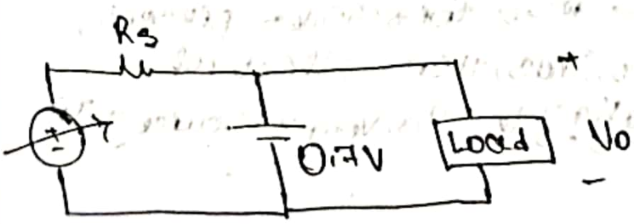


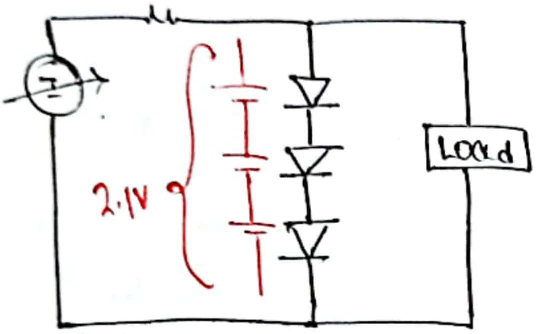




* Regulator

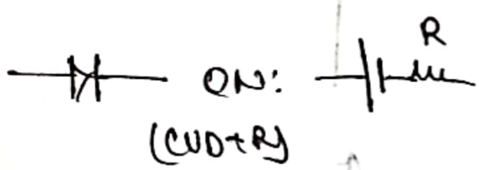




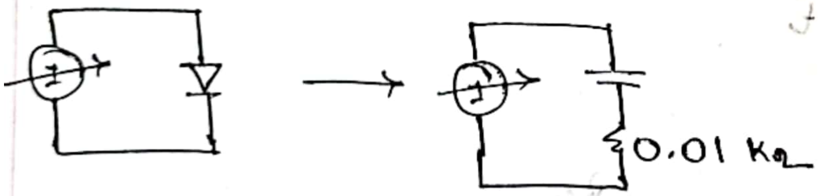


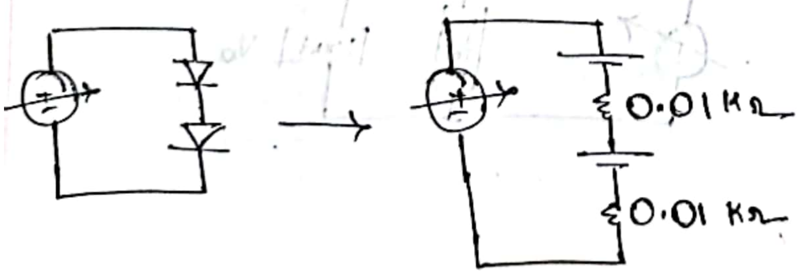
(i) Voltage values are limited

(ii) R_Z can't be ignored if we add multiple diodes.



$R_Z = 0.01 K\Omega$

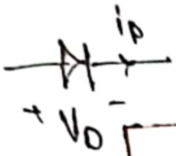


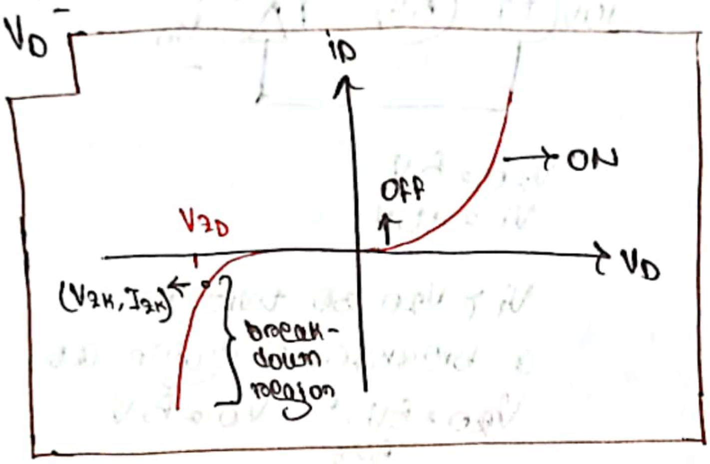


* If there is only one diode present, and it is closed, resistor does not have any effect on the Vout. Thus, $V_{out} = V_{source}$

* If there are more than one ~~resistors~~ diodes present, then there are more resistors. Thus, the effect of these resistors cannot be negligible. So, $V_{out} = V_{source} + IR$

* Zener Diode (special type of diode)



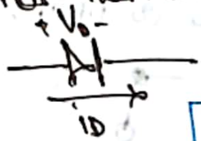


$V_{ZK} \rightarrow$ Knee voltage

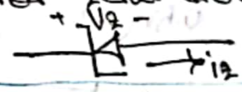
$I_{ZK} \rightarrow$ Knee current

* breakdown region
  as slope $\uparrow$ (Alon)
* zener diode is used for breakdown region.
* We use zener diode if we need the breakdown region.

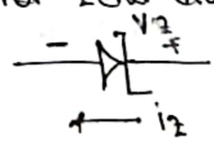
For normal diode,



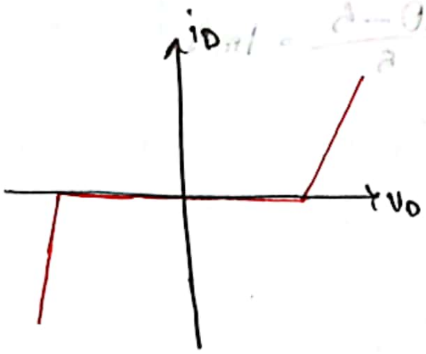
For zener diode,



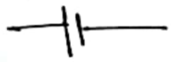
For zener diode,



$V_Z = -V_D, \; I_Z = -I_D$



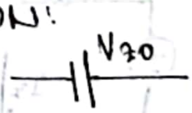
ON: $i_D > 0$

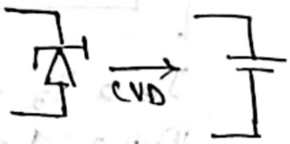


OFF: $V_{ZK} < V_D \leq V_{D0}$

BR: $i_D \leq -I_{ZK}$

ON:

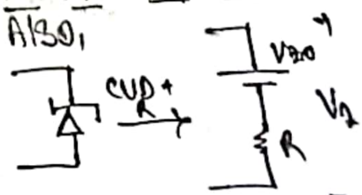




V_{Z0}: 2 ~ 200 V

$V_Z = V_{Z0}$

Also,

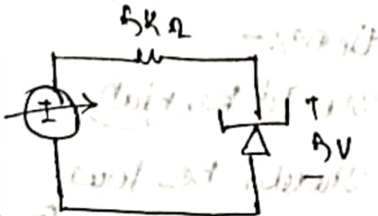


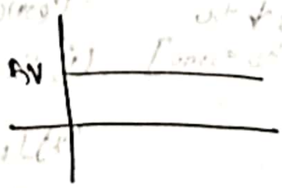
$V_{Z0} = -V_{D0} = -0.7$

$V_Z = V_{Z0} + I_R V_R$

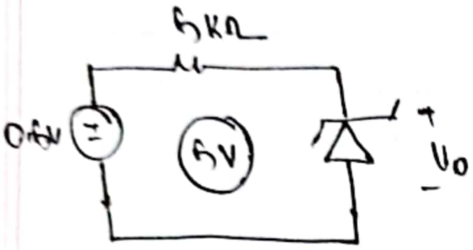
$V_Z = -V_{D0} + I_R V_R$

Piece-wise linear model,





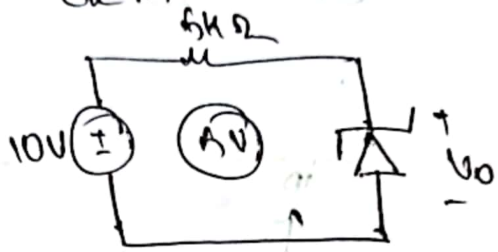
Ex 1:



$V_{Z0} = 5V$
$V_i = 0.5V$

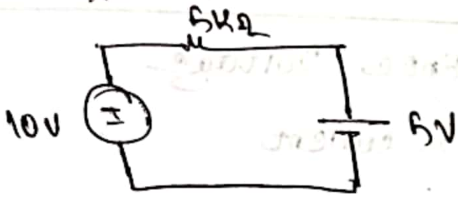
$V_i < V_{Z0}$, so it does not reach breakdown. The circuit is open.

Ex 2:

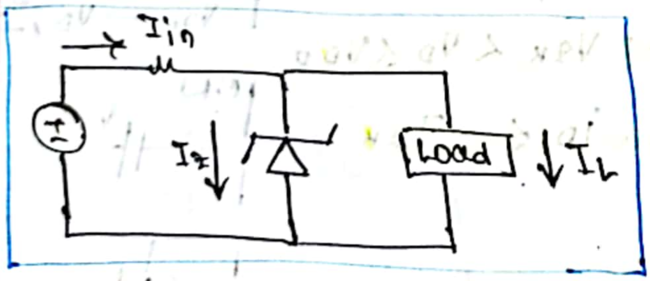


$V_{Z0} = 5V$,
$V_i = 10V$

$V_i > V_{Z0}$, so there is a breakdown region at $V_{Z0} = 5V$. $\therefore V_0 = 5V$



$I_Z = \frac{10-5}{5} = 1mA$.



$I_{in} = I_Z + I_L$
$10mA = 4 + 6$
$\downarrow \quad \downarrow$
$3 \quad 7$

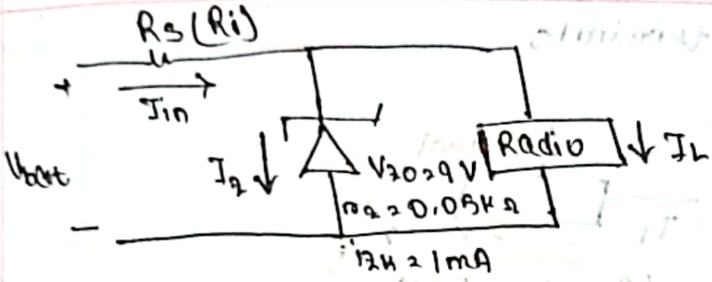
[if $I_L \uparrow$, $I_Z \downarrow$ to keep I_{in} the same]

For regulator to work properly, zener MUST be in breakdown region.

Conditions:-

(1) V_{in} should be high
(2) I_L should be low
(3) $I_Z > I_{ZK}$

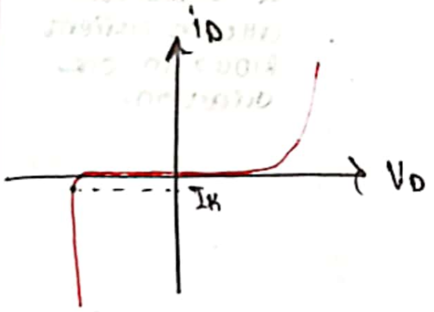
[$V_{in} \uparrow\downarrow \Rightarrow I_Z \uparrow\downarrow$,
$I_L \uparrow\downarrow \rightarrow I_Z \downarrow\uparrow$]

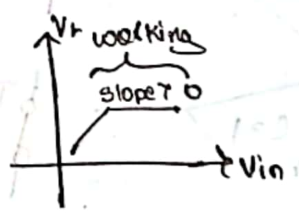


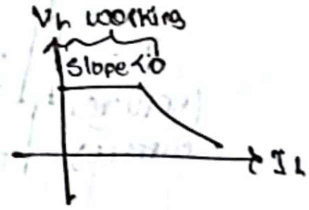
For worst case scenario,
(1) $V_{in} = V_{in}$ (MIN)
(2) $I_L = I_L$ (MAX)
(3) $I_z = I_z$ (MIN) $= I_{zk}$

Radio requires ≈ 9V
V_{bat} : between 11 to 13.6 V
I_L : between 0 to 9mA

at worst case, calculate I_z, I_L, V_z, V_{bat} = ?







line regulation

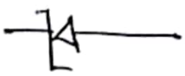
$$\left[\frac{\Delta dV_L}{\Delta dV_{in}} (mV/V)\right] = \frac{r_z}{R_i + r_z}$$

load regulation

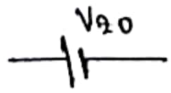
$$\left[\frac{\Delta V_L}{\Delta I_L} (mV/mA)\right] = -\frac{r_z R_i}{R_i + r_z}$$

Soln: at worst case, $I_z = I_{z,min}$
$= I_{zk}$
$= 1 mA$

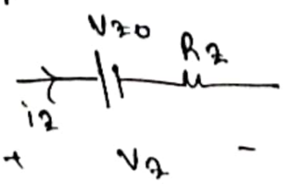
$V_{bat} = 11V$



CVD :



CVD + R :



$V_z = V_{z0} + I_z R_z$
$V_z = 9 + (1 \times 0.05)$
$V_z = 9.05$ V

$I_{in} = \dfrac{V_{bat} - V_z}{R_s}$

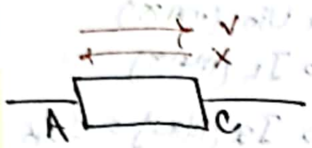
$I_L = 9 mA$
$I_{in} = I_z + I_L$
$= 1 + 9$
$I_{in} = 10$ mA
$I_{in} = \dfrac{V_{bat} - V_z}{R_s} \Rightarrow 10 = \dfrac{11 - 9.05}{R_s}$
$R_s = 0.195 k\Omega$

$V_s = I_{in} * R_s$
$= 10 * 0.195$
$= 1.95V$

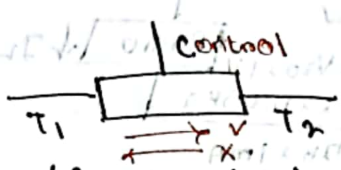
LECTURE 14

MONDAY DATE: 27/03/2023

* Transistor : Circuit with 3 terminals



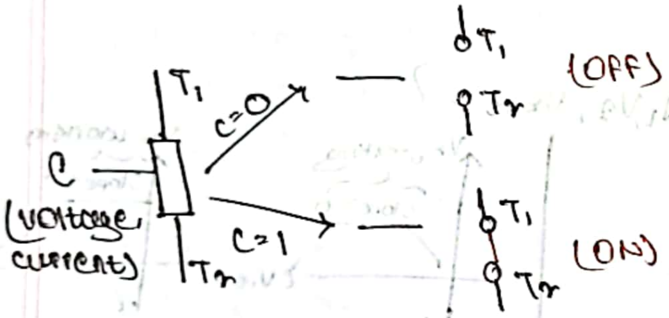
(2-terminal)



(3-terminal)

* Control terminal is used to control flow betn T_1 & T_2

* Both ~~A-t~~ diode & transistor allows current flow in one direction.



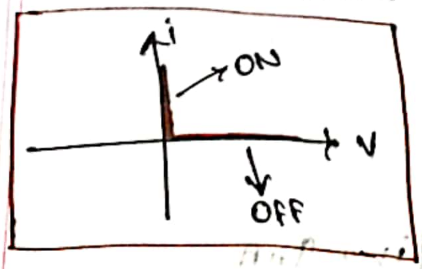
Application

* As a switch

* As an amplifier $\quad$ 0.1V ⟶ 1V (10 times amplified)

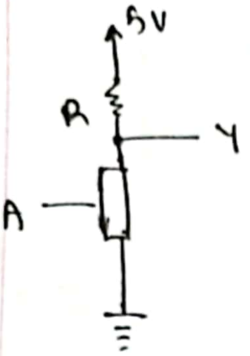
* As logic gates

I–V characteristics



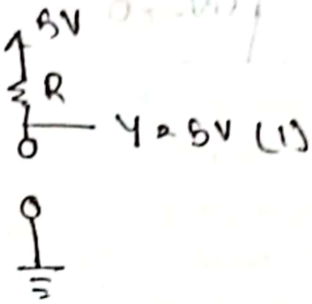
*AS LOGIC GATES

5V → 1, 0V → 0

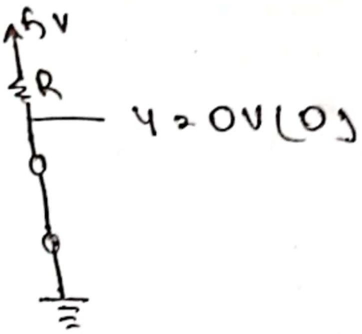


NOT GATE $Y = \overline{A}$

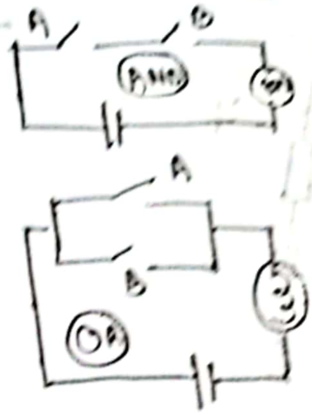
A = 0 (0V) ——



A = 1 (5V) ——



*Switch as gate



~~voltage/current assigned as~~

5V → 1, 0V → 0

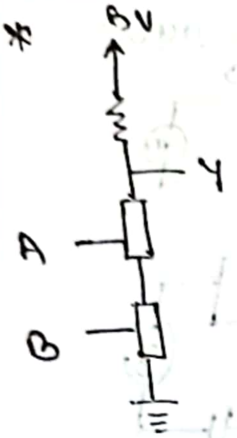
3.3 – 5V → 1, 0 – 2.7V → 0

5mA → 1, 0 mA → 0

* Binary values assigned for voltage/current.

*

*

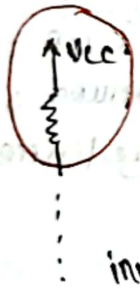


A	B	Y
0	0	5V → 1
0	1	5V → 1
1	0	5V → 1
1	1	0V → 0

NAND GATE

$Y = \overline{A \cdot B}$

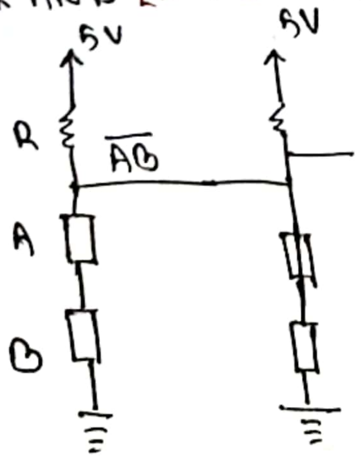
*



pull – up network

inverts the logic below

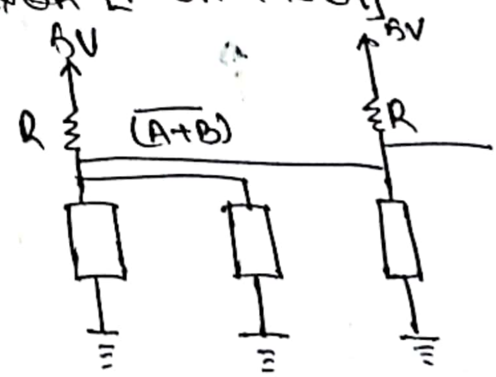
* AND [NAND + NOT]



$y = \overline{\overline{AB}}$

$= AB$

* OR [NOR + NOT]



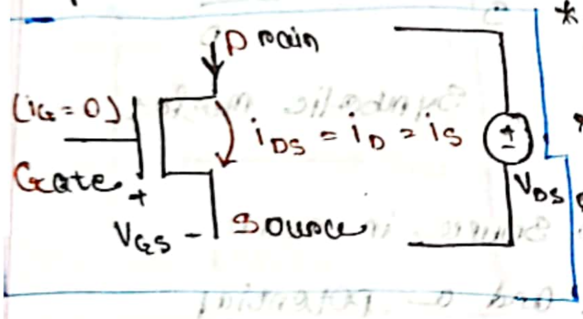
$y = \overline{\overline{(A+B)}}$

$= (A+B)$

* Transistor
  - → MOSFET (Control = V)
  - → BJT (Control = I)

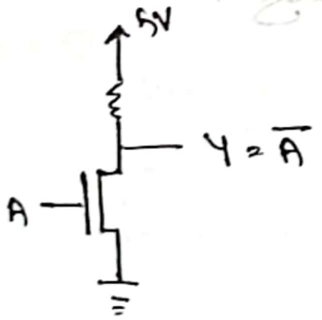
* MOSFET :

Symbol:

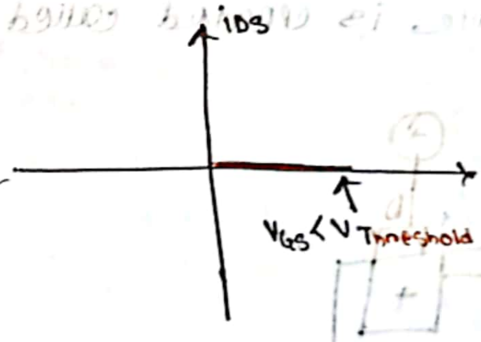


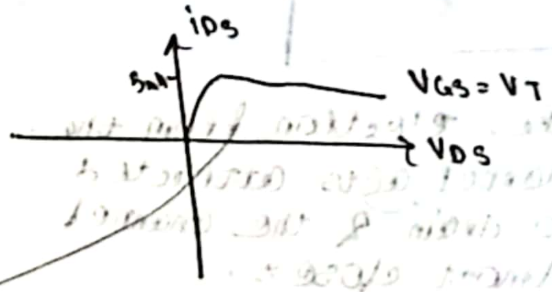
* Current always flows from Drain to source.
* Current does not flow from source to Drain.
* A voltage difference is created bet^n drain & source to allow current flow.

