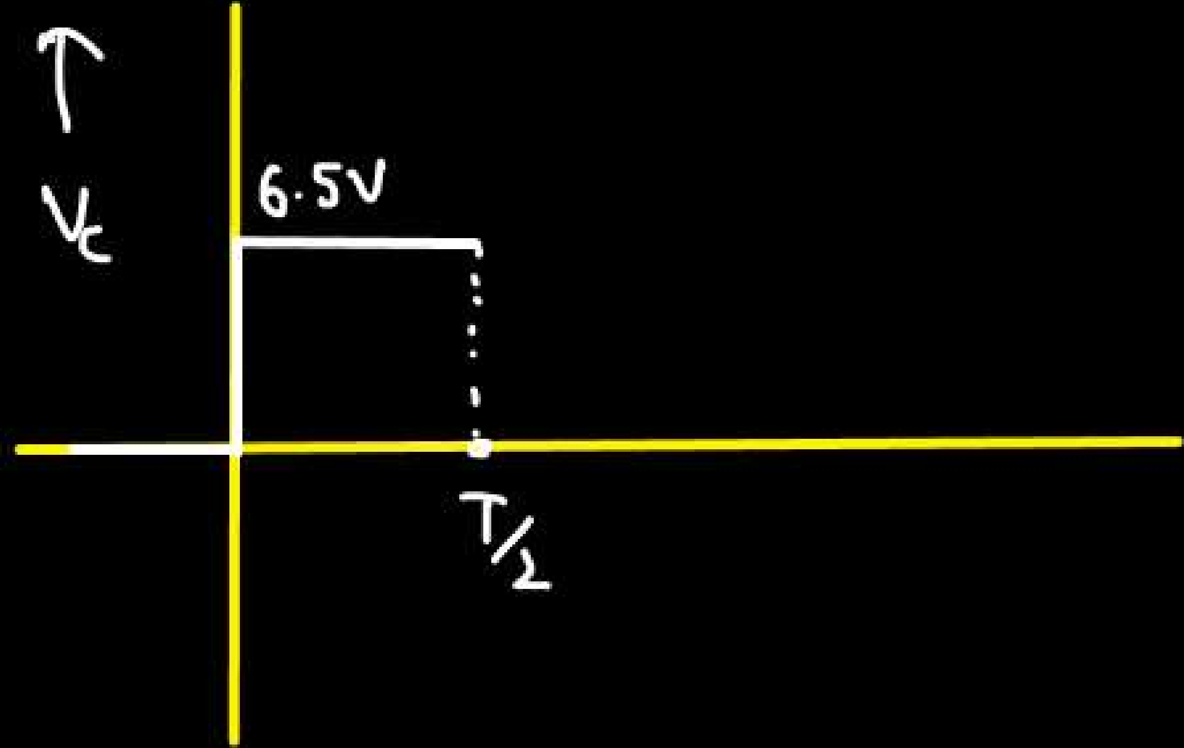
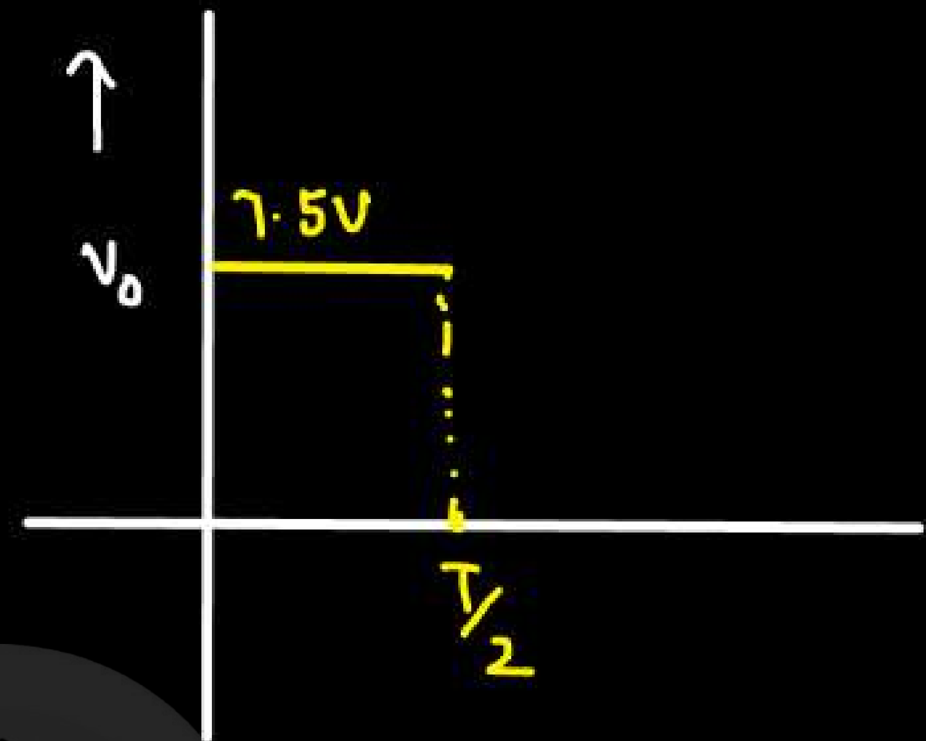




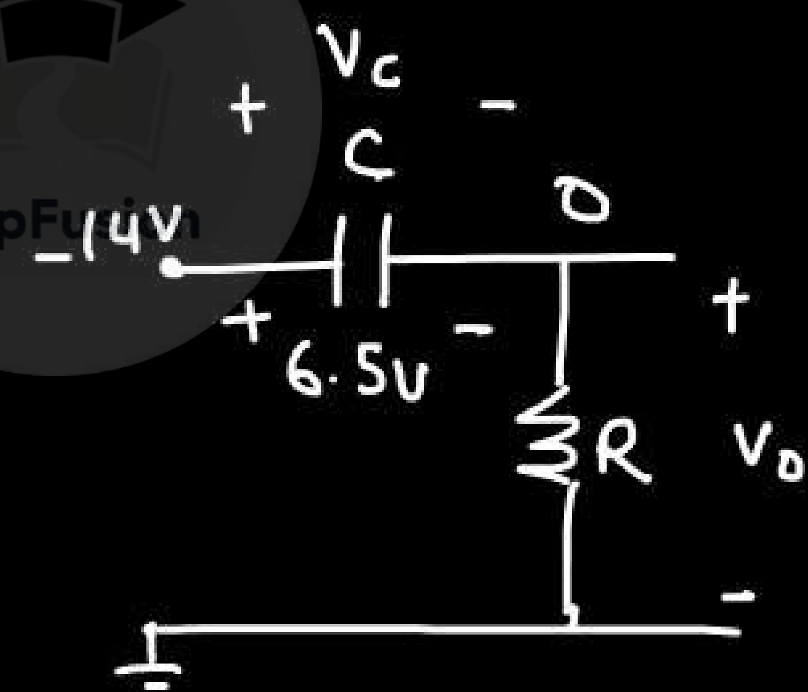
@ $t = T/2^{+}$

$V_{in} = -14V$

D_1 and D_2 both are off

$V_o(T/2^{+}) = -20.5V$

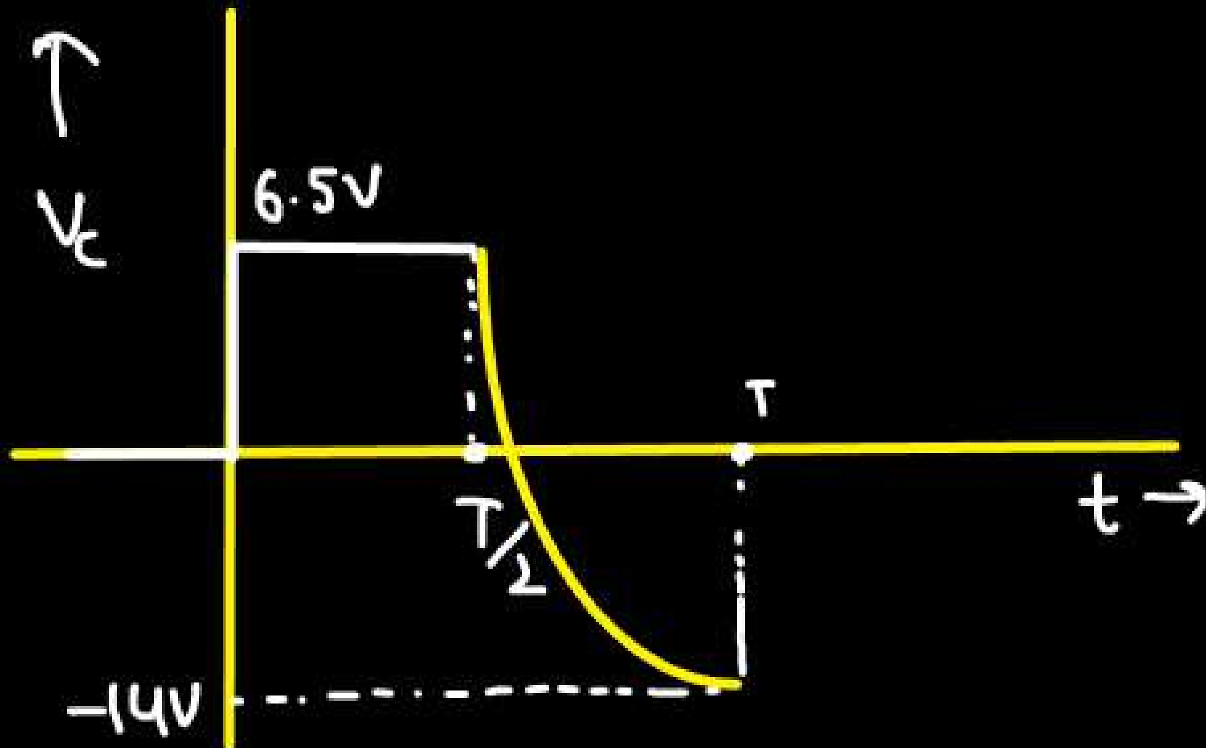
$V_o(s.s.) = 0V$, $V_c(s.s.) = -14V$



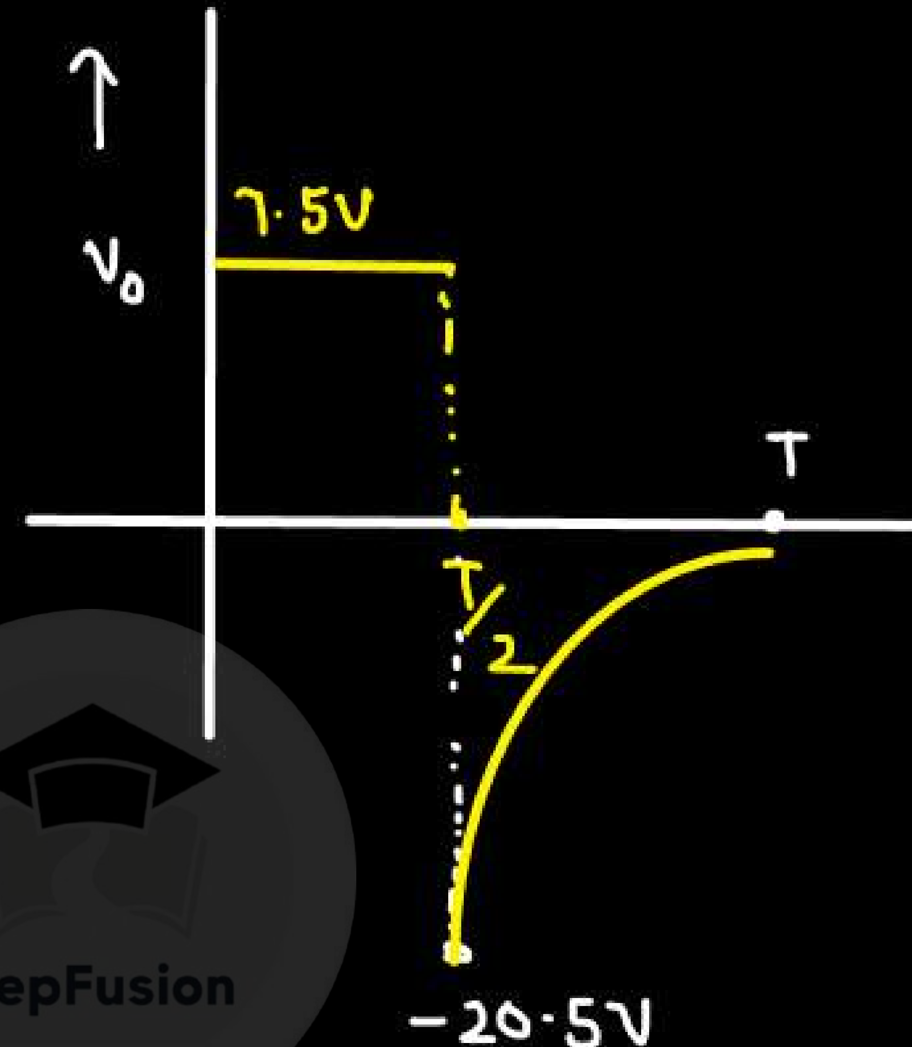
$RC <<< \underline{T}$

⇓

You have enough time to reach s.s.



6.5V
V_c
T
t →
T/2
-14V



7.5V
V_0
T
T/2
-20.5V

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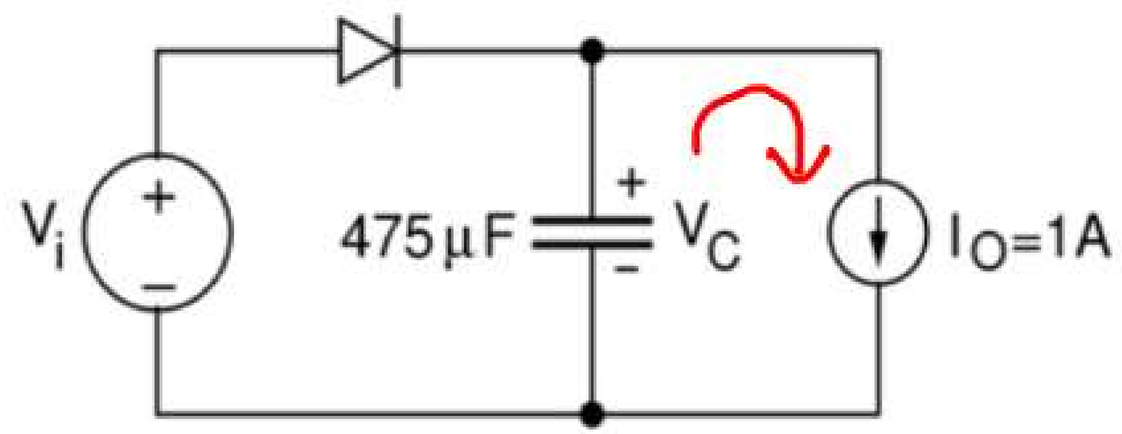
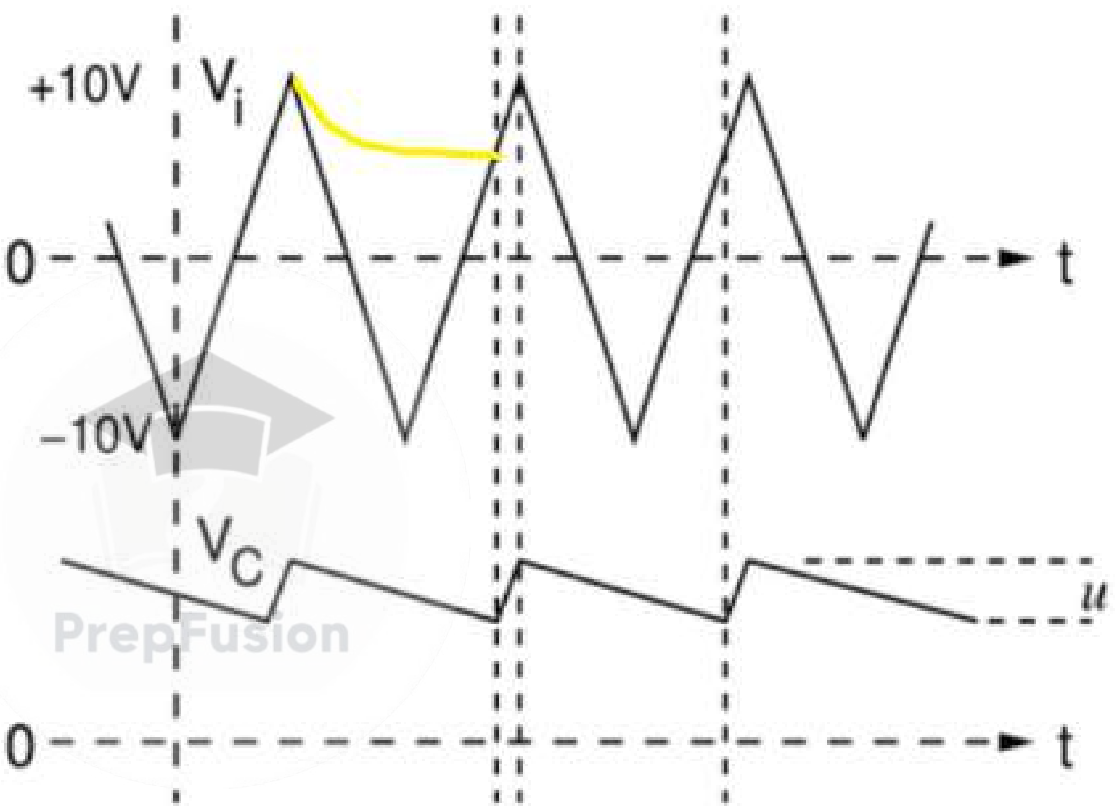
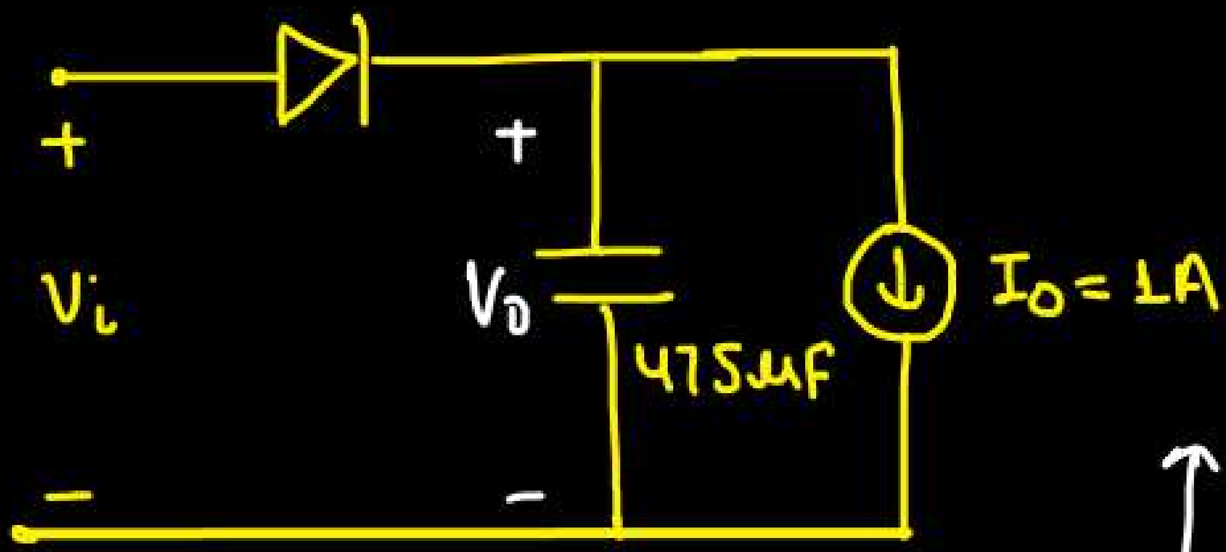
The figure shows a half-wave rectifier with a 475 μF filter capacitor. The load draws a constant current $I_O = 1$ A from the rectifier. The figure also shows the input voltage V_i, the output voltage V_C and the peak-to-peak voltage ripple u on V_C. The input voltage V_i is a triangle-wave with an amplitude of 10 V and a period of 1 ms.





The value of the ripple u (in volts) is ________



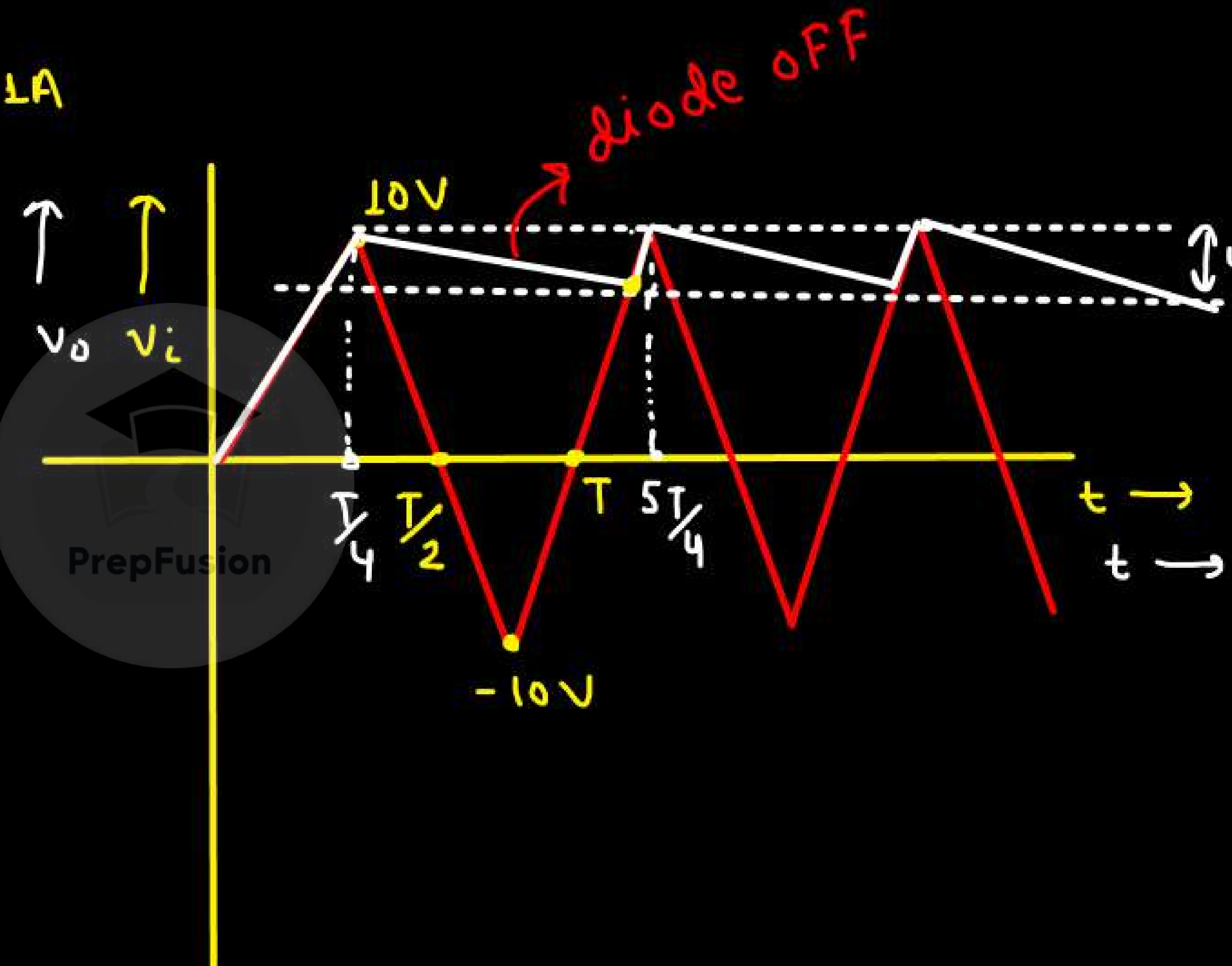
$V_i = +ve \ (@ \ t = 0^+)$

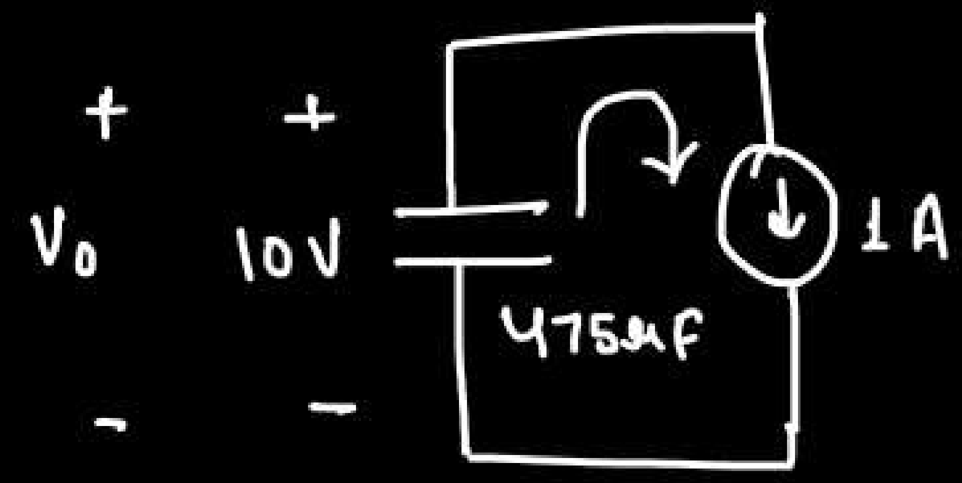
diode ON

$@ \ t = T/4^+$

$V_i = 9.9$ (let) , $V_o = 10$

$\Rightarrow$ diode OFF





$$v_0(t) = 10 - \frac{\left(t - \frac{T}{4}\right)}{475\mu}$$

$$v_0\left(\frac{5T^-}{4}\right) = 10 - \frac{T}{475\mu}$$

$$= 10 - \frac{1000\mu}{475\mu}$$

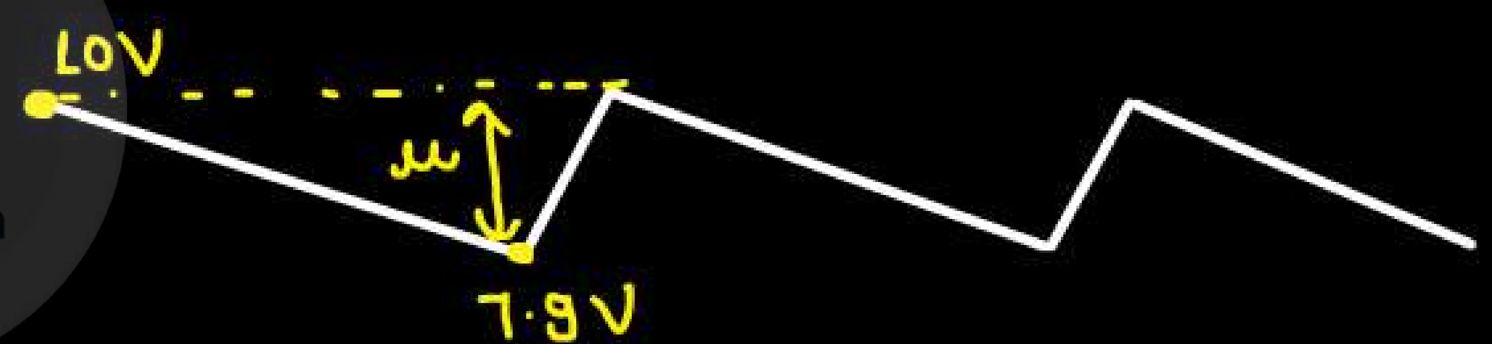
$$= 10 - 2.1$$

$$\boxed{v_0\left(\frac{5T^-}{4}\right) = 7.9\text{ V}}$$

$$i = C\frac{dv_c}{dt}$$

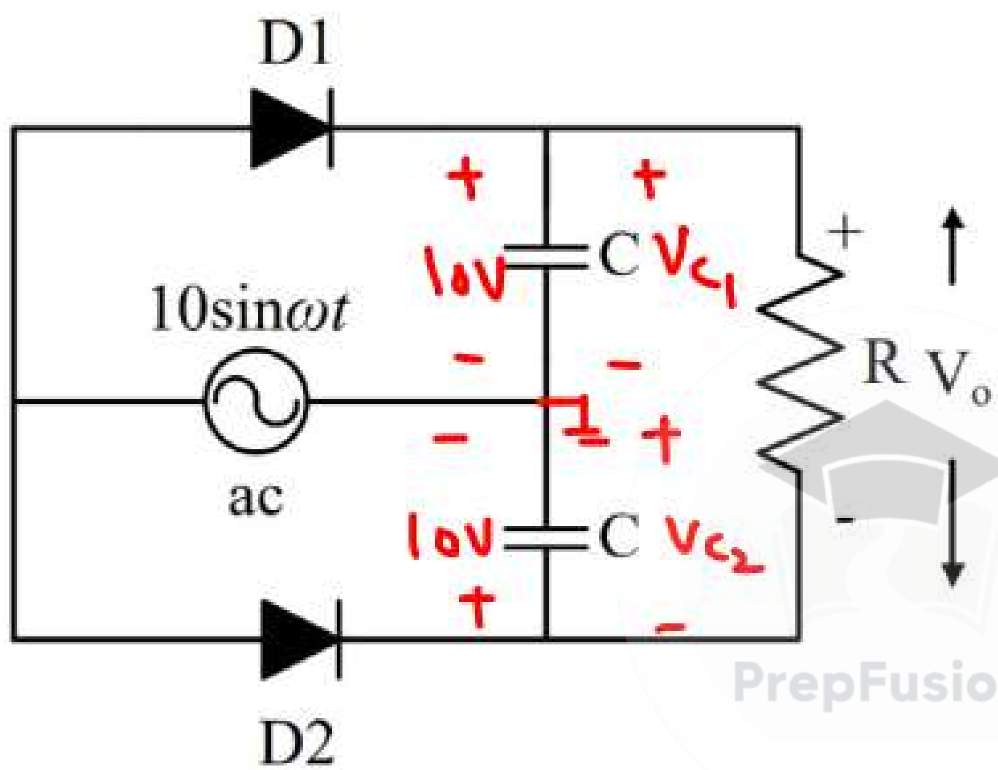
$$v_c = \frac{1}{C}\int_{-\infty}^{t} i_c \cdot dt$$

$$\boxed{V_c = \frac{i_c(t)}{C}}$$

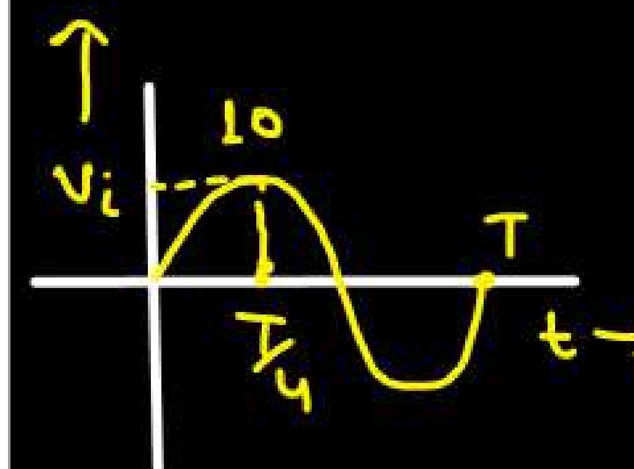


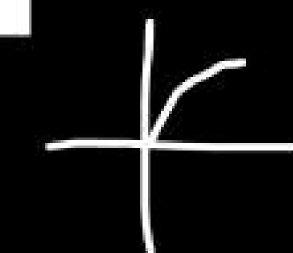
$$\boxed{\mu = 2.1\text{V}}$$

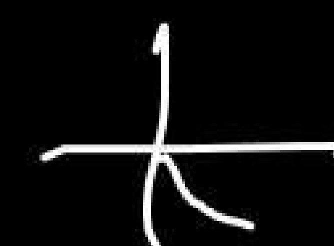
The diodes D1 and D2 in the figure are ideal and the capacitors are identical. The product RC is very large compared to the time period of the ac voltage. Assuming that the diodes do not breakdown in the reverse bias, the output voltage V_O (in volt) at the steady state is ___________



$$\left[V_o = -V_{c_1} + V_{c_2}\right]_{S.S.}$$







$0 < t < T/4$

$V_i = +ve$, D_1 and D_2 are ON

$V_{c_1}(T/4) = 10V$ $\qquad$ $V_{c_2}(T/4) = -10V$

@ $t = T/4^{+}$

$V_i = 9.9$ {let} $V_{c_1} = 10V$, $V_{c_2} = -10V$

D_1 and D_2 are off.

{ To turn ON D_1 and D_2

$V_i > 10V$

$\Downarrow$

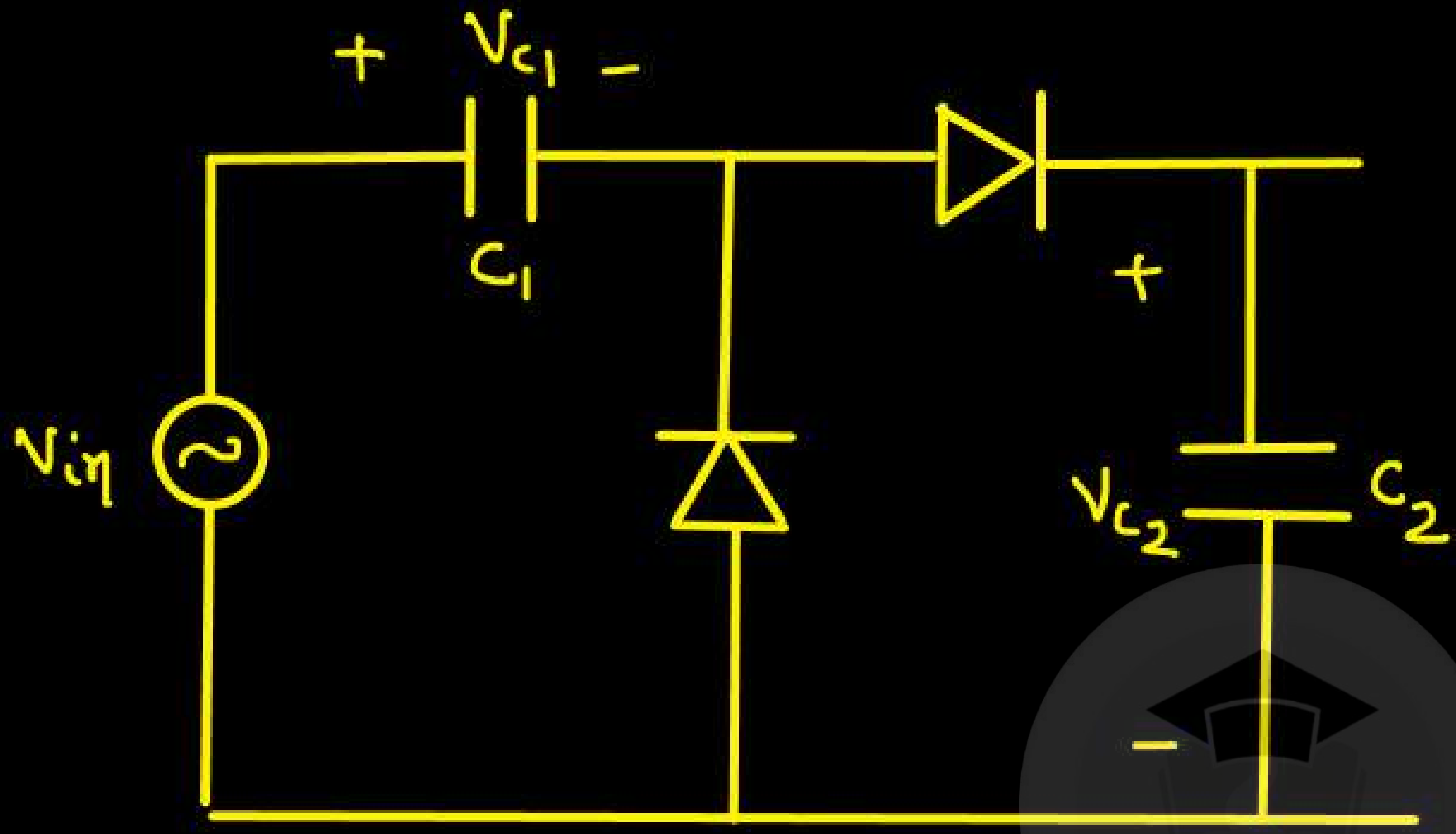
NOT POSSIBLE }

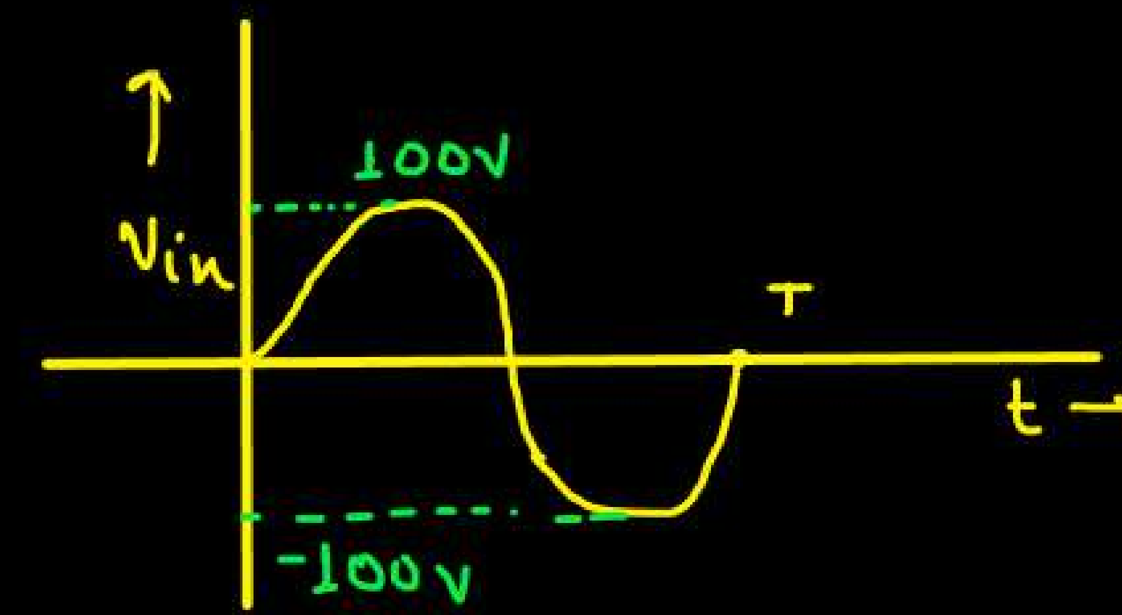
$\Rightarrow$ Steady state reached

$V_{c_1} = 10V$, $V_{c_2} = -10V$

$$\boxed{V_0 = V_{c_1} + V_{c_2} = 0V}$$

Q.



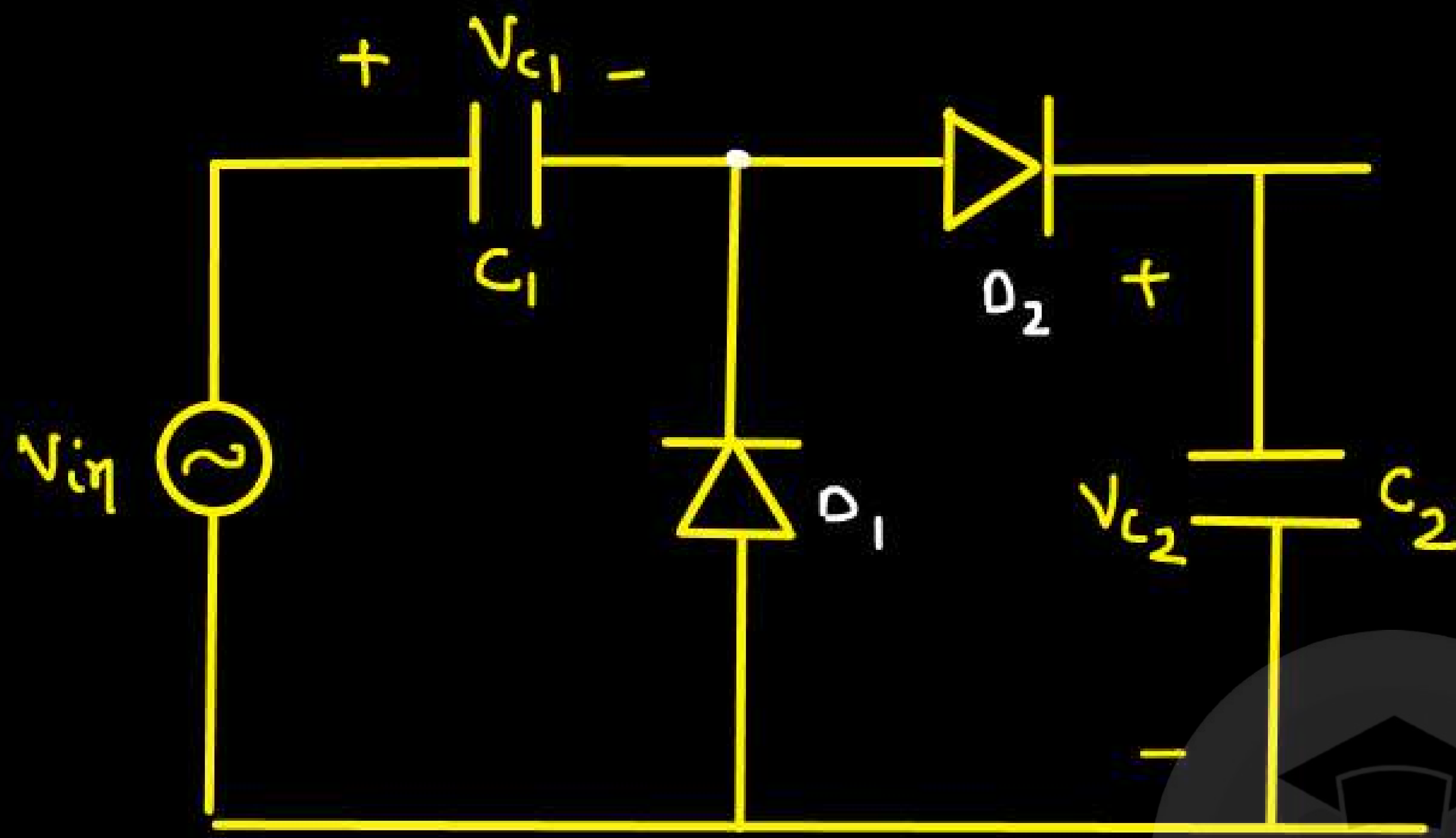


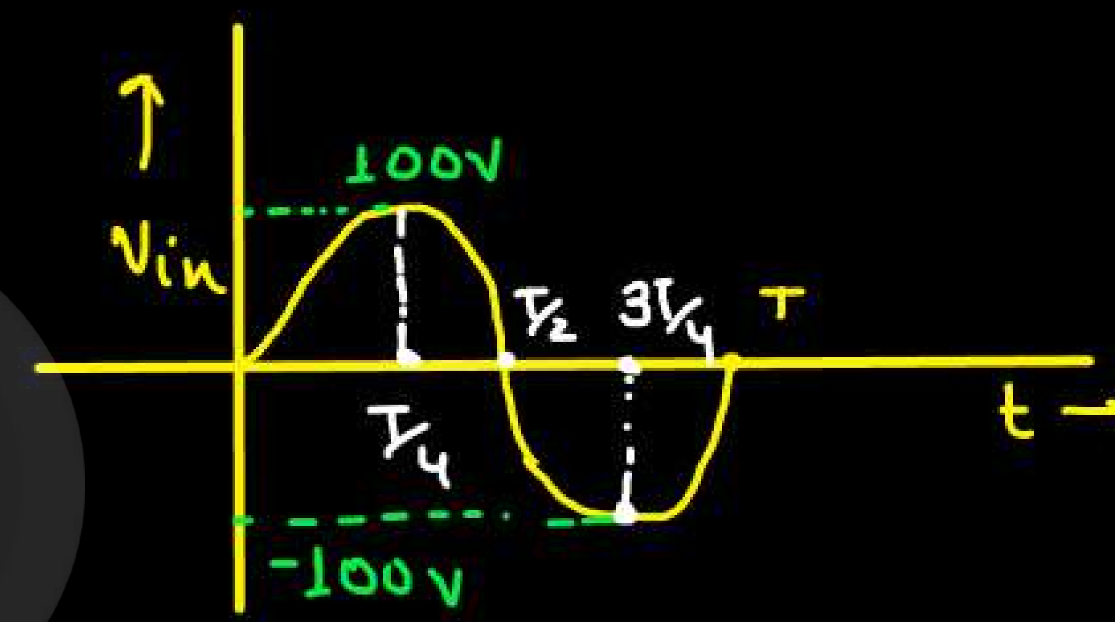
$V_{in} = V_m \sin \omega t$

$C_1 = C_2 = C$

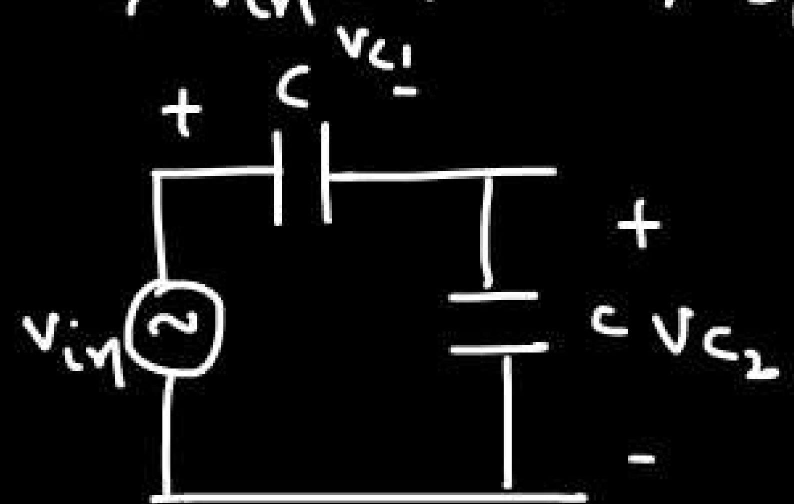
Find V_{C_1} and V_{C_2} @ $t = T$

→ $V_{C_1}(T) = -V_m$, $V_{C_2}(T) = 2V_m$ ✗ ⇒ This is steady state. (NOT after one cycle)





@ $t = 0^+$ $\Rightarrow V_{in} = +ve \Rightarrow D_1$ off, D_2 ON



$0 < t < T/4 \Rightarrow V_{in} \Rightarrow [0 \rightarrow 100V]$

$\Downarrow$

$V_{c_1} \Rightarrow [0 \rightarrow 50V]$

$V_{c_2} \Rightarrow [0 \rightarrow 50V]$

$@\ t = T/4^{+}$

$V_i = 99V$ {let} $\quad V_{c_1} = V_{c_2} = 50V$

D_1 and D_2 both are off

Both C_1 and C_2 will retain their voltages.

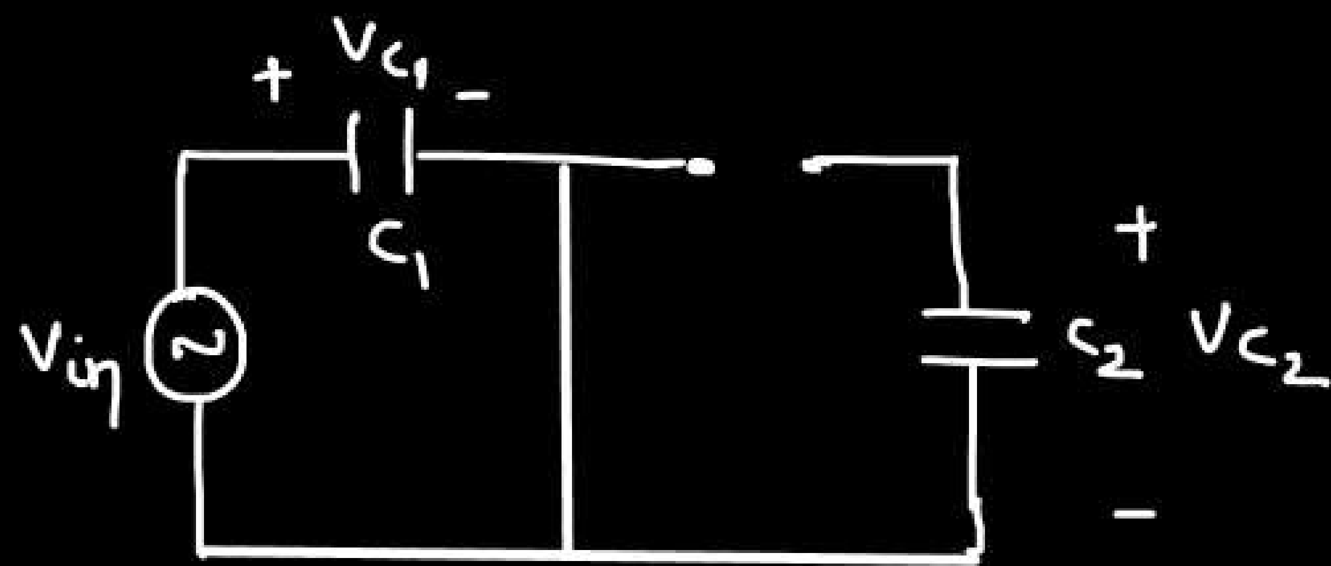
{But till what time?}

when $V_i - 50 < 0 \Rightarrow D_1$ turns ON, D_2 still remains off

untill $V_i < 50V$, both D_1 and D_2 are off.

NOW

$@\ t = \frac{5T}{12}^{+}$ $\quad V_i = 49V$ {let} $\Rightarrow D_1$ turns ON, D_2 still off



C_1 will follow the i/p

C_2 will retain its voltage

@ $t = \frac{3T}{4}^{+}$ $v_i = -99V$ {let} $V_{C_1} = -100V$, $V_{C_2} = 50V$

D_1 turns OFF, D_2 still OFF

How D_2 will turn ON = ?

$V_{in} + 100 > 50 \Rightarrow V_{in} > -50$

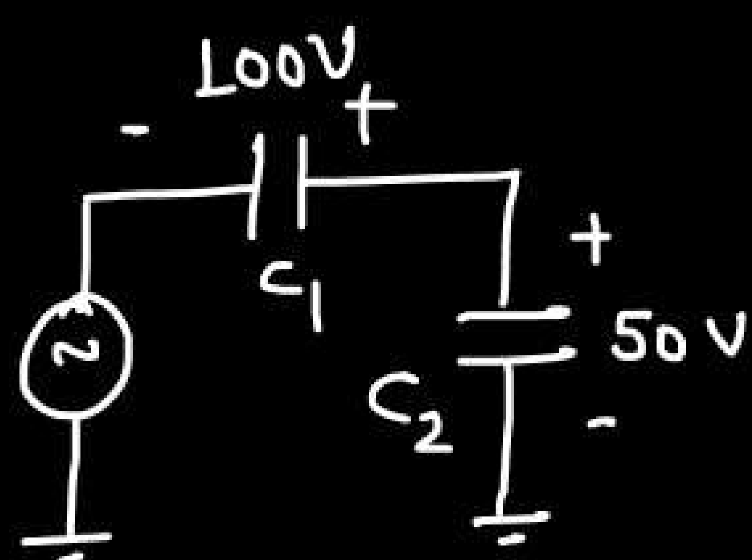
Untill $V_i > -50V$, both D_1 and D_2 are off

Both C_1 & C_2 are retaining their voltage.

@ $t = \frac{11T}{12}^{+}$; $V_{in} = -49V$ {let}

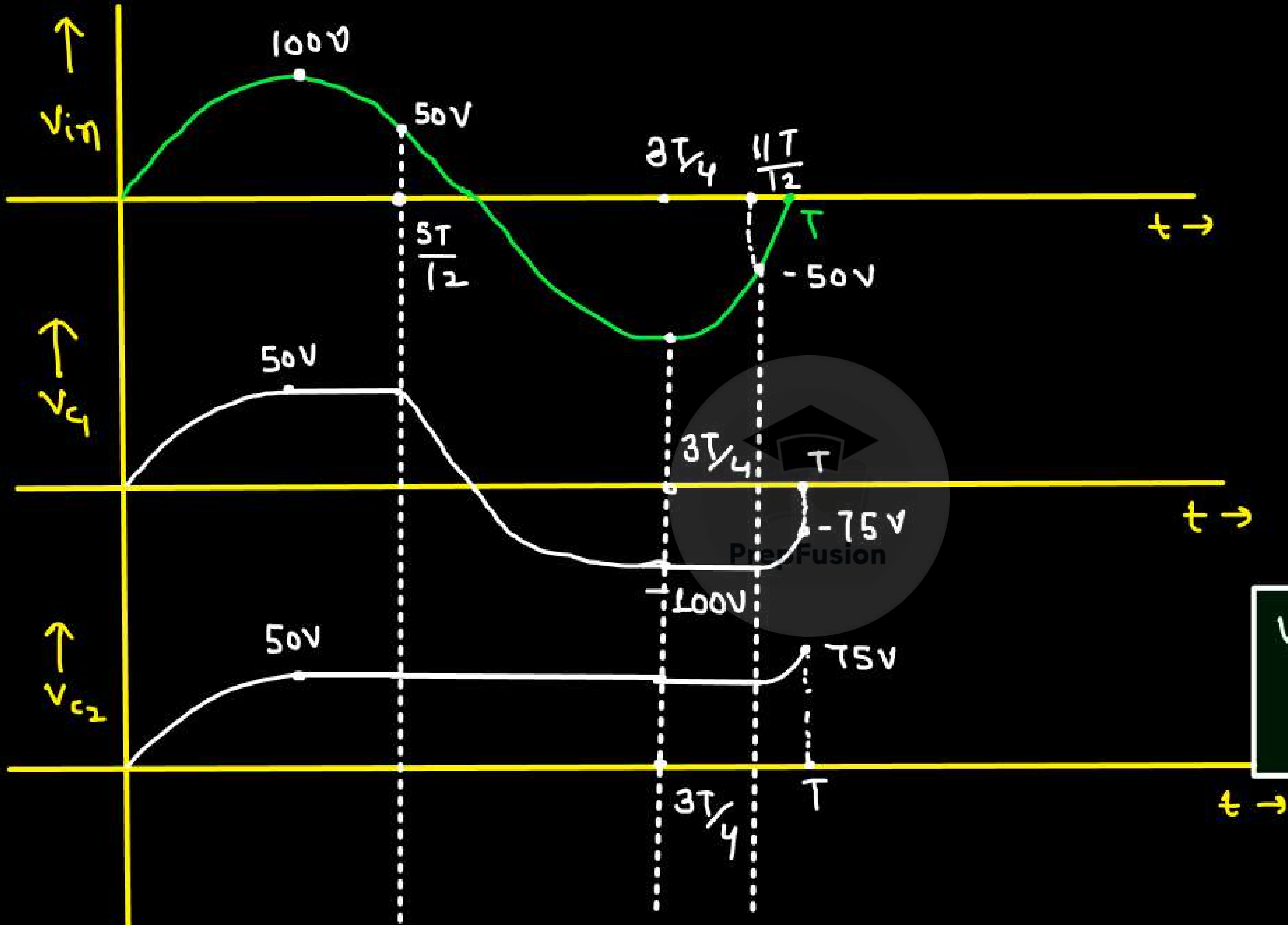
$V_{C_1} = -100V$, $V_{C_2} = 50V$

D_1 is off, D_2 turns off



$V_{in} \Rightarrow [-50 \rightarrow 0] \Rightarrow$ increased by 50V

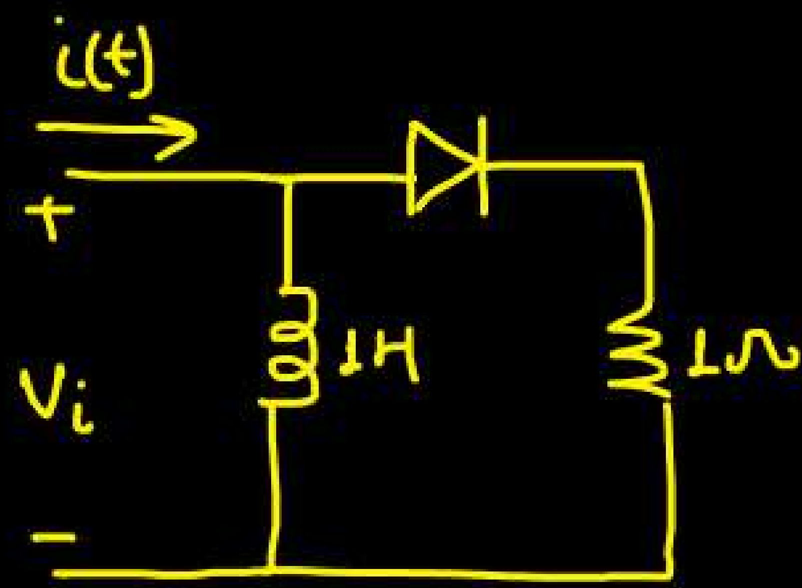
V_{C_1} and V_{C_2} will also increase by 25V each.

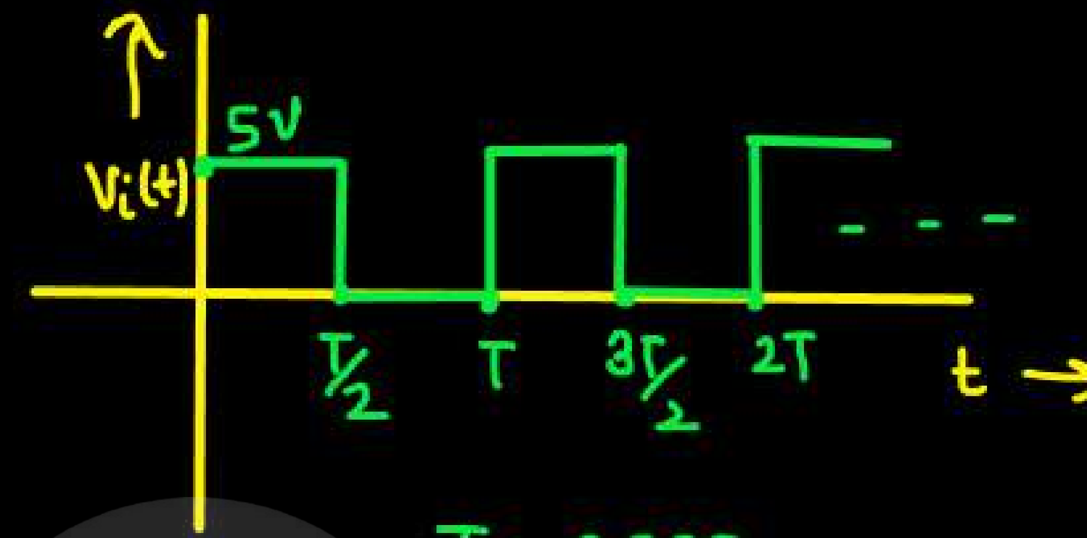


$$V_{c_1}(T) = -75\,V$$

$$V_{c_2}(T) = 75\,V$$

Q.

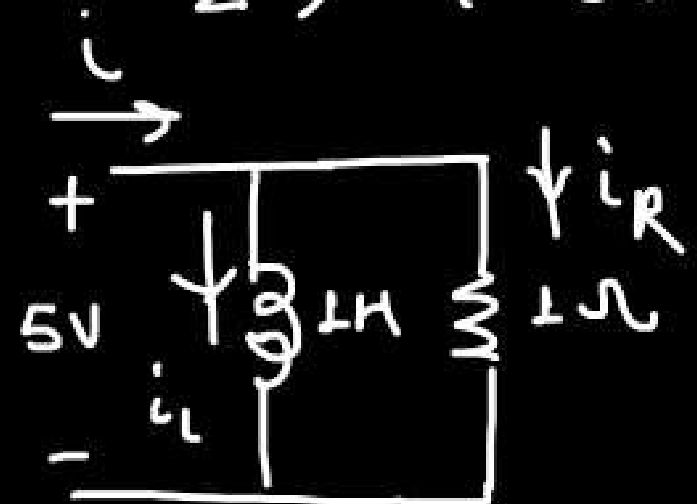




$T = 2\,sec.$

plot $i(t) = ?$

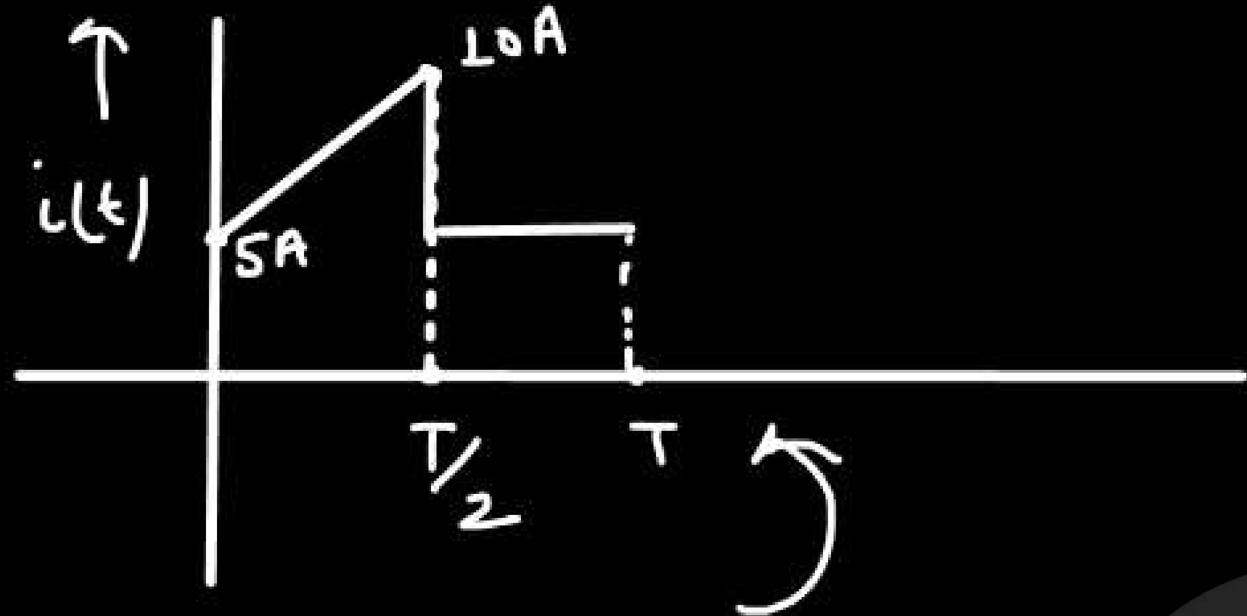
$0 < t < T/2$; $V_i = 5V \Rightarrow$ diode ON



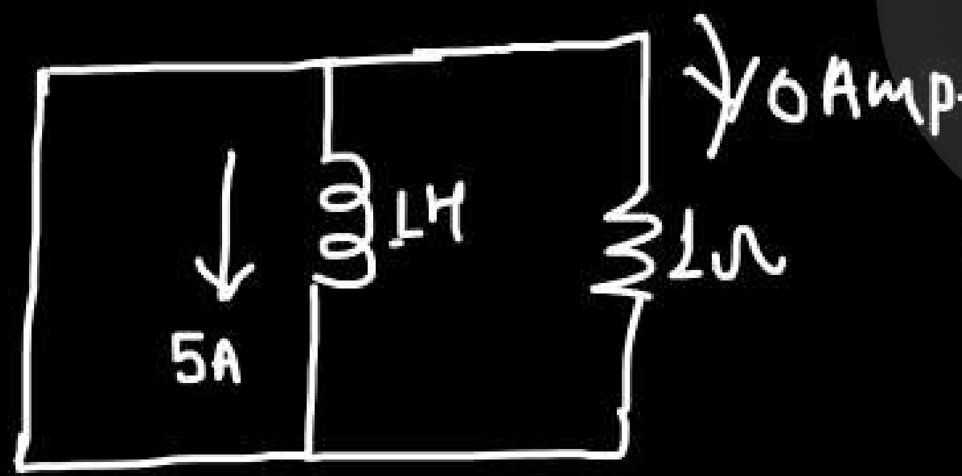
$$i(t) = i_L(t) + i_R(t)$$

$$i(t) = 5t + 5 \quad \left\{ 0 < t < T/2 \right\}$$

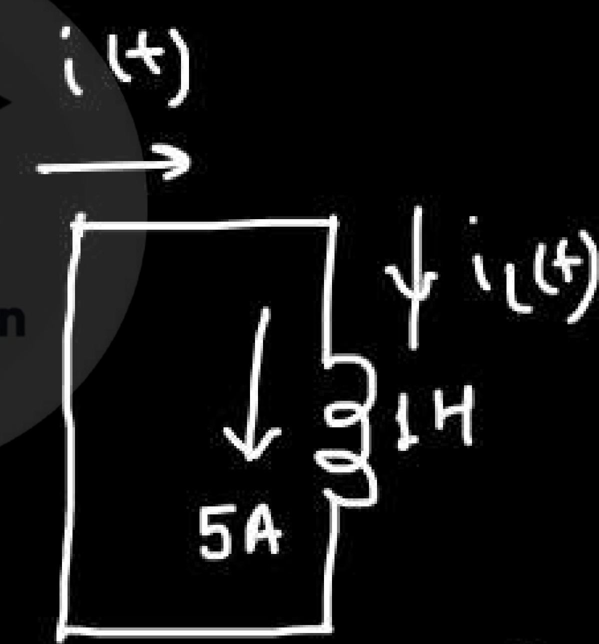
$$i(T/2) = \underbrace{5}_{} + 5 = 10 \text{ Amp.}$$



$$@\ t = \frac{T}{2}^{+} \Rightarrow v_L = 0V$$



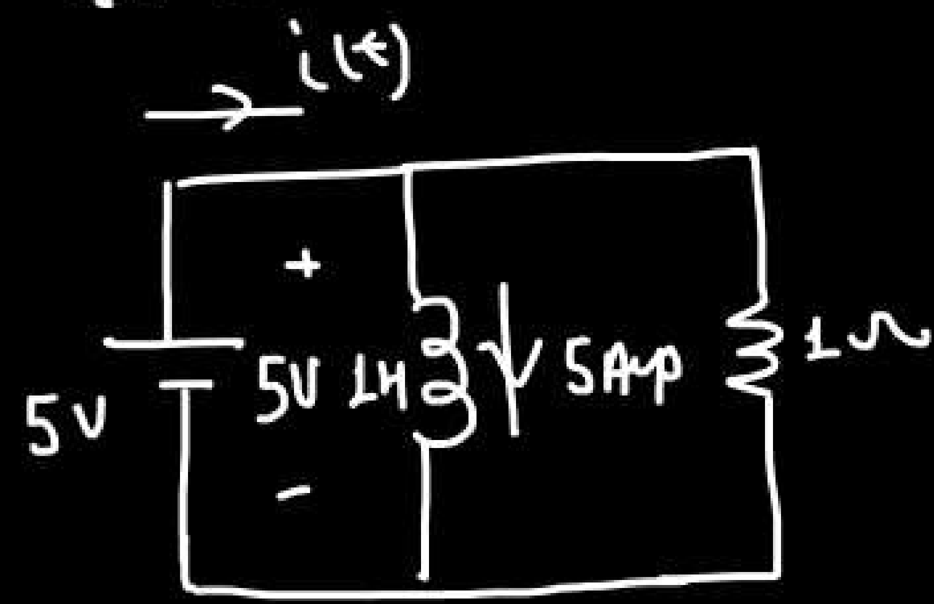
$\equiv$



$$\left\{ \frac{T}{2} < t < T \right\}$$

@ $t = T^+$

$V_i = 5V$

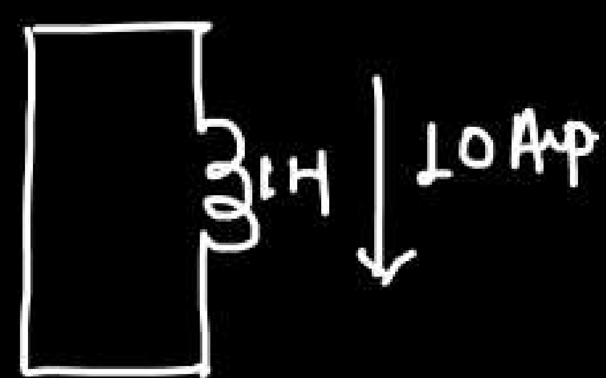


$$i(t) = \underbrace{5A + 5(t-T)}_{\text{Inductor}} + \underbrace{5A}_{\text{Resistor}}$$

$$i\left(\frac{3T}{2}\right) = \underbrace{5A + 5A}\ + 5A$$

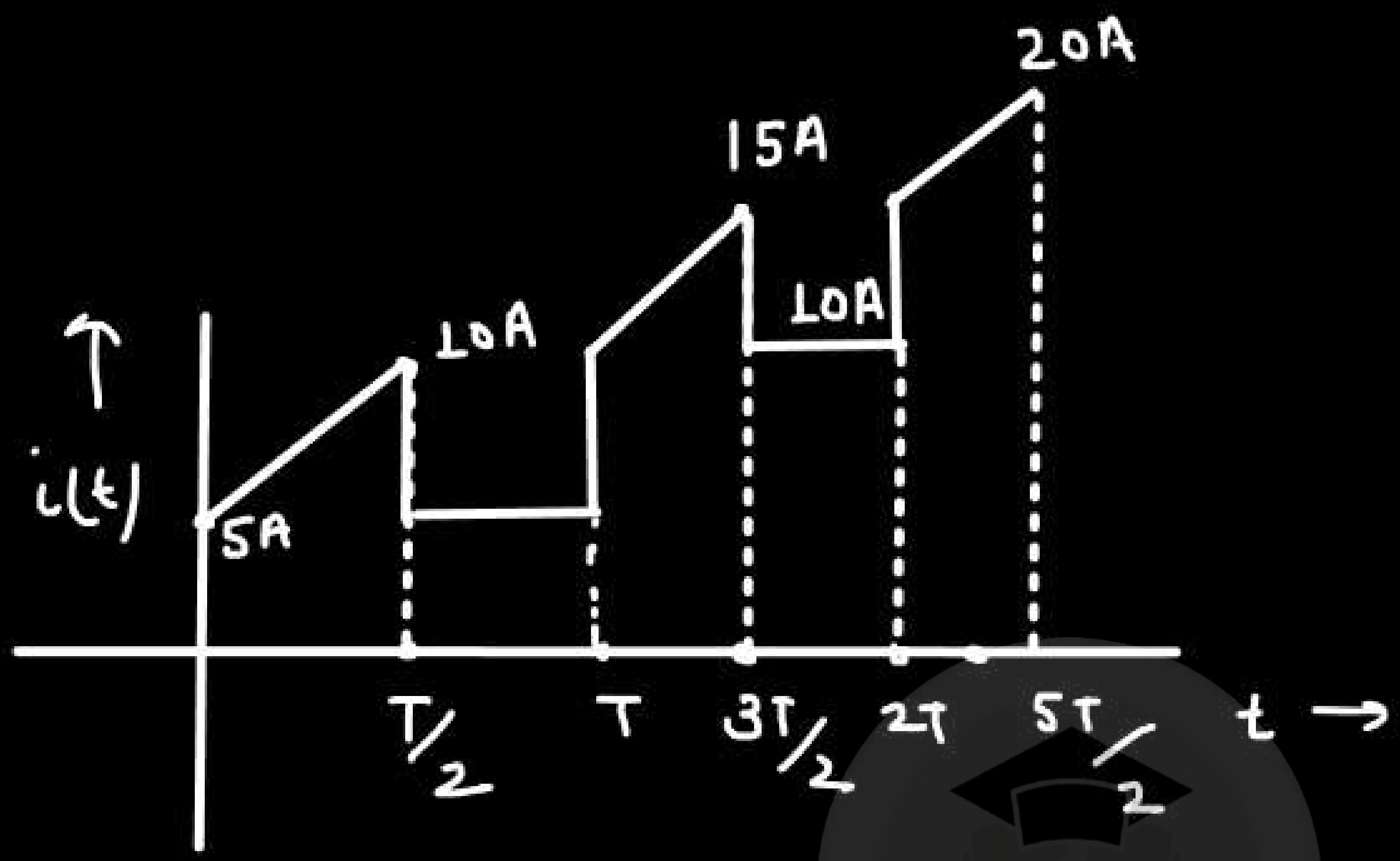
$$= 15A$$

@ $3T/2^+$



@ $t = 2T^+$

$$i(t) = 10A + 5(t - 2T) + 5A$$



20A
15A
10A
10A
5A
i(t)
T/2
T
3T/2
2T
5T/2
t

Basic Semiconducto...
BASIC SEMICONDUCTOR PHYSICS
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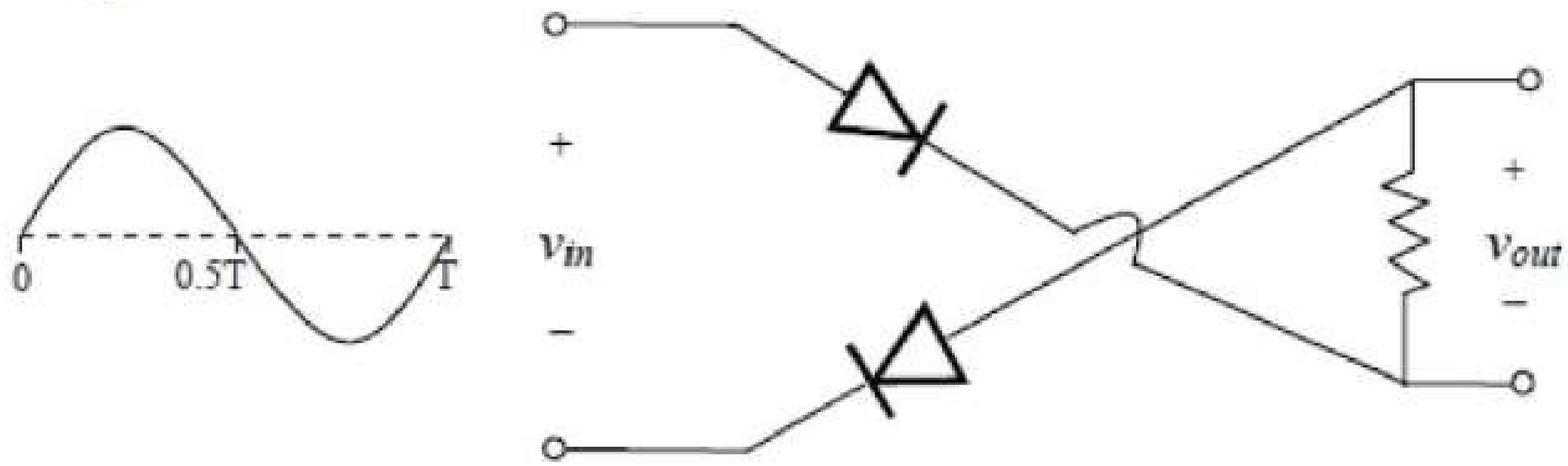
AIR 27 (ECE)
AIR 45 (IN)

For the circuit with ideal diodes shown in the figure, the shape of the output (v_{out}) for the given sine wave input (v_{in}) will be



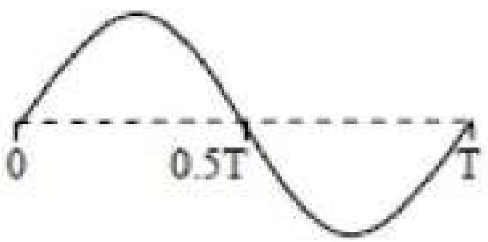
$V_{in} = +ve$

$V_o = -V_{in}$

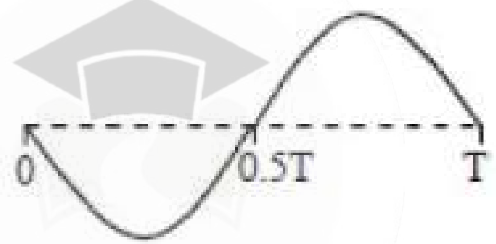
$V_{in} = -ve$

$V_o = 0V$

(A)

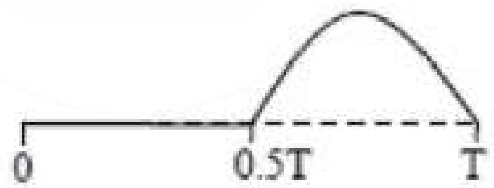


(B)



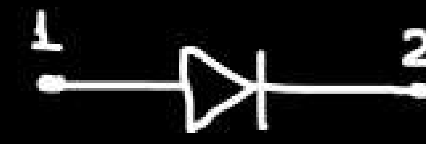
(C)

(D)



☆ What we have studied?

⇒ Diode → Two terminal device →



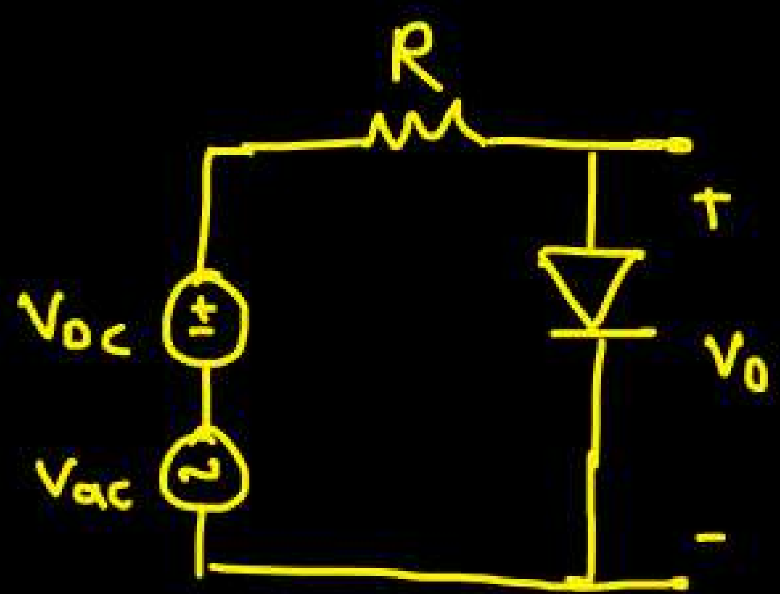
☆ What did we get from diode?

1. Clipper → clips off undesired part.
2. Clamper → Sets a new dc value of the i/p.
3. Peak detector → detects peak value of i/p and gives dc o/p.
4. Voltage Multipliers → gives the o/p more than the max value of i/p signal (dc o/p)

5 Small signal Analysis :-

ON: $r_d = \frac{nV_T}{I_{dc}}$

OFF: $r_d = \infty$



diode ON $\Rightarrow$ $V_0 = (V_0)_{DC} + \frac{r_d}{r_d + R} v_{ac}$

diode OFF $\Rightarrow$ $V_0 = V_{DC} + v_{ac}$

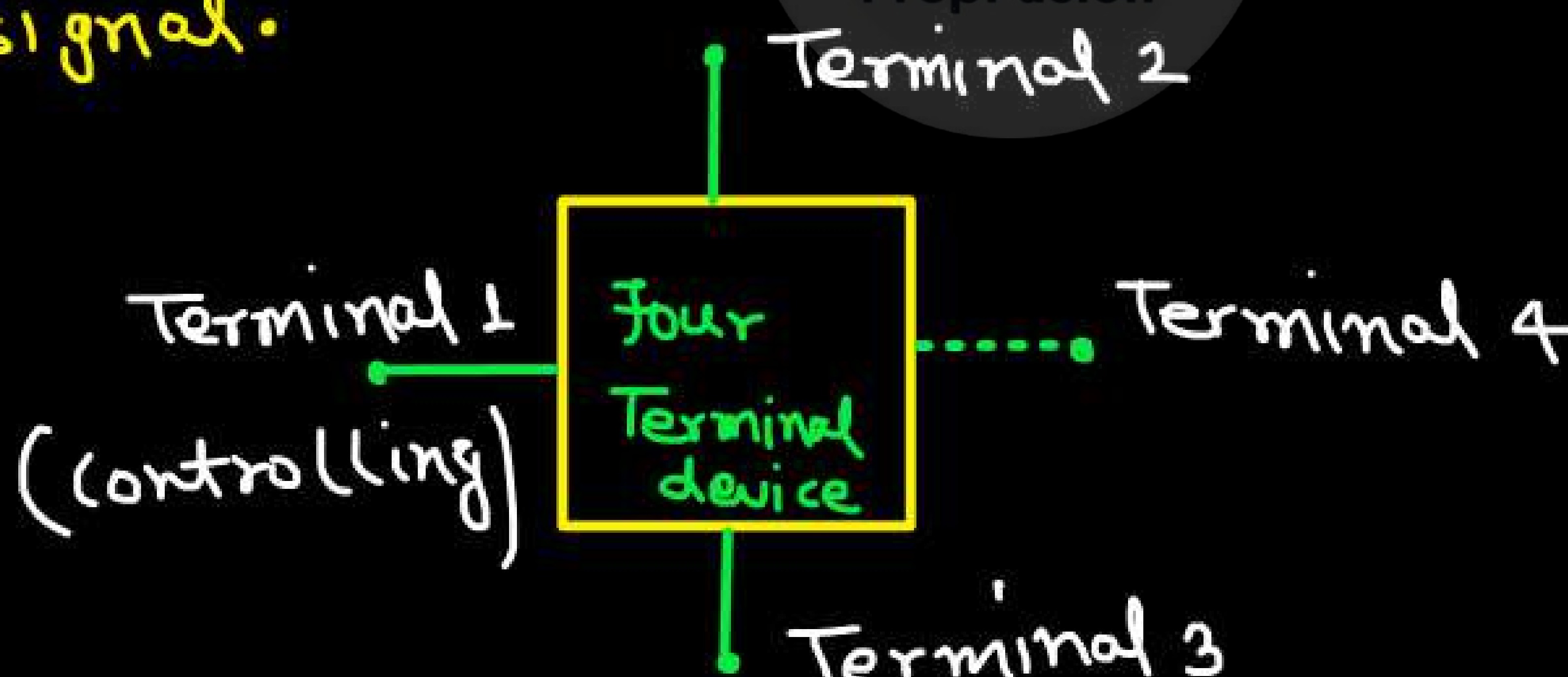
$\Rightarrow$ NOT Getting Amplified o/p.

$= K V_m \sin\omega t$

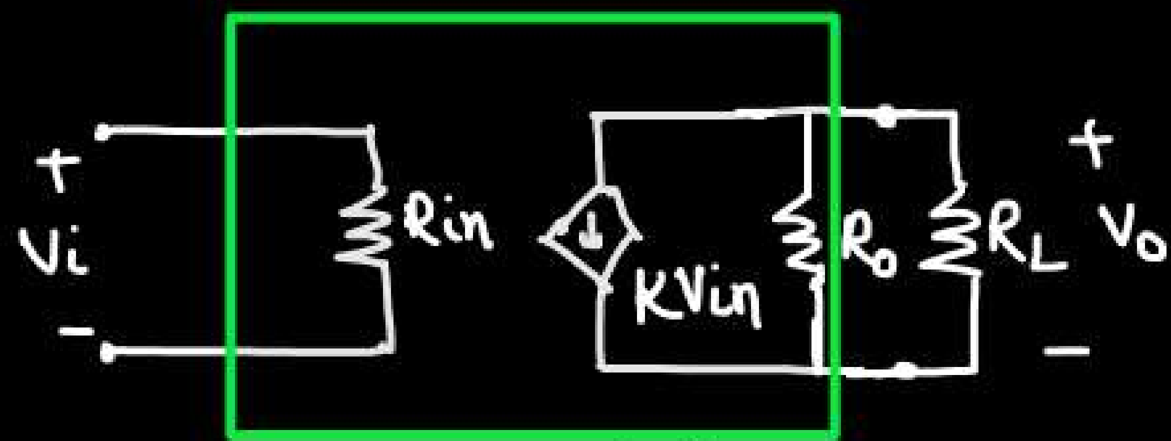
where $|K| > 1$

$\Rightarrow$ NOT POSSIBLE

$\Rightarrow$ You need some three/four terminal device for Amplification of i/p ac signal.