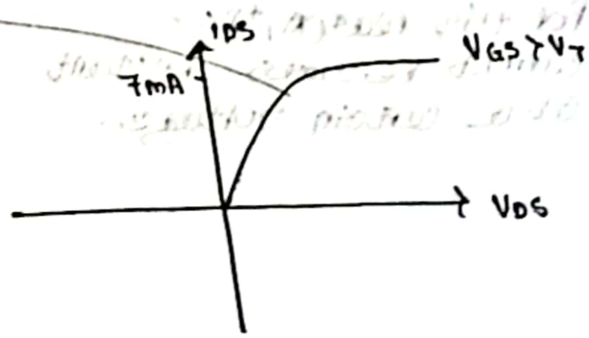
* NOT Gate

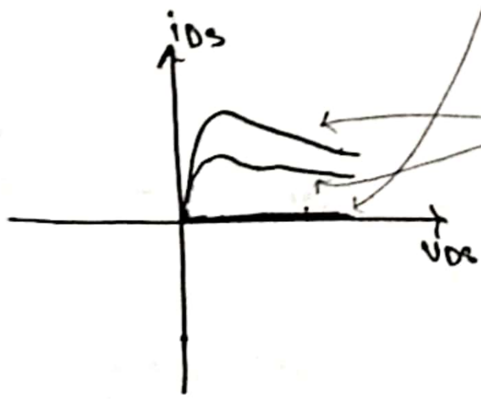


* i – V characteristics of mosfet



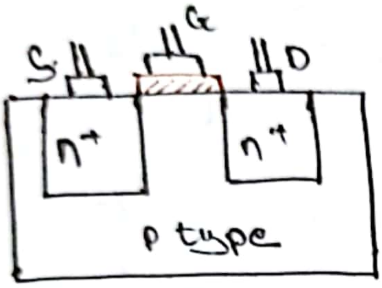




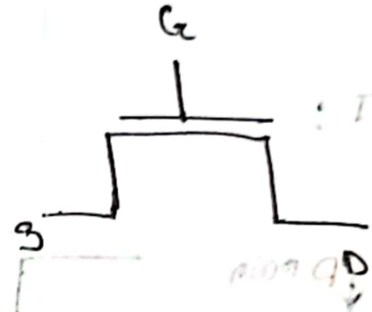


Metal
↑ semi-conductor
MOSFET
↓ Oxide ↓ Field ↓ Effect ↓ Transistor

How Does a mosfet works?:



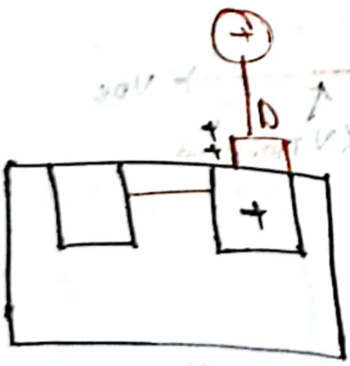
$n \to e^-$ বেশি
$p \to e^-$ কম



Real mosfet

Symbolic mosfet

* When apply voltage from gate to source in such a way that creates a channel and a potential difference is created called "Threshold voltage".



* The electron from the channel gets attracted to drain & the channel almost closes.
For this reason, the current becomes constant at a certain voltage.

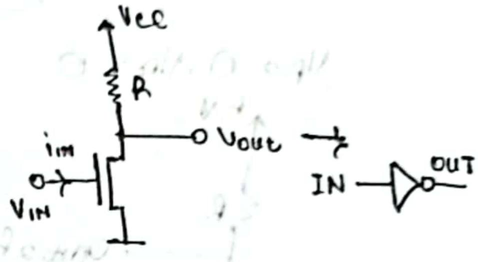
LECTURE 13

MONDAY DATE: 03/04/23

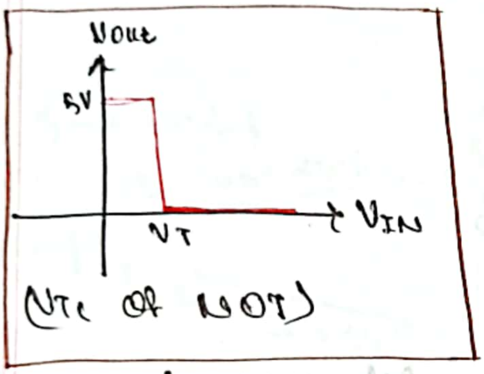
VOLTAGE TRANSFER CHARACTERISTICS

$V_{GS} < V_T \longrightarrow$ OFF (0) $V_O = V_{CC} = 5V \to 1$

$V_{GS} \geq V_T \longrightarrow$ ON (1) $V_O = V_{CC} = 0V \to 0$



Binary 0 → when mosfet is OFF

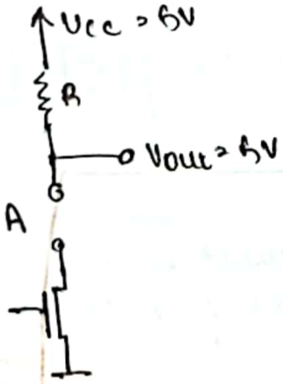


* $V_{GS} < V_T \to V_{out} = 5V$
* $V_{GS} \geq V_T \to V_{out} = 0V$

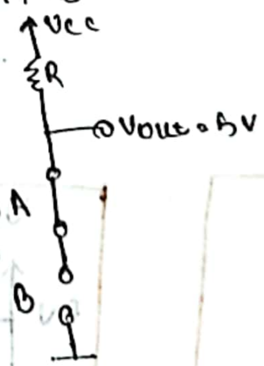
AND: AB | NAND: $\overline{AB}$
OR: $A+B$ | NOR: $\overline{(A+B)}$
XOR: $\bar{A}B + A\bar{B}$ | XNOR: $AB + \bar{A}\bar{B}$

* V_{TC} of NAND:

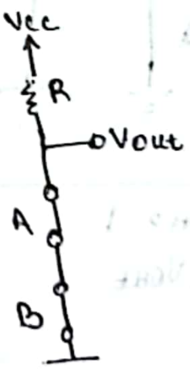
$V_A = 0$

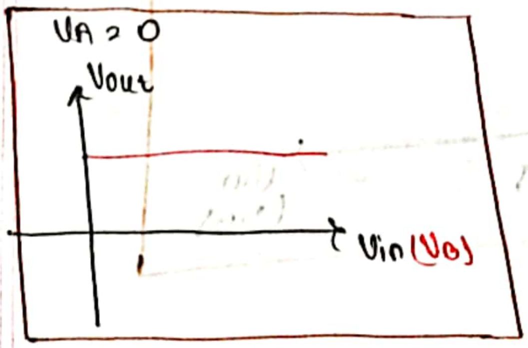


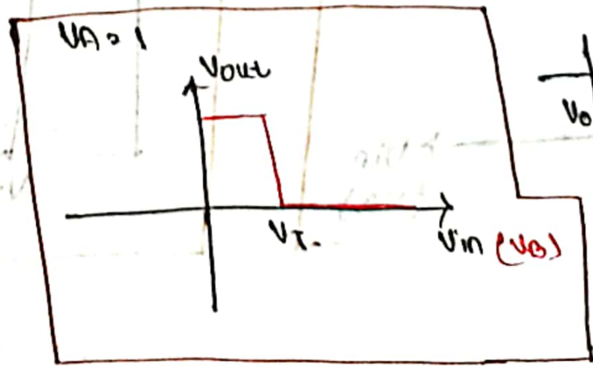
$V_A = 1, V_B = 0$



$V_A = 1, V_B = 1$







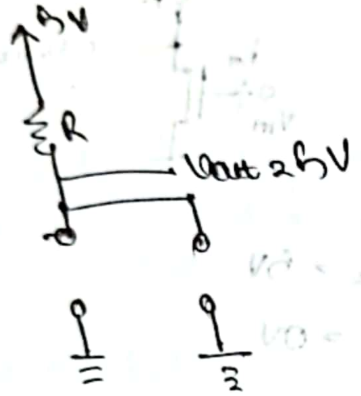
	0	1
Vo	5	0

VA	VB	Vout
0	0	1
0	1	1
1	0	1
1	1	0

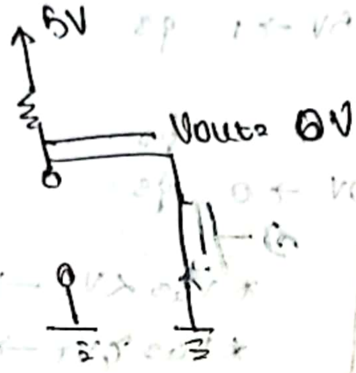
* When $V_A = 0$, no current flows through A & B

* VTC for NOR gate

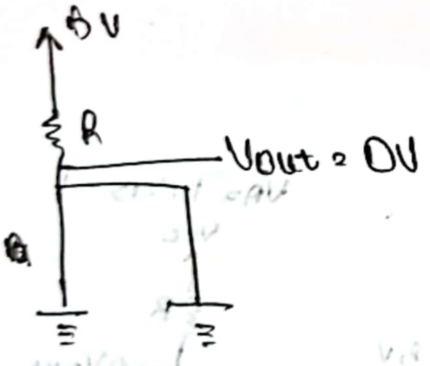
$V_A = 0, V_B = 0$



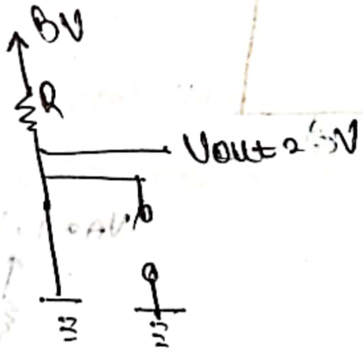
$V_A = 0, V_B = 1$

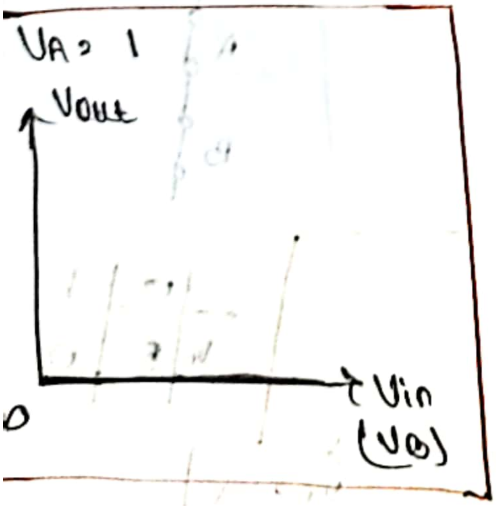


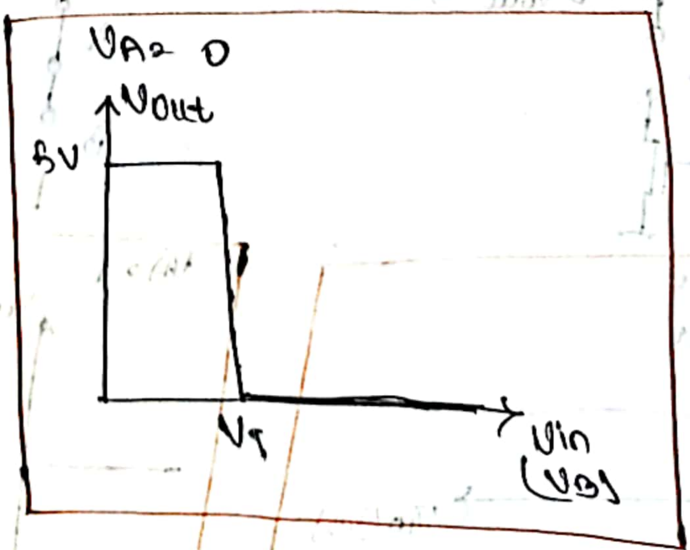
$V_A = 1, V_B = 1$



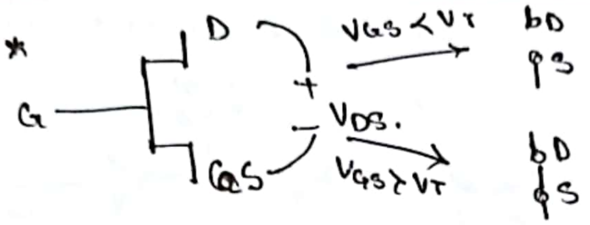
$V_A = 1, V_B = 0$



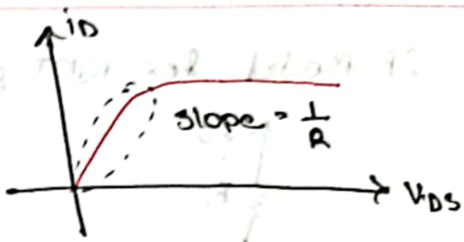




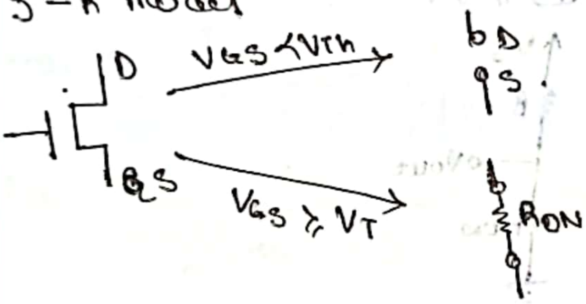
*

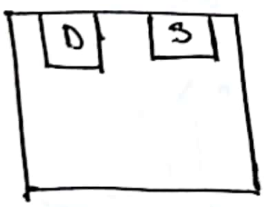


[S- Model]



S-R model





The distance between D & S in real mosfet is L and the width is W.

$$R_{ON} = \frac{1}{K'_n \frac{W}{L}(V_{GS}-V_T)} \Rightarrow R_{ON} = \frac{1}{K V_{OV}}$$

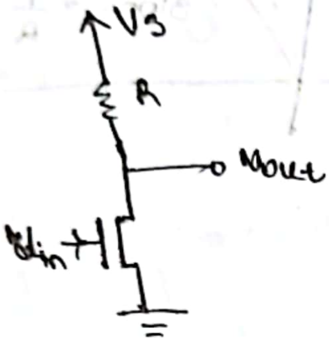
→ process transconductance

$K = K'\frac{W}{L}$

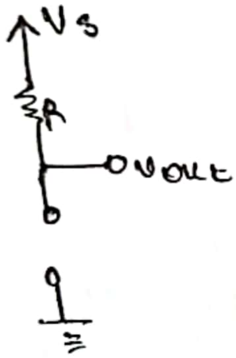
$V_{OV} = V_{GS} - V_T$

($V_{overdrive}$)

SR model for NOT gate



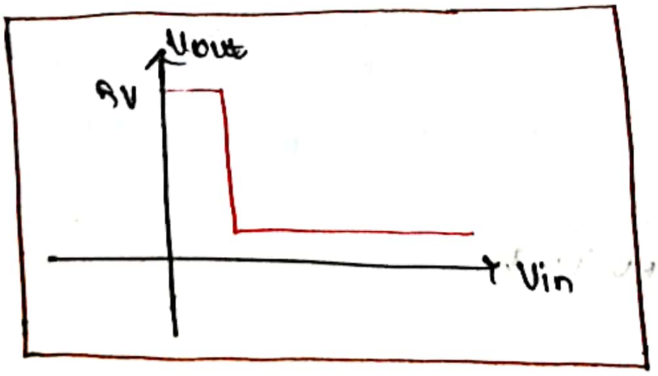
$V_{GS} < V_T$



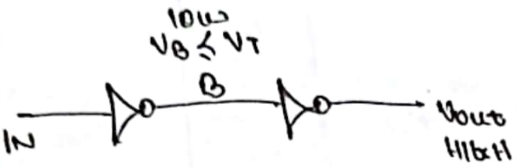
$V_{out_1} = 5V$ high

$V_{GS} \geq V_T$

$V_{out_1, low} = V_S \dfrac{R_{ON}}{R_{ON} + R_L} \neq 0$



DESIGN OF LOGIC GATES



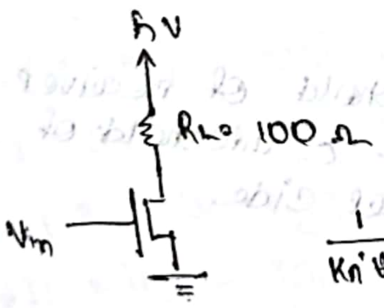
HIGH
$[V_{IN} \geq V_T]$

Condition for designing logic gates:

$V_B = \frac{V R_{ON}}{R_{ON} + R_L}$ must be smaller than V_T $\left[\frac{V R_{ON}}{R_{ON}+R_L} < V_T\right]$

$$R_{ON} = \frac{1}{K'\frac{W}{L}(V_{GS} - V_T)} = \frac{1}{K'\frac{W}{L}V_{OV}}$$

QUESTION:



$$\frac{1}{K_n' \, V_{OV}} = 5$$

$V_T = 1V$

$R_{ON} \leq 2.5$

$$R_{ON} = \frac{1}{K'_n \frac{W}{L}(V_{OV})} \leq 2.5$$

$$\Rightarrow \frac{5}{\frac{W}{L}} < 2.5$$

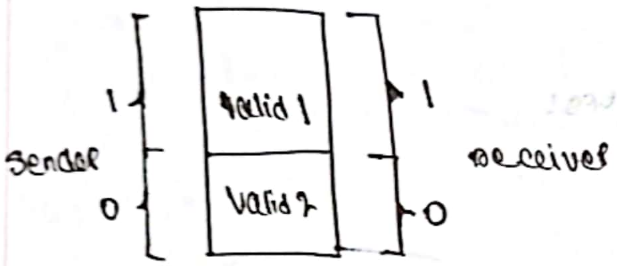
$$\Rightarrow \frac{W}{L} > \frac{5}{2.5} = 2$$

$\therefore \frac{W}{L} > 2$ ~~nm~~ → let $L = 2nm$, $W > 8\ nm$
$= 8.02\ nm$

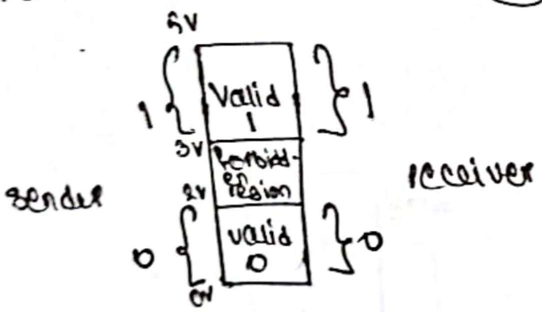
DIGITAL REPRESENTATION

0 → 2.5V (0)

2.5 → 5V (1)

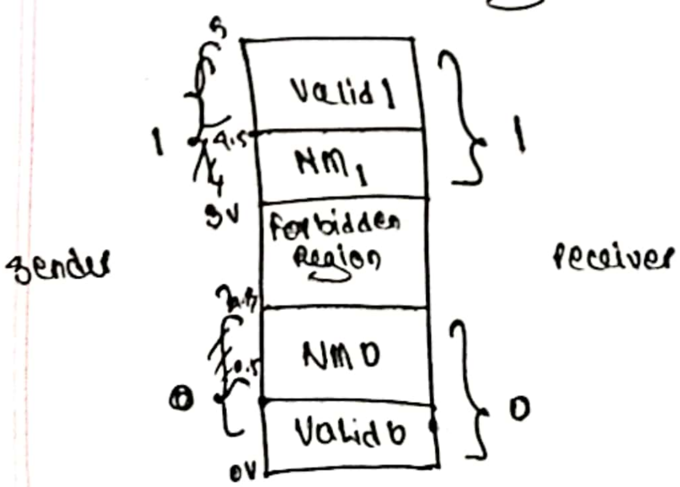


Double threshold based system

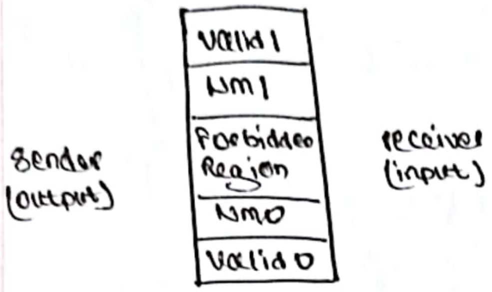


Threshold of receiver side > Threshold of sender side

Four threshold based system



[Slide 37 - 44]
not included in final.