A Basic Amplifier :-



Amplifier

Gives Rise to Transistors

$$V_o = \underbrace{-KR_L}\, V_{in}$$

$\Downarrow$

Amplification

★

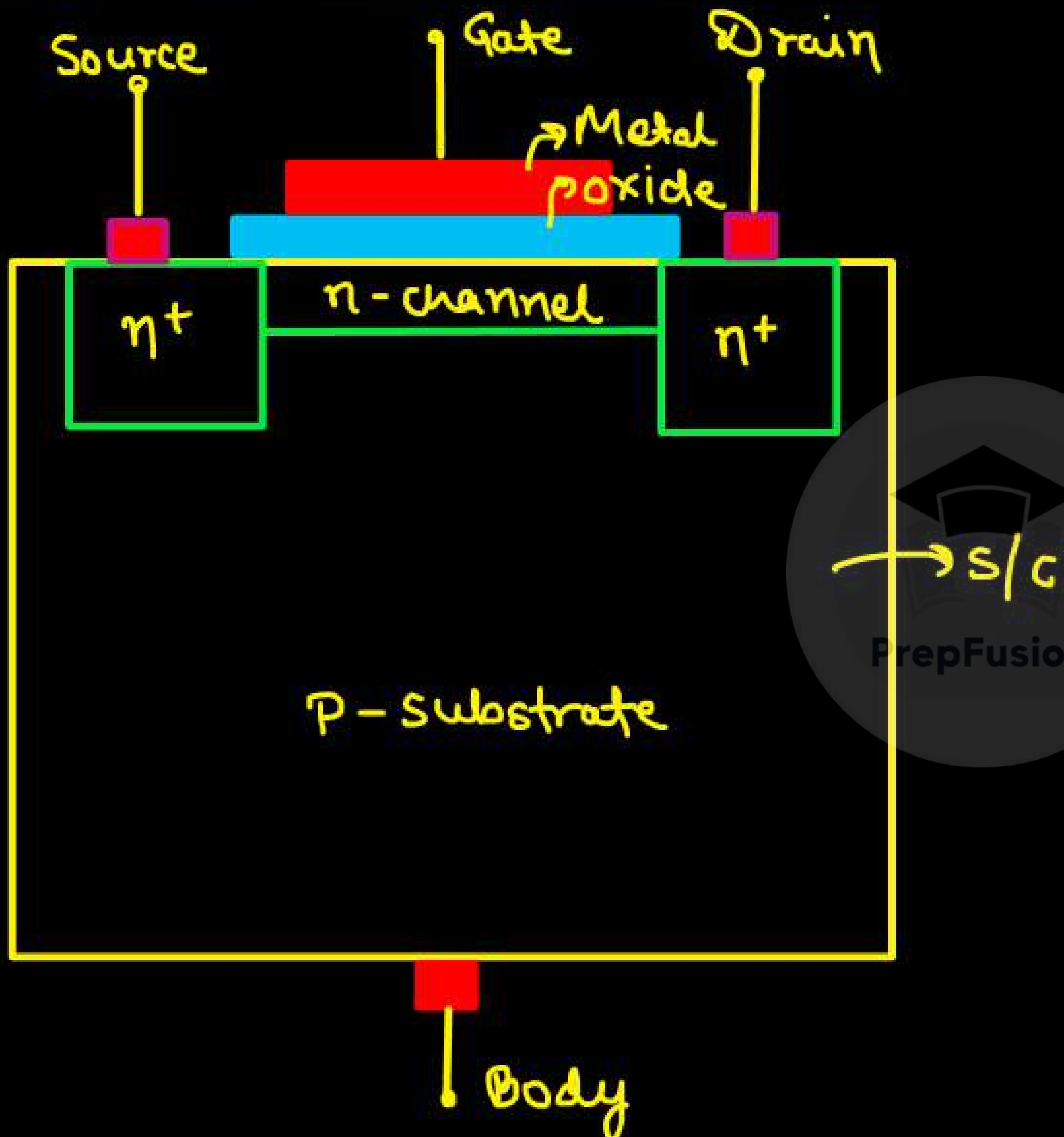
Field Effect Transistors
(FET)

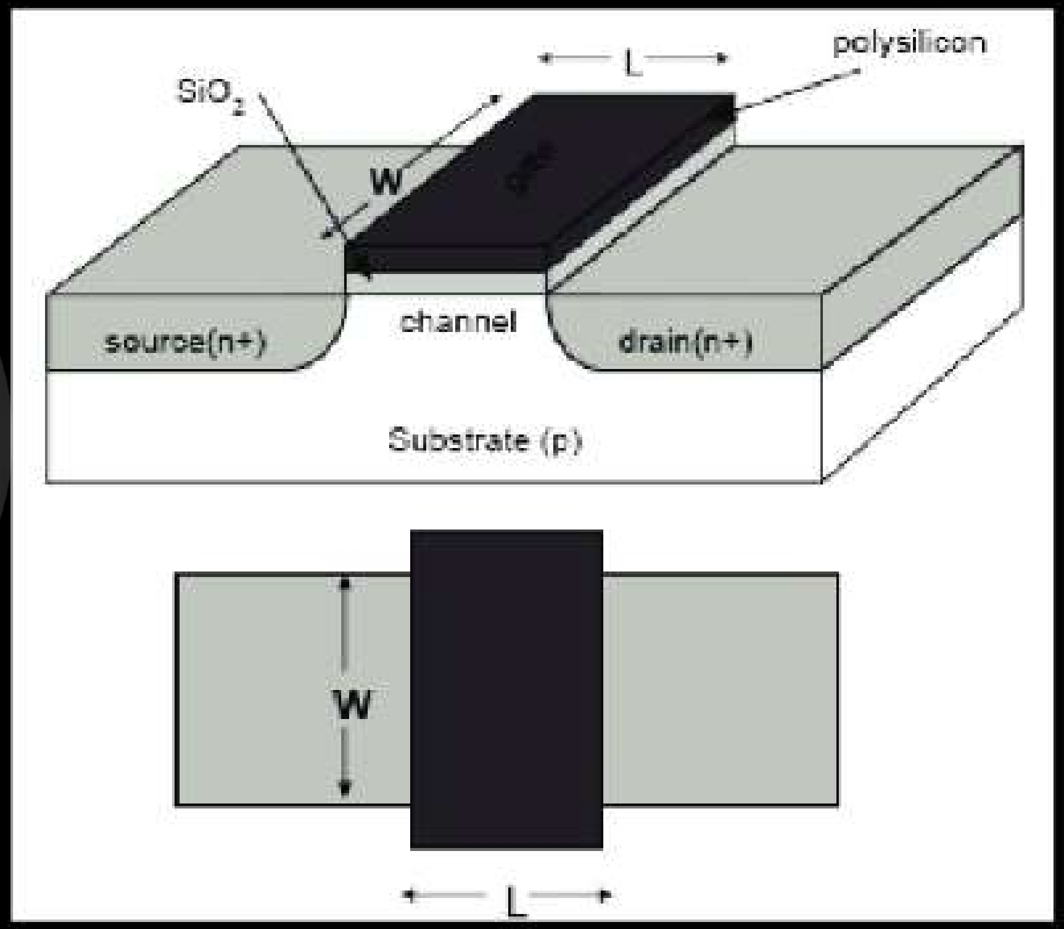
↓

MOSFETs
(Metal oxide semiconductor)

- Depletion Type
  - n-channel
  - P-channel
- Enhancement type
  - n-channel
  - P-channel

① n-type depletion MOSFETs :- [Channel is already +nt]





[Photo from ResearchGate]

MOS → 4 terminal device
(Gate, Source, Drain, Body)

① **Source** :- Supplies the charge carrier to the channel.

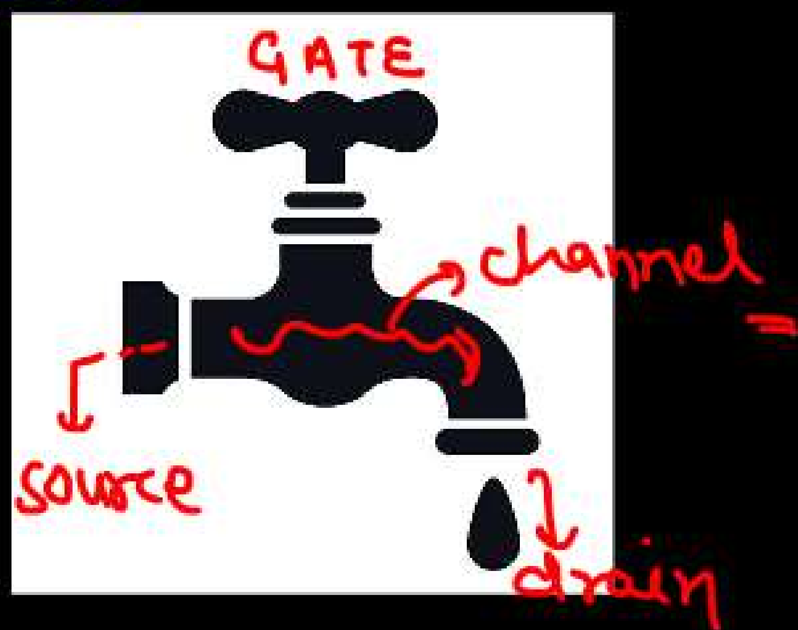
② **Drain** :- Collects the charge carrier from the channel.

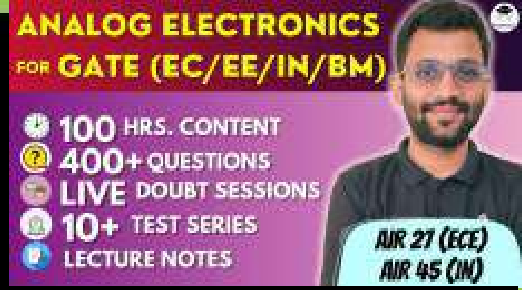
③ **Gate** :- Controls the flow of charge carriers.

④ **Channel** :- The path b/w drain and source from where the charge carrier travels.

⑤ **FET (Field Effect Transistor)** :- The flow of current is modulated by applied voltage or Electric field.

Analogy :-


GATE
channel
source
drain

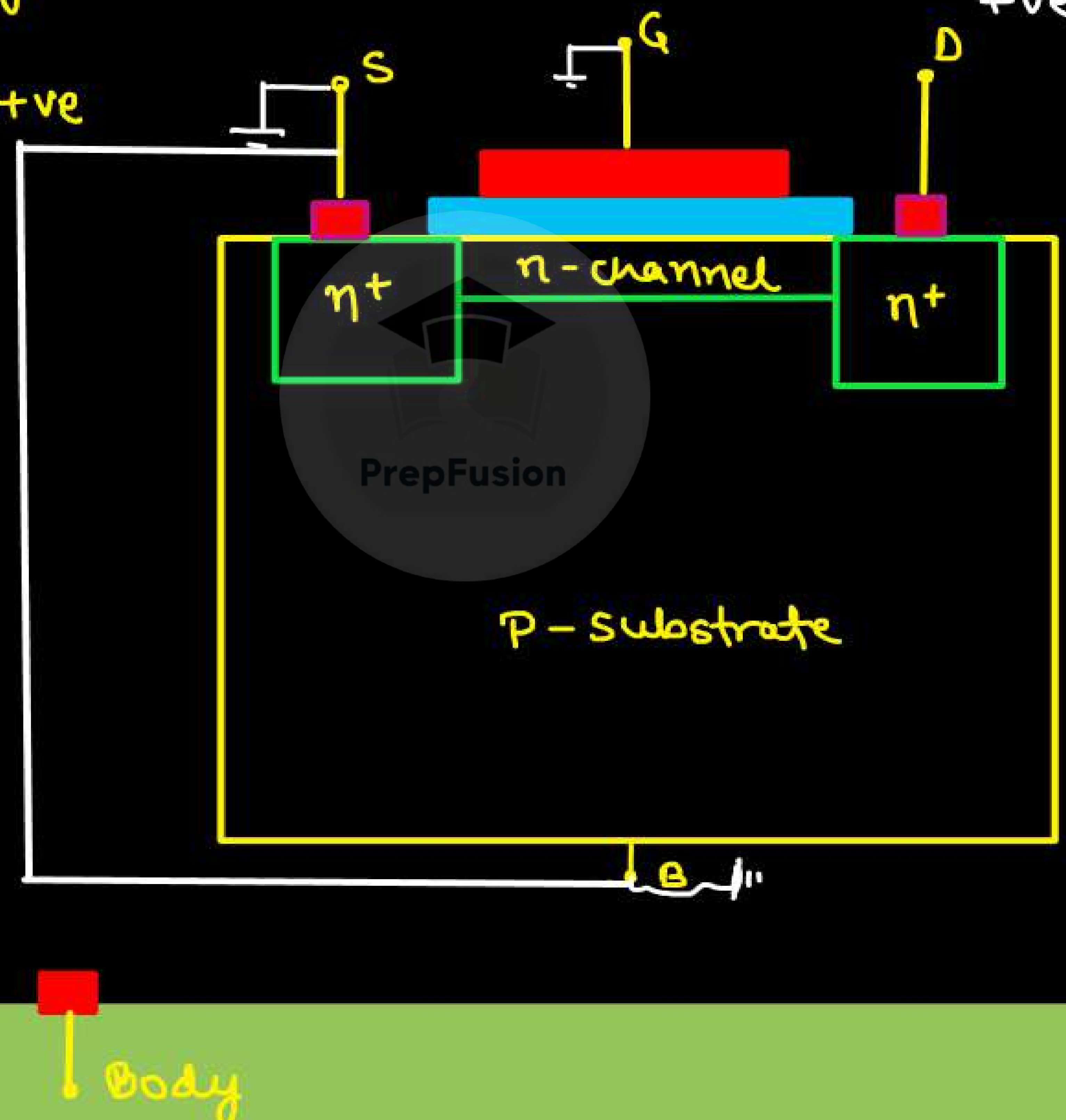

ANALOG ELECTRONICS
FOR GATE (EC/EE/IN/BM)
100 HRS. CONTENT
400+ QUESTIONS
LIVE DOUBT SESSIONS
10+ TEST SERIES
LECTURE NOTES
AIR 27 (ECE)
AIR 45 (IN)

For n-channel depletion type MOSFET :-

Codⁿ 1 :-

(i) $V_{GS} = 0V$

(ii) $V_{DS} = +ve$



→ charge carrier $= e^{\ominus}$

$n^+ \to$ Highly doped $\to$ more conductivity

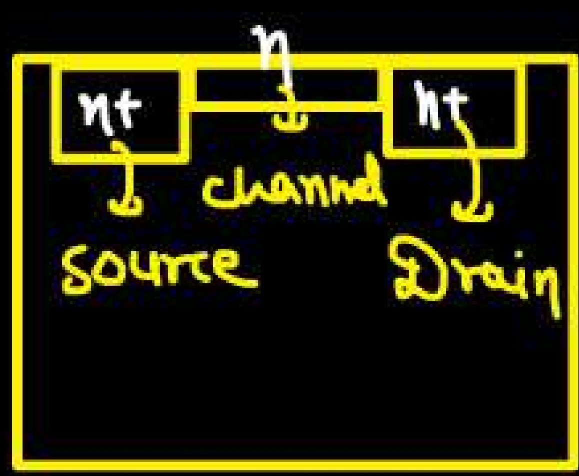
$\Downarrow$

less resistance

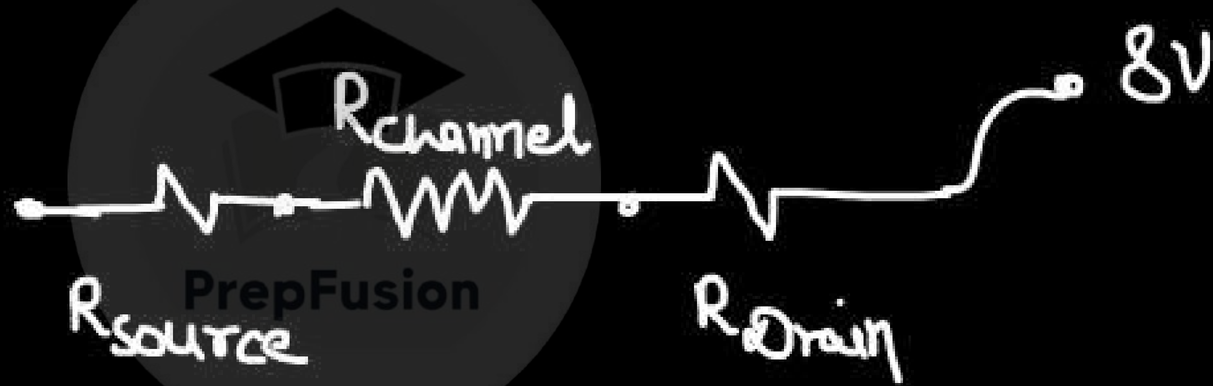
$n \to$ lightly doped $\to$ less conductivity

$\Downarrow$

More resistance



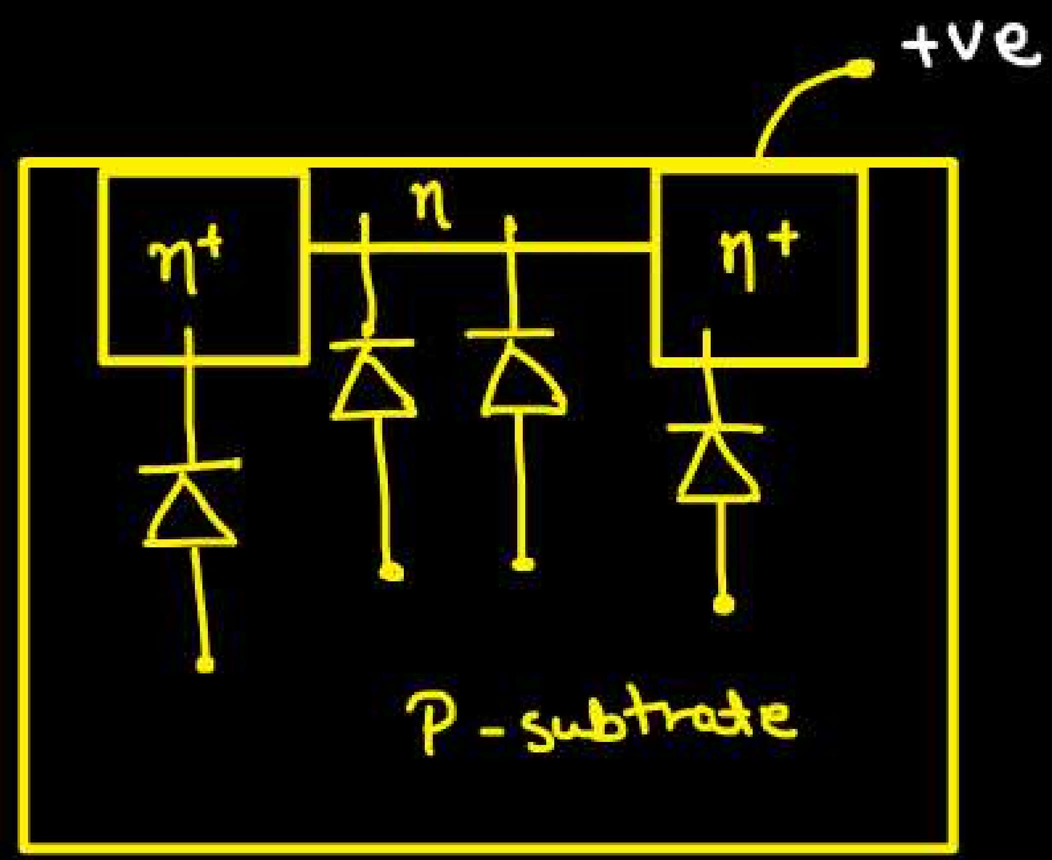
$\equiv$

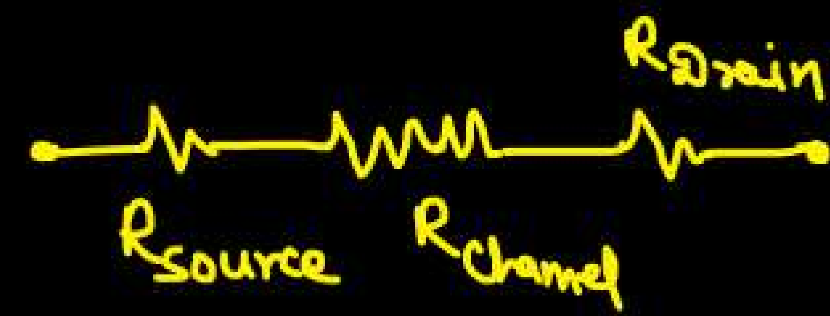


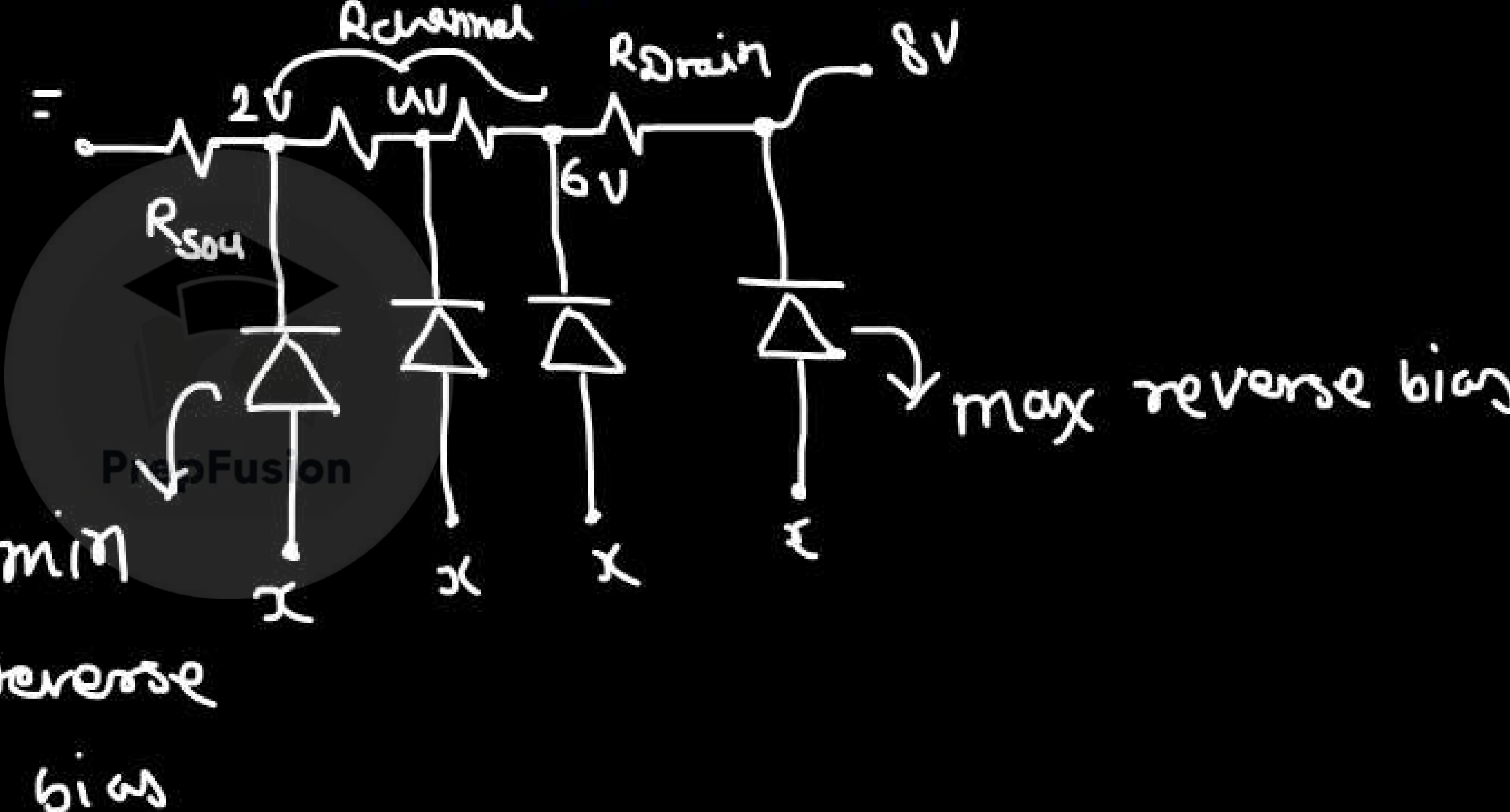
$R_{channel} > R_{Drain}, R_{source}$

Assumption

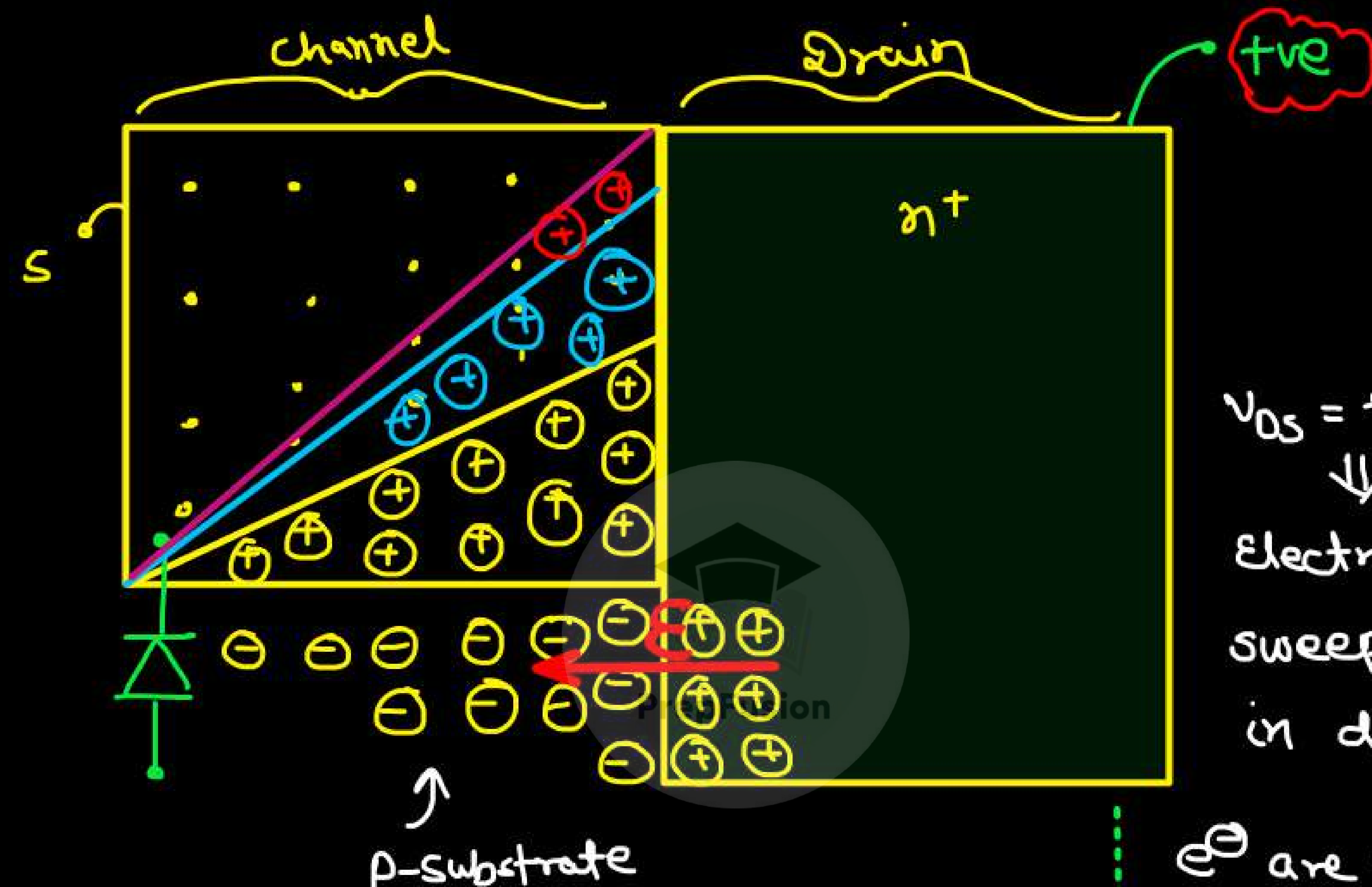
$R_{ch} = 2R_D = 2R_s$





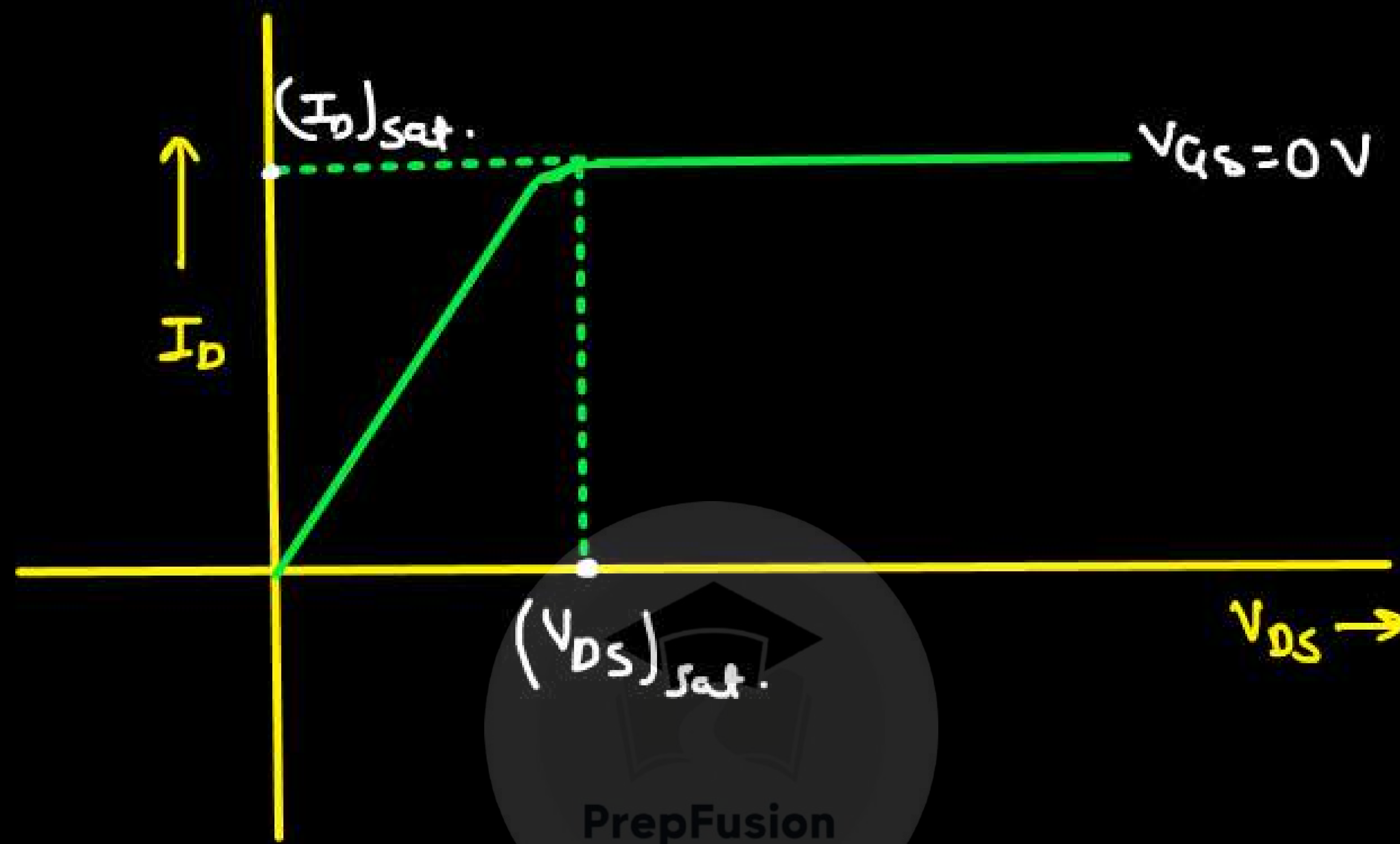


From drain to source, Reverse bias ↓ ⇒ depletion width ↓



V_{DS} = +ve
⇓
Electric field ε will sweep away the $e^\ominus$ in drain terminal
⇓
$e^\ominus$ are moving from source to drain
⇓
current will flow from Drain to source.

What if V_{DS} ↑↑ ⇒ "ε" will be strong ⇒ $e^\ominus$ will travel fast ⇒ current ↑



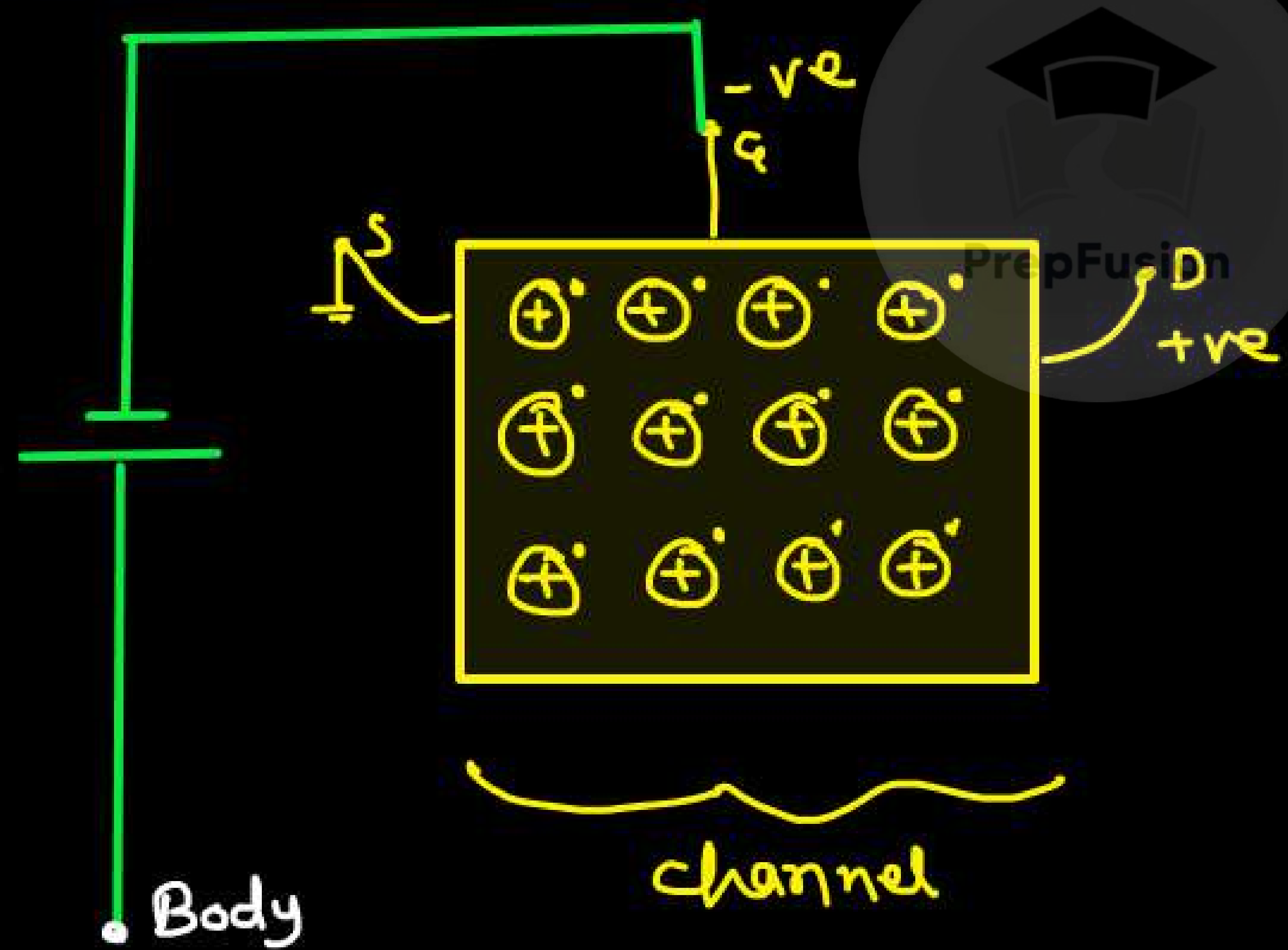
But @ a certain value of V_{DS}, the channel will start having very less charge carriers. Although the "E" field is strong but the charge carriers are less and because of that current saturates.

Cond^n 2:-

$V_{DS} = +ve$ {Fixed}

$V_{GS} =$ varying [$-ve \rightarrow +ve$]

① $V_{GS} = -ve$



V_G is increasing in negative dir^n

⇓

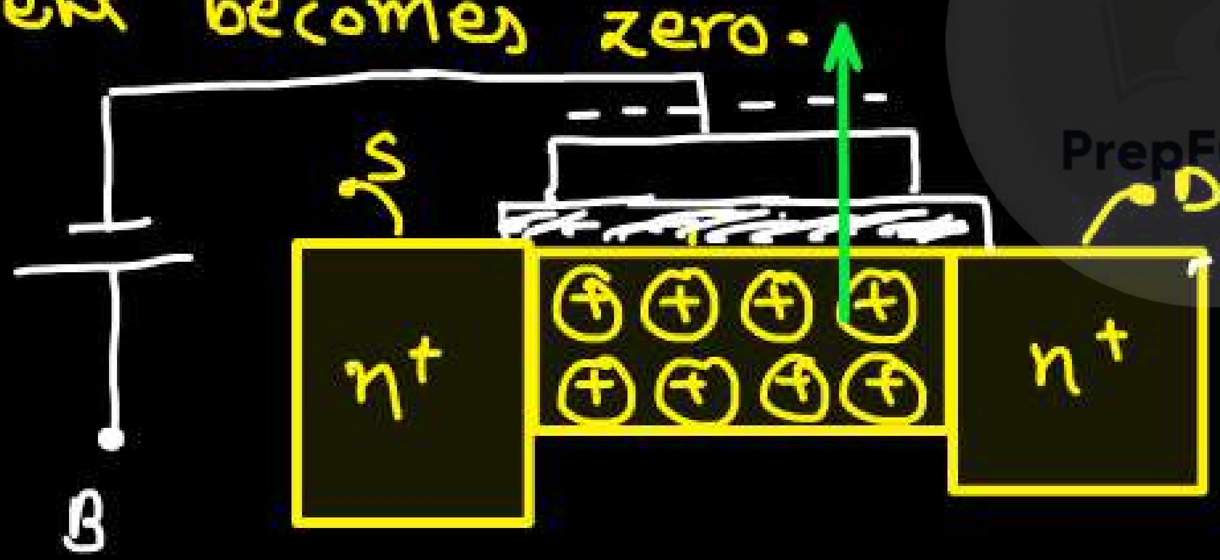
Channel is getting depleted of charge carrier

⇓

Current is decreasing

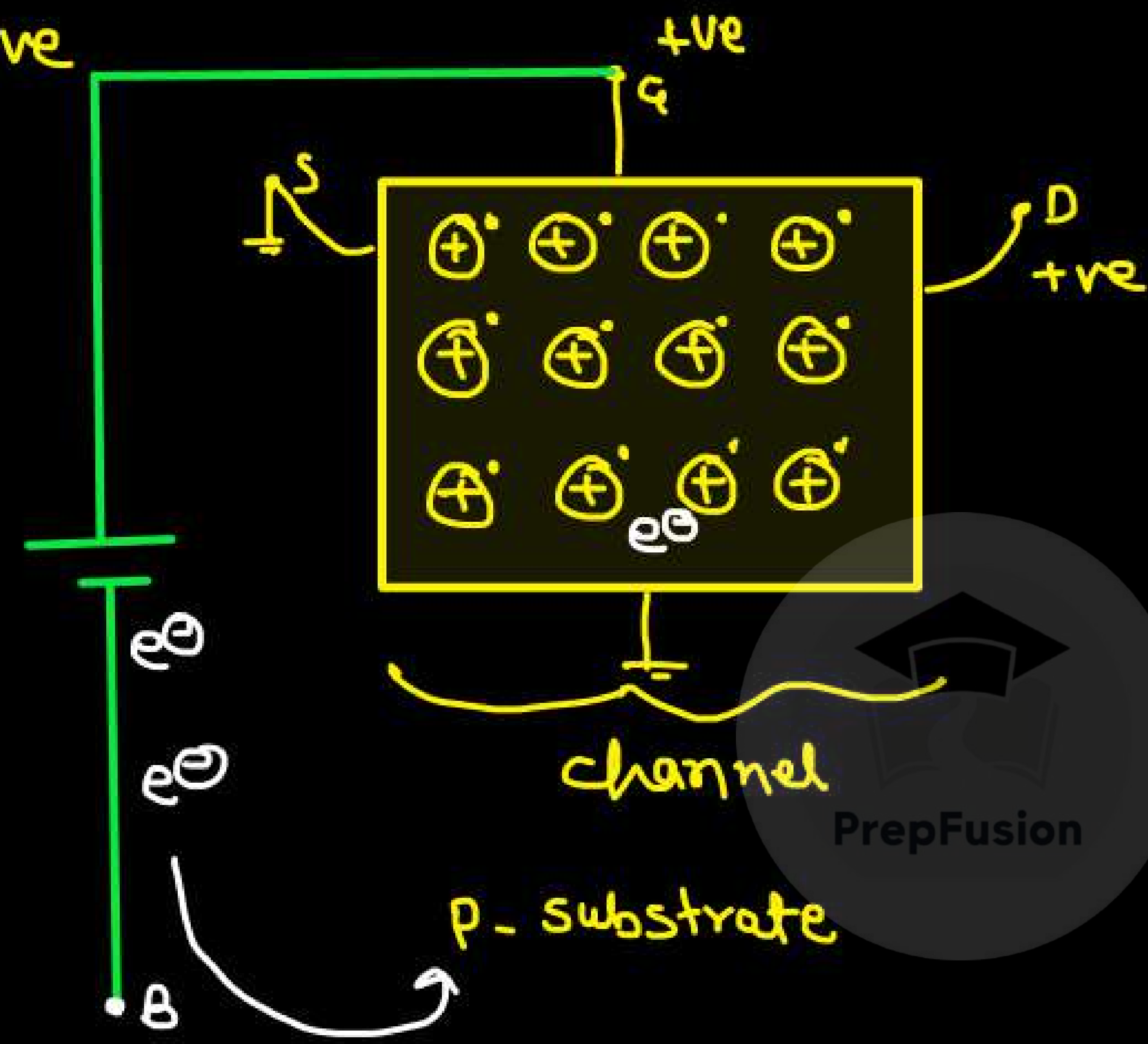
if we keep on decreasing V_{GS} value, then

@ some -ve V_{GS} value, the channel will be depleted of charge carrier and the electric field in vertical direction will be so strong that the e⊖ from source side will not be reaching the drain side and the current becomes zero.



⇒ Negative potential is known as pinch-off voltage.

2 $V_{GS} = +ve$

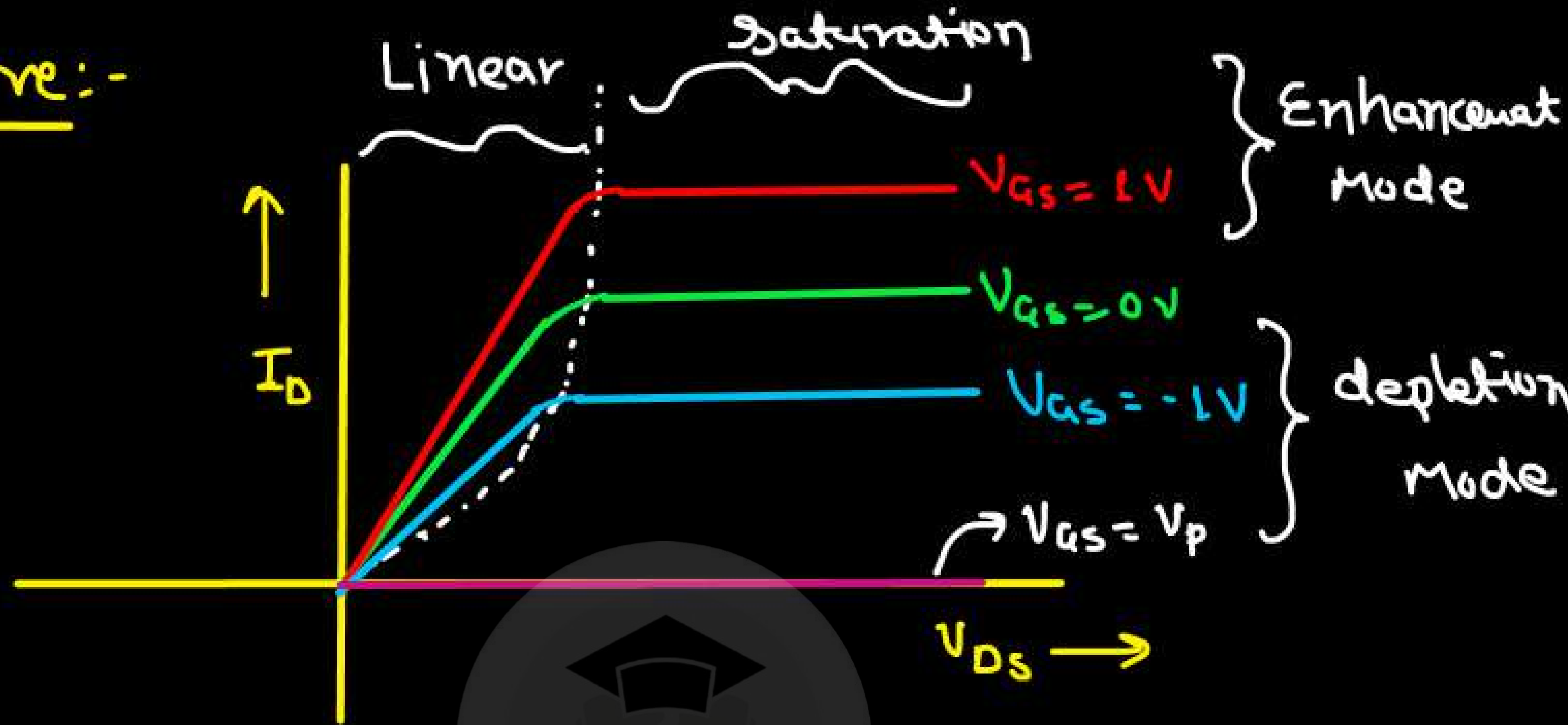


$V_G \uparrow \Rightarrow$ more $e^\ominus$ in channel

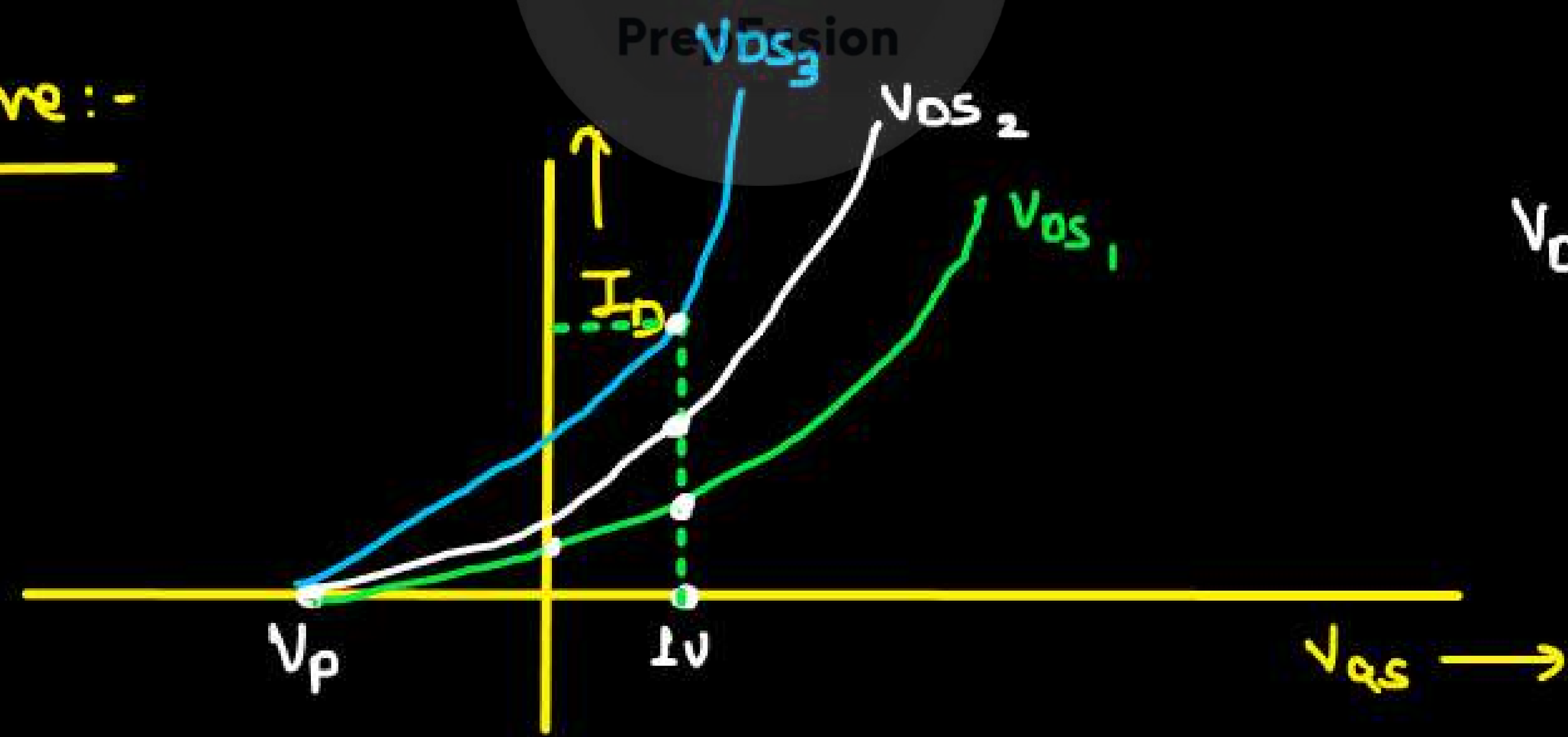
$\Downarrow$

$I_D \uparrow$

I_D v/s V_{DS} curve:-

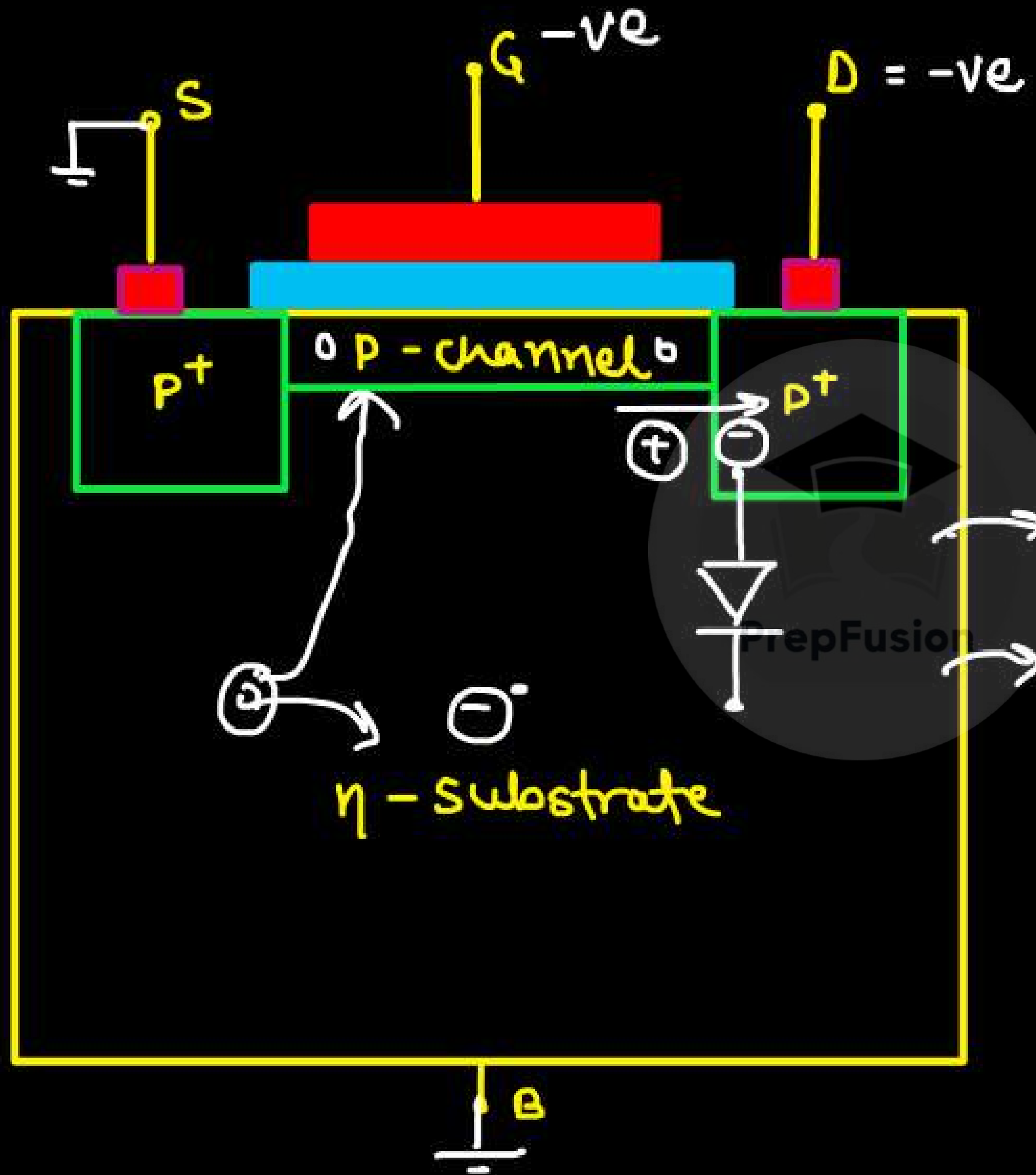


I_D v/s V_{GS} curve:-



$V_{DS_3} > V_{DS_2} > V_{DS_1}$

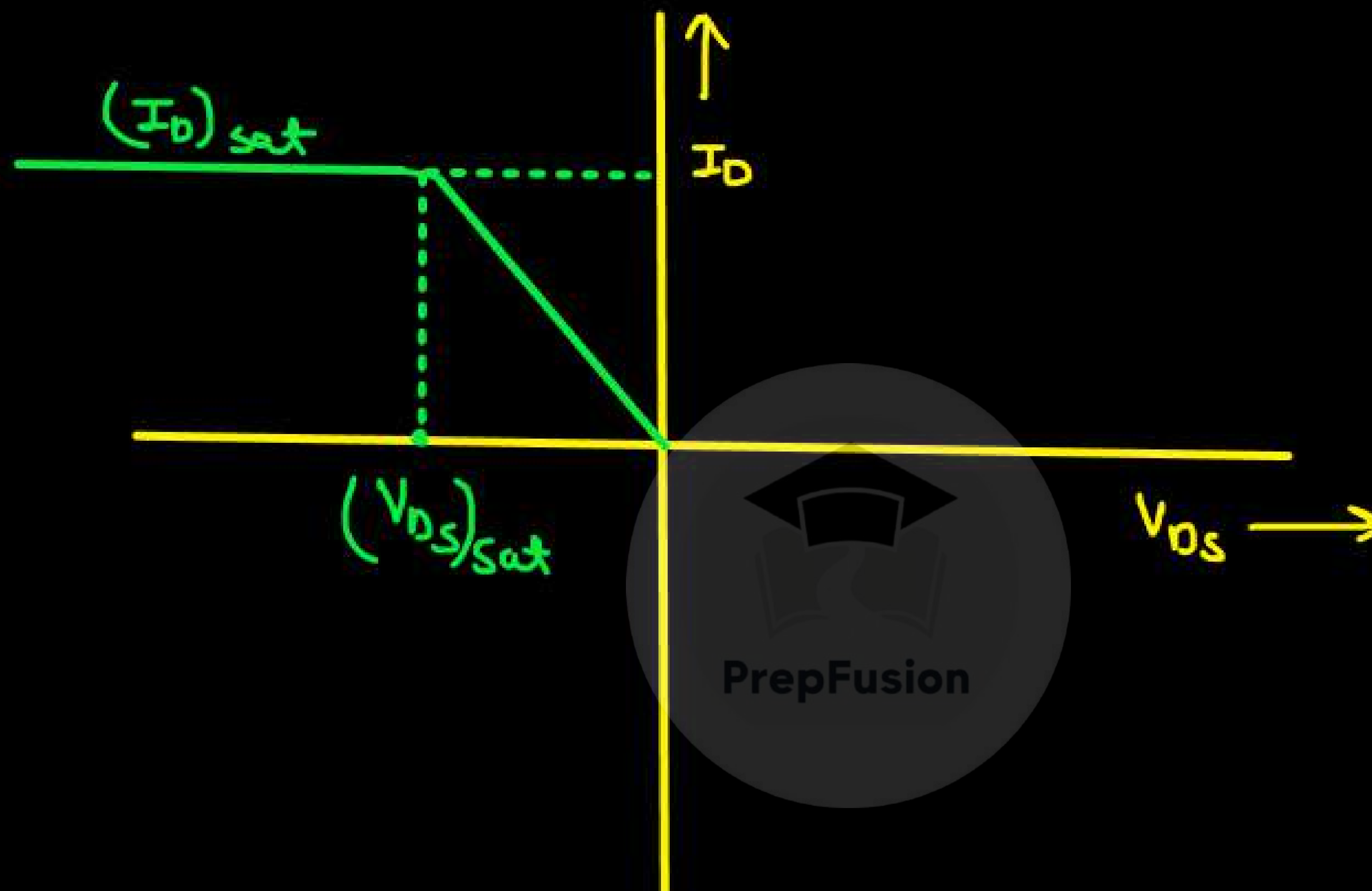
P-channel depletion type MOSFET :-



charge carrier = holes

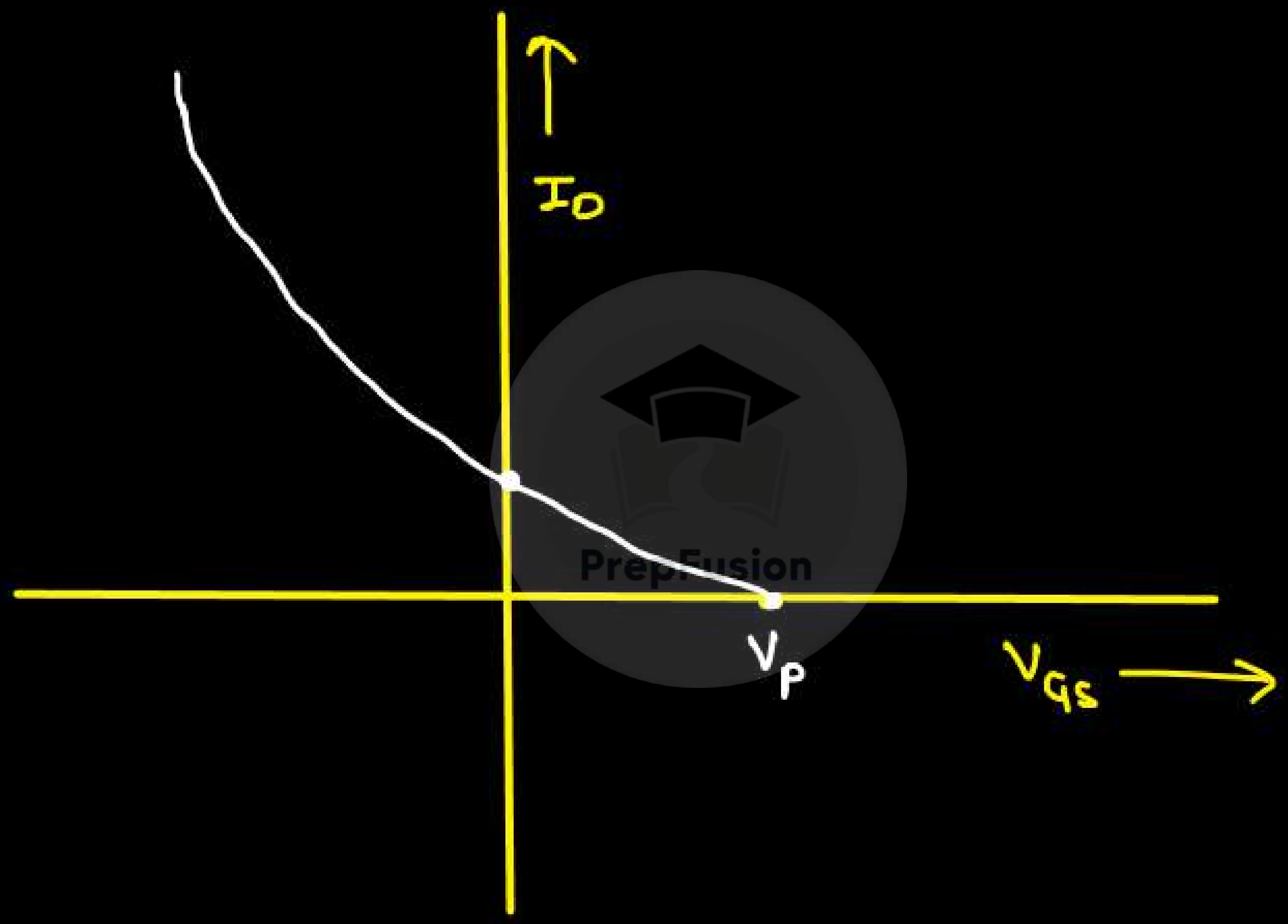
current dir^n ⇒ source to drain

I_D v/s V_{DS} curve:-



I_D direction $\Rightarrow$ source to drain

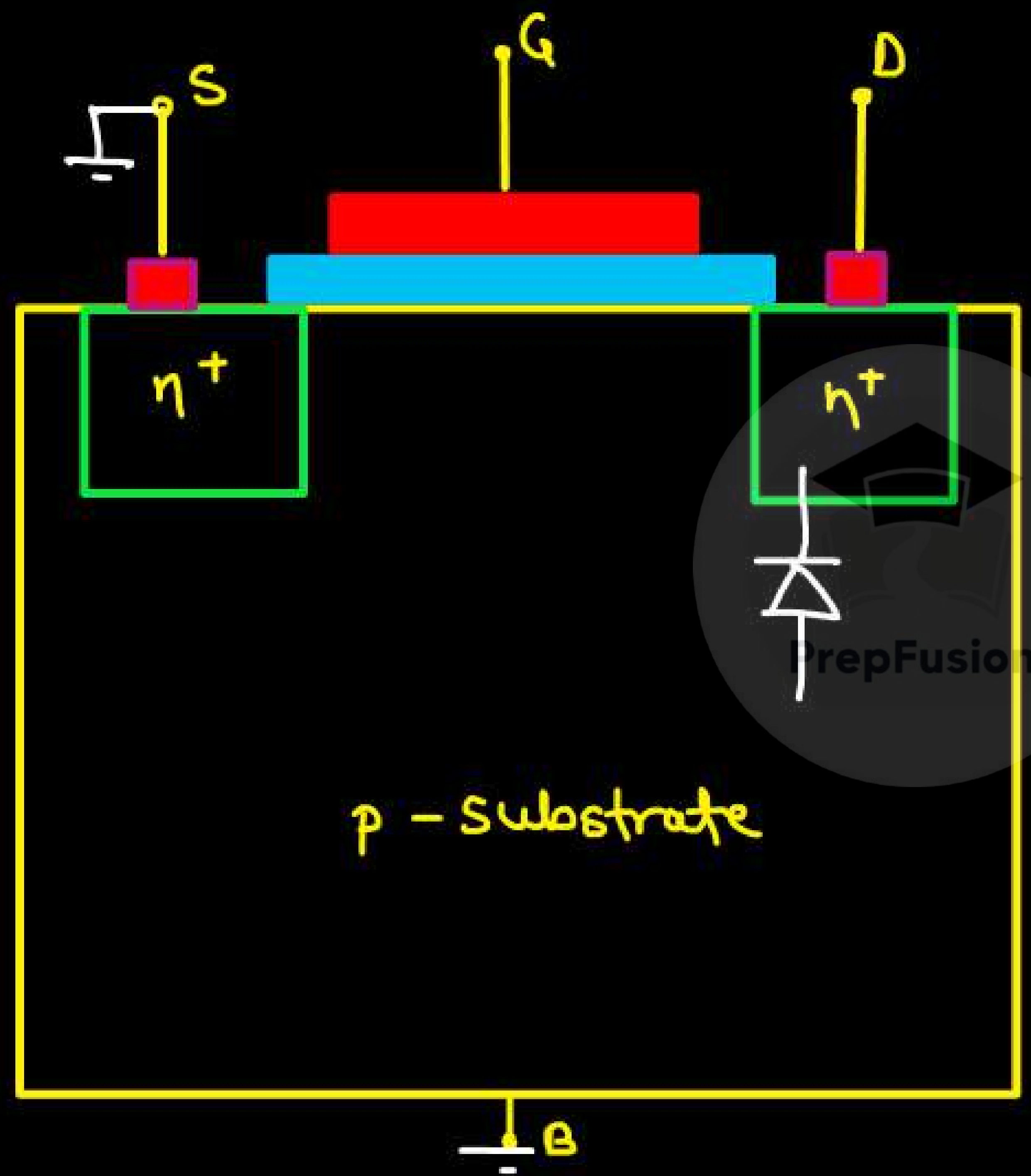
I_D v/s V_{GS} curve :-



N.B.:- In depletion type MOSFET, the channel (p or n) was already present. Even if you don't apply any controlling voltage @ Gate terminal ($V_{GS} = 0V$), still there will be some current flowing in the MOS and you will have some o/p @ the load.

For Amplifier design, we need a input controlled energy source. That's why we can't use depletion type MOSFET for amplifiers.

✯ n-channel enhancement type MOSFET :- (NMOS)



→ no initial channel

Cod^n - 1

$V_{GS} = 0\,V$

$V_{DS} = 0\,V$ $\Rightarrow$ $I_D = 0$ Amp.

Cod^n - 2

$V_{GS} = 0\,V$

$V_{DS} = -ve$ $\Rightarrow$ $I_D = 0$ Amp.

Cod^n - 3

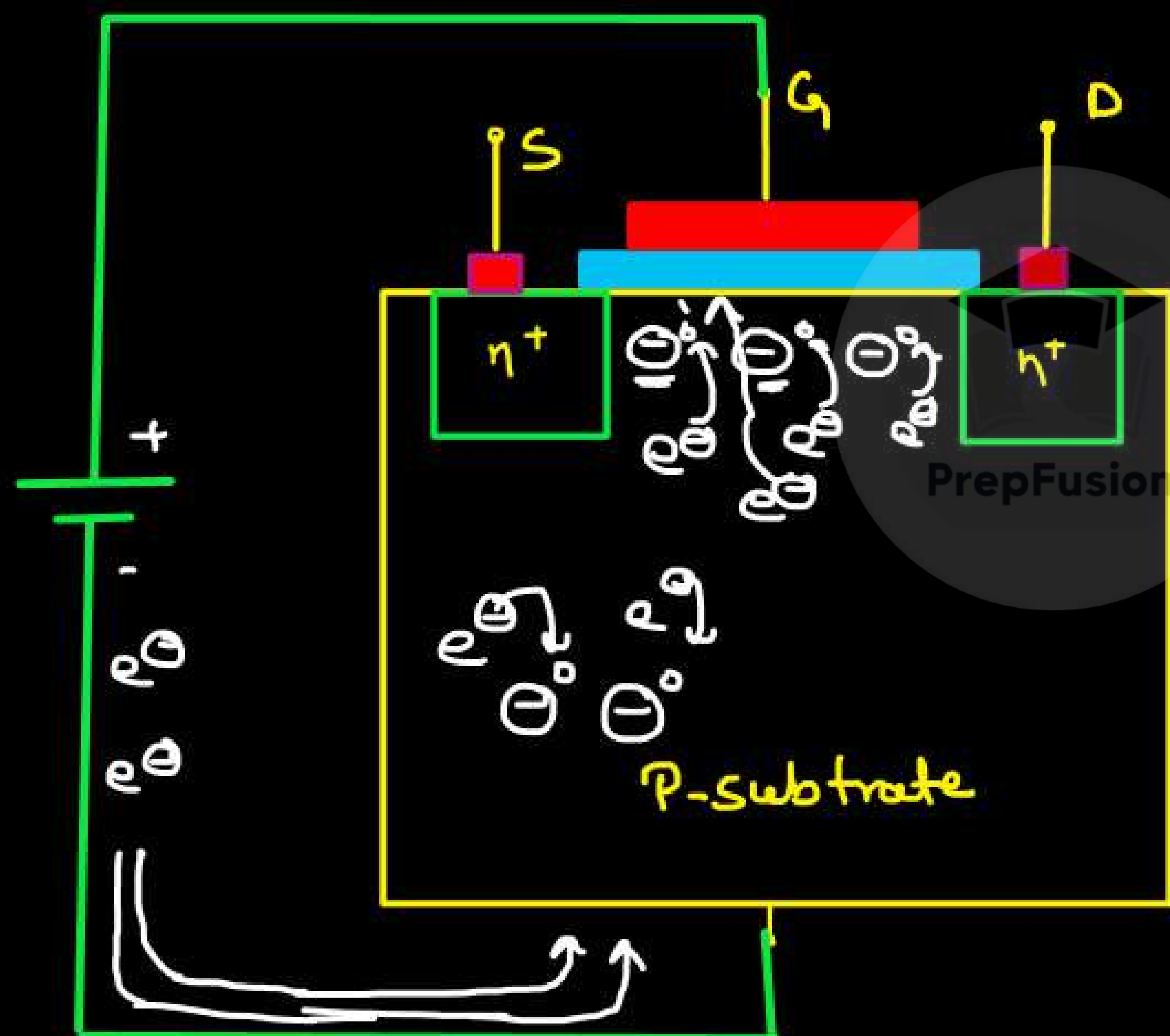
$V_{GS} = 0\,V$

$V_{DS} = +ve$ $\Rightarrow$ $I_D = 0$ Amp

Cod^n-4

V_{GS} = +ve {very less}

V_{DS} = +ve



V_G ↑ ⇒ electron will come into substrate & recombine with Hole

→ mobile ions

can't conduct current

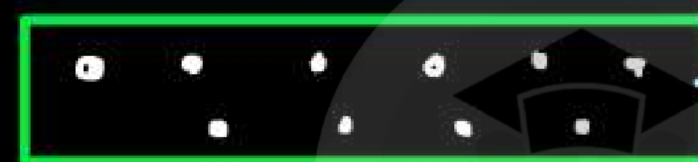
B

still $I_D = 0$ Amp

$\Downarrow$

I have to increase V_G potential

@ some positive potential of V_G, the channel will be framed



$\rightarrow$ Inversion layer
(P-substrate, we have framed n-channel)

since, the channel is perent now, so the current I_D flows.
direction of current is from drain to source.

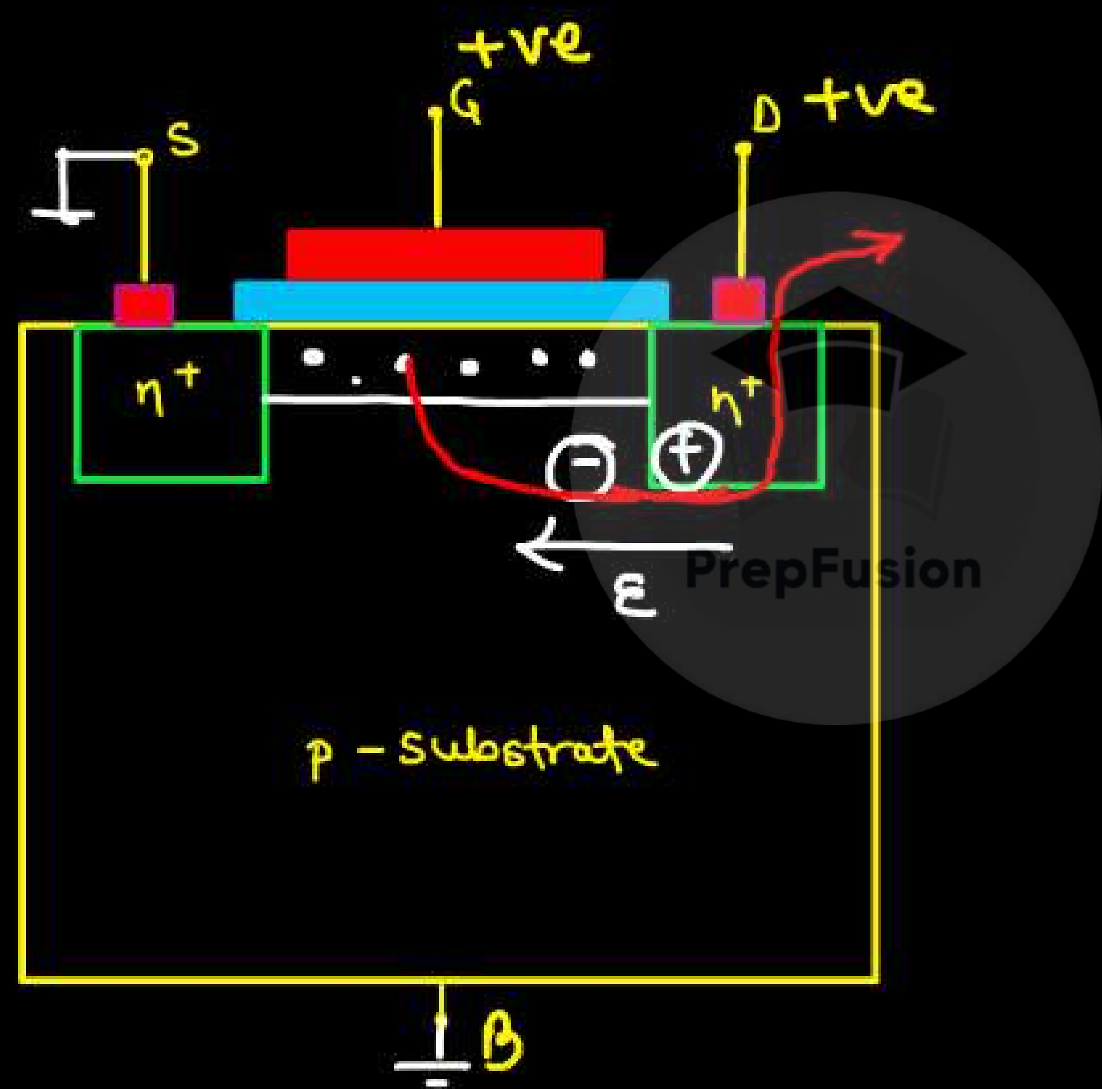
★ The value of V_{GS} @ which the current flows, is known as threshold voltage (V_T).

$\underline{\underline{\text{Cond}^n\text{. 5}}}$

$V_{DS} = +ve$

$V_{GS} > V_T$

$\Rightarrow I_D$ flows from drain to source.

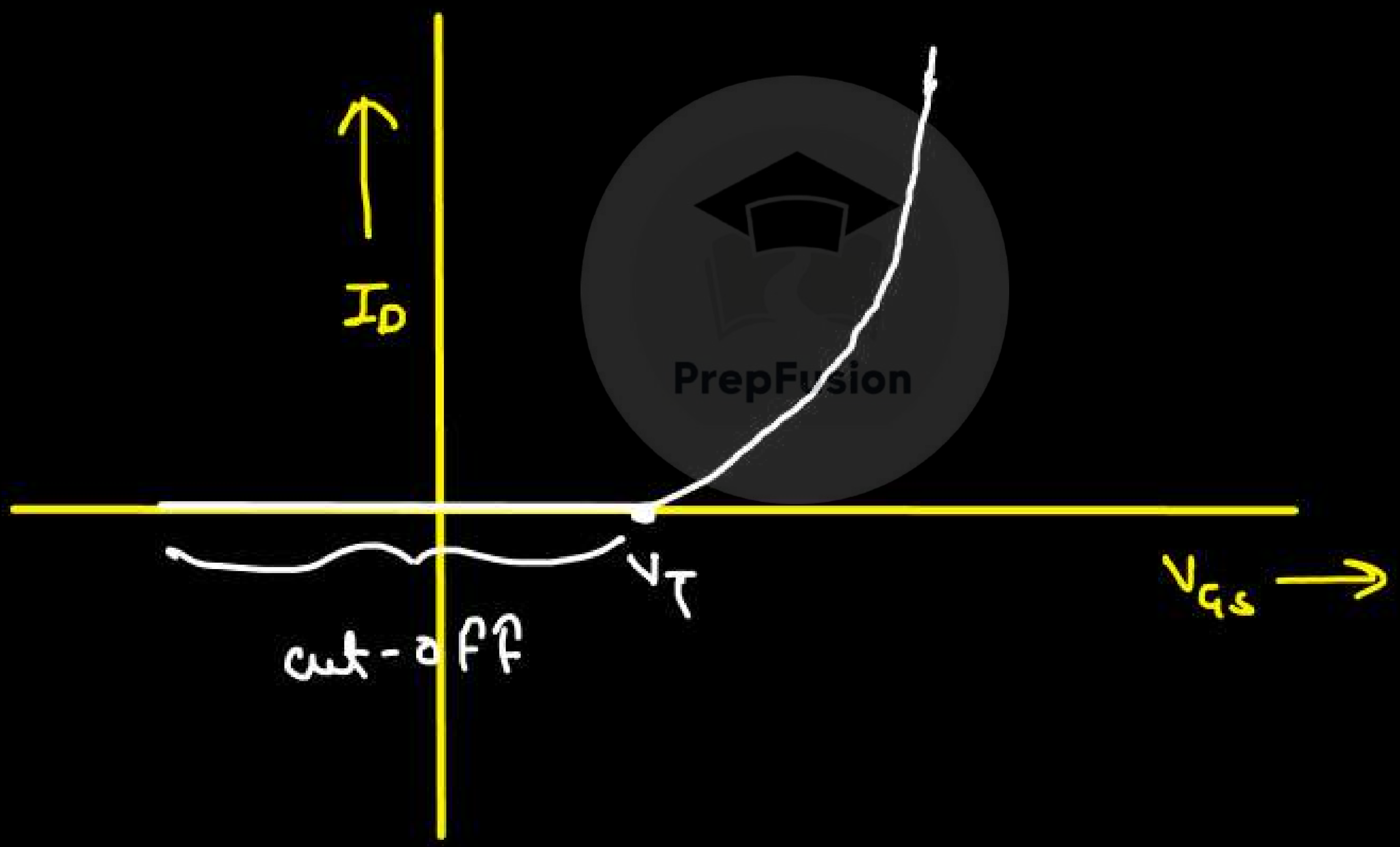


After V_{TH}, Increasing V_{GS} ↑ ⇒ more $e^{\ominus}$ in channel

⇓

I_D ↑

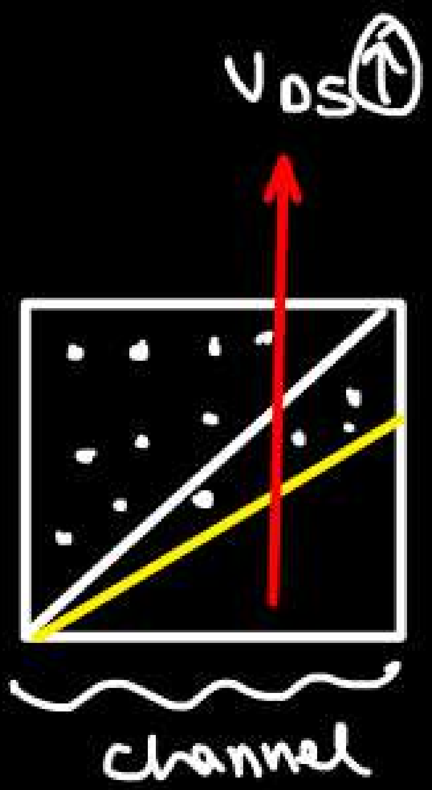
*** I_D v/s V_{GS} curve :-

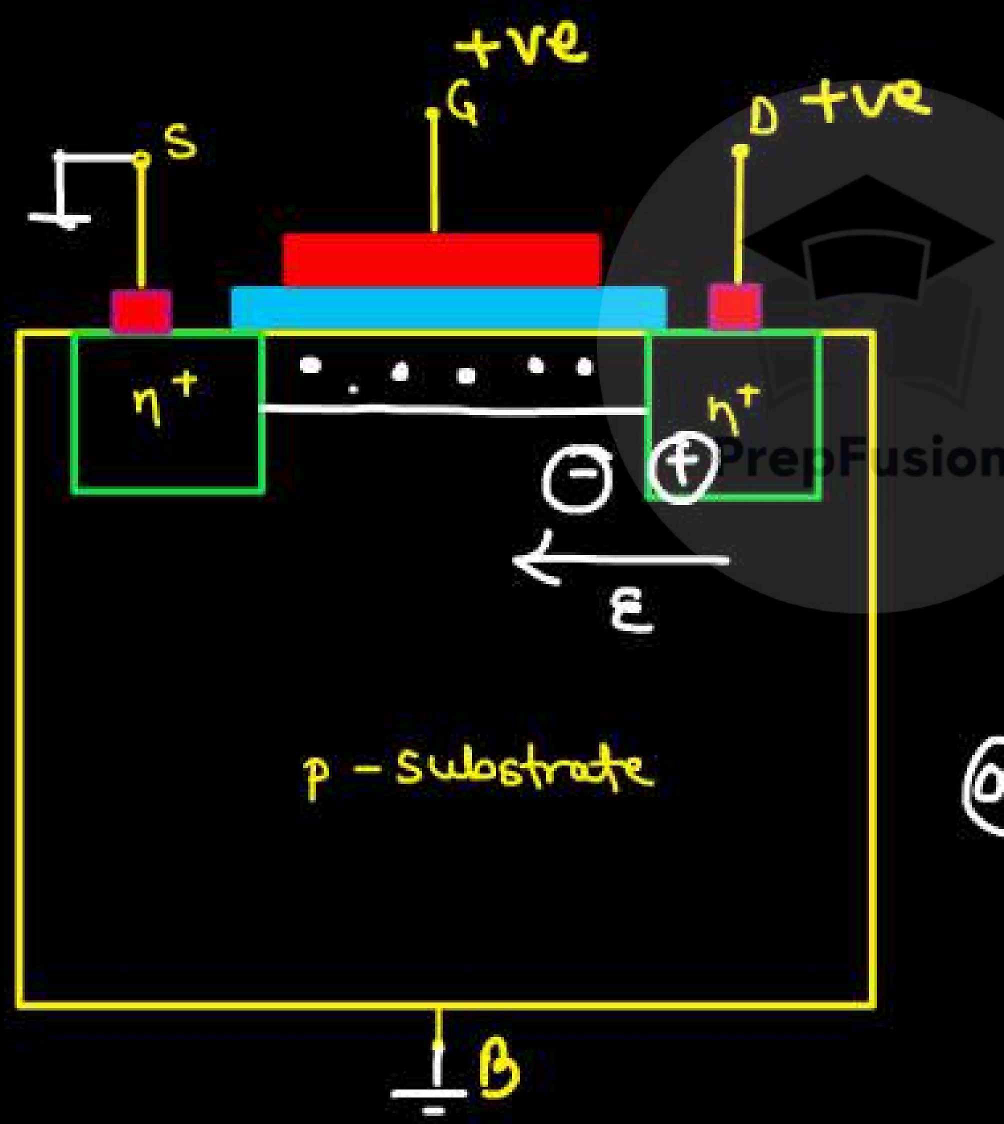


Cod^n - 6

$V_{GS} > V_T$ {Fixed}

$V_{DS} = +ve$ {Increasing}

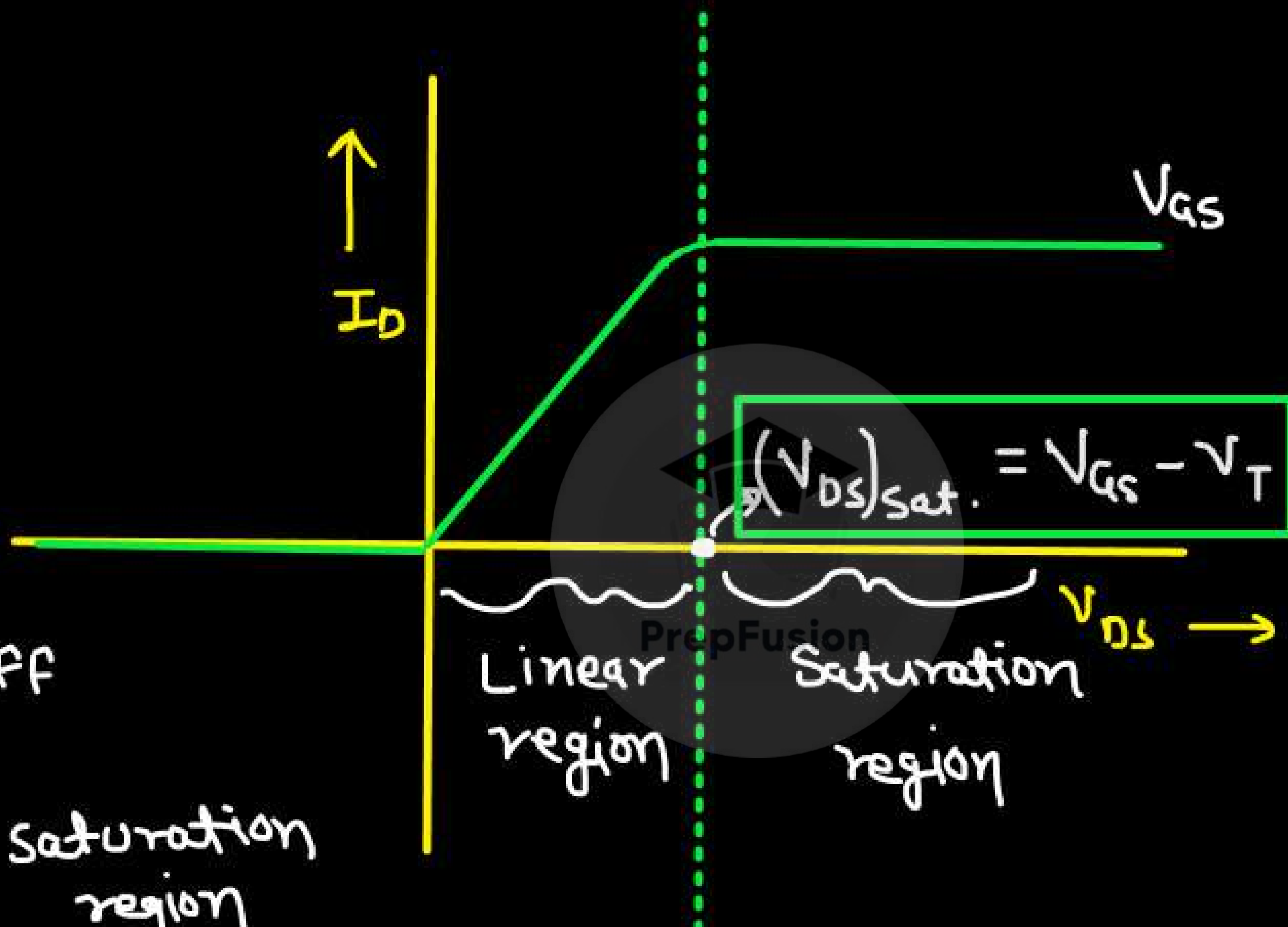




$V_{DS}\uparrow \Rightarrow \varepsilon \uparrow \Rightarrow e^{\ominus}$ gets more force
$\Downarrow$
more current

@ some value of V_{DS}, the current will saturate.

I_D v/s V_{DS} curve :-

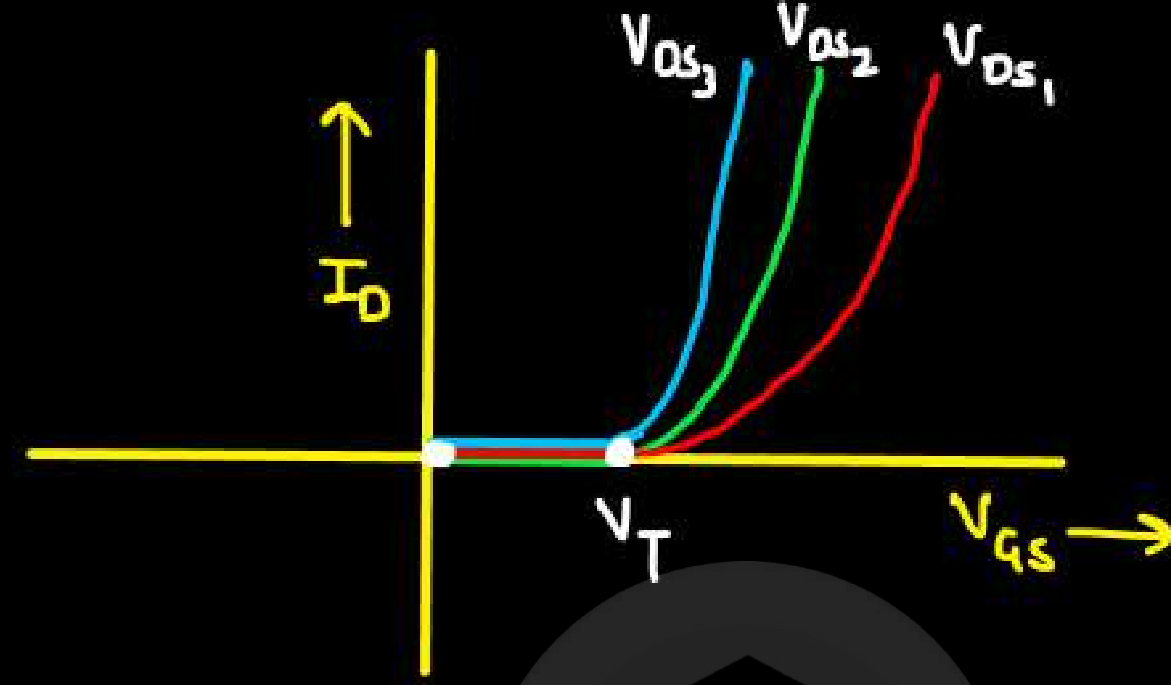


$V_{DS} < 0 \Rightarrow$ cut off

$V_{DS} > V_{GS} - V_T \Rightarrow$ saturation region

$V_{DS} < V_{GS} - V_T \Rightarrow$ linear

I_D v/s V_{GS}



$V_{DS_3} > V_{DS_2} > V_{DS_1}$

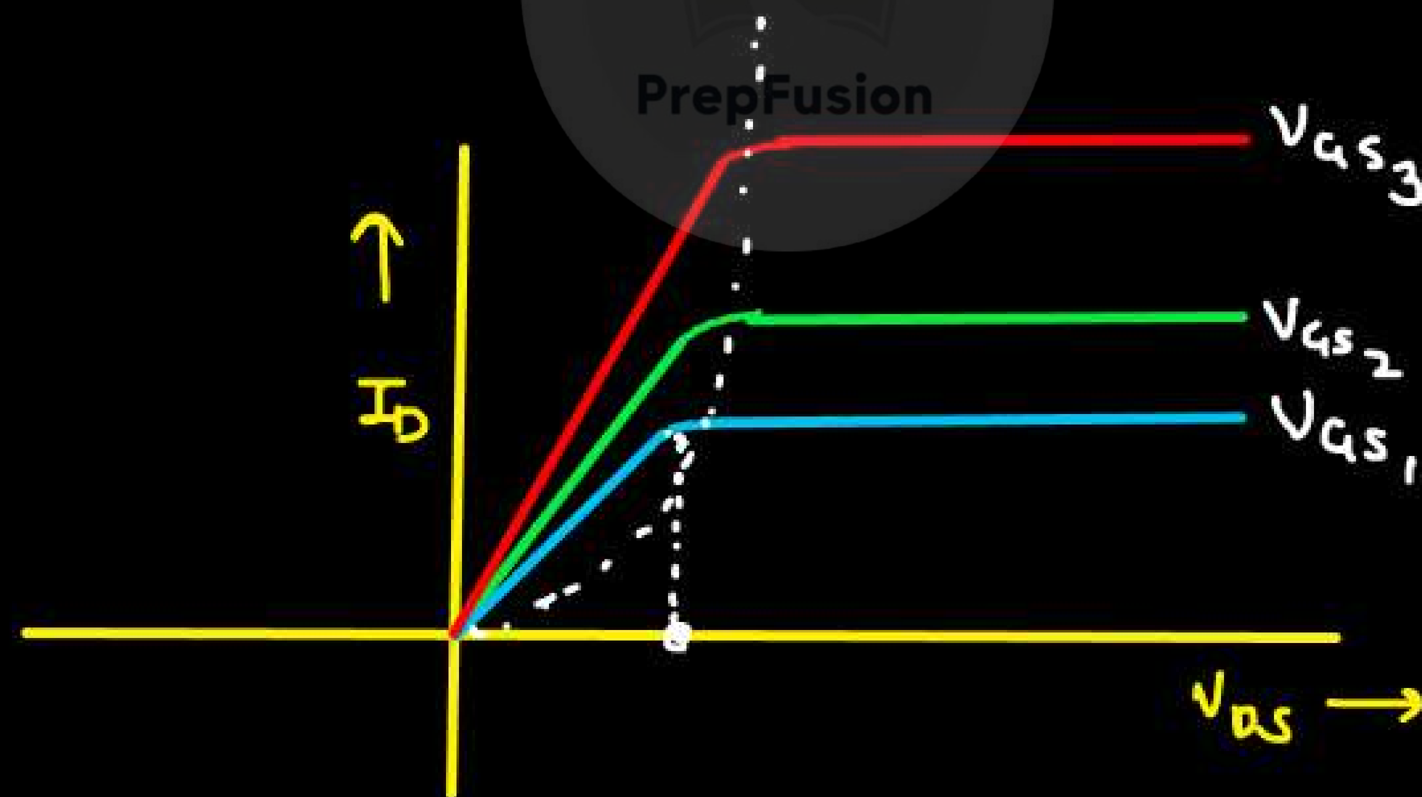
I_D v/s V_{DS}

Sat. voltage

$V_{DS_1} = V_{GS_1} - V_T$

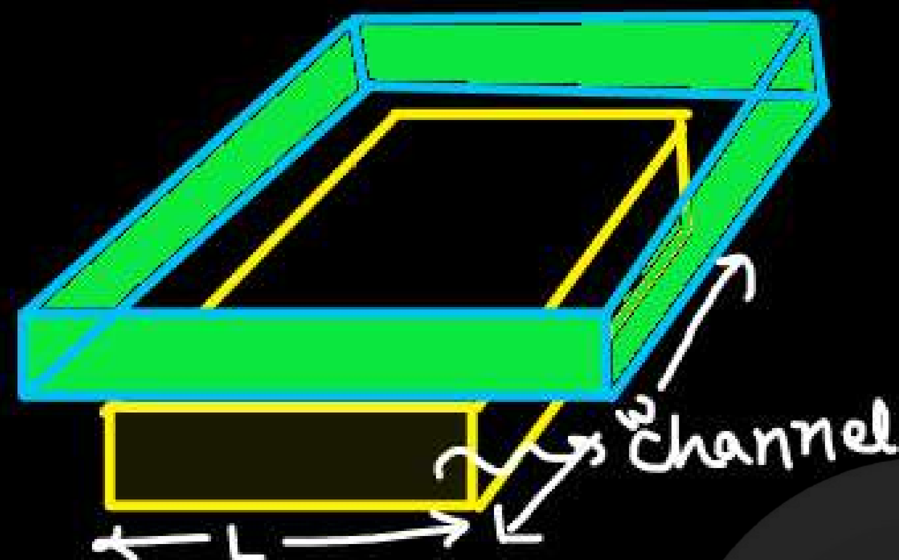
$V_{DS_2} = V_{GS_2} - V_T$

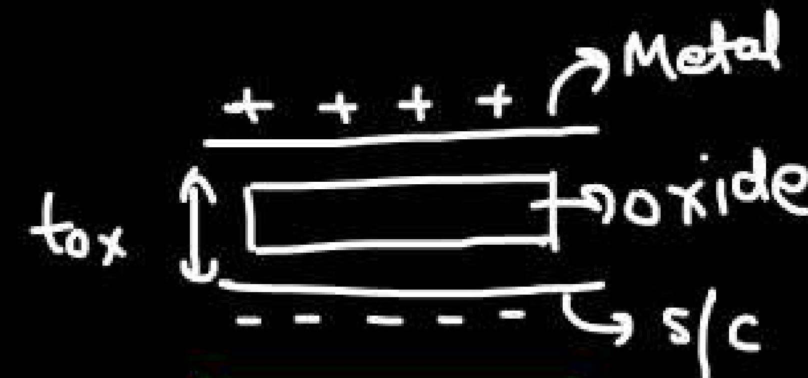
$V_{DS_3} = V_{GS_3} - V_T$



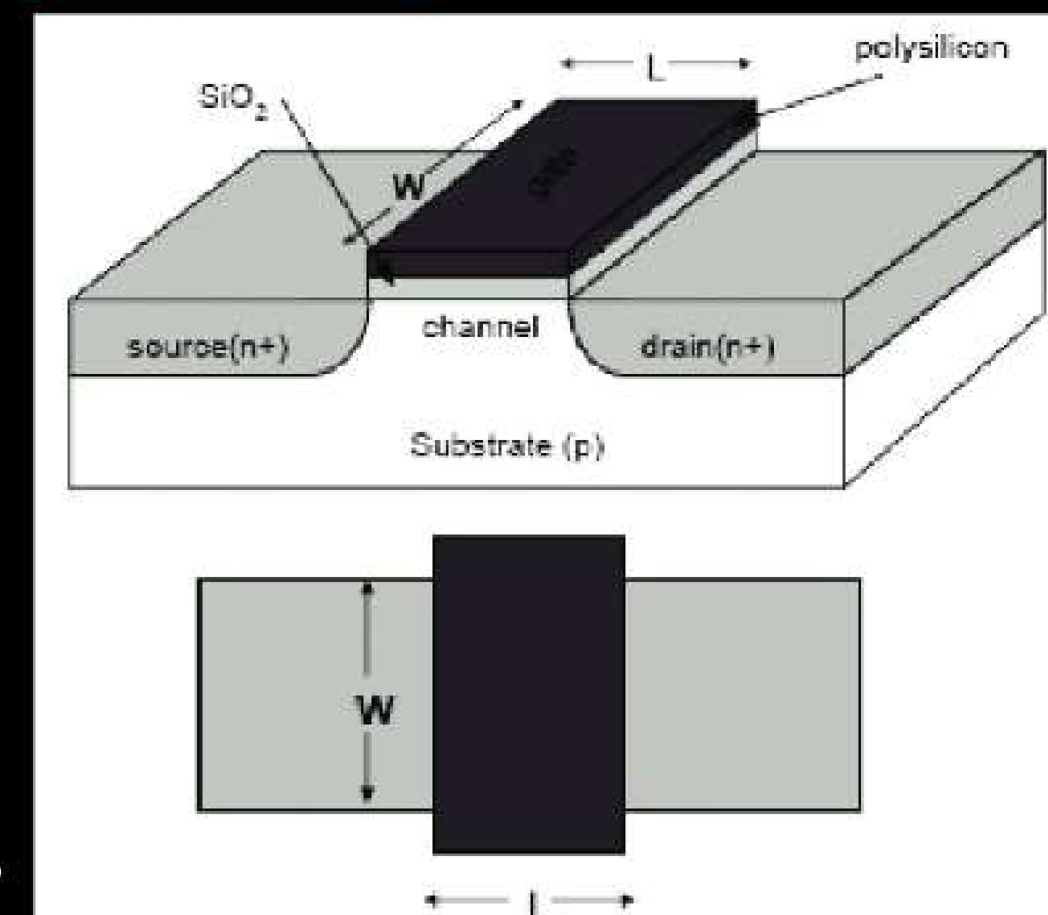
$V_{GS_3} > V_{GS_2} > V_{GS_1}$

MOSFET Current Equation (NMOS):-





$$\boxed{C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}}$$ → permittivity of oxide layer



Current in linear region:- $[V_{DS} < V_{GS} - V_T]$

★★★

$$\boxed{I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS} - V_{Tn})V_{DS} - \frac{V_{DS}^2}{2}\right]}$$

μ_n → mobility of $e^{\ominus}$

W → channel width

L → channel length

V_{T_n} → Threshold voltage

Current in saturation region:- $[V_{DS} \geq V_{GS} - V_T]$

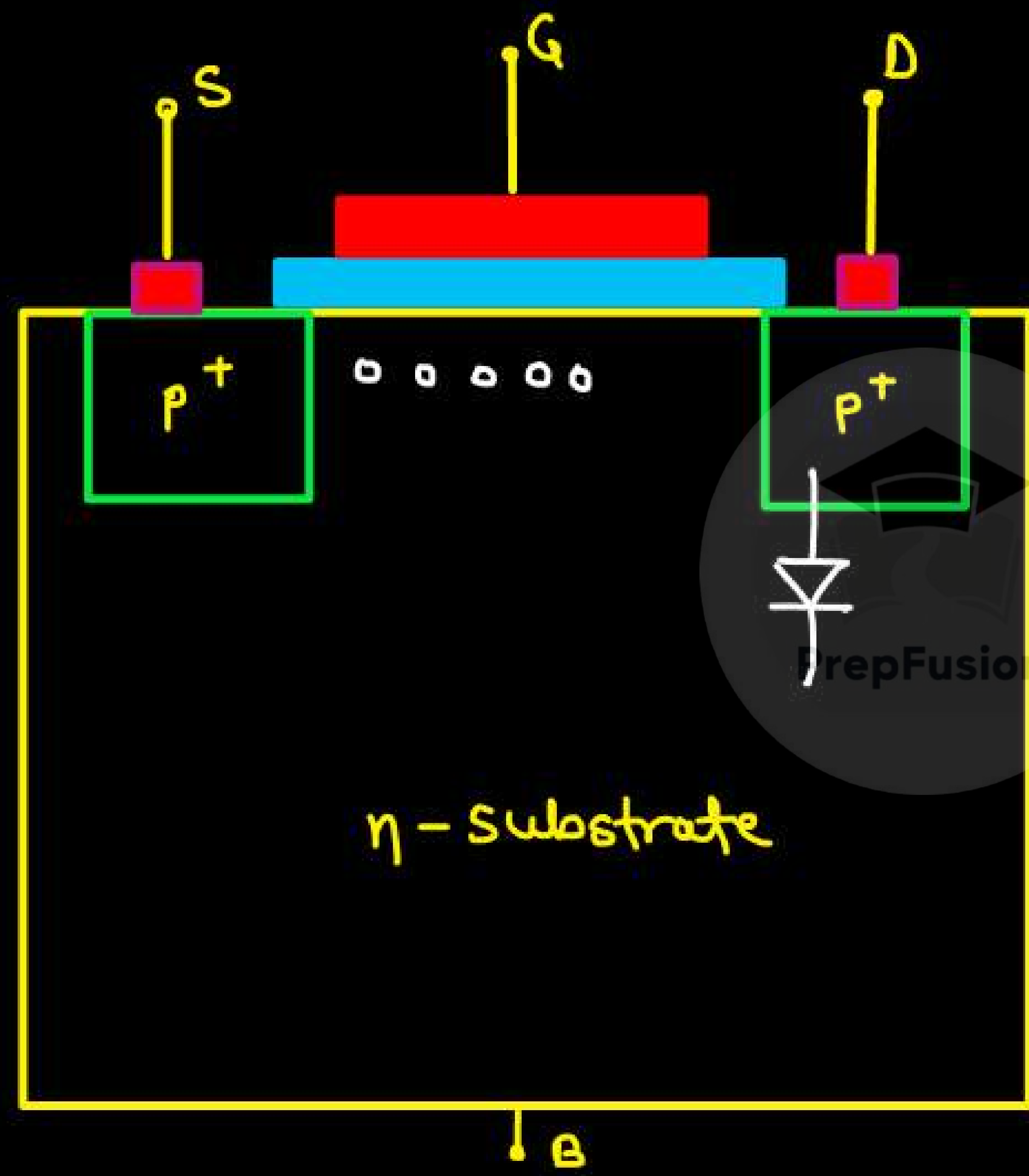
$$\boxed{(I_D)_{Sat.} = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_{T_n})^2}$$

N.B.:- In case NMOS; Higher potential node ⇒ drain

Lower potential node ⇒ source

Current flow ⇒ drain to source

✲ P-channel enhancement type MOSFET :-



Cond^n 1:-

$$V_{GS} = 0 = V_{DS} \Rightarrow I_D = 0$$

Cod^n 2:-

$$V_{GS} = 0 \quad , \quad V_{DS} = +ve \Rightarrow I_D = 0$$

Cod^n 3:-

$$V_{GS} = 0 \quad , \quad V_{DS} = -ve \Rightarrow I_D = 0$$

Cond^n 4 :-

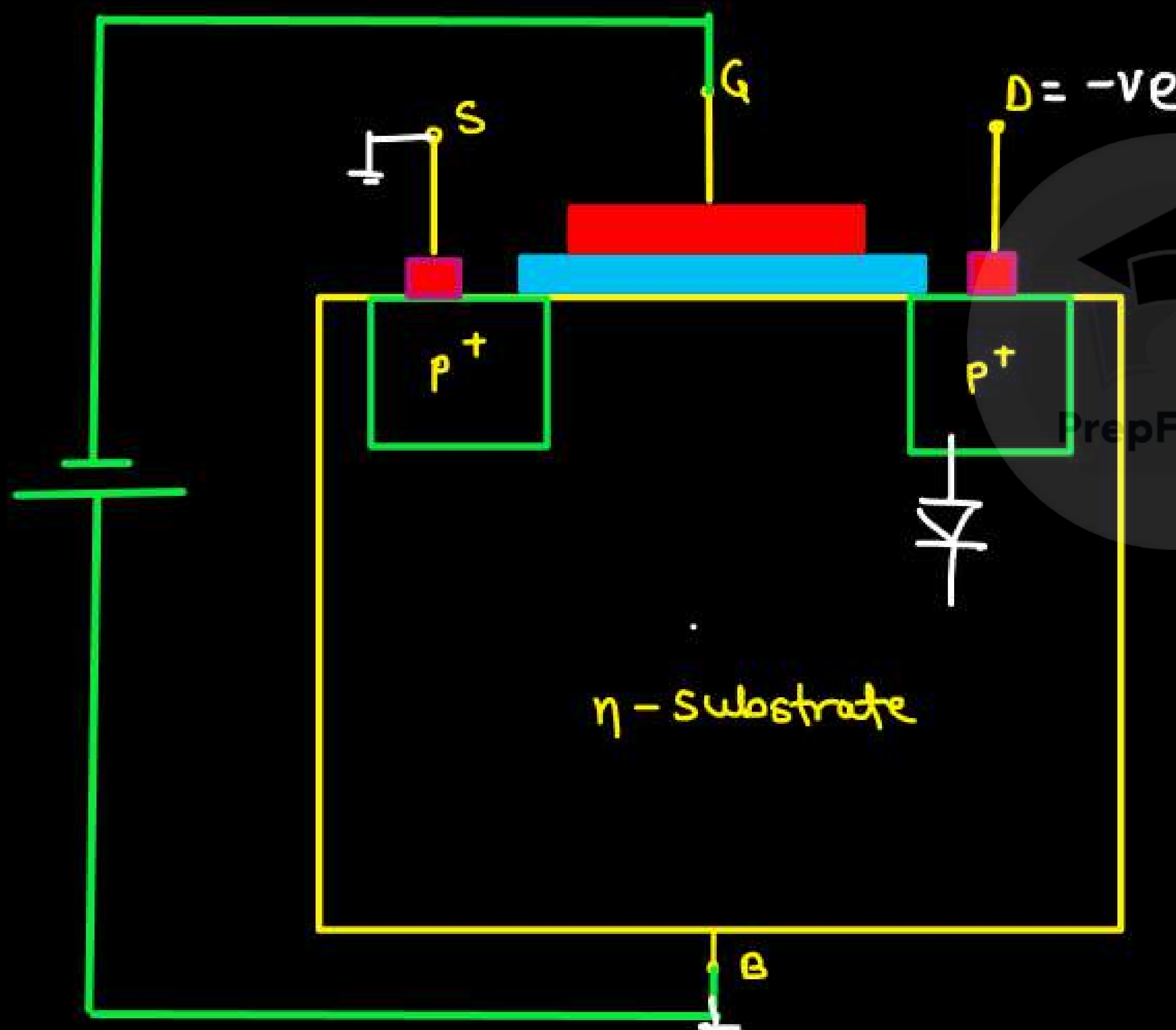
$V_{GS} = -ve$ (very less)

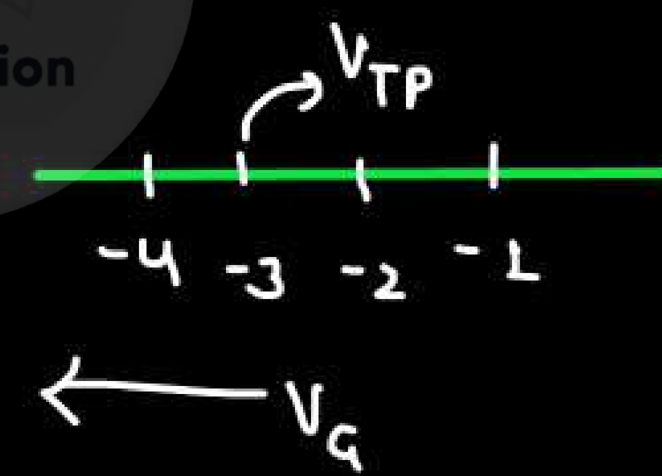
$V_{DS} = -ve$

$\Rightarrow$ channel is not framed

$\Downarrow$

You have to apply more negative potential.





$\Rightarrow V_{GS} < V_{TP}$

$\Downarrow$

Current flows

When $V_{GS} < V_{Tp}$

Channel

NMOS → PMOS :-

$V_{GS} \longrightarrow V_{SG}$

$V_{DS} \longrightarrow V_{SD}$

$V_{Tn} \longrightarrow |V_{Tp}|$

	NMOS	PMOS
1) Cut-off ⇒	$V_{GS} < V_{Tn}$	$V_{SG} < \lvert V_{Tp}\rvert$
2) ON ⇒	$V_{GS} > V_{tn}$	$V_{SG} > \lvert V_{Tp}\rvert$
3) Linear region ⇒	$V_{DS} < V_{GS} - V_{Tn}$	$V_{SD} < V_{SG} - \lvert V_{Tp}\rvert$
4) Saturation ⇒	$V_{DS} \geq V_{GS} - V_{Tn}$	$V_{SD} \geq V_{SG} - \lvert V_{Tp}\rvert$

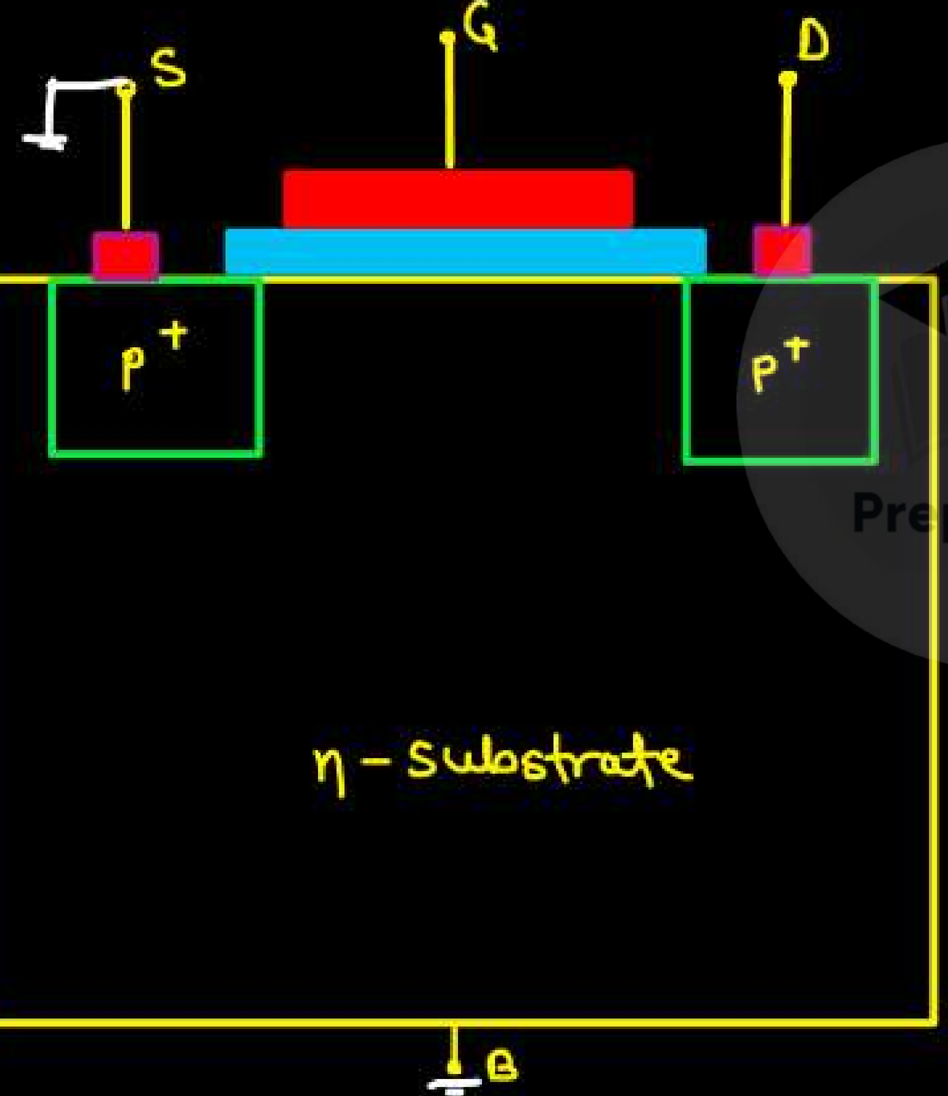
Codⁿ 5: -

(i) $V_{GS} < V_{Tp}$ OR $V_{SG} > |V_{Tp}|$ $\Rightarrow$ I_D flows

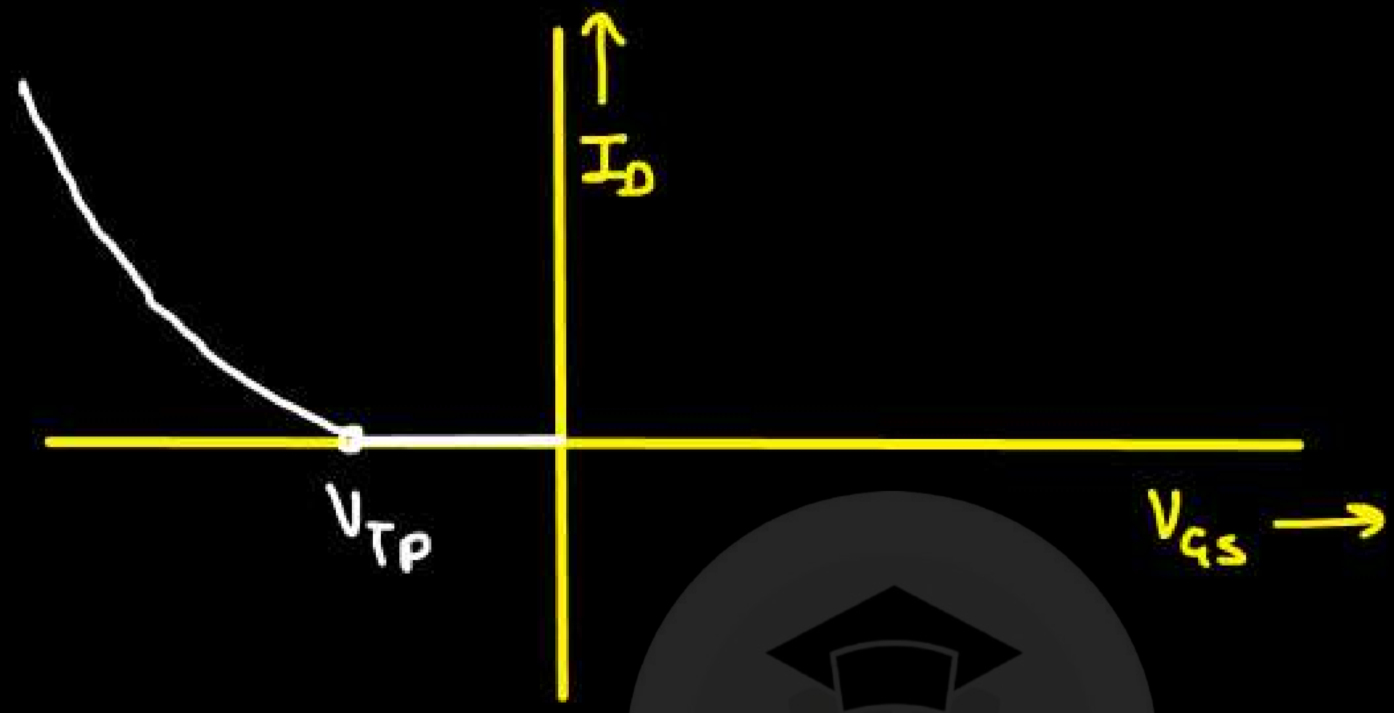
(ii) $V_{DS} = -ve$ OR $V_{SD} = +ve$

$\Downarrow$

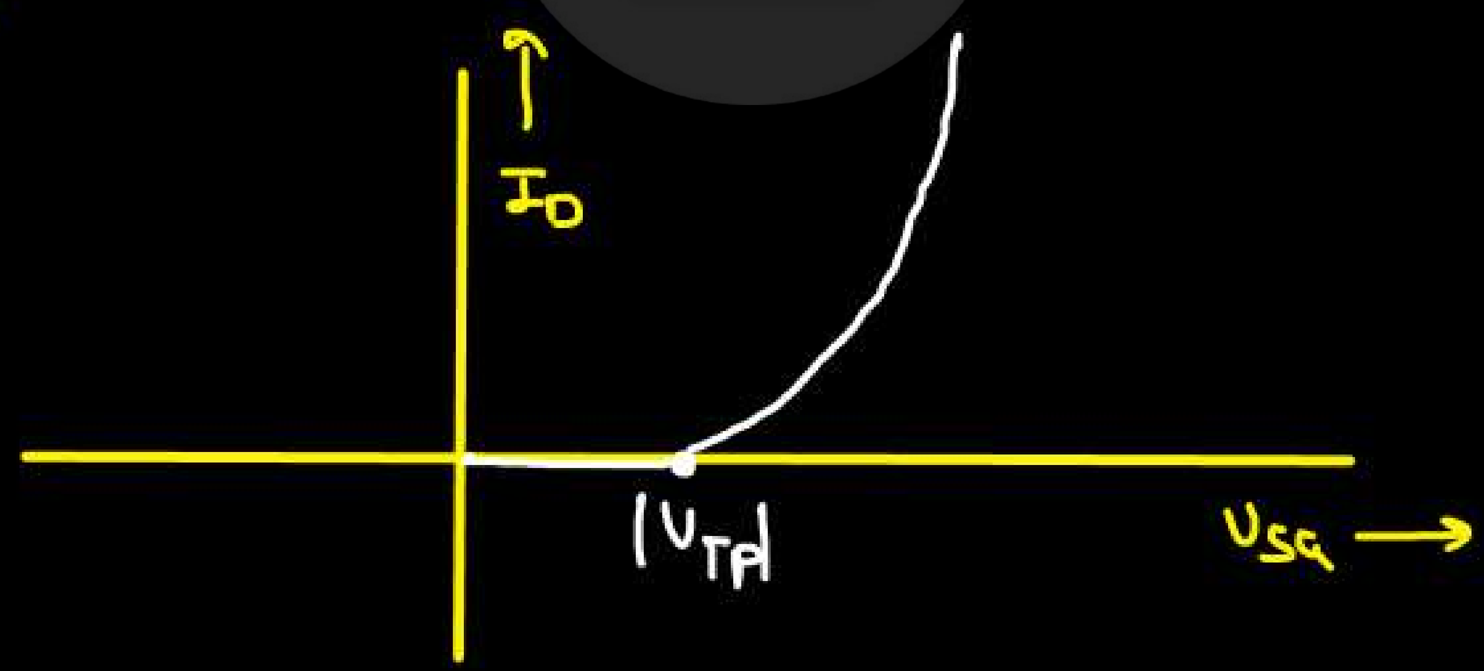
source to drain



I_D v/s V_{GS} curve :-



I_D v/s V_{SG} curve :-



current dir^n :-

source to drain

$V_{SG} > |V_{Tp}|$

Cod^n 6:-

$V_{GS} < V_T$ {Fixed}

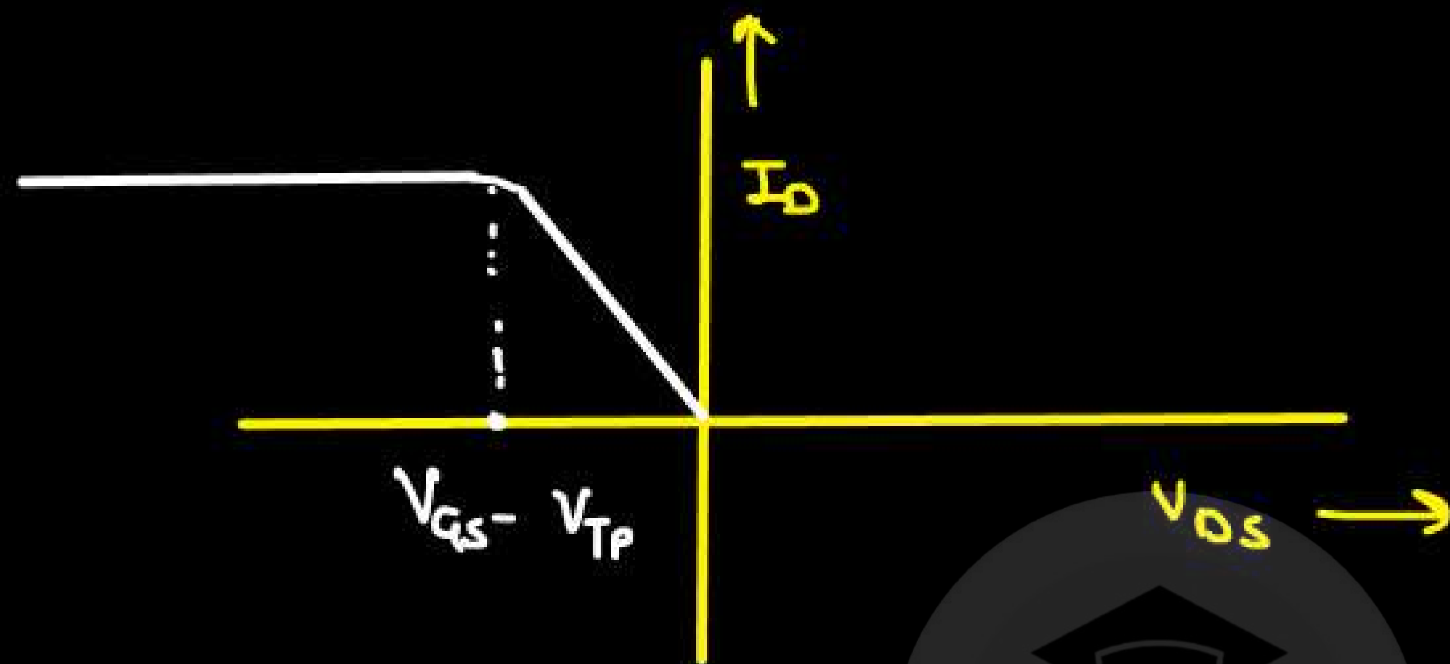
$V_{DS} = -ve$ {negative supply increasing}

$\Downarrow$

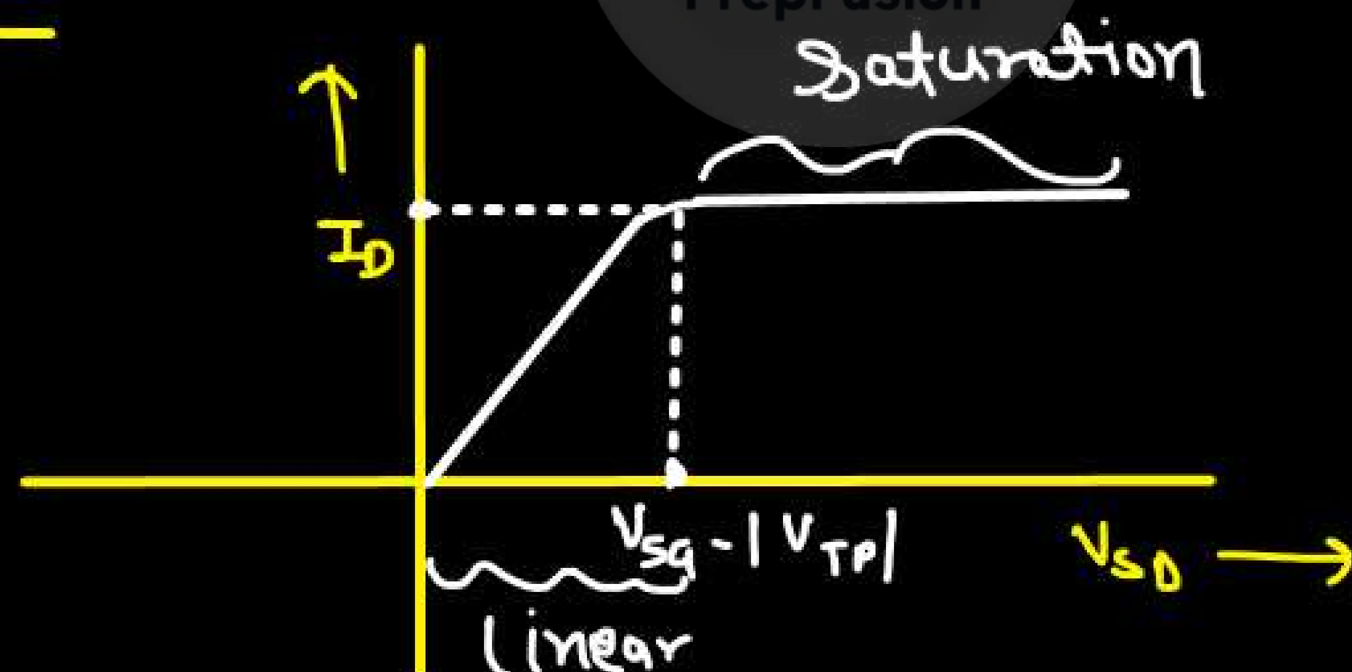
current initially increases linearly

and then saturates.

I_D v/s V_{DS} curve

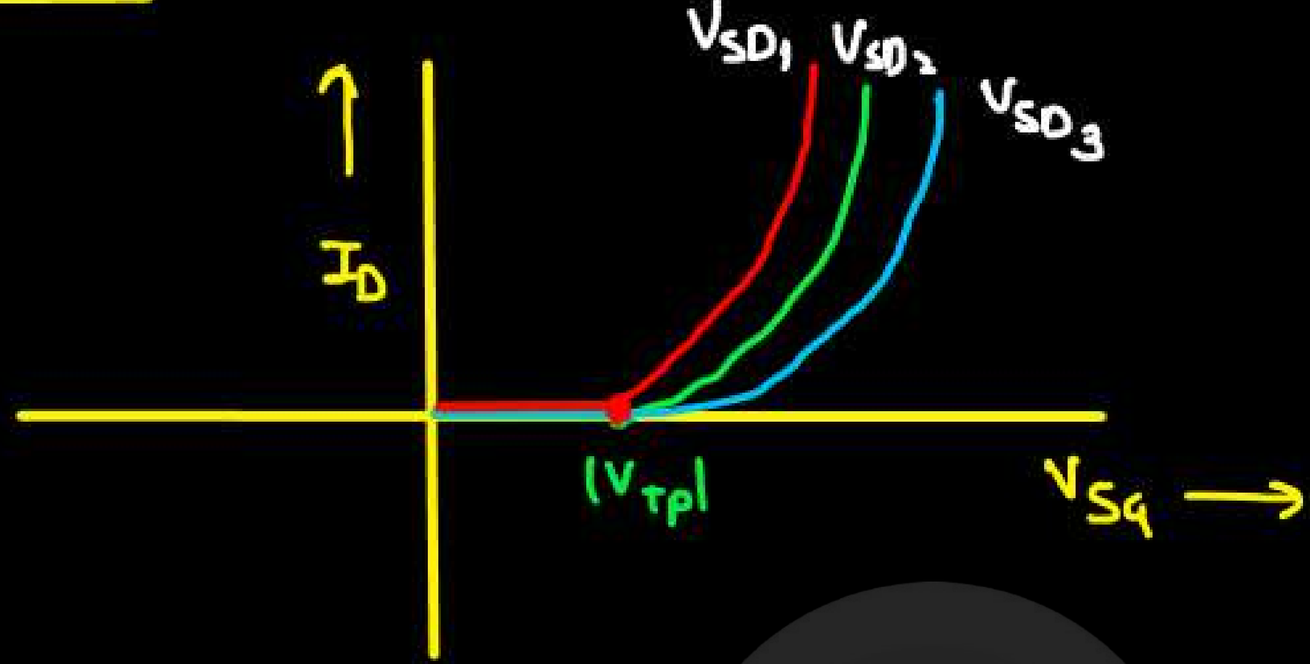


I_D v/s V_{SD} curve :-



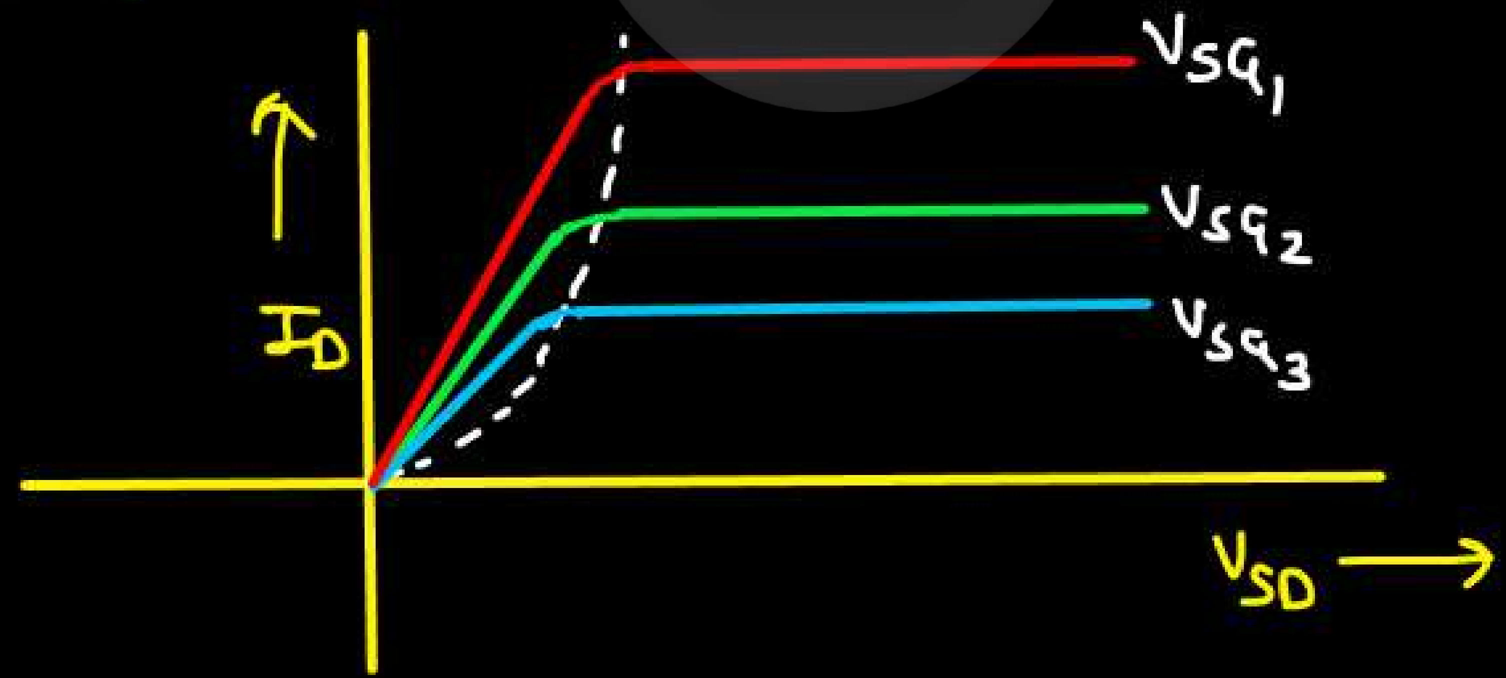
$$(V_{SD})_{sat} = V_{SG} - |V_{Tp}|$$

I_D v/s V_{SG} curve:-



$V_{SD_1} > V_{SD_2} > V_{SD_3}$

I_D v/s V_{SD} curve:-



$V_{SG_1} > V_{SG_2} > V_{SG_3}$

Current equation:- (PMOS)

NMOS $\rightarrow$ PMOS

$V_{GS} \rightarrow V_{SG}$

$V_{DS} \rightarrow V_{SD}$

$V_{Tn} \rightarrow |V_{Tp}|$

① **Linear region:-** $[V_{SD} < V_{SG} - |V_{Tp}|]$

$$I_D = \frac{\mu_p C_{ox} W}{L}\left[(V_{SG} - |V_{Tp}|)V_{SD} - \frac{V_{SD}^2}{2}\right]$$

② **Saturation region:-** $[V_{SD} \geq V_{SG} - |V_{Tp}|]$

$$I_D = \frac{\mu_p C_{ox} W}{2L}(V_{SG} - |V_{Tp}|)^2$$

N.B. -

IN PMOS,

Higher potential = Source

lower potential = Drain

dir^n of current = Source to Drain

IN NMOS,

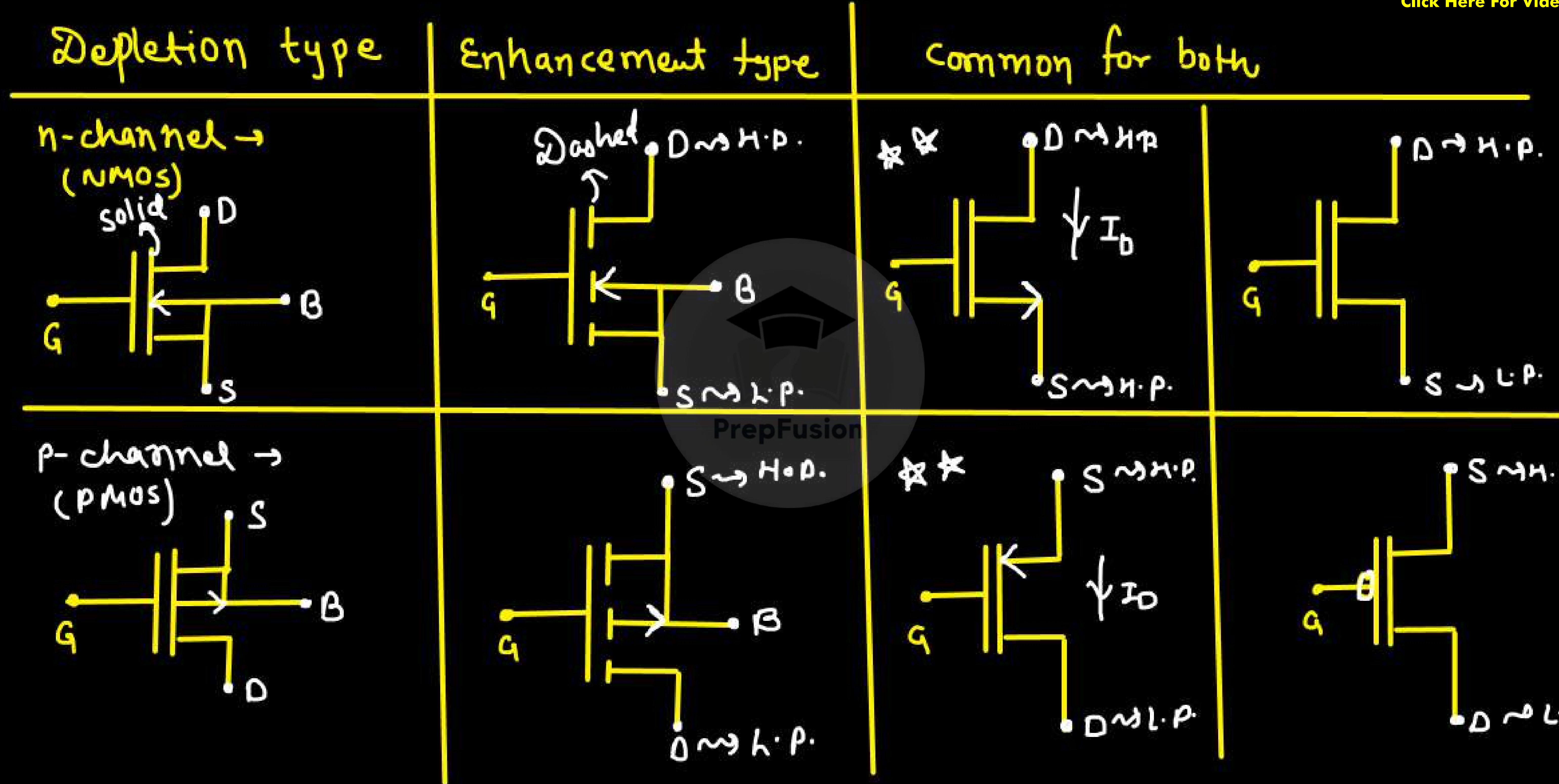
Higher potential = Drain

lower potential = source

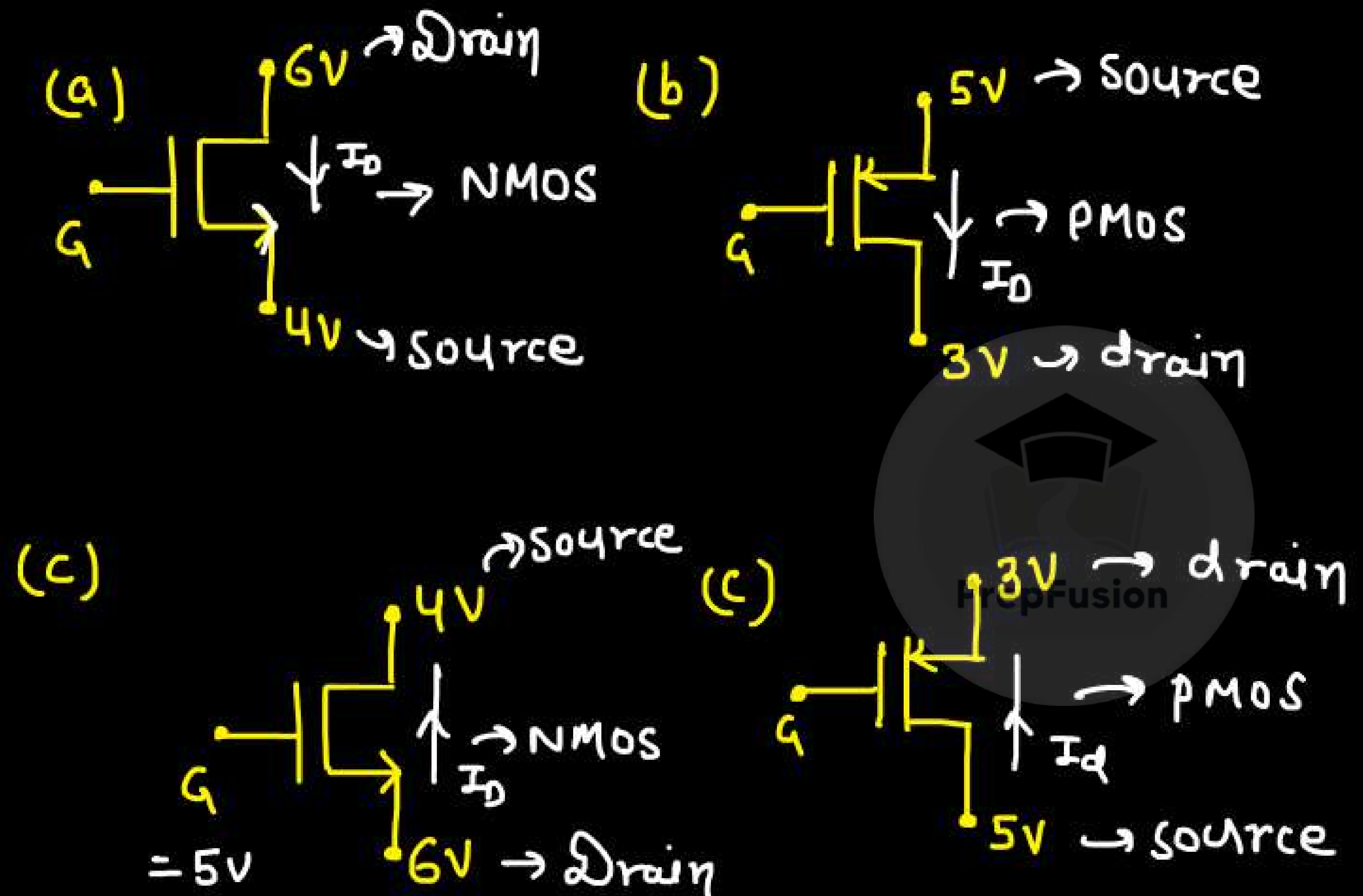
dir^n of current = Drain to Source

✱ MOSFET Circuit Symbol:-

H.P. → Higher potential
L.P. → Lower potential



Q. Mark Source and drain and the current dir^n.



Q. Given $\mu_p = 0.4\mu_n$.

What must be the relative width of n-channel and p-channel devices if they are to have equal drain currents when operated in the saturation mode with overdrive voltage of the same magnitude.

→ overdrive voltage $\boxed{V_{ov} = V_{GS} - V_{T_n}}$ (NMOS), $\boxed{V_{ov} = V_{SG} - |V_{Tp}|}$ (PMOS)

$$(I_D)_p = (I_D)_N$$

$$\frac{\mu_p \cancel{C_{ox}}}{\cancel{2}}\left(\frac{W}{L}\right)_p \underbrace{\left(V_{SG} - |V_{Tp}|\right)}_{V_{ov}}\!\cancel{}^2 = \frac{\mu_n \cancel{C_{ox}}}{\cancel{2}}\left(\frac{W}{L}\right)_n \underbrace{\left(V_{GS} - V_{tn}\right)}_{V_{ov}}\!\cancel{}^2$$

$$\mu_p \left(\frac{W}{L}\right)_p = \mu_n \left(\frac{W}{L}\right)_n$$

$$0.4 \left(\frac{W}{L}\right)_p = \left(\frac{W}{L}\right)_n$$

$$\boxed{\left(\frac{W}{L}\right)_p = 2.5 \left(\frac{W}{L}\right)_n}$$

Q. For n-channel MOSFET, if conduction parameter (K_n) is $0.249\ mV/A^2$, Gate to source voltage is $2V_T$. where $V_T = 0.75$, $V_{DS} = 0.4V$. Find drain current.

Given:
$$\left\{ K_n = \frac{\mu_n C_{ox} W}{2L} \right\}$$

→

$$\frac{\mu_n C_{ox} W}{2L} = 0.249\ mA/V^2$$

$V_{GS} = 2V_T = 1.5V$

$V_T = 0.75V$

$V_{DS} = 0.4V$

Drain current = ? → Sat. ? / Linear. ?

$V_{ov} = V_{GS} - V_T = 0.75V$

$V_{DS} = 0.4V$

$$\underbrace{V_{DS} < V_{ov} \text{ OR } V_{DS} < V_{GS} - V_T}$$

⇓

Linear region

MOS is working in Linear region

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$= 2 \times \underbrace{0.249}_{\frac{mA}{V^2}}\left[0.75 \times 0.4 - \frac{(0.4)^2}{2}\right] \times V^2$$

$$\boxed{I_D = 0.109\,mA}$$

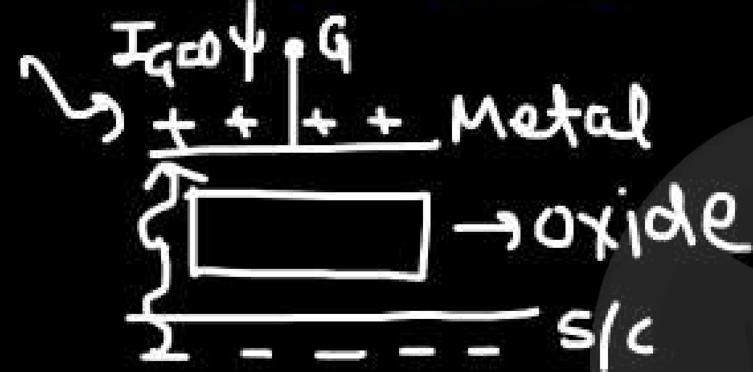
Q. How many charge carriers are there in a MOS?

→ One one. PMOS → Holes

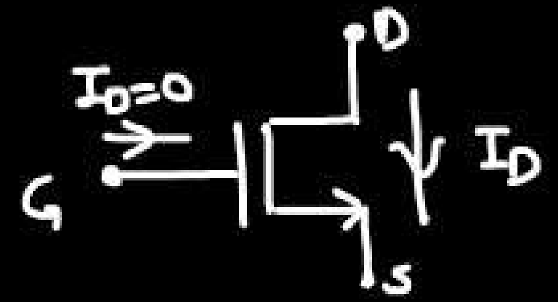
NMOS → Electrons

Q. What is the need of oxide layer in MOS.

→

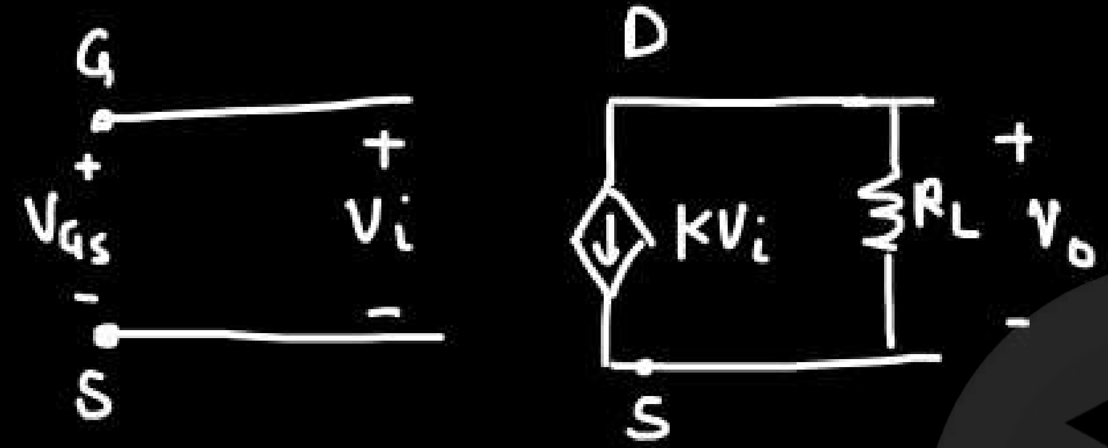


Because of this oxide layer only, the $e^{\ominus}$ or the negative charge near the s/c is not reaching to the metal and we are able to frame the channel and this channel helps in generating drain current.



Q. Why do we use MOSFET in enhancement mode for amplification?

→



Enhancement type MOSFETs doesn't conduct for zero i/p voltage.

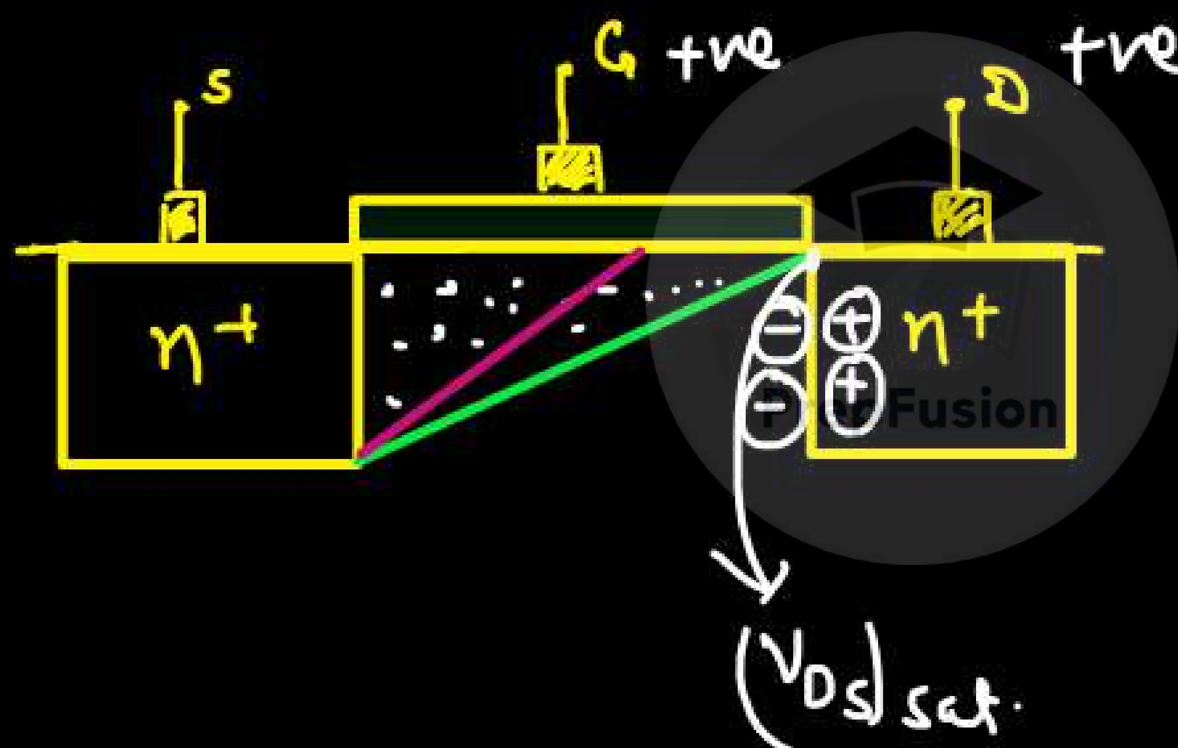
For conduction, $\boxed{V_{GS} > V_T}$

And the drain current depends on the applied i/p voltage.

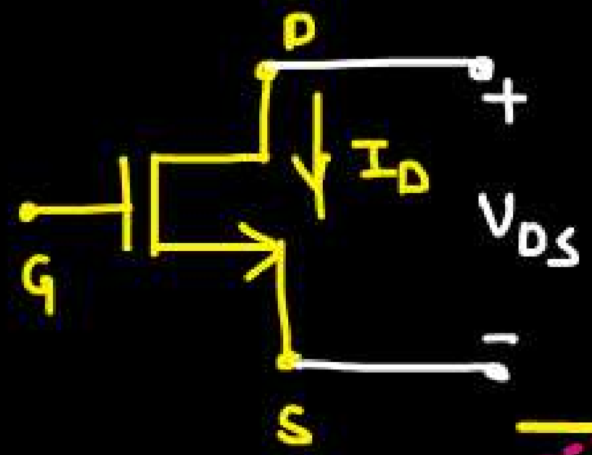
Channel length Modulation (CLM):-

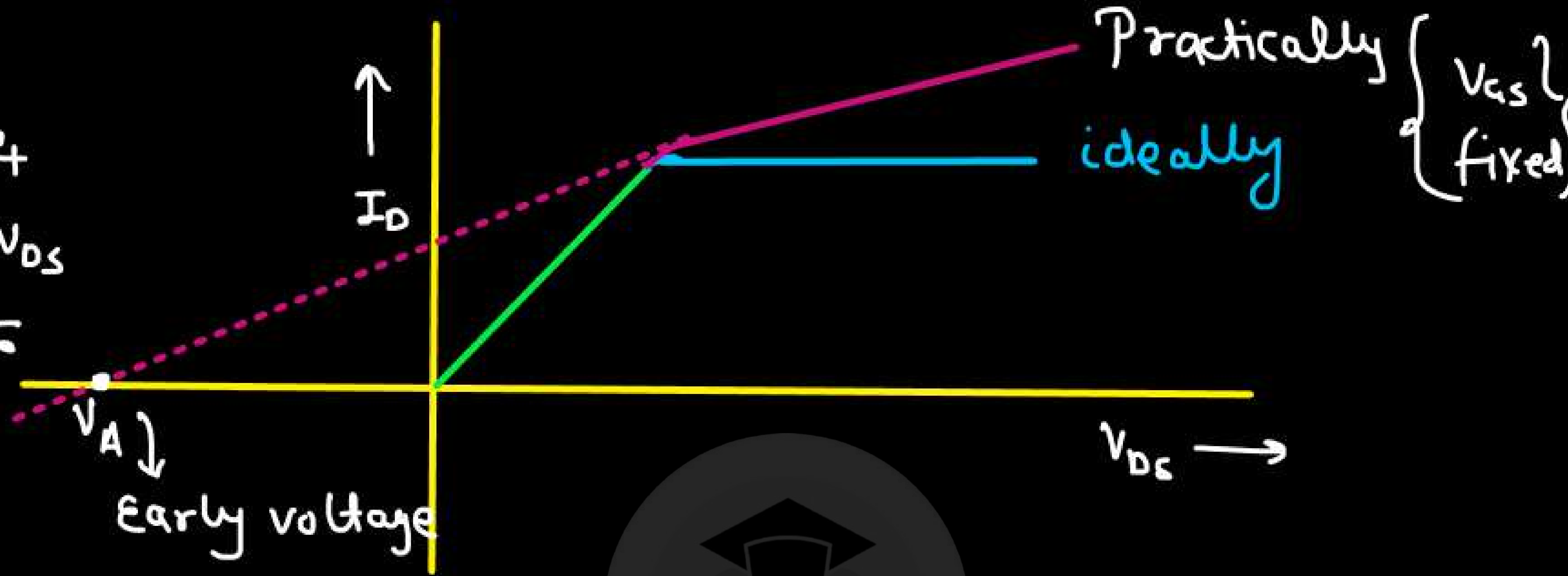
Ideally, for $V_{DS} > (V_{DS})_{sat} \Rightarrow$ Current saturates

Practically, for $V_{DS} > (V_{DS})_{sat} \Rightarrow$ Current rises slightly



$V_{DS} > (V_{DS})_{sat} \Rightarrow$ depletion width $\uparrow$ $\Rightarrow$ strong electric field $\Rightarrow$ increases the current slightly.



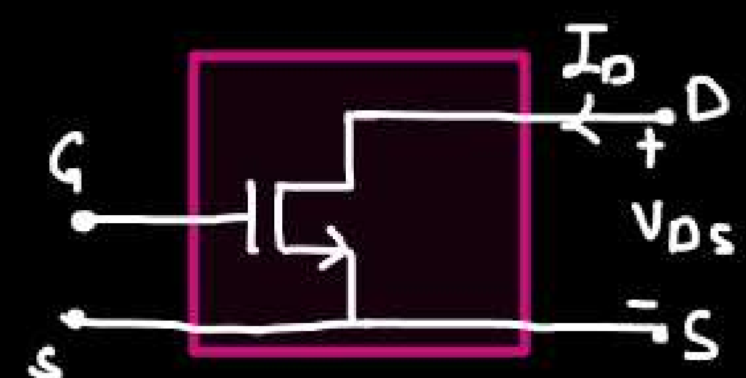


Ideal case:- (Saturation)

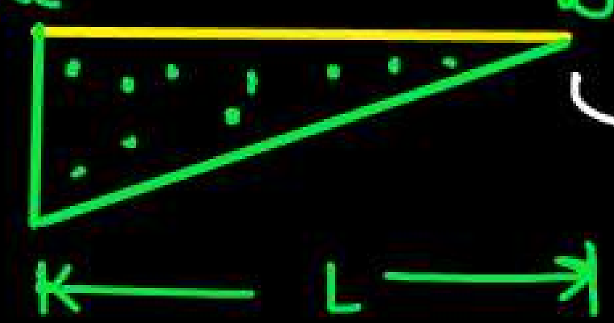
$$(I_D)_{sat.} = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2 \Rightarrow \text{constant for fixed } V_{GS} \text{ (Independent of } V_{DS})$$

Drain-Source ON Resistance:- (Saturation)

$$\frac{1}{r_{ds}} = \frac{\partial I_D}{\partial V_{DS}} = 0 \Rightarrow \boxed{r_{ds} = \infty}$$



Practically:-



$\hookrightarrow$ @ $V_{DS} = (V_{DS})_{sat}$.

Further increasing V_{DS}:-

$$(I_D)_{sat} = \frac{\mu_n C_{ox} W}{2(L - \Delta L)} (V_{GS} - V_T)^2$$

$$(I_D)_{sat} = \frac{\mu_n C_{ox} W}{2(L-\Delta L)}(V_{GS}-V_T)^2$$

$$= \frac{\mu_n C_{ox} W}{2L\left[1-\frac{\Delta L}{L}\right]}(V_{GS}-V_T)^2$$

$$= \frac{\mu_n C_{ox} W}{2L}(V_{GS}-V_T)^2\left[1-\frac{\Delta L}{L}\right]^{-1}$$

$$\left[(I_D)_{sat}\right]_{CLM} = \left[(I_D)_{sat}\right]_{ideal}\left[1+\frac{\Delta L}{L}\right] \quad \text{--- (1)} \qquad \left\{(1-x)^{-1} = 1+x\right\}$$

$$\Rightarrow \quad \frac{\Delta L}{L} \propto V_{DS}$$

$$\Rightarrow \quad \frac{\Delta L}{L} = \lambda V_{DS} \quad \text{--- (2)}$$

$$\boxed{\left[(I_D)_{sat.}\right]_{CLM} = \left[(I_D)_{sat.}\right]_{ideal}\left[1+\lambda V_{DS}\right]}$$

$\lambda \rightarrow$ process technology parameter (V^{-1})

Drain - Source ON resistance [Saturation] [CLM is present] :-

$$\boxed{r_{ds} = \frac{1}{\dfrac{\partial I_D}{\partial V_{DS}}} = \frac{1}{\lambda\left[(I_D)_{sat.}\right]_{ideal}}}$$

$$\underbrace{\text{if } \lambda = 0 \Rightarrow \text{No CLM} \Rightarrow \boxed{r_0 = \infty}}_{\text{ideal case}}$$

Early voltage.

$$\left[(I_D)_{sat.}\right]_{CLM} = \left[(I_D)_{sat.}\right]_{ideal}\left[1 + \lambda V_{DS}\right]$$

$$= 0$$

$$\Rightarrow 1 + \lambda V_{DS} = 0$$

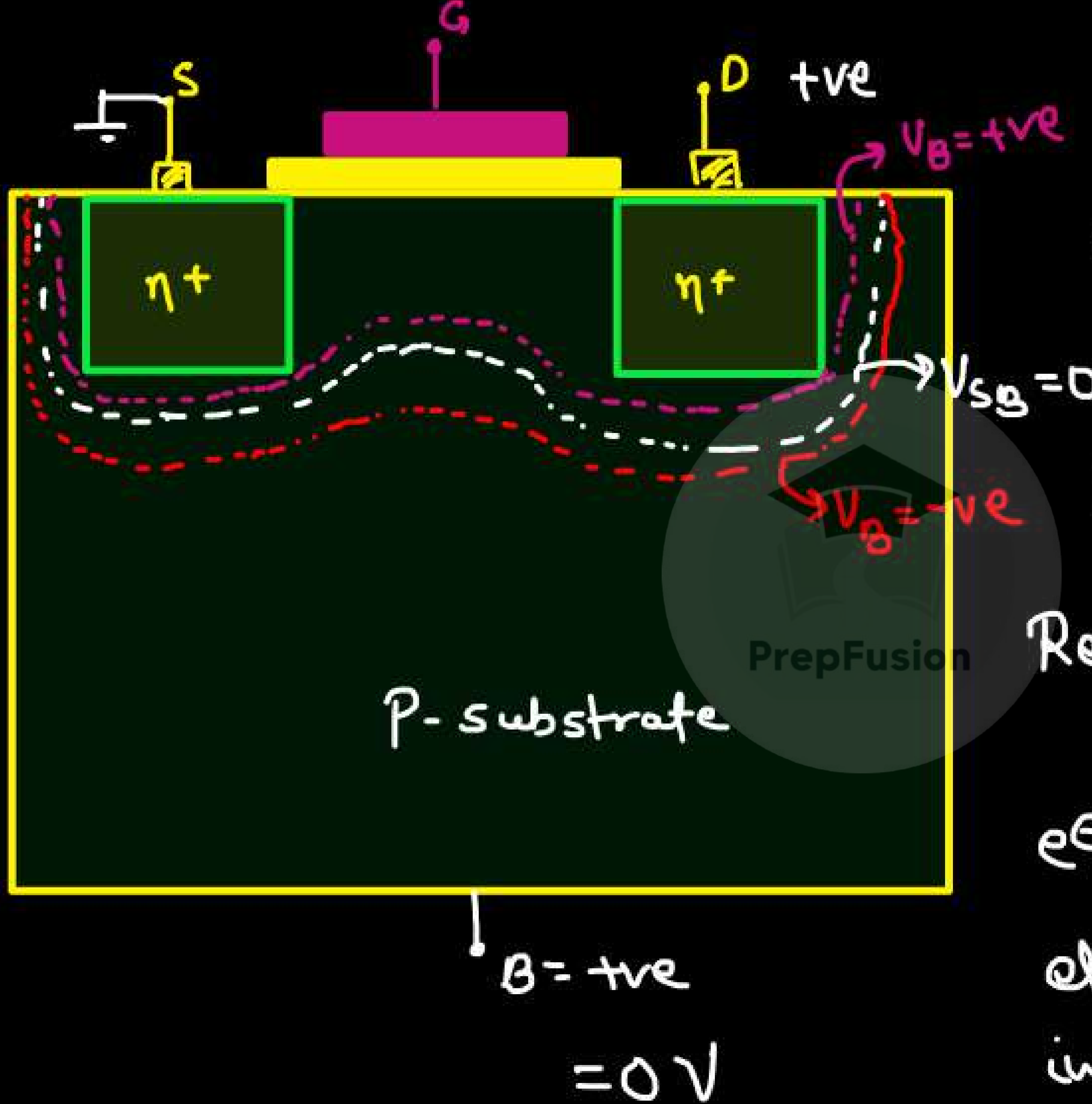
$$\boxed{V_{DS} = \frac{-1}{\lambda}}$$

$\Rightarrow$ The value of V_{DS} @ which the drain current becomes zero, That is known as early voltage.

$$\boxed{V_A = \frac{1}{\lambda}}$$

Body effect :-

Threshold voltage of NMOS → $\boxed{V_T = V_{T_0} + \gamma\left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right]}$



① $V_{SB} = 0$

⇒ No change in Threshold voltage.

② $V_{SB} = +ve$; $V_B = -ve$

Reverse bias @ source side ↑

⇓

$e^{\ominus}$ from source will feel High electric field pushing them back into the source terminal

⇓

Higher V_G required ⇒ $\boxed{V_T \uparrow}$

③ $V_{SB} = -ve$, $V_B = +ve$

⇓

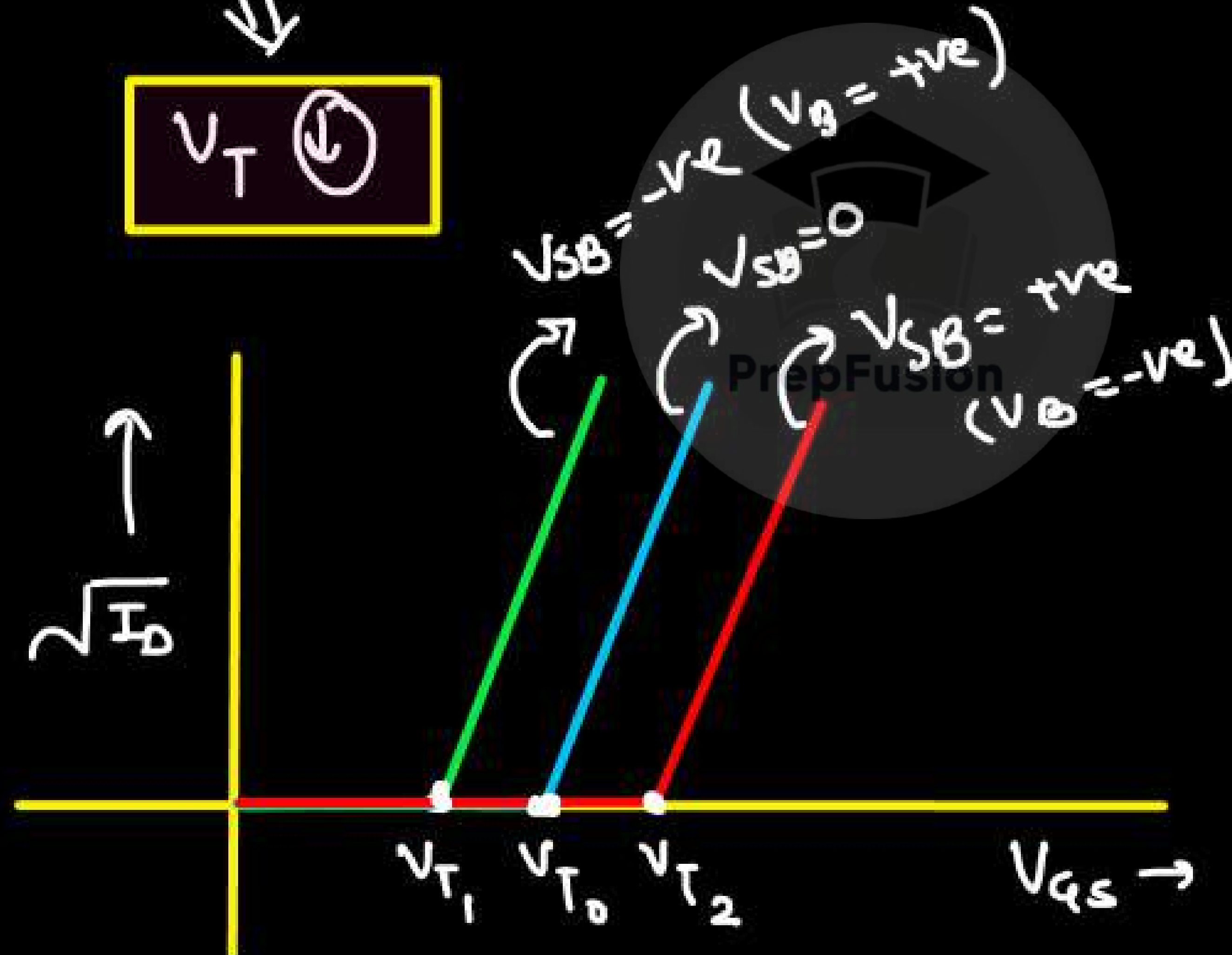
Forward bias Towards source side ↑

⇓

Source can supply more electrons @ lower V_G

⇓

$\boxed{V_T \downarrow}$



(i) $V_{SB} = +ve$, $V_B = -ve$ $\Rightarrow V_T \uparrow$ (NOT Desirable)

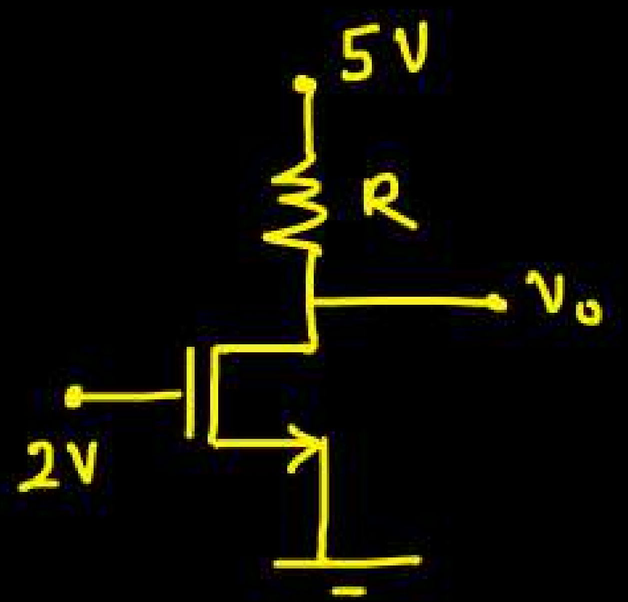
(ii) $V_{SB} = -ve$, $V_B = +ve$ $\Rightarrow$ Unwanted power cosumption
(NOT Desirable)

$\Rightarrow$ **We always try to keep $V_{SB} = 0V$; Source-Body shorted**

{or at least source to body diode should be reverse biased}

Assignment - 4

Q.



$W/L = 10$

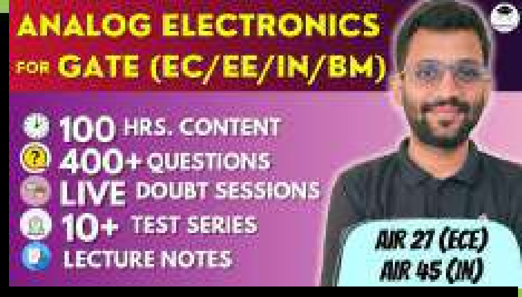
$\mu_n C_{ox} = 200 \mu A/V^2$

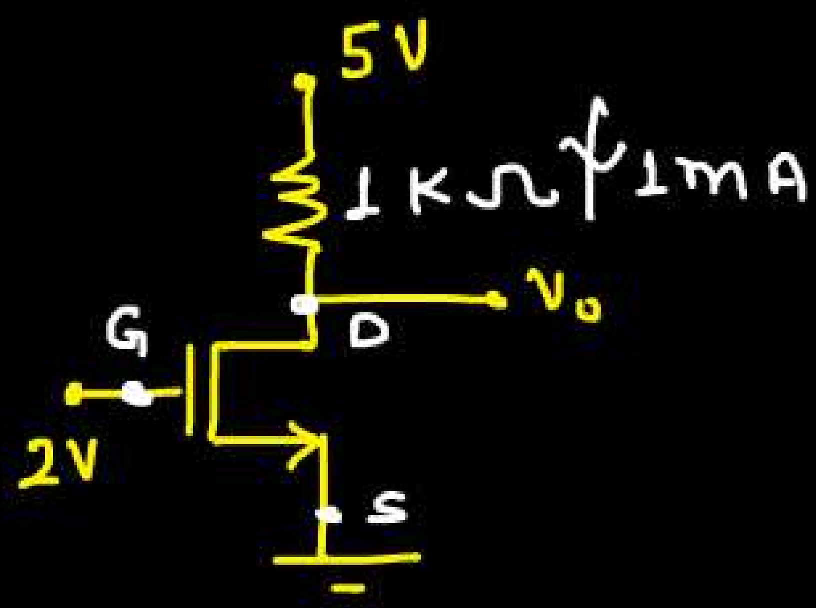
$V_T = 1V$

Find $v_o = ?$

(i) $R = 1k\Omega$

(ii) $R = 4.5k\Omega$





(a)

$$V_{GS} = 2\,V$$

$$V_{DS} = V_o$$

$$V_T = 1\,V$$

Let, MOS is working in sat. region

$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2$$

$$= \frac{200\mu \times 10}{2}(2-1)^2$$

$$\boxed{I_D = 1\,mA}$$

$$\boxed{V_o = 5 - 1k(1m) = 5 - 1 = 4V}$$

$V_{GS} = 2V$, $V_T = 1V$, $V_{ov} = V_{GS} - V_T$

$= 2 - 1 = 1V$

$V_{DS} = 4V$

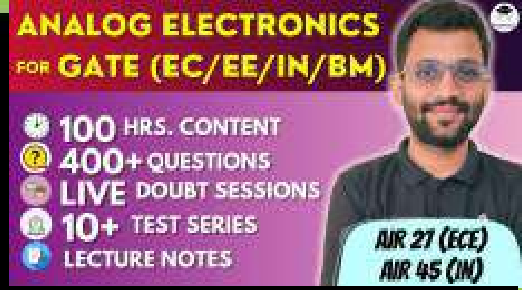
Here, $V_{DS} > V_{GS} - V_T$

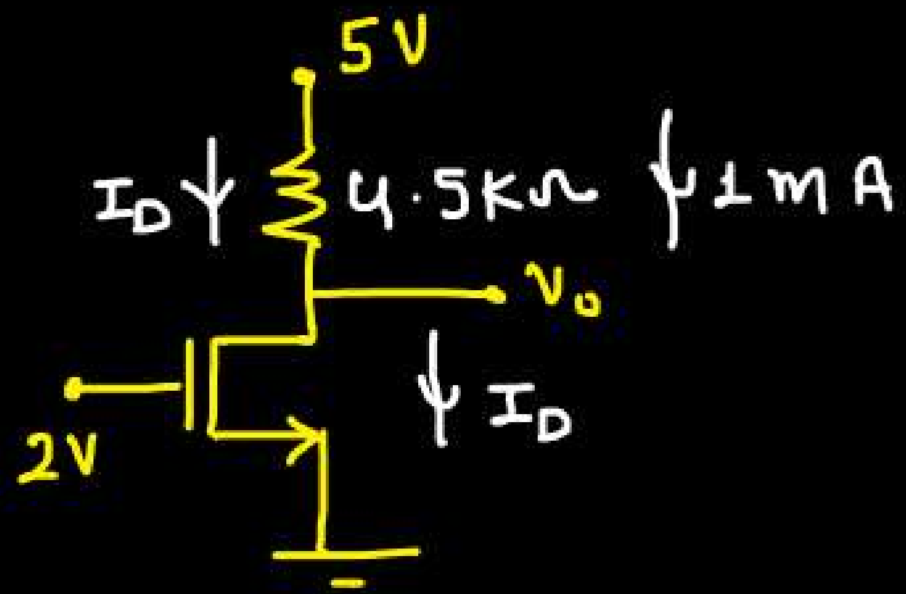
OR

$V_{DS} > V_{ov}$ $\Rightarrow$ MOS is in sat.

Assumption correct ✓

$\Rightarrow$ $\boxed{V_0 = 4V}$





Assuming, Sat. region

$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2$$

$$= \frac{200\mu \times 10}{2}(2-1)^2$$

$$\boxed{I_D = 1\,mA}$$

$$V_o = 5 - 4.5K(1m)$$

$$\boxed{V_o = 0.5V}$$

now, $V_{DS} = V_o = 0.5V$

$V_{GS} - V_T = 2 - 1 = 1V$

Here, $\boxed{V_{DS} < V_{GS} - V_T} \rightarrow$ linear region

Assumption wrong

Assuming, linear region;

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$\frac{5-V_0}{4.5K} = \underbrace{200\mu \times 10}_{2m}\left[1 \times V_0 - \frac{V_0^2}{2}\right]$$

$$5 - V_0 = 9\left[V_0 - \frac{V_0^2}{2}\right]$$

$$4.5V_0^2 - 10V_0 + 5 = 0$$

$$V_0 = \frac{10 \pm \sqrt{100-90}}{9}$$

$\swarrow$ $\searrow$

1.46V 0.76V

$$V_0 \rightarrow 1.46\ V$$
$$V_0 \rightarrow 0.76\ V$$

Let, $V_0 = 1.4V = V_{DS}$

$V_{GS} - V_T = 1V$

Here $V_{DS} > V_{GS} - V_T$

$\Rightarrow$ sat.

$\times$

$V_0 = 0.76V = V_{DS}$

$V_{GS} - V_T = 1V$

$V_{DS} < V_{GS} - V_T$

$\Rightarrow$ linear ✓

$\Downarrow$

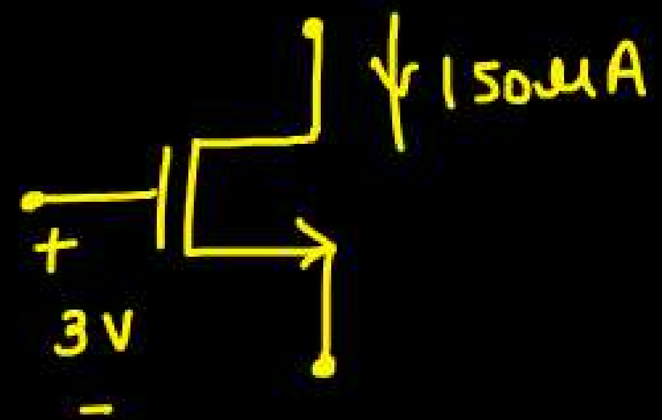
Assumption correct

$$\boxed{V_0 = 0.76V}$$

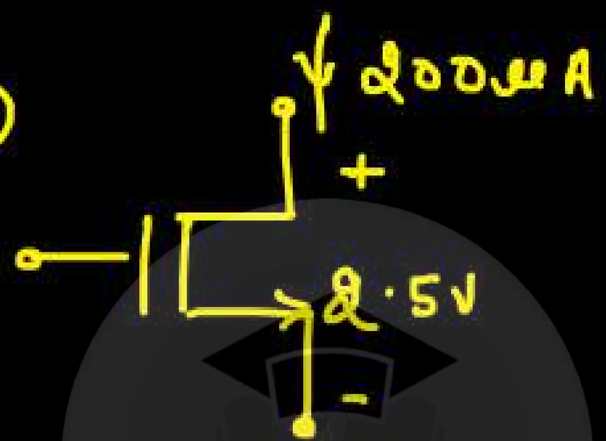
Q. Given, $\mu_n C_{ox} = 100\,\mu A/V^2$, $W/L = 1$, $V_T = 1V$

Find region of operation.