* The sender is taken as output and the receiver is taken as input.
* The input receiver provides the input voltage.

$V_{OL} = 0.5V$

$V_{OH} = 4.5V$

STATIC DISCIPLINE

* V_{OL} & V_{OH} do not change with time, so it falls under static discipline.

V_{OH} = output high voltage threshold

V_{OL} = output low voltage threshold

V_{IH} = input high voltage threshold

V_{IL} = input low voltage threshold

Noise Margins

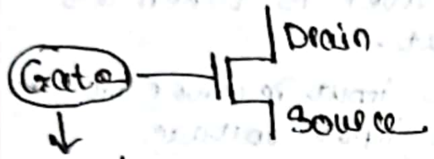
$NM_1 = V_{OH} - V_{IH}$

$NM_0 = V_{IL} - V_{OL}$

$V_{OL} < V_{IL} < V_{IH} < V_{OH}$

ONLINE
L-2
LECTURE
16

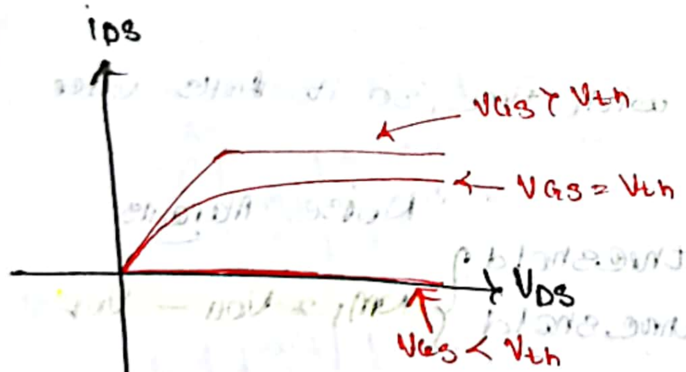
MOSFET



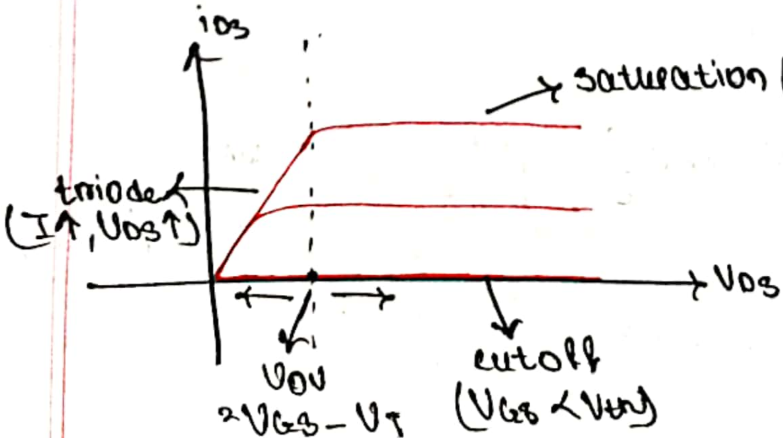
control terminal

$V_{GS} < V_{th} \longrightarrow$ D S (OFF)

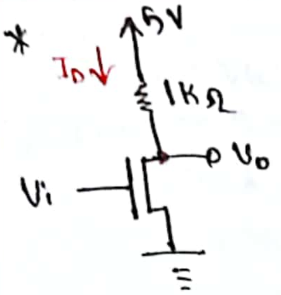
$V_{GS} \geq V_{th} \longrightarrow$ D S (ON)



* i–V:



↳ At this point, RHS → saturation
" " LHS → triode

* 

$\boxed{?}$ $I_D = ?$

* cutoff : $V_{GS} < V_{th}$, $I_D = 0$

* triode : $I_D = K\left[V_{ov}V_{DS} - \frac{1}{2}V_{DS}^2\right]$, $V_{GS} \geq V_T$, $V_{DS} < V_{ov}$

$K = K_n' \frac{W}{L}$ Unit: mA/V^2

$\longrightarrow$ process trans-conductance

V_{ov} = overdrive voltage [drain এবং source এর ভিতরে যে voltage থাকে]

* $V_{th} = 1V$

$V_{GS} = 0.8V \longrightarrow$ OFF

$V_{GS} = 0.99V \longrightarrow$ OFF

$V_{GS} = 1V \longrightarrow$ ON

$V_{GS} = 1.8V \longrightarrow$ ON

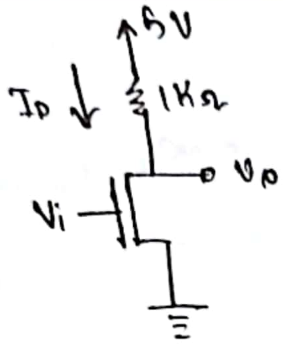
$V_{ov} = V_{GS} - V_{th} = 1.8 - 1 = 0.8V$

* saturation: $V_{GS} \geq V_{Th}$, $V_{DS} \geq V_{ov}$

$i_{DS} = \frac{1}{2}KV_{ov}^2$

For MOSFET, find assumption using saturation at first.

*



(i) $I_D = ?$

(ii) $V_D = ?$

Given,

$K = 0.5 \; mA/V^2$

$V_{Th} = 1V$

(i) $V_i = 2V$, (ii) $V_i = 5V$

Method of assumed state:

Step 1: Assume

Step 2: Solve

Step 3: Verify

(i) $V_i = 2V$

* Sol^n: Let the mosfet is in saturation region

$\therefore i_{DS} = \frac{1}{2} K V_{OV}^2$

$V_{OV} = V_{GS} - V_{Th} = (V_G - V_S) - V_{Th}$

$= (V_i - 0) - 1$

$= (2 - 0) - 1$

$= 1V$

$\therefore i_{DS} = \frac{1}{2} K V_{OV}^2$

$= \frac{1}{2}(0.5)(1)^2$

$i_{DS} = 0.25 \; mA$

$I_D = i_{DS} = 0.25 \; mA$

$I_D = \frac{5 - V_0}{1} \Rightarrow I_D = 5 - V_0$

~~$I_D = 5$~~

$0.25 = 5 - V_0$

$V_0 = 4.75V$ $\therefore V_D = V_0 = 4.75V$

Here,

$V_{GS} = V_G - V_S$

$= 2 - 0$

$= 2 > V_{Th}$ .... $V_{GS} \geq V_{Th}$ ✓

$V_{DS} = V_D - V_S$

$= 4.75 - 0$

$= 4.75 > 1V$ ..... $V_{DS} \geq V_{ov}$ ✓

∴ The assumption is correct.

(ii) $V_i = 5V$

* Sol^n: let the mosfet is in saturation region

$i_{DS} = \frac{1}{2} K V_{ov}^2$

$V_{ov} = V_{GS} - V_{th}$

$= (V_G - V_S) - V_{th}$

$= (5 - 0) - 1$

$V_{oc} = 4$

∴ $i_{DS} = \frac{1}{2} K V_{ov}^2$

$= \frac{1}{2}(0.25)(4)^2 = 4mA$

$V_D = 5 - i_D = 5 - 4 = 1V = V_D$

$V_{DS} = V_D - V_S = 1 - 0 = 1V$

Here,

$V_{GS} = V_G - V_S = 5V > V_{Th}$ ✓

$V_{DS} = V_D - V_S = 1V < V_{ov}$ ✗

∴ The assumption is incorrect.

let the mosfet is in saturation region

$i_D = K\left[V_{ov} V_{DS} - \frac{1}{2} V_{DS}\right]^2$

$V_{DS} = V_D - V_S$

$= V_D - 0 = V_D$

$i_D = 0.5\left[4V_D - \frac{1}{2}V_D^2\right]$

$i_D = \frac{5 - V_D}{1} \Rightarrow 5 - V_D = i_D$

$\therefore 5 - V_D = 0.5\left[4V_D - \frac{1}{2}V_D^2\right]$

$\Rightarrow 10 - V_D = 0.5\left[8V_D - V_D^2\right]$

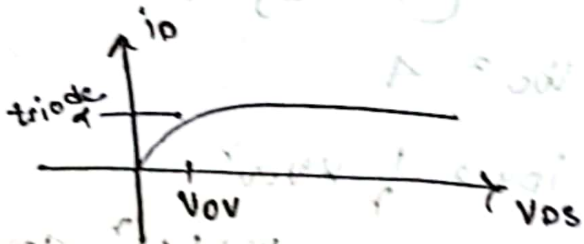
$\Rightarrow 10 - V_D = 4V_D - \frac{1}{2}V_D^2$

$\Rightarrow \frac{1}{2}V_D^2 - 5V_D + 10 = 0$

$\therefore V_D = 2V, 10V$

$V_{DS} = V_D - V_S$
$\qquad\quad \downarrow 0$

$V_{DS} = V_D$



$V_{GS} = V_G - V_S$

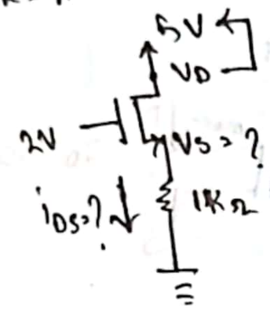
$= 5 - 1 = 4V > V_{Th}$ $\qquad V_{GS} > V_{Th}$ ✓

$V_{DS} = 2V, V_{ov} = 1V$

$\therefore$ ~~Vosk Real~~ $\qquad V_{DS} < V_{ov}$ ✓

CamScanner

Ex-2



$K = 4 mA/V^2$

$V_{th} = 1V$

Here $V_D = 5V$, $V_G = 2V$

let the ~~SA~~ mosfet is in the saturation region

$i_{DS} = \frac{1}{2} K V_{ov}^2$

Here $V_{ov} = V_{GS} - V_{Th} = (V_G - V_S) - V_{Th}$

$= (2 - V_S) - 1$

$= 1 - V_S$

$\therefore i_{DS} = \frac{1}{2} K V_{ov}^2$

$= \frac{1}{2} \times 4 \times (1 - V_S)^2$

$= 2(1 - V_S)^2$

$i_{DS} = \frac{V_S - 0}{1} = V_S$

$\therefore V_S = 2(1 - V_S)^2$

$\Rightarrow 2V_S^2 - 5V_S + 2 = 0$

$\Rightarrow V_S = 0.5V,\ V_S = 2V$

Here,

$V_{GS} = V_G - V_S$

$= 2 - 0.5 > 1V$

$= 1.5 > 1$ ✓

$V_{DS} = V_D - V_S$

$= 5 - 0.5$

$= 4.5 > V_{ov}$ ✓

$V_{ov} = V_{GS} - V_{Th} = 1.5 - 1$

$= 0.5V$

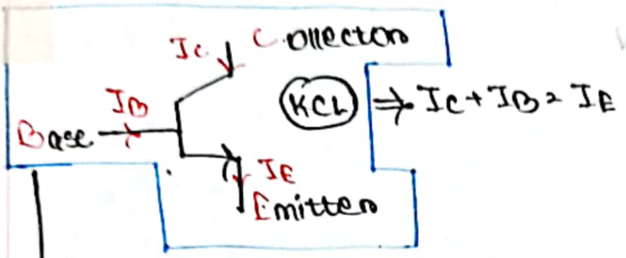
sat
$\begin{cases} V_{GS} \geq V_{Th} \\ V_{DS} \geq V_{ov} \end{cases}$

LECTURE 17

WEDNESDAY

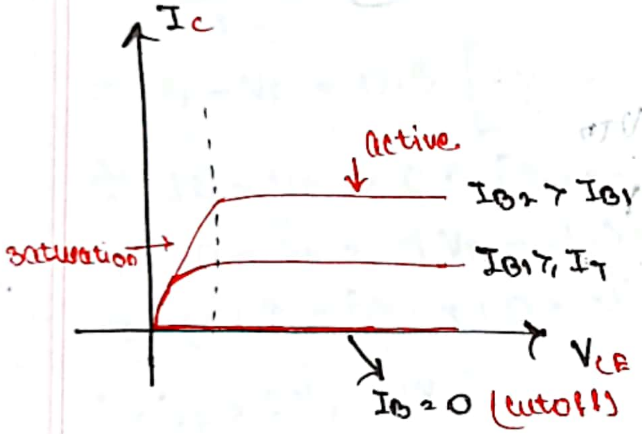
DATE: 05/04/23

* Bipolar Junction Transistor (BJT):



control terminal

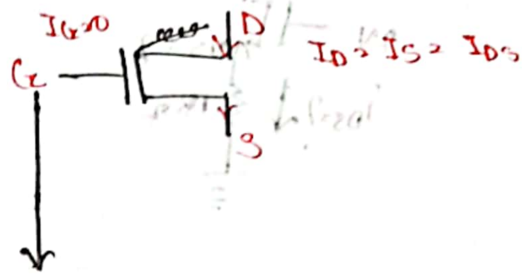
control signal: I_B



$\mu_{BJT} > \mu_{MOS}$

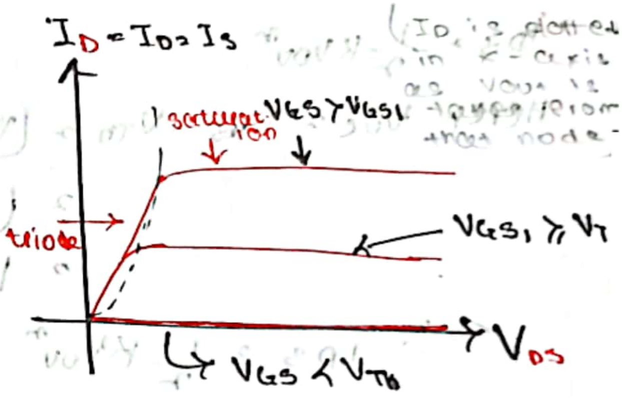
$R_{BJT} < R_{MOS}$

* MOSFET

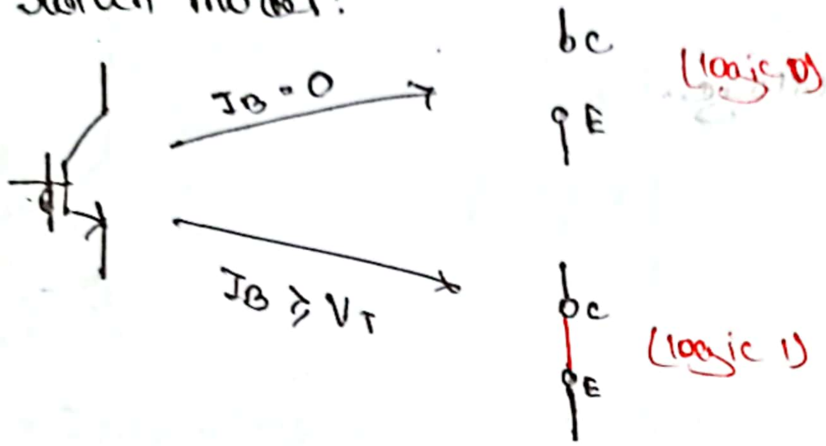


control terminal

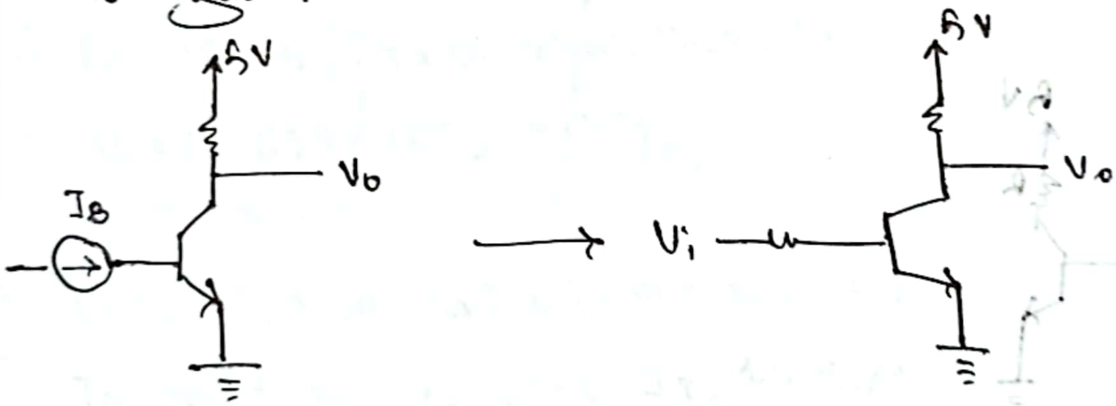
control signal: V_{GS}



* Switch model:



* NOT gate:

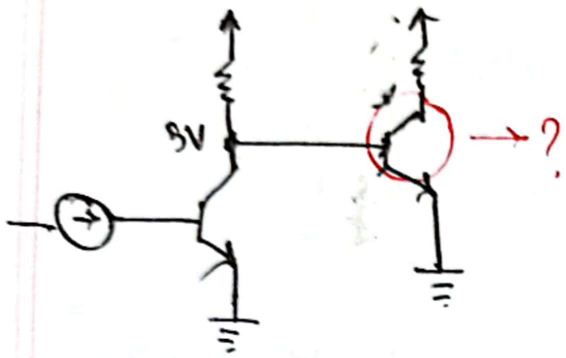


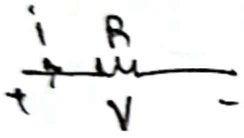
$I_B = 0 \rightarrow$ OFF $\rightarrow V_o = 5V$ (1)

$I_B \geq V_T \rightarrow$ ON $\rightarrow V_o = 0V$ (0)

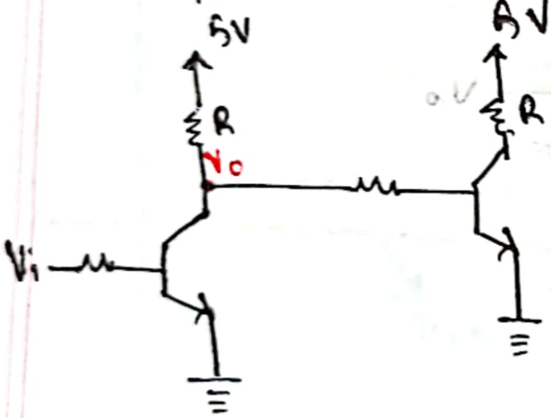
*Problem

(i) input current, output voltage.