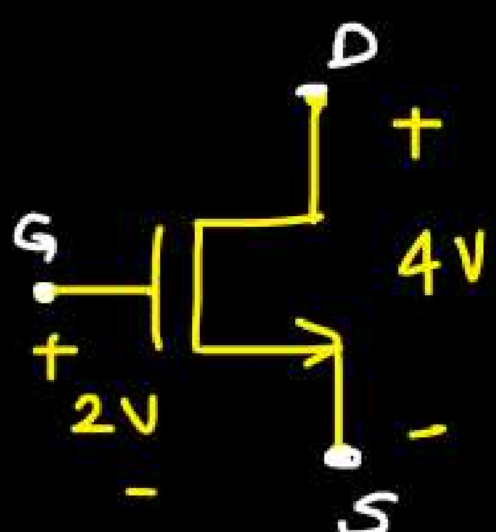
①



②



③



$V_{DS} = 4V$

$V_{GS} = 2V$

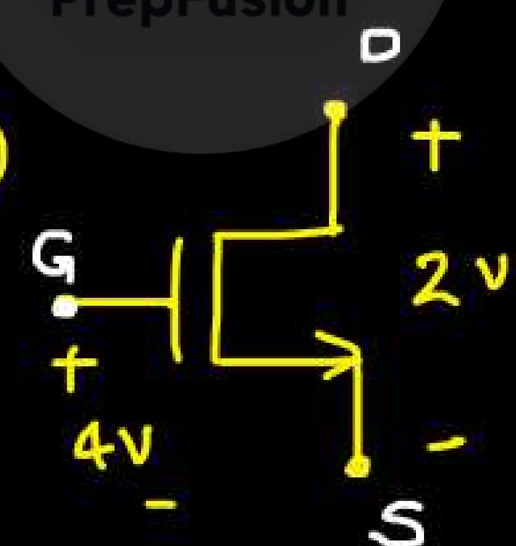
$V_{OV} = 1V$

$V_{DS} > V_{OV}$

$\Downarrow$

$\boxed{\text{Sat. region}}$

④



$V_{DS} = 2V$

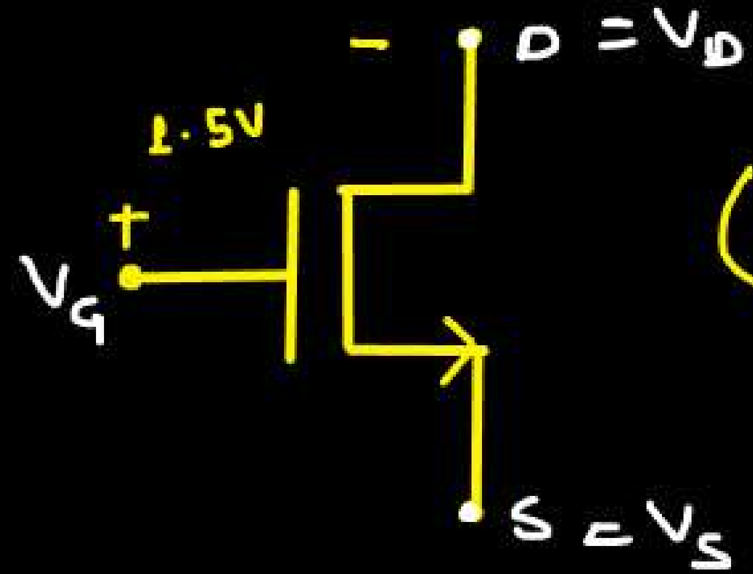
$V_{OV} = 3V$

$V_{DS} < V_{OV}$

$\Downarrow$

$\boxed{\text{Linear region}}$

(5)



(Let $V_{GS} > 1V$)

$V_{DS} = V_D - V_S$

$V_{GS} = V_G - V_S$

$= V_D + 1.5 - V_S$

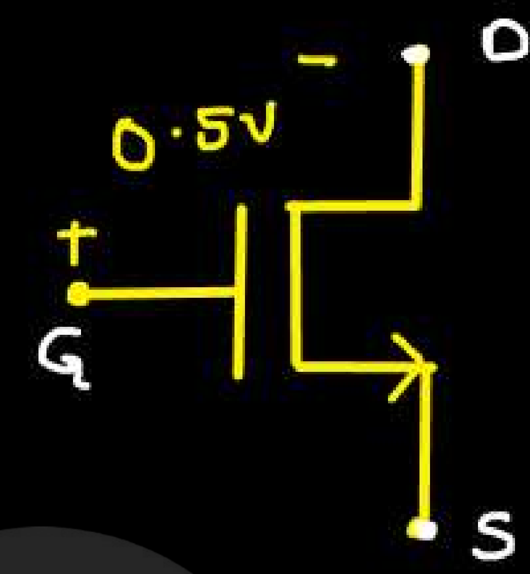
$V_{GS} = 1.5 + V_{DS}$

$V_T = 1V$

$V_{OV} = 0.5 + V_{DS}$

$\boxed{V_{DS} < V_{OV}}$ ⇒ linear region

(6)



$V_{DS} = V_D - V_S$

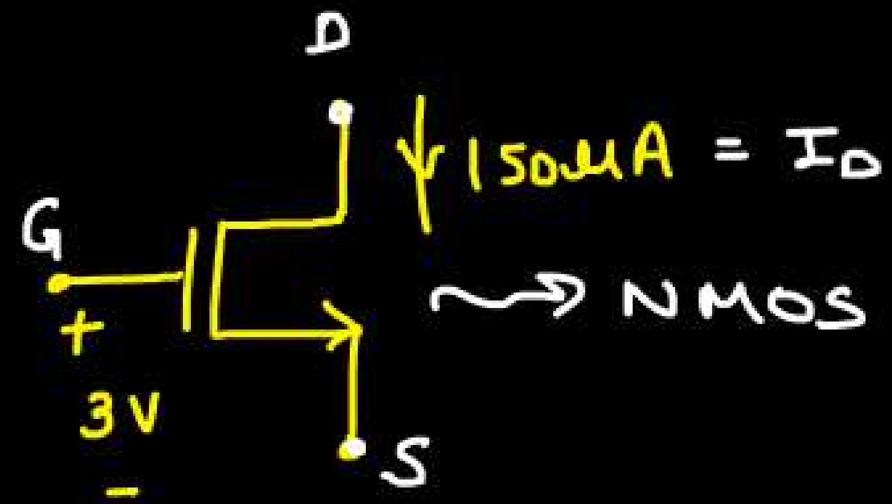
$V_{GS} = V_D + 0.5 - V_S$

$V_{GS} = V_{DS} + 0.5$

$V_T = 1V$

$V_{OV} = V_{DS} - 0.5$

$\boxed{V_{DS} > V_{OV}}$ ⇒ sat. region



(a)

$V_{GS} = 3\,V$

$V_T = 1\,V$

$I_D = 150\,\mu$ Amp.

Let MOS is in sat. region

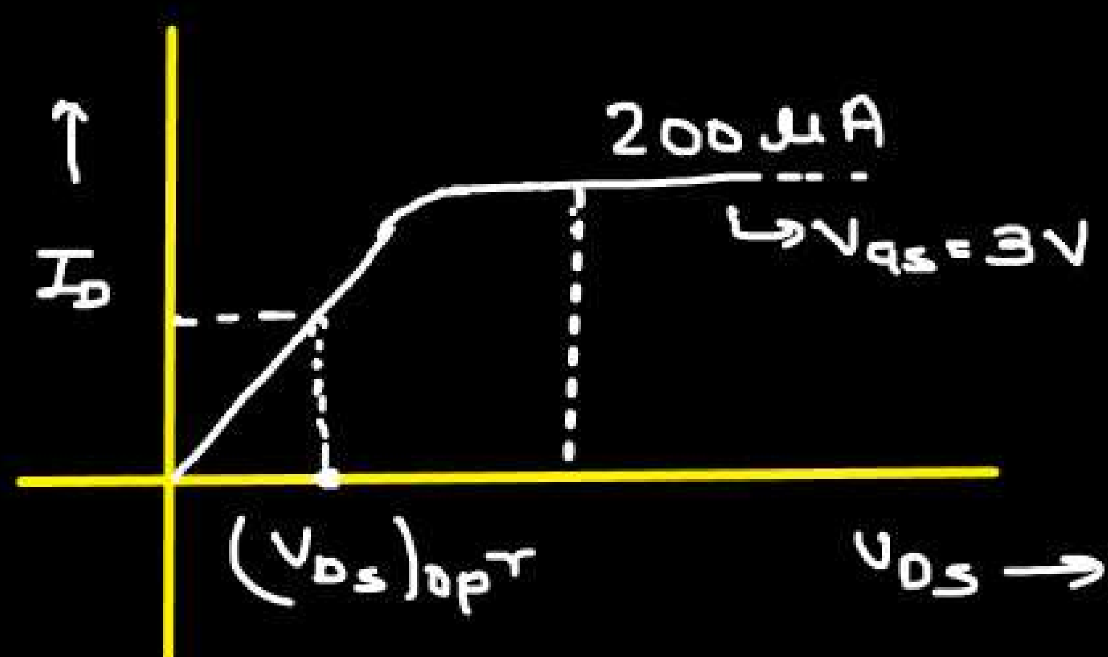
$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2$$

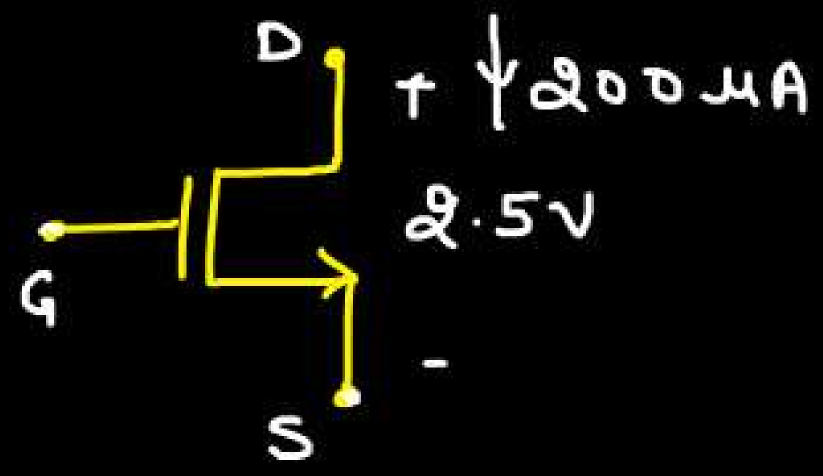
$$= \frac{100\mu \times 10}{2}(3-1)^2$$

$$\boxed{I_D = 200\,\mu A}$$

⇓

Mos is not in sat. but in $\boxed{\text{linear}}$





$$I_D = 200\ \mu A$$

Let, sat. region

$$I_D = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2$$

$$200\mu = \frac{100\mu \times 1}{2} (V_{GS} - 1)^2$$

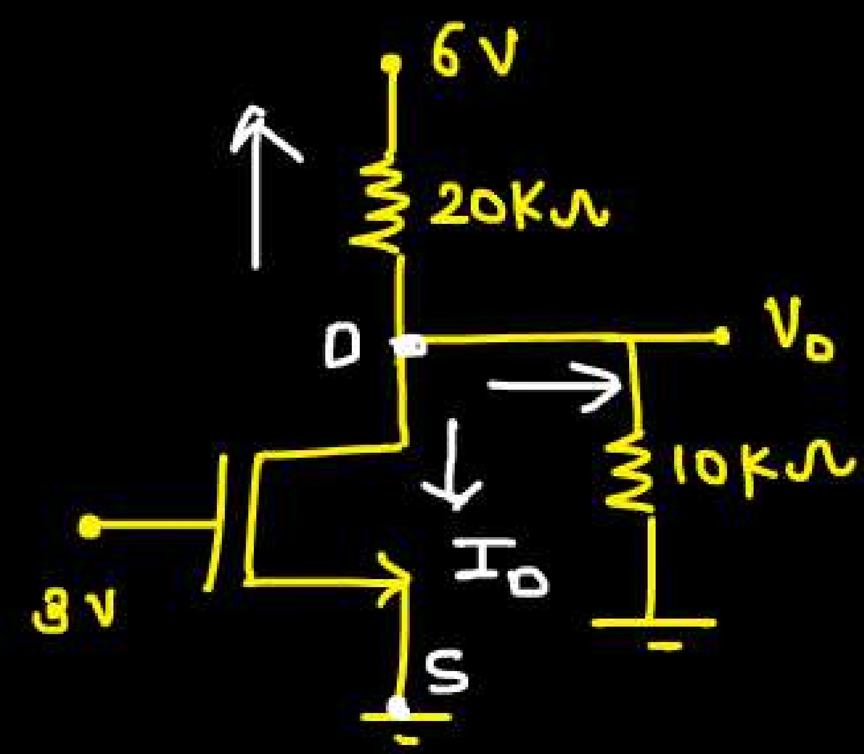
$$\boxed{V_{GS} = 3\ V}$$

$$V_{DS} = 2.5V$$

$$V_{OV} = 3 - 1 = 2V$$

Here $V_{DS} > V_{OV} \Rightarrow \boxed{\text{sat. region}} \Rightarrow$ Assumption ✓

Q.



$\mu_n C_{ox} = 100\ \mu A/V^2$

$W/L = 1$

$V_T = 1V$

Find $V_o = ?$

Find drain current of MOS.

$V_{DS} = V_o$

KCL @ node V_o

$\rightarrow$

$$I_D + \frac{V_o}{10K} + \frac{V_o - 6}{20K} = 0$$

$$I_D = \frac{6 - V_o}{20K} - \frac{V_o}{10K} \rightarrow (1)$$

Let, MOS is in sat.

$$I_D = \frac{100\mu}{2}(3-1)^2$$

$$\boxed{I_D = 200\,\mu A}$$

$$200\mu = \frac{6-V_o}{20k} - \frac{V_o}{10k}$$

$$4 = 6 - V_o - 2V_o$$

$$\boxed{V_o = 2/3 = 0.67V}$$

$$V_{OV} = V_{GS} - V_T = 2V$$

$V_o = V_{DS} < V_{OV} \Rightarrow$ Linear region $\Rightarrow$ Assumption $\times$

Assuming, MOS in linear region

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$\frac{6-V_0}{20K} - \frac{V_0}{10K} = 100\mu \times 1\left[2V_0 - \frac{V_0^2}{2}\right]$$

$$6 - V_0 - 2V_0 = 2\left[2V_0 - \frac{V_0^2}{2}\right]$$

$$6 - 3V_0 = 4V_0 - V_0^2$$

$$V_0^2 - 7V_0 + 6 = 0$$

$$\Rightarrow V_0 \rightarrow 1V,\ 6V$$

if $V_0 = 1V$

$V_{OV} = 2V$

$V_{DS} < V_{OV}$

$\Rightarrow$ linear region ✓

$\boxed{V_0 = 1V}$

if $V_0 = 6V$

$V_{OV} = 2V$

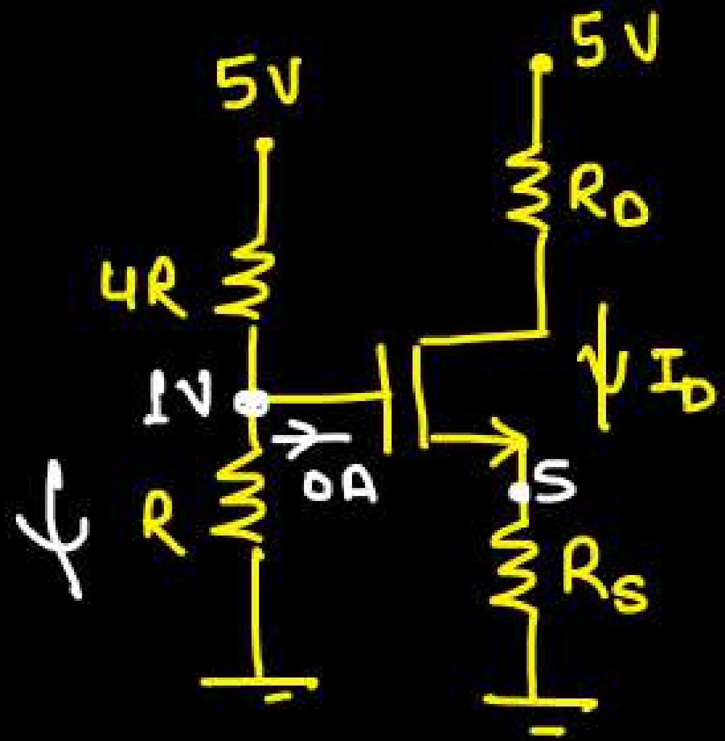
$V_{DS} > V_{OV}$

$\Downarrow$

Sat.

✗

Q.



Find R_s such that MOS works in saturation region.

Given

$I_D = 119\,\mu Amp.$, $V_T = 0.5V$

$K_n = \frac{\mu_n C_{ox} W}{2L} = 4.12\,mS/V$

$V_G = 1V$

$V_S = I_D R_S$

$V_{GS} = 1 - I_D R_S$

$V_T = 0.5V$

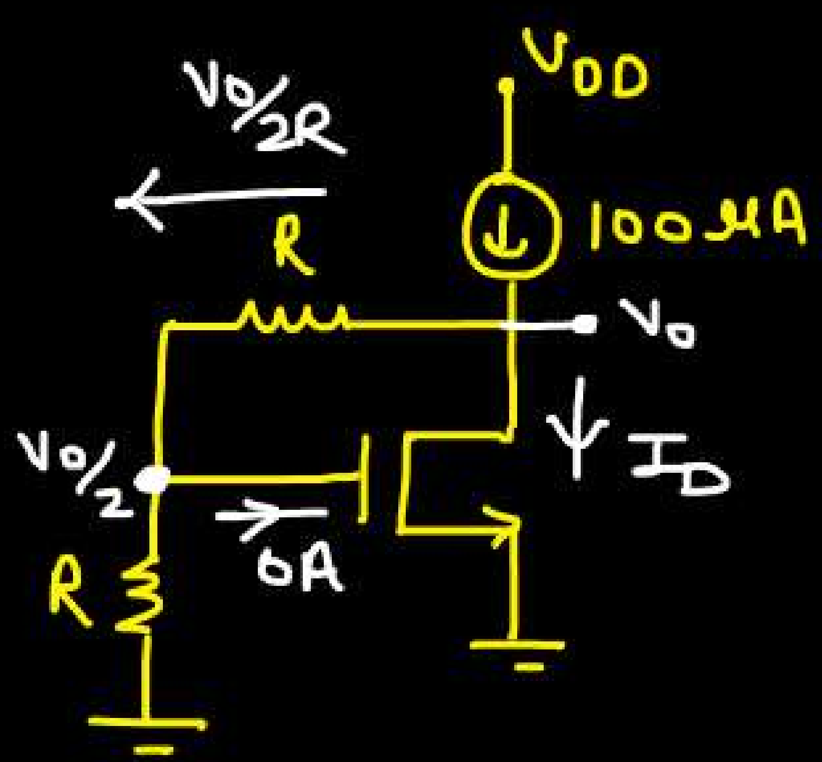
$$I_D = K_n(\underbrace{V_{GS} - V_T})^2$$

$$119\mu = 4.12m\left(1 - 119\mu \times R_S - 0.5\right)^2$$

$$0.17 = 0.5 - 119\mu \times R_S$$

$$\Rightarrow \boxed{R_S = 2.77\,K\Omega}$$

Q.



$$\frac{\mu_n C_{ox} W}{L} = 100\,\mu S/V$$

$V_T = 1V$, $R = 40K\Omega$

Find bias current in Transistor.

$V_{DS} = V_o$

$V_{GS} = V_o/2$

$V_T = 1V$

$$100\mu = \frac{V_o}{2R} + I_D$$

$$I_D = 100\mu - \frac{V_o}{80K}$$

$$I_D = 100\mu - \frac{1000}{80} V_o \times \mu$$

$$\boxed{I_D = 100\mu - 12.5V_0\mu}$$

Let, MOS in sat,

$$I_D = \frac{100\mu}{2}\left(\frac{V_0}{2}-1\right)^2$$

$$100\mu - 12.5\mu V_0 = 50\mu\left(\frac{V_0}{2}-1\right)^2$$

$$100 - 12.5V_0 = 50\left(\frac{V_0^2}{4}+1-V_0\right)$$

$$100 - 12.5V_0 = 12.5V_0^2 + 50 - 50V_0$$

$$12.5V_0^2 - 37.5V_0 - 50 = 0$$

$$V_0^2 - 3V_0 - 4 = 0 \rightarrow V_0 = 4V, \quad V_0 = -1V$$

Let $V_0 = -1V = V_{DS} \Rightarrow$ MOS goes into cut-off

Check:-

MOS cut-off

$I_D = 0$ Amp.

$$\frac{V_0}{2R} = 100\mu$$

$V_0 = 8V$, $V_{GS} = 4V$

$$V_{OV} = \frac{V_0}{2} - V_T = 3V$$

$V_0 > V_{OV}$

also $V_{GS} > V_T$ $\Big\} \Rightarrow$ MOS goes into sat. $\Downarrow$ (Can't be cut-off)

also $V_{DS} > 0V$

if $V_o = 4V$

$V_{DS} = 4V$

$V_{GS} = 2V$

$V_T = 1V$

$V_{ov} = 1V$

$\Rightarrow V_{DS} > V_{ov} \Rightarrow$ sat. region $\Rightarrow$ Assumption ✓

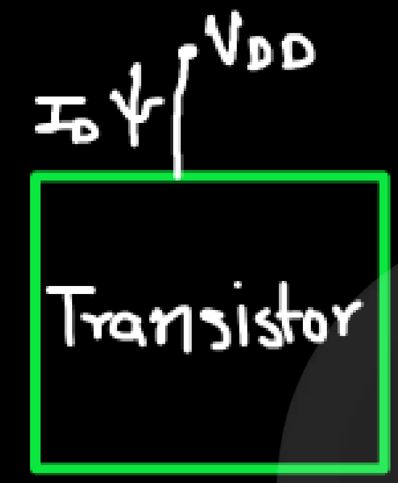
$$\boxed{V_o = 4V}$$

$$I_D = 100\mu - 12.5\mu \times 4$$

$$\boxed{I_D = 50\mu}$$

Biasing:-

The process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor.



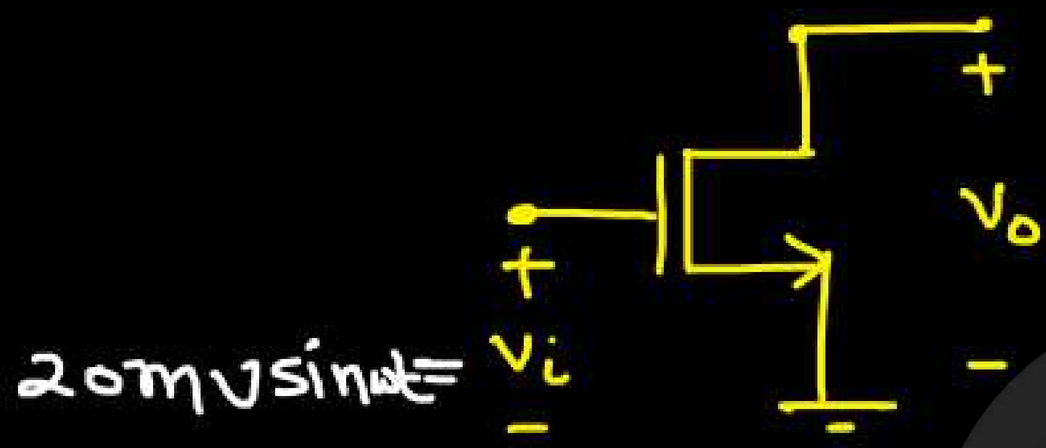
Why biasing is required?

↳ Why we needed MOSFET:-

$20mV \sin\omega t = v_i$

$v_o = 100mV \sin\omega t$

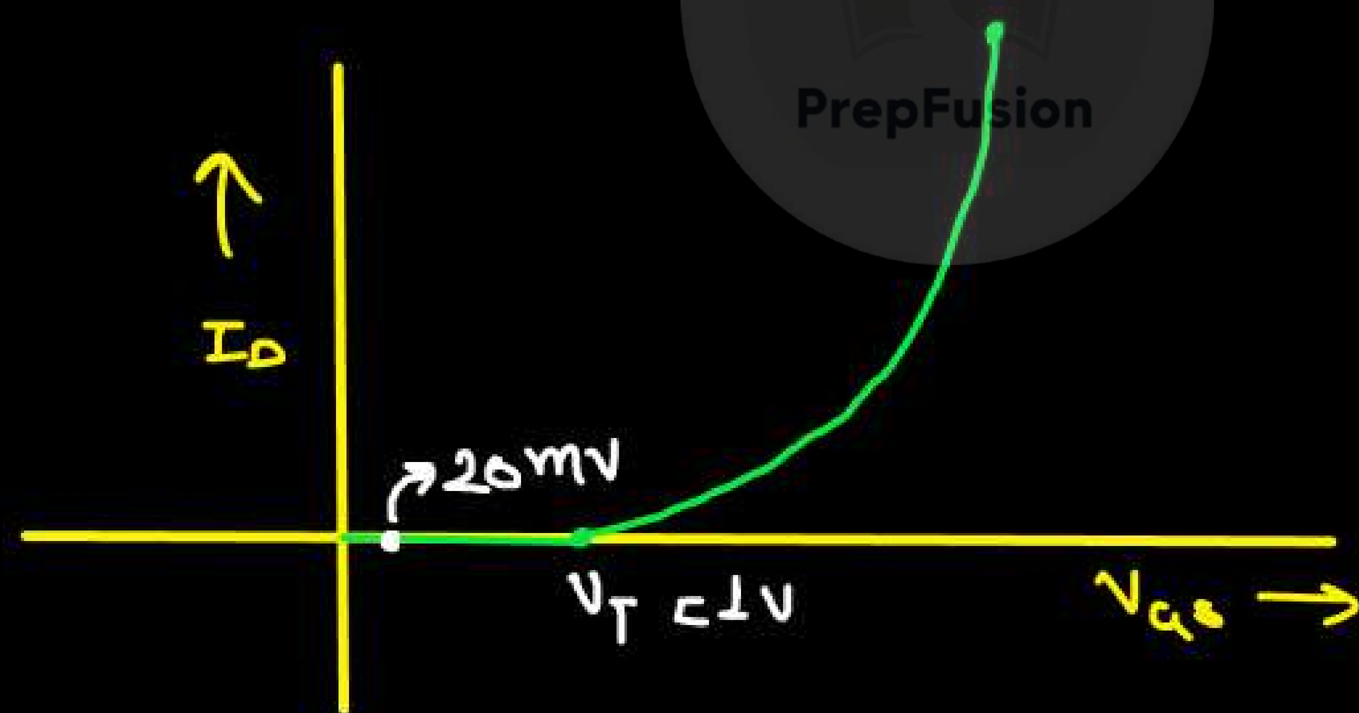
✿ Let I don't apply an dc bias to my Amplifier and directly give small signal ac voltage.



⇒ $V_{GS} = 20mV \sin\omega t$

max = 20mV

min = −20mV

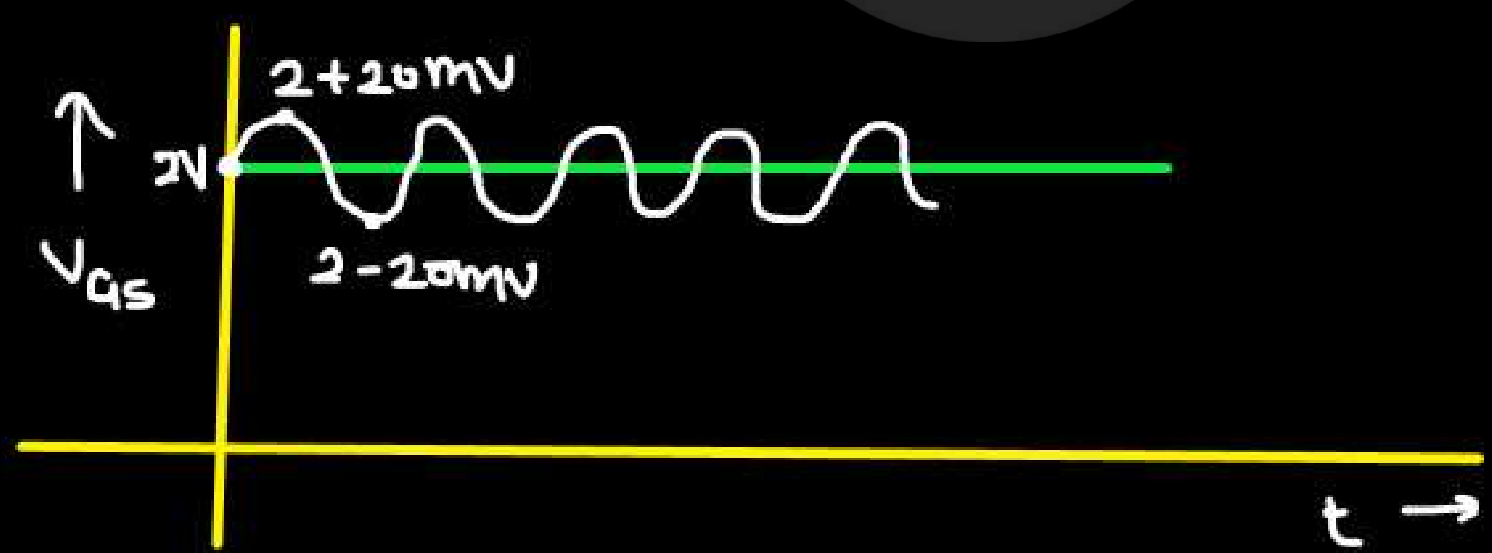


⇒ Transistor doesn't even turn on.

So, to make sure that the transistor is always in "ON condition", we give some dc bias to the MOS and apply small signal voltage (20mV, 10mV, 40mV) on it.

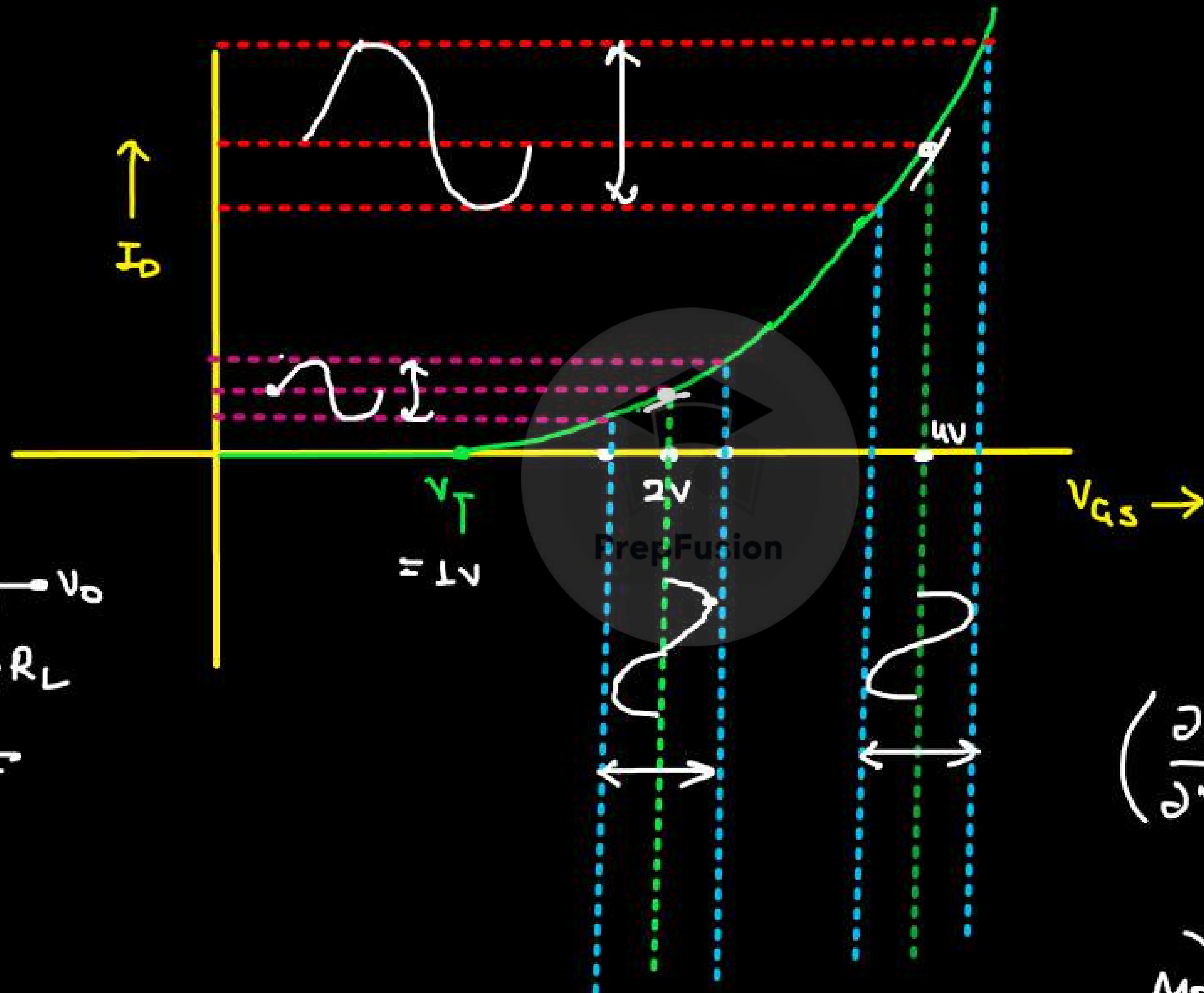
$\Rightarrow \; V_{GS} = V_{GG} + v_i$

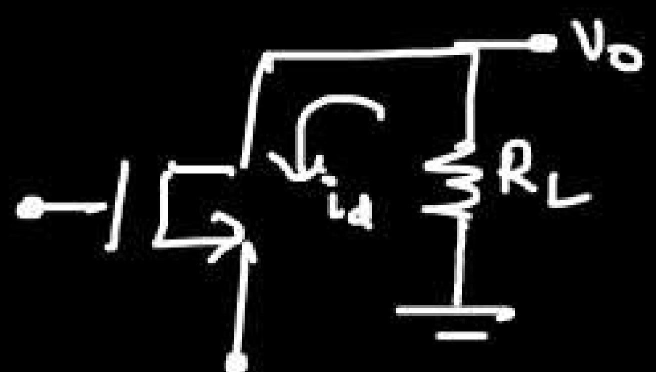
$V_{GS} = 2V + 20mV \sin\omega t$



Transfer Characteristics :-

$V_{DS} < V_{OV}$ ↓





$$V_{GS_1} = 2 + v_i$$

$$V_{GS_2} = 4 + v_i$$

$$\left(\frac{\partial I_D}{\partial V_{GS}}\right)_{V_{GS_2}} > \left(\frac{\partial I_D}{\partial V_{GS}}\right)_{V_{GS_1}}$$

⇓

MORE GAIN

@ Higher V_{GS}, you get Higher value of $\frac{\partial I_D}{\partial V_{GS}}$

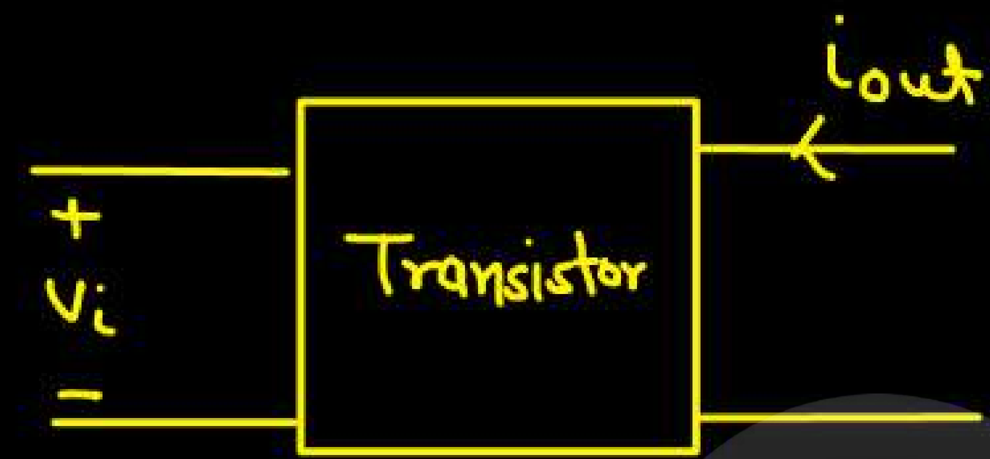
and that eventually gives more gain.

But, while using MOS as an amplifier, you can't keep V_{GS} (dc) value to be very High. Why?

(i) More power consumption

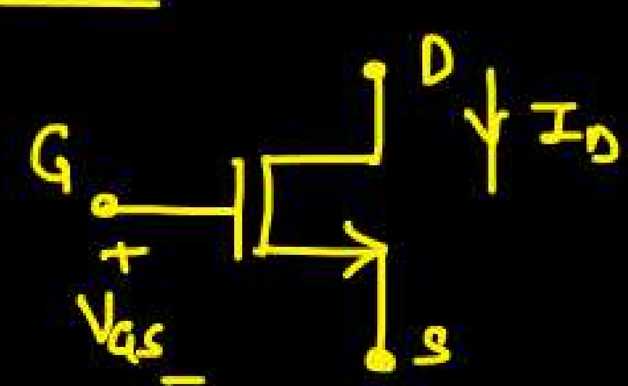
(ii) MOS will fall out of saturation.

Concept of Transconductance :- (g_m)



$$\boxed{g_m = \frac{\partial i_{out}}{\partial V_{in}}}$$

considering NMOS :-



$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

Transconductance for Triode region:-

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$\boxed{g_m = \frac{\partial I_D}{\partial V_{GS}}}$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{\mu_n C_{ox} W}{L}\left[V_{DS} - 0\right]$$

$$\boxed{(g_m)_{\text{Triode}} = \frac{\mu_n C_{ox} W}{L} \times V_{DS}}$$

Transconductance for saturation region:-

$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_t)^2 \quad \text{--- (1)}$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

$$\boxed{g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{\mu_n C_{ox} W}{L}(V_{GS} - V_T)} \quad \text{--- (2)}$$

From eq^n (1)

$$\frac{2I_D}{V_{GS} - V_T} = \frac{\mu_n C_{ox} W}{L}(V_{GS} - V_T) = g_m$$

$$* \quad \boxed{g_m = \frac{2 I_D}{V_{GS} - V_T}} \longrightarrow (3)$$

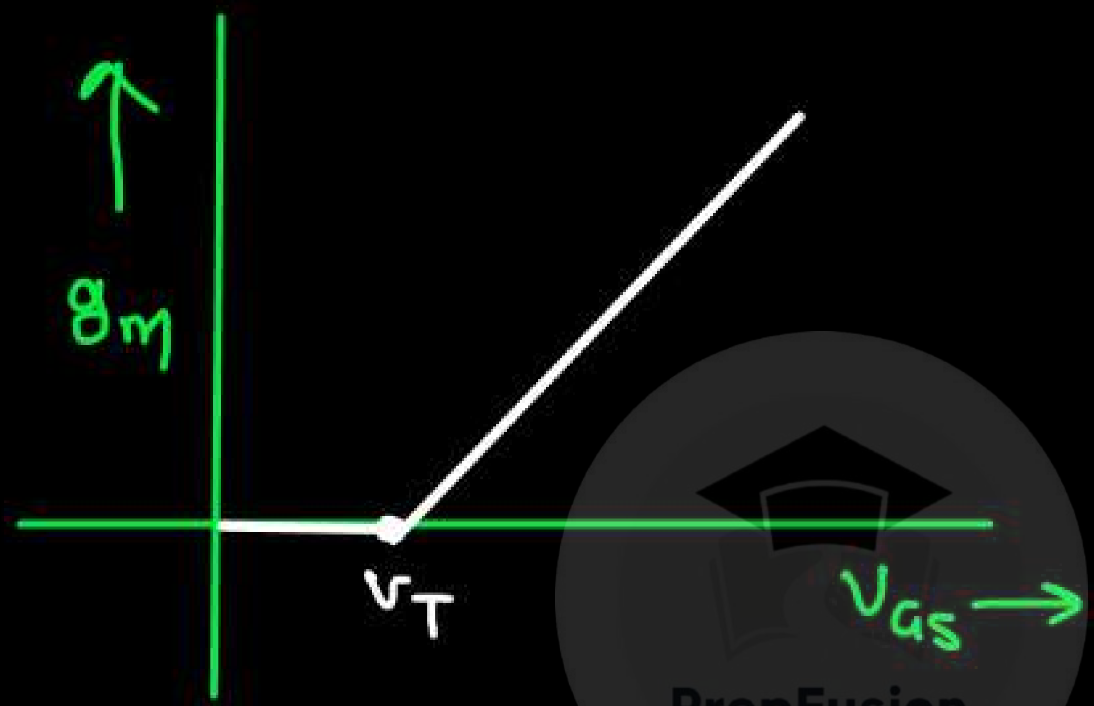
$$I_D = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_t)^2$$

$$2 \frac{\mu_n C_{ox} W}{L} I_D = \left(\frac{\mu_n C_{ox} W}{L}\right)^2 (V_{GS} - V_T)^2$$

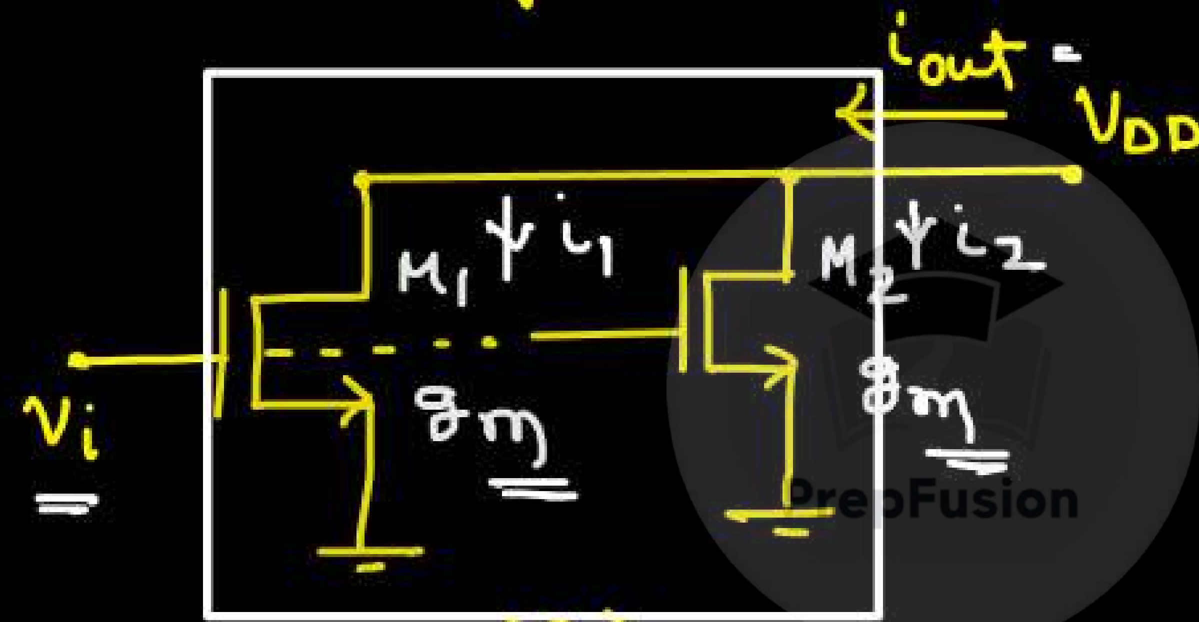
$$\sqrt{2 \frac{\mu_n C_{ox} W}{L} I_D} = \frac{\mu_n C_{ox} W}{L} (V_{GS} - V_T) = g_m$$

$$\boxed{g_m = \sqrt{2 \times \frac{\mu_n C_{ox} W}{L} I_D}} \longrightarrow (5)$$

Saturation region :-



Q. Find the overall Transconductance of the given fig. M_1 and M_2 are identical MOS with Transconductance g_m.



(a)

$\Rightarrow$ overall Transconductance $G_m = \dfrac{\partial i_{out}}{\partial v_{in}}$

For M_1,

$$g_m = \frac{\partial i_1}{\partial v_i}$$

For M_2

$$g_m = \frac{\partial i_2}{\partial v_{in}}$$

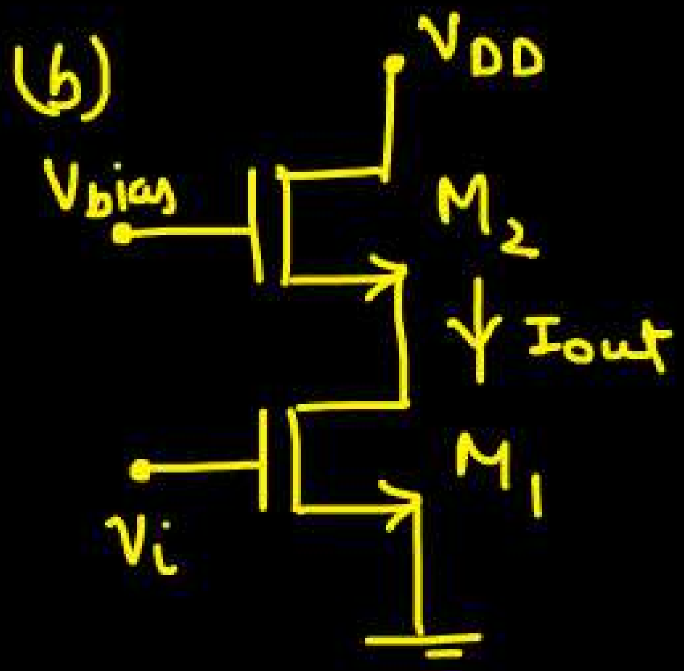
$$G_m = \frac{\partial i_{out}}{\partial v_{in}} \quad ; \quad i_{out} = i_1 + i_2$$

$$G_m = \frac{\partial (i_1 + i_2)}{\partial v_{in}}$$

$$G_m = \frac{\partial i_1}{\partial v_{in}} + \frac{\partial i_2}{\partial v_{in}}$$

$$\boxed{G_m = 2g_m}$$

(b)



Transconductance of M_1 and M_2 is g_{m_1} and g_{m_2} respectively.

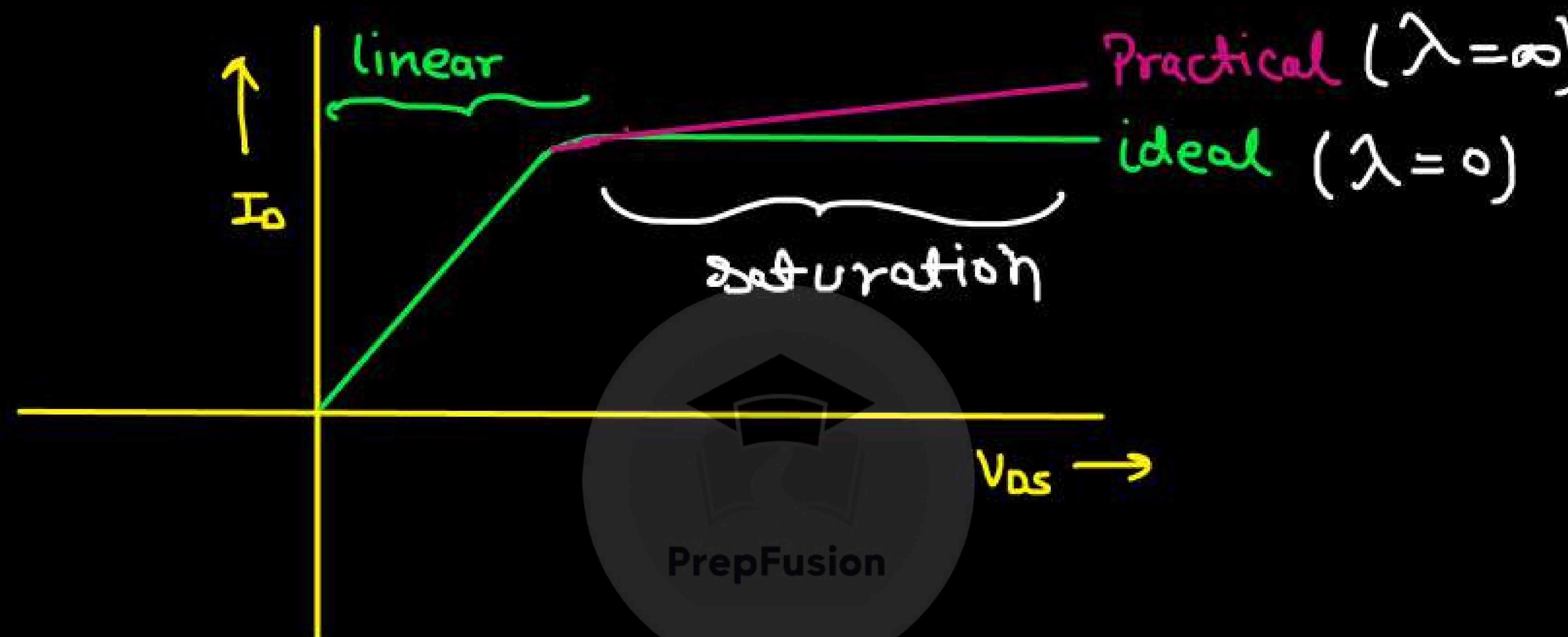
Find overall Transconductance of given ckt.

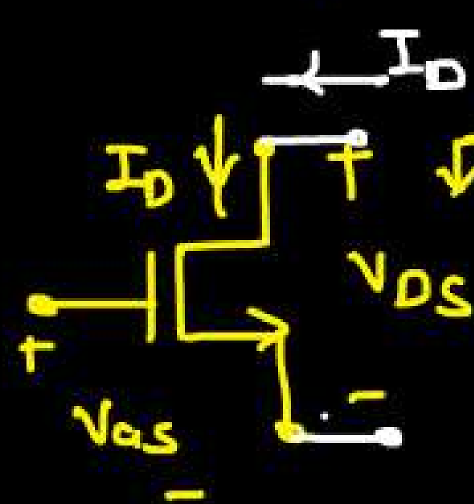
$\rightarrow$ overall Transconductance $= \boxed{\dfrac{\partial i_{out}}{\partial V_{in}} = G_m}$

$$g_{m_1} = \frac{\partial I_{out}}{\partial V_i} = G_m$$

$$\boxed{G_m = g_{m_1}}$$

☆ O/P characteristics of MOS:-





$$\text{Resistance} = \frac{\partial V_{DS}}{\partial I_D}$$

$$(I_D)_{sat.} = \frac{\mu_n C_{ox} W}{2L}(V_{GS}-V_T)^2(1+\lambda V_{DS})$$

$$(I_D)_{linear} = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

For saturation region:-

$$r_{ds} = \frac{\partial V_{DS}}{\partial I_D} = \frac{1}{\frac{\partial I_D}{\partial V_{DS}}}$$

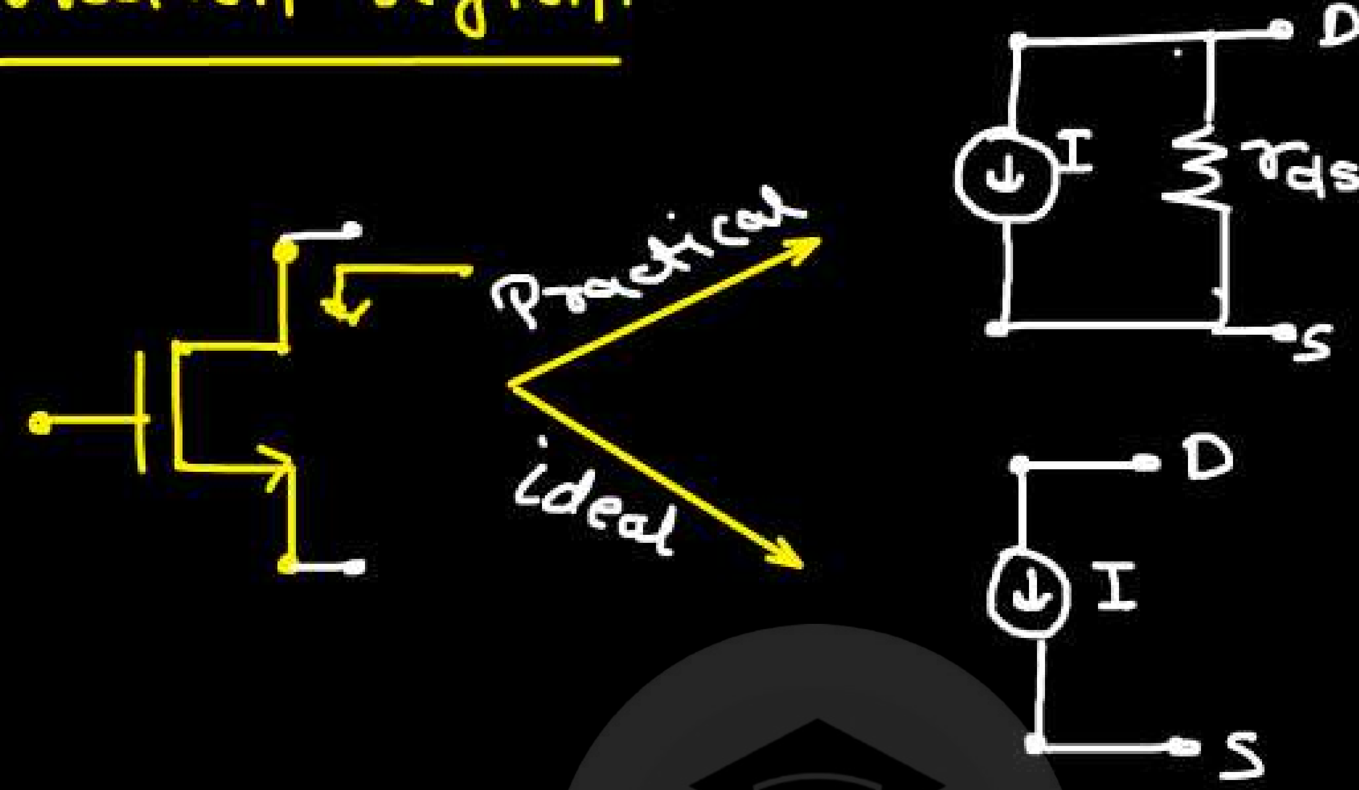
practical

$$\boxed{r_{ds} = \frac{1}{\lambda [I_D]_{sat-ideal}}}$$

ideal

$$\boxed{r_{ds} = \infty}$$

MOS in saturation region:-



$$r_{ds} = \frac{1}{\lambda (I_D)_{sat-ideal}}$$

$$\boxed{I = f(V_{GS})}$$

$\Rightarrow$

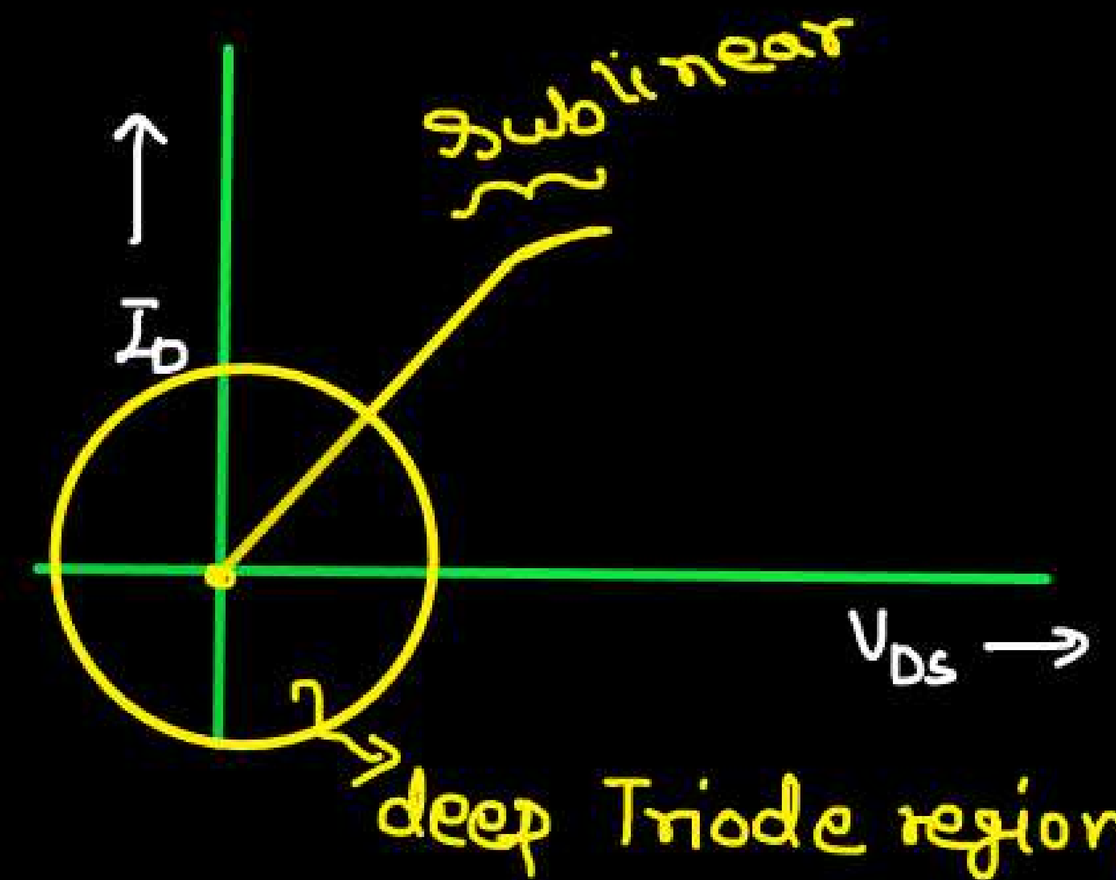
For Triode region:-

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

For deep Triode region:-

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$R_{ON} = \frac{\partial V_{DS}}{\partial I_D} = \frac{1}{\partial I_D / \partial V_{DS}}$$



For deep Triode region,

V_{DS} is very small

$$\left[V_{DS} < \frac{(V_{GS} - V_T)}{2}\right]$$

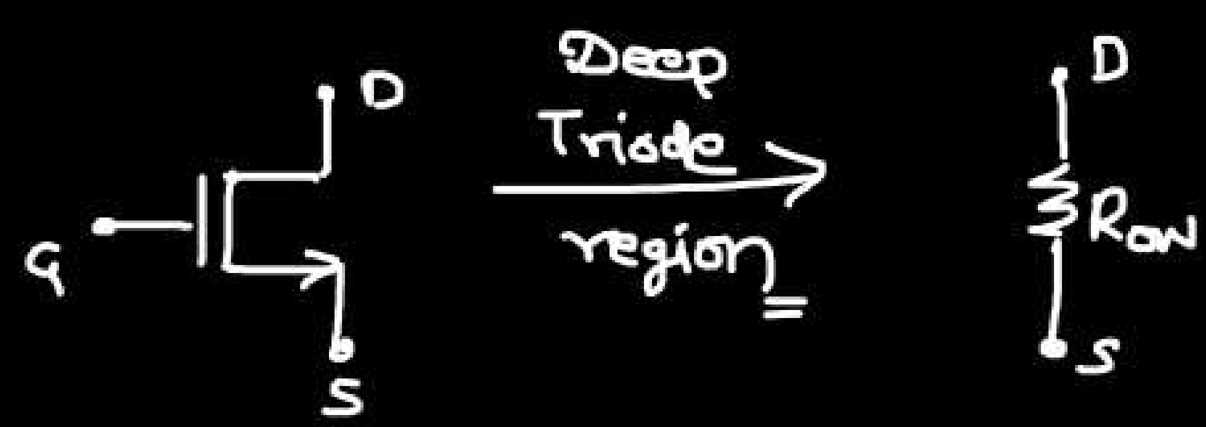
$$V_{DS} \approx 0$$

$$I_D = \frac{\mu_n C_{ox} W}{L} (V_{GS} - V_T) V_{DS}$$

$$\frac{\partial I_D}{\partial V_{DS}} = \frac{\mu_n C_{ox} W}{L} (V_{GS} - V_T)$$

$$\boxed{R_{on} = \frac{1}{\frac{\partial I_D}{\partial V_{DS}}} = \frac{1}{\frac{\mu_n C_{ox} W}{L} \cdot (V_{GS} - V_T)}}$$

MOS in deep Triode region



Assignment - 5 (Fusion_Special)

Q. 1 V_x is varying from 0 to 3V.

Take $V_{T_n} = 0.7V = |V_{T_p}|$

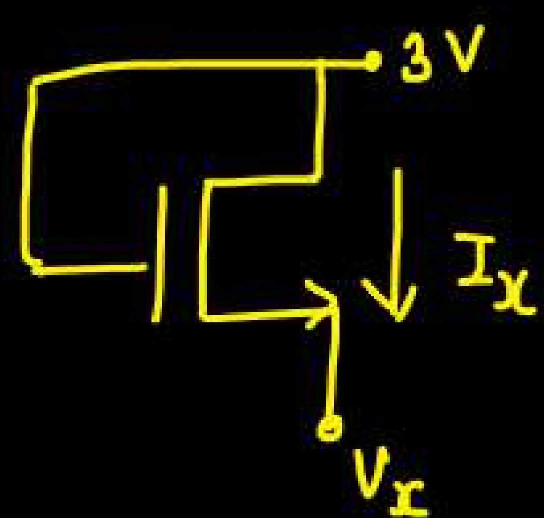
Plot I_x v/s V_x and g_m v/s V_x.

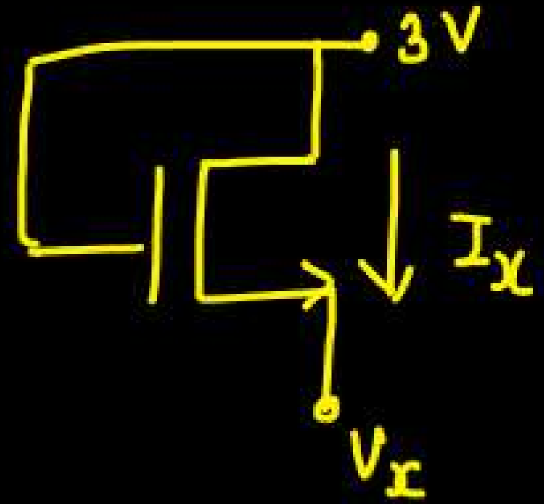
where $g_m = \dfrac{\partial I_D}{\partial V_{GS}}$, $g_m = \dfrac{\partial I_D}{\partial V_{SG}}$

$I_D \rightarrow$ current from D to S (NMOS)

$\rightarrow$ current from S to D (PMOS)

(a)





(a)

$V_{DS} = 3 - V_x$

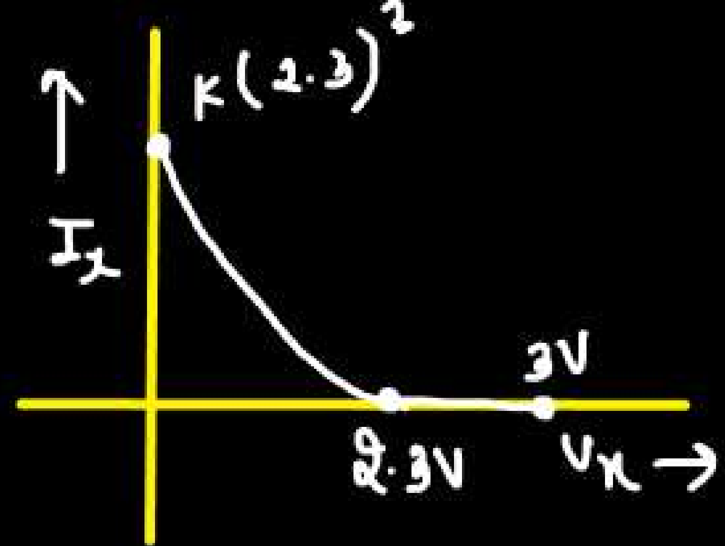
$V_{GS} = 3 - V_x$

$V_T = 0.7$

$V_{OV} = V_{GS} - V_T = 2.3 - V_x$

$V_{DS} > V_{OV} \Rightarrow$ always $\Rightarrow$ sat.

$$\boxed{I_x = K(2.3 - V_x)^2 \text{ — (1) } \{0 < V_x < 2.3V\}}$$



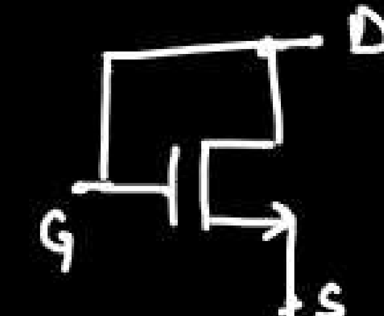
For cut off :-

$V_{GS} < V_T$

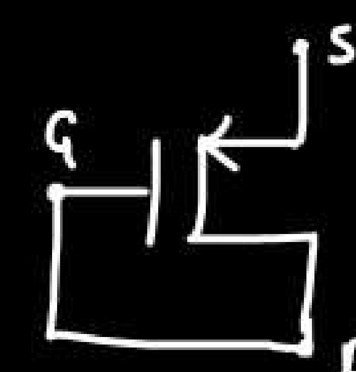
$3 - V_x < 0.7$

$$\boxed{\begin{array}{l} V_x > 2.3V \\ \Rightarrow I_x = 0 \text{ Amp} \end{array}}$$

If Gate and Drain are shorted, the MOS will always be in sat.



$V_{DS} > V_{GS} - V_T$



$V_{SD} > V_{SG} - V_T$

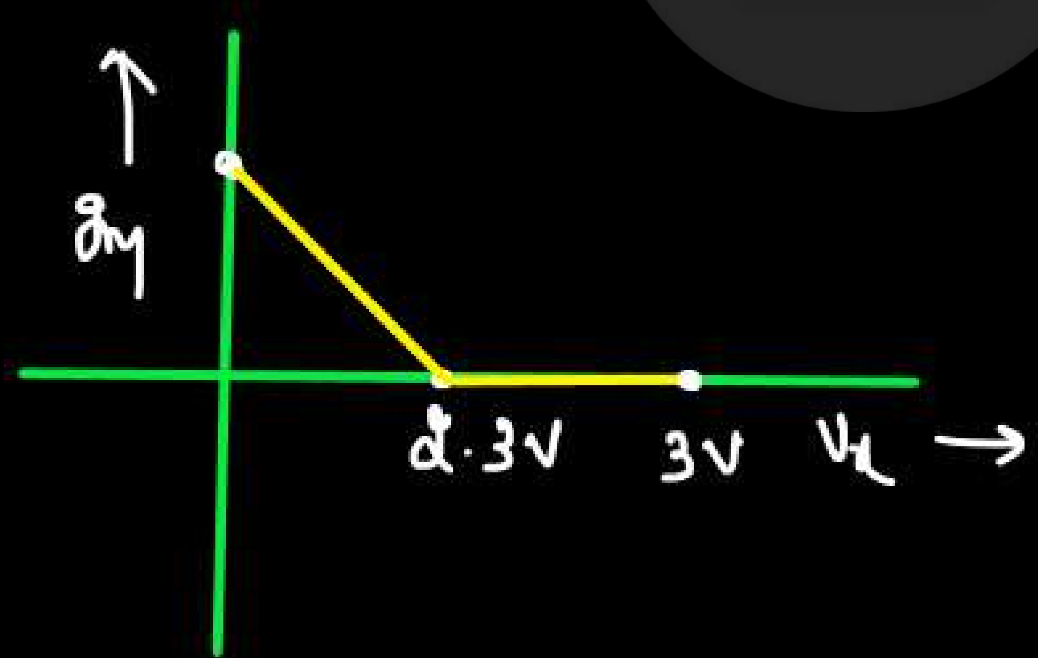
Talking about g_m :-

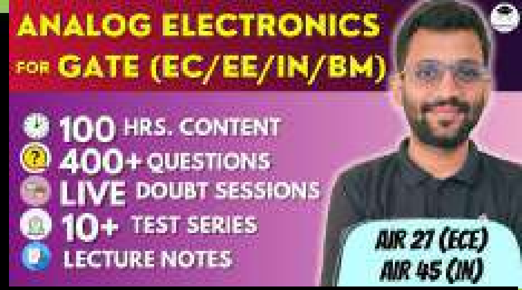
MOS is always in sat. $\{0 < V_x < 2.3\}$

$$(g_m)_{sat} = K'(V_{GS} - V_T)$$

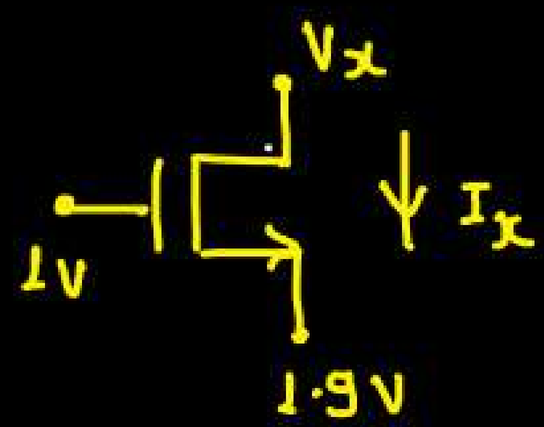
$$\boxed{g_m = K'(2.3 - V_x)}$$

$$\boxed{\text{when } V_x \geq 2.3V \Rightarrow I_x = 0 \Rightarrow g_m = 0}$$





(b)

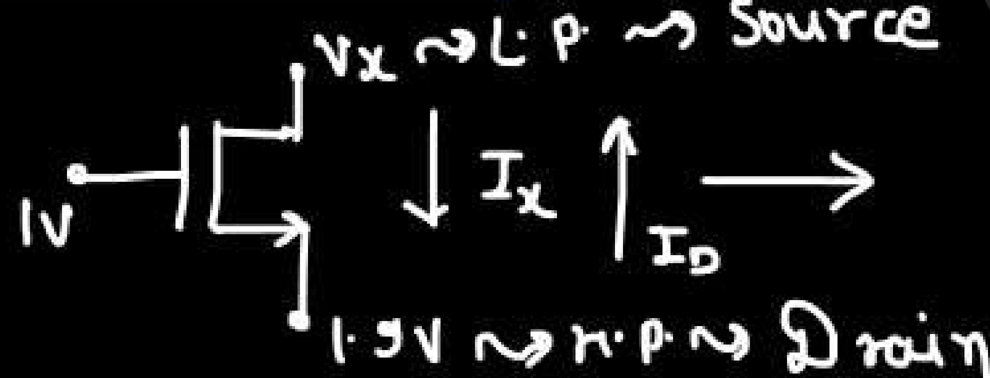


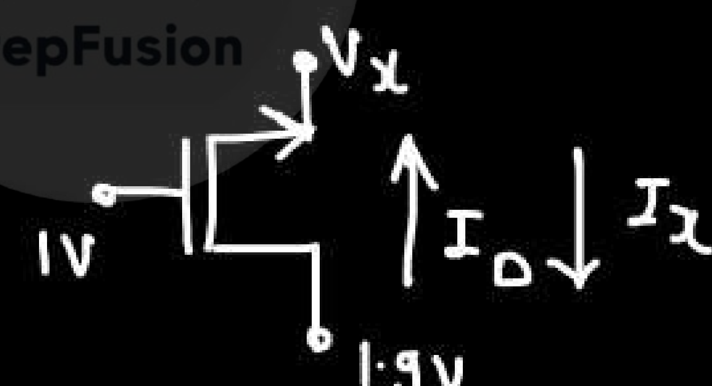
$V_x \equiv 0 \to 3V$

$V_T = 0.7V$

→ $\boxed{V_{GS} = 1 - 1.9V = -0.9V < V_T \Rightarrow I_x = 0\ Amp.}$ X X

$\boxed{0 < V_x < 1.9V}$





$V_{DS} = 1.9 - V_x$

$V_{GS} = 1 - V_x$

$V_T = 0.7V$

$V_{OV} = 0.3 - V_x$

For cut off $\Rightarrow V_{GS} < V_T \Rightarrow V_{OV} < 0$

$V_x > 0.3V$

$\Rightarrow \boxed{V_{DS} > V_{GS} - V_T \Rightarrow Sat.}$

$0 < V_x < 0.3 \Rightarrow$ Sat.

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

$$I_D = K(0.3 - V_x)^2$$

$$\boxed{I_x = -K(0.3 - V_x)^2}$$

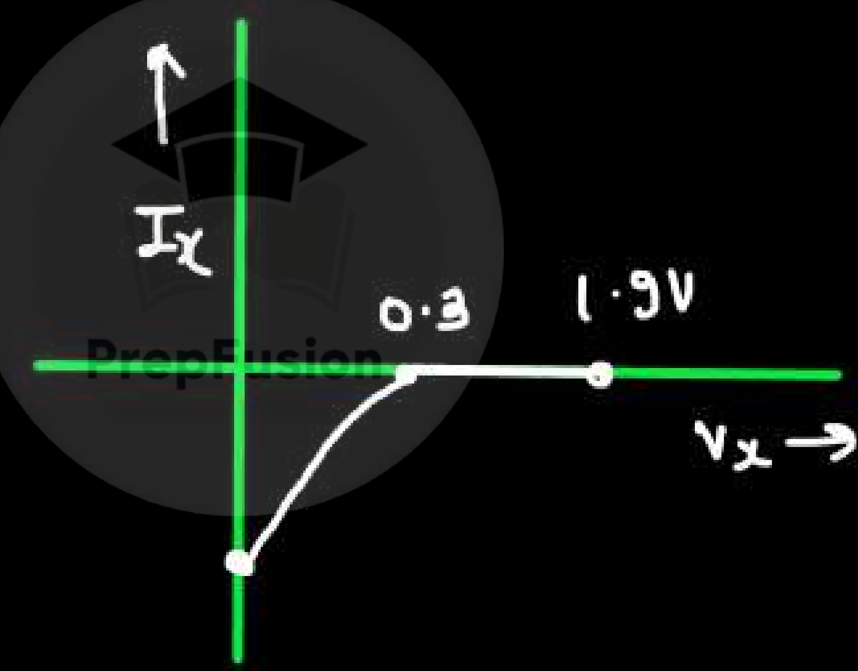
$$g_m = K'(V_{GS} - V_T)$$

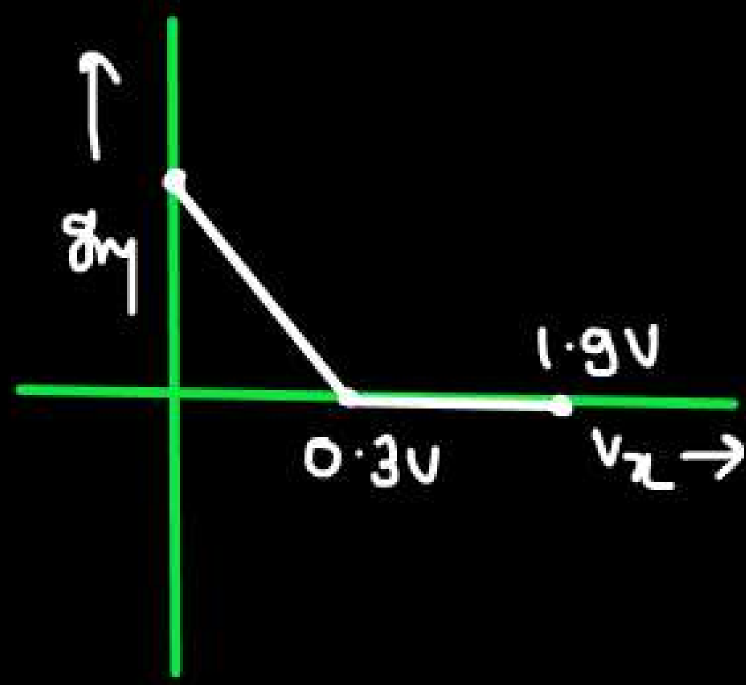
$$\boxed{g_m = K'(0.3 - V_x)}$$

$0.3 < V_x < 1.9V \Rightarrow$ cut-off

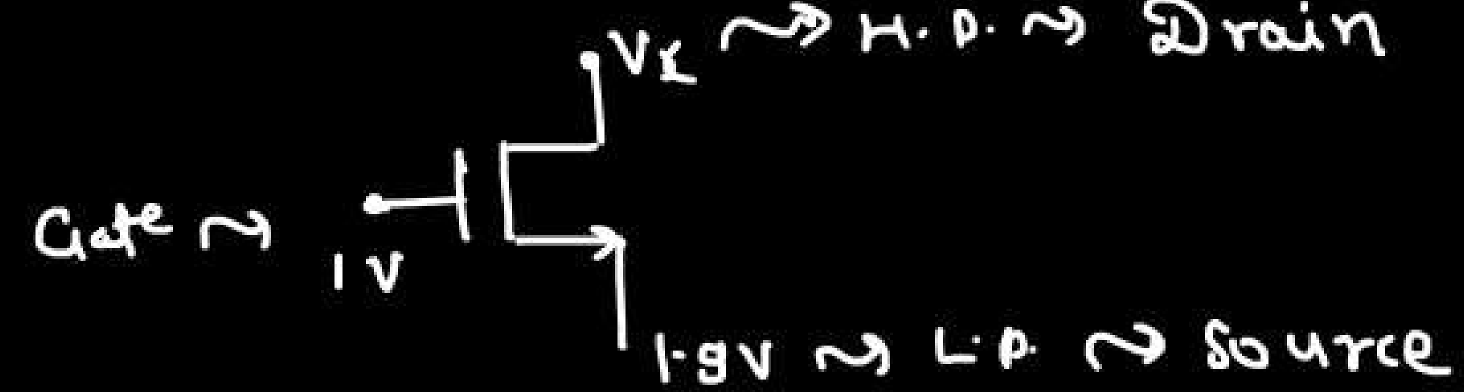
$$\boxed{I_x = 0 \text{ Amp.}}$$

$$\boxed{g_m = 0}$$



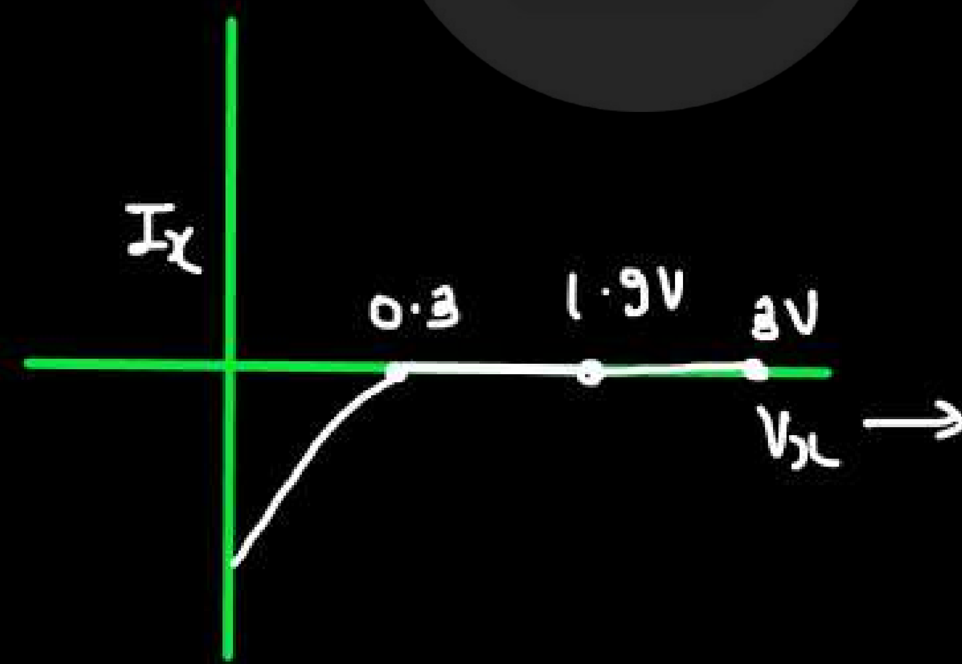


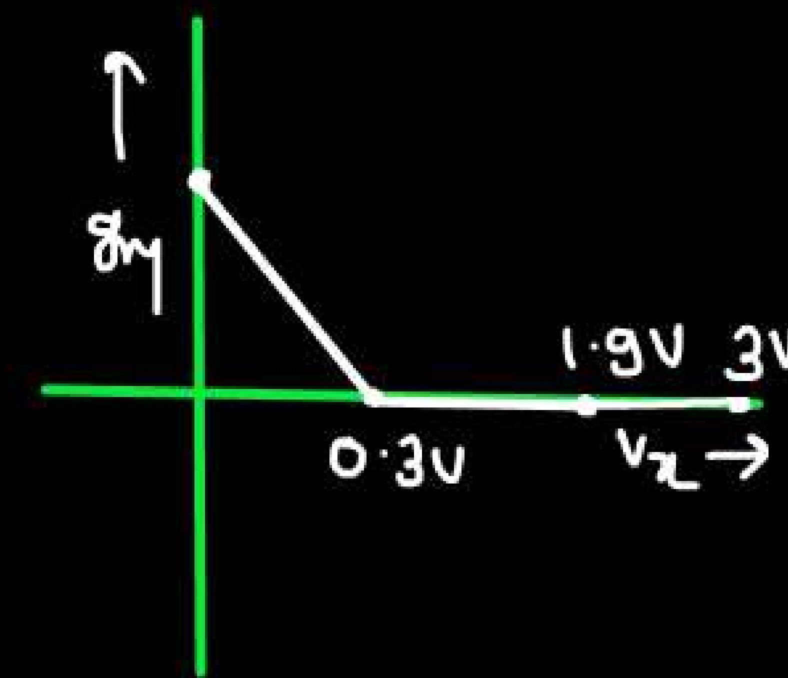
For $V_x > 1.9V$



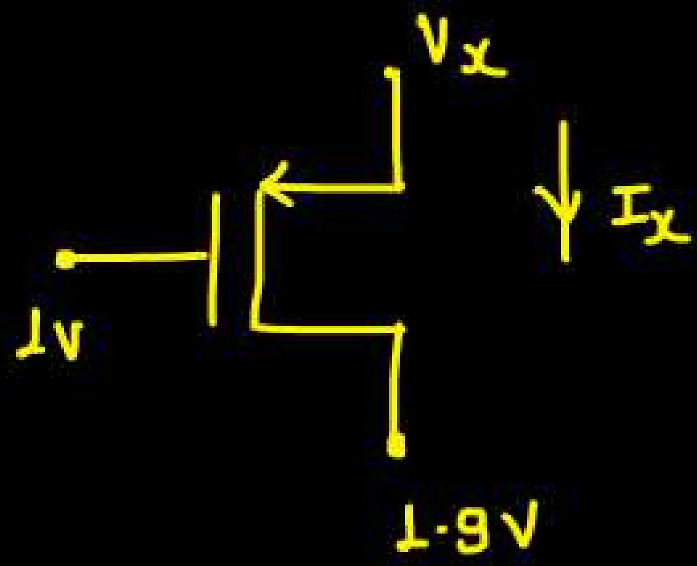
$V_{GS} = 1 - 1.9 = -0.9 < V_T \Rightarrow$ MOS is off

$\boxed{I_x = 0 \text{ Amp.}}$ $\boxed{g_m = 0}$





(c)



$V_x \equiv 0 \rightarrow 3V$

$|V_{T_p}| = 0.7V$

$\rightarrow \boxed{0 < V_x < 1.9V}$

$V_{SG} = 0.9V$

$V_{SD} = 1.9 - V_x$

$V_{ov} = 0.9 - 0.7 = 0.2V \rightarrow$ MOS is ON

For sat.

$V_{SD} > V_{ov}$

$1.9 - V_x > 0.2V$

$\boxed{V_x < 1.7V}$

$\Rightarrow V_x < 1.7 \Rightarrow$ Sat.

$1.9 > V_x > 1.7 \Rightarrow$ linear

$\boxed{V_x < 1.7\,V}$:-

$$I_D = k'(V_{SG} - V_T)^2$$

$$I_D = k'(0.2)^2$$

$$I_x = -I_D$$

$$\boxed{I_x = -k'(0.2)^2} \rightsquigarrow \text{constant}$$

$$g_m = k(V_{SG} - V_T)$$

$$\boxed{g_m = k(0.2)} \rightsquigarrow \text{const.}$$

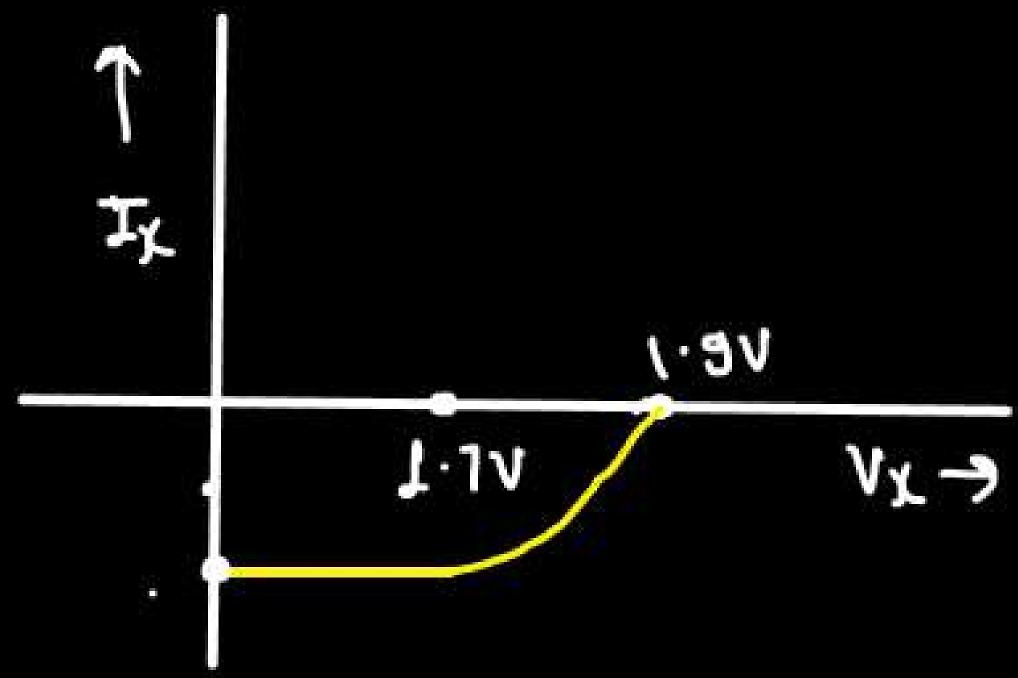
$\boxed{1.9\,V < V_x < 1.7\,V}$:-

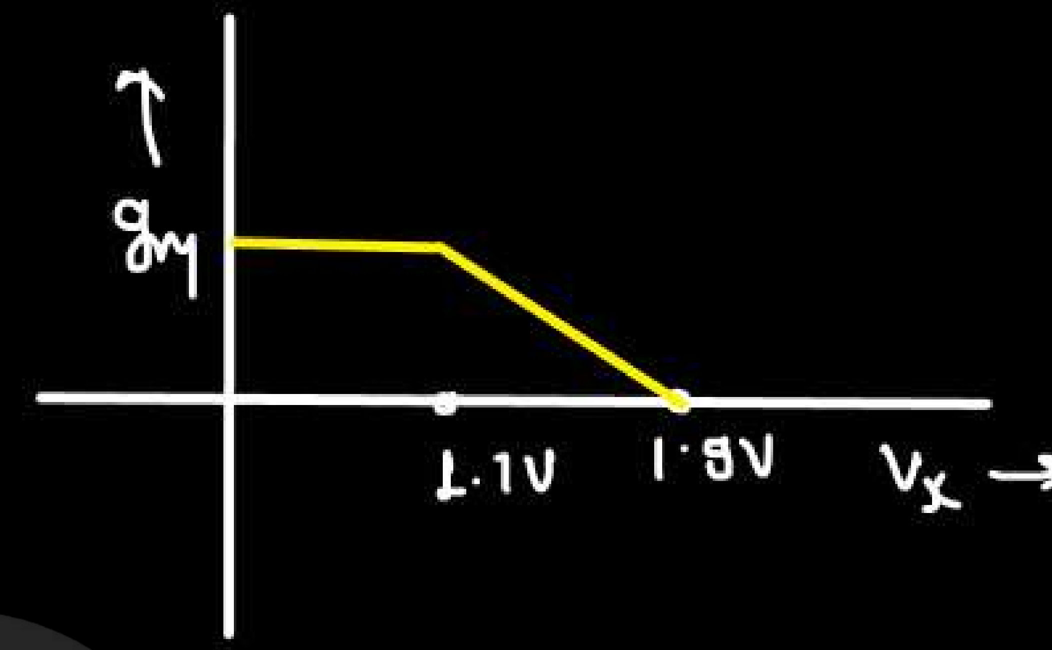
$$I_D = k''\left[(V_{SG} - V_T)V_{SD} - V_{SD}^2/2\right]$$

$$\boxed{I_x = -k''\left[0.2(1.9 - V_x) - \frac{(1.9 - V_x)^2}{2}\right]}$$

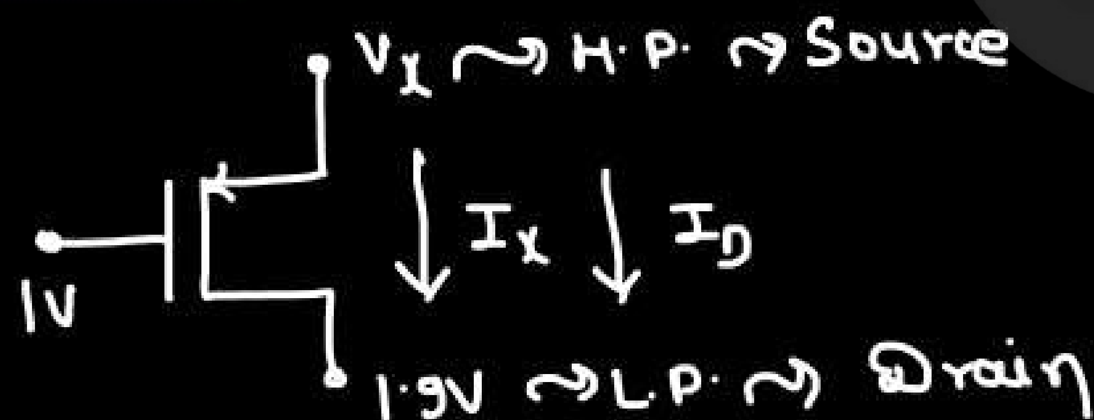
$$(g_m)_{linear} = k''' \times V_{SD}$$

$$\boxed{g_m = k''' \times (1.9 - V_x)}$$





For $\boxed{V_X > 1.9V}$



$V_{SD} = V_X - 1.9V$

$V_{SG} = V_X - 1$

$V_T = 0.7V$

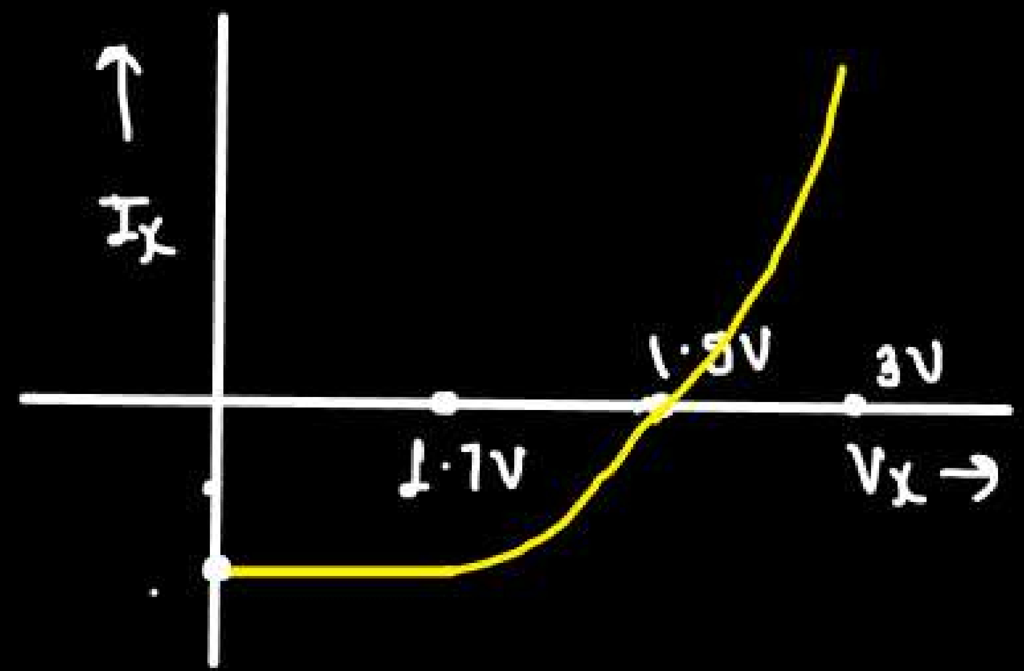
$V_{OV} = V_X - 1.7V$

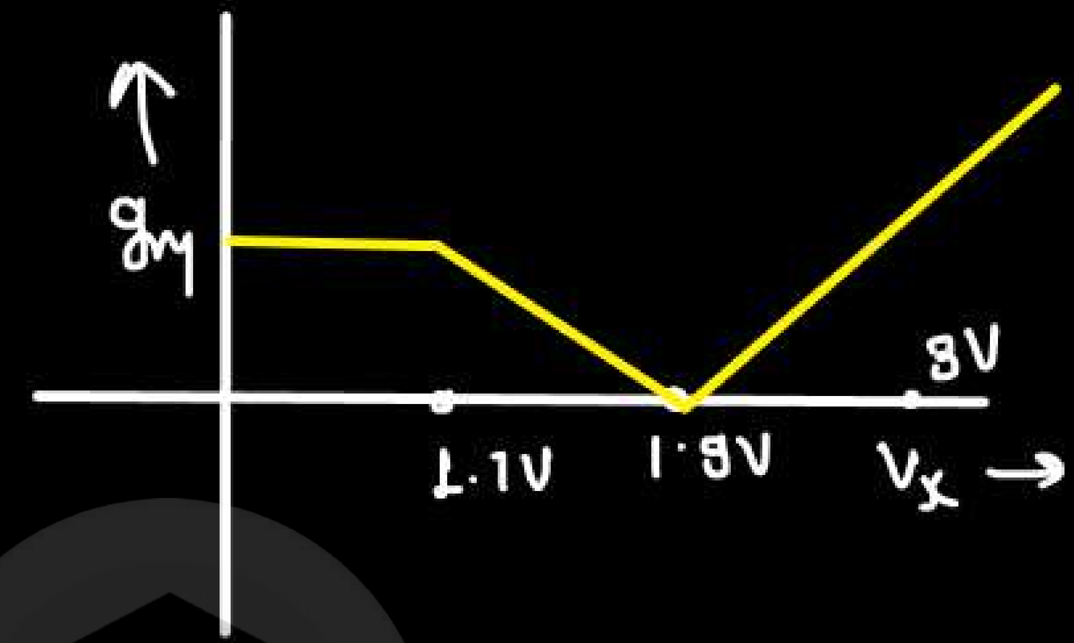
$\Rightarrow V_{SD} < V_{OV} \Rightarrow$ linear region

$$I_D = K\left[(V_{SG} - V_T)V_{SD} - \frac{V_{SD}^2}{2}\right]$$

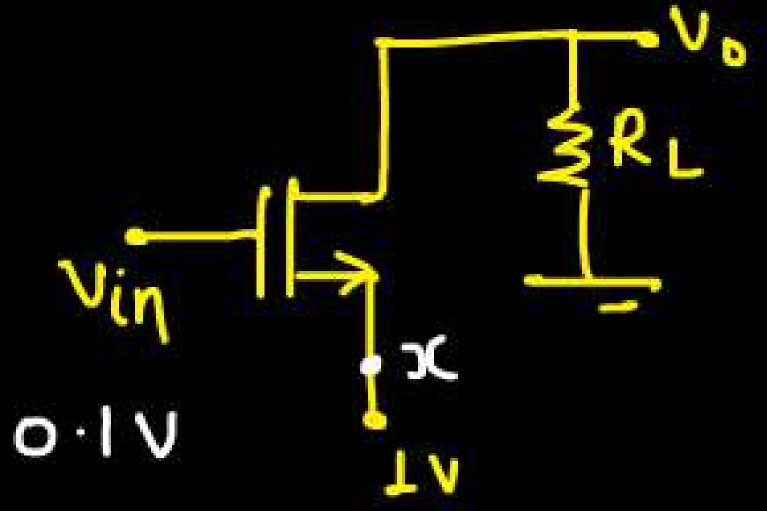
$$\boxed{I_D = I_x = K\left[(V_x - 1.7)(V_x - 1.9) - \frac{(V_x - 1.9)^2}{2}\right]}$$

$$\boxed{g_m = K'[V_x - 1.9]}$$


I_x
1·1V
1·5V
3V
V_x →


g_m
1·1V
1·9V
3V
V_x →

Q.



$V_{in} \equiv 0 \rightarrow 3V$

$V_T = 0.7V$

Plot V_0 v/s V_{in}.

Given $R_L \rightarrow$ very low

Find max value of V_0.

$\rightarrow$

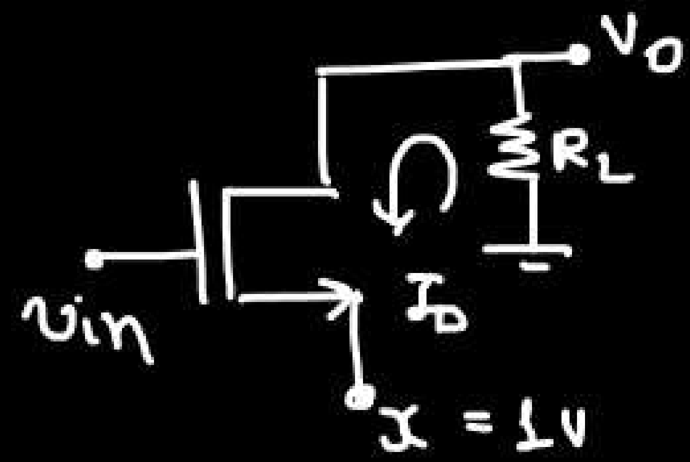
$\boxed{\text{For } v_i < 1.7V \Rightarrow \text{MOS off}}$ XX

initially, MOS current = 0 Ap $\Rightarrow$ $V_0 = 0V$

$\Rightarrow V_0 \rightarrow$ Source

$V_x \rightarrow$ Drain

Let's assume, potential x is source $\Rightarrow V_0 = -ve$



$\Downarrow$

But $V_S = V_x = 1V$

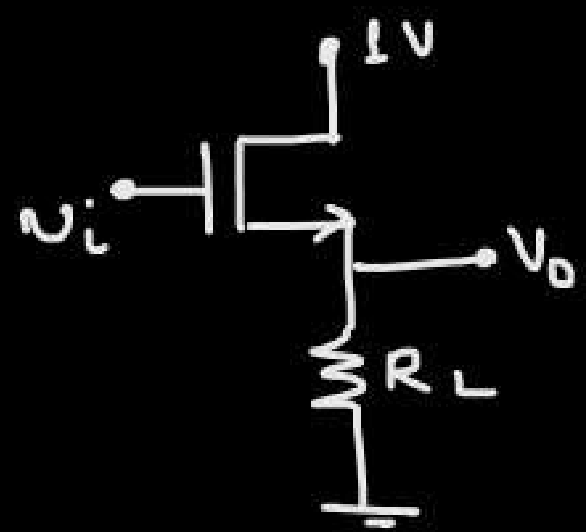
and $V_0 = V_D = -ve$

$\Downarrow$

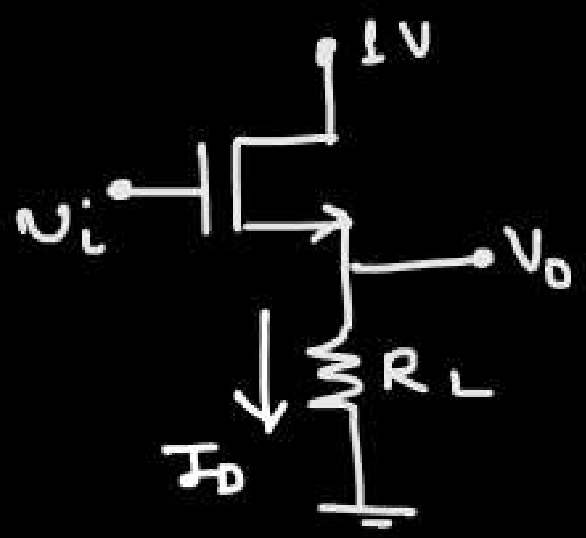
NOT POSSIBLE

$\Rightarrow$ x will always be drain

V_0 will always be source



$\rightsquigarrow$ Final ckt



$$\boxed{V_0 = I_D R_L}$$

initially, $v_0 = 0V$

$v_{in} < V_T \Rightarrow \boxed{V_{in} < 0.7V \Rightarrow \text{MOS off} \quad [V_{GS} < V_T]}$

when $v_{in} = 0.7^{+}V$

$\Rightarrow$ MOS is ON

when MOS just turns ON $\Rightarrow$ I_D is very small

$V_0 = I_D R_L$ = very small

$V_{DS} = 1 - V_0$

$V_{GS} = v_i - v_0$

$V_{ov} = v_i - 0.7 - v_0$

$\Rightarrow$ for sat.

$1 - V_0 > v_i - 0.7 - v_0$

$\boxed{v_i < 1.7V} \Rightarrow$ sat.

$\boxed{v_i > 1.7V} \Rightarrow$ linear

for $0 < v_i < 1.7V$

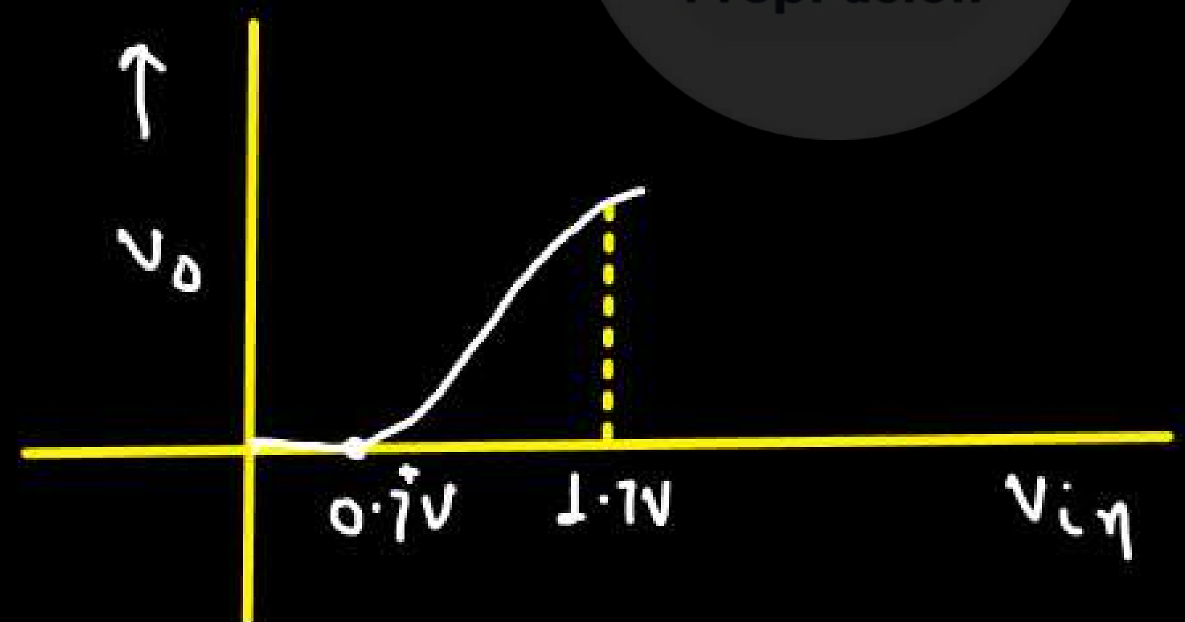
$$I_D = K[v_i - 0.7 - V_0]^2$$

$$V_0 = I_D R_L$$

$$\boxed{V_0 = K[V_i - 0.7 - V_0]^2 R_L}$$

if we increase $v_i \Rightarrow I \uparrow \Rightarrow V_0 \uparrow$

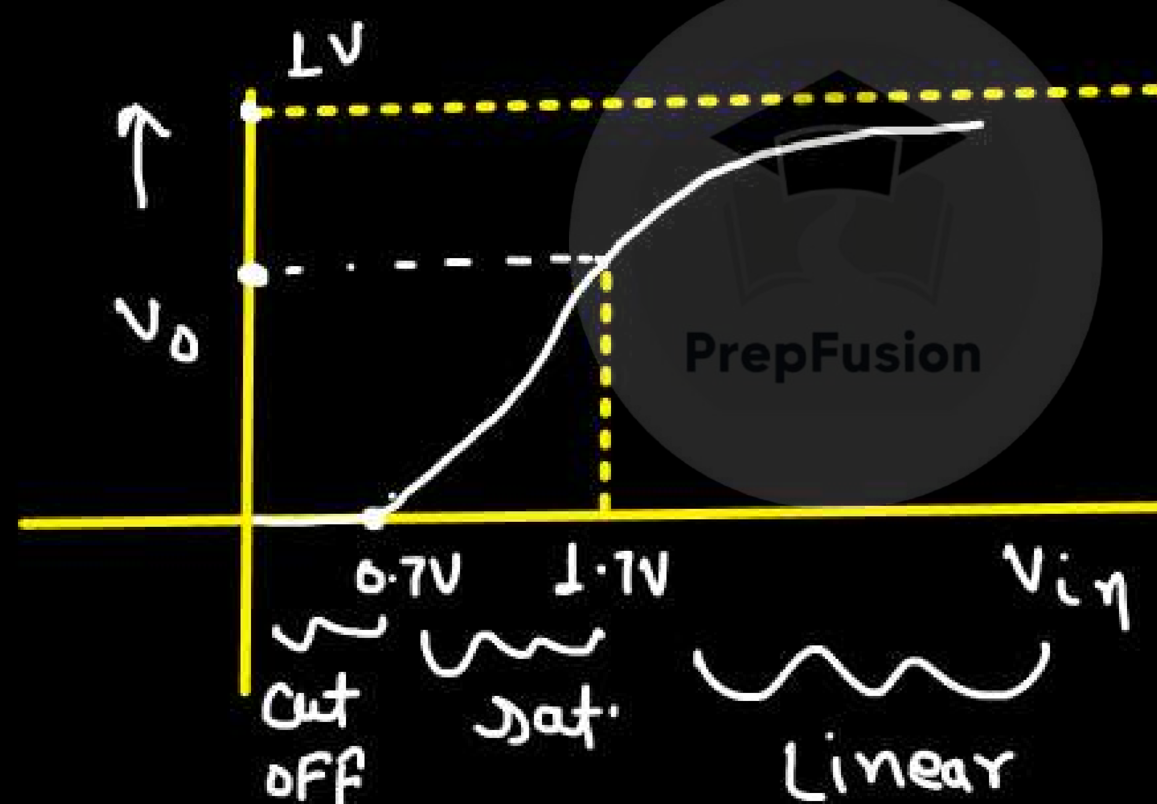
But V_0 will not increase as much as V_i.

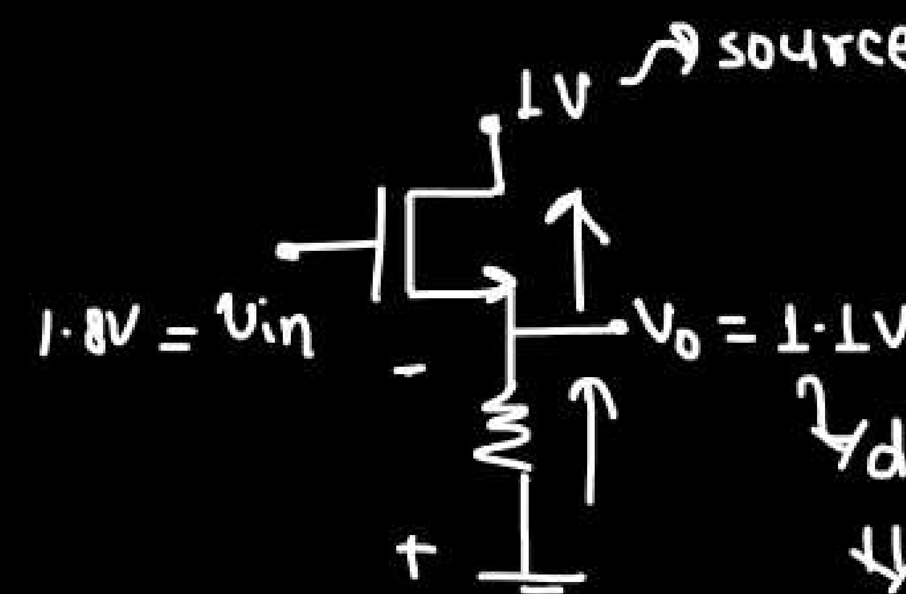


For $V_i > 1.7V \Rightarrow$ diode Triode

$$I_D = K\left[(V_i - 0.7 - V_0)(1 - V_0) - \frac{(1-V_0)^2}{2}\right]$$

$$V_0 = I_D R_L$$





drain

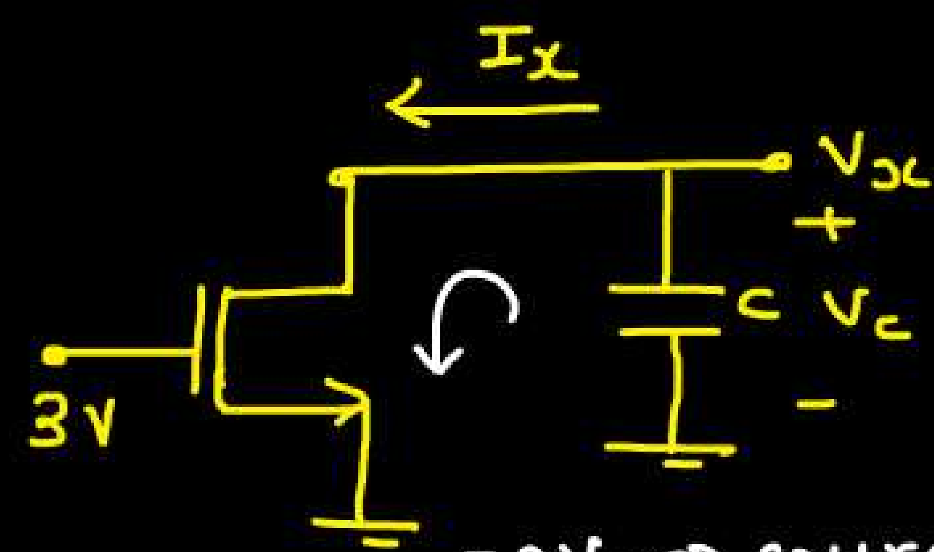
⇓

negative potential

⇓

NOT possible

Q.



$V_x = 3V \rightsquigarrow$ Drain

$= 0V \rightsquigarrow$ source

$V_c(0^-) = 3V$

$V_T = 1V$

V_x v/s $t = ?$

I_x v/s $t = ?$

$\rightarrow$ $V_{GS} = 3V$, $V_{DS} = V_x = V_c$

$V_T = 1V$

$V_{ov} = 2V$

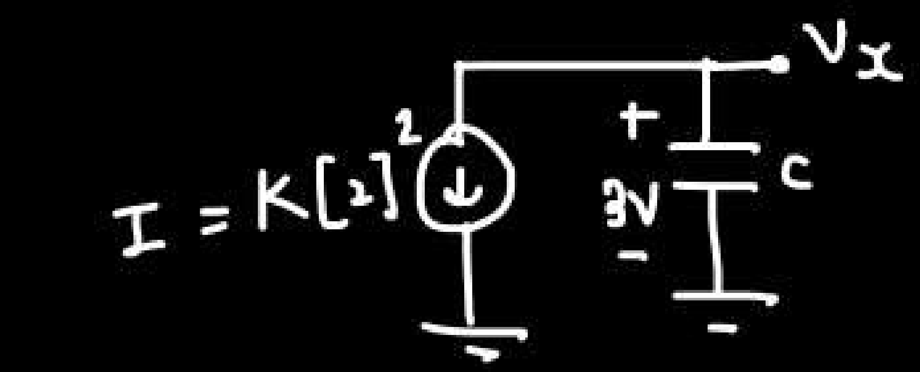
@ $t = 0^+$

$V_{DS} = 3$

@ $t = 0^+$, $V_{DS} > V_{ov} \Rightarrow$ sat. region

$I_x = K[2]^2$

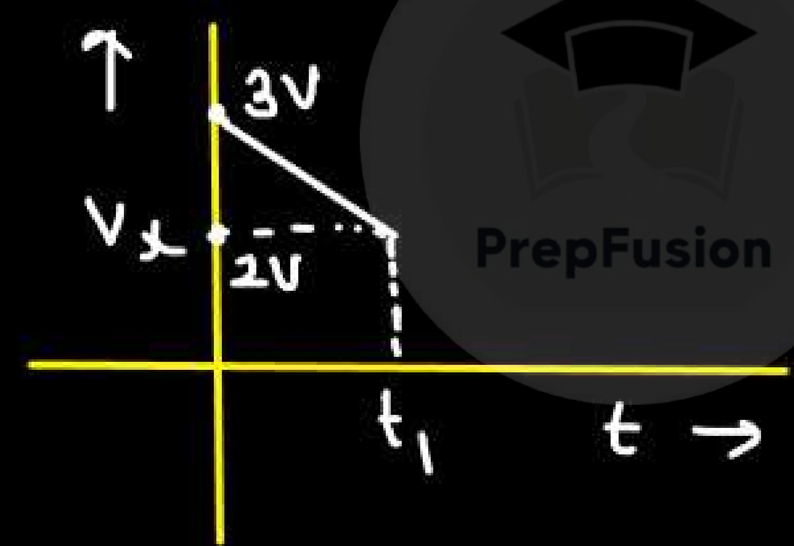
@ $t=0^+$

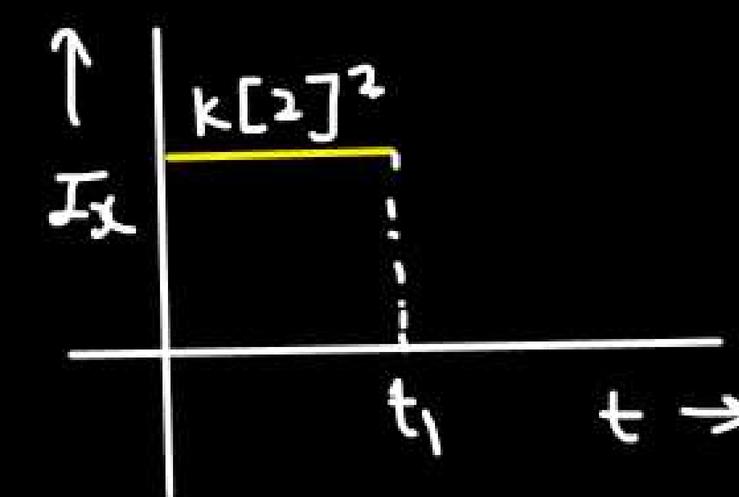


$\Rightarrow$ cap. will start discharging linearly.

$$V_x = V_c(t) = 3 - \frac{1}{C}\int I \cdot dt$$

$$= 3 - \frac{I}{C}t$$

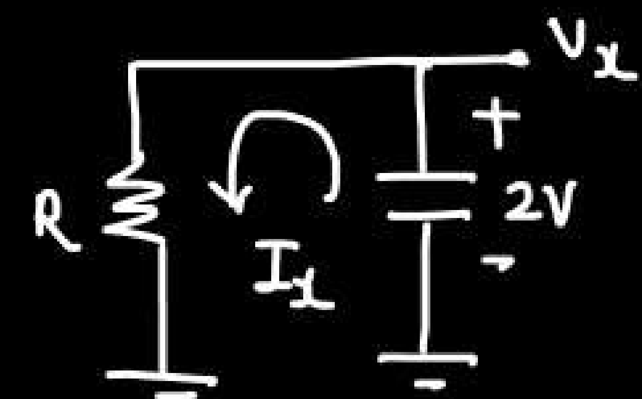


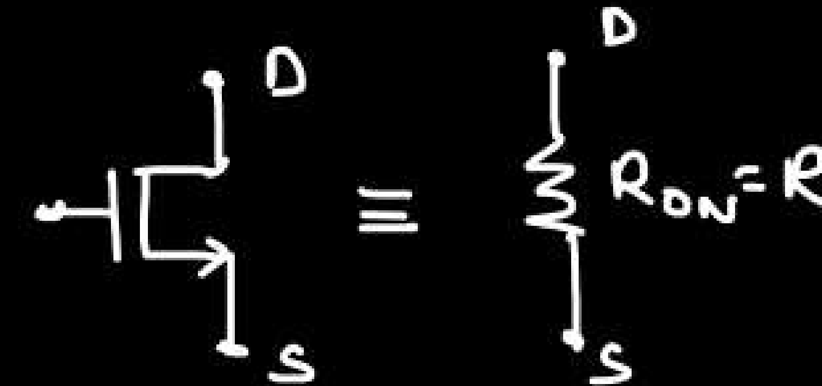


when V_{DS} or $V_x < 2$

$\Rightarrow V_{DS} < V_{ov} \Rightarrow$ MOS will go into Triode $\Rightarrow$ MOS acts as resistance

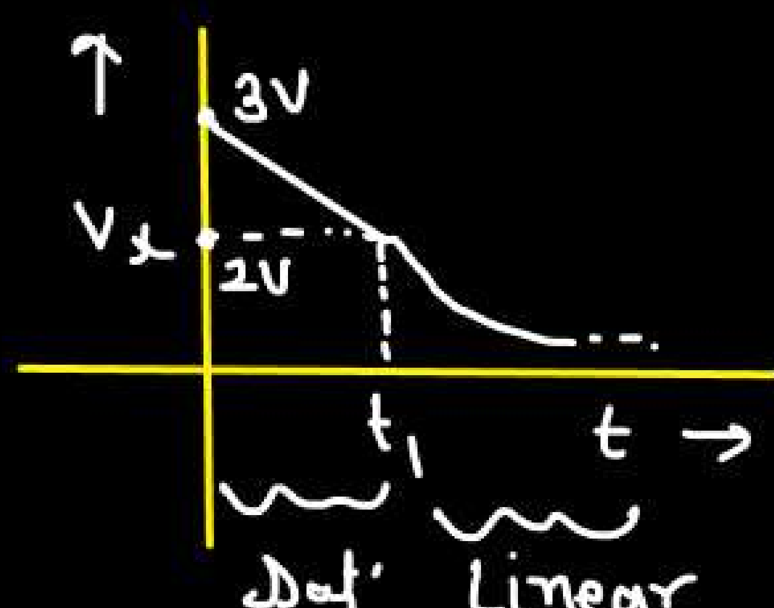
For $t > t_1 \Rightarrow$ MOS goes into linear region.

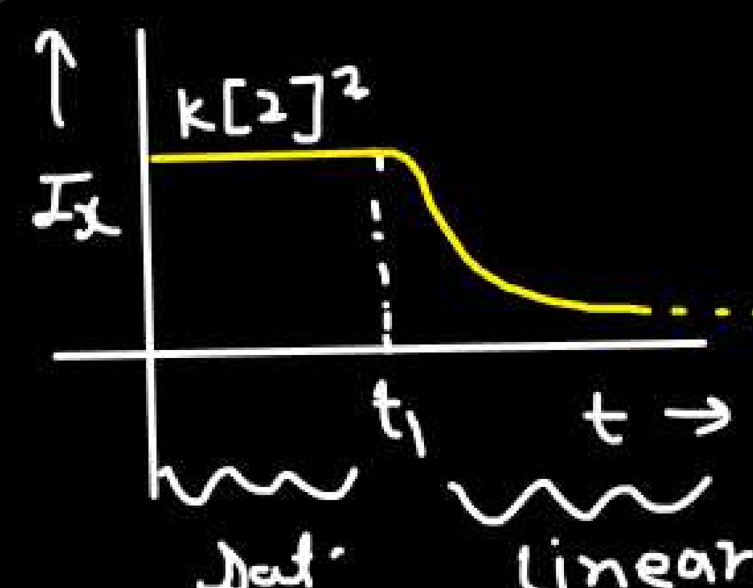




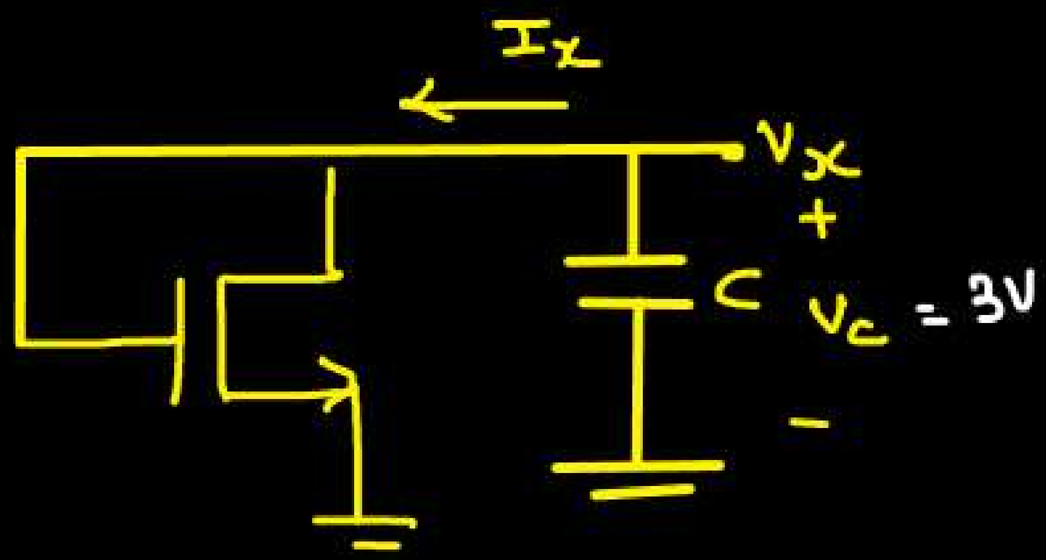
$$I_x = k\left[2 \cdot V_x - \frac{V_x^2}{2}\right]$$

$\Rightarrow$ Both V_x and I_x will go down to zero





Q. ✩✩



$V_T = 1V$

$V_c(0^-) = 3V$

V_x v/s $t = ?$

I_x v/s $t = ?$

Find min. value of V_x

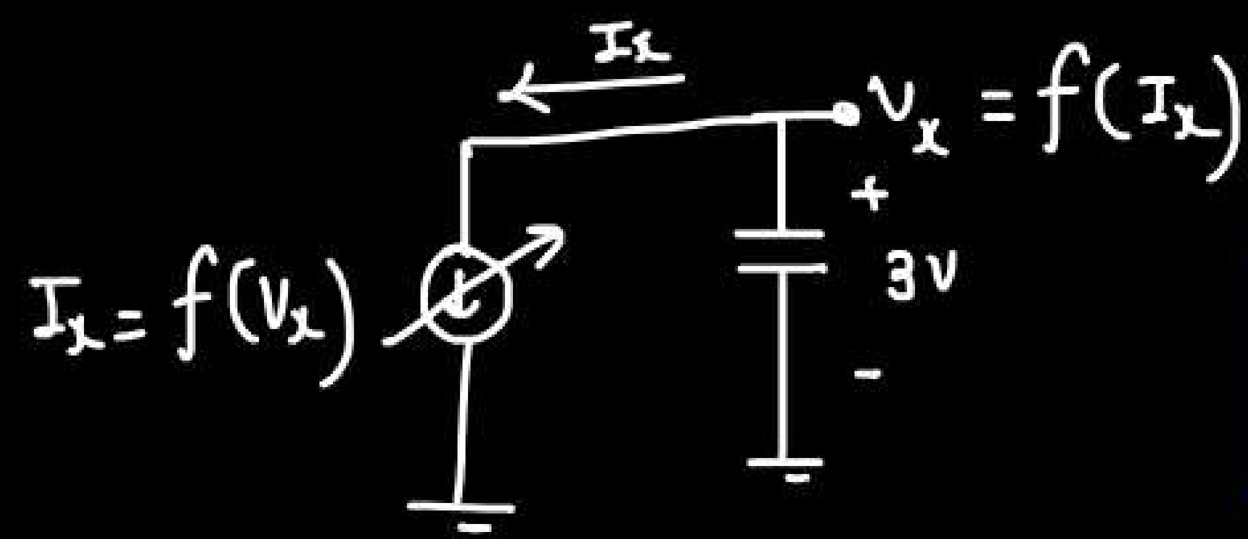
→ D and G are shorted ⇒ MOS always be in sat.

$V_{GS} = V_x$

$V_{DS} = V_x$ ⇒ sat.

$V_{ov} = V_x - 1$

$$\boxed{I_x = K[V_x - 1]^2}$$



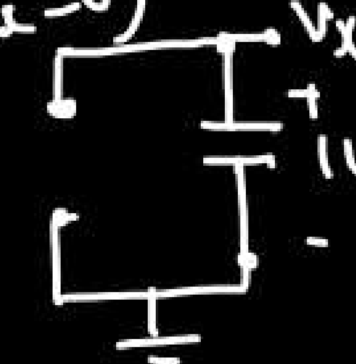
$$\boxed{V_x = 3 - \frac{1}{C}\int I_x(t)\cdot dt}$$

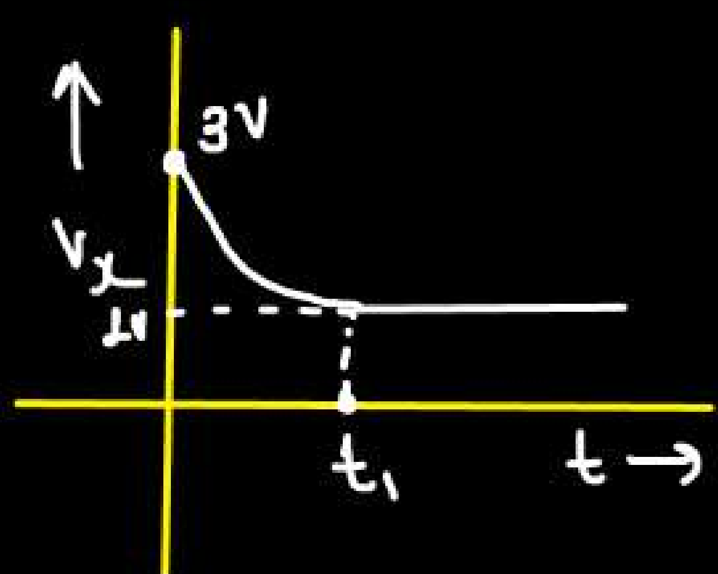
Here, V_x is going down. when $V_{GS} < V_T \Rightarrow$ MOS will be off

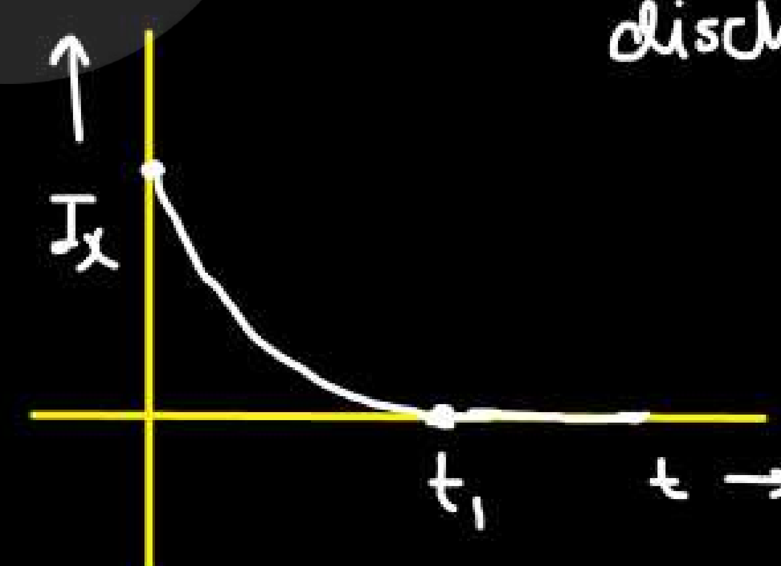
$\boxed{V_x < 1} \Rightarrow$ No current $(I_x = 0)$

$\Downarrow$

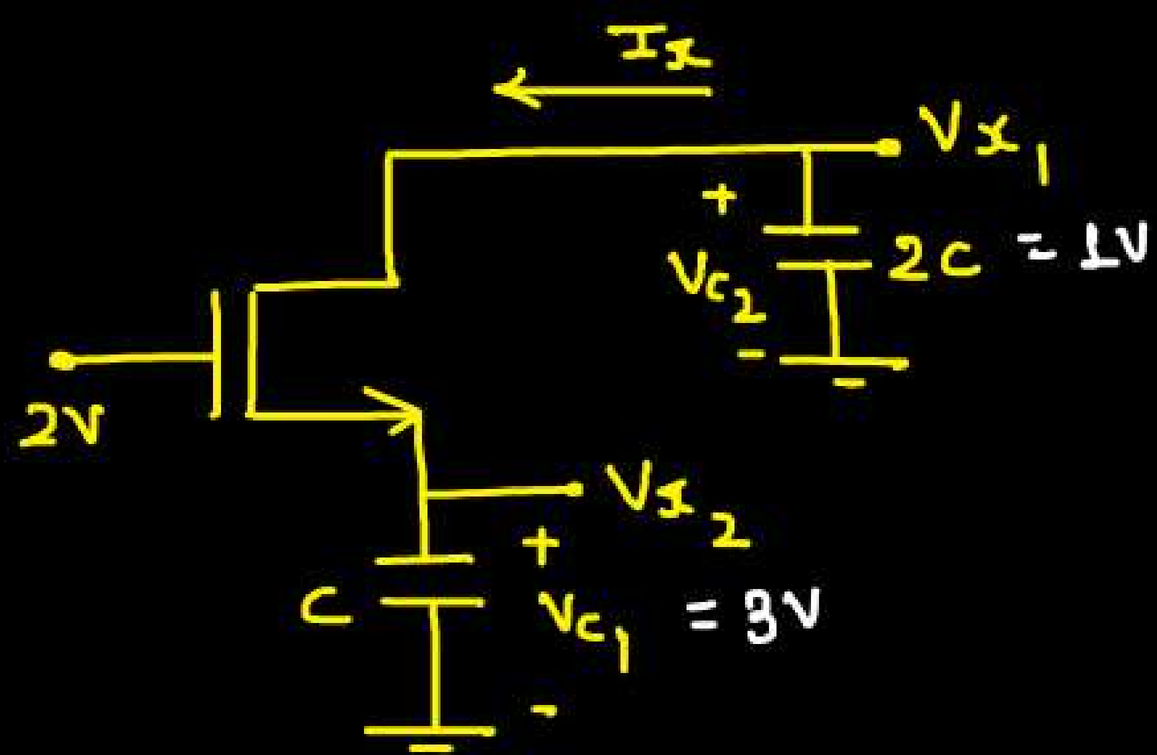
No further discharging







Q.



$V_{c_1}(0^-) = 3V$

$V_{c_2}(0^-) = 1V$

$V_T = 0.7V$

V_{x_1} v/s $t = ?$

V_{x_2} v/s $t = ?$

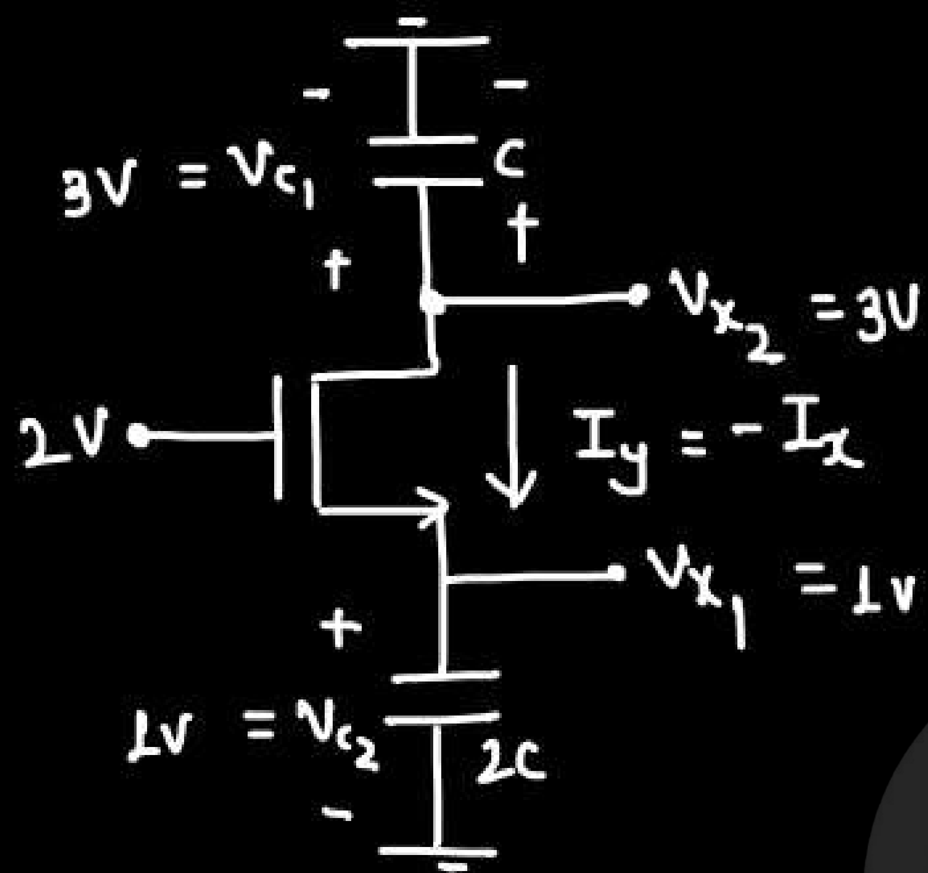
I_x v/s $t = ?$

@ $t = 0^+$

$V_{x_2} = 3V$, $V_{x_1} = 1V$

↓ H.P. ↓ Drain

↓ L.P. ↓ source



C → discharged

2C → charged

$V_{GS} = 1V$

$V_T = 0.7V$

$\Rightarrow V_{OV} = 0.3$

$V_{DS} = 2V$

$\Rightarrow V_{DS} > V_{OV} \Rightarrow$ sat.

$I_y = f(V_{x_1})$

⇒ Cap. 2C can charge upto 1.3V only.

Because, if 2C charges above 1.3V ⇒ MOS will be off

$V_{x_1}(s.s.) = 1.3V$

when V_{x_1} was increasing from 1V to 1.3V

$\Downarrow$

There was I_y current flowing out of cap. C

Both cap. C and 2C are having same current

$$I_C = I_{2C}$$

$$\frac{\Delta Q_C}{\Delta t} = \frac{\Delta Q_{2C}}{\Delta t}$$

$$\Delta Q_C = \Delta Q_{2C}$$

$$C(\Delta V_C) = 2C(1.3-1)$$

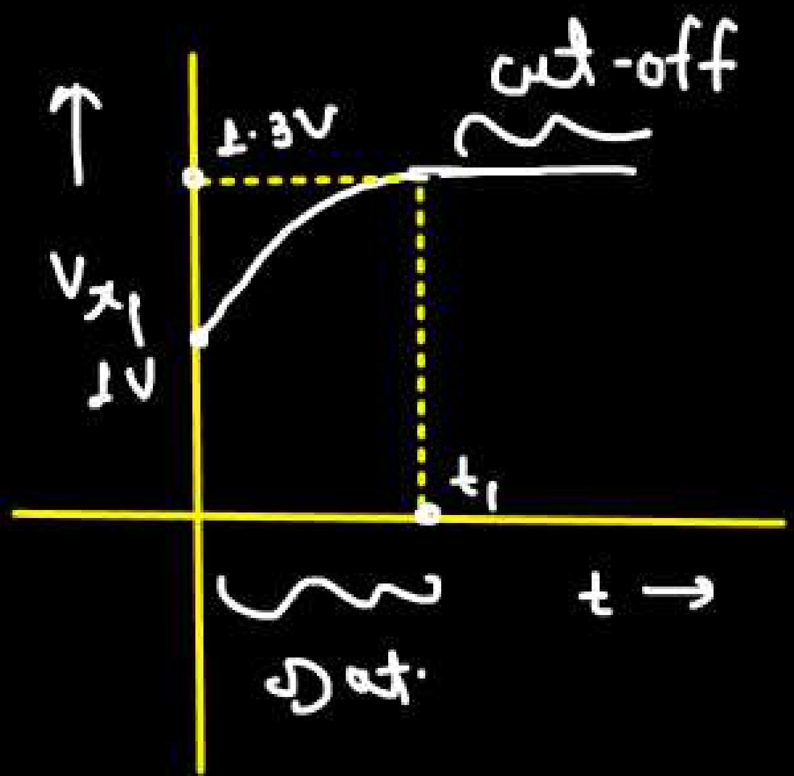
$$\boxed{\Delta V_C = 0.6\,V}$$

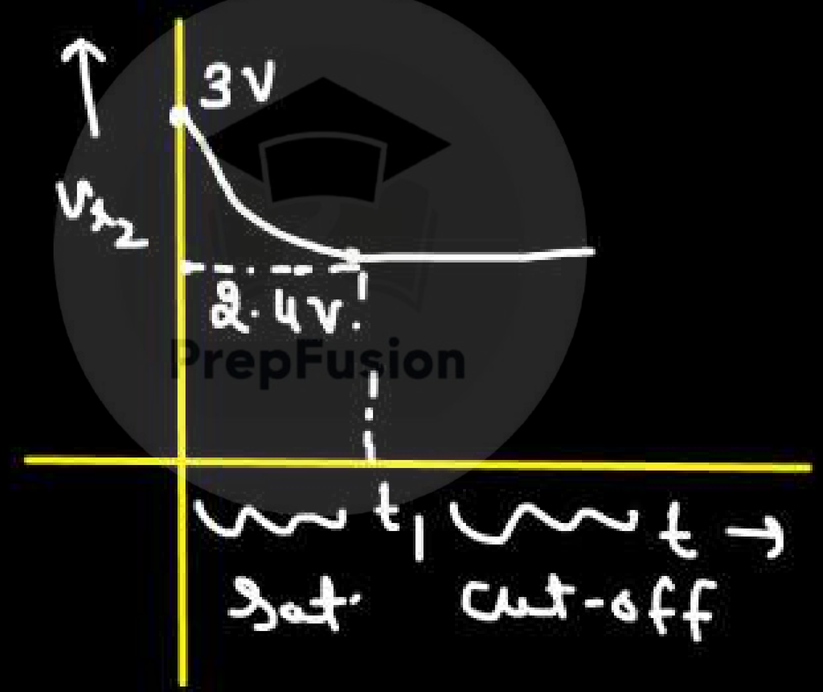
$\Rightarrow$ change in capacitor C voltage would be 0.6 V

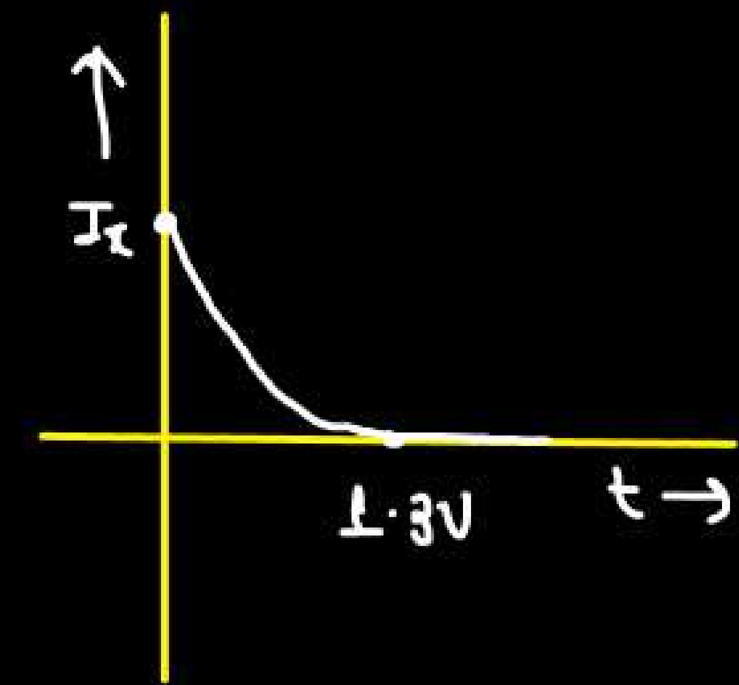
Cap. C will discharge from 3V to 2.4V

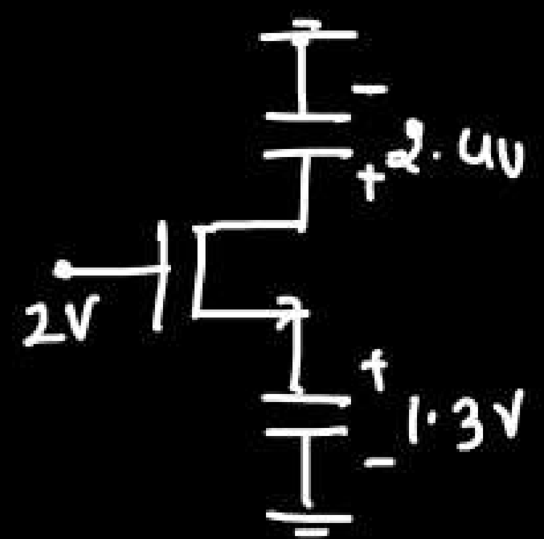
V_{x_2} will decay down from 3V to 2.4V

$$\boxed{V_{C_1}(s.s.) = 2.4V}$$







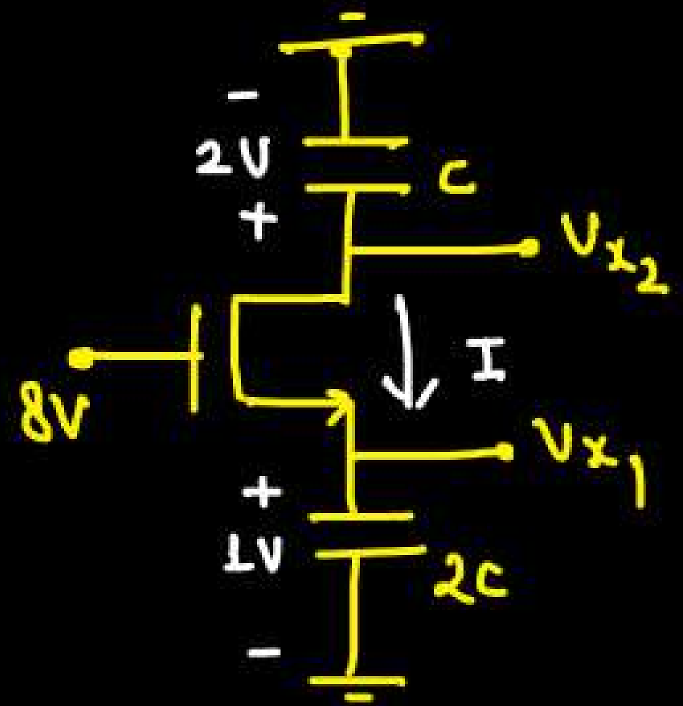


$V_{DS} = 1.1V$
$V_{GS} = 0.7V$
$V_{ov} = 0$

$\boxed{V_{DS} > 0V}$

$\Rightarrow$ Sat.

Q.



$V_{x_2}(t=0^-) = 2V$

$V_{x_1}(t=0^-) = 1V$

$V_T = 1V$

Find s.s. V_{x_1} and V_{x_2} = ?

$\boxed{V_{x_1}(s.s) = 7V}$ $\{1 \rightarrow 7\}$

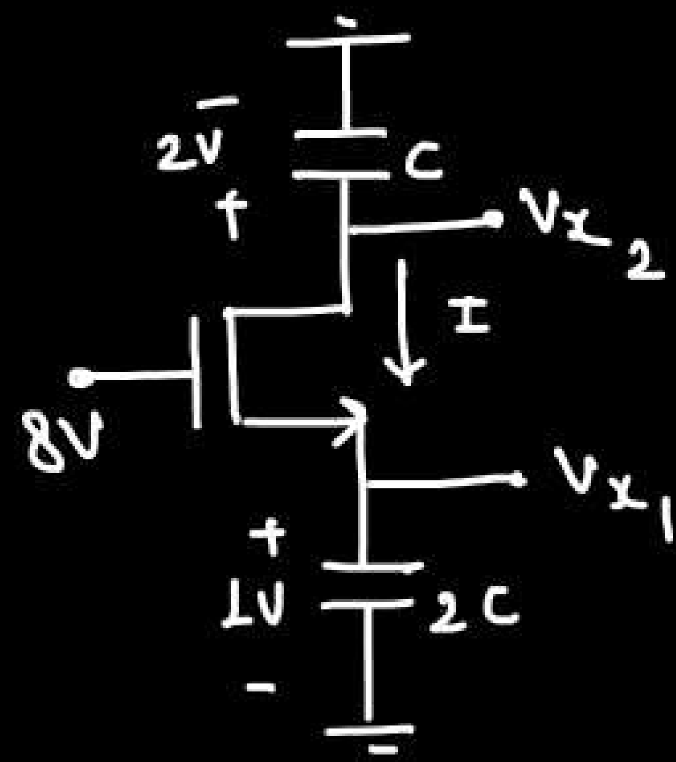
$2c(6V) = c(\Delta V_c)$

$\boxed{\Delta V_c = 12V}$

c is discharging

$\boxed{V_{x_2}(s.s) = 2 - 12 = -10V}$

$\Rightarrow V_{DS} = -10 - 7 = -17V$ X



$C \rightarrow$ discharging

$2C \rightarrow$ charging

$$I_{2C} = I_C$$

$$\Delta Q_{2C} = \Delta Q_C$$

$$2C(\Delta V_{2C}) = C(\Delta V_C)$$

$$\boxed{\Delta V_C = 2\Delta V_{2C}}$$

Let $\Delta V_{2C} = x \Rightarrow 2C$ is gaining x voltage

$$\boxed{V_{x_1}(s.s) = 1 + x}$$

if x gains x voltage $\Rightarrow$ c loses $2x$ voltage

$$\boxed{V_{x_2}(s.s.) = 2 - 2x}$$

@ s.s. $\Rightarrow$ $V_{DS} = 0$ $\{I = 0\}$

$$V_{x_2} - V_{x_1} = 0$$

$$V_{x_2} = V_{x_1}$$

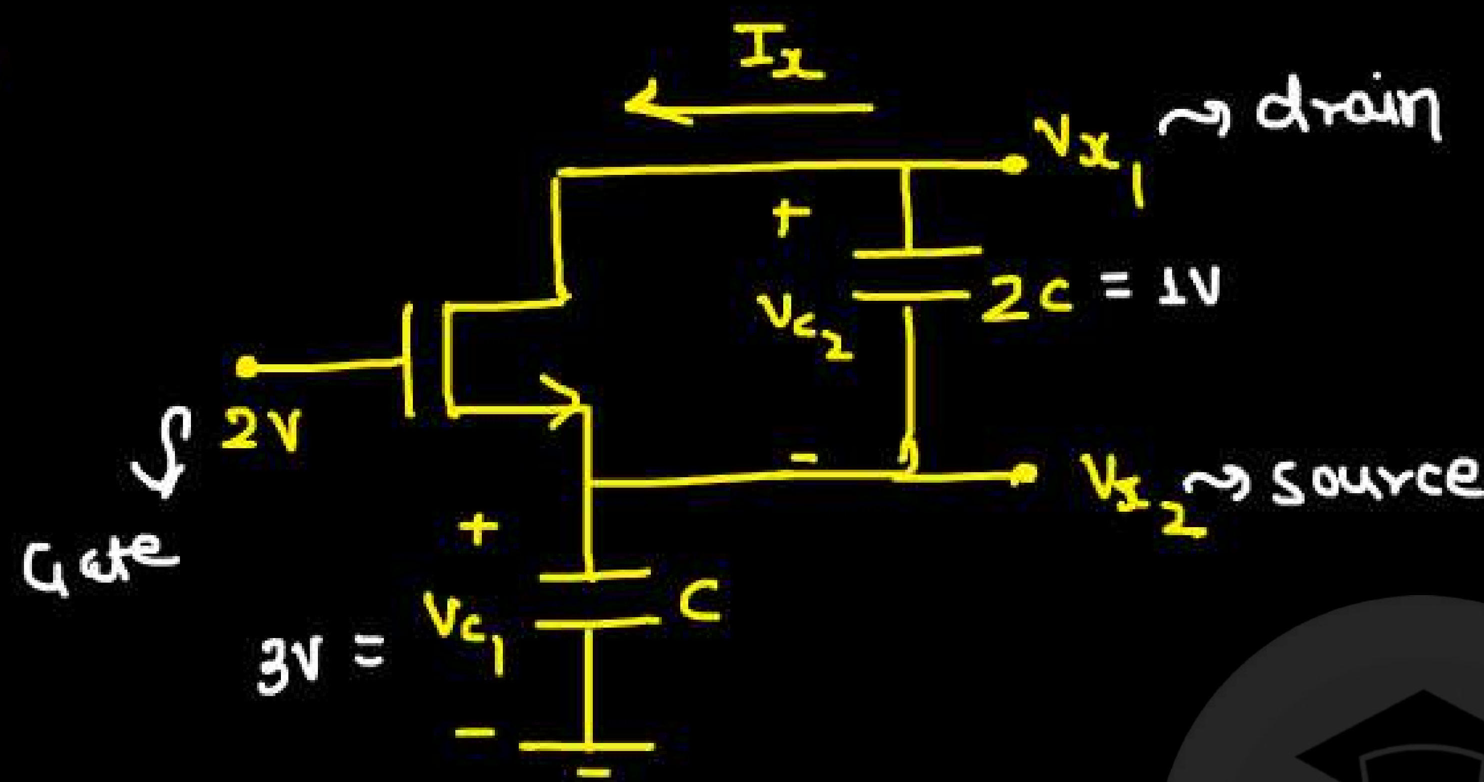
$$2 - 2x = 1 + x$$

$$\boxed{x = \tfrac{1}{3}V}$$

$$\boxed{V_{x_1}(s.s.) = 1.33V}$$

$$\boxed{V_{x_2}(s.s.) = 1.33V}$$

Q.



$V_{c_1}(0^-) = 3V$

$V_{c_2}(0^-) = 1V$

V_{x_1} v/s t = ?

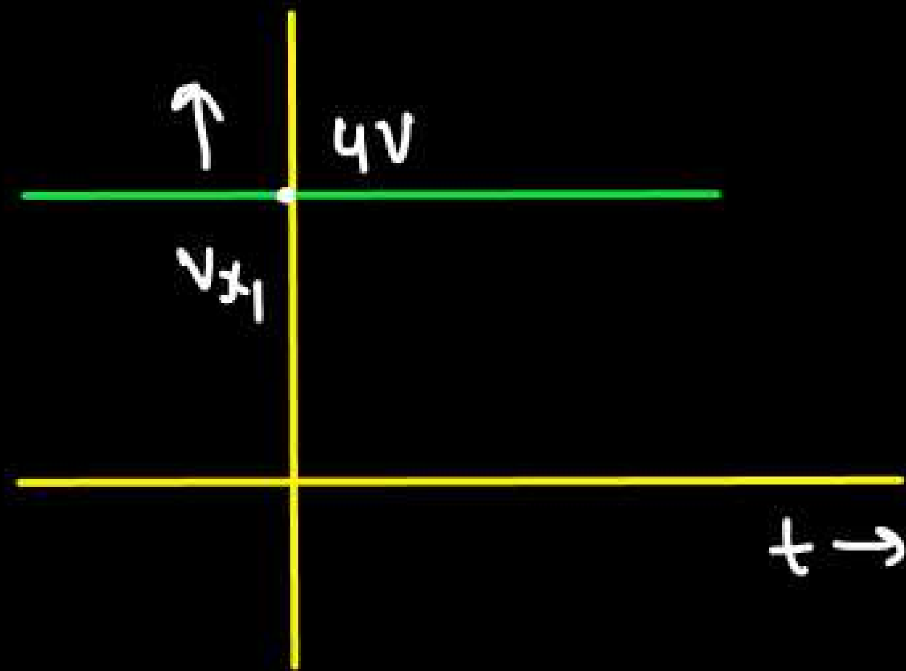
V_{x_2} v/s t = ?

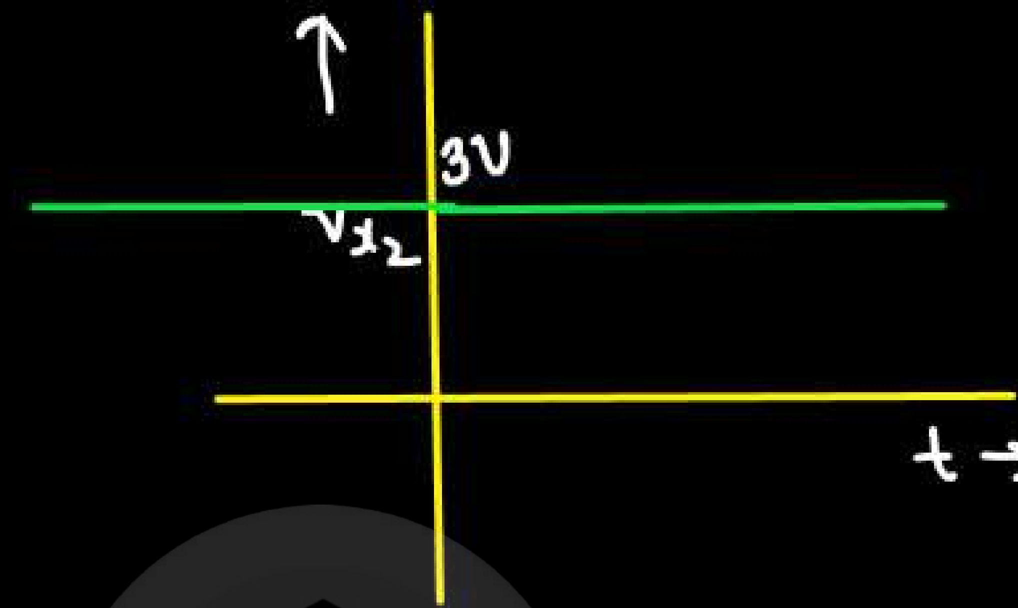
I_x v/s t = ?

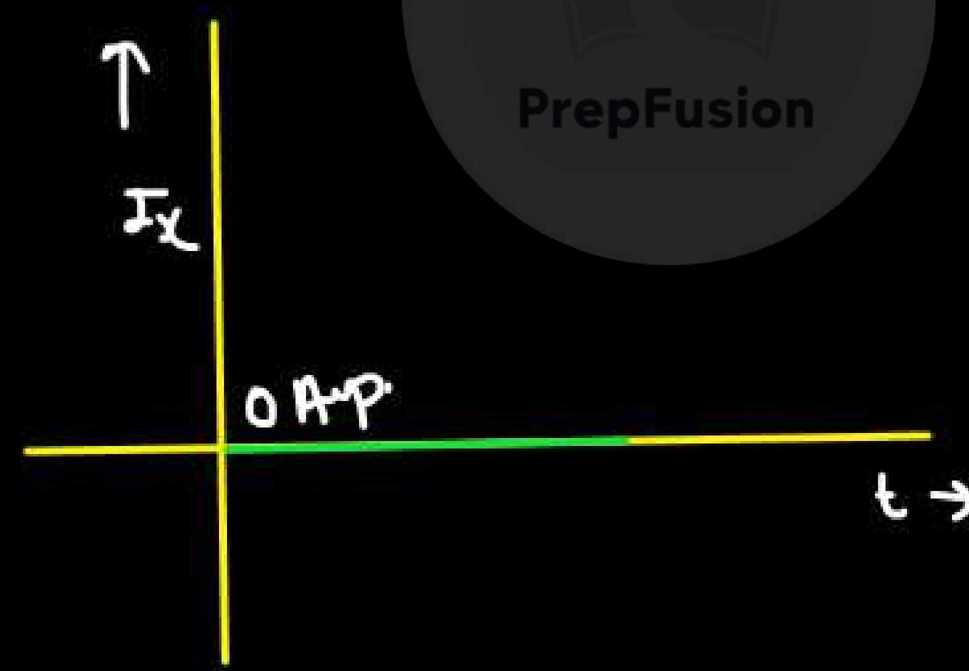
$V_{x_1}(t=0^+) = 4V$ ~ Drain

$V_{x_2}(t=0^+) = 3V$ ~ source

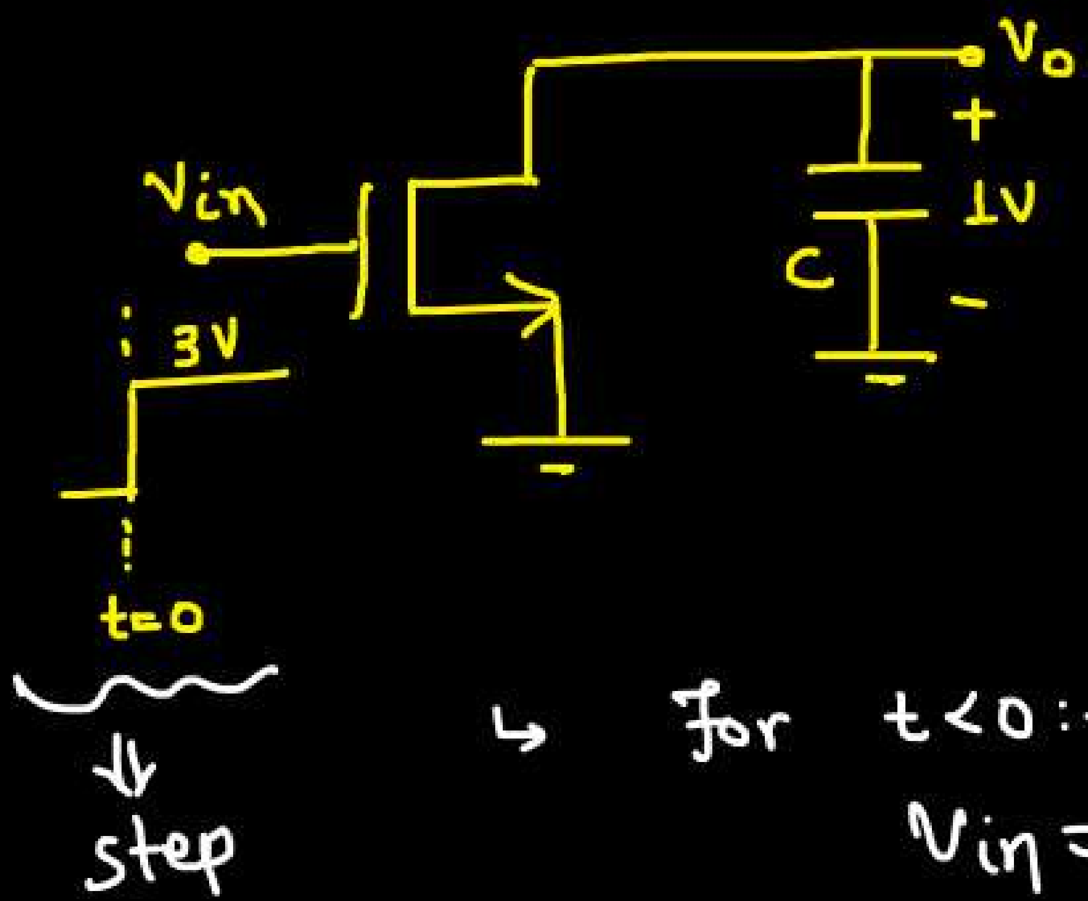
$V_{GS} = 2-3 = -1V < V_T \Rightarrow$ MOS doesn't even turn ON $\Rightarrow I_x = 0 \Rightarrow$ S.S.


4V
V_{x_1}
t →


3V
V_{x_2}
t →


I_x
0 A.P.
t →

Q.



V_o v/s t = ?

$V_T = 1V$

↳ for $t<0$:-

$V_{in} = 0V$

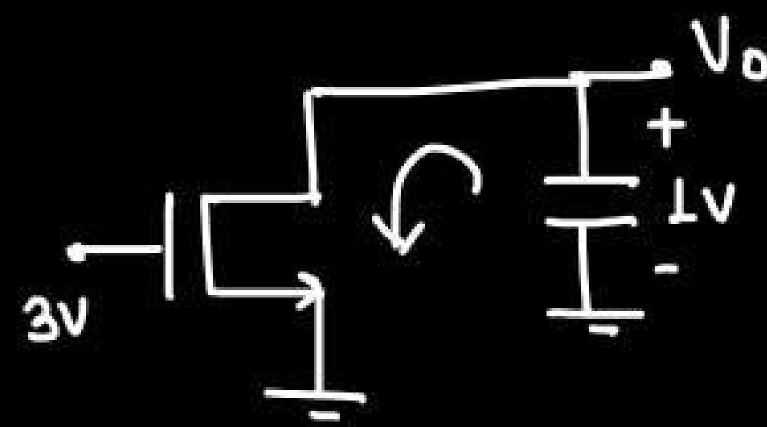
$V_{GS} = 0V$ ⇒ NO current

$V_o(t=0^-) = V_c(t=0^-) = 1V$

for $t>0$:-

@ $t=0^+$

$V_{in} = 3V$



@ $t=0^+$

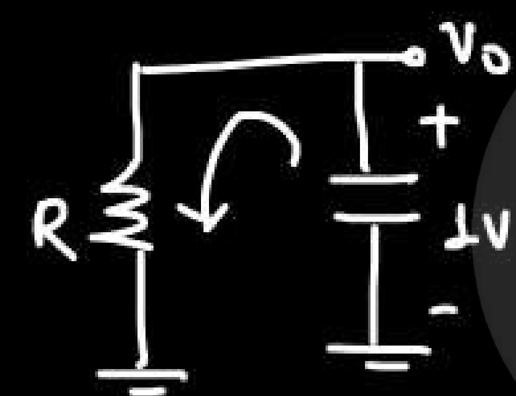
$V_{DS} = V_0 = 1V$

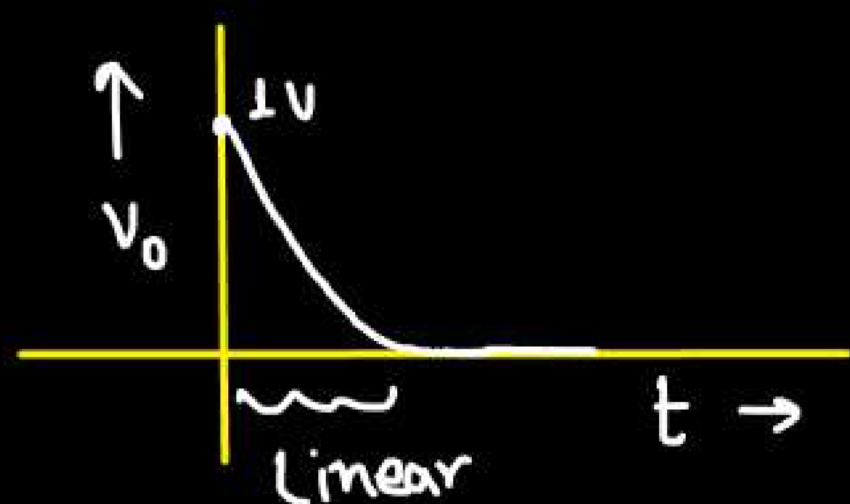
$V_{GS} = 3V$

$V_T = 1V$

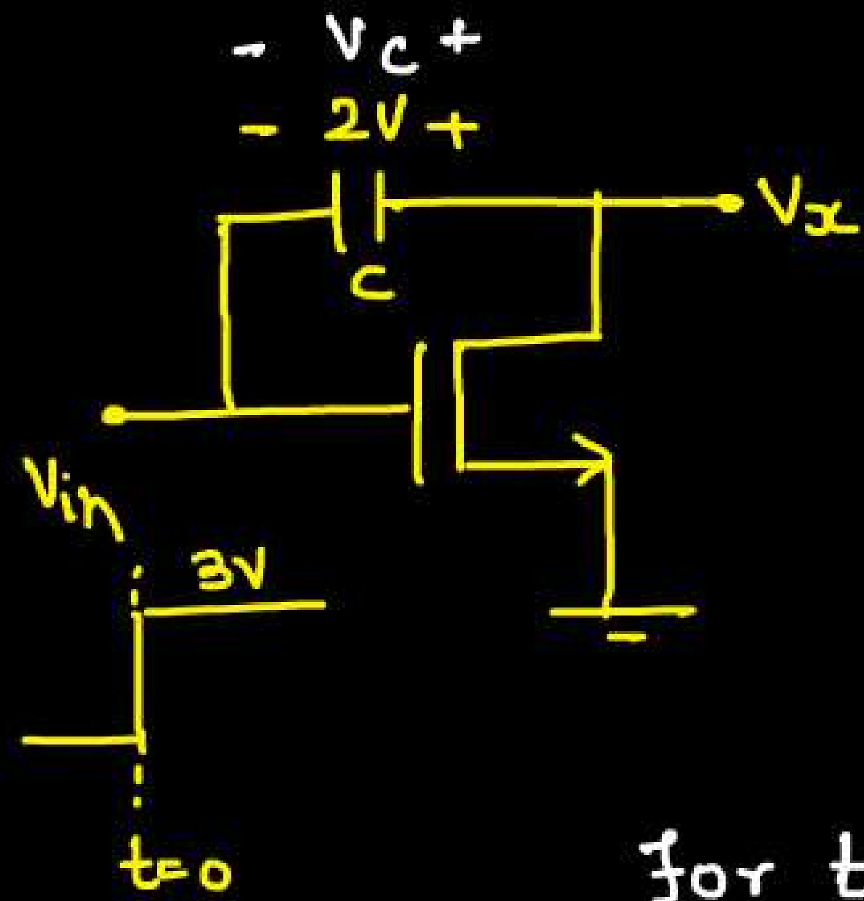
$V_{ov} = 2V$

$\Rightarrow$ linear region





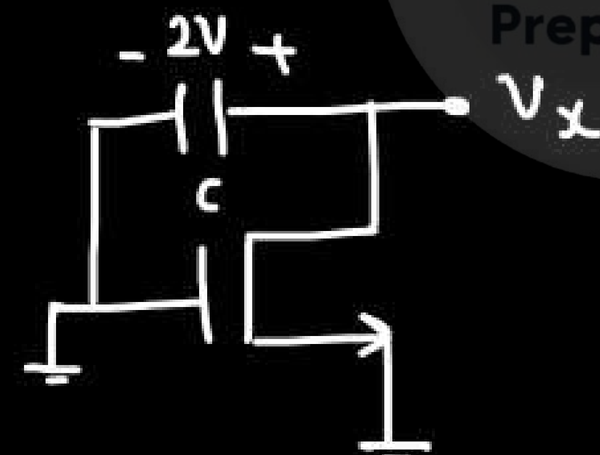
Q.



$V_T = 1V$

V_x v/s $t = ?$

for $t<0$:-



$V_{GS} = 0V$

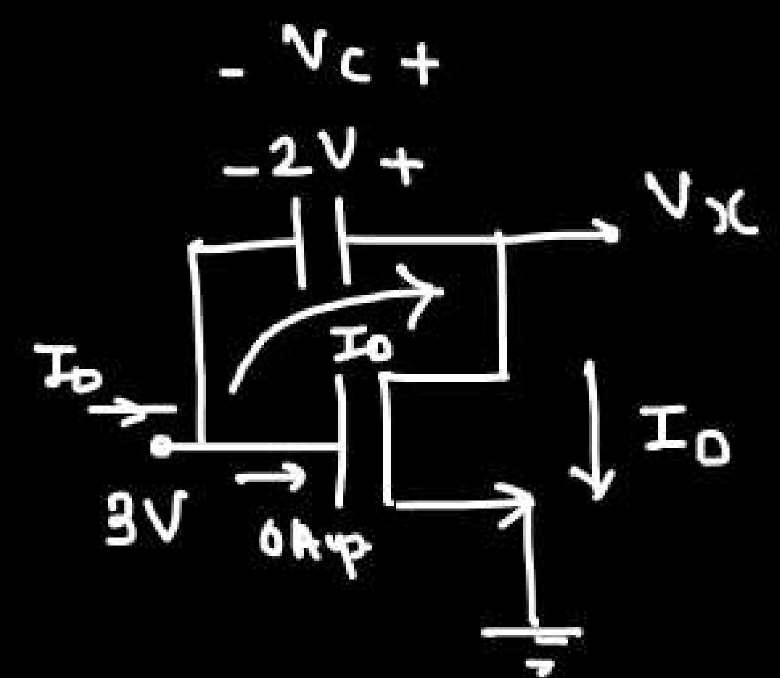
$\Rightarrow I_D = 0$

S.S.

$V_c(t=0^-) = 2V = V_c(t=0^+)$

$V_x(t=0^-) = 2V$

For $t>0$



$V_x(t=0^+) = 5V$

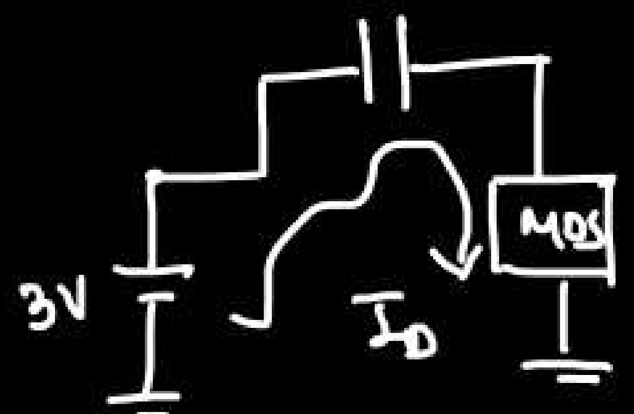
$V_{GS} = 3V$, $V_T = 1V \Rightarrow$ ON

$V_{DS} = 5V$

$V_{ov} = 2V$

$V_{DS} > V_{ov} \Rightarrow$ sat.

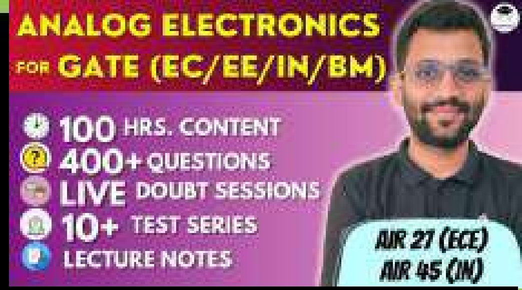
$(I_D)_s = K[2]^2$



cap. is getting charged in opposite direction.

V_c value will decrease.