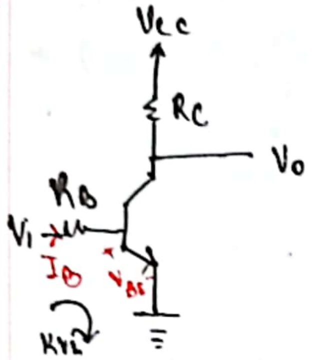




$i = \frac{V}{R}$



(ii) difficult to build a good current source.
I_D এর জন্য D তে CS দিয়ে I flow করলে ON/OFF হয়, ওই CS এর জন্য আবার mosfet use করা, এটাই problem.



$V_i = I_B R_B + V_{BE}$

if $I_B = I_T$,

$\therefore V_i = V_T R_B + V_{BE}$

if $R_B = 100K\Omega$, $I_T = 0.022mA$, $V_{BE} = 0.7V$

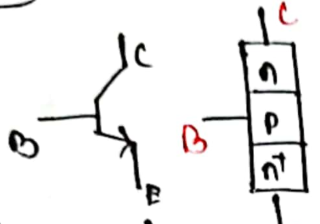
$\therefore V_i = (0.022 * 100) + 0.7$
$\approx 3V$

[If $Vi != 3V$, then BJT will not be ON]

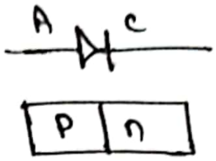
$\therefore I_B$ must be at least I_T to turn the BJT on

$\therefore V_i$ must be at least $(I_T R_B + V_{BE})$ .... BJT on.

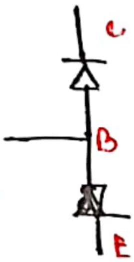
Physical structure:

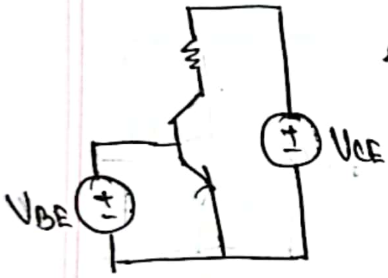


(3 terminal)



(2 terminal)





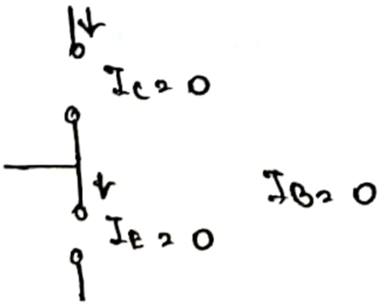
BC	BE	
OFF	OFF	cutoff
ON	ON	saturation
ON	OFF	Active
OFF	ON	reverse active

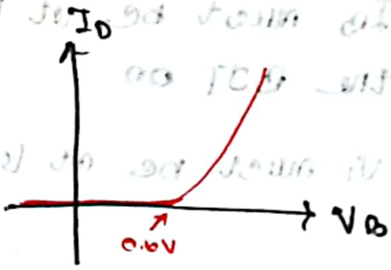
$V_{BC} = V_B - V_C$

$= (V_B - V_E) - (V_C - V_E) = V_{BE} - V_{CE}$

* case 1: BC off, BE off [cutoff]

$V_{BE} - V_{CE} < 0.6$ $\qquad$ $V_{BE} < 0.7$





to turn BC off,

$V_{BC} < 0.6\,V$

$\Rightarrow V_{BE} - V_{CE} < 0.6$

to turn BE off,

$V_{BE} < 0.7V$ [active]

$V_{BE} < 0.8V$ [saturation]

Ic and IE = 0, so there is no route for IB to flow.

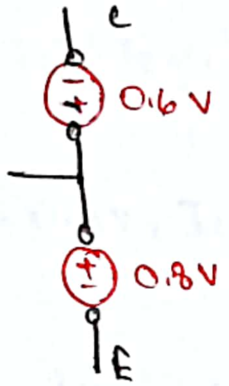
$\therefore I_B = 0$

* Case 2 : BC ON , BE ON [saturation]

$V_{BE} - V_{CE} \geq 0.6$

~~VBE~~ $I_B > 0$

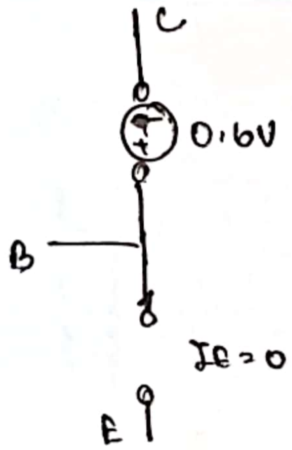
$I_C > 0$



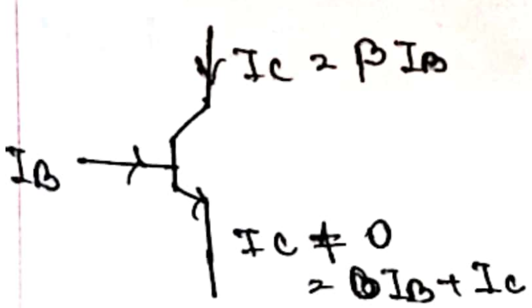
$\cancel{V_{BE}} - V_{CE} = V_{BE} - V_{BC}$
$= 0.8 - 0.6$
$= 0.2V$

~~* case 3:~~

* Case 3 : BC ON , BE OFF [active]



For this condition, if we use diode, I_E will be 0. But, here will be needing the value of I_E. So, BJT is used instead.



MOSFET

region	formula	condition
saturation	$I_D = \frac{1}{2} K V_{ov}^2$	$V_{GS} \geq V_T$ $V_{DS} \geq V_{ov}$
triode	$I_D = K(V_{DS}V_{ov} - \frac{1}{2}V_{DS}^2)$	$V_{GS} \geq V_T$ $V_{DS} < V_{ov}$
cutoff	$I_D = 0$	$V_{GS} < V_T$

BJT

region	formula	condition
active	$V_{BE} = 0.7V$ $I_C = \beta I_B$	$V_{CE} > 0.2$
saturation	$V_{BE} = 0.8V$ $V_{CE} = 0.2V$	$\frac{I_C}{I_B} < \beta$
cutoff	$I_B = I_C = I_E = 0$	$V_{BE} < 0.7$

LECTURE 18

MONDAY DATE: 10/01/23

*Method of Assumed State

Step 1: Assume

- cutoff $[I_B = I_C = I_E = 0]$
- active $[V_{BE} = 0.7V, I_C = \beta I_B]$
- saturation $[V_{BE} = 0.8V, V_{CE} = 0.2V]$

Step 2: Solve

Step 3: Verify

- cutoff $V_{BE} < 0.7V$
- active $V_{CE} > 0.2V$
- saturation $\frac{I_C}{I_B} < \beta$

For BJT, start assuming with active region.

*Ex 1: $\beta = 100$

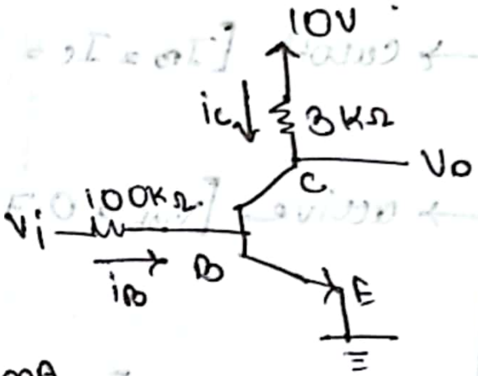
$V_i = 1V$

Let, the BJT is in active region.

$\therefore V_{BE} = 0.7V$

$V_B - \underset{\downarrow \atop 0}{V_E} = 0.7$

$\Rightarrow V_B = 0.7V$



$\therefore I_B = \dfrac{V_i - V_B}{100} = \dfrac{1 - 0.7}{100} = 0.003 \text{ mA}$

$\therefore I_C = \beta I_B$

$= (100)(0.003)$

$= 0.3 \text{ mA}$

Here, $I_C = \dfrac{10 - V_C}{3}$

$\therefore V_C = 10 - 3 * 0.3$

$= 9.1V$

$\therefore V_E = 0, V_{CE} = V_C = 9.1V > 0.2V$

ex 1: $\beta = 100$
$V_1 = 5\,V$

let the BJT is in active region

$\therefore V_{BE} = 0.7\,V$

$V_B - V_E = 0.7$

$V_B = 0.7\,V$

$\therefore I_B = \dfrac{5 - V_B}{100} = \dfrac{5 - 0.7}{100} = 0.043\,mA$

$I_C = \beta I_B$

$= (100)(0.043)$

$= 4.3\,mA$

Here, $I_C = \dfrac{10 - V_C}{3}$

$V_C = 10 - (3 \times 4.3)$

$V_C = -2.9\,V$

$\therefore V_{CE} = \cancel{0.2}$, $V_{CE} = V_C = -2.9 < 0.2\,V$

$\therefore$ The assumption is incorrect for the active region.

* BJT in Active mode acts like a current controlled current source & amplifier.
* MOSFET in saturation mode acts as a voltage controlled current source.

Let the BJT is in saturation region

$V_{BE} = 0.8V$

$\Rightarrow V_B - \underbrace{V_E}_{0} = 0.8$

$\Rightarrow V_B = 0.8V$

$I_B = \dfrac{5 - V_B}{100}$

$= \dfrac{5 - 0.8}{100}$

$= 0.042 \text{ mA}$

$V_{CE} = 0.2V$

$\Rightarrow V_C - V_E = 0.2$

$\therefore V_C = 0.2V$

$I_C = \dfrac{10 - V_C}{3}$

$= \dfrac{10 - 0.2}{3}$

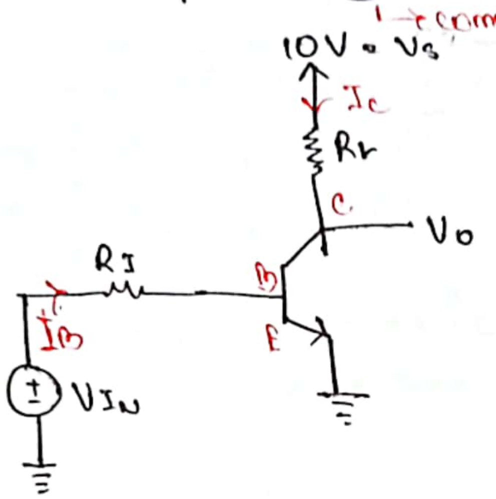
$I_C = 3.3 \text{ mA}$

$\dfrac{I_C}{I_B} = \dfrac{3.3}{0.042} = 78.57 < \beta$ ✓

LECTURE 19

WEDNESDAY DATE: 12/04/23

*BJT amplifier (CE configuration):
→ common emitter



R_I → connected to V_{IN}

R_L → connected to V_S

Types of amplifiers

(1) Voltage amplifier (IN = V, Out = V)

(2) Current amplifier (IN = I, Out = I)

(3) Transconductance amplifier (IN = V, Out = I)

(4) Transresistance amplifier (IN = I, Out = V)

→ Check, $\frac{O/P}{I/P} = \frac{V}{I} = R$

→ Check, $\frac{O/P}{I/P} = \frac{I}{V} = \frac{1}{R} = G$ (Conductance)

emitter is between V_I and V_0, so emitter is common here.

For amplification, we have to choose the active region.

Active

$I_C = \beta I_B$ [Increasing V_{in}, increase I_B which increases I_C]

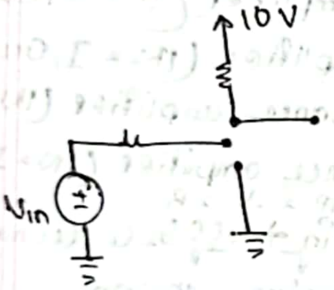
$$0.7 < V_{in} < 0.7 + \frac{V_S - 0.7}{\beta R_L} R_I$$

* If $V_{in} < 0.7$, BJT will be in cutoff region and no current flows.

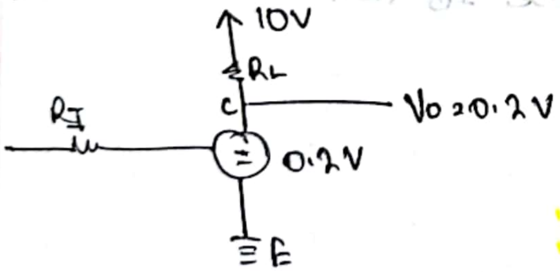
* If $V_{in} > 0.7 + \frac{V_S - 0.7}{\beta R_L} R_I$, BJT will be in saturation region.

	cutoff	active	saturation
	$0.7 <$	$V_{in} <$	$0.7 + \frac{V_S - 0.2}{\beta R_L} R_I$
V_o	V_S	$V_S + \frac{0.7\beta R_L}{R_I} - \frac{\beta R_L}{R_I} V_{IN}$	0.2

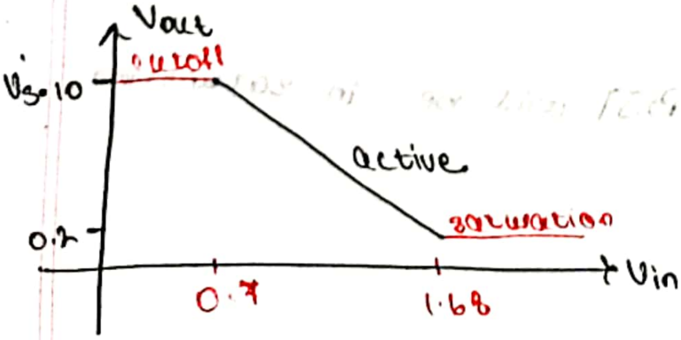
at cutoff,



at saturation,



Transfer characteristics



say,

$R_I = 100\,K\Omega$

$\beta = 100$

$V_S = 10$ V

$R_L = 10K\Omega$

$$0.7 + \frac{V_S - 0.2}{\beta R_L} R_I = 1.68\text{V}$$

$$\therefore V_o = V_S + \underbrace{\frac{0.7\beta R_L}{R_I}}_{\text{constant}} - \underbrace{\frac{\beta R_L}{R_I}}_{\text{amplifier factor}} V_{IN}$$

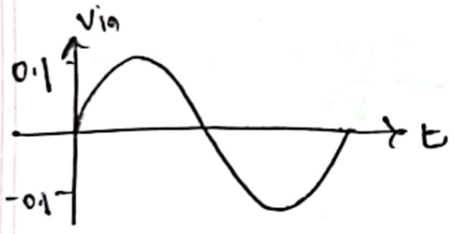
$$V_o = 17 - 10\,V_{IN}$$

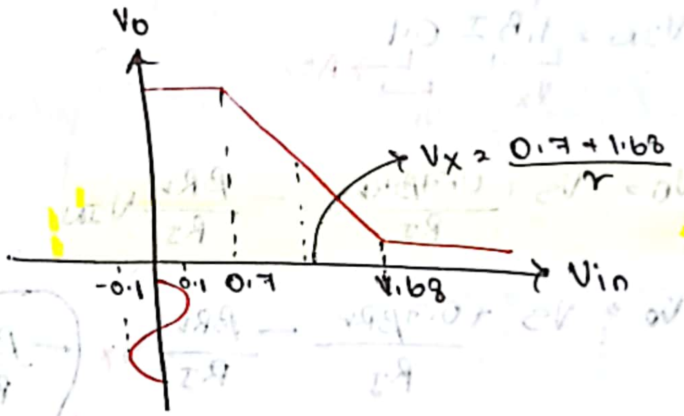
$$\boxed{0.7 < V_{in} < 1.68}$$

→ BJT will be in active region in this range.

V_{IN}	V_O
0.6V	10V
0.8V	✓
1V	7V
1.5V	✓
1.8	0.2V

* This model is called "small signal ~~amplification~~ approximation" as it only works for smaller input.





$V_i = 0.1 \underbrace{\sin\omega t}$

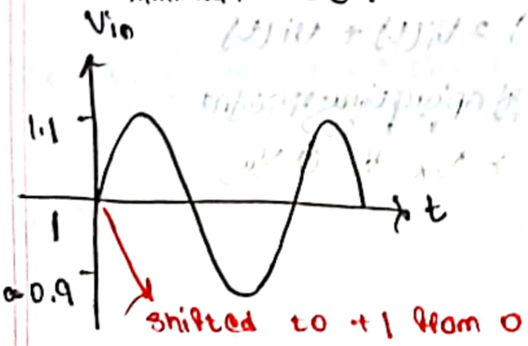
max^m = 1

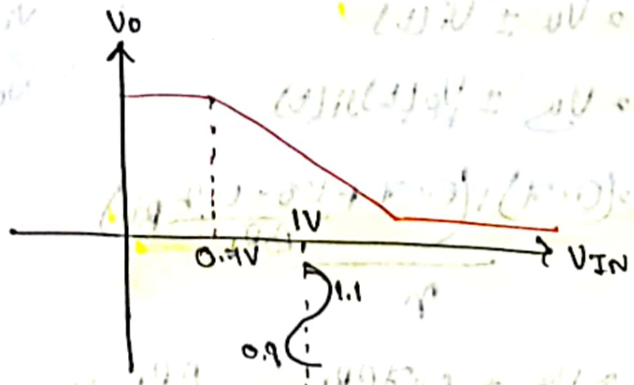
minimum = -1

max^m = +0.1

minimum = -0.1

* The Vin ~~for~~ is less than 0.7, so it lies in cutoff. Thus, cannot be amplified using a BJT.





* A DV voltage is used to shift the cutoff region to the middle of active region.

* V_L & V_H are the operating points.

* A DC ~~volt~~ offset voltage needs to be added.

* The curve must lie completely within the active region.

* Midpoint of active region needs to be find out to get the appropriate swing point.