$V_x = 3 + V_c \Rightarrow V_x$ goes down



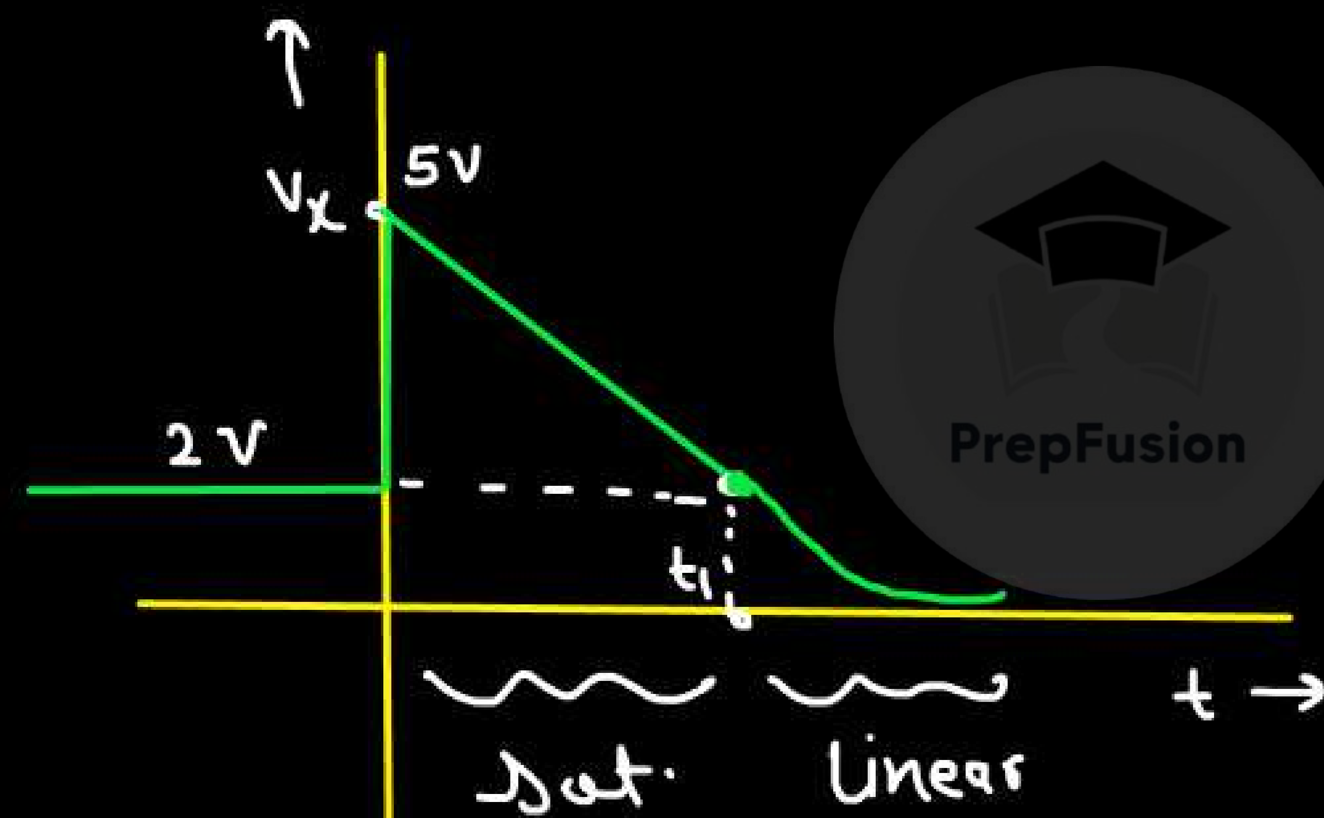
$$V_c = 2 - \frac{1}{C}\int I \cdot dt$$

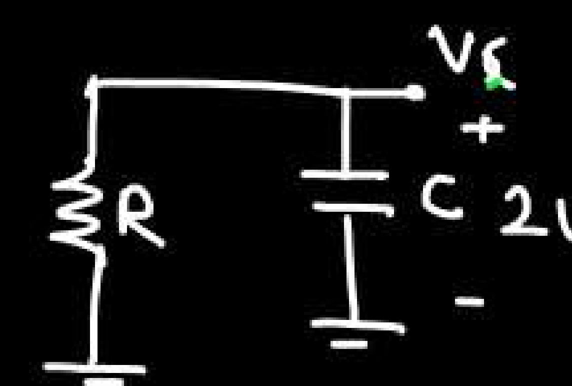
$$\boxed{V_c = 2 - \frac{I}{C}t}$$

$V_{DS} = V_x$

$V_{ov} = 2$

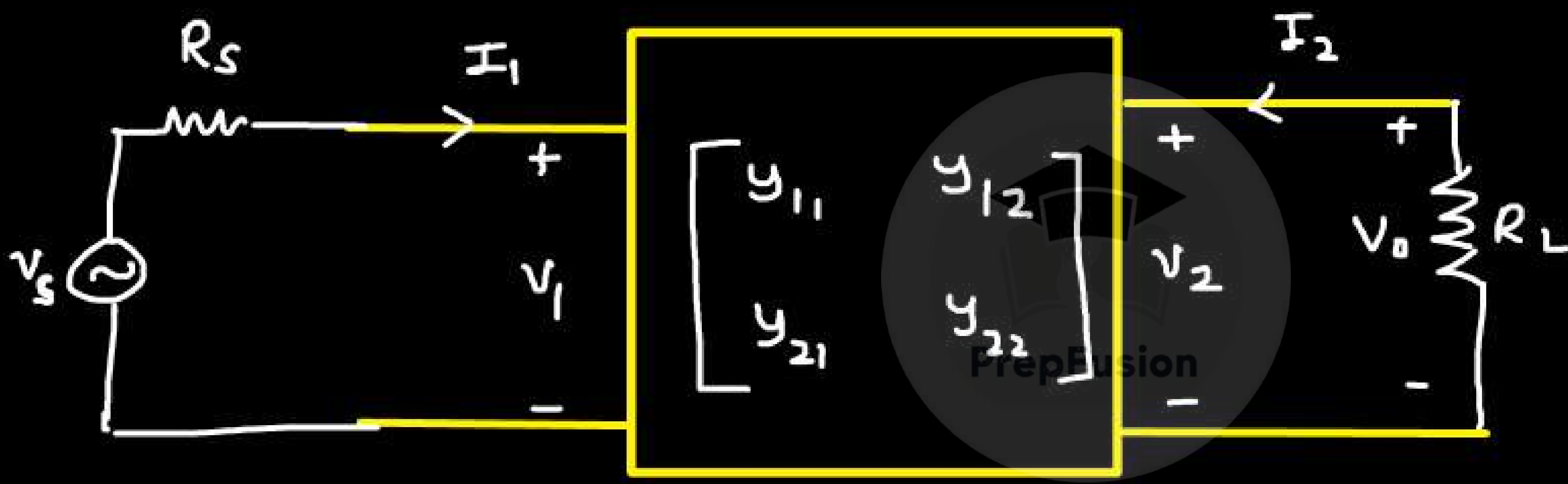
$V_x < 2V \Rightarrow$ linear region





$$\boxed{V_c(S.S.) = -3V}$$

Q. In a two port N/w, find the condⁿ on y-parameter for which the voltage gain is maximum.

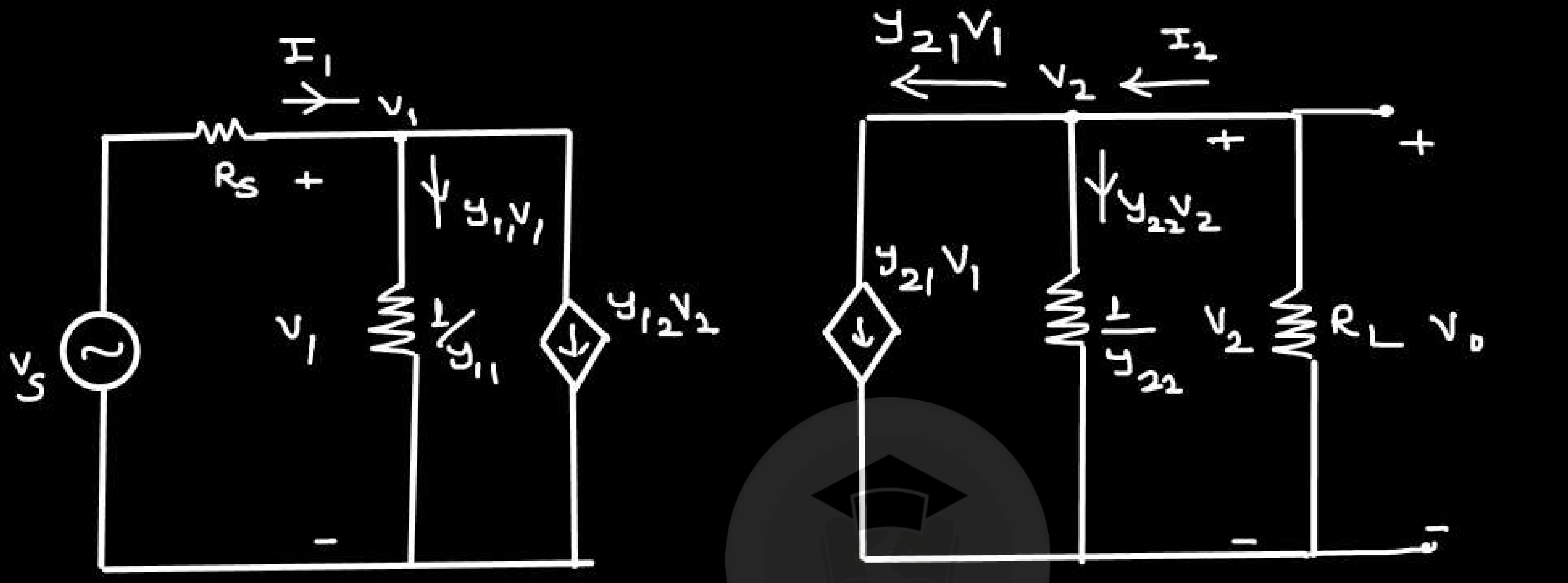


$\frac{V_0}{V_S} \rightarrow$ maximize

$\rightarrow$

$$I_1 = y_{11}V_1 + y_{12}V_2 \quad \text{— (1)}$$

$$I_2 = y_{21}V_1 + y_{22}V_2 \quad \text{— (2)}$$

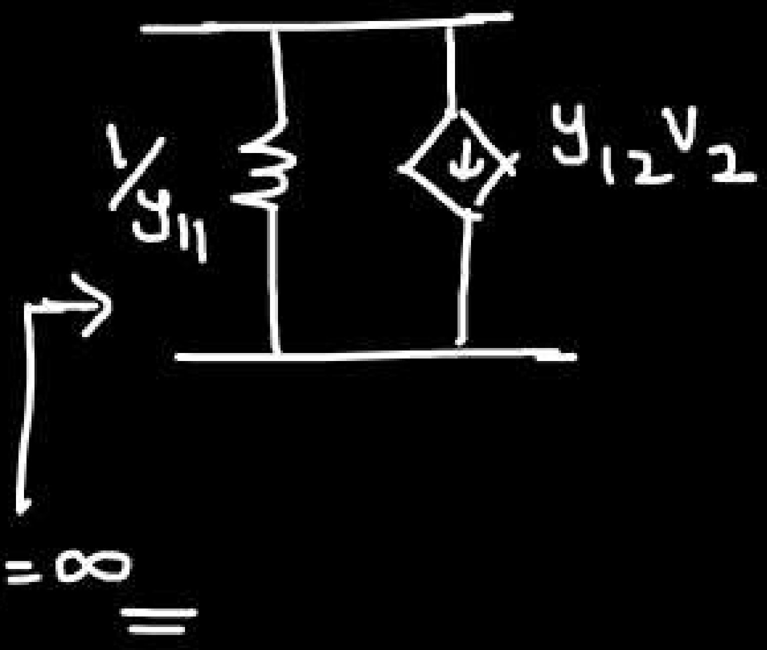


$\frac{V_0}{V_S} \rightarrow$ maximize

$$I_1 = y_{11}V_1 + y_{12}V_2 \quad \text{—} \; (1)$$

$$I_2 = y_{21}V_1 + y_{22}V_2 \quad \text{—} \; (2)$$

1. maximize V_1



if $R = \infty$

$V_1 = V_s$

$$\boxed{y_{11} = 0 \quad , \quad y_{12} = 0}$$

$$\Downarrow$$

** $\boxed{y_{11} = \text{min} \quad , \quad y_{12} = \text{min}}$

2. maximize V_o / minimize $y_{22}V_2$

$\Rightarrow$ $\boxed{y_{22} = 0}$ ** $\boxed{y_{22} = \text{min}}$

$$V_0 = -y_{21} V_1 R_L \quad \text{— (1)}$$

$$V_1 = V_S$$

$$\boxed{\frac{V_0}{V_S} = -y_{21} R_L}$$

**

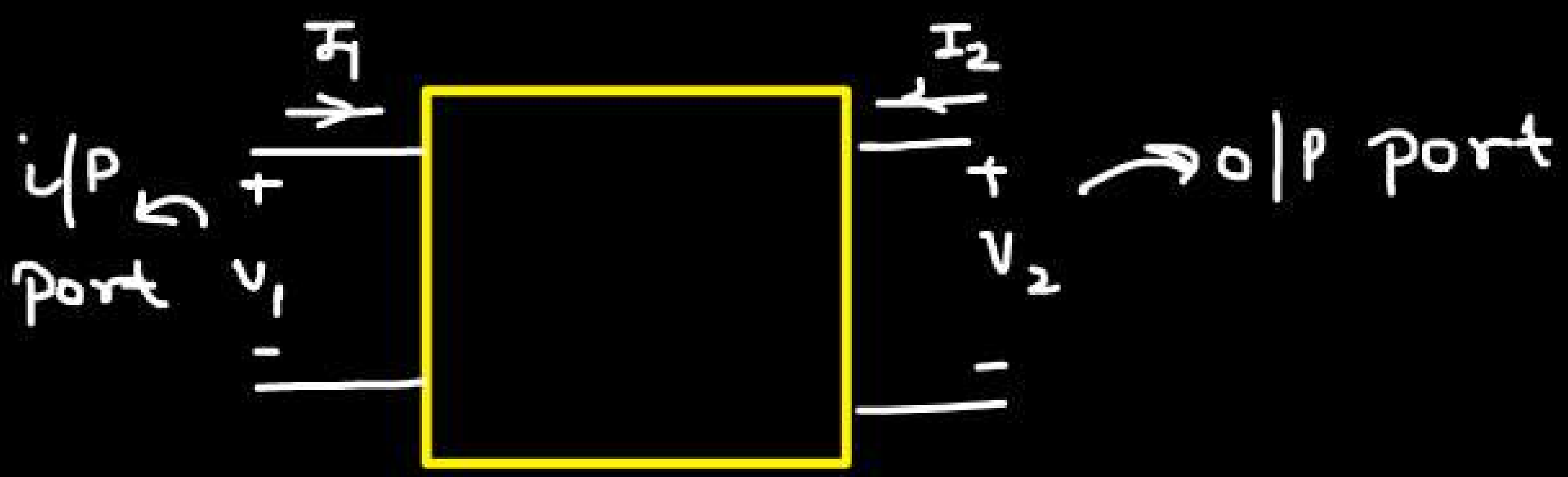
To have max^m gain $\boxed{y_{21} = \text{max}^m}$

*

$$\Rightarrow \boxed{y_{11} = \text{min}, \; y_{12} = \text{min}, \; y_{22} = \text{min}, \; y_{21} = \text{max}^m}$$

$$I_1 = y_{11} V_1 + y_{12} V_2 \quad \text{— (1)}$$

$$I_2 = y_{21} V_1 + y_{22} V_2 \quad \text{— (2)}$$



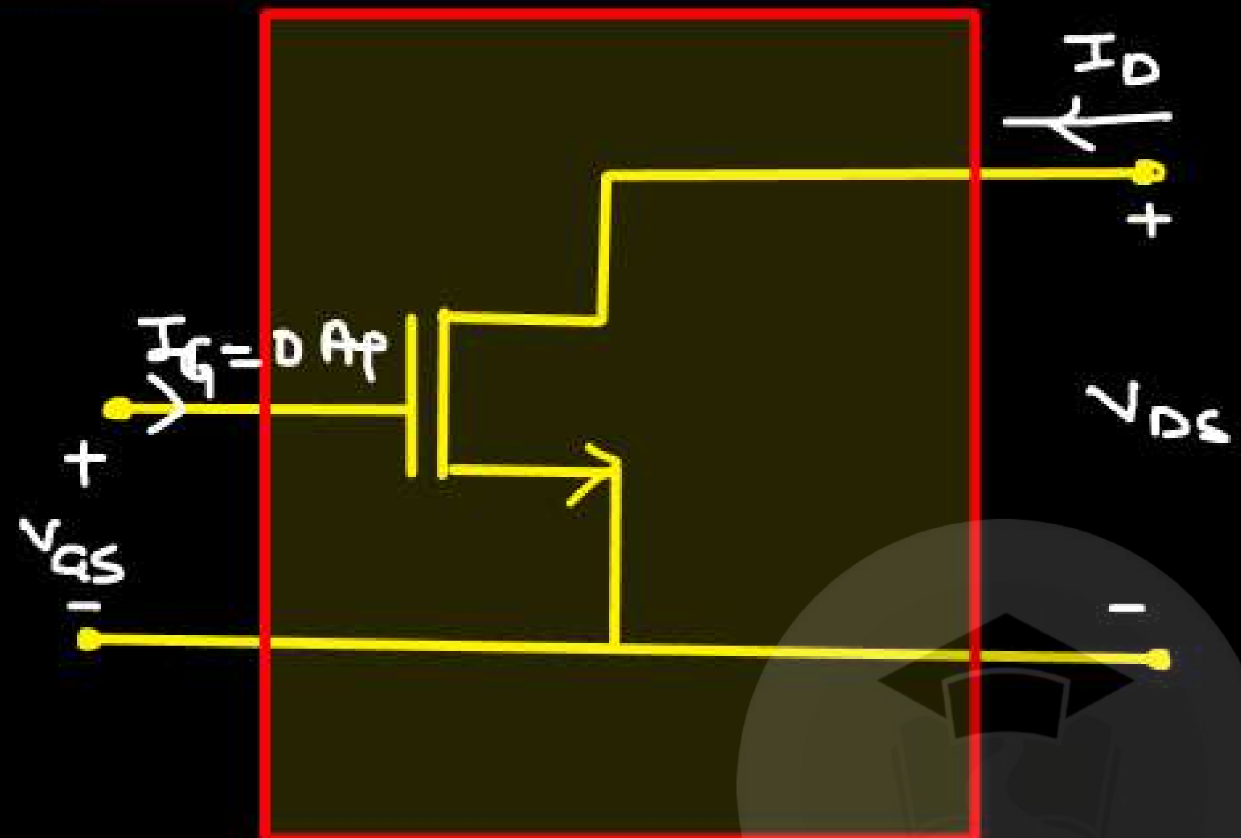
$$y_{11} = \left.\frac{\partial I_1}{\partial V_1}\right|_{V_2 = \text{const.}}$$

$$y_{12} = \left.\frac{\partial I_1}{\partial V_2}\right|_{V_1 = \text{const.}}$$

$$y_{21} = \left.\frac{\partial I_2}{\partial V_1}\right|_{V_2 = \text{const.}} = g_m = \text{large}$$

$$y_{22} = \left.\frac{\partial I_2}{\partial V_2}\right|_{V_1 = \text{const.}} = \frac{1}{\text{o/p resistance}} = \text{low}$$

Consider a MOS :-



For both Triode and Sat. region

$$\boxed{\frac{\partial I_G}{\partial V_{GS}} = y_{11} = 0} \quad , \quad \boxed{\frac{\partial I_G}{\partial V_{DS}} = y_{12} = 0}$$

$\frac{\partial I_D}{\partial V_{GS}}$ for sat. and Triode

$$\boxed{(g_m)_{Triode} = \frac{\mu_n C_{ox} W}{L}(V_{DS})}$$

in case of Triode region, $V_{DS} < V_{GS} - V_T$

$\Rightarrow V_{DS}$ is very low

$\Downarrow$

g_m will be very low in Triode region

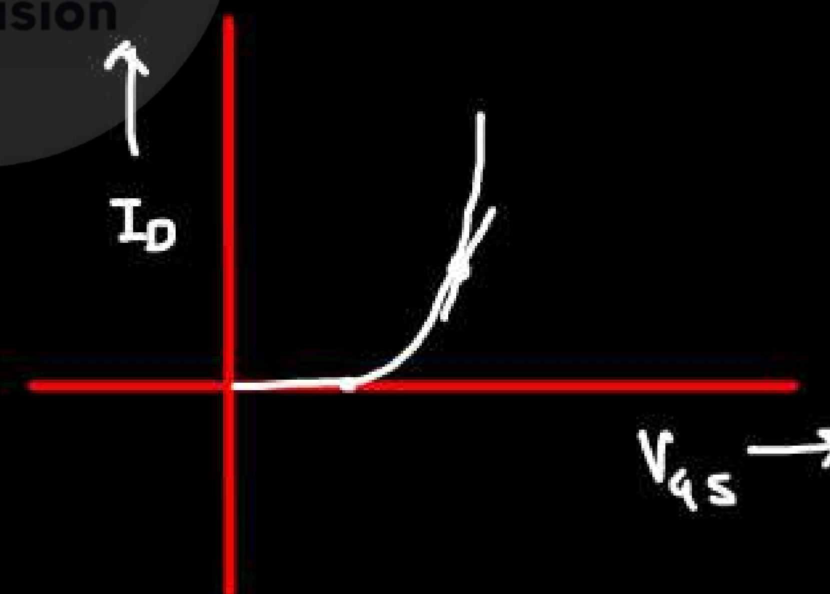
$$\boxed{(g_m)_{sat.} = \frac{\mu_n C_{ox} W}{L} (V_{GS} - V_T)}$$

$$(I_D)_{sat.} = \frac{\mu_n C_{ox} W}{2L} \left[(V_{GS} - V_T)^2 \right]$$

I_D and V_{GS} follow square law relation $\Rightarrow$ slope $\frac{\partial I_D}{\partial V_{GS}}$ will be High

**

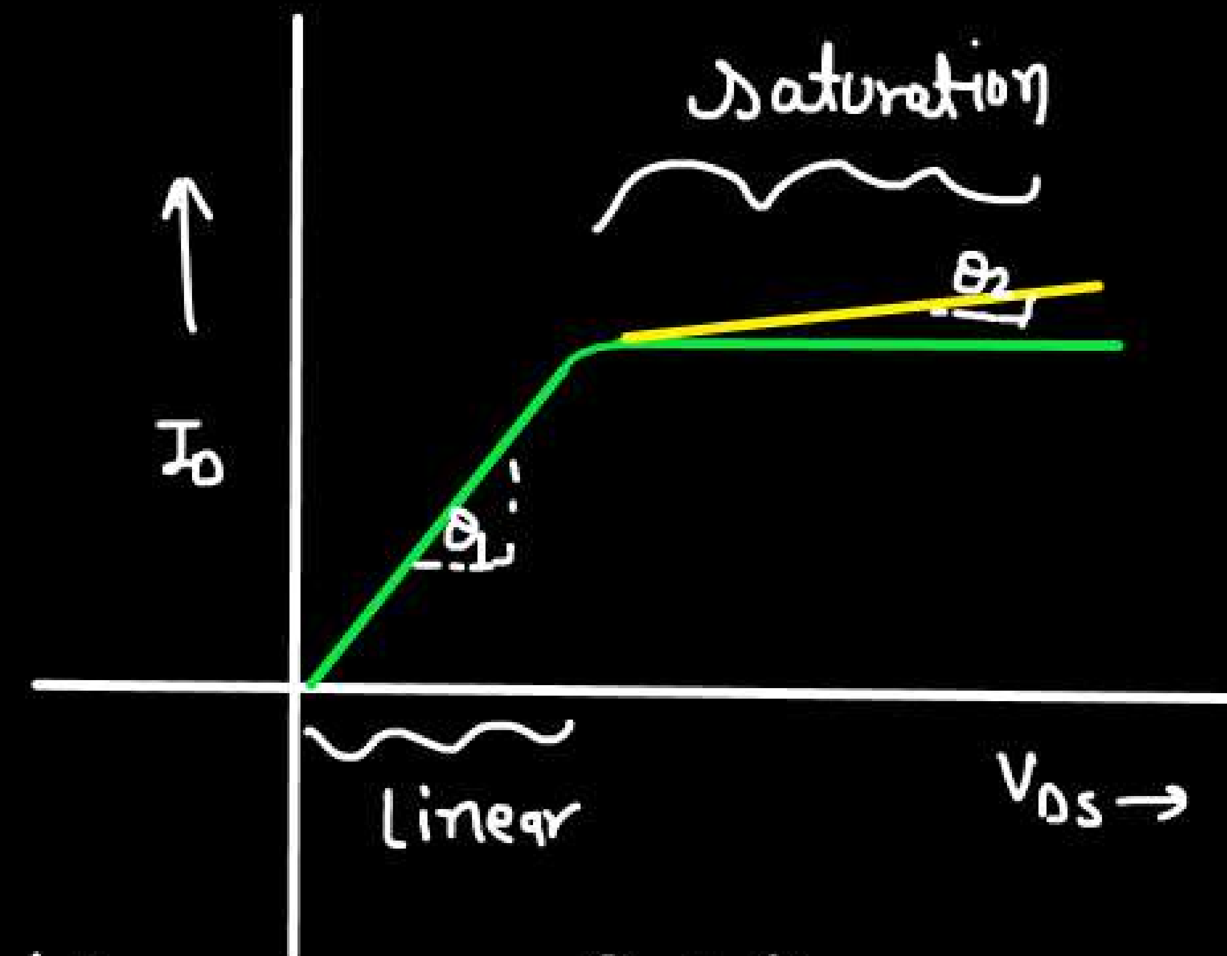
$$\boxed{(g_m)_{sat.} > (g_m)_{Triode}}$$



$\frac{\partial I_D}{\partial V_{DS}}$ for linear and sat. region :-

$$\left(\frac{\partial I_D}{\partial V_{DS}}\right)_{\text{deep linear}} = \frac{\mu_n C_{ox} W}{L}(V_{GS} - V_T)$$

$$\left(\frac{\partial I_D}{\partial V_{DS}}\right)_{\text{sat.}} \begin{cases} \frac{1}{\lambda (I_D)_{sat}} & (\lambda \neq 0) \\ \infty & (\lambda = 0) \end{cases}$$



For sat. $\frac{\partial I_D}{\partial V_{DS}} \rightarrow$ less $\Rightarrow \frac{\partial V_{DS}}{\partial I_D} \rightarrow$ High

$\theta_1 > \theta_2$

For sat. region,

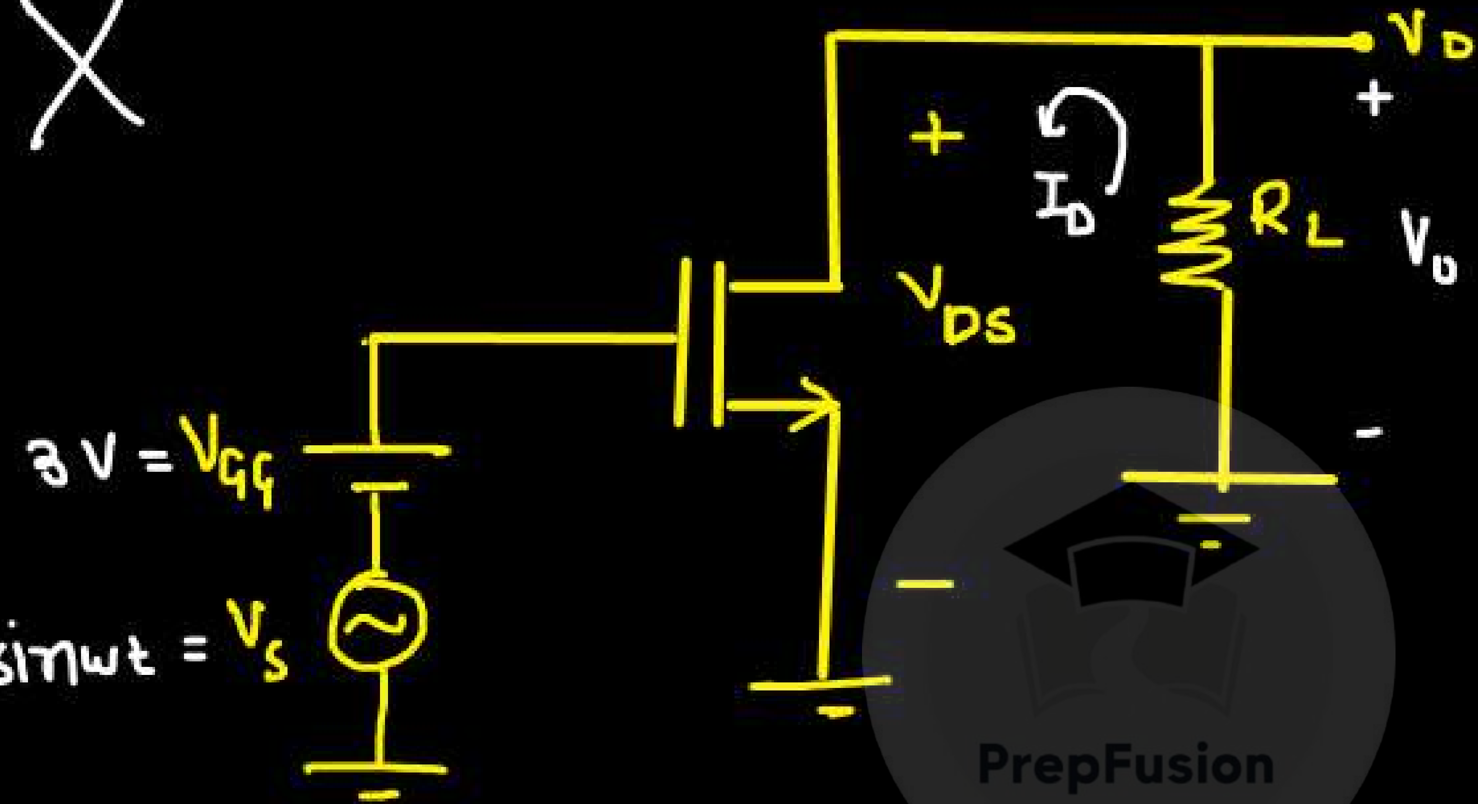
o/p resistance is High

⇒ Why we use MOSFET in sat. region for Amplification?

→ Because, in sat. region, we get Higher g_m and Higher o/p resistance that maximizes our voltage gain.

⇒ How to bias a MOS for Amplification?

Try-1 ✗



$V_T = 1V$

for sat. →

$V_{DS} > V_{GS} - V_T$

$V_{DS} > 3 + 20mV \sin\omega t - 1$

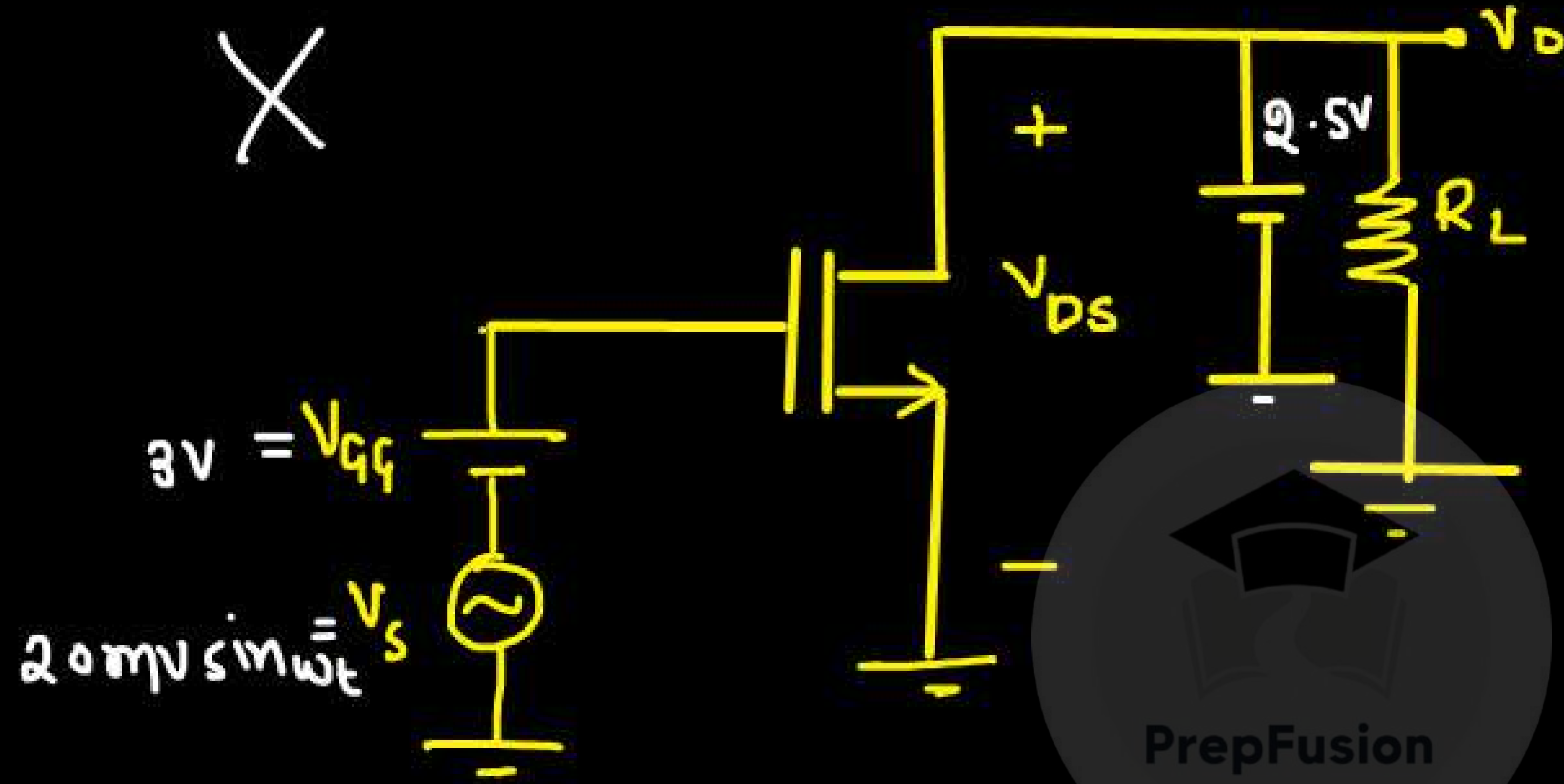
$\boxed{V_{DS} > 2V}$

$$\boxed{\begin{aligned} V_{DS} &= -I_D R_L \\ &= \text{negative} \end{aligned}}$$

NOT DESIRED

[MOS will be in CUT-OFF]

Try-2   Fixing V_{DS}



$\boxed{V_{DS} > 2V}$ → for sat.

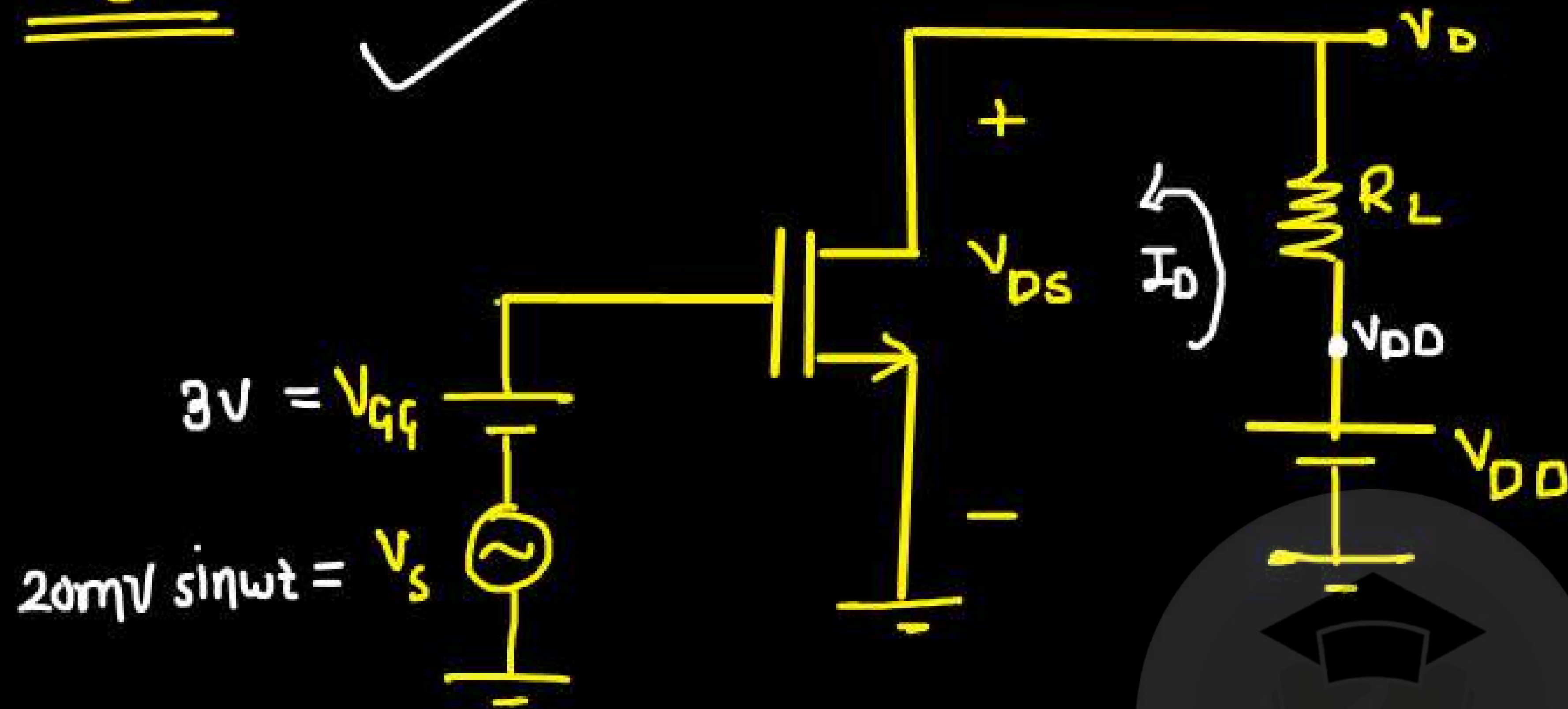
Here, $\boxed{V_{DS} > V_{GS} - V_T \Rightarrow \text{sat. } \checkmark}$

$\boxed{V_0 = 2.5V \rightarrow \text{fixed}}$

$\Downarrow$

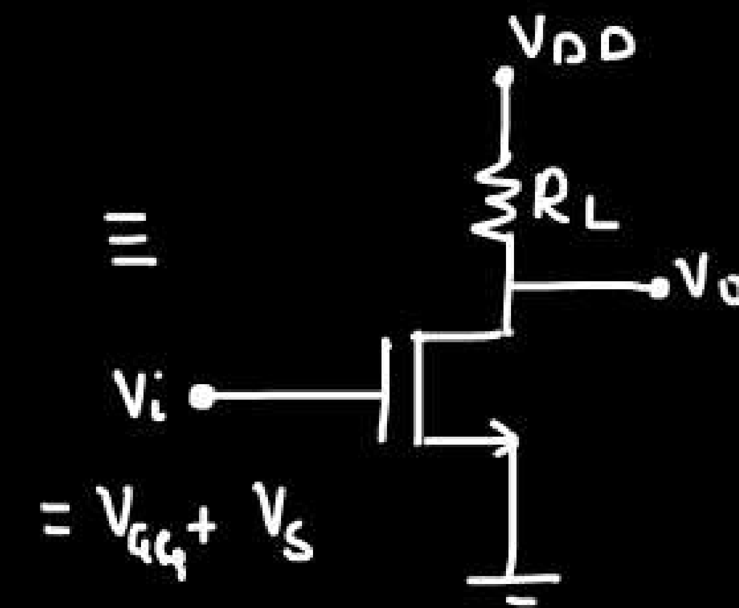
NOT working as an amplifier

Try-3



$V_T = 1V$

$\equiv$



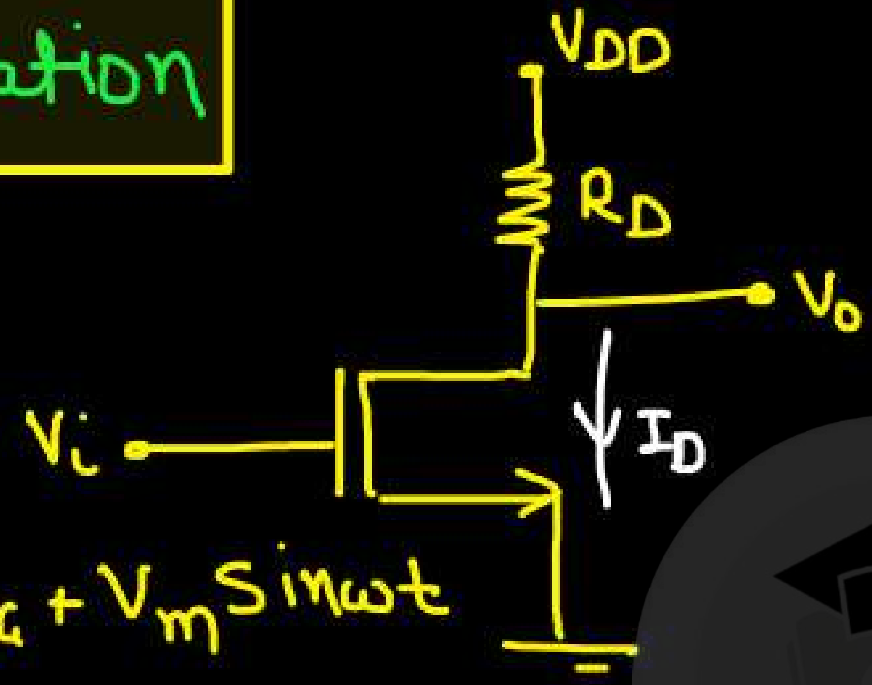
$$\boxed{V_{DS} = V_{DD} - I_D R_L}$$

You can adjust V_{DD} such that your MOS works in saturation region.

also, O/P is NOT fixed.

Small signal Analysis of MOS Amplifiers:-

MOS in saturation



$= V_{GG} + V_m \sin\omega t$

$$V_i = \underset{(dc)}{V_{GG}} + \underset{\substack{(ac)\\(v_{gs})}}{V_m \sin\omega t}$$

$\underbrace{v_{gs} = V_m \sin\omega t}$ → small signal ac input

$$I_D = \frac{\mu_n C_{ox} W}{2L}\left[V_{GS} - V_T\right]^2$$

$$= \frac{\mu_n C_{ox} W}{2L}\left[V_{GG} + V_m \sin\omega t - V_T\right]^2$$

$$I_D = \frac{\mu_n C_{ox} W}{2L}\left[V_{GG} - V_T + V_m \sin\omega t\right]^2$$

$$I_D = \frac{\mu_n C_{ox} W}{2L}\left[V_{GG} - V_T\right]^2 \left[1 + \frac{V_m \sin\omega t}{\underbrace{V_{GG} - V_T}_{\Downarrow \ \text{small}}}\right]^2$$

$$\left\{ (1+x)^2 \approx 1 + 2x \right\}$$

$$I_D = \underbrace{\frac{\mu_n C_{ox} W}{2L}\left[V_{GG} - V_T\right]^2}\left[1 + \frac{2V_m \sin\omega t}{V_{GG} - V_T}\right]$$

$$I_D = I_{DC}\left[1 + \frac{2V_m \sin\omega t}{V_{GG} - V_T}\right]$$

$\Downarrow$

Current if only V_{GG} (dc) was applied

$$I_D = I_{DC} + \frac{2I_{DC}}{V_{GG}-V_T} V_m \sin\omega t$$

$$\boxed{I_D = \underbrace{I_{DC}}_{\text{dc component}} + \underbrace{g_m V_{gs}}_{\text{ac component}}}$$

$\left\{ V_{gs} = V_m \sin\omega t = \text{small signal ac i/p} \right\}$

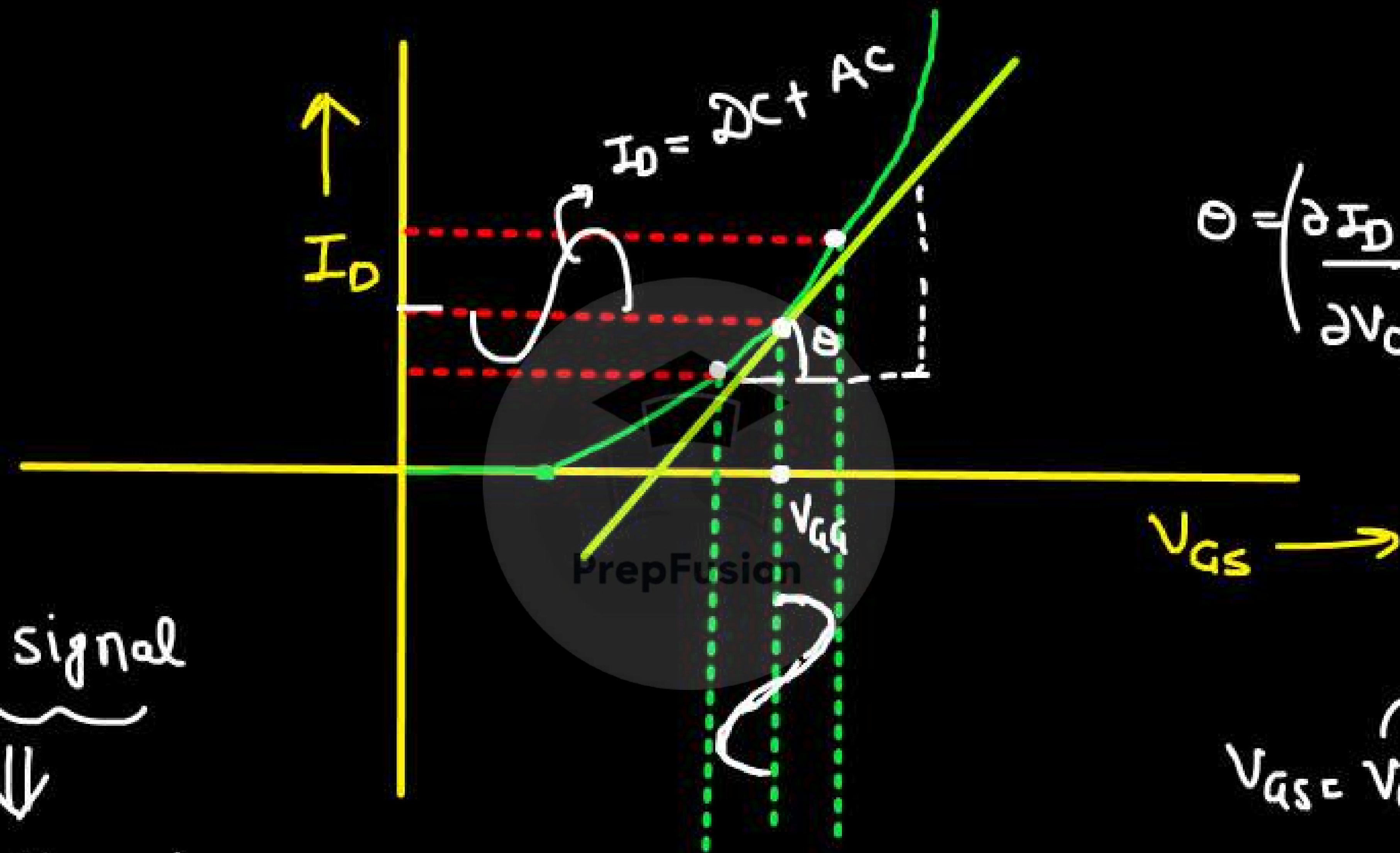
$$V_o = V_{DD} - I_D R_D$$

$$= V_{DD} - [I_{DC} + g_m V_{gs}] R_D$$

$$\boxed{V_o = \underbrace{V_{DD} - I_{DC}R_D}_{DC} - \underbrace{g_m V_{gs} R_D}_{AC}}$$

$$\boxed{\begin{aligned} ** (I_D)_{ac} &= g_m V_{gs} = i_d \\ (V_o)_{ac} &= -g_m V_{gs} R_D \end{aligned}} \neq f(V_{DD}, V_{GG})$$

Method 2 (Understanding by Graph) :-



$$\theta = \left(\frac{\partial I_D}{\partial V_{GS}}\right)\Bigg|_{V_{GG}} = g_m$$

$$I_D = \underbrace{I_{DC}}_{DC} + \underbrace{Ac\ signal}$$

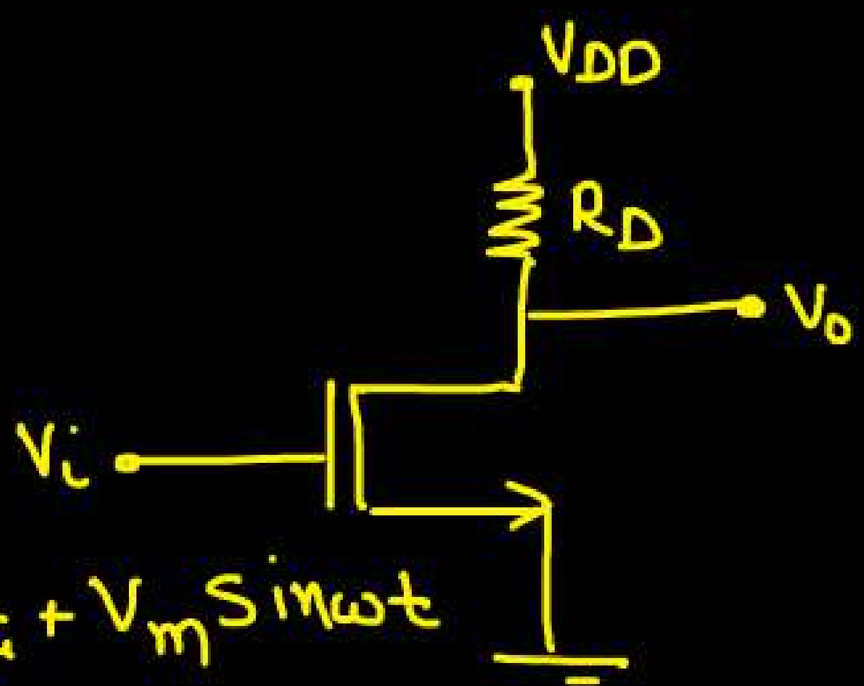
$$\Downarrow$$

$$g_m v_{gs} = i_d$$

$$V_{GS} = \overset{dc}{V_{GG}} + \overset{ac\,(v_{gs})}{V_m \sin \omega t}$$

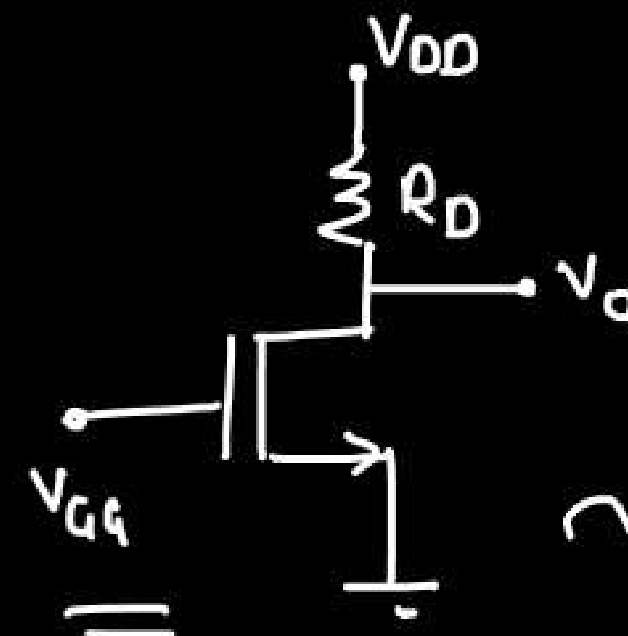
$$= 2 + 20mV \sin \omega t$$

For Analysis Purpose:-



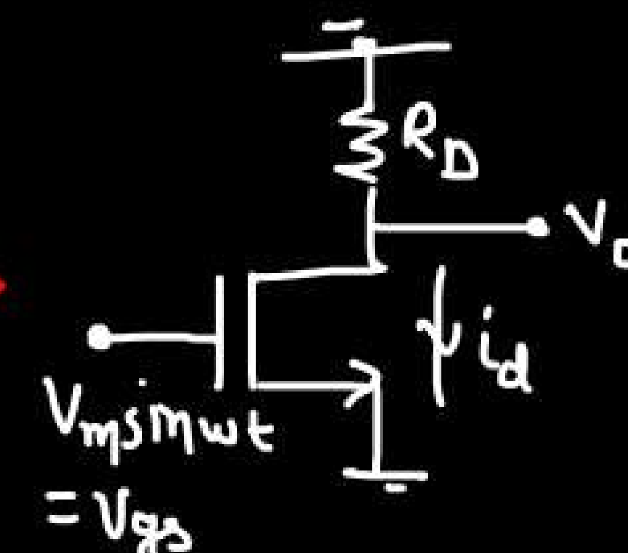
$= V_{GG} + V_m \sin\omega t$

DC Analysis



$\rightsquigarrow g_m = \dfrac{2I_{DC}}{V_{GG} - V_T}$

AC Analysis

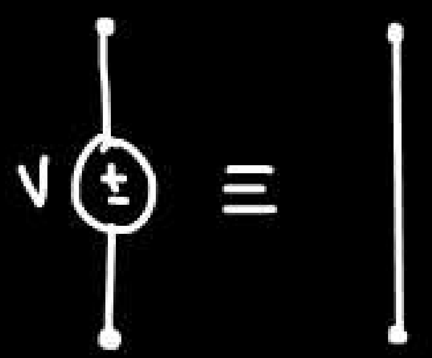


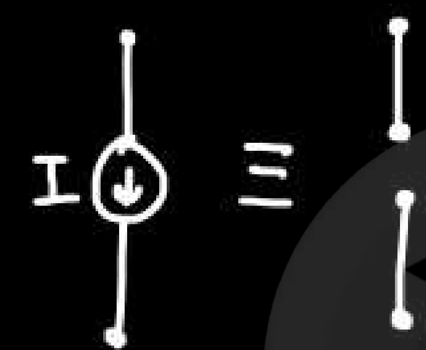
$$\boxed{\begin{aligned} V_o &= -i_d R_D \\ V_o &= -g_m v_{gs} R_D \end{aligned}}$$

Small Signal Model of MOSFET :-

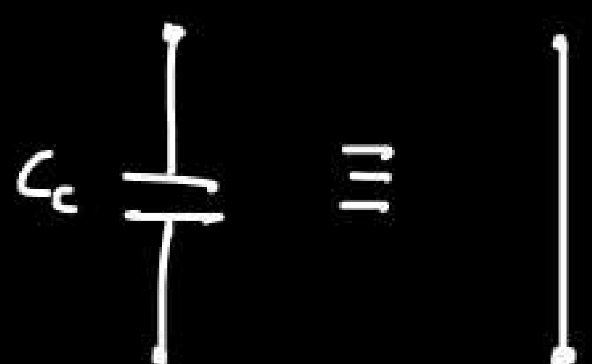
★ AC Analysis :-

① Nullify all the dc sources.





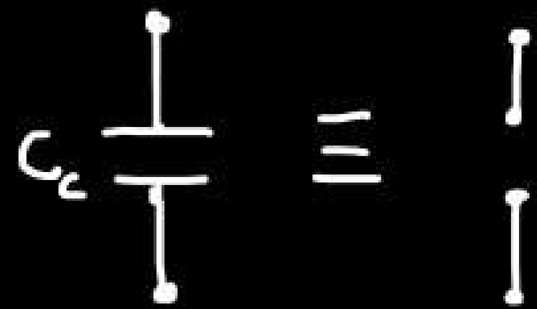
② Coupling Cap. will be shorted. (Generally)



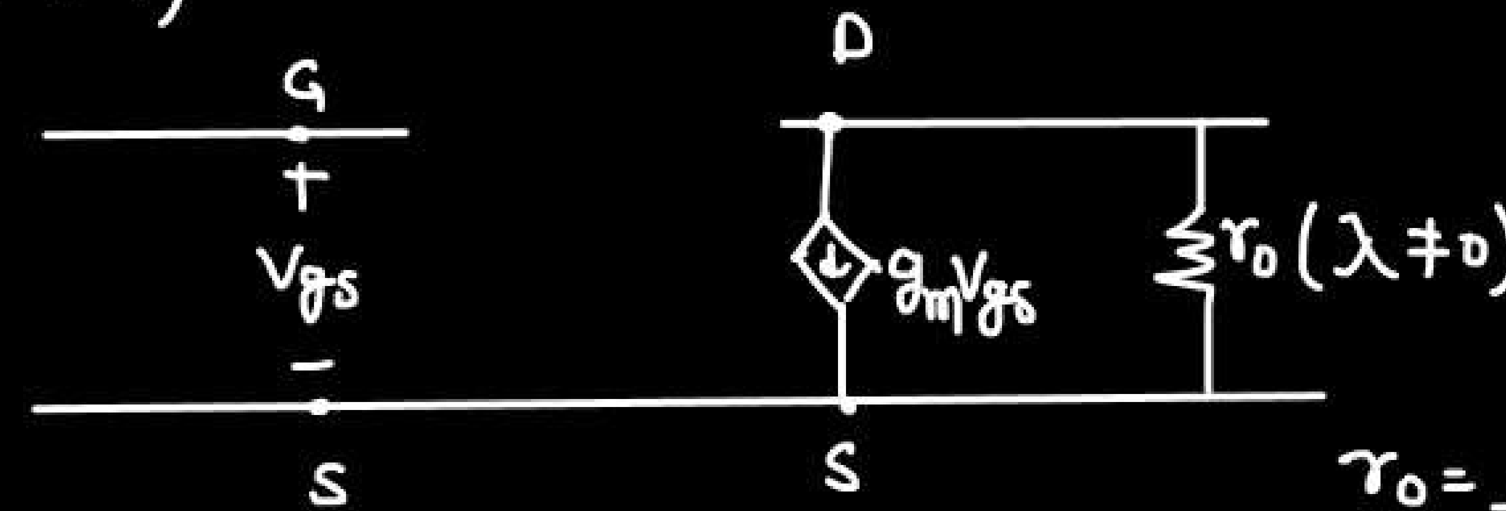
DC Analysis:-

① Nullify all the ac sources.

② Coupling cap. will be open circuited.

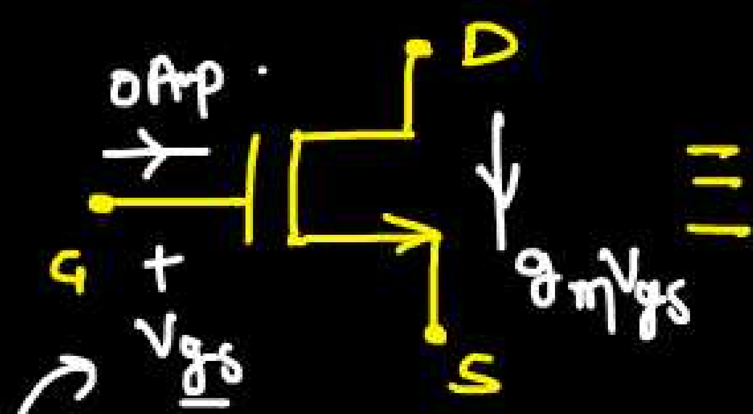


NMOS :- (Small Signal Model)



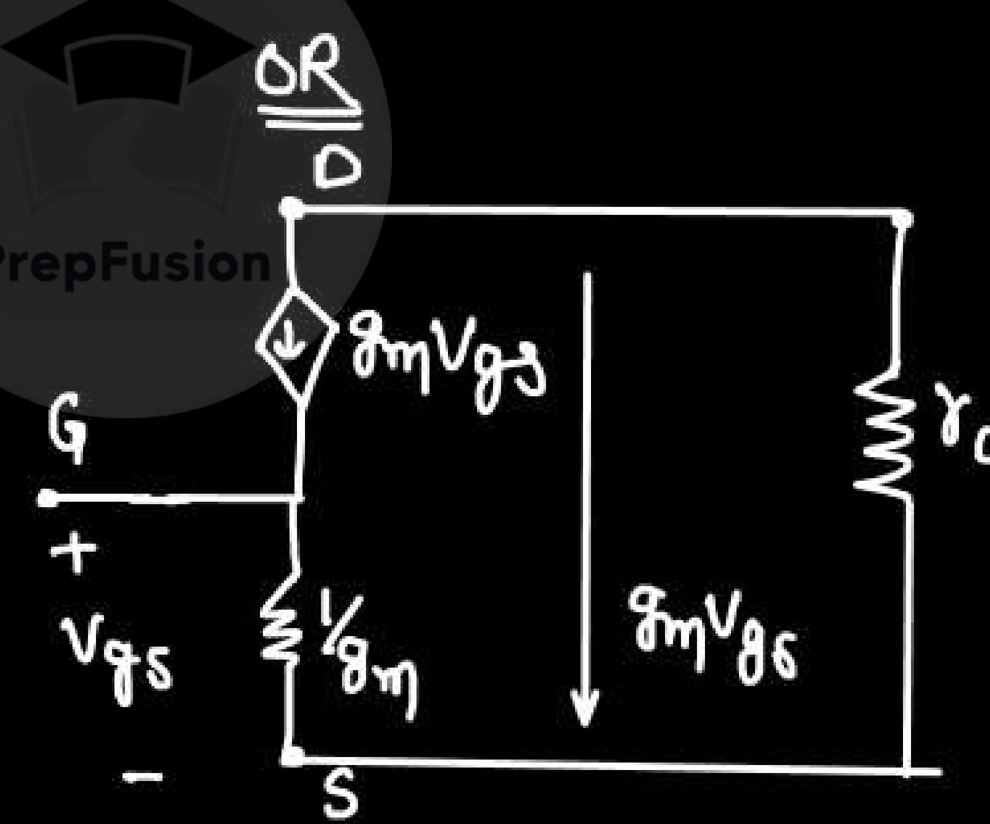
$$r_0 = \frac{1}{\lambda (I_D)_{sat.-ideal}}$$

π- model

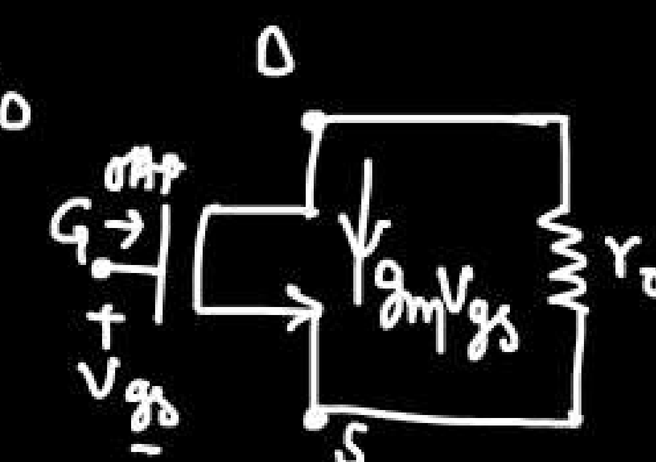


Small signal voltage

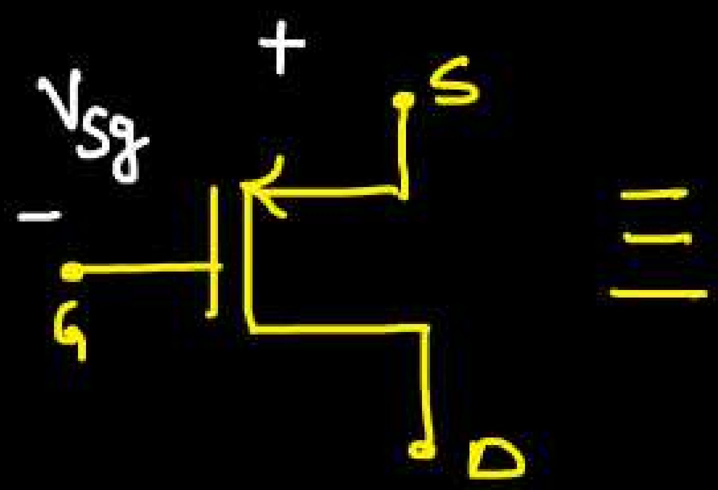
OR



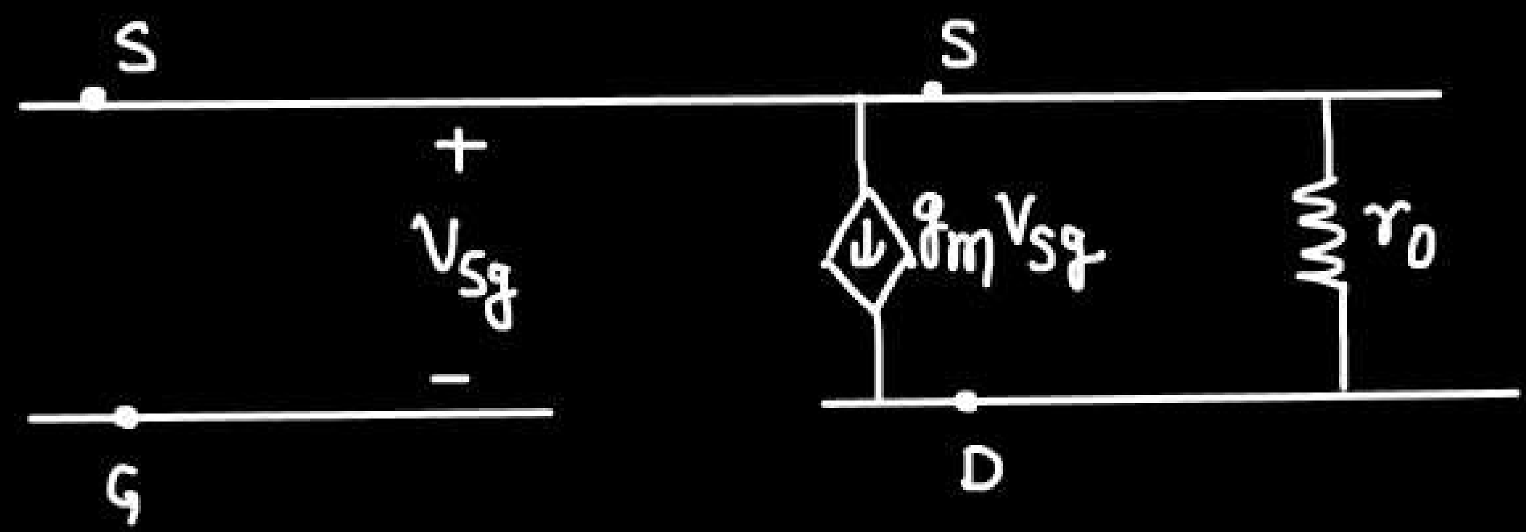
OR



PMOS:-

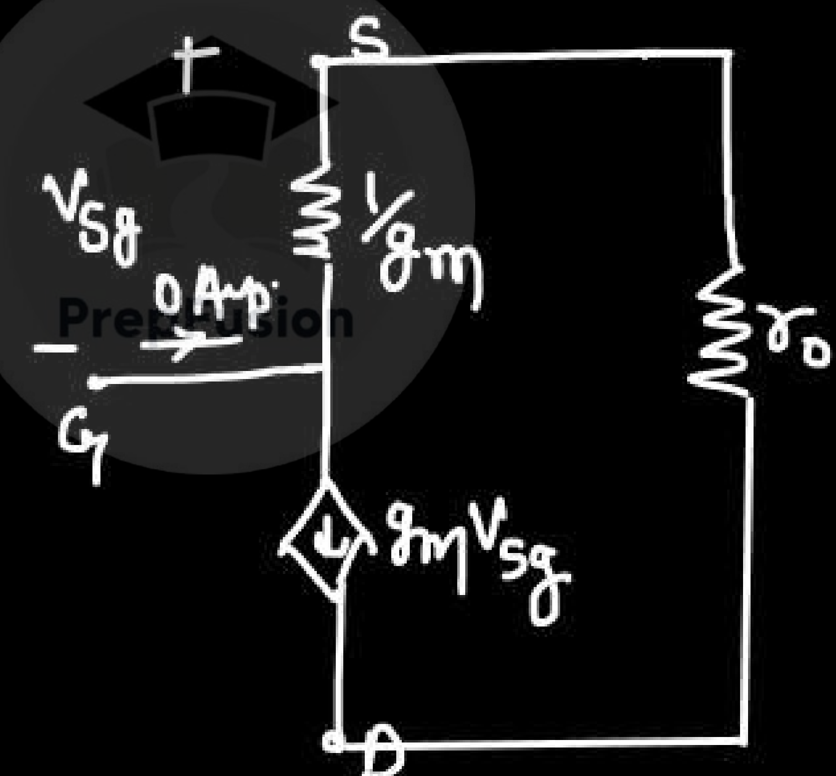


Vsg
+
−
S
G
D
≡



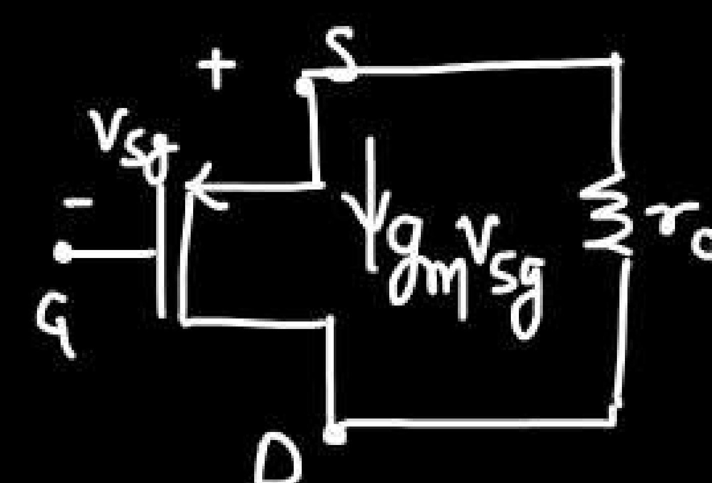
S
S
+
Vsg
−
G
gmVsg
r0
D

OR



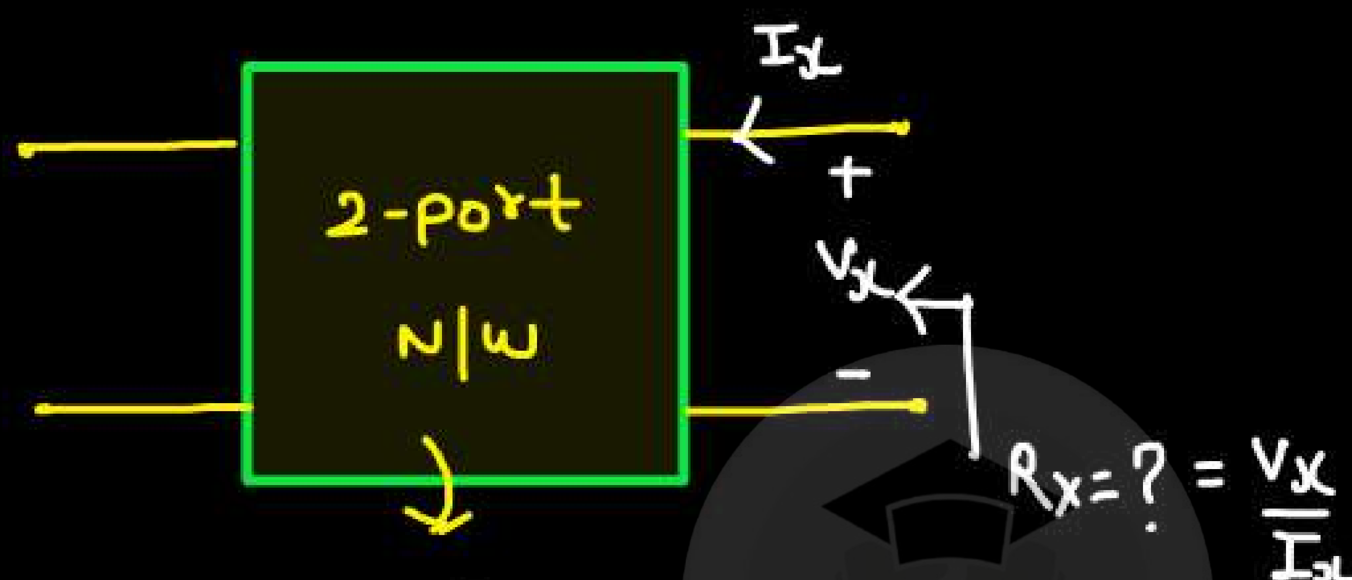
+
S
Vsg
1/gm
0 Amp.
−
G
r0
gmVsg
D

OR



+
S
Vsg
−
G
gmVsg
r0
D

Concept of port impedance :-



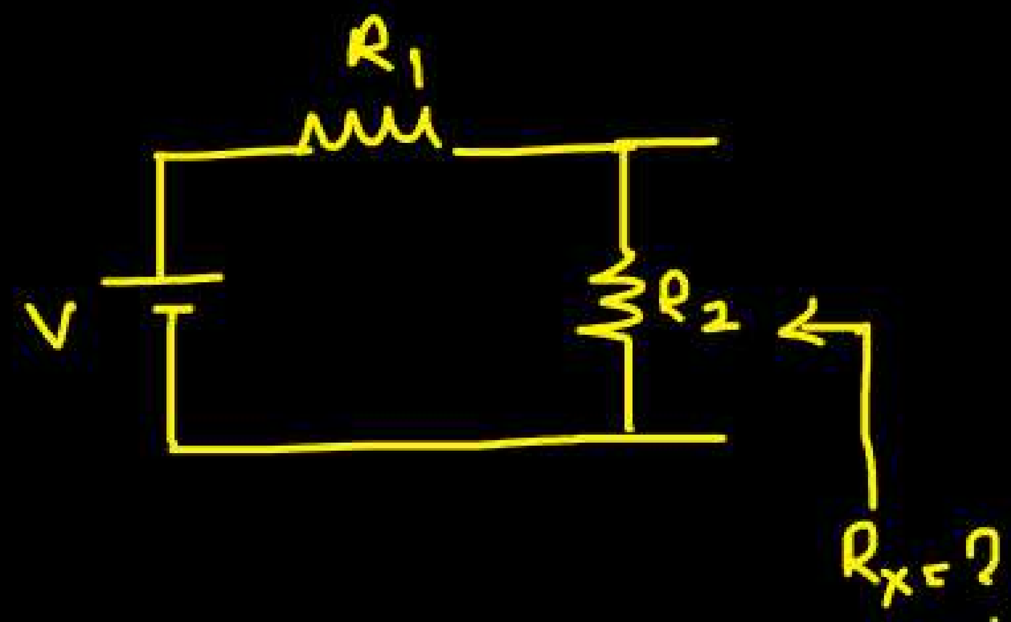
(i) All independent source = 0

(ii) Apply V_x and get I_x out of it, @ the port where you need to find the impedance.

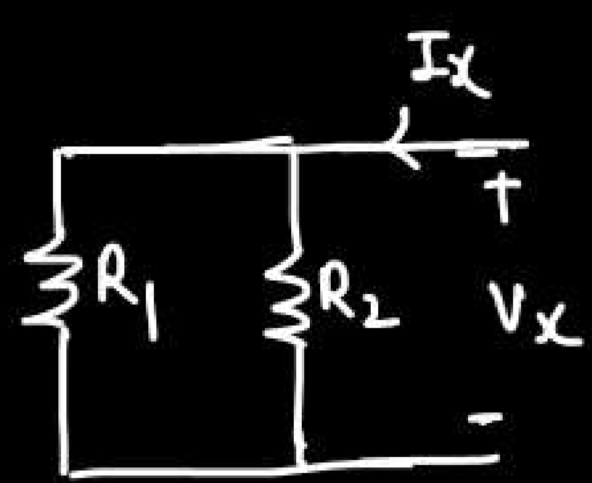
(iii) $R_x = \frac{V_x}{I_x}$

Eg. →

①



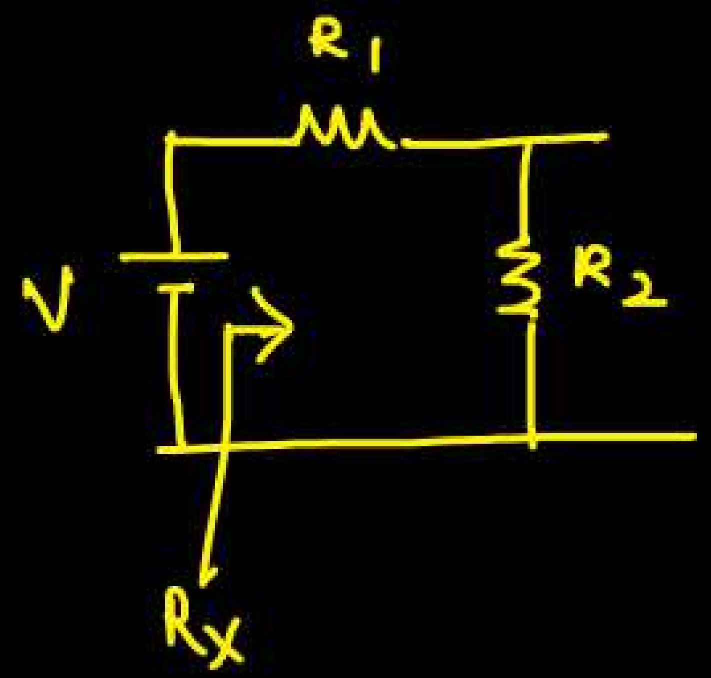
⇛



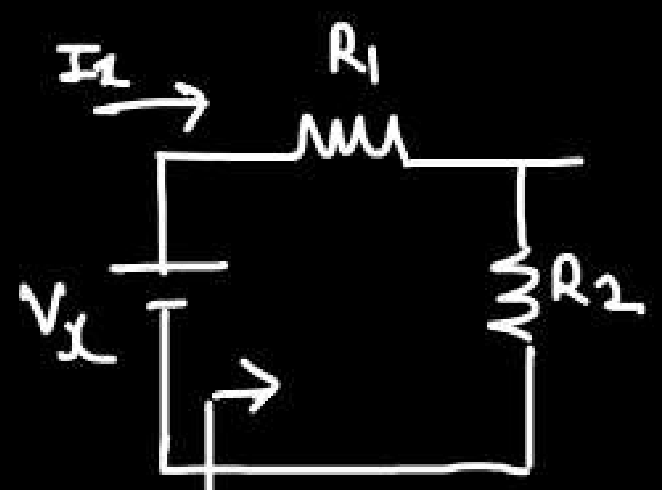
$$\frac{V_x}{R_2} + \frac{V_x}{R_1} = I_x$$

$$\boxed{\frac{V_x}{I_x} = R_x = R_1 \parallel R_2}$$

2

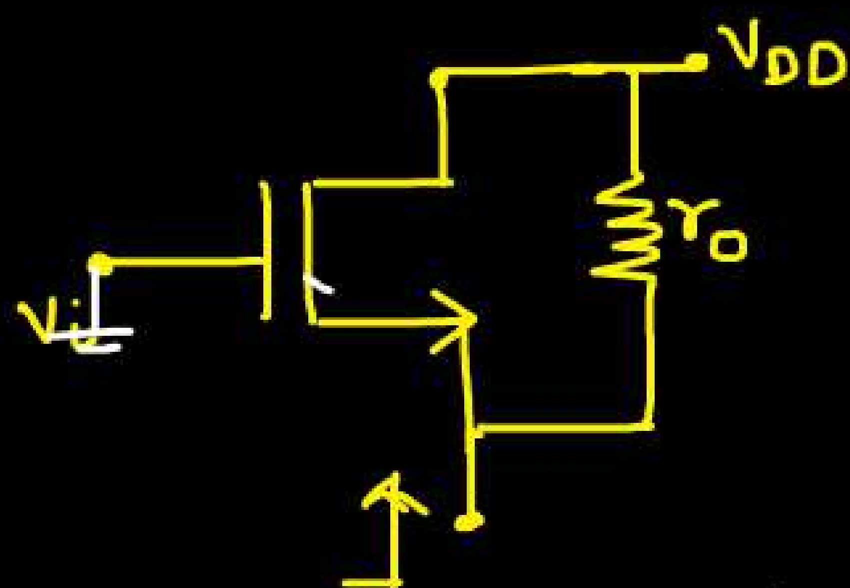


$\Rightarrow$

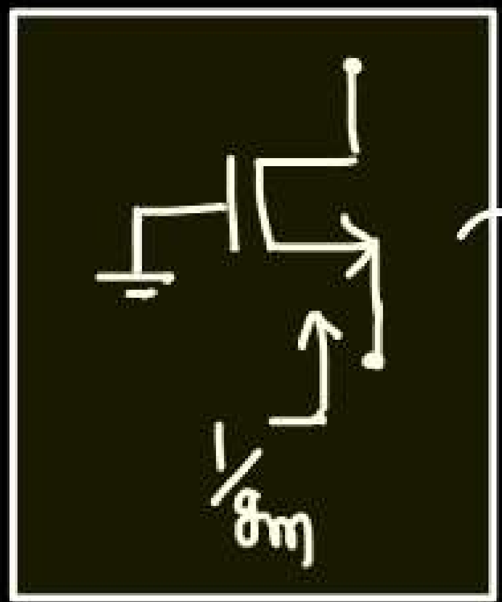


$$\boxed{R_x = R_1 + R_2}$$

③

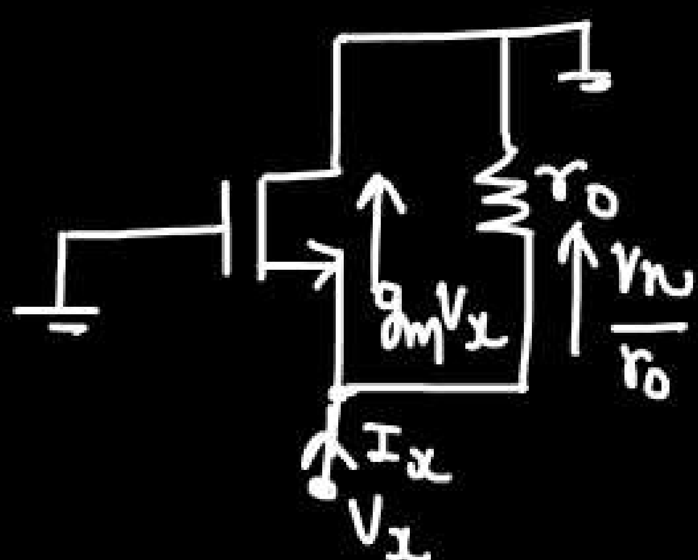


R_x (Small signal resistance)



→ From source to ground, I see $1/g_m$

→



$V_{gs} = -V_x$

Nodal @ V_x

$$\frac{V_x}{r_o} + g_m V_x = I_x$$

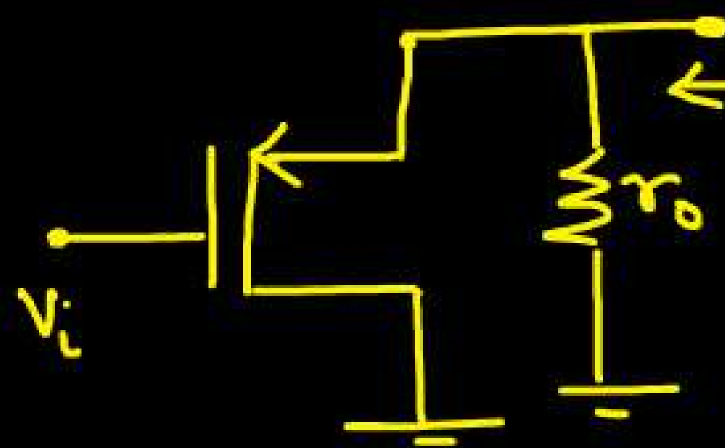
$$V_x\left[\frac{1 + g_m r_o}{r_o}\right] = I_x$$

$$\boxed{R_x = \frac{r_o}{1 + g_m r_o}}$$

↑

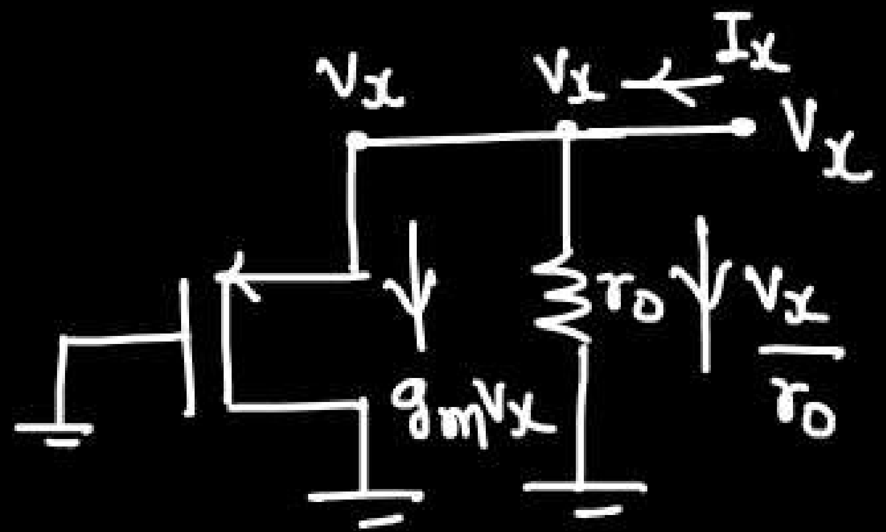
$$\boxed{R_x = \frac{1}{g_m} \parallel r_o}$$

4



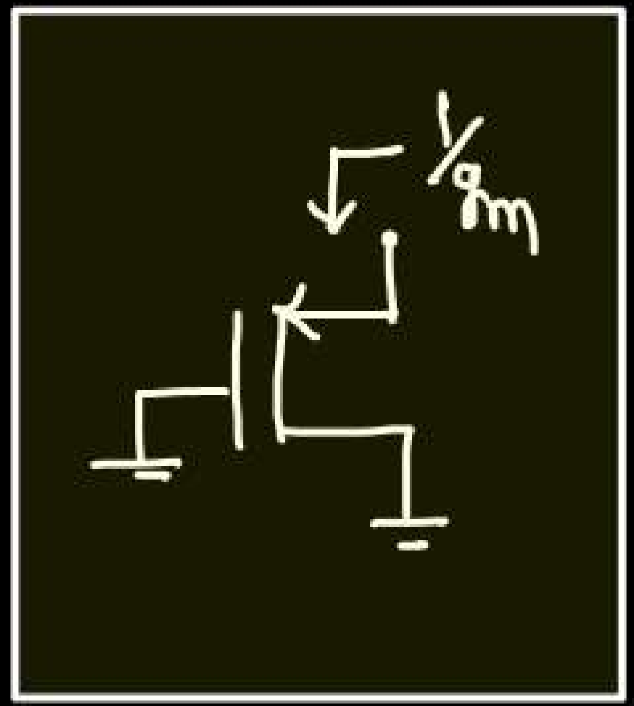
R_x (Small signal resistance)

→

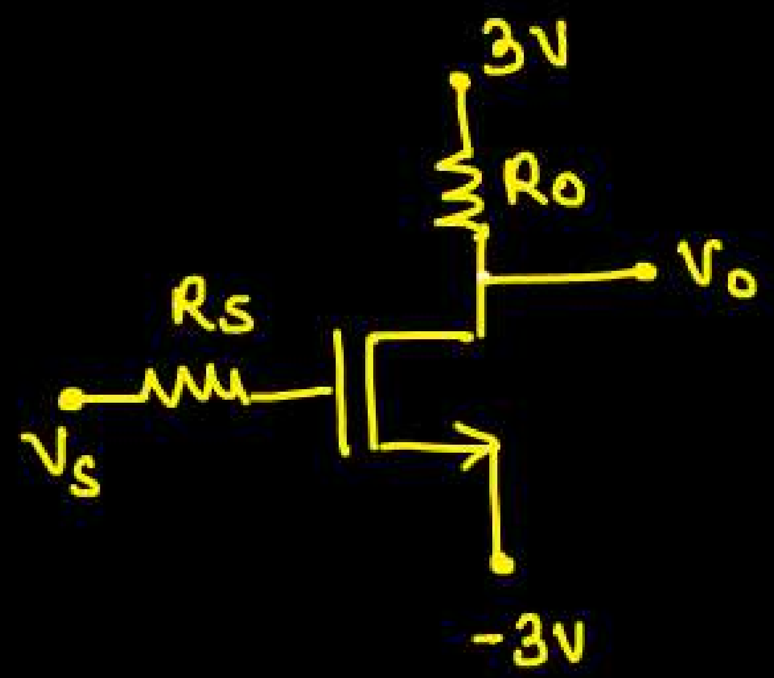


$$g_m V_x + \frac{V_x}{r_0} = I_x$$

$$\boxed{R_x = \frac{1}{g_m} \| r_0}$$



Q.