$V_{IN} = \underbrace{1.5}_{V_x} \pm \underbrace{0.1}_{V_i}$ (1.5 → DC, 0.1 → AC)

$$V_O = V_S + \frac{0.7\beta R_L}{R_I} - \frac{\beta R_L}{R_I} V_{IN}$$

$$V_o = \underbrace{V_S + \frac{0.7\beta R_L}{R_I} - \frac{\beta R_L}{R_I} V_x}_{V_y} - \frac{\beta R_L}{R_I} V_i(t)$$

$$+ K V_i(t)$$

$V_i = V_x \pm V_i(t)$

$V_i(P\text{-}P) = V_i(t) + V_i(t)$

$V_o = V_y \pm |K| * V_i(t)$

$V_o(P\text{-}P) = |K| * V_i(t)$

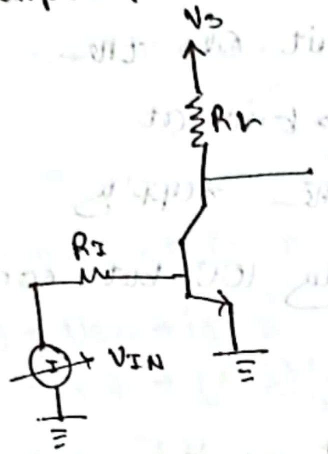
$$V_x = \frac{(0.7) + \left(0.7 + \frac{V_S - 0.2}{\beta R_L} R_I\right)}{2}$$

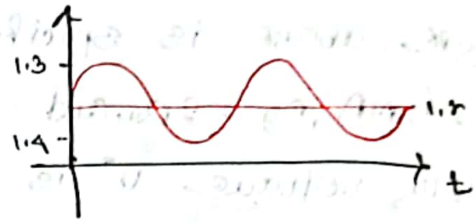
$$V_y = V_S + \frac{0.7\beta R_L}{R_I} - \frac{\beta R_L}{R_I} V_x$$

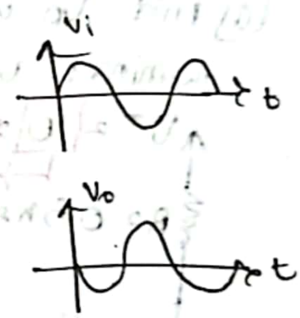
$$K = -\frac{\beta R_L}{R_I}$$

$V_i(t) = V_x - 0.7$ or $V_i(t) = V_x + \frac{V_S - 0.2}{\beta R_L} R_I - V_x$

Example 1







(a) $V_{o} = V_S + \frac{0.7\beta R_L}{R_I} - \frac{\beta R_L}{R_I} V_{IN}$

(b) $K = -\frac{\beta R_L}{R_I}$

(c) $V_i\ (P-P) = 0.1 + 0.1 = 0.2V$

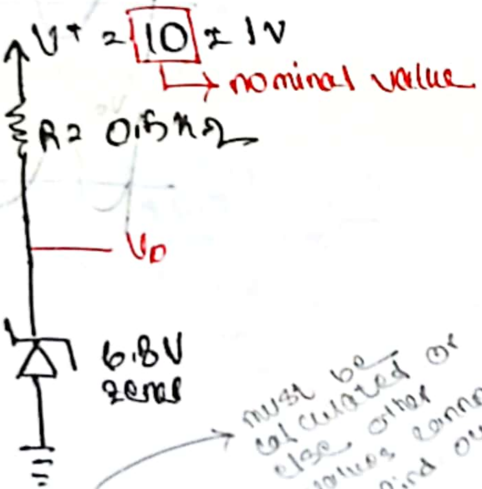
(d) $V_o\ (P-P) = |K| * V_i\ (P-P)$?

PRACTICE PROBLEM

The ~~6~~6.8-V zener diode in the circuit of the figure above is specified to have $V_Z = 6.8V$ at $I_Z = 5mA$, $r_Z = 20\Omega$, and $I_{ZK} = 0.2mA$. The supply voltage V^+ is ~~not really~~ nominally 10V but can vary by ±1V.

I_{ZK} → Knee current

(a) find V_o with no load and with V^+ at its nominal value.

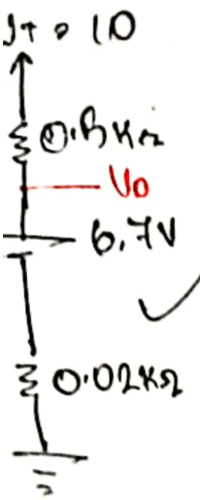


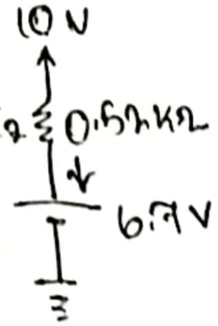
must be calculated or else other values cannot be find out.

$V_Z = V_{Z0} + i_Z r_Z$

$6.8 = V_{Z0} + (5 \times 0.02)$ $\left[\frac{20}{1000} k\Omega\right]$

$V_{Z0} = 6.7V$





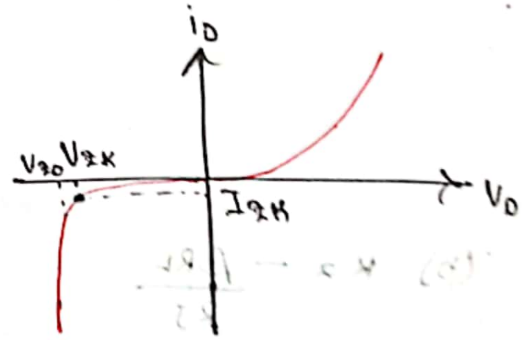
$I_Z = \frac{10-6.7}{0.52}$

$= 6.35 \text{ mA}$

$I_Z = \frac{10 - V_o}{0.5}$

$V_o = 10 - 0.5 * I_Z \Rightarrow \boxed{V_o = 6.83V}$

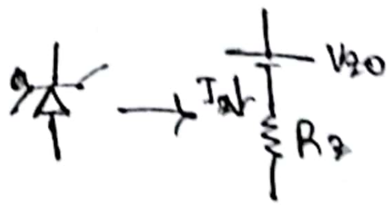
REVIEW



zener diode starts to work as regulator

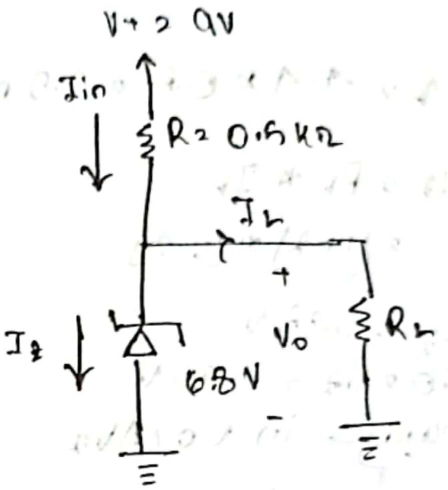
V_{ZK} (Knee voltage): The voltage at which current starts to drop.

I_{ZK} (Knee current): The current at V_{ZK}.



$V_Z = V_{Z0} + I_Z r_Z$

(b) What is the minimum value of R_L for which the diode still operates as an operator? (worst case → minimum value নিতে হবে)



$V^+ = 9V$

$I_Z = I_{ZK} = 0.2\,mA$

$V_Z = V_{Z0} + i_Z R_Z$

$= 6.7 + (0.2)(0.02)$

$\approx 6.7\,V$

$$I_{in} = \frac{9 - V_Z}{0.5}$$

$$= \frac{9 - 6.7}{0.5}$$

$\approx 4.6\,mA$

Applying KCL,

$I_{in} = I_Z + I_L$

$4.6 = 0.2 + I_L$

$I_L = 4.4\,mA$

$$R_L = \frac{V_Z}{I_L} = \frac{6.7}{4.4} = (1.52)\,k\Omega$$

(c) Explain the change in output voltage if the load current is reduced by 50%.

$I_L = 4.4 * 0.5 = 2.2$ mA

$V_2 = R_L * I_L$

$= (1.52) * (2.2)$

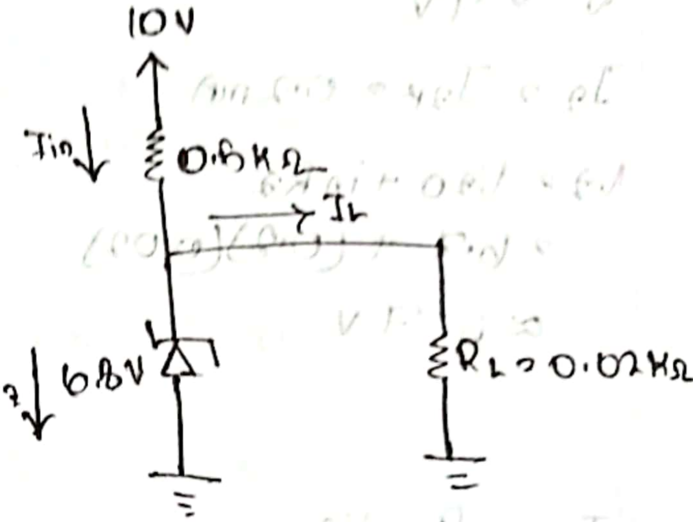
$V_2 = 3.35$ V

$V_O = V_2 = 3.35$ V

change in V_O / ΔV_2

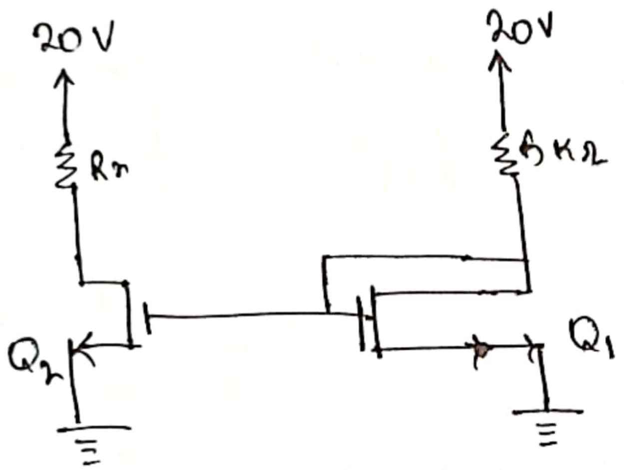
$= 6.7 - 3.35$

$= 3.35$ V



In this circuit above, the MOSFETs have the following parameters, $K'_n = 2mA/V^2$, $\frac{W}{L} = 2.5$, $V_T = 0.5V$

(a) find out the operating mode of Q_1 [Hint: for Triode mode $V_{DS} < V_{OV}$ and for saturation $V_{DS} \geq V_{OV}$]



$V_S = 0V$

$V_{GS} = V_G - V_S = V_G$

$V_{DS} = V_D - V_S = V_D$

$V_{OV} = V_{GS} - V_T$

Here, $V_D = V_G$

$V_{DS} = V_{GS}$

$\therefore V_{DS} > V_{OV}$

$\therefore$ saturation

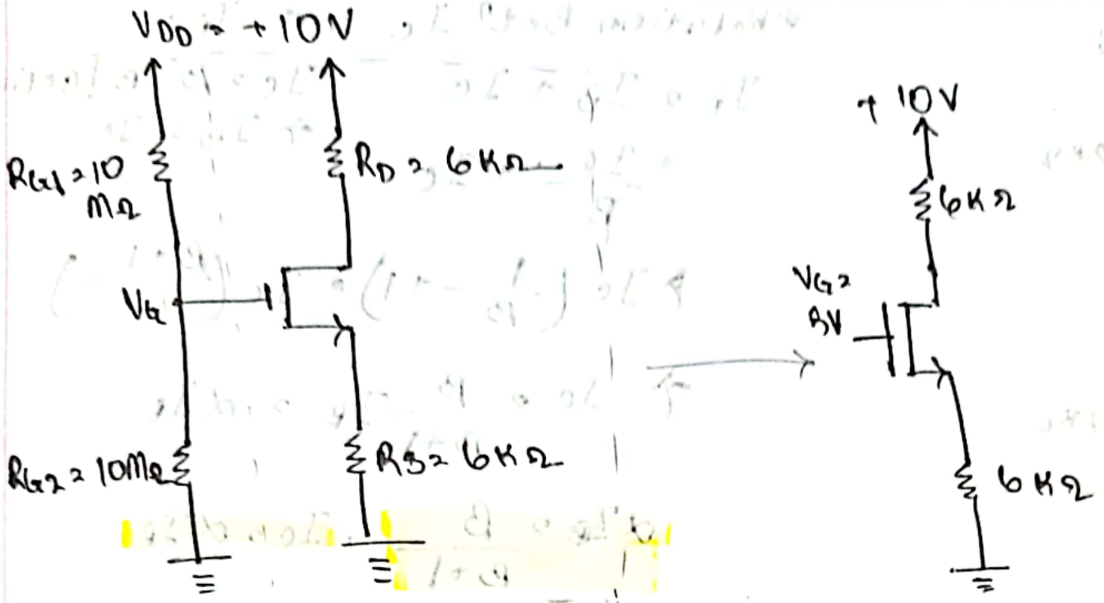
$$i_D = \frac{1}{2} K_n V_{OV}^2 = \frac{1}{2}\left(K_n' \frac{W}{L}\right) * V_{OV}^2$$

$$= \frac{1}{2} \times 2 \times 2.5 \left(V_{GS} - V_T\right)^2$$

$$= 2.5\left(V_D - 0.5\right)^2$$

$$\therefore i_D = \frac{20 - V_D}{5} = 2.5\left(V_D - \frac{1}{2}\right)^2$$

(b) Find the value of R_2 that results in Q_2 operating at the edge of saturation point.



$$V_G = \frac{R_{G2}}{R_{G2} + R_{G1}} * V_{DD}$$

$$= \frac{10}{10+10} * 10$$

$$V_G = 5\,V$$

Let the diode be in saturation region

$$i_D = \frac{1}{2} K (V_{GS} - V_T)^2$$

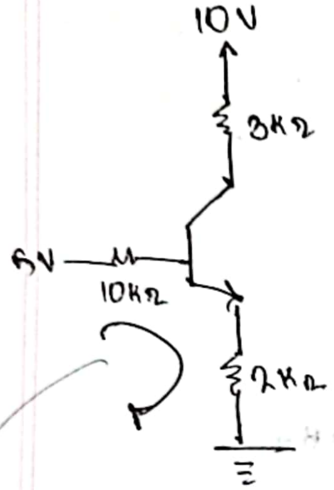
known values

$$= \frac{1}{2} K ((V_G - V_S) - V_T)^2$$

$= i_S$ value need to find

$$= \frac{V_S - 0}{6}$$

$V_S =$



*Relation Betn I_C and I_E:

$I_E = I_B + I_C$

$= \frac{I_C}{\beta} + I_C$

$\Rightarrow I_C\left(\frac{1}{\beta}+1\right) = I_C\left(\frac{\beta+1}{\beta}\right)$

$\Rightarrow I_C = \frac{\beta}{\beta+1} I_E = \alpha I_E$

$I_C = \beta I_B$ [active]

$\Rightarrow I_B = \frac{I_C}{\beta}$

$\alpha = \frac{\beta}{\beta+1}$, $I_C = \alpha I_E$

Here,

$V_{BE} = 0.7$ V [active]

$\beta = 100$

applying KCL, $5 = 10 I_B + V_{BE} + 2 I_E$

$= 10 I_B + V_{BE} + 2 * \frac{\beta}{\alpha} I_B$

$I_C = \alpha I_E$

$\beta I_B = \alpha I_E$

$I_E = \frac{\beta}{\alpha} I_B$

Here,

$\beta = 100$

$\alpha = \frac{100}{100+1}$

$\frac{\beta}{\alpha} = 100 \times \frac{101}{100}$

$= 101$

$5 = 10 I_B + 0.7 + 2 * 101 * I_B$

$I_B = 0.02$ mA

$I_C =$

$I_E =$

$I_C = \frac{10 - V_C}{3} \Rightarrow \frac{10 - 3I_C}{2}$

Assignment 2 (AP1)

(1) (a) $V_Z = V_{ZO} + I_Z r_Z$

$\Rightarrow 5.75 = V_{ZO} + (5 \times 0.05)$

$\Rightarrow V_{ZO} = 5.5 V$

(b) $V_{in} = V_{in(min)} = 10 - 0.1 = 9.9 V$

$I_Z = I_{ZK} = 0.3 \text{ mA}$

$V_Z = V_{ZO} + I_Z r_Z$

$= 5.5 + (0.3 \times 0.05)$

$V_Z = 5.51 V$

(c) $I_L = \dfrac{V_Z}{R_L}$

$= \dfrac{5.51}{10}$

$I_L = 0.551 \text{ mA}$

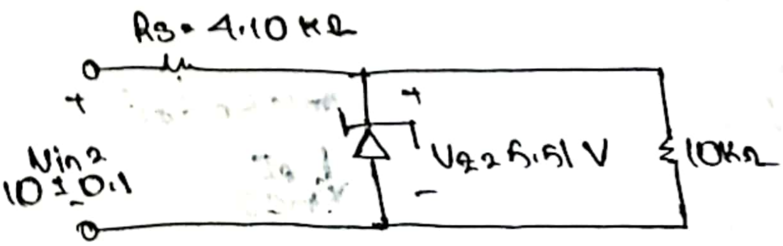
$I_S = I_Z + I_L$

$I_S = 0.3 + 0.551 \Rightarrow I_S = 0.851 \text{ mA}$

(d) $I_S = \dfrac{V_{in} - V_Z}{R_S}$

$0.851 = \dfrac{9 - 5.51}{R_S}$

$R_S = 4.10 \text{ k}\Omega$



(3) (a) $I_Z = I_{ZK} = 0.75$ mA

$V_Z = V_{Z0} + I_Z r_{Z}$

$V_Z = 4 + (0.75 * 0)$

$V_Z = 4V$

$V_Z = I_L R_L$

$4 = I_L(1)$

$I_L = 4$ mA

$I_3 = I_Z + I_L \Rightarrow I_3 = 0.75 + 1$

$\Rightarrow I_3 = 1.75$ mA

(b) $I_3 = \dfrac{V_{bat} - V_Z}{R_3}$

$1.75 = \dfrac{V_{bat} - 4}{0.1}$

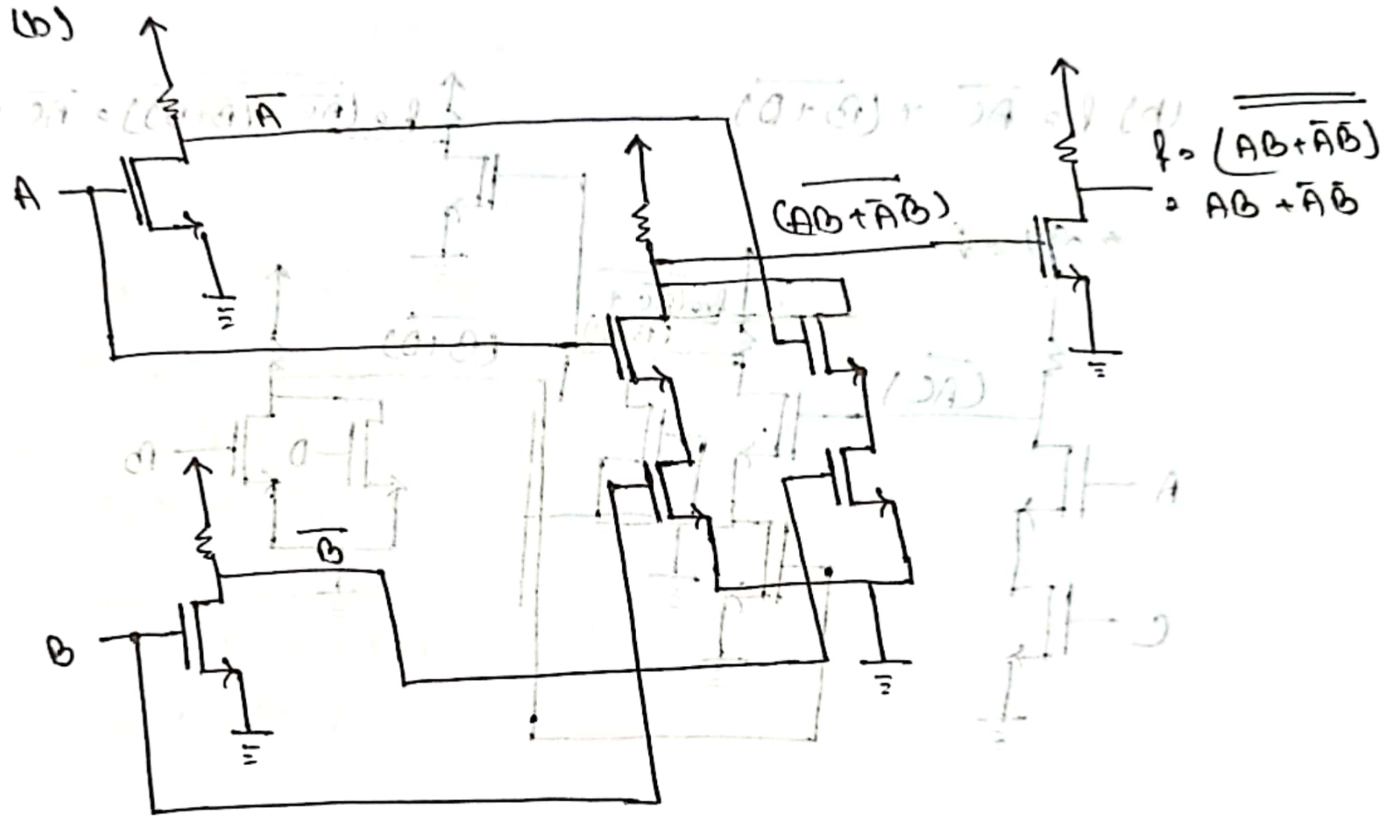
$V_{bat} = 4.175$ V

(c) $V_{bat} \uparrow, I_3 \uparrow, I_Z \uparrow. I_Z > I_{ZK}$ for regulation.

$\therefore V_{bat} \uparrow$ does not affect regulation.

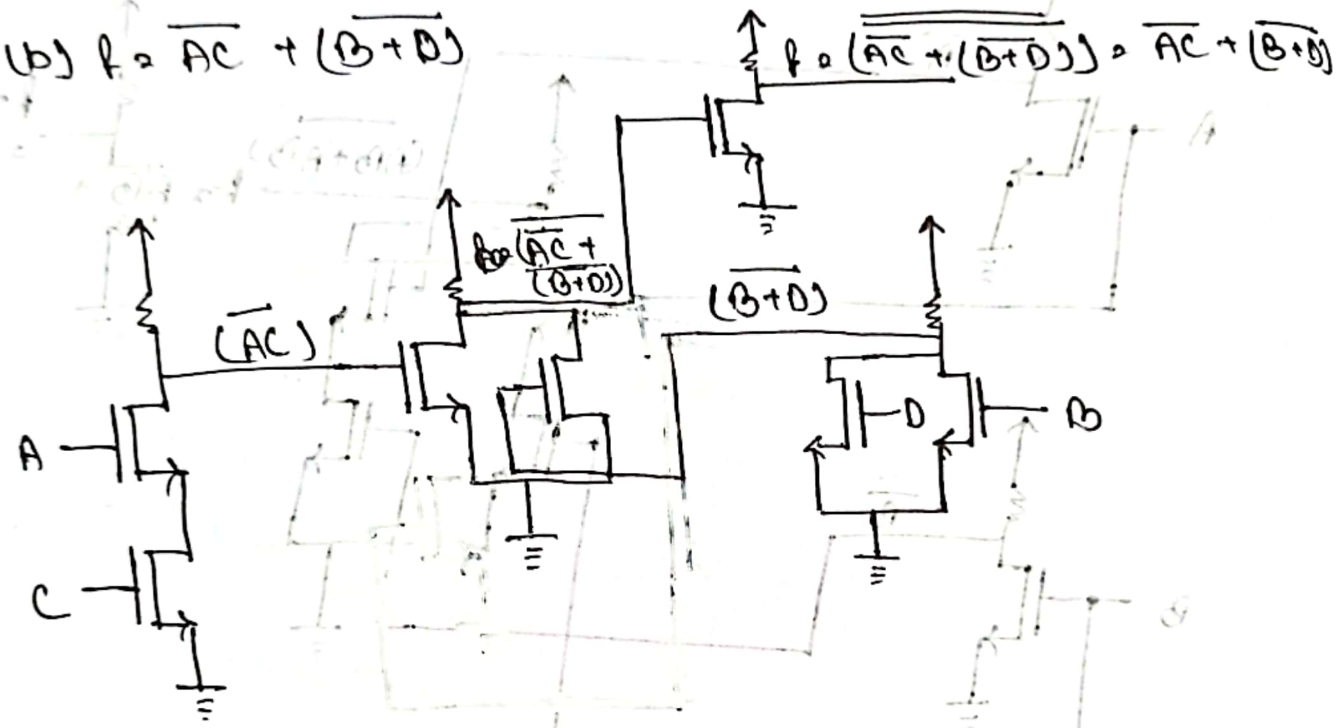
(A) (a) $f = AB + \bar{A}\bar{B}$

(b)



(2) (a) $f = \overline{D(\overline{A}B + C)}$

(b) $f = \overline{AC} + \overline{(B+D)}$



(6)(a) $I_Z = I_{ZK}(min) = 1mA$

$V_Z = V_{Z0} + I_Z R_Z$

$= 9 + (1 * 0.05)$

$V_Z = 9.05 V$

$V_{in} = V_{in}(min) = 11V$

$I_L = I_L(max) = 9mA$

(b) $I_S = I_L + I_Z$

$= 9 + 1$

$I_S = 10 \, mA$

$V_S = V_{in} - V_Z$

$V_S = 11 - 9.05$

$V_S = 1.95 \, V$

(c) $V_S = I_S R_S$

$1.95 = 10 R_S$

$R_S = 0.195 \, k\Omega$

(d) line regulation $= \frac{r_Z}{r_Z + R_S} = \frac{0.05 \times 10^3}{(0.05 + 0.195) * 10^{-3}} = 204.08$

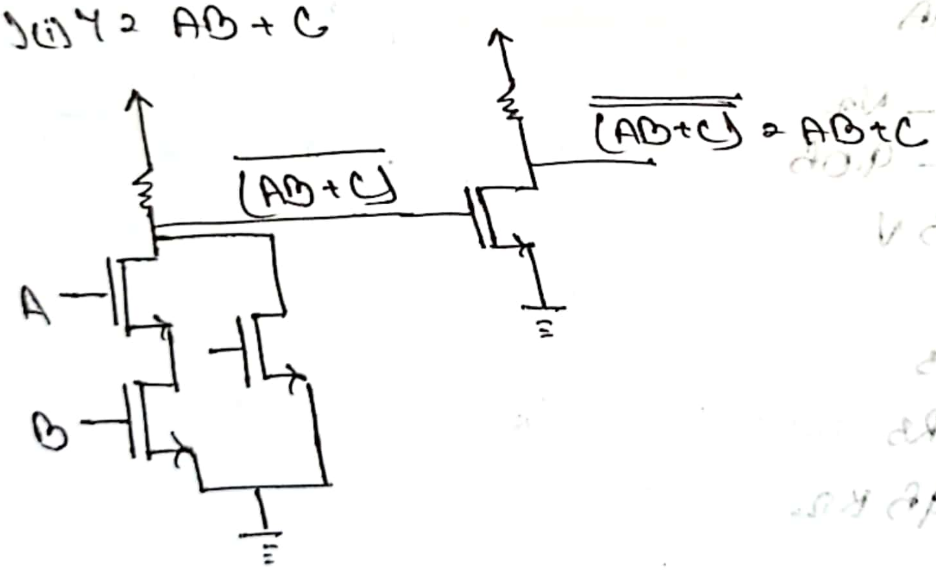
(4) Ckt-1:

$f = \overline{\overline{(A+B)}C}$

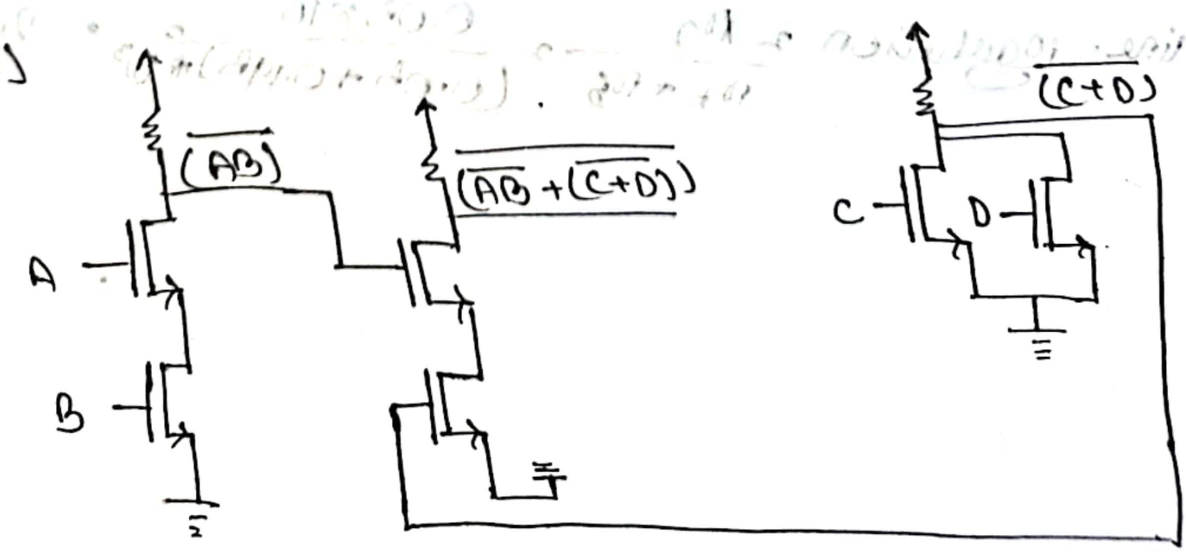
Ckt-2

$f = \overline{\overline{A(B+C)}D}$

(7)(i) $Y = AB + C$

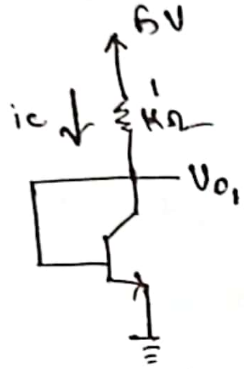


(ii)



Assignment 3 (AEC)

(1)(a)



Let BJT be in active state.

$V_{O_1} = V_C = V_B$

$V_B - V_E = V_{BE}$

$V_B - 0 = 0.7$

$V_B = 0.7V$

$V_{BE} = 0.7V$

$V_{CE} = V_C - V_E$

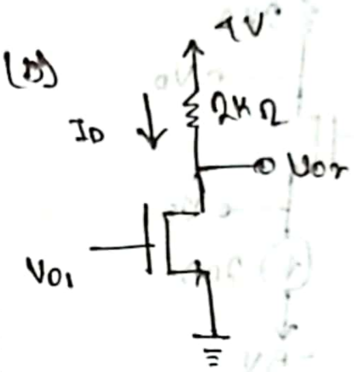
$= 0.7 - 0 = 0.7 > 0.2$ ✓

∴ Assumption is correct.

$V_{O_1} = V_C = 0.7V$

$i_c = \frac{5 - 0.7}{1} \Rightarrow i_c = 4.3mA$

(b)



$V_{O_1} = 0.7V$

Let mosfet be in saturation region

$I_D = \frac{1}{2}K(V_{GS} - V_T)^2$

$= \frac{1}{2}(4)(0.7 - 0 - 0.2)^2$

$I_D = 0.5\ mA$

$V_{GS} = 0.7 - 0 = 0.7 > 0.2$ ✓

$I_{DS} = \frac{4 - V_D}{2}$

$0.5 = \frac{4 - V_D}{2} \Rightarrow V_D = 3V$

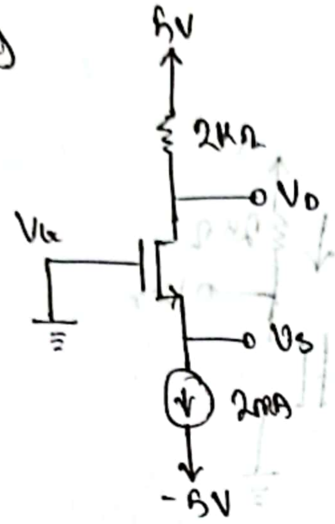
$V_{DS} = 3 - 0 = 3 > 0.5$ ✓

∴ Assumption is correct.

$I_D = 0.5mA$

$V_{O_2} = V_D = 3V$

(2)



(a) $V_G = 0V$, $I_{DS} = 2mA$

(b) $I_{DS} = \frac{5 - V_D}{2}$

$2 = \frac{5 - V_D}{2}$

$V_D = 1V$

(c) Let the mosfet be in saturation region

$I_D = \frac{1}{2}K(V_{GS} - V_T)^2$

$2 = \frac{1}{2}(4)(0 - V_S - 1)^2$

$1 = (-V_S - 1)^2$

$V_S^2 + 2V_S + 1 = 1$

$V_S(V_S + 2) = 0$

$V_S = 0V, V_S = -2V$

$V_{GS} = 0 - 0 \not\geq 1$ ×

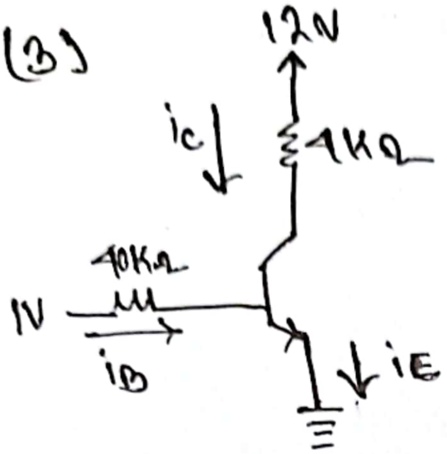
$V_{GS} = 0 - (-2) \geq 1$ ✓

$V_{DS} = 1 - (-2) = 3 \geq 1$ ✓

∴ Assumption is correct

$V_S = -2V$

(3)



Let BJT be in active state

$V_{BE} = 0.7$

$V_B - V_E = 0.7 \Rightarrow V_B - 0 = 0.7$

$\Rightarrow V_B = 0.7V$

$i_B = \dfrac{1-0.7}{40} \Rightarrow i_B = 7.5 \times 10^{-3}$ mA

$i_c = \beta i_B \Rightarrow i_c = (100)(7.5 \times 10^{-3}) = 0.75$ mA

$i_c = \dfrac{12 - V_c}{4} \Rightarrow 0.75 = \dfrac{12 - V_c}{4} \Rightarrow V_c = 9V$

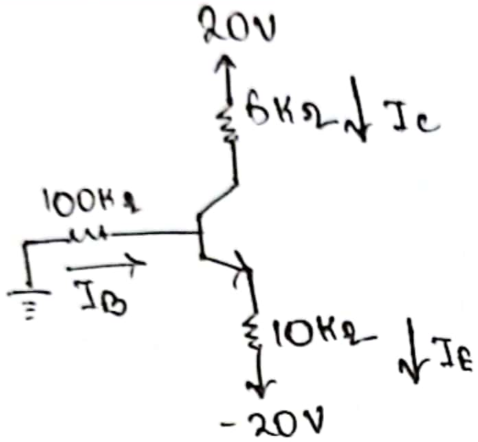
$V_{CE} = V_c - V_E = 9 - 0 = 9 > 0.2$ ✓

∴ Assumption is correct

$i_c = 0.75$ mA

$V_{CE} = 9V$

(4)



Let BJT be in active state

$V_{BE} = 0.7V$

$I_B = \frac{0 - V_B}{100} \Rightarrow V_B = -100 I_B$

$I_C = \frac{20 - V_C}{6} \Rightarrow V_C = 20 - 6 I_C$

$I_E = \frac{V_E + 20}{10} \Rightarrow V_E = 10 I_E - 20$

$I_B + I_C = I_E$ $[I_C = \beta I_B = 100 I_B]$

$I_E = I_B + 100 I_B$

$\Rightarrow I_E = 101 I_B$

$I_E = \frac{-101}{100} V_B$

$V_E = 10\left(\frac{-101 V_B}{100}\right) - 20$

$V_E = \frac{-101}{10} V_B - 20$

$V_{BE} = V_B - V_E$

$0.7 = V_B - \left[\frac{-101}{10} V_B - 20\right]$

$V_B = -1.74V$

$V_E = \frac{-101}{10}(-1.74) - 20$

$V_E = -2.43V$

$I_C = \beta I_B$

$\frac{20 - V_C}{6} = 100\left[\frac{0 - (-1.74)}{100}\right]$

$V_C = 11.3V$

$V_{CE} = V_C - V_E = 11.3 - (-2.43)$

$V_{CE} = 13.73 > 0.2$ ✓

∴ Assumption is correct.

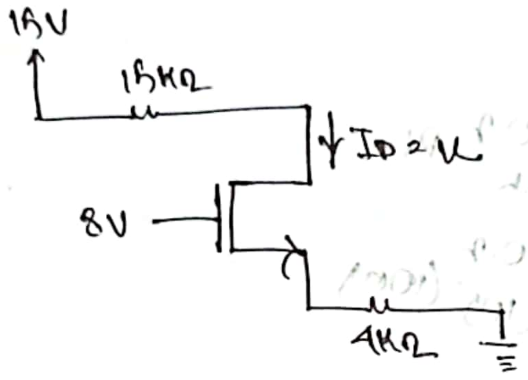
$I_B = \frac{0 - (-1.74)}{100} \Rightarrow I_B = 0.0174 \text{ mA}$

$I_C = 100(0.0174) \Rightarrow I_C = 1.74 \text{ mA}$

$I_E = 0.0174 + 1.74$

$I_E = 1.76 \text{ mA}$

(5)



Let MOSFET be in saturation region

$I_D = \frac{1}{2}K(V_{GS}-V_T)^2$ $\quad I_D = \frac{15-V_D}{15} \Rightarrow V_D = 15-15x$

$I_D = \frac{1}{2}(4)(8-4x-1)^2$ $\quad I_D = \frac{V_S-0}{4} \Rightarrow V_S = 4x$

$x = 2(7-4x)^2$

$x = 2[49-56x+16x^2]$

$16x^2 - 113x + 98 = 0$

$x = 6.05\text{ mA}, x = 1.01\text{ mA}$

$V_{GS} = 8-4x$

$V_{GS} = 8-4(6.05) = -16.2V \not> 1$ ×

$V_{GS} = 8-4(1.01) = 3.96V > 1$ ✓

$V_{DS} = (15-5x)-(4x)$

$= [15-5(1.01)] - 4(1.01)$

$V_{DS} = 5.91 > 2.96$ ✓

∴ Assumption is correct

$I_D = 1.01\text{ mA}$

$V_{DS} = 5.91V$

Assignment 4 (AFL)

(1) (a) $0.7 < V_{in} < 0.7 + \frac{V_3 - 0.7}{\beta R_L} R_i$

$\Rightarrow 0.7 < V_{in} < 0.7 + \frac{12 - 0.7}{(75)(10)}(100)$

$\Rightarrow 0.7 < V_{in} < 2.27$

(b) $K = -\frac{\beta R_L}{R_i} = -\frac{(75)(10)}{100} = -7.5$

(c) $V_{il} = \frac{0.7 + 2.27}{2} \Rightarrow V_{il} = 1.49V$

$V_y = V_3 + \frac{0.7\beta R_L}{R_i} - \frac{\beta R_L}{R_i} V_{il}$

$= 12 + \frac{0.7(75)(100)}{10} - \frac{(75)(100)}{10}(1.49)$

$V_y = -580.5V$

(d) $V_{i(max)} = (2.27 - 1.49) = 0.78V$

$V_{y(max)} = 12 + \frac{0.7(75)(100)}{10} - \frac{(75)(100)}{(10)}(0.78)$

$V_{y(max)} = -48V$

(2)(ii) $V_u = \dfrac{0.7 + 0.7 + \dfrac{V_3 - 0.7}{\beta R_L} R_i}{2}$

$$= \frac{0.7 + 0.7 + \dfrac{20 - 0.7}{(60)(2)}(10)}{2}$$

$V_u = 1.5425\ V$

$V_y = V_3 + \dfrac{0.7 \beta R_L}{R_i} - \dfrac{\beta R_L}{R_i} V_u$

$$= 20 + \frac{0.7(60)(2)}{(10)} - \frac{(60)(2)}{(10)}(1.5425)$$

$V_y = 10.1\ V$

(ii) $K = \dfrac{-\beta R_L}{R_i} = -\dfrac{(60)(2)}{(10)} = -12$

Assignment 4 (F3H)