$\mu_n C_{ox} = 100\mu A/V^2$

$W/L = 1$

$V_T = 1V$

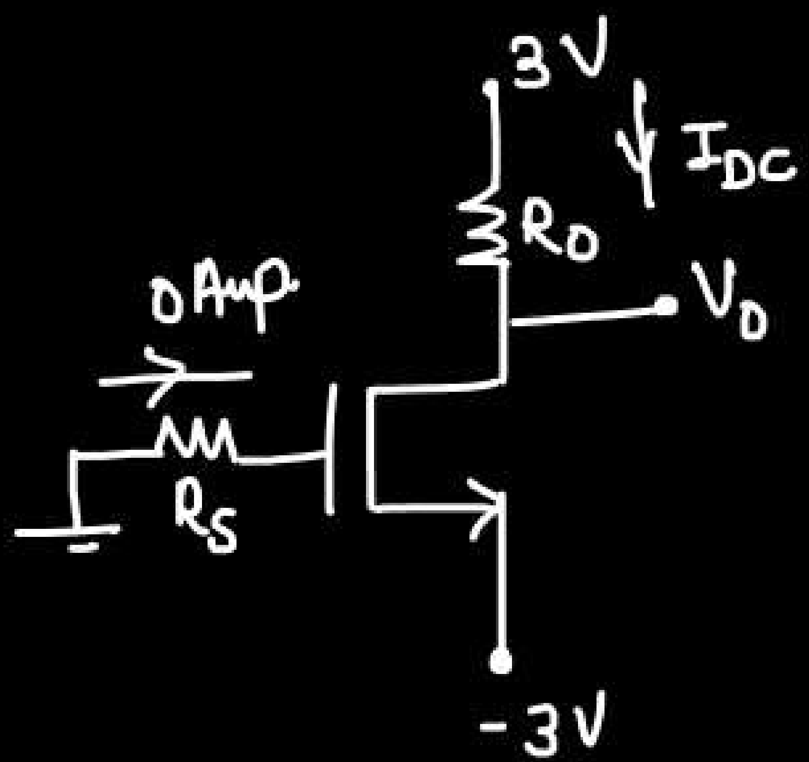
$V_s \rightarrow$ small signal source (ac)

① Find R_D such that quiescent drain voltage is zero. (DC)

② Find small signal voltage gain. (ac) $\left(\frac{V_o}{V_s}\right)$

DC Analysis

Target $V_0 = 0V$



$$I_{DC} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2$$

$$I_{DC} = \frac{100\mu}{2} (3-1)^2$$

$$\boxed{I_{DC} = 200\,\mu\text{Amp}}$$

$V_{DS} = 3V$

$V_{GS} = 3V$

$V_T = 1V$

$V_{OV} = 2V$

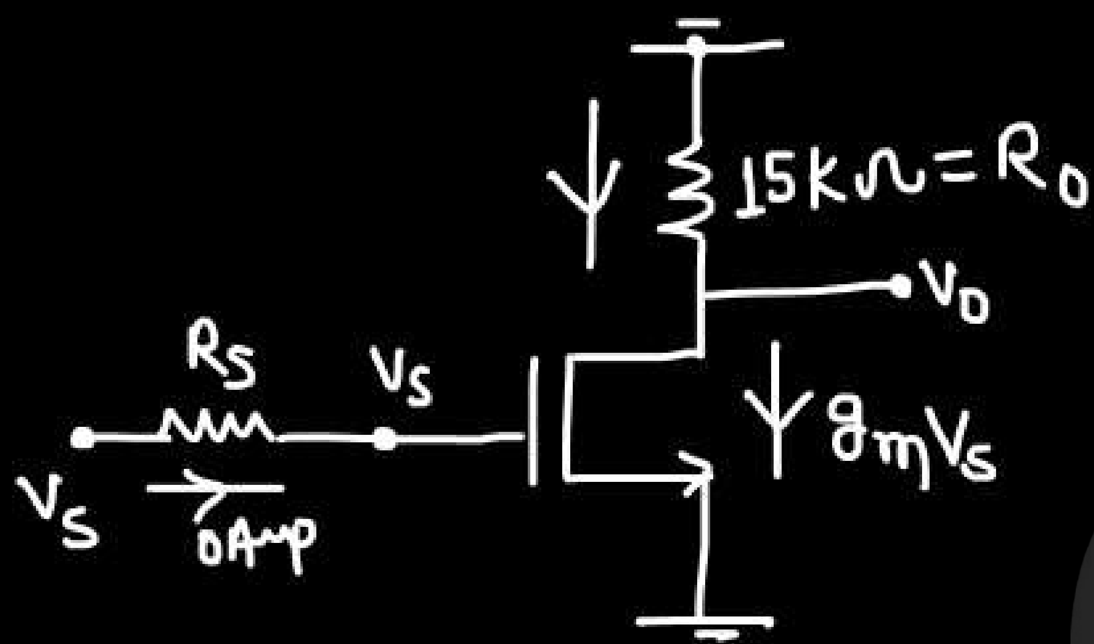
$V_{DS} > V_{OV} \Rightarrow \text{sat.}$

$$V_0 = 3 - I_{DC} R_D = 0$$

$$I_{DC} R_D = 3$$

$$R_D = \frac{3}{200\mu} \Rightarrow \boxed{R_D = 15\,k\Omega}$$

AC Analysis:-



$$\frac{V_0}{V_s} = ?$$

$$V_0 = -g_m V_s \times R_0$$

$$\boxed{\frac{V_0}{V_s} = -g_m R_0}$$

$R_0 \checkmark = 15\,k\Omega$

g_m ?

$$g_m = \frac{\mu_n C_{ox} W}{L}(V_{GS} - V_T)$$

$$= 100\mu(3-1)$$

$$\boxed{g_m = 200\,\mu\mho}$$

$$\frac{V_0}{V_s} = -200 \times 10^{-6} \times 1.5 \times 10^4$$

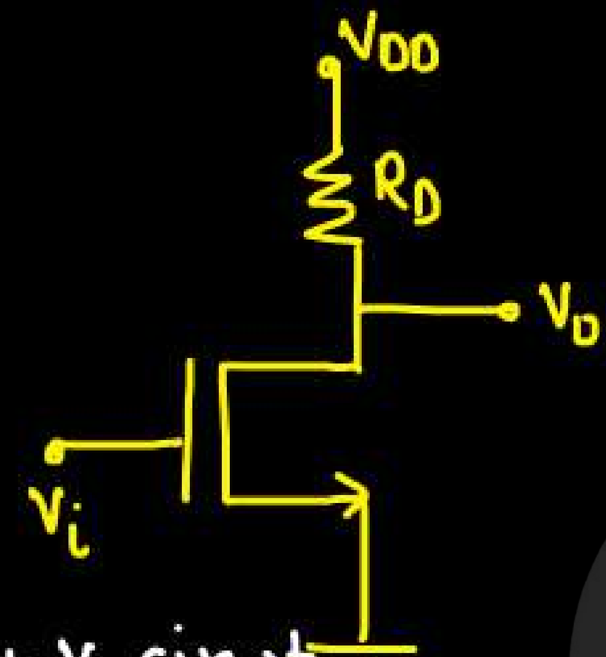
$$\boxed{\frac{V_0}{V_s} = -3\ V/V}$$

$$\boxed{g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D}} = \sqrt{2 \times 100\mu \times 200\mu}$$

$$= 200\mu\mho$$

$$\boxed{g_m = \frac{2I_{DC}}{V_{GS}-V_T}} = \frac{2 \times 200\mu}{2} = 200\mu\mho$$

Common Source Amplifiers:-



$= V_{GG} + V_m \sin\omega t$

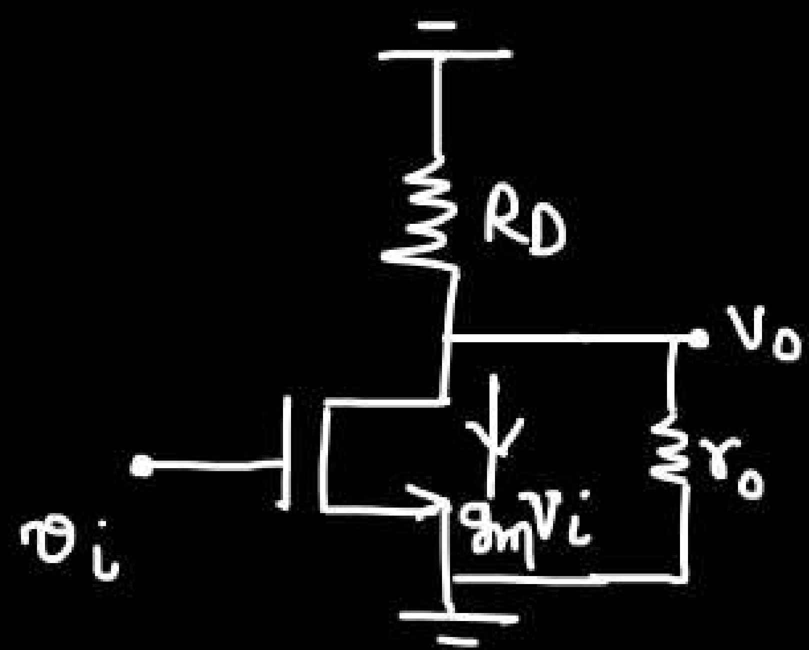
$= V_{DC} + v_i$

MOS is biased such that it's working in sat. region.

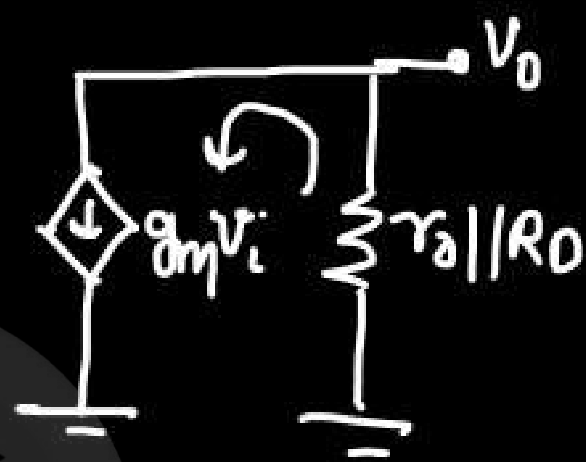
Common source amplifier →

input → Gate , o/p → Drain

Small signal Analysis (ac):-



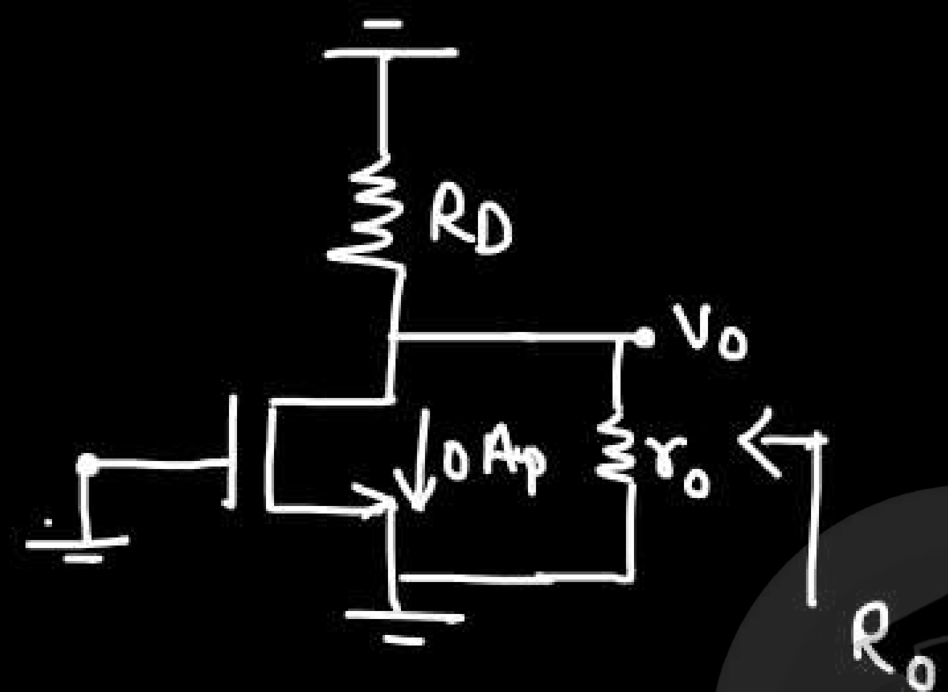
$\equiv$

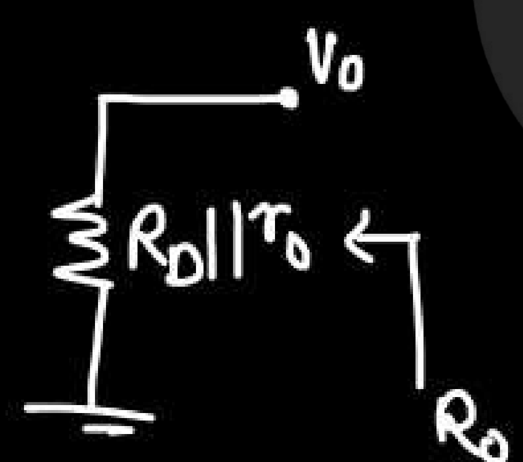


$$v_o = -g_m v_i [R_D || r_o]$$

$$\boxed{\frac{v_o}{v_i} = -g_m [R_D || r_o]}$$ → small signal gain

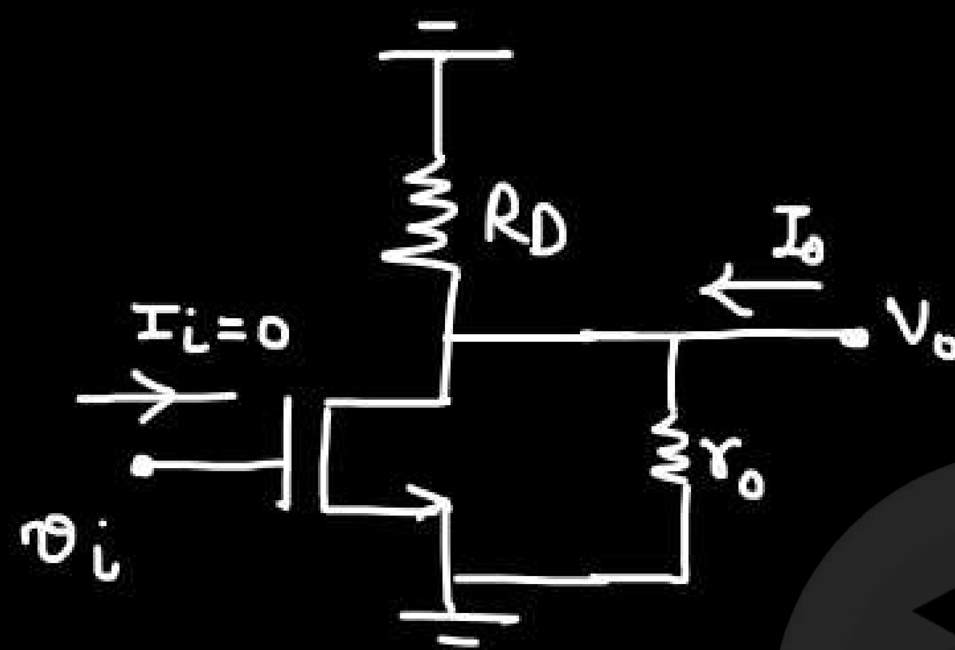
② Small signal o/p resistance (R_o):-





$$\boxed{R_o = R_D \| r_o}$$

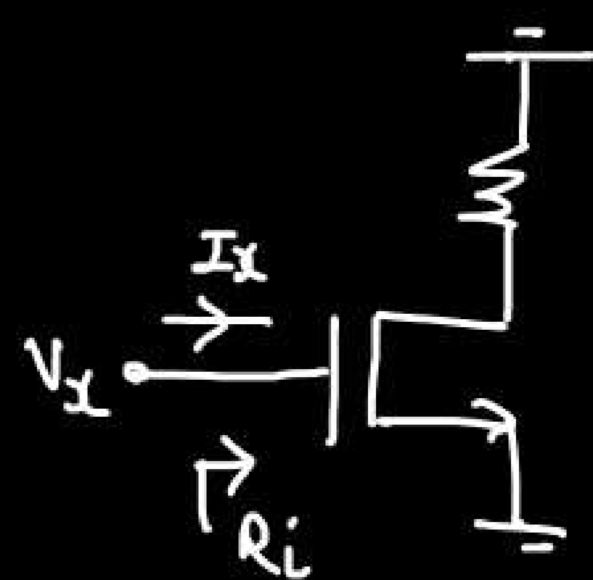
③ Small Signal Current gain:-



$$\text{Current gain} = \frac{I_o}{I_i} = \frac{I_o}{0}$$

$$\boxed{A_I = \infty}$$

④ Small signal i/p resistance:-



$$R_i = \frac{V_x}{I_x} = \frac{V_x}{0} = \infty$$

$$\boxed{R_i = \infty}$$

Problem with common source amplifier:-

$$A_V = -g_m R_D \quad [\lambda = 0,\ r_0 = \infty]$$

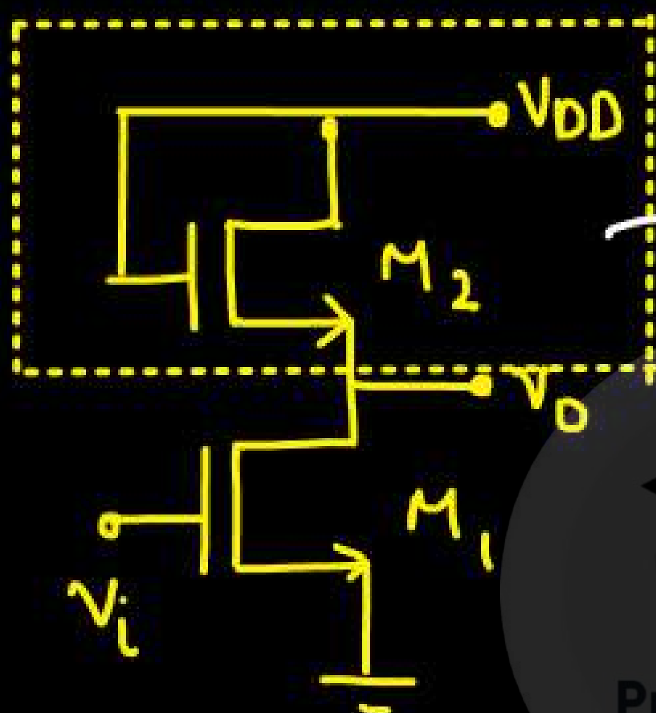
$$\boxed{A_V = -\sqrt{\frac{2\mu_n C_{ox} W}{L} I_D} \times R_D}$$

$$\boxed{\begin{aligned} A_V &= f(I_D) \\ I_D &= g(T) \\ A_V &= h(T) \end{aligned}}$$

$$\boxed{T\uparrow \Rightarrow I_D\uparrow}$$

Because of Temp. change, the gain can change ⇒ NOT Desirable

Using diode connected load in common Source Amplifier:-



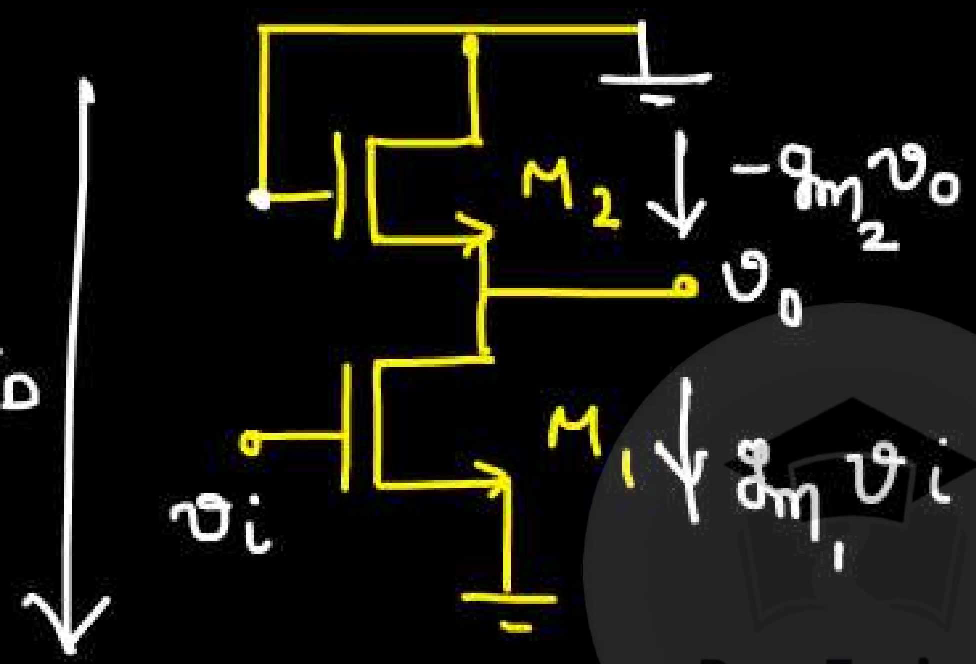
→ diode connected load.

→

Small signal Analysis:-

Assuming $[\lambda = 0]$

$I_{D_1} = I_{D_2} = I_D$



$(V_{gs})_{M_2} = 0 - v_o$

$$g_{m_1} v_i = -g_{m_2} v_o$$

$$\boxed{\frac{v_o}{v_i} = -\frac{g_{m_1}}{g_{m_2}}} \rightarrow \text{small signal gain}$$

$$A_v = \frac{-g_{m_1}}{g_{m_2}}$$

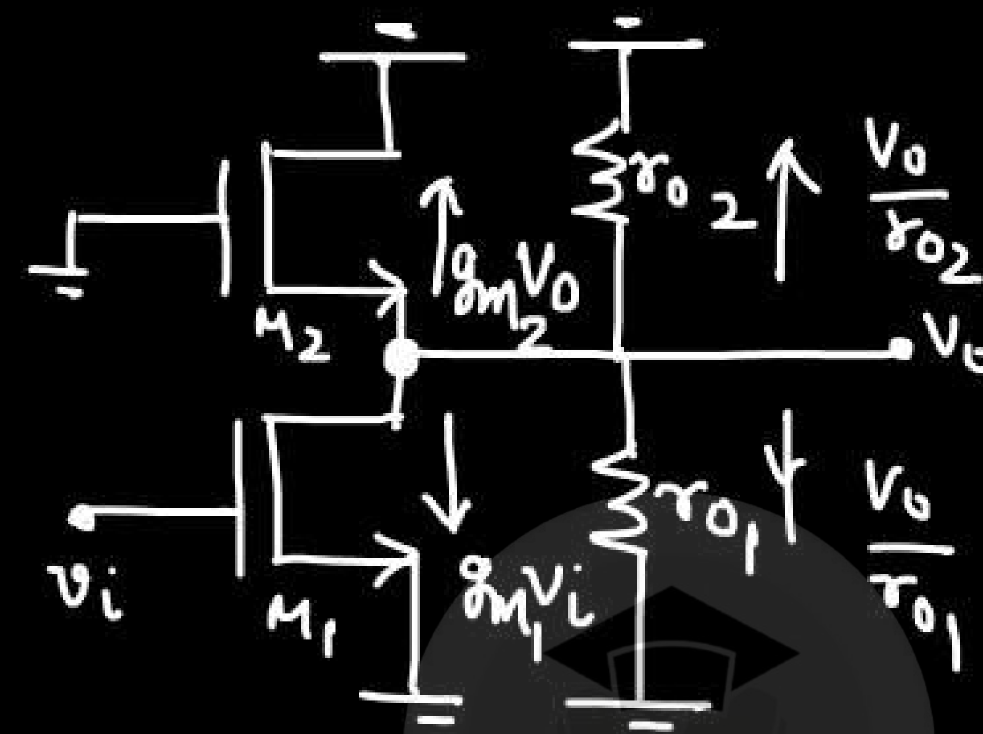
$$A_v = \frac{\sqrt{2\left(\frac{\mu_n C_{ox} W}{L}\right)_{M_1} I_{D_1}}}{\sqrt{2\left(\frac{\mu_n C_{ox} W}{L}\right)_{M_2} I_{D_2}}}$$

Here $I_{D_1} = I_{D_2} = I_D$

$$\boxed{A_v = \frac{\sqrt{(W/L)_1}}{\sqrt{(W/L)_2}}}$$ → constant gain

$$\boxed{\frac{W}{L} \neq f(T)}$$

$\Rightarrow$ Small signal gain considering $\lambda \neq 0$



KCL @ v_o :-

$$g_{m_2}v_o + g_{m_1}v_i + \frac{v_o}{r_{o_2}} + \frac{v_o}{r_{o_1}} = 0$$

$$v_o\left[\underbrace{g_{m_2} + \frac{1}{r_{o_2}} + \frac{1}{r_{o_1}}}\right] = -g_{m_1}v_i$$

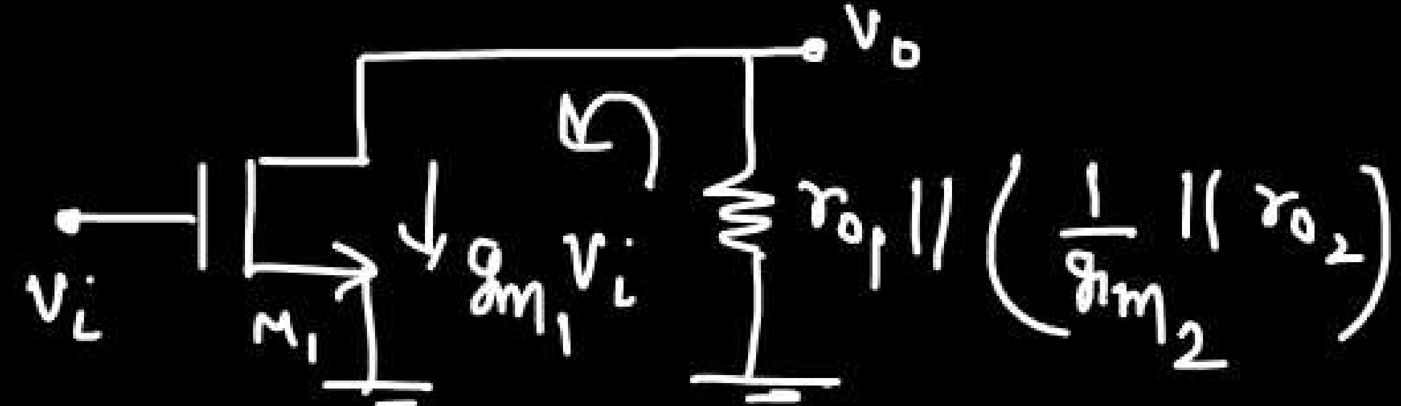
$$\frac{v_o}{\left[\frac{1}{g_{m_2}} \| r_{o_1} \| r_{o_2}\right]} = -g_{m_1}v_i$$

$$\boxed{\frac{v_o}{v_i} = -g_{m_1}\left[\frac{1}{g_{m_2}} \,||\, r_{o_1} \,||\, r_{o_2}\right]} \rightarrow \text{small signal gain}$$

if $r_{o_1} = r_{o_2} = \infty$

$$\boxed{\frac{v_o}{v_i} = \frac{-g_{m_1}}{g_{m_2}}}$$

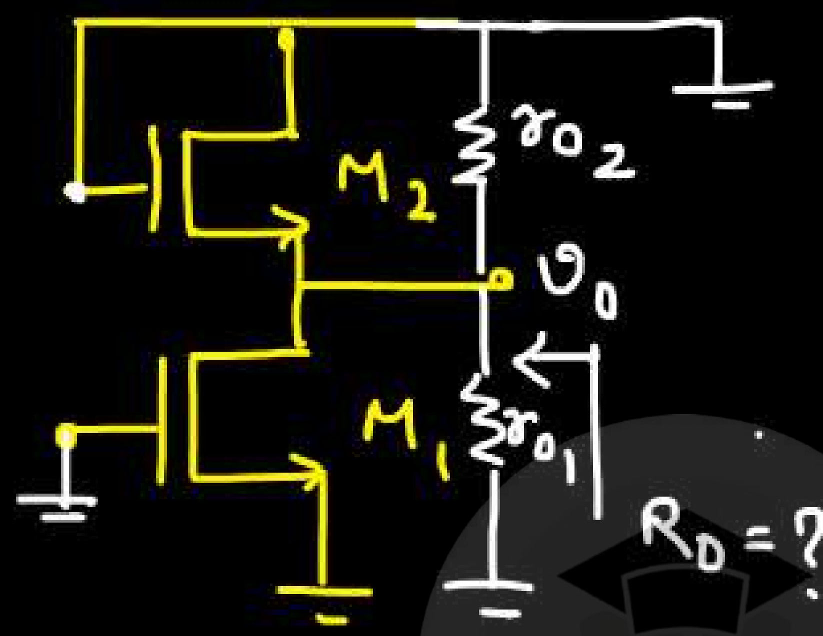
M-II



$$V_o = -g_{m_1}\left[r_{o_1} \,||\, \frac{1}{g_{m_2}} \,||\, r_{o_2}\right] v_i$$

$$\boxed{\frac{v_o}{v_i} = -g_{m_1}\left[r_{o_1} \,||\, r_{o_2} \,||\, \frac{1}{g_{m_2}}\right]}$$

o/p resistance:-

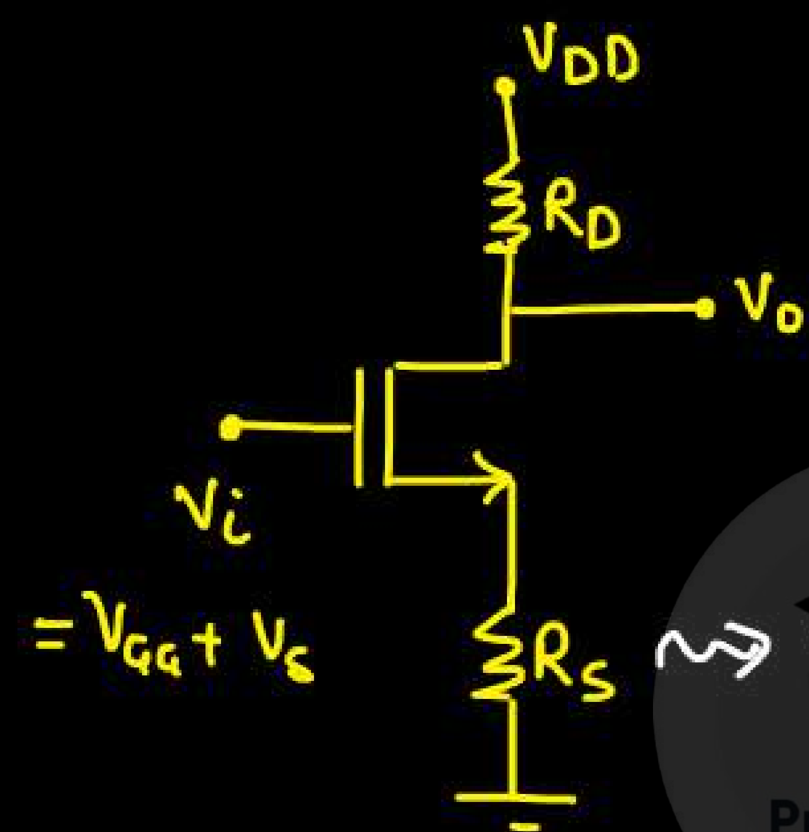


$$\boxed{R_o = r_{o1} \| r_{o2} \| \frac{1}{g_{m2}}}$$

if $\lambda = 0 \Rightarrow r_{o1} = r_{o2} = \infty$

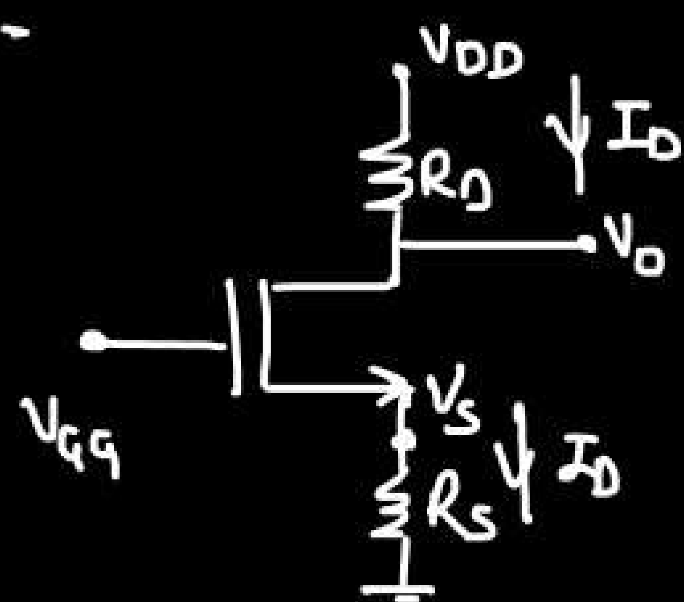
$$\boxed{R_o = \frac{1}{g_{m2}}}$$

Common source Amplifier with degeneration:-



$\rightsquigarrow$ degenration resistance

DC Analysis:-

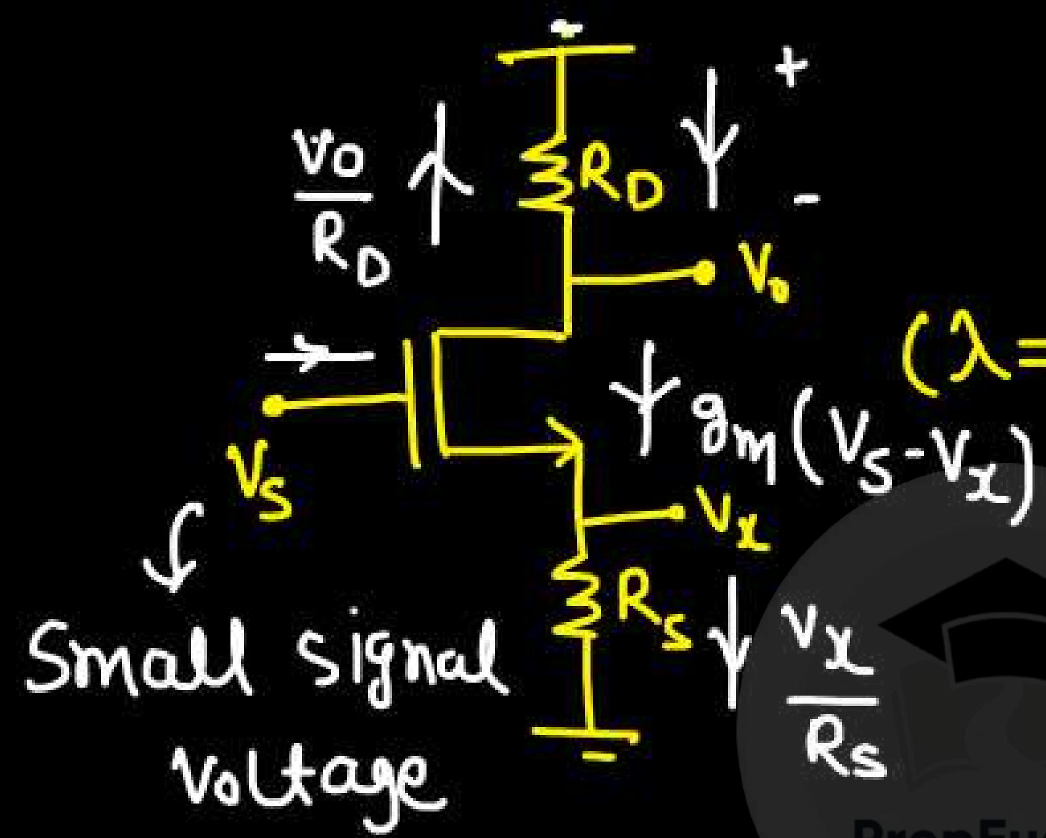


Let's assume, Because of Temp. $I_D \uparrow$

$I_D \uparrow \Rightarrow V_S \uparrow \Rightarrow V_{GS} \downarrow \Rightarrow I_D \downarrow$

$\Rightarrow$ $\boxed{\text{Stability achieved}}$

Small signal Analysis:-



$(\lambda = 0) \Rightarrow r_o = \infty$

$$V_o = -g_m(V_s - V_x) \times R_D$$

$$V_o = -g_m R_D (V_s - V_x) \quad \text{— (1)}$$

$$\frac{V_o}{R_D} = -\frac{V_x}{R_s} \quad \Rightarrow \quad V_x = -\frac{R_s}{R_D} V_o \quad \text{— (2)}$$

By eq^n 1 and 2

$$v_o = -g_m R_D \left[V_s + \frac{R_S}{R_D} v_o \right]$$

$$v_o = -g_m R_D V_s - g_m R_S v_o$$

$$v_o \left[1 + g_m R_S \right] = -g_m R_D v_s$$

$$\boxed{\frac{v_o}{V_s} = \frac{-g_m R_D}{1 + g_m R_S}}$$ → small signal voltage gain

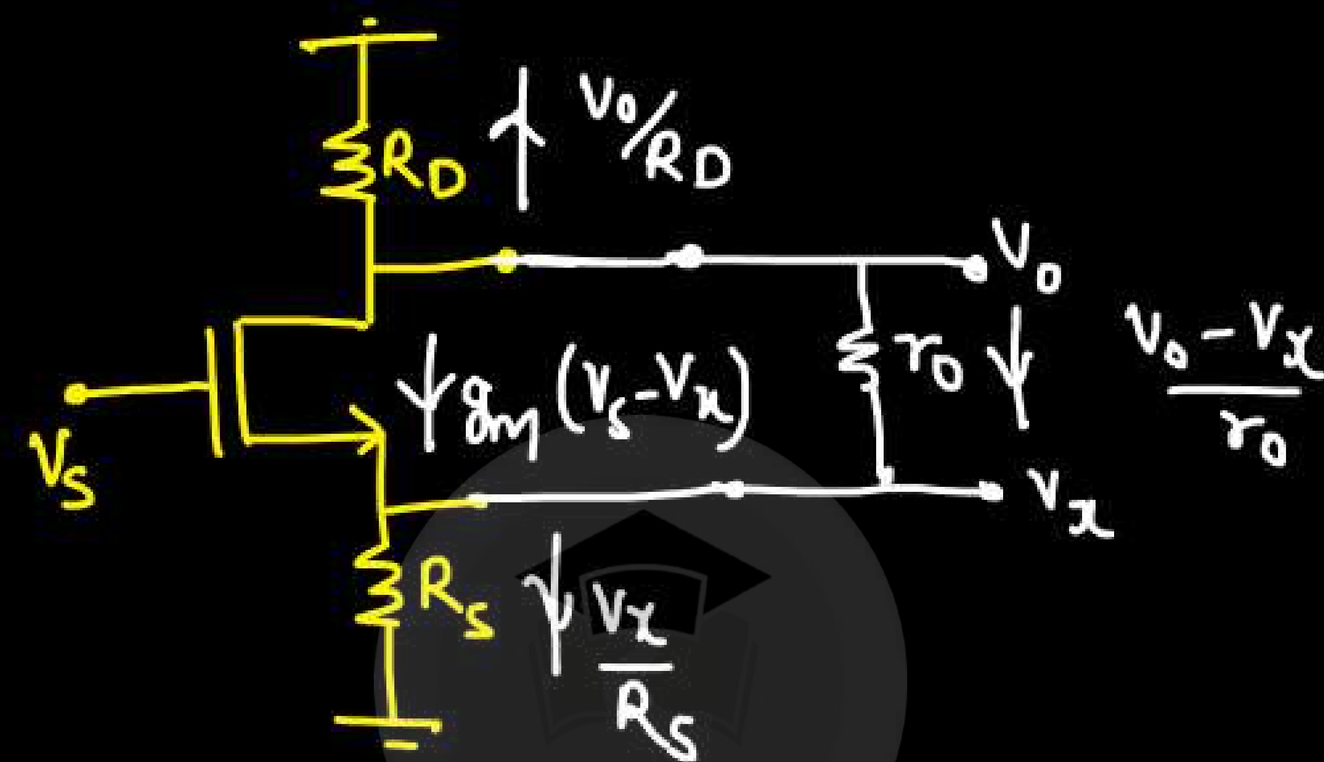
current gain:-

$$\boxed{A_I = \frac{I_o}{I_i} = \frac{I_o}{0} = \infty}$$

input Resistance:-

$$\boxed{R_{in} = \frac{V_i}{I_i} = \frac{V_i}{0} = \infty}$$

Voltage gain considering r_o :-



KCL @ V_o

$$g_m(V_s - V_x) + \frac{V_o}{R_D} + \frac{V_o - V_x}{r_o} = 0 \longrightarrow (1)$$

$$\frac{V_o}{R_D} = \frac{-V_x}{R_s} \quad \Rightarrow \quad V_x = \frac{-R_s}{R_D} V_o \longrightarrow (2)$$

By eq^n ① and ②

$$g_m\left(v_s + \frac{R_S}{R_D}v_o\right) + \frac{v_o}{R_D} + \frac{v_o}{r_o}\left[1 + \frac{R_S}{R_D}\right] = 0$$

$$g_m v_s + v_o\left[\frac{g_m R_S}{R_D} + \frac{1}{R_D} + \frac{1}{r_o} + \frac{R_S}{r_o R_D}\right] = 0$$

$$g_m v_s = -v_o\left[\frac{g_m r_o R_S + r_o + R_D + R_S}{r_o R_D}\right]$$

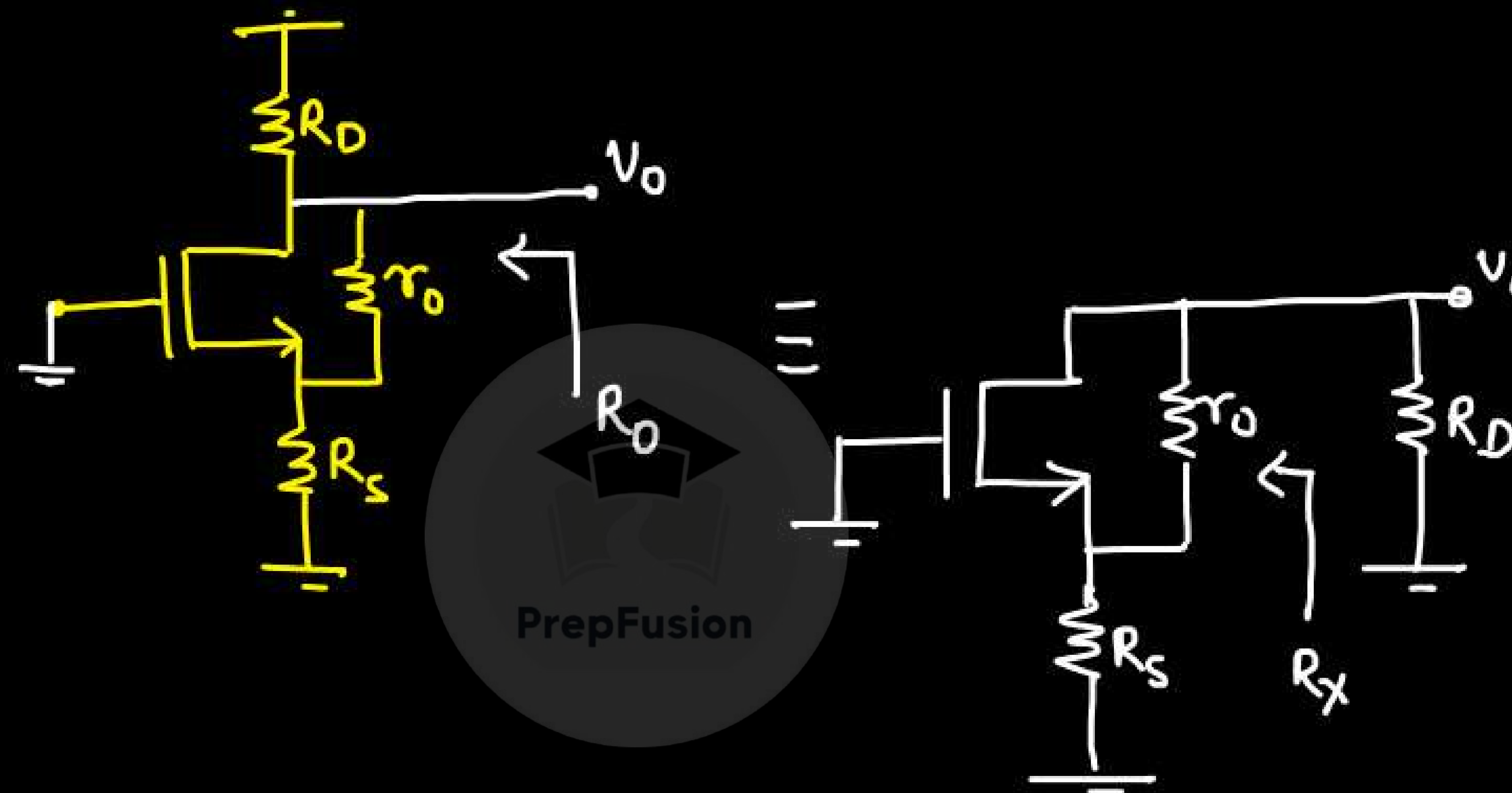
$$\boxed{\frac{v_o}{v_s} = -g_m R_D\left[\frac{r_o}{g_m r_o R_S + r_o + R_D + R_S}\right]}$$

if $r_o = \infty$ [very large]

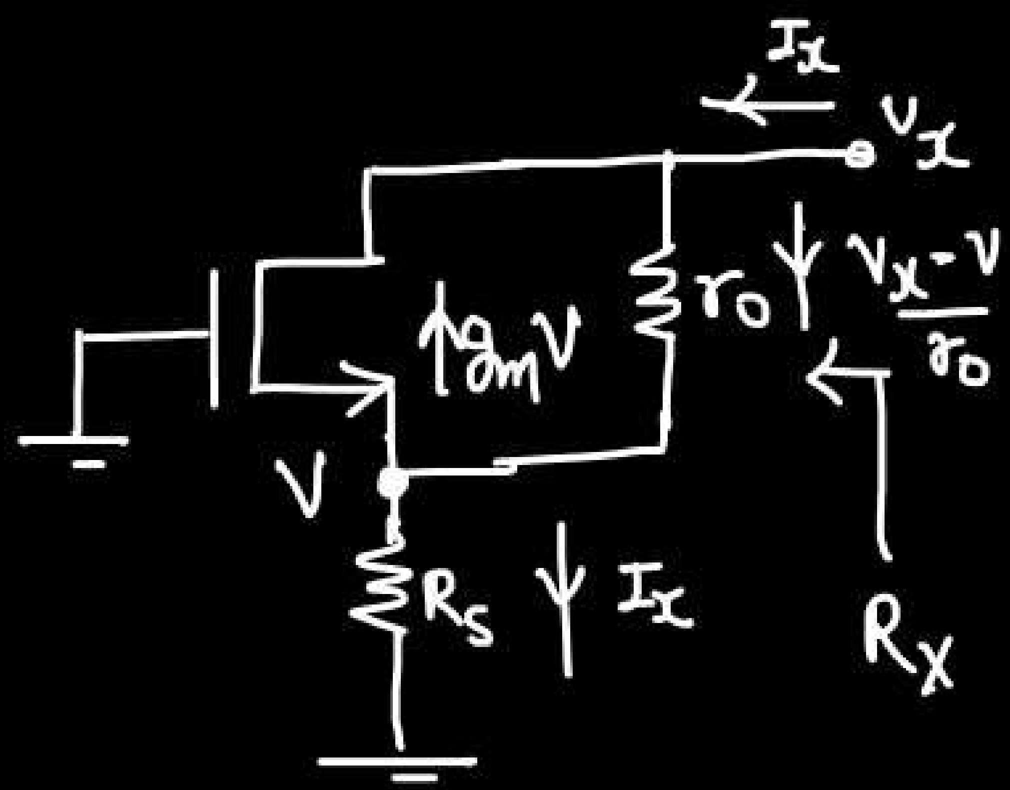
$$\frac{V_0}{V_S} = -g_m R_D \left[\frac{r_0}{g_m r_0 R_S + r_0}\right]$$

$$\boxed{\frac{v_0}{v_S} = \frac{-g_m R_D}{1 + g_m R_S}}$$

O/P resistance :-



$$\boxed{R_0 = R_D \| R_X}$$



$$R_x = \frac{V_x}{I_x}$$

Nodal @ V_x :-

$$I_x + g_m V = \frac{V_x - V}{r_0}$$

$$I_x r_0 + g_m r_0 V = V_x - V \quad \text{—} \quad (1)$$

$$V = I_x R_S \quad \text{—} \quad (2)$$

By eq^n 1 and 2

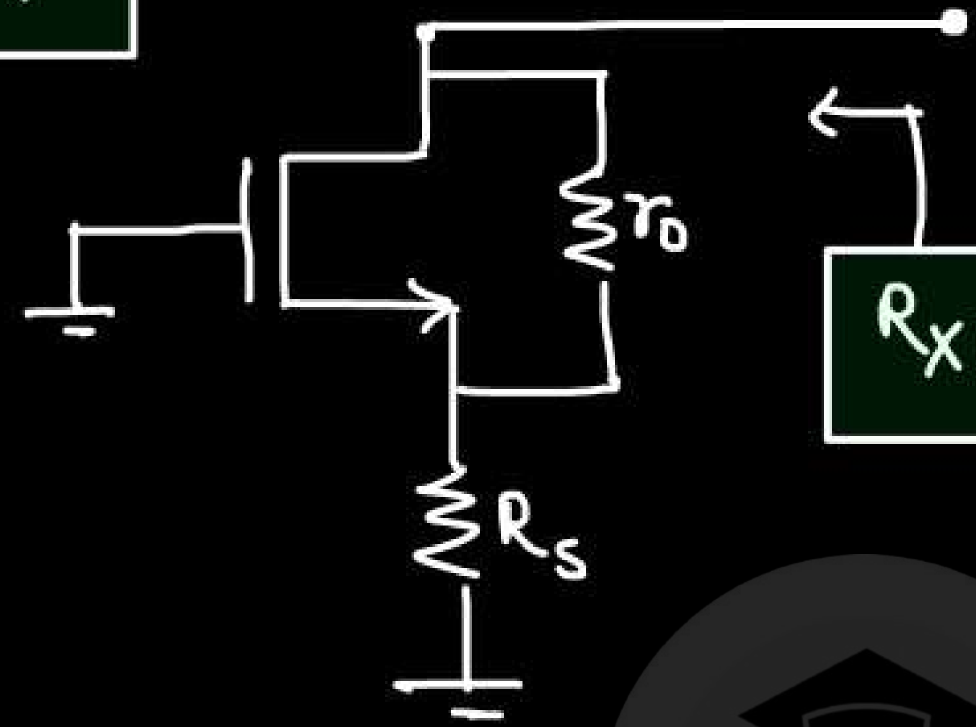
$$I_x r_o + g_m r_o [I_x R_S] = V_x - I_x R_S$$

$$I_x [r_o + g_m r_o R_S + R_S] = V_x$$

$$\boxed{R_x = \frac{V_x}{I_x} = R_S + r_o + g_m r_o R_S} \approx g_m r_o R_S \quad \{g_m r_o R_S >> R_S + r_o\}$$

$$\boxed{\begin{aligned} R_x &= R_S + (1 + g_m R_S) r_o \\ R_x &= r_o + (1 + g_m r_o) R_S \end{aligned}}$$

To REMEMBER:-



$$\boxed{R_X = r_o + R_S + g_m r_o R_S}$$

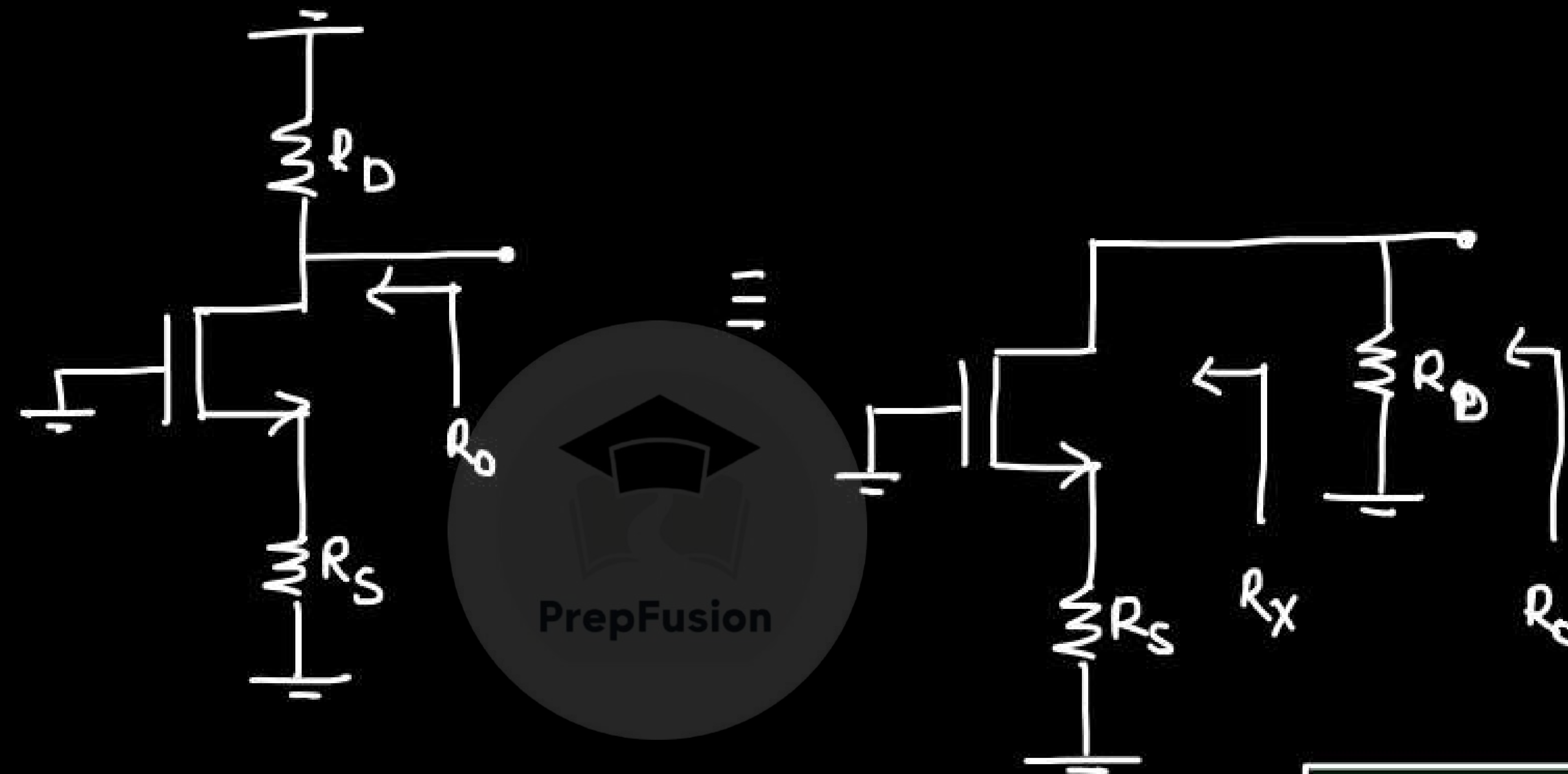
$$\approx g_m r_o R_S$$

O/P resistance:-

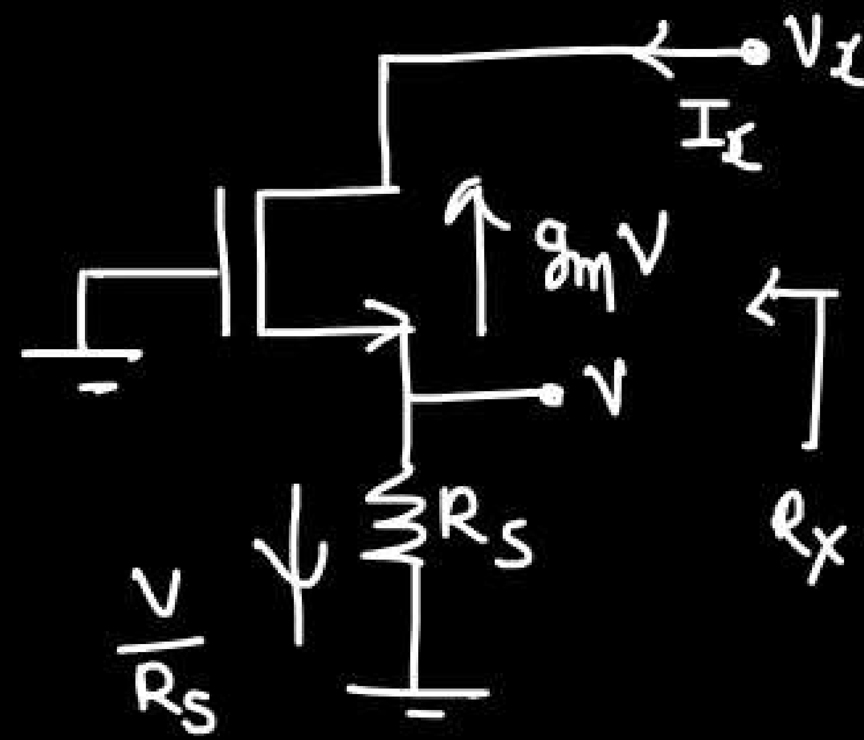
$$R_o = R_D \,||\, R_X$$

$$\boxed{R_o = R_D \,||\, (r_o + R_S + g_m r_o R_S)}$$

★ o/p resistance of common source with degeneration ($\lambda = 0$)



$$\boxed{R_o = R_D \,||\, R_X}$$



$$r_x = \frac{V_x}{I_x}$$

$$g_m V = -I_x \quad \text{—— (1)}$$

$$\frac{V}{R_S} = I_x \quad \text{—— (2)}$$

By eq^n (1) and (2)

$$g_m I_x R_s = -I_x$$

$$I_x\left[g_m R_S + 1\right] = 0$$

$$\boxed{I_x = 0}$$

$$\Rightarrow \boxed{r_x = \frac{V_x}{0} = \infty}$$

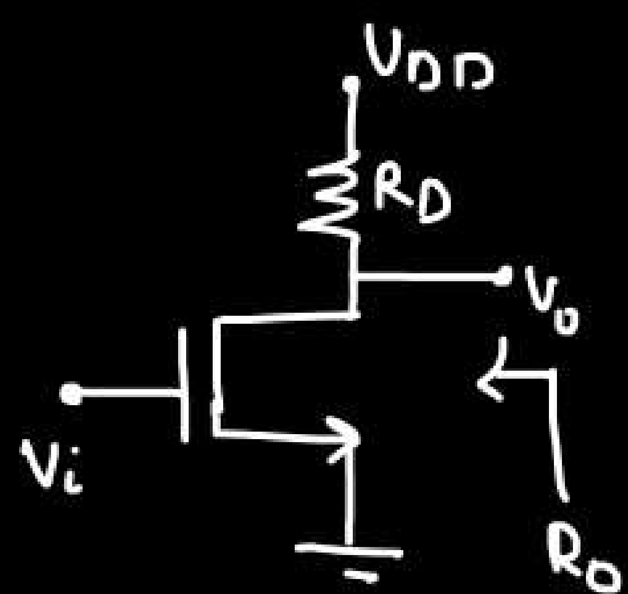
$$R_o = R_D \| r_x$$

$$R_o = R_D \| \infty$$

$$\boxed{R_o = R_D}$$

Common Source Amplifier:-

without degeneration

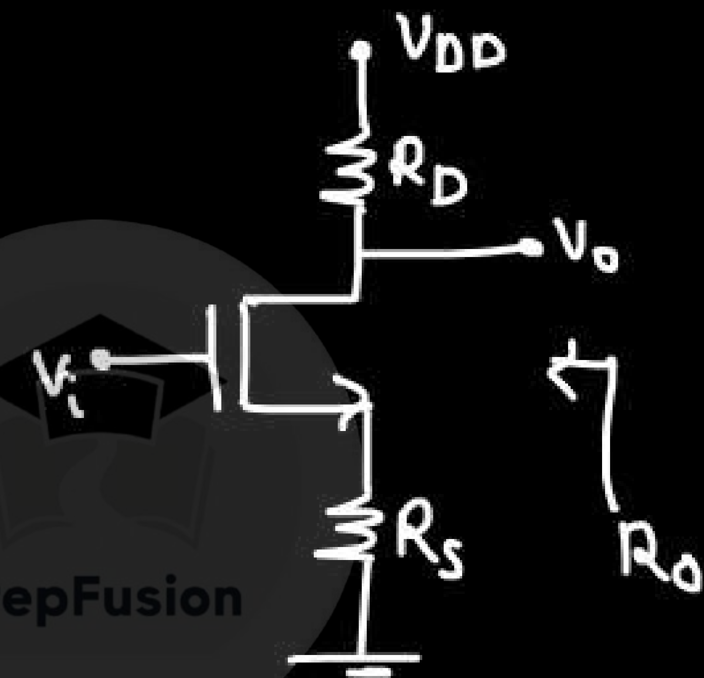


① Less stability

② $\frac{V_o}{V_i} = -g_m R_D \rightarrow$ more gain

③ $R_o = R_D \| r_o$

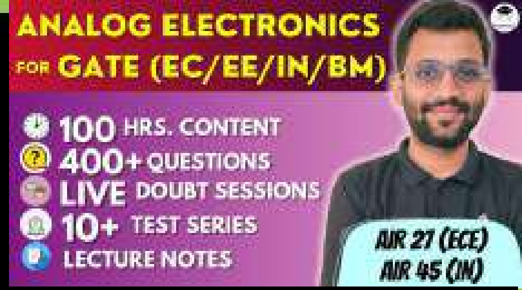
with degeneration



① Better stability

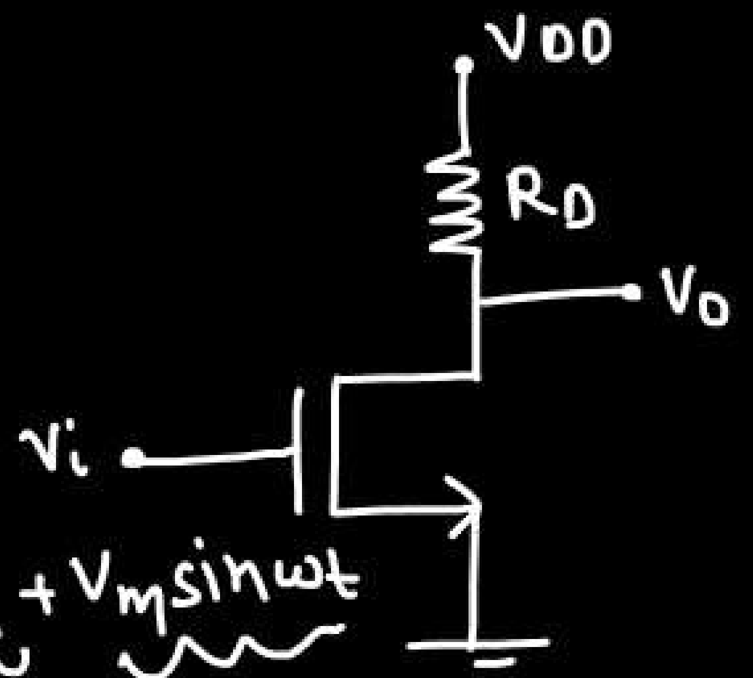
② $\frac{V_o}{V_i} = \frac{-g_m R_D}{1 + g_m R_S} \longrightarrow$ less gain

③ $R_{out} = R_D \| (R_S + r_o + g_m R_S r_o)$



Best way of biasing a Common Source Amplifier:-

* Previous biasing:-



$= V_{GG} + V_m \sin\omega t$

→ Here, for giving the dc bias, you need to use two supplies V_{DD} and V_{GG}

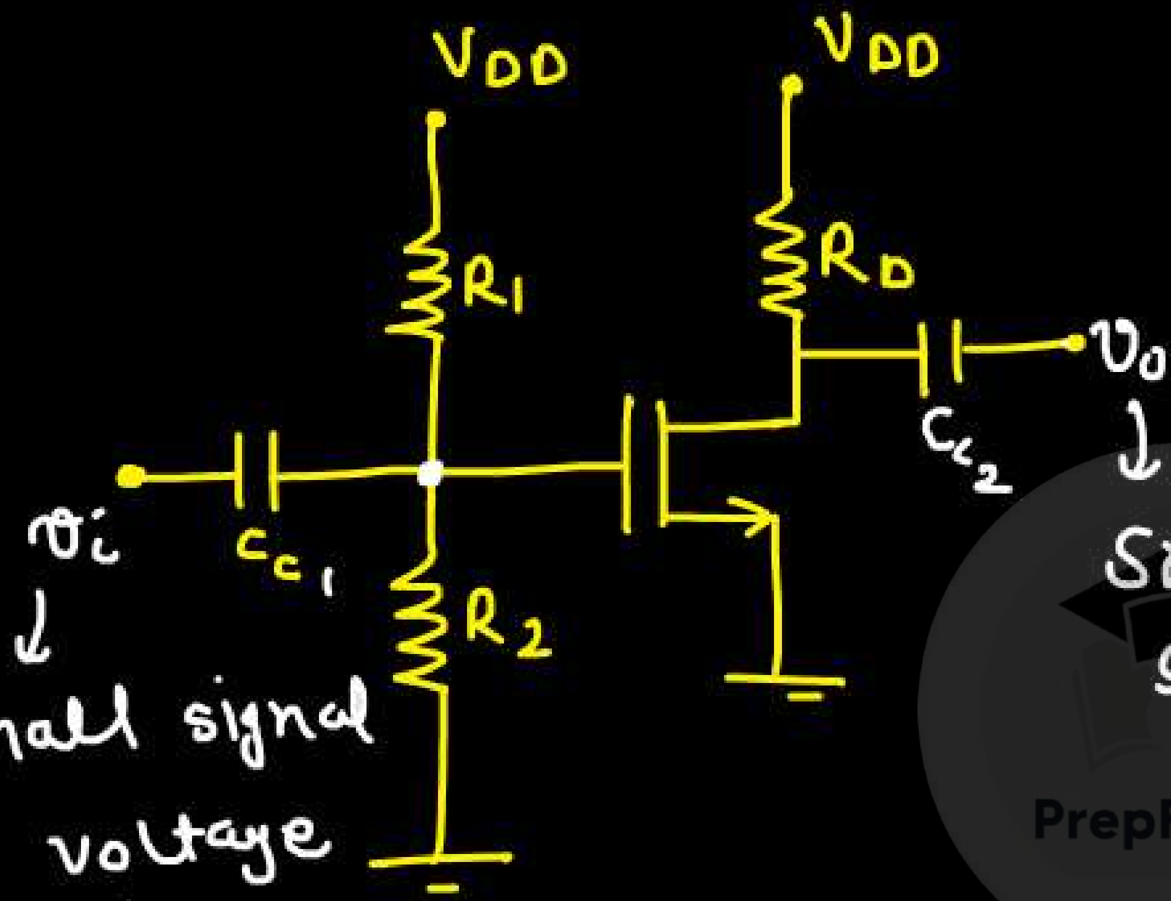
⇓

NOT DESIRABLE

⇒ I will use only one supply.

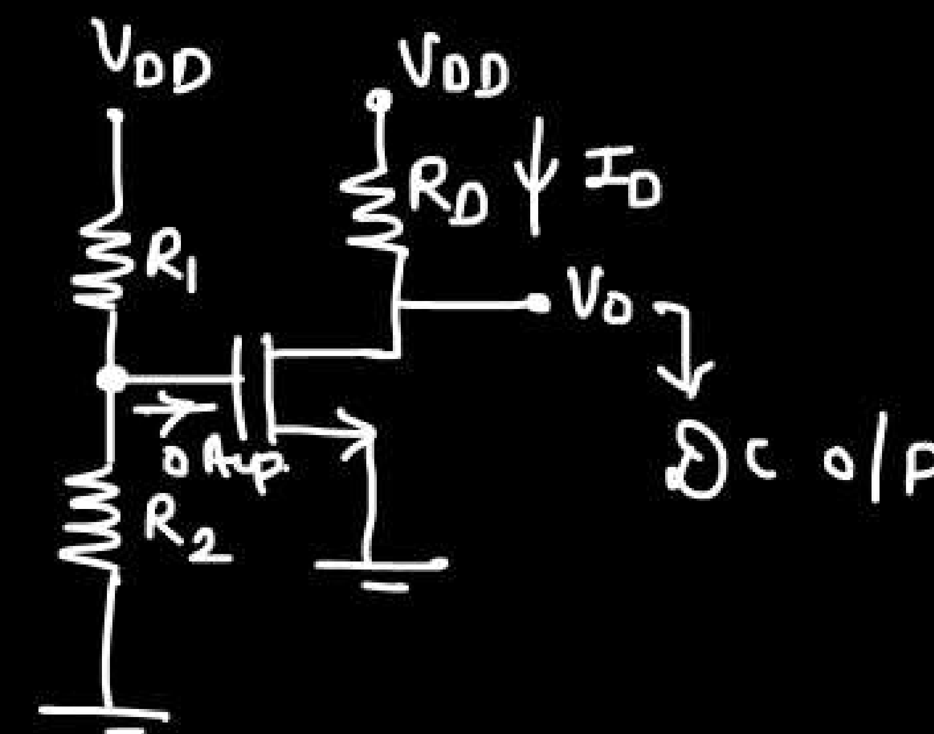
New way of biasing:-

(1)



small signal voltage $= V_m \sin \omega t$

DC Analysis:-



(1) Set R_1 and R_2; such that $V_{GS} > V_T$

$$\boxed{\frac{V_{DD} \times R_2}{R_2 + R_1} > V_T}$$

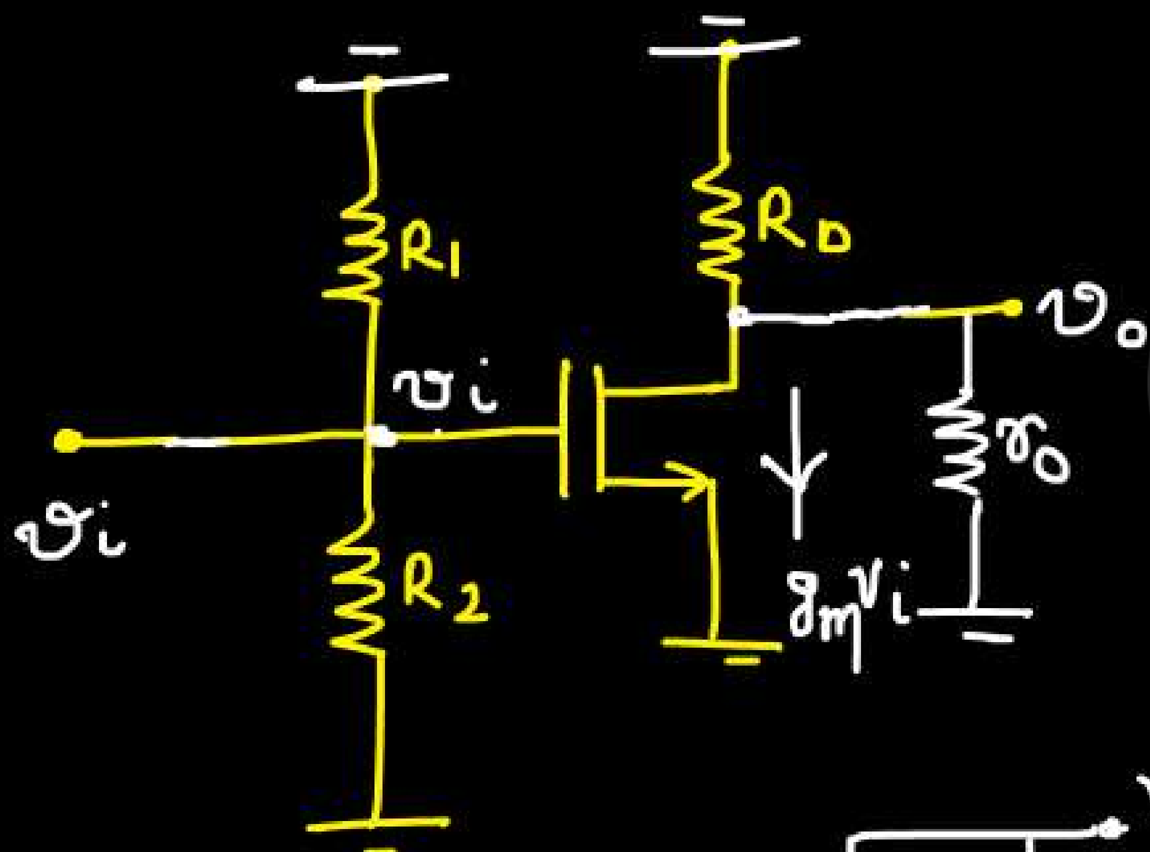
$$\boxed{V_{GS} = \frac{V_{DD} R_2}{R_2 + R_1}}$$

$$\boxed{I_D = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2}$$

$$\Rightarrow \boxed{V_0 = V_{DD} - I_D R_D}$$

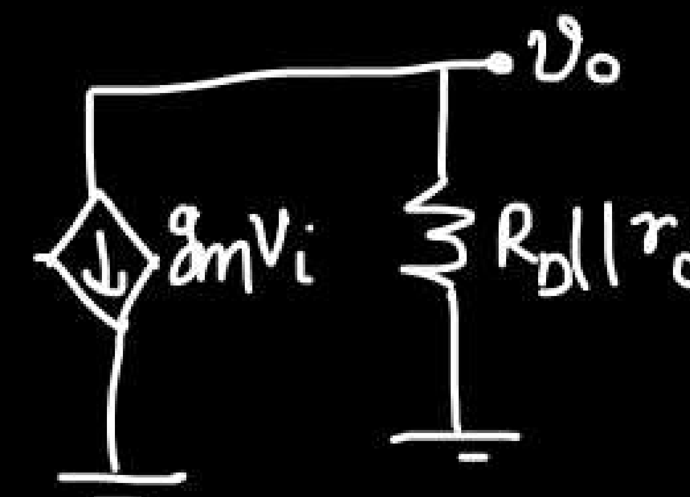
② Set R_2, R_1 and R_2 such that $\boxed{V_{DS} > V_{GS} - V_T}$ → Ensuring sat. region

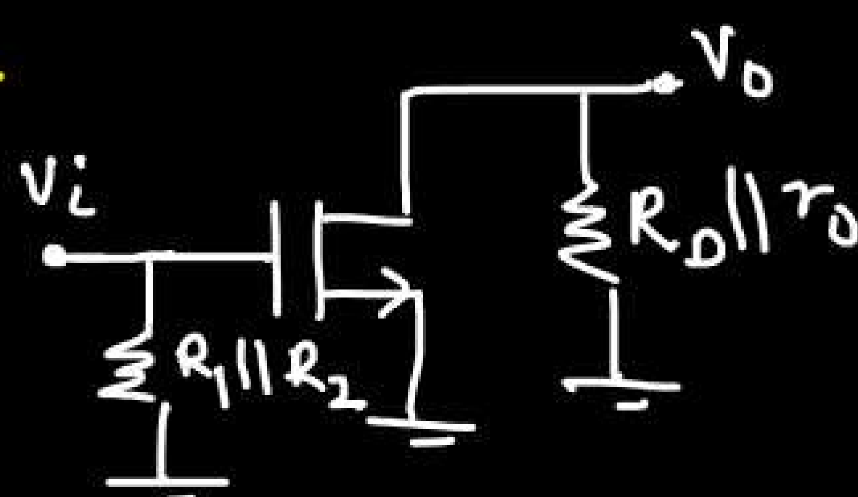
⇒ <u>AC Analysis:-</u>



$v_{gs} = v_i$

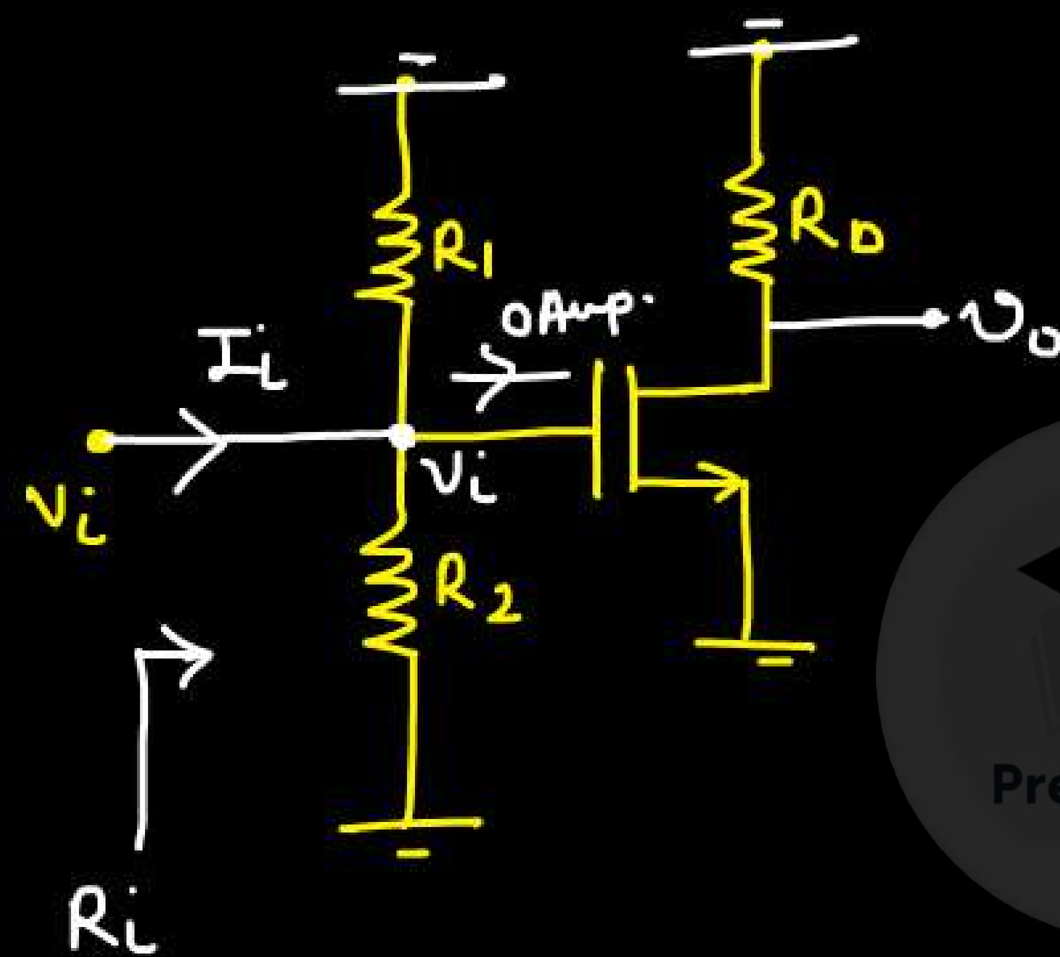
⇒





$$\boxed{\frac{v_o}{v_i} = -g_m (R_D \| r_o)}$$ → Voltage gain

Small signal i/p resistance:-



$$R_i = \frac{v_i}{I_i}$$

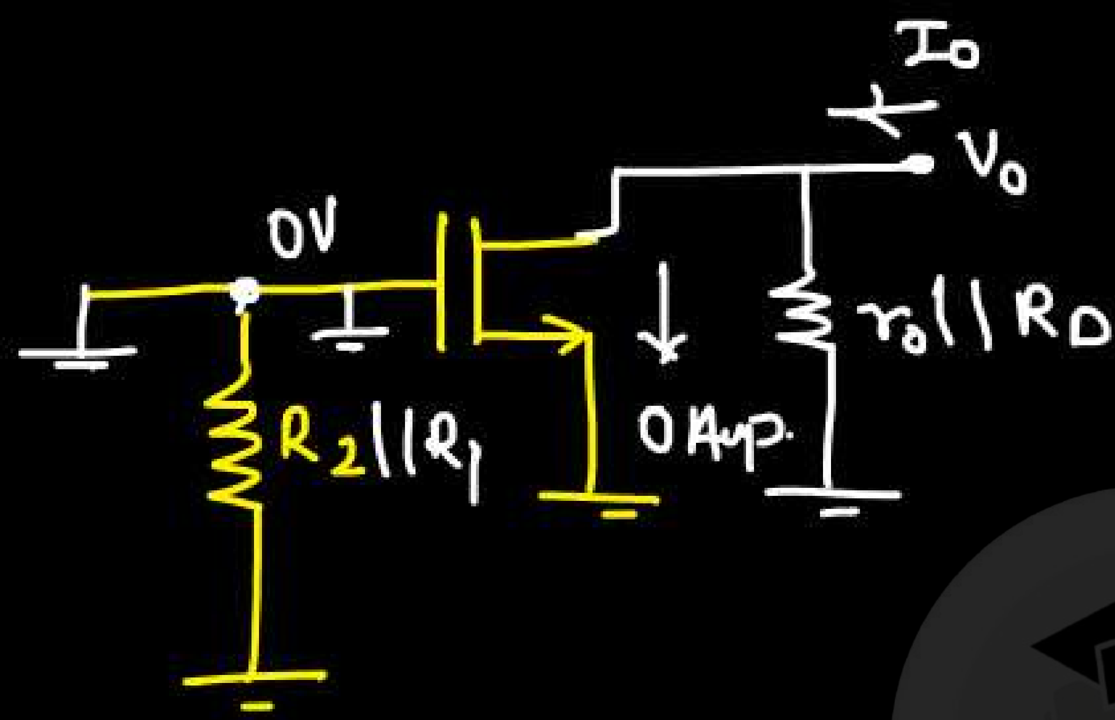
Nodal @ v_i

$$\frac{v_i}{R_1} + \frac{v_i}{R_2} = I_i$$

$$\frac{v_i}{I_i} = R_1 \| R_2$$

$$\boxed{R_i = R_1 \| R_2}$$

o/p resistance:-



$v_{gs} = 0V$

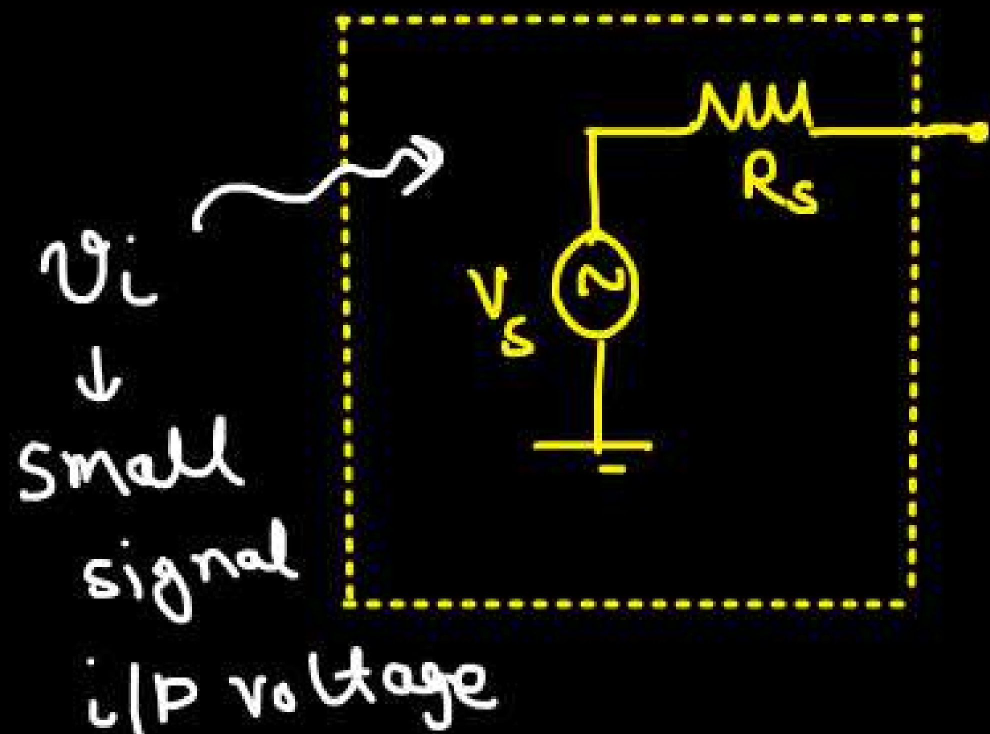
$$\boxed{R_{out} = r_o \| R_D}$$

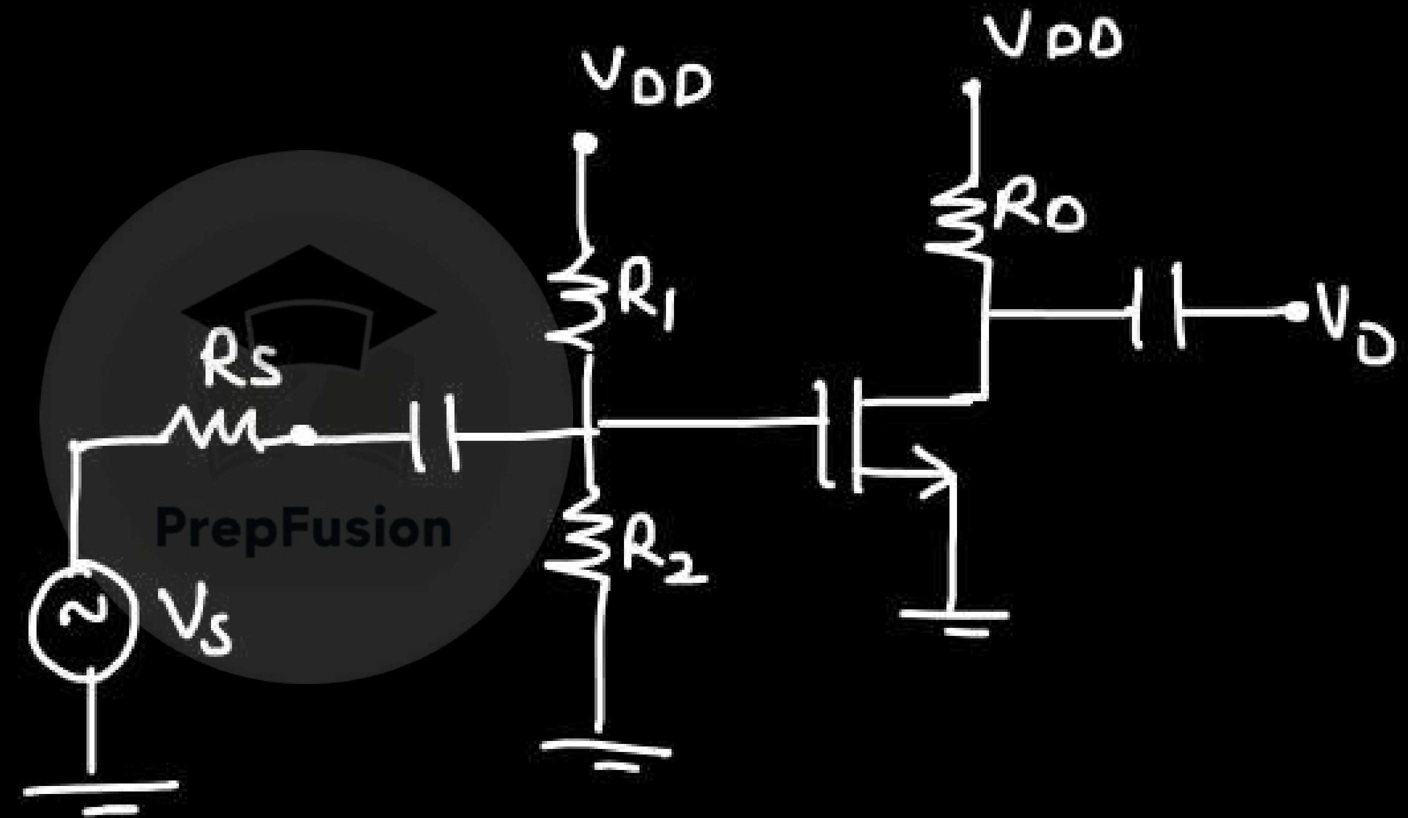
Why we use coupling capacitor (C_c)?

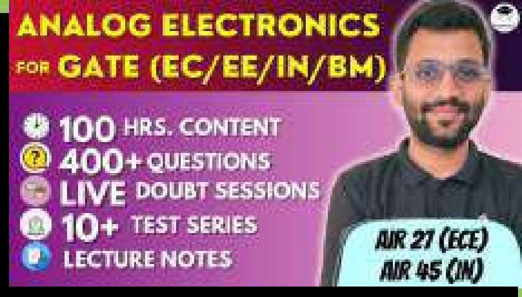
① Helps in isolating the dc bias setting.

② If you are cascading two or more stages, then only ac signal from the 1st stage will pass to the next stage while Dc is blocked.