(1) $I_Z = I_{ZK} = 1.5\ mA$

$V_Z = V_{ZO} + I_Z R_Z$

$= 4.5 + (1.5)(5)$

$V_Z = 12V$

$I_L = \frac{V_Z}{R_L} \Rightarrow I_L = \frac{12}{4} = 3\ mA$

$I_i = I_Z + I_L = 1.5 + 3 = 4.5\ mA$

$V_i = I_i R_i$

$V_i = (4.5)(300)$

$\boxed{V_i = 1350V}$

(2) $V_{in} = V_{in}(min) = 15 - (15\ of\ 10\%) = 13.5\ V$

$I_Z = I_{ZK} = 2mA$

$V_Z = V_{ZO} + I_Z r_Z$

$= 5 + (2)(\frac{10}{1000})$

$V_Z = 5.02V$

$I_i = \frac{V_i}{Ri} = \frac{13.5}{\frac{250}{1000}} = 54\ mA$

$I_L = I_i - I_Z$

$= 54 - 2$

$I_L = 52\ mA$

$R_L = \frac{V_Z}{I_L} \Rightarrow R_L = \frac{5.02}{52} \Rightarrow R_L = 0.0965\ K\Omega$

$R_L = 96.5\Omega$

CamScanner

(3) $I_Z = I_{ZK} = 1.6mA$

$V_Z = V_{Z0} + I_Z r_Z$

$= 4 + (1.6 * \frac{430}{1000})$

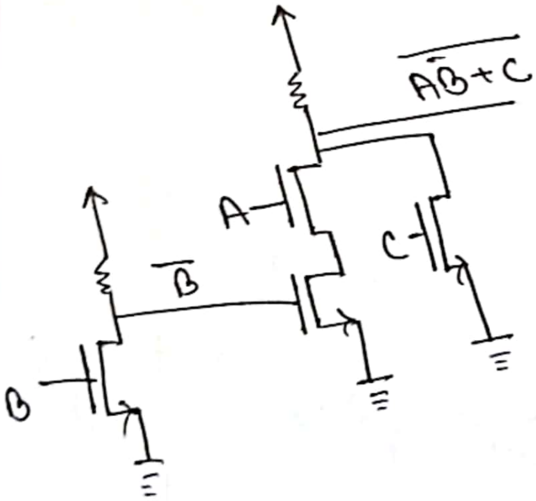
$V_{Z0} = 4.68V$

$V_L = V_Z - 0$

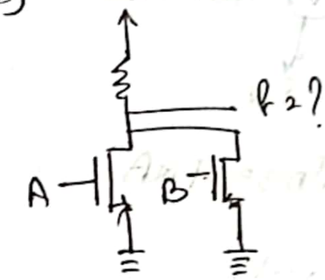
$V_L = 4.68V$

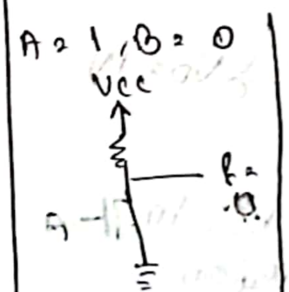
(4) $f = \overline{(\overline{AB} + C) D}$

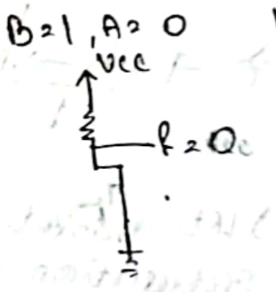
(a) $F = \overline{A\bar{B} + C}$

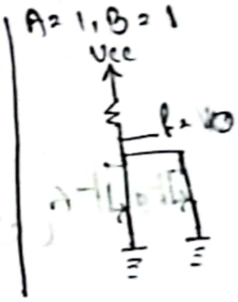


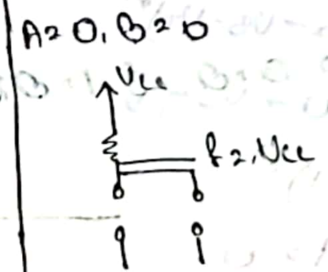
(6) NOR Gate



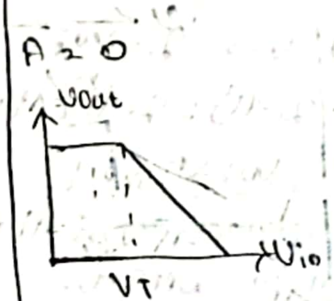


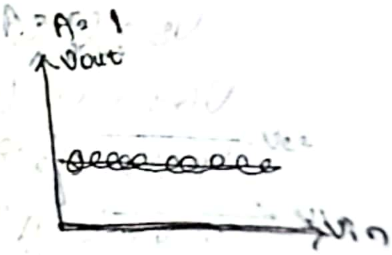






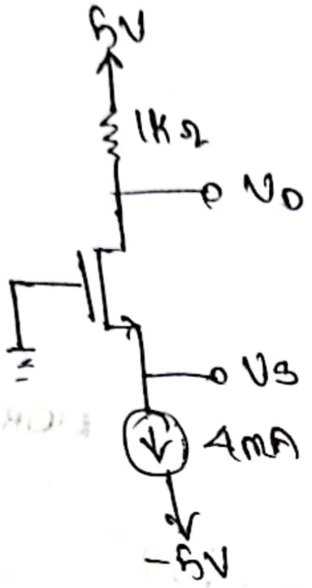
A	B	Vout
0	0	1
0	1	0
1	0	0
1	1	0





Assignment 6 (F3A)

(1)



(a) $V_G = 0V$, $I_{DS} = 4\,mA$

(b) $I_{DS} = \dfrac{5 - V_D}{1}$

$\Rightarrow 4 = \dfrac{5 - V_D}{1} \Rightarrow V_D = 1V$

(c) Let mosfet be in saturation region

$I_{D} = \frac{1}{2} k (V_G - V_S - V_T)^2$

$4 = \frac{1}{2}(4)(0 - V_S - 1)^2$

$2 = (-V_S - 1)^2$

$V_S^2 + 2V_S - 1 = 0$

$V_S = 2.41V$, $V_S = -2.41V$

$V_{GS} = 0 - (-2.41) = 2.41 > 1$ ✓

$V_{OV} = 2.41 - 1 = 1.41V$

$V_{DS} = 1 - (-2.41) = 3.41 > 1.41$ ✓

∴ Assumption is correct.

[illegible] , $I_{DS} = 1mA$

(2) $V_S \dfrac{R_{on}}{R_{on}+R_L} < V_T$

(6) $\dfrac{R_{on}}{R_{on}+5} < 0.9$

$\Rightarrow 6R_{on} < 0.9R_{on} + 4.5$

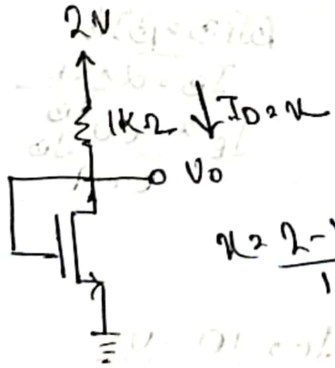
$\Rightarrow R_{on} < 0.882$

$R_{on} = \dfrac{1}{k_n' V_{ov}\left(\frac{W}{L}\right)}$

$0.882 > \dfrac{0.25}{\left(\frac{W}{L}\right)}$

$\dfrac{W}{L} > 0.283$

(3)



$x = \dfrac{2-V_D}{1} \Rightarrow V_D = 2-x$

$V_G = 2-x$

$V_G = V_D$

Let the mosfet be in saturation region

$I_D = \frac{1}{2}k(V_{GS}-V_t)^2$

$\therefore x = \frac{1}{2}(4)(2-x-0.2)^2$

$\therefore x = 2(1.8-x)^2$

$x = 2(3.24 - 3.6x + x^2)$

$2x^2 - 8.2x + 6.48 = 0$

$x = 3.03\text{ mA}, \; x = 1.07\text{ mA}$

$V_{GS} = (2-1.07) = 0.93 > 0.2$ ✓

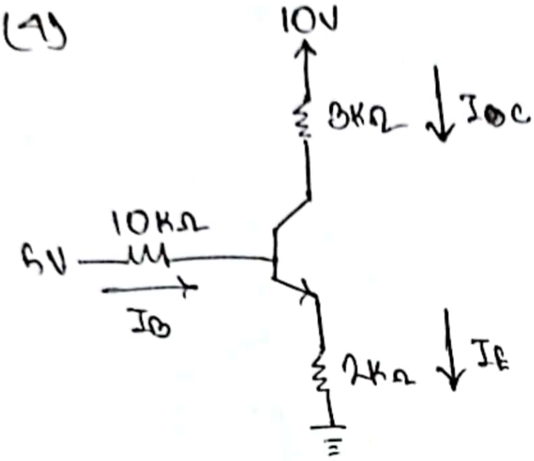
$V_{DS} = (2-1.07) = 0.93 > 0.73$ ✓

$\therefore$ Assumption is correct.

$V_o = V_D = 0.93\text{ V}$

$I_{DS} = x = 1.07\text{ mA}$

(9)



Let BJT be in active state

$V_{BE} = 0.7V$, $I_C = \beta I_B = 100 I_B$

$$5 + 10 I_B + V_{BE} + 2 I_E + 0 = 0$$

$$5 + 10\left(\frac{0.99}{100} I_E\right) + 0.7 + 2 I_E = 0$$

$$\alpha = \frac{\beta}{1+\beta} = \frac{100}{1+100} = 0.99$$

$I_C = \beta I_B$

$I_C = \alpha I_E$

$\beta I_B = \alpha I_E$

$I_B = \frac{\alpha I_E}{\beta}$

$I_E = -2.72 \text{ mA}$

$I_C = (0.99)(-2.72) = -2.69 \text{ mA}$

$I_B + I_C = I_E$

$I_B = (-2.72) - (-2.69)$

$I_B = -0.03 \text{ mA}$

$$I_C = \frac{10 - V_C}{3}$$

$\cancel{\Rightarrow V_C = 3(-2.69)}$

$\Rightarrow V_C = 10 - 3(-2.69) = 18.07$

$$I_E = \frac{V_E - 0}{2}$$

$V_E = 2(-2.72)$

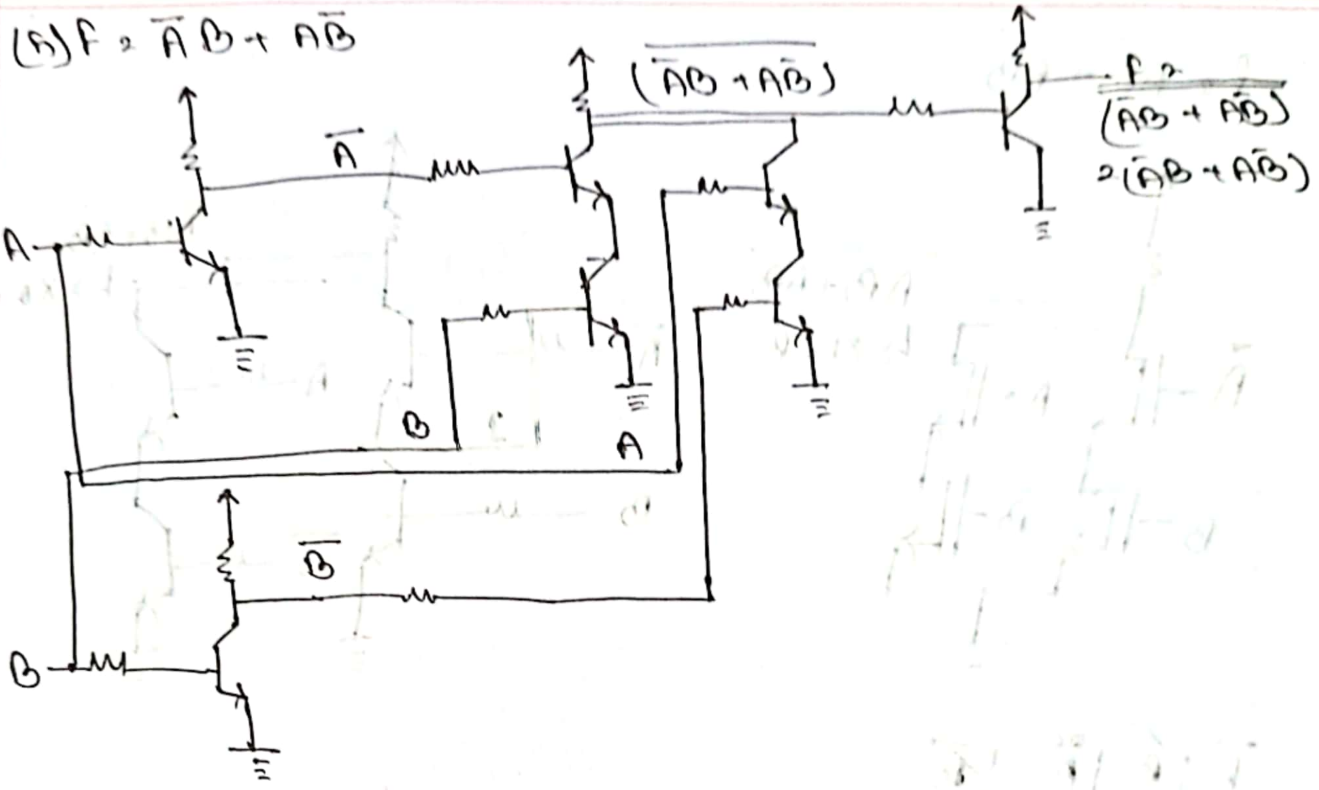
$V_E = -5.44V$

$V_{CE} = V_C - V_E$

$= 18.07 - (-5.44)$

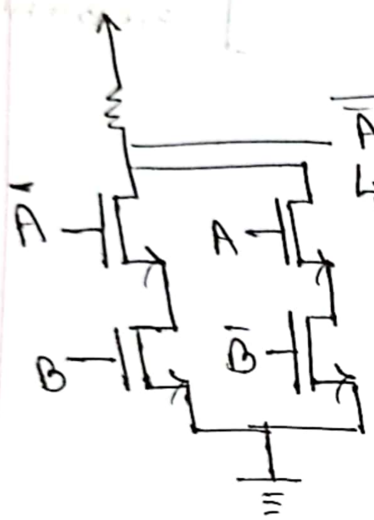
$= 23.51 V > 0.2V$ ✓

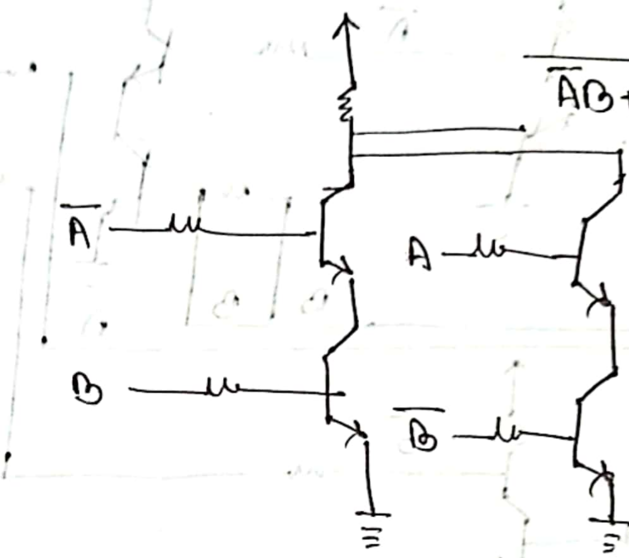
(a) $f = \bar{A}B + A\bar{B}$



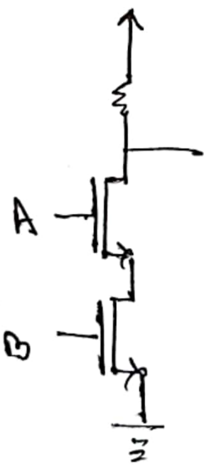
(b) $f = (\overline{AB + C + D})$

$f = \overline{\bar{A}B + A\bar{B}}$



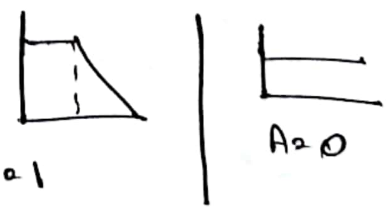


$\bar{A}$	B	$\bar{A}$	$\bar{B}$
0	0	0	0



NAND

A	B	Vout
0	0	1
0	1	1
1	0	1
1	1	0



A = 1 A = 0

BJT

active: $V_{BE} = 0.7$

$I_C = \beta I_B$ $\alpha = \frac{\beta}{\beta+1}$

$V_{CE} > 0.2$

$I_C = \alpha I_E$

saturation: $V_{BE} = 0.8V$

$V_{CE} = 0.2V$

$\frac{I_C}{I_B} < \beta$

cutoff: $I_C = I_B = I_E = 0mA$

$V_{BE} < 0.7V$

MOSFET

saturation: ~~V_{DS}~~ V_{GS} ~~$\geq V_T$~~ $\geq V_T$

$V_{DS} \geq V_{OV}$ $I_D = \frac{1}{2} K V_{OV}^2$

Triode: $V_{GS} \geq V_T$, $V_{DS} < V_{OV}$

$I_D = K\left(V_{DS}V_{OV} - \frac{1}{2}V_{DS}^2\right)$

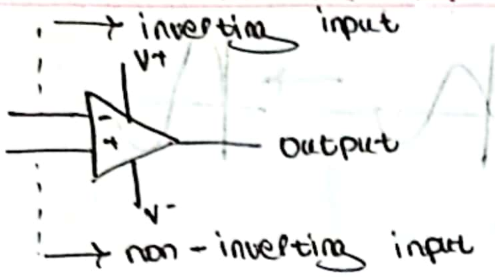
cutoff: $I_{DS} = 0$ mA, $V_{GS} < V_T$

LAB

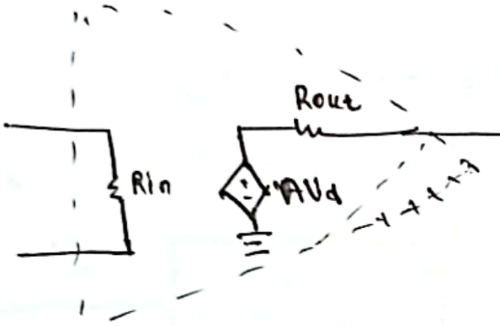
LAB 1

TUESDAY

DATE : 31/01/23



comparator



$[V_o = A V_d]$

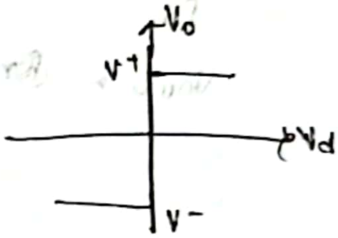
$= A(V^+ - V^-)$

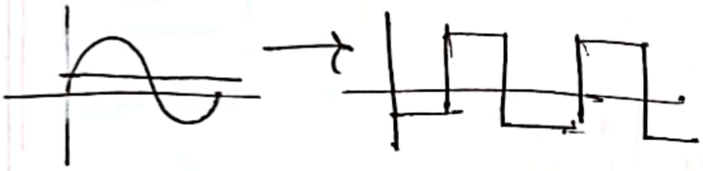
For ideal op. amp

$R_{in} \to \infty$

$R_{out} \to 0$

$A \to \infty$

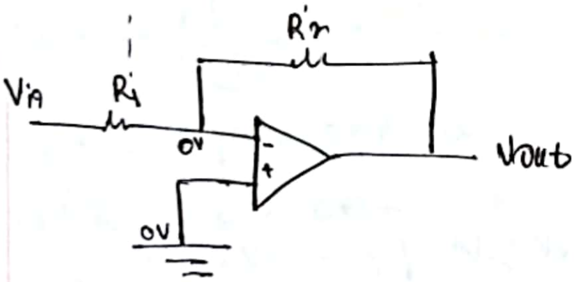


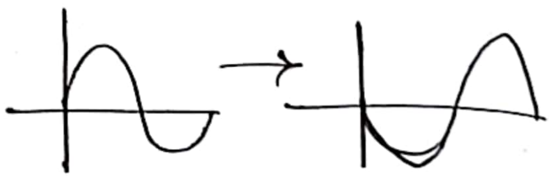


i/p × o/p × —— × —— × —— ×

→ feedback

inverting amplifier





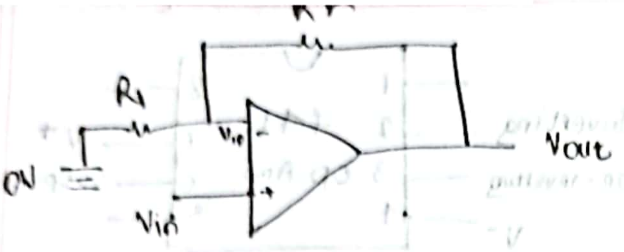
$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_f}$$

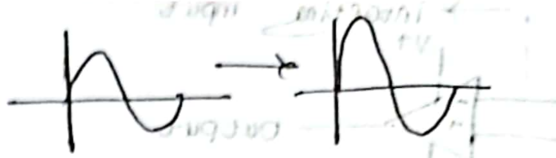
phase shift

$$V_{out} = \underbrace{\left(\frac{-R_f}{R_1}\right)}_{\text{amplification}} V_{in}$$

—— × —— × —— × —— × —— × —— × —— × ——

Non-inverting amplifier



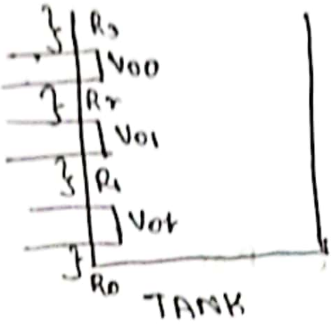


$$\frac{0 - V_{in}}{R_1} = \frac{V_{in} - V_{out}}{R_r}$$

$$V_{out} = \underbrace{\left(1 + \frac{R_r}{R_1}\right)}_{\text{always +ve} > 1} \times V_{in}$$

LAB 7

Decision Block



Water level

15V [5, 5, 5] → R_0

11V [1, 5, 5] → R_1

7V [1, 1, 5] → R_2

3V [1, 1, 1] → R_3

Single indicator of WL

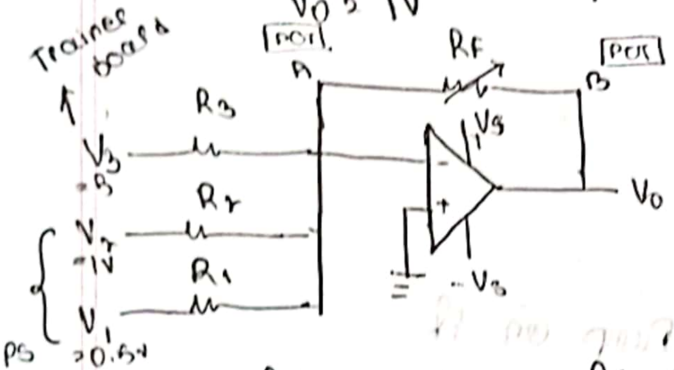
$V_{ind} = (V_{01} + V_{02} + V_{03})\left(\frac{1}{2}\right)$ → to keep the output in range

$V_{ind} \propto \frac{1}{h}$

$V_{ind} \propto$ depth of water

When probe in water | When probe out of water

$V_0 = 1V$ | $V_0 = 5V$



MUST SHORT GROUND OF TRAINER BOARD AND POWER SUPPLY

$V_0 = -\frac{R_f}{R_3}V_3$, $V_0 = -\frac{R_f}{R_2}V_2$, $V_0 = -\frac{R_f}{R_1}V_1$

$$V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

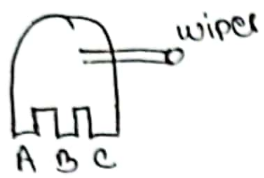
$R_f = 100K | 50K | 25K$ etc

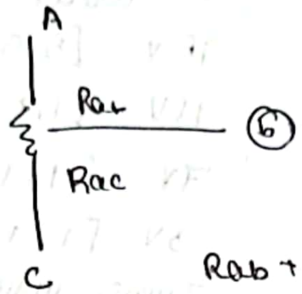
$R_1 = R_2 = R_3 = 100k$

$V_0 = -(V_1 + V_2 + V_3)$ | $-(V_1 + V_2 + V_3) \times 0.5$ | $-(V_1 + V_2 + V_3) \times 0.25$

to make the R_f smaller

Potentiometer

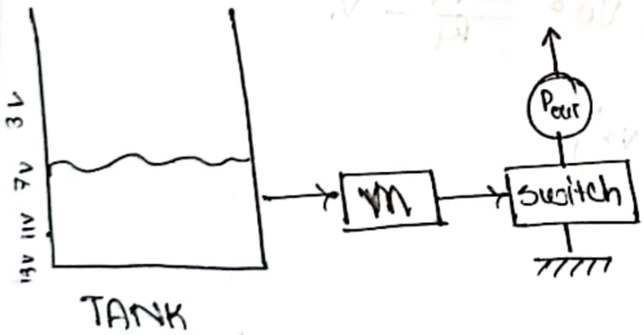




$R_{ab} + R_{bc} = R_{ac}$

Decision Block

level of water ↓ V↑



W.L = Out of ~~tank~~ actual

= V_{IN}

Pump on if

V_{IN} $\boxed{>}$ V_{REF} ⇒ Pump on 5V

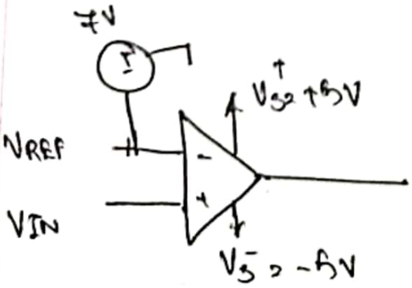
V_{IN}↑

Pump off if

V_{IN} $\boxed{<}$ V_{REF} ⇒ Pump off −5V

V_{IN}↓

পানির level বাড়লে voltage কমবে, pump off হবে।

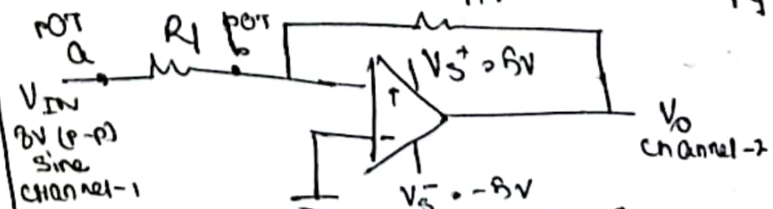


$V^+ > V^- \Rightarrow V_o = V_s^+$

$V^+ < V^- \Rightarrow V_o = V_s^-$

Schmitt Trigger

$R_f = 100K$ $P = \frac{R_f}{R_1}$



If $V_o = V_s^-$

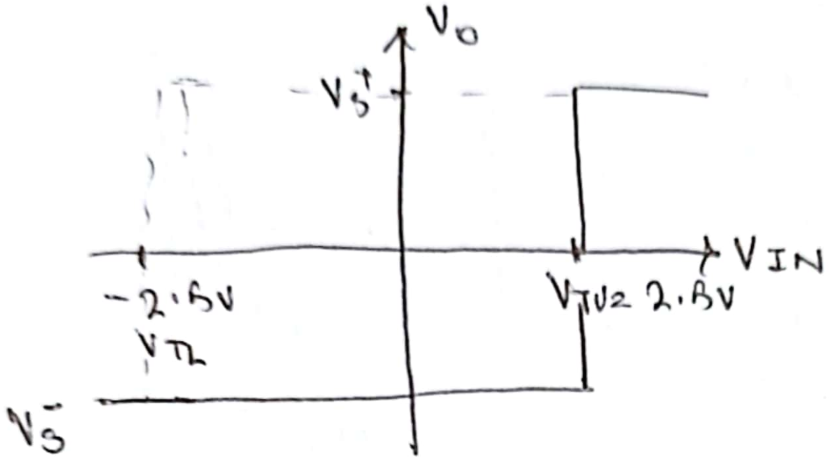
$V_{TU} = -\frac{V_s^-}{P}$

$= 2.5V$

If $V_o = V_s^+$

$V_{TL} = -\frac{V_s^+}{P}$

$= -2.5V$

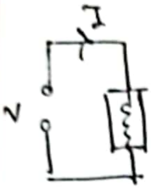


input is very (-ve) → $-\infty$

LAB 3

TUESDAY DATE: 14/02/23

I-V characteristics

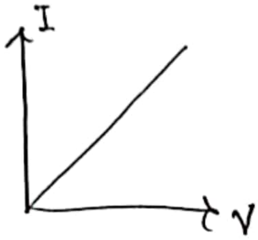


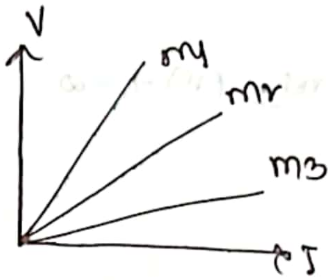
$V = IR$

$I = \frac{1}{R} \cdot V$

$\uparrow \quad \uparrow \quad \uparrow$

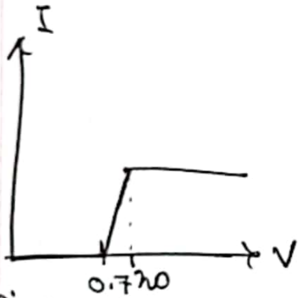
$y = m\,x + 0$



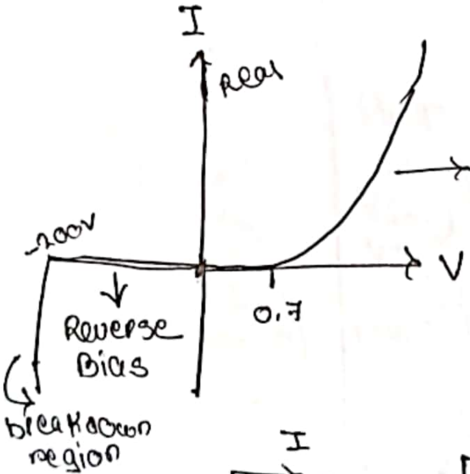


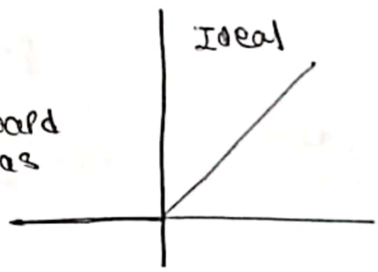
$m_1 > m_2 > m_3$

$R_1 < R_2 < R_3$

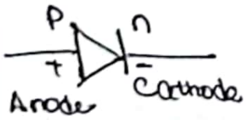


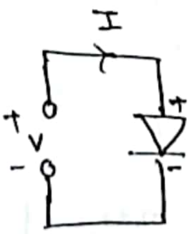
Piece wise linear approximation

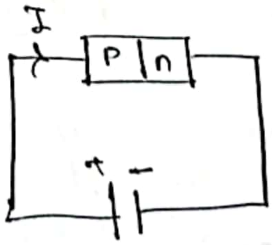




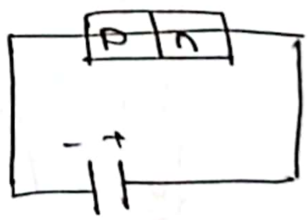
Diode





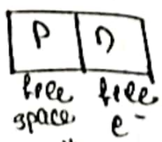


Forward Bias



~~Backward~~ Bias Reverse Bias

P-n junction diode



* Depletion layer: barrier betw P & n

$I_d = I_s \left\{ \exp \frac{V_D}{n V_T} - 1 \right\}$

V_D → applied voltage

I_s → reverse saturation current

n → ideality factor

V_T → thermal voltage

~~applied voltage~~ voltage

~~Depletion~~ when * free $\bar{e}$ from ~~layer~~: n moves to the free space in P. ~~a barrier is created.~~

$V = IR$

$I = \frac{V \rightarrow \text{volt}}{R \rightarrow k\Omega}$

$I = mA$

$\frac{V}{10^3} = \frac{10^{-3}}{\Omega}$ $\quad \frac{1}{1k} = 1mA$ $\quad \frac{1}{10^3} = 10^{-3}$ mA

$I_d = I_s \left\{ \exp\left(\frac{V_D}{nV_T}\right) - 1 \right\}$

$V_D >> nV_T$

$I_d = I_s \exp\left(\frac{V_D}{nV_T}\right)$

$\frac{1}{nV_T} = \alpha$

$I_d = I_s \exp(\alpha V_D)$

$I_{d1} = I_s \exp(\alpha V_{D1})$ — (i)

$I_{d2} = I_s \exp(\alpha V_{D2})$ — (ii)

$\frac{(i)}{(ii)} = \frac{I_{d1}}{I_{d2}} = \exp \alpha (V_{d1} - V_{d2})$

$\alpha = \frac{\ln\left(\frac{I_{d1}}{I_{d2}}\right)}{V_{d1} - V_{d2}}$

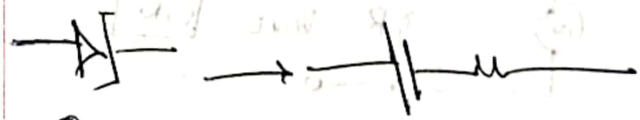
$n \rightarrow 1$ to 2

$V_T \rightarrow 25$ mV

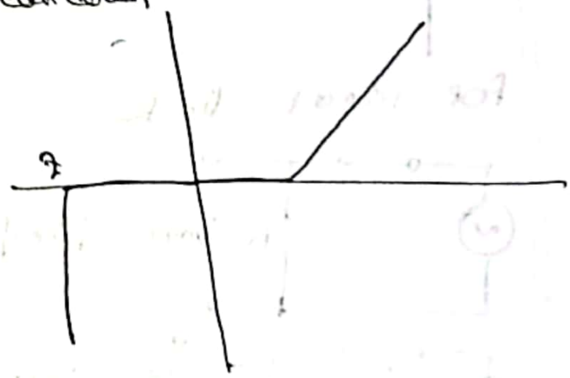
$r_d = \frac{nV_T}{I_D}$

Zenner diode → operate at breakdown

$V_d > V_Z$ → does not go beyond V_Z



ON



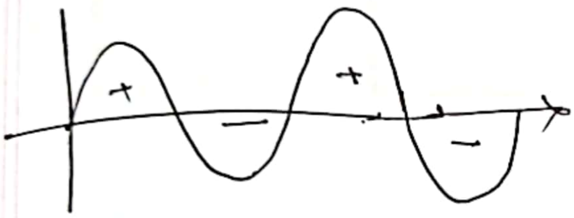
LAB 4

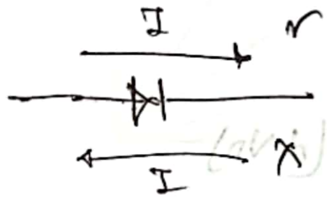
TUESDAY DATE: 28/02/23

Half wave and Full wave rectifier

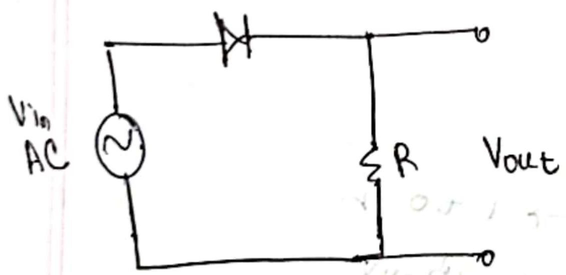
AC → DC

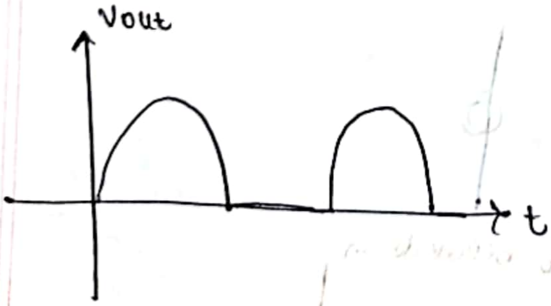
220 V AC
50 Hz

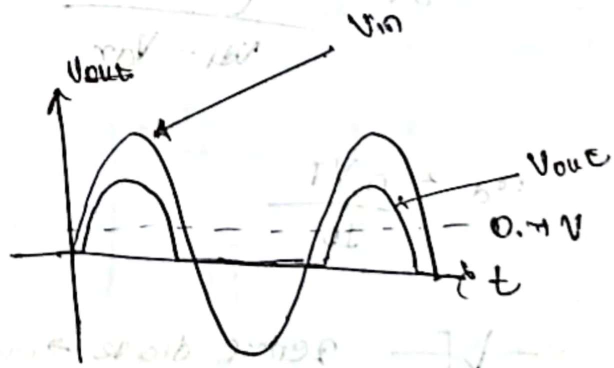




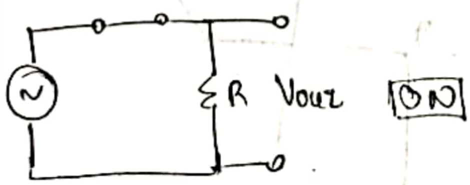
Half-wave rectifier:-

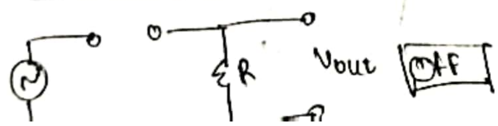




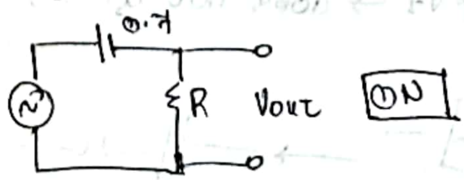


For ideal diode



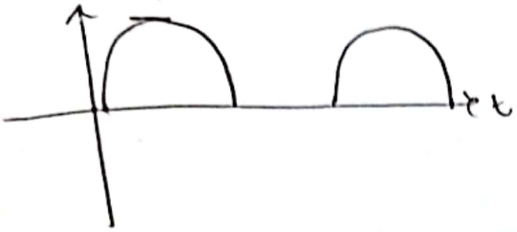


For real diode



$V_{out} = V_{in} - 0.7$

V_{out} $V_p = V_m - 0.7V$



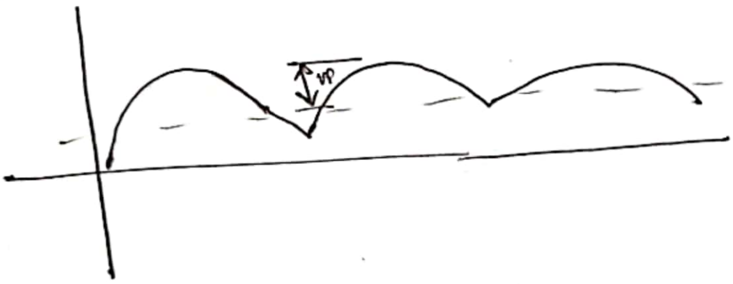
$V_o = V_{DC} + V_{AC}$

$V_{DC} = \frac{V_m}{\pi} - \frac{V_{D0}}{2}$

$V_{AC} = V_{rms}$

Position scale of Vin & Vout should be 2V.
* Scale Ch1 = Scale Ch2 = 2V
* Bias Ch1 = Bias Ch2 = 0V

with capacitor



$V_p = \frac{V_p}{fCR}$

$r = \frac{V_{rms}}{V_{avg}}$ [Ripple factor]

$r = \frac{V_{AC}}{V_{DC}}$