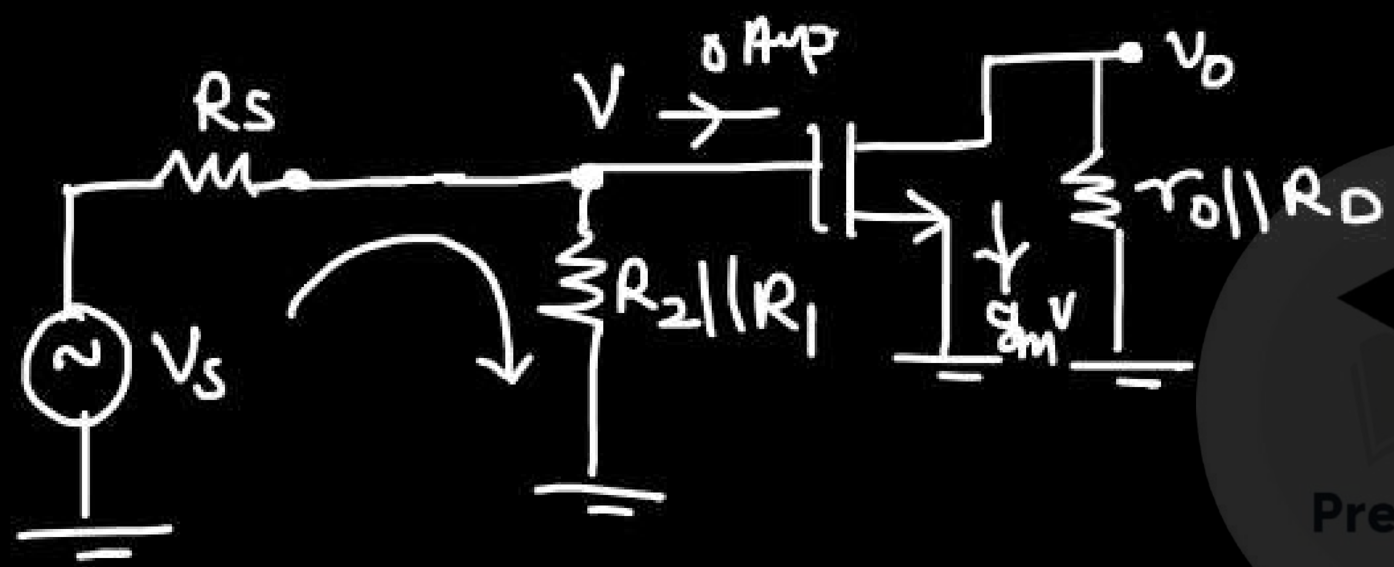
If small signal input source has some Resistance R_S.







Small Signal Analysis:-



$$V_0 = -g_m V \, [R_D || r_0]$$

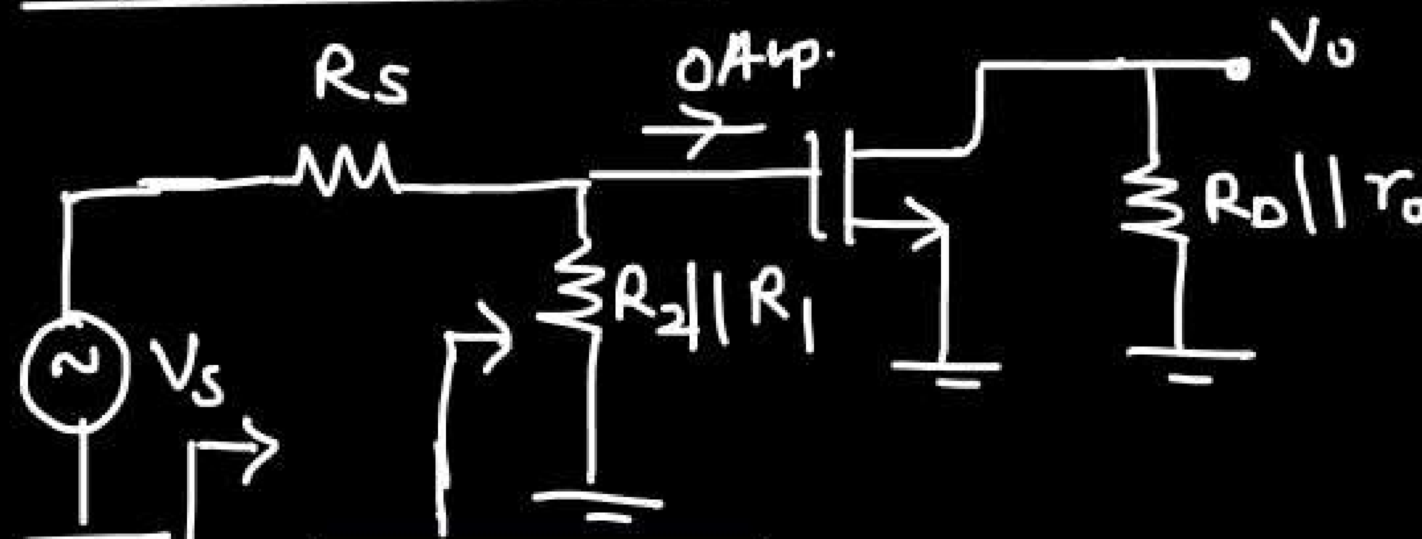
$$\boxed{V_0 = -g_m \, [R_D || r_0] \, V} \quad \text{— ①}$$

$$\boxed{V = \frac{R_2 || R_1}{(R_2 || R_1) + R_s} \times V_s} \quad \text{— ②}$$

$$\boxed{A_V = \frac{V_0}{V_s} = -g_m \, [R_D || r_0] \times \frac{[R_2 || R_1]}{[R_2 || R_1] + R_s}}$$

→ Voltage gain

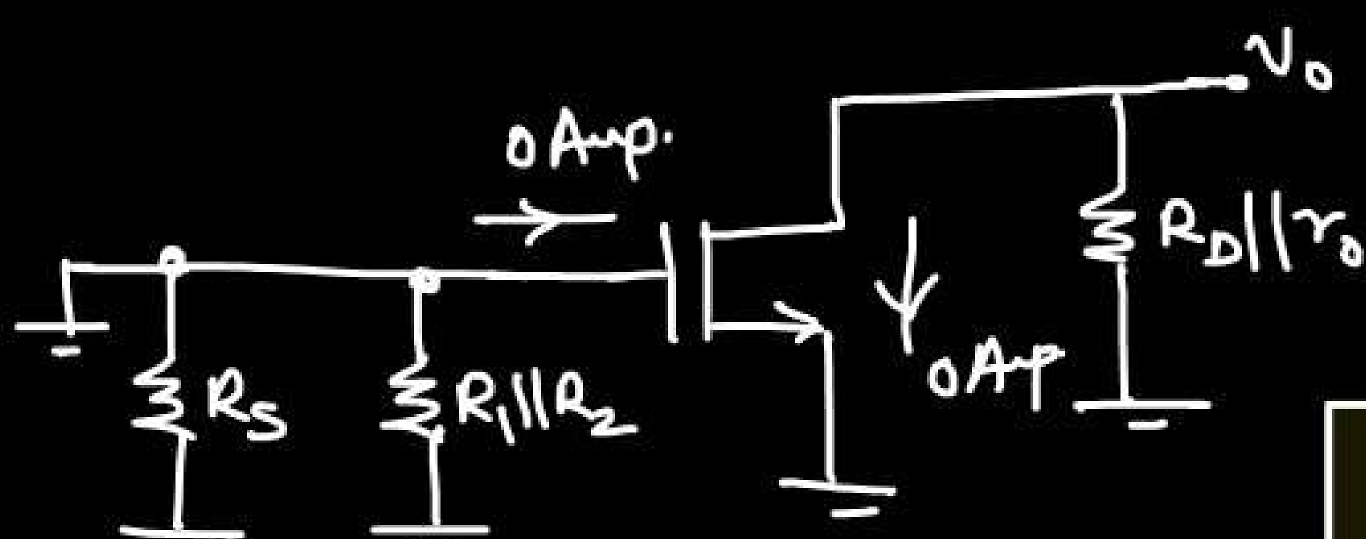
input resistance:-



$$\boxed{R_{i_2} = R_1 \| R_2}$$

$$\boxed{R_{i_1} = R_s + R_1 \| R_2}$$

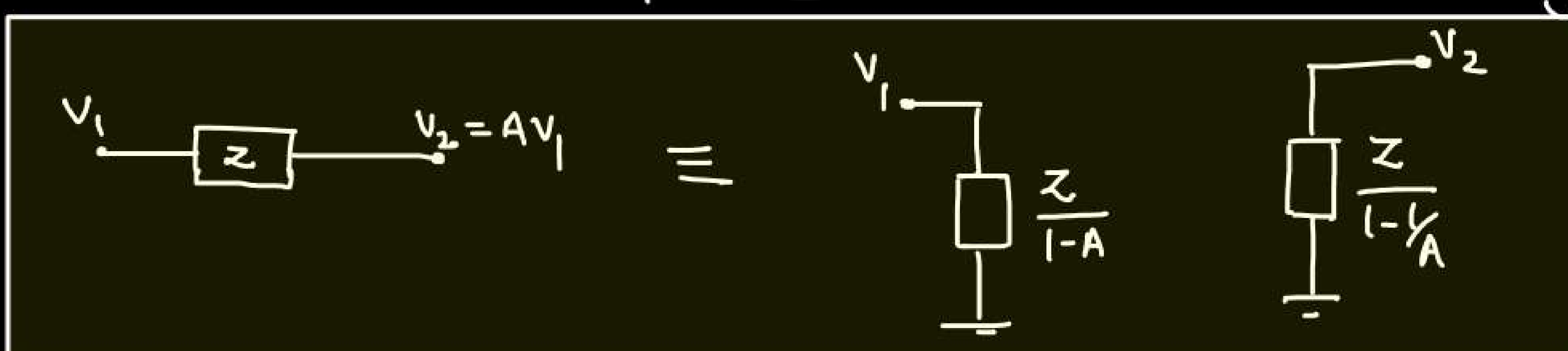
output resistance:-



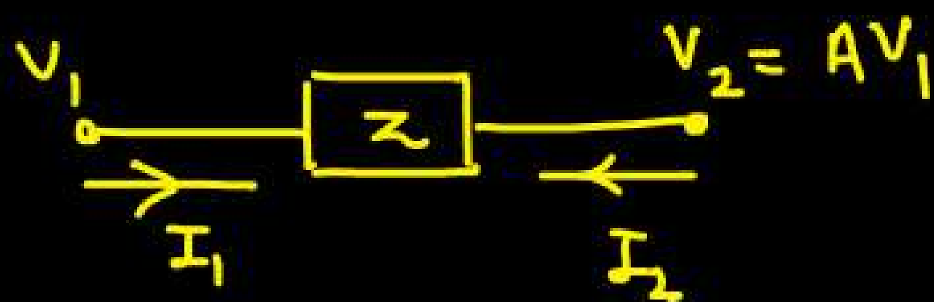
$$\boxed{R_o = R_D \| r_o}$$

Miller's Theorem :-

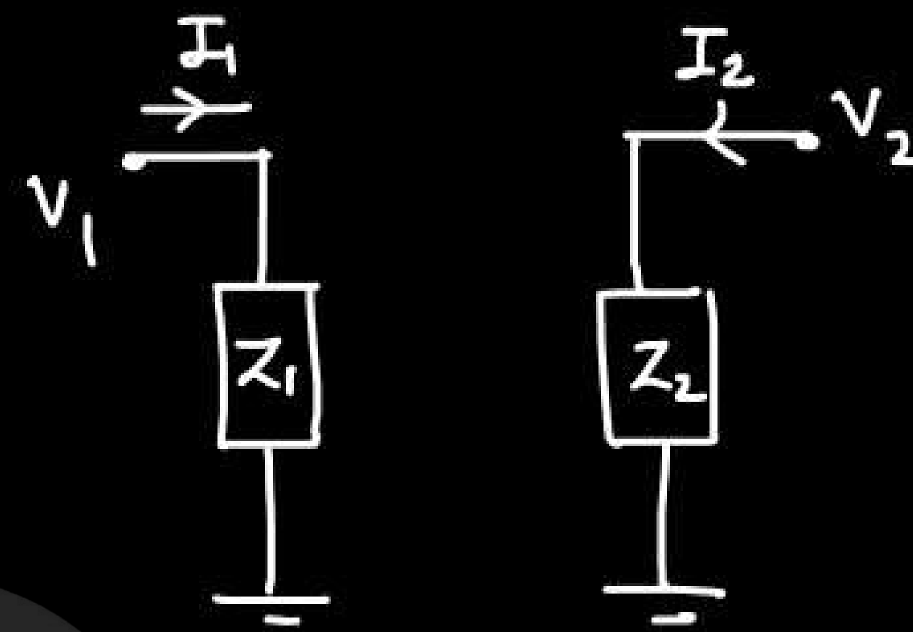
In a linear ckt, if there exist a branch with impedance Z, connecting two nodes with nodal voltage V_1 and V_2. We can replace this branch by two branches connecting the corresponding to ground by impedance respectively $\frac{Z}{1-A}$ and $\frac{Z}{1-\frac{1}{A}}$; where $A = V_2/V_1$



Derivation:-



$\equiv$



$$I_1 = -I_2$$

$$\boxed{Z_1 = \frac{V_1}{I_1}}$$

$$\frac{V_1 - V_2}{Z} = I_1$$

$$\frac{V_1 - AV_1}{Z} = I_1$$

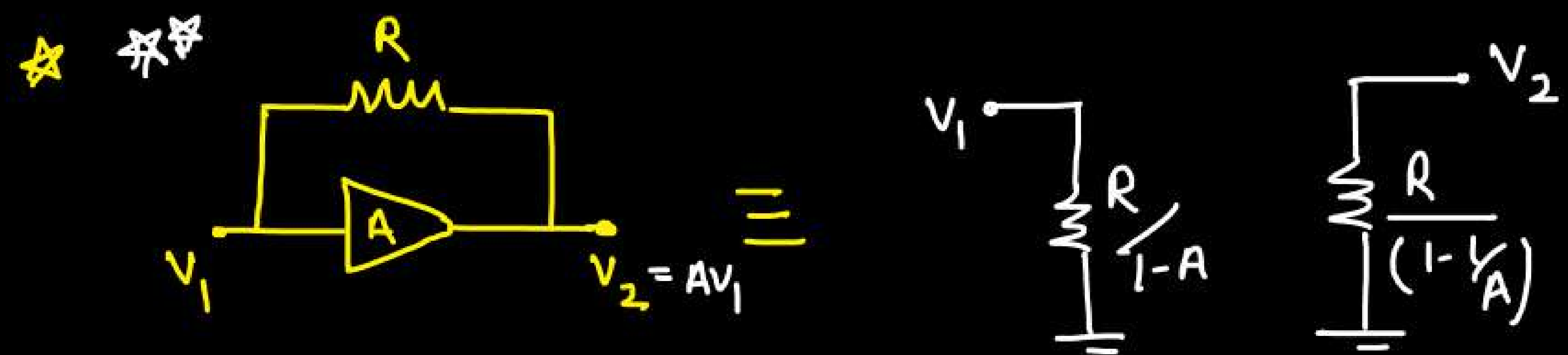
$$\boxed{\frac{V_1}{I_1} = \frac{Z}{1-A} = Z_1}$$

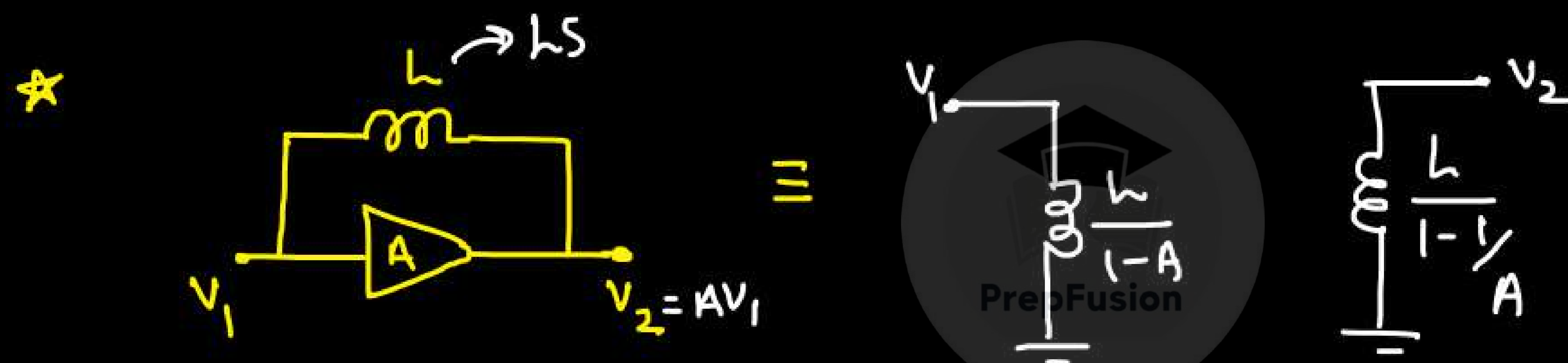
$$\boxed{Z_2 = \frac{V_2}{I_2}}$$

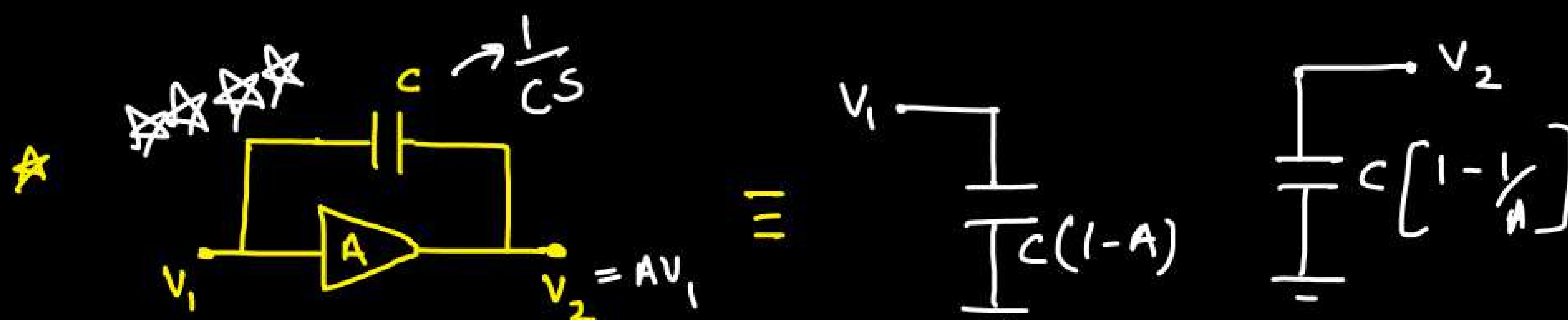
$$\frac{V_2 - V_1}{Z} = I_2$$

$$\frac{V_2 - V_2/A}{Z} = I_2$$

$$\boxed{\frac{V_2}{I_2} = \frac{Z}{1 - 1/A} = Z_2}$$

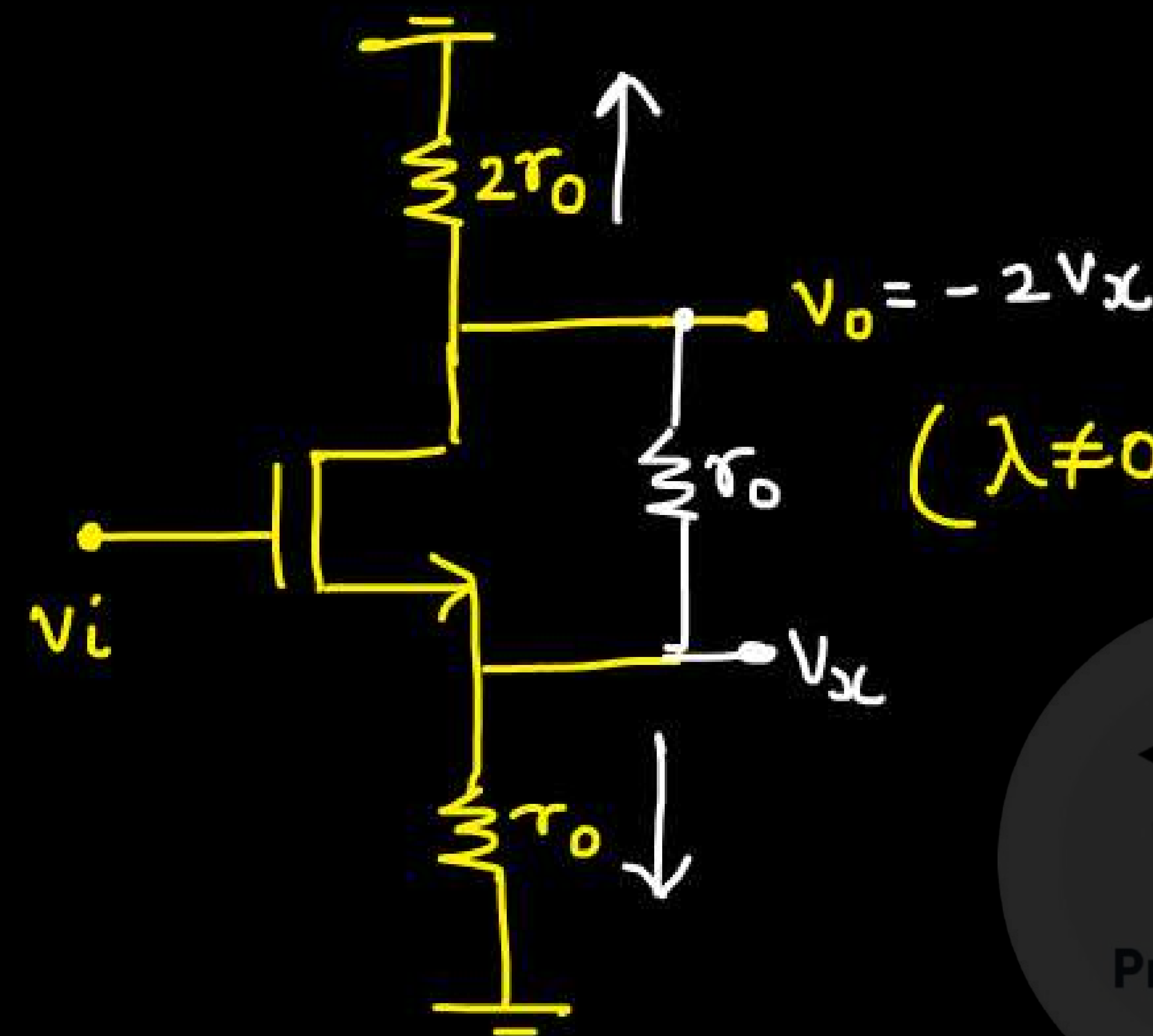

R
A
V_1
$V_2 = AV_1$
≡
V_1
$R/(1-A)$
V_2
$R/(1-1/A)$


L → LS
A
V_1
$V_2 = AV_1$
≡
V_1
$L/(1-A)$
V_2
$L/(1-1/A)$

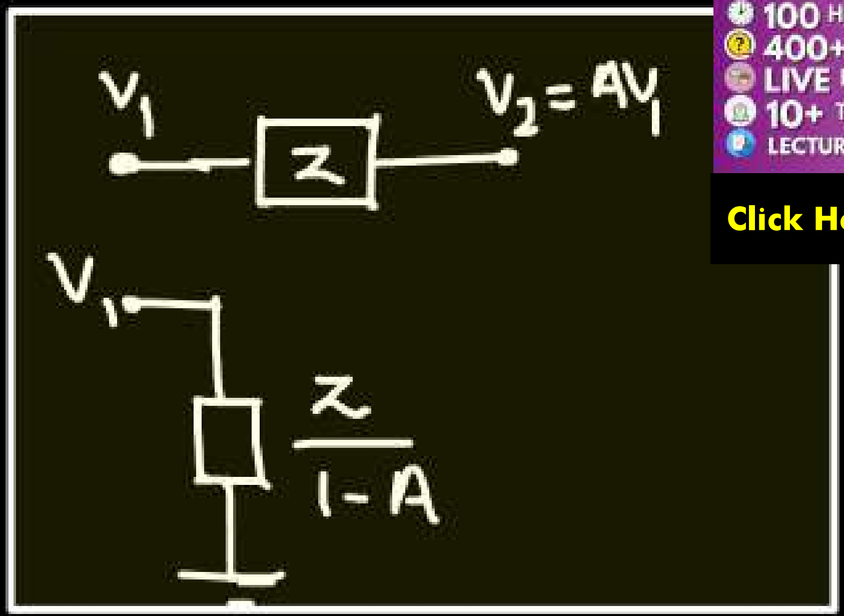

C → 1/CS
A
V_1
$V_2 = AV_1$
≡
V_1
$C(1-A)$
V_2
$C[1-1/A]$

1

Eg.



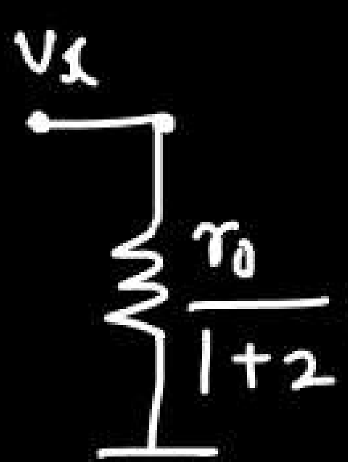
$(\lambda \neq 0,\ r_o = \text{finite})$



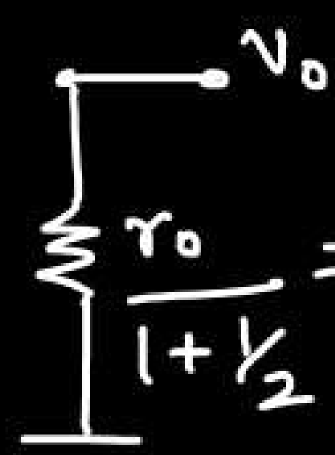
$$\frac{V_x}{r_o} = -\frac{V_o}{2r_o}$$

$$\frac{V_o}{V_x} = -2 \Rightarrow \boxed{V_o = -2V_x}$$

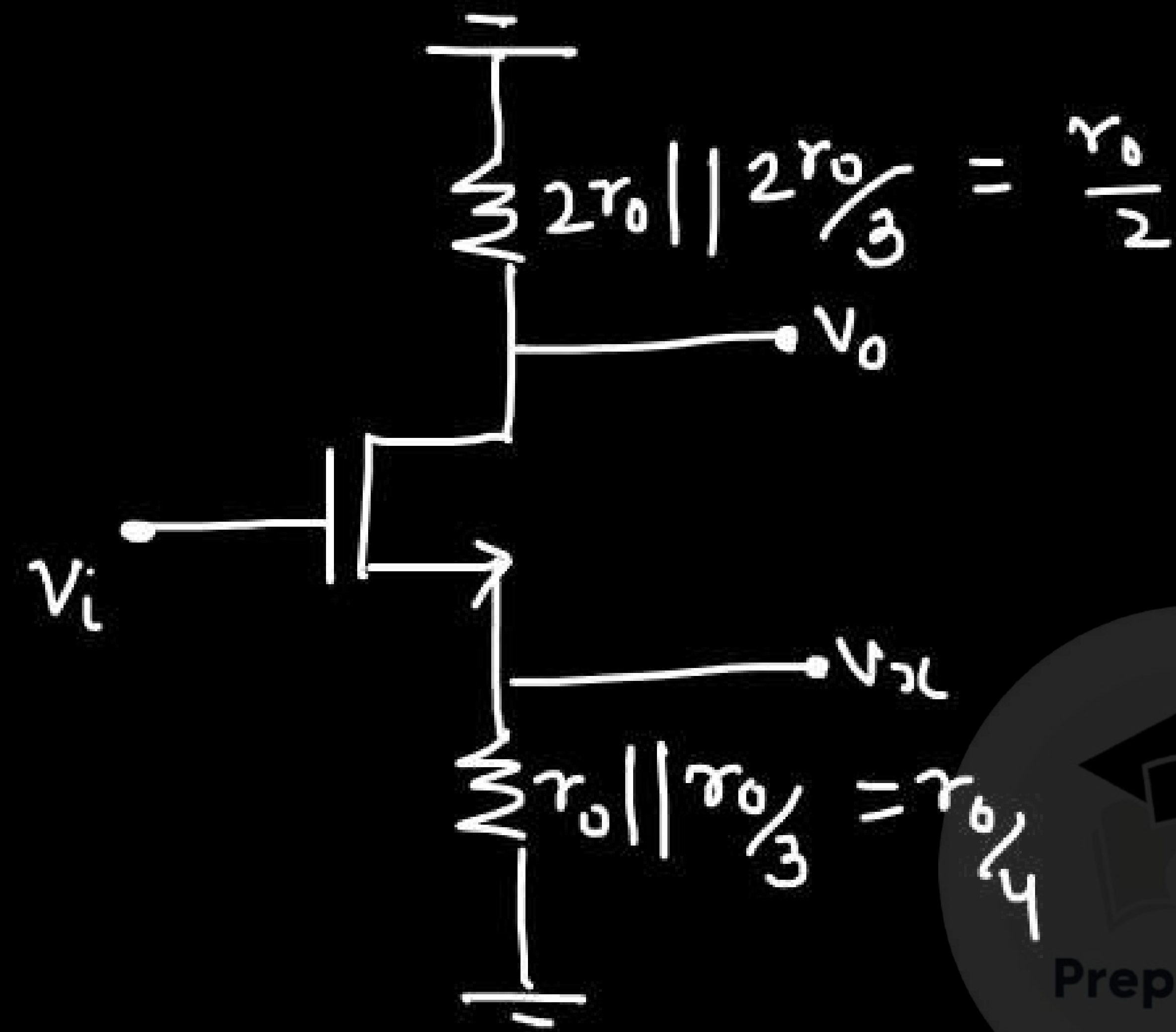
$$\boxed{A = -2}$$



$$\frac{r_0}{1+2} = r_0/3$$



$$\frac{r_0}{1+1/2} = \frac{2r_0}{3}$$

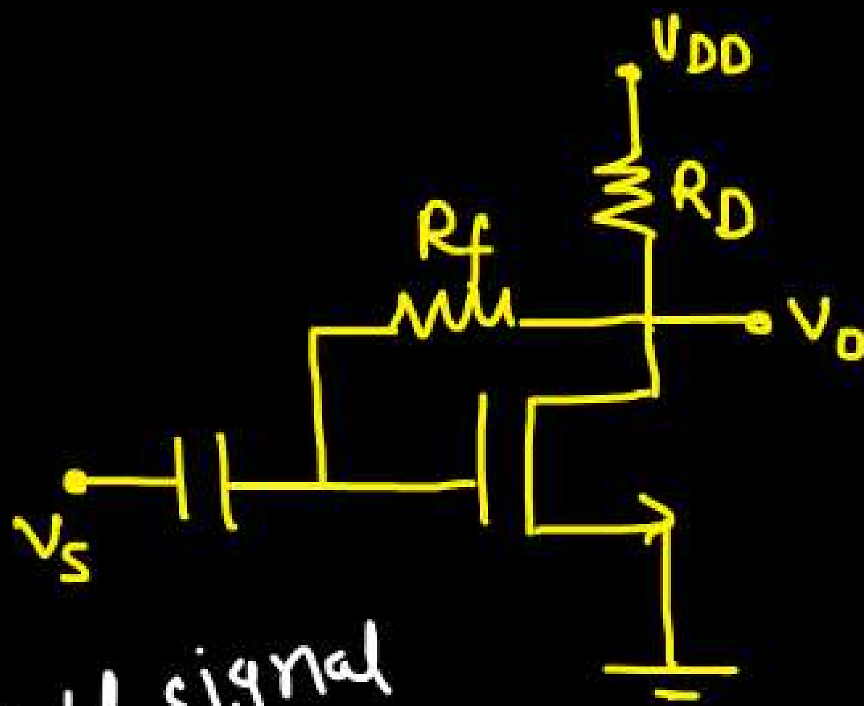


$$\frac{v_0}{v_i} = \frac{-g_m\left[r_0/2\right]}{1 + g_m\left[r_0/4\right]}$$

$$= \frac{-g_m r_0/2}{\frac{4 + g_m r_0}{4}}$$

$$\boxed{\frac{v_0}{v_i} = \frac{-2g_m r_0}{4 + g_m r_0}}$$

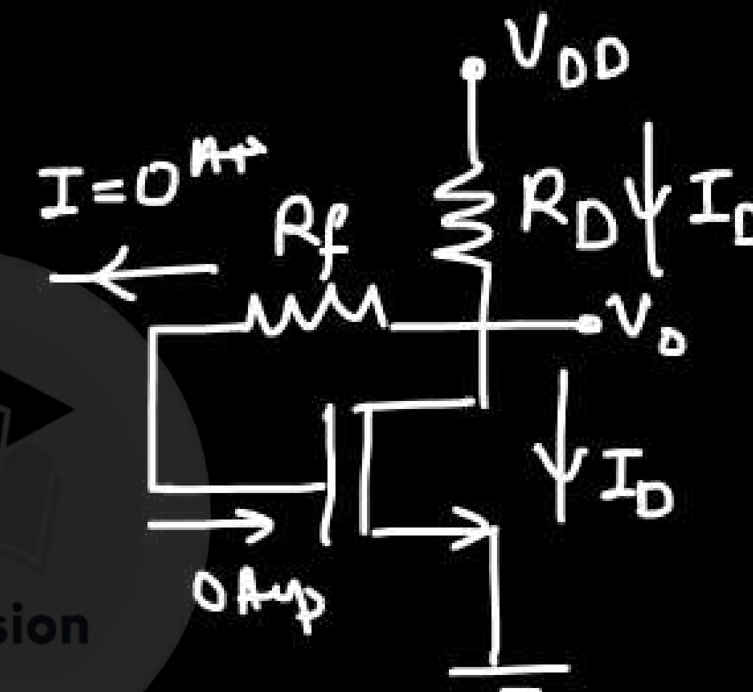
② Self bias stage:-



↙ Small signal i/p voltage

⇒

DC Analysis:-



$V_{GS} = V_0$

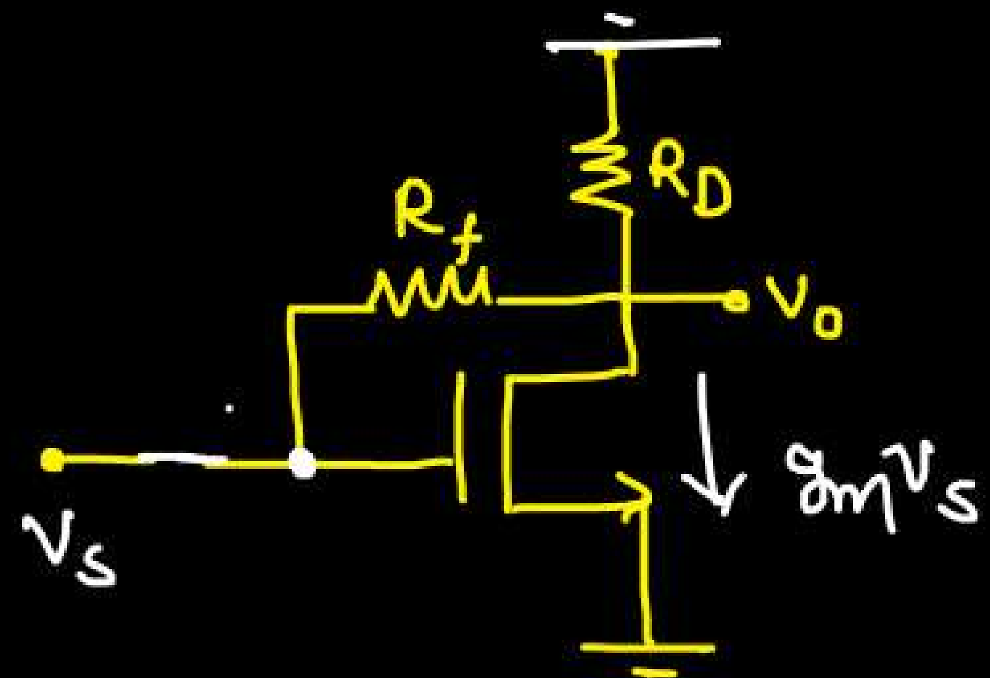
$V_{DS} = V_0$

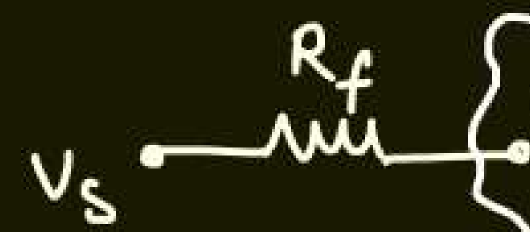
$V_{ov} = V_0 - V_T$

$\Rightarrow V_{DS} > V_{ov} \Rightarrow$ Always in sat.

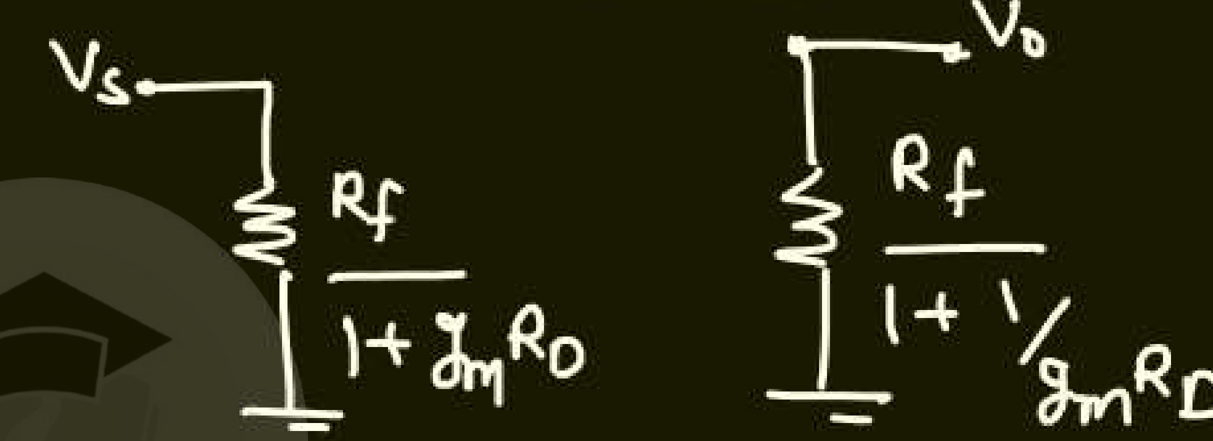
① Make sure that $\boxed{V_{DD} - I_D R_D > V_T}$ → Ensuring MOS is ON

AC Analysis:



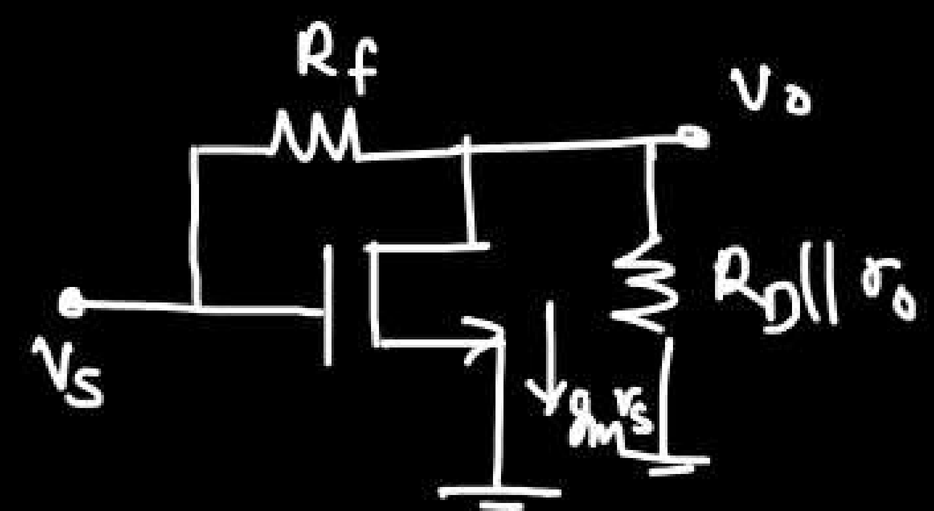


$\cancel{V_o = -g_m R_D V_s}$



Correct only $R_f \to$ very High

$\Rightarrow$



nodal @ V_o

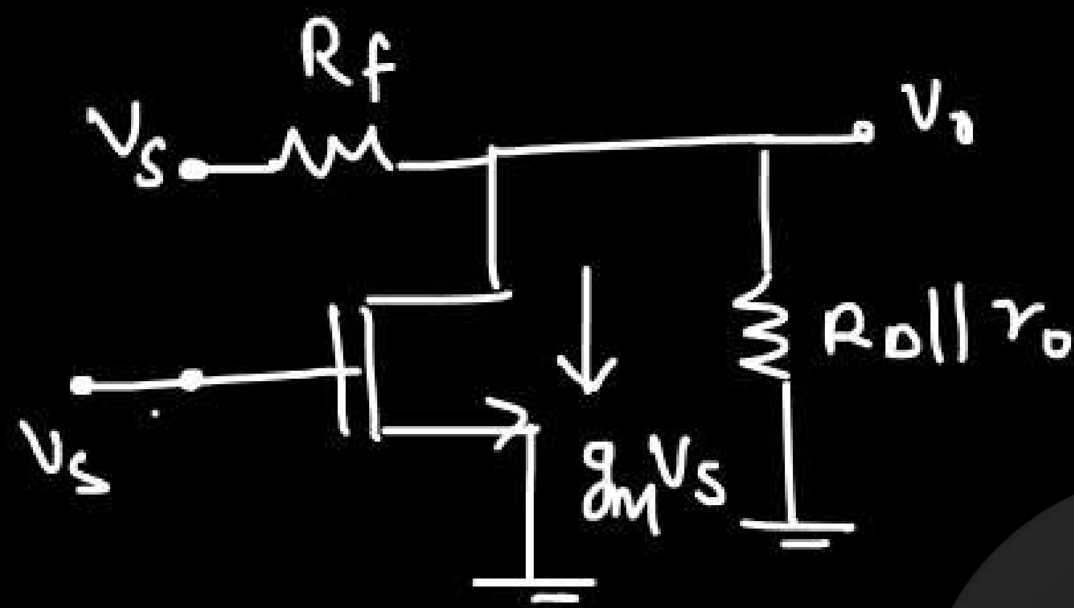
$$\frac{V_o}{R_D \| r_o} + g_m V_s + \frac{V_o - V_s}{R_f} = 0$$

$$\frac{V_o}{R_D \| r_o} + \frac{V_o}{R_f} = \frac{V_s}{R_f} - g_m V_s$$

$$\frac{V_o}{R_f \| R_D \| r_o} = \frac{V_s}{\left(-1/g_m \| R_f\right)}$$

$$\boxed{\frac{V_o}{V_s} = \frac{R_f \| R_D \| r_o}{-1/g_m \| R_f}} = A$$

M - II :-

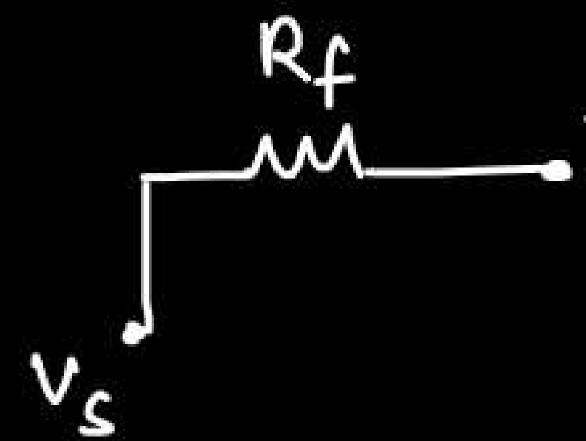


$\Rightarrow$

$$V_o = -g_m\left[R_D \| r_o \| R_f\right] V_s + \left[\frac{R_D \| r_o}{R_f + (R_D \| r_o)}\right] V_s$$

$$\boxed{\frac{V_o}{V_s} = -g_m\left[R_D \| r_o \| R_f\right] + \frac{R_D \| r_o}{R_f + (R_D \| r_o)}} = A$$

★

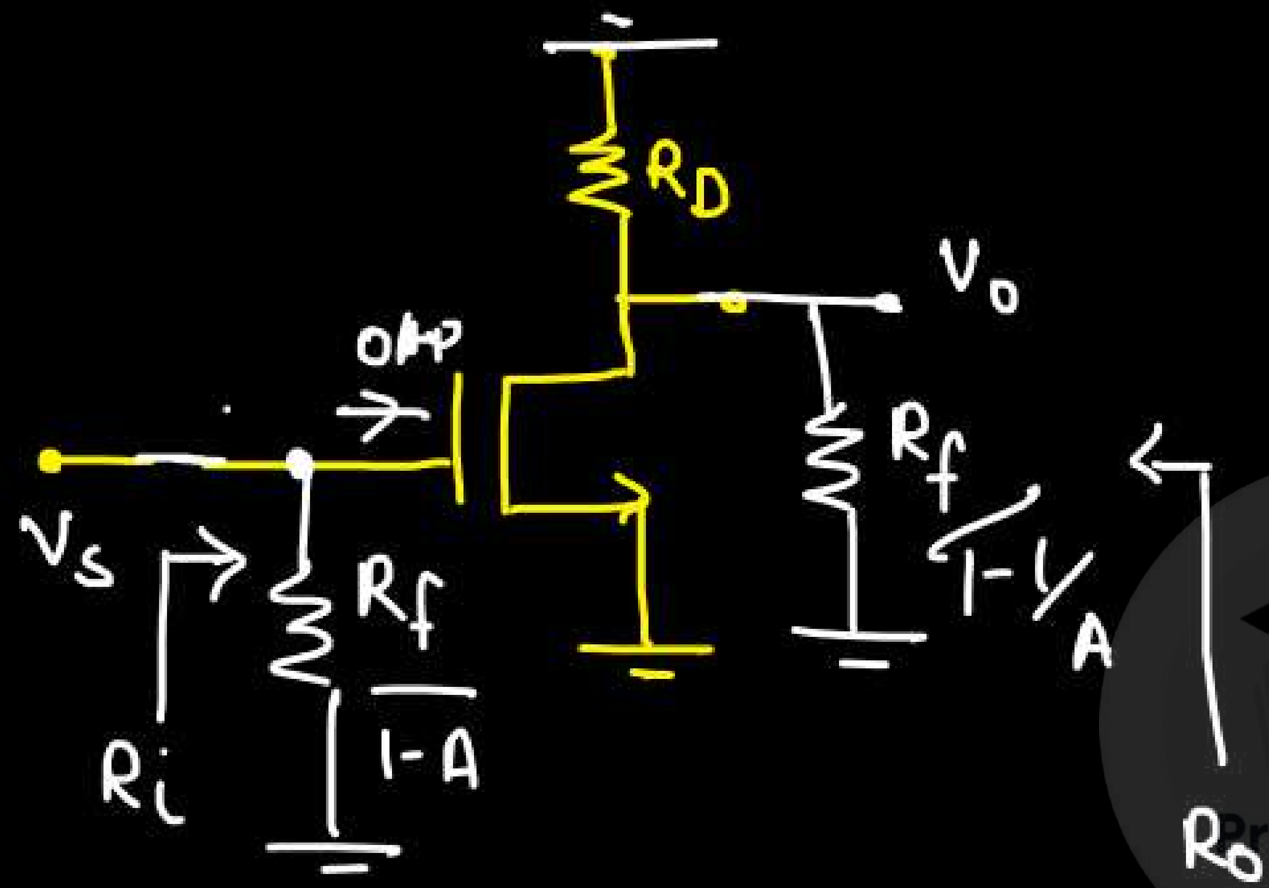


$$V_o = A V_s$$

$$A = -g_m\left[R_D \| r_o \| R_f\right] + \frac{R_D \| r_o}{R_f + (R_D \| r_o)}$$

$\Rightarrow$

input resistance :- / Output resistance :-



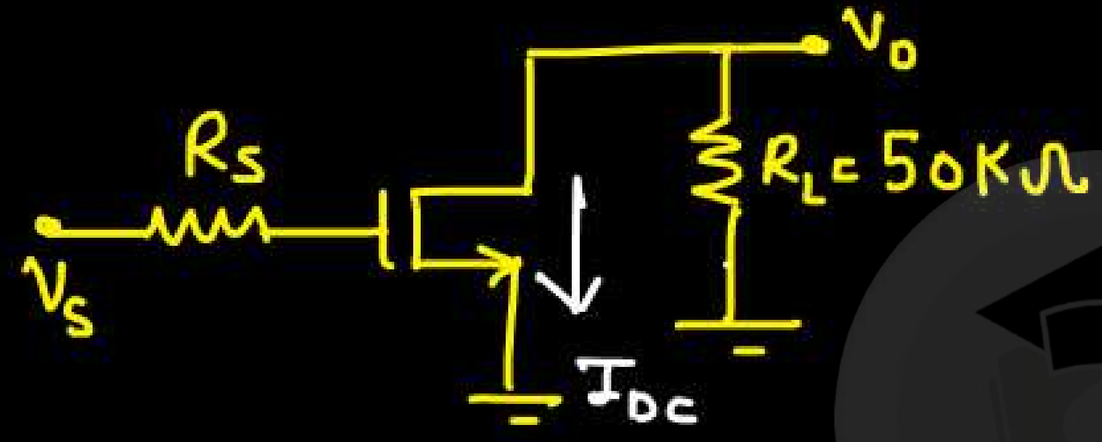
$$R_i = \frac{R_f}{1-A}$$

$$R_o = R_D \| r_o \| \frac{R_f}{1-1/A}$$

$$A = -g_m[R_D \| R_f \| r_o] + \frac{R_D \| r_o}{(R_D \| r_o) + R_f}$$

Assignment - 6

Q.



$\mu_n C_{ox} = 100\,\mu A/V^2$

$W/L = 1$

$V_T = 1V$, $\lambda = 0$

Small signal model is drawn. The gain magnitude is 8. Determine the bias current flowing through the MOS.

→ $|-g_m R_L| = 8$ $\Rightarrow$ $g_m \times 50K = 8$

$$\boxed{g_m = 0.16\,mS}$$

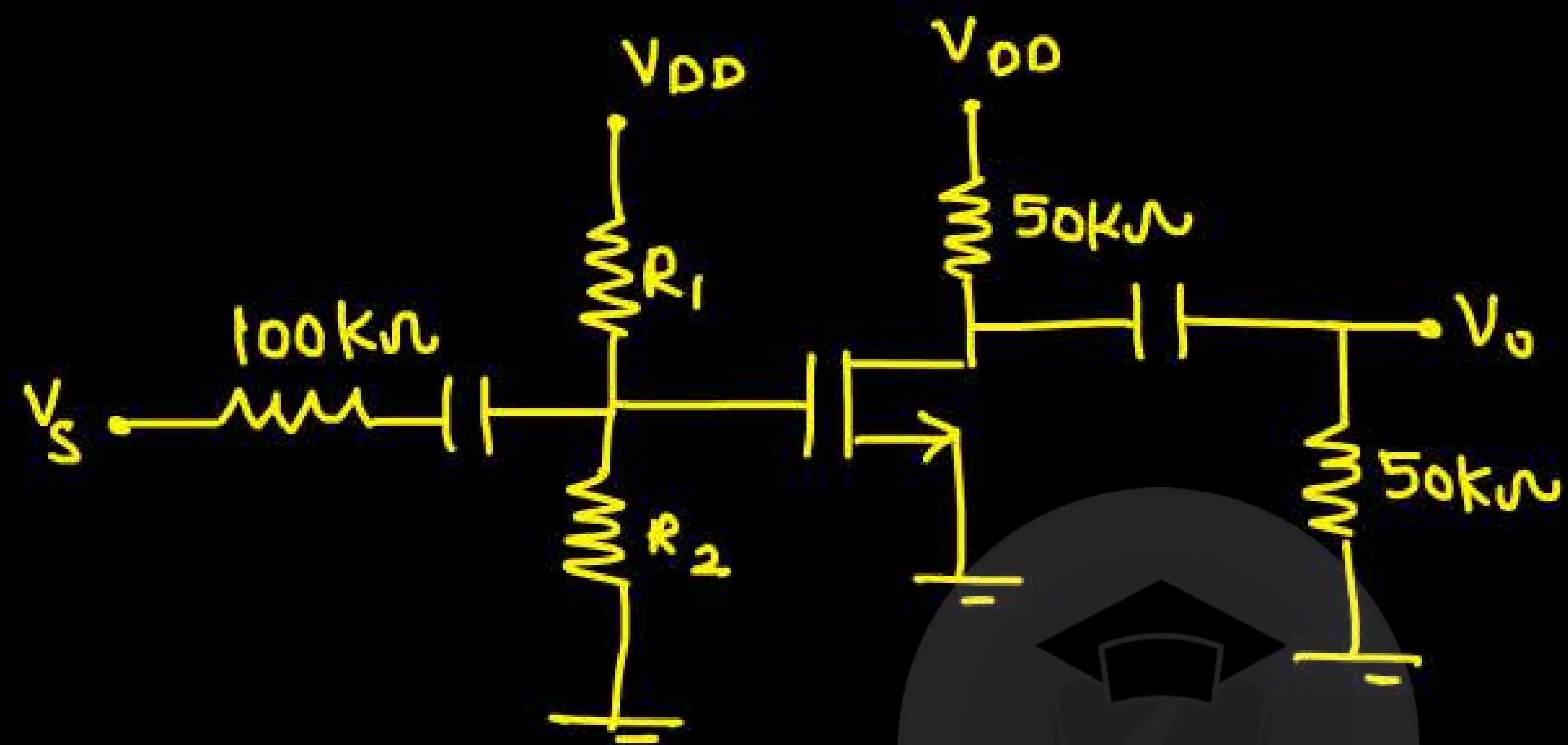
$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L} I_{DC}} = 0.16m$$

$$\sqrt{2 \times 100\mu \times I_{DC}} = 16 \times 10^{-5}$$

$$2 \times 10^{-4} \times I_{DC} = 256 \times 10^{-10}$$

$$\boxed{I_{DC} = 128\ \mu\text{Amp.}}$$

Q. 2



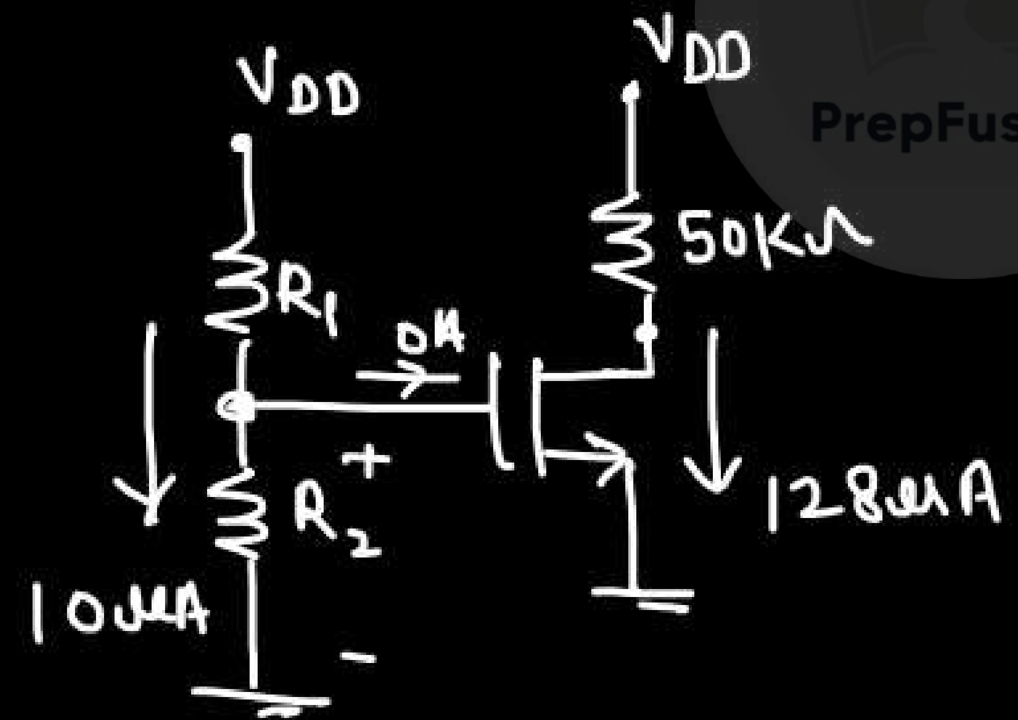
$\mu_n C_{ox} = 100\,\mu A/V^2$, $W/L = 1$, $V_T = 1V$. The transistor is biased @ $128\,\mu A$.

At operation point ; $V_{DS} = V_{GS} + 1$

The bias current flowing through $R_{1,2}$ is $10\,\mu A$.

1. Determine V_{DD}.
2. Determine R_1 & R_2.
3. Determine small signal gain $\frac{v_o}{v_s}$.

(1) DC Analysis :-



$V_{DS} = V_{GS} + 1$ [Given]

$V_{ov} = V_{GS} - V_T = V_{GS} - 1$

$V_{DS} > V_{ov} \Rightarrow$ Sat. region

$\Rightarrow V_{DS} = V_{DD} - 50K \times 128\mu$

$\boxed{V_{DS} = V_{DD} - 6.4}$ — (1)

$$I_D = 128\,\mu A \quad [\text{Given}]$$

$$\frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2 = 128\mu$$

$$\frac{100\mu}{2}(V_{GS} - 1)^2 = 128\mu$$

$$V_{GS} - 1 = \sqrt{2.56}$$

$$\boxed{V_{GS} = 2.6V} \longrightarrow 2$$

$$V_{DS} = V_{GS} + 1 \quad [\text{Given}]$$

$$V_{DD} - 6.4 = 2.6 + 1$$

$$\boxed{V_{DD} = 10V} \text{ ANS.}$$

(2) $R_1 = ?$, $R_2 = ?$

Given, $\dfrac{V_{DD}}{R_1+R_2} = 10\,\mu A$

$$\frac{10}{R_1+R_2} = 10\,\mu A$$

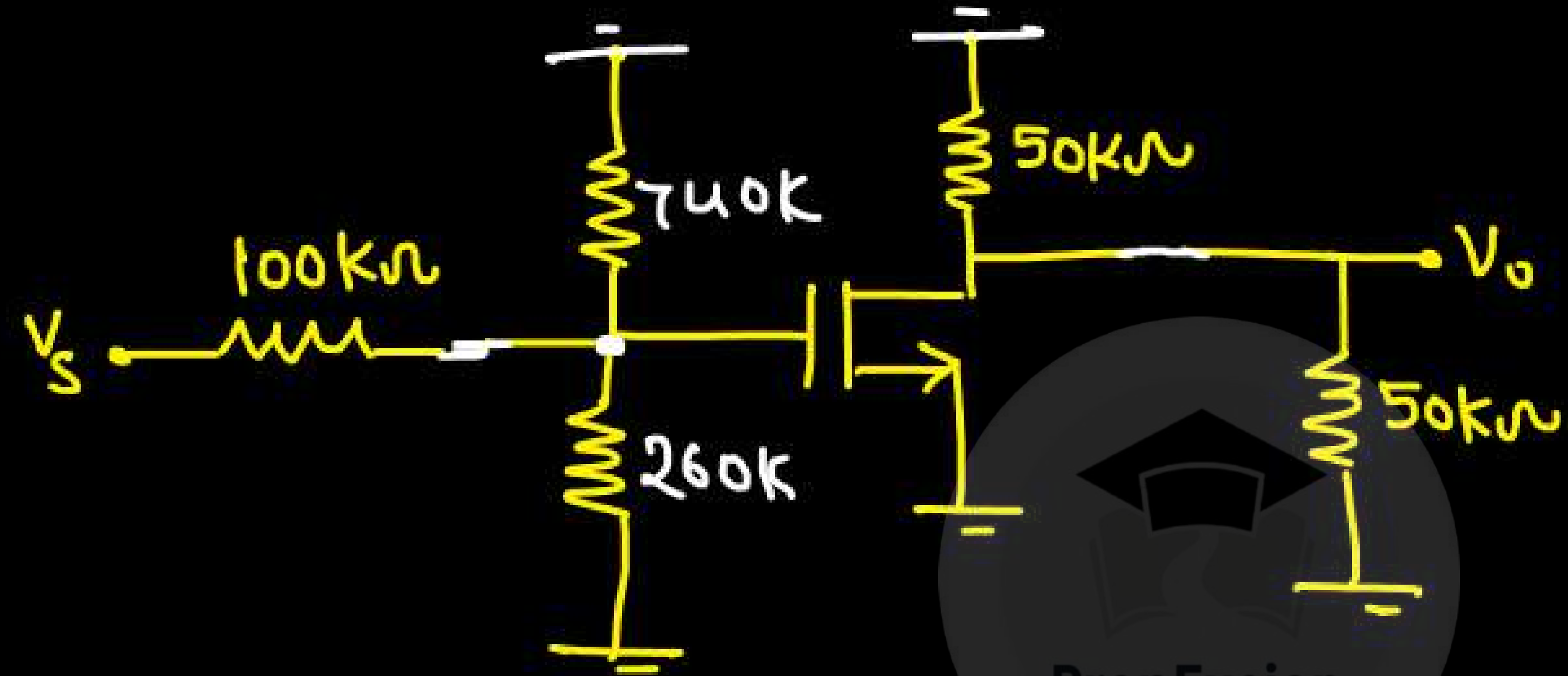
$$\boxed{R_1 + R_2 = 1\,M\Omega} = 1000\,k\Omega$$

Here, $V_{GS} = 10\mu \times R_2 = 2.6$

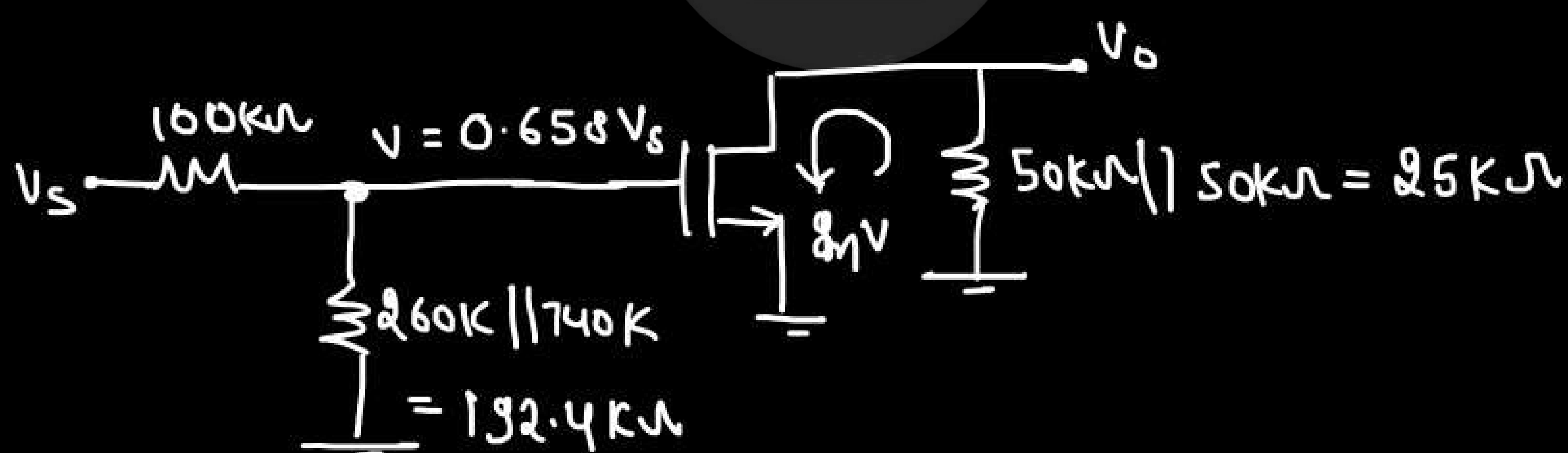
$$\boxed{R_2 = 260\,k\Omega}$$ Ans

$$\boxed{R_1 = 740\,k\Omega}$$ Ans.

③ Small signal voltage gain:-



⇒



$$V_o = -g_m [25 k\Omega] \times 0.658 V_s$$

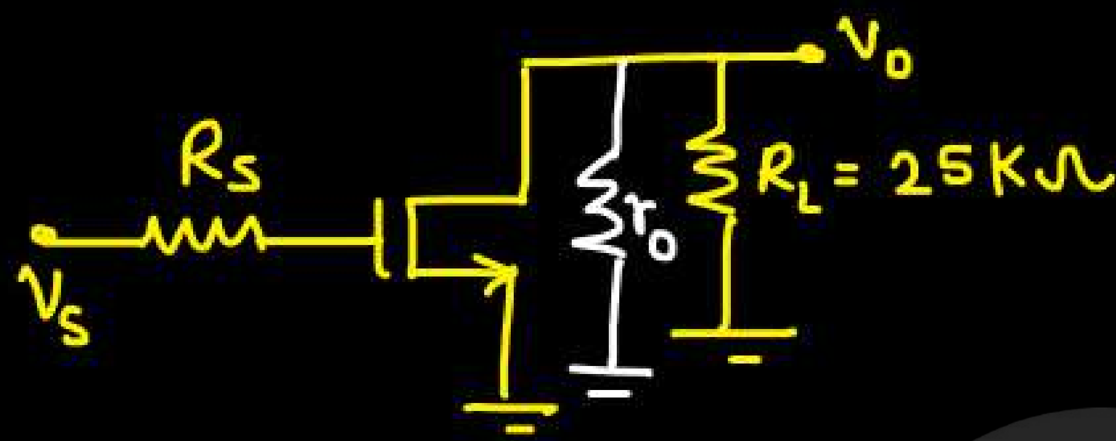
$g_m = ?$

$$g_m = \frac{2 I_{DC}}{(V_{GS} - V_T)} = \frac{2 \times 128 \mu}{1.6} = 160 \mu S$$

$$V_o = -160 \times 10^{-6} \times 25 \times 10^{3} \times 0.658 V_s$$

$$\boxed{\frac{V_o}{V_s} = -2.63 \ V/V}$$

Q.



$\mu_n C_{ox} = 100\mu A/V^2$

$W/L = 1$

$V_T = 1V$

Considering $\lambda = 0$, you calculated the gain to be -4.

Later, you realised that $\lambda = 0.0625\ V^{-1}$.

Find the actual small signal gain.

$\rightarrow$ $-g_m \times 25K\Omega = -4$

$$g_m = \frac{4}{25K} = 0.16mS$$

$$\text{Actual gain} = -g_m \left[r_o \parallel 25\,k\Omega \right] \quad \text{—— (1)}$$

$$r_o = ?$$

$$r_o = \frac{1}{\lambda [I_D]_{sat.-ideal}}$$

$$g_m = 0.16\,mS$$

$$\sqrt{2 \times 100\mu \times I_D} = 0.16$$

$$\boxed{I_D = 128\,\mu A}$$

$$\Rightarrow r_o = \frac{1}{0.0625 \times 128\mu}$$

$$r_o = \frac{10^6}{8}$$

$$\boxed{r_o = 125\,k\Omega}$$

$$\text{Actual gain} = -0.16\times10^{-3}\,[125\,||\,25]\times10^{3}$$

$$\boxed{A_V = -3.33}\ \text{Ans}$$

N.B. -

Usually, we consider same g_m value for both of the cases $\lambda = 0$ & $\lambda \neq 0$

$$[g_m]_{\lambda=0} = \frac{\mu_n C_{ox} W}{L}(V_{GS}-V_T)^2$$

$$[g_m]_{\lambda\neq0} = \frac{\mu_n C_{ox} W}{L}(V_{GS}-V_T)^2[1+\lambda V_{DS}]$$

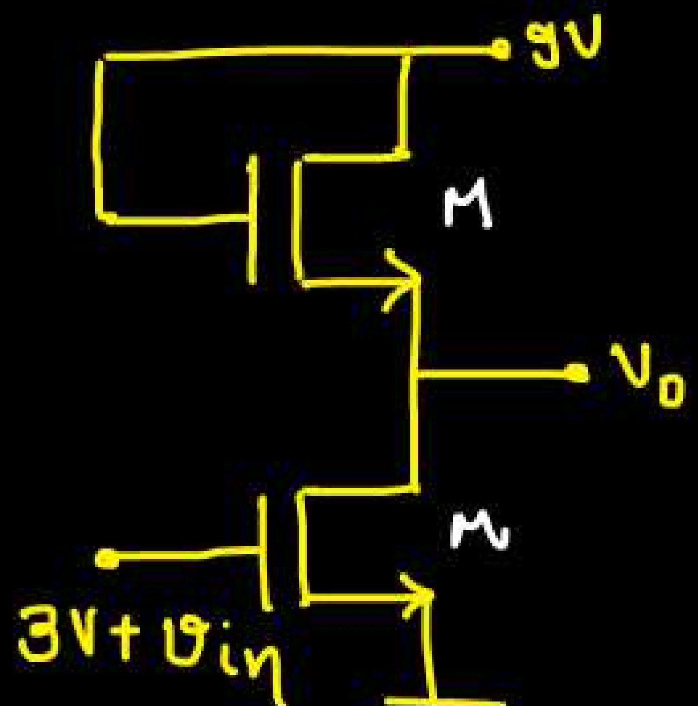
since λ = very small $\Rightarrow$ $\boxed{[g_m]_{\lambda=0} = [g_m]_{\lambda\neq0}}$

Q. All the transistor are identical with

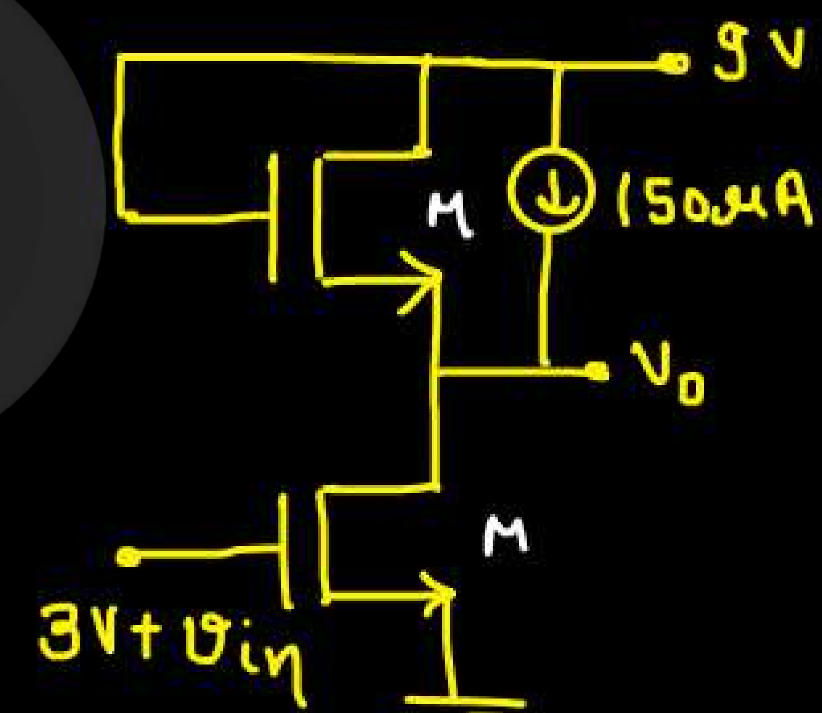
$$\frac{\mu_n C_{ox} W}{L} = 100\,\mu A/V^2 \;,\; V_T = 1V \;,\; \lambda = 0$$

(biased in sat. region)

Determine small signal voltage gain for (a) & (b).

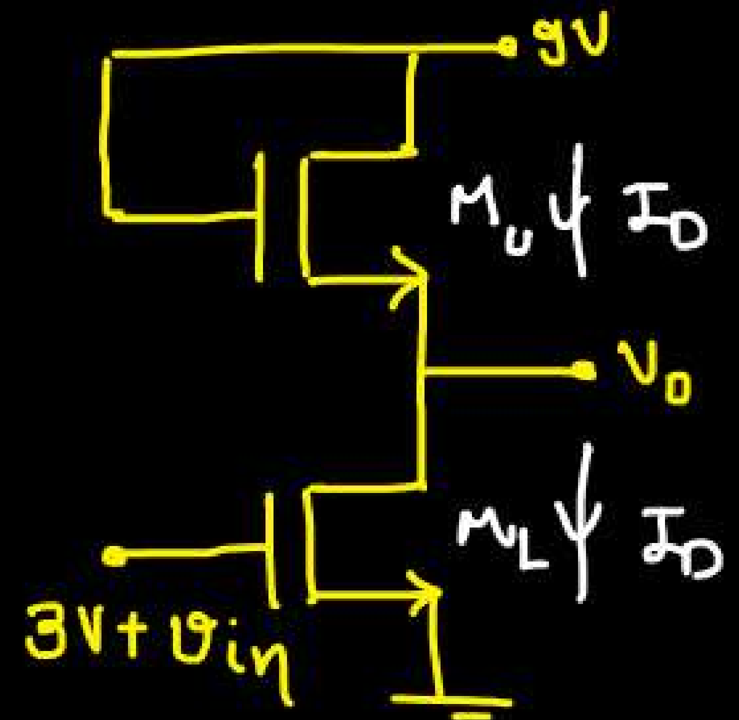


(a)



(b)

(i)

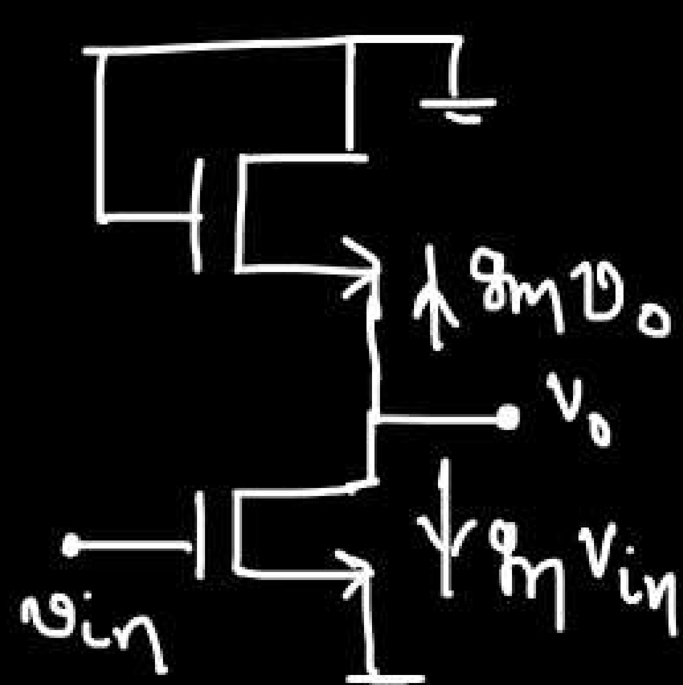


(a)

Both M_U and M_L will have same g_m value.

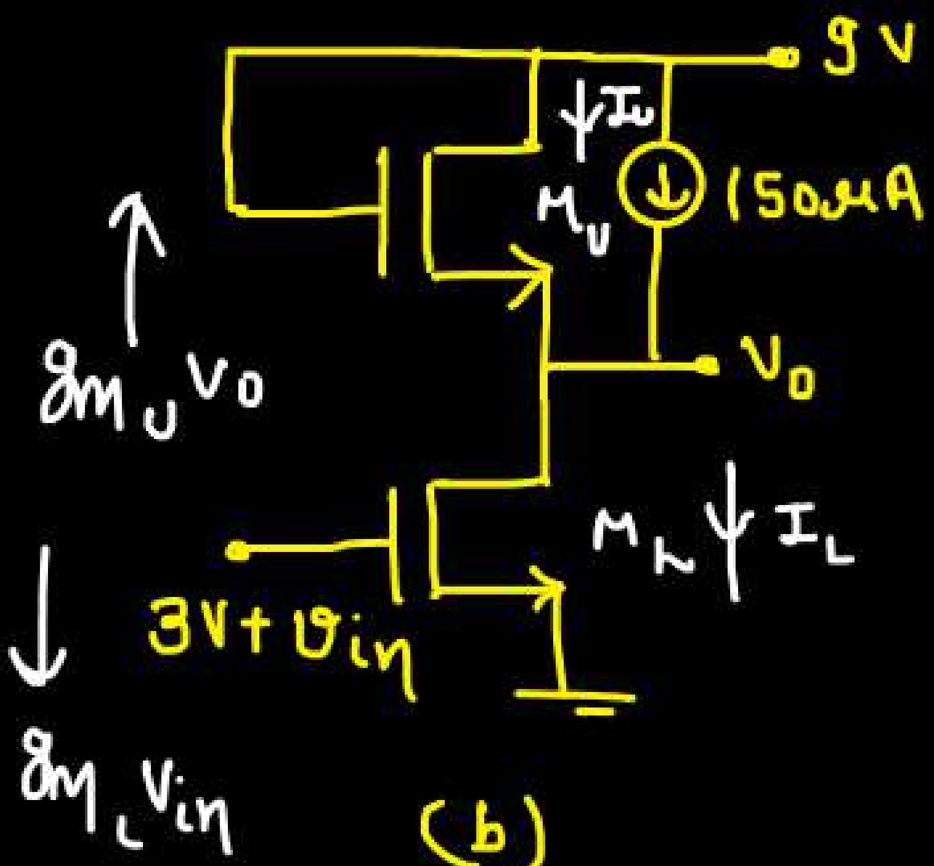
$$\left[g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D} \right]$$

⇒



$$g_m v_{in} = -g_m v_0$$

$$\boxed{\frac{v_0}{v_{in}} = -1}$$



(b)

$$I_U = 150\mu - I_L$$

Here the dc current is not same in both transistors, so g_m will be different.

$$I_L = \frac{100\mu}{2}(3-1)^2$$

$$\boxed{\begin{aligned} I_L &= 200\,\mu A \rightarrow g_{m_L} \\ I_U &= 50\,\mu A \rightarrow g_{m_U} \end{aligned}} \quad \text{—— (1)}$$

Small signal gain

$$\boxed{A_V = \frac{-g_{m_L}}{g_{m_U}}} \quad \text{—— (2)}$$

$$g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D} \Rightarrow \boxed{g_m \propto \sqrt{I_D}}$$

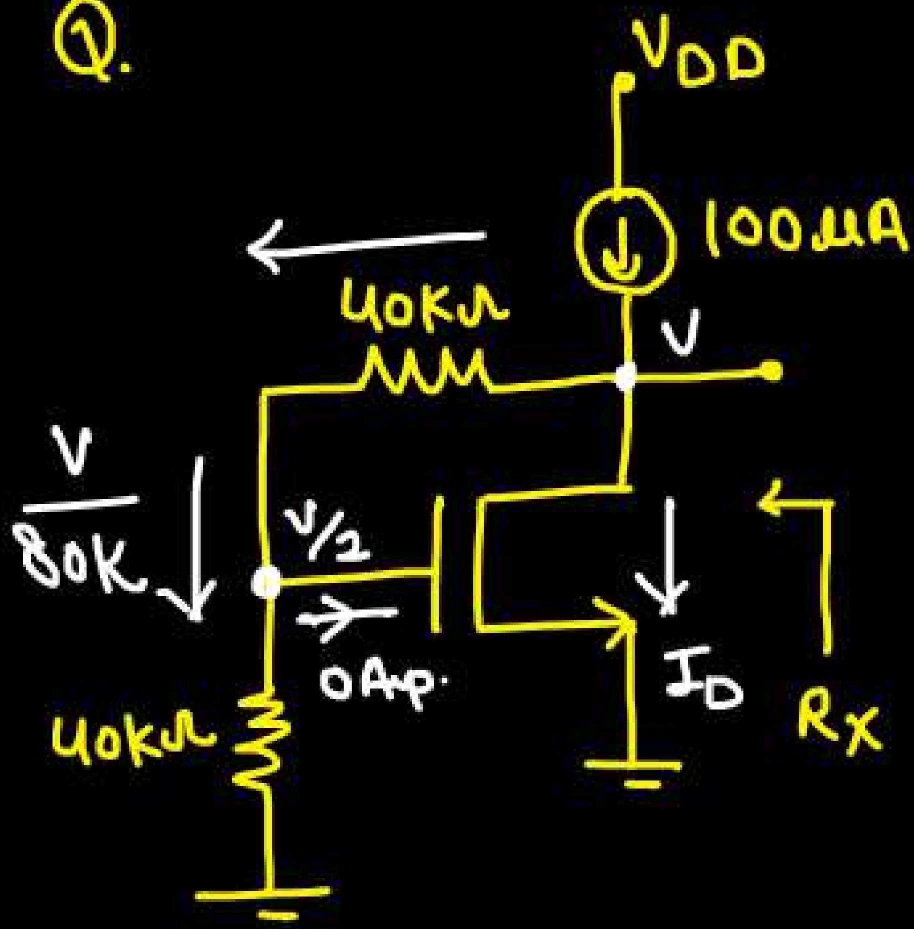
$$\frac{g_{m_L}}{g_{m_U}} = \frac{\sqrt{I_{D_L}}}{\sqrt{I_{D_U}}}$$

$$\frac{g_{m_L}}{g_{m_U}} = \frac{\sqrt{200\mu}}{\sqrt{50\mu}}$$

$$\frac{g_{m_L}}{g_{m_U}} = 2$$

$$\Rightarrow \boxed{A_v = -2}$$

Q.



$\frac{\mu_n C_{ox} W}{L} = 100\mu A/V^2$, $V_T = 1V$, $\lambda = 0$

① Determine the bias current in the transistor.

② Find small signal resistance R_X.

$$\boxed{100\mu A = \frac{V}{80k} + I_D} \quad \text{— ①}$$

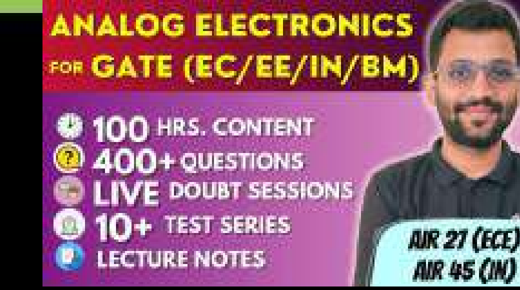
$$I_D = \frac{100\mu}{2}\left(\frac{V}{2} - 1\right)^2 \quad \text{— ②}$$

① $V_{DS} = V$

$V_{GS} = V/2$

$V_{OV} = V/2 - 1$

$\Rightarrow V_{DS} > V_{OV} \Rightarrow$ Sat.



$$100\mu = \frac{V}{0.08} \times \mu + 50\mu \left(\frac{V}{2} - 1\right)^2$$

$$100 = 12.5V + 50\left(\frac{V^2}{4} + 1 - V\right)$$

$$100 = 12.5V + 12.5V^2 + 50 - 50V$$

$$12.5V^2 - 37.5V - 50 = 0$$

$$V^2 - 3V - 4 = 0$$

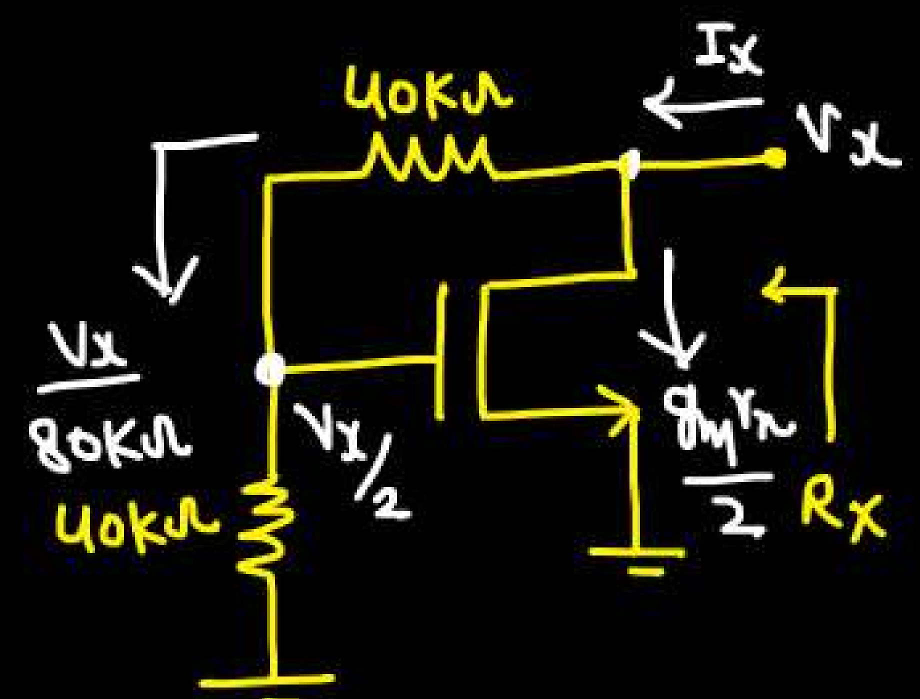
$$V^2 - 4V + V - 4 = 0$$

$$V \begin{cases} \nearrow -1 \\ \searrow 4 \ \checkmark \end{cases} \Rightarrow \boxed{V = 4V} \qquad \boxed{V_{DS} = 4V, \ V_{GS} = 2V}$$

$$I_D = \frac{100\mu}{2}(2-1)^2$$

$$\boxed{I_D = 50\,\mu\text{Amp.}}$$

Small Signal Analysis:-



$$\boxed{R_x = \frac{V_x}{I_x}}$$

$$\frac{V_x}{80K} + \frac{g_m V_x}{2} = I_x$$

$$\boxed{R_x = 80K \parallel 2/g_m}$$

$$g_m = ?$$

$$g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D}$$

$$= \sqrt{2 \times 100\mu \times 50\mu}$$

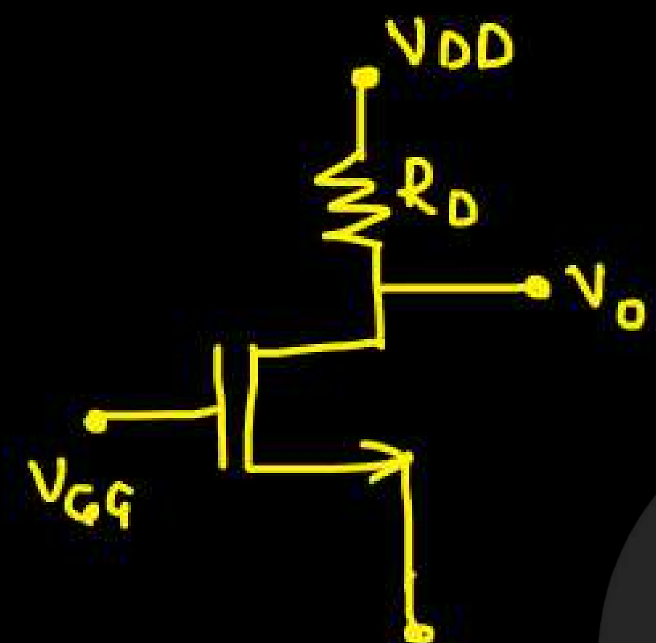
$$\boxed{g_m = 100\,\mu S}$$

$$R_x = 80K \parallel \frac{2}{10^{-4}}$$

$$R_x = 80K \parallel 20K$$

$$\boxed{R_x = 16K\Omega}$$ ANS.

Common Gate Amplifier:-

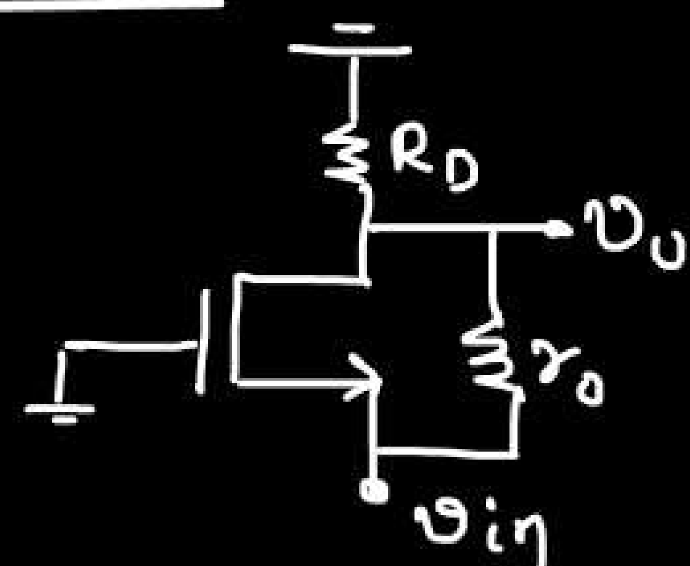


$V_{in} = V_{SS} + v_{in}$

Small signal i/p → source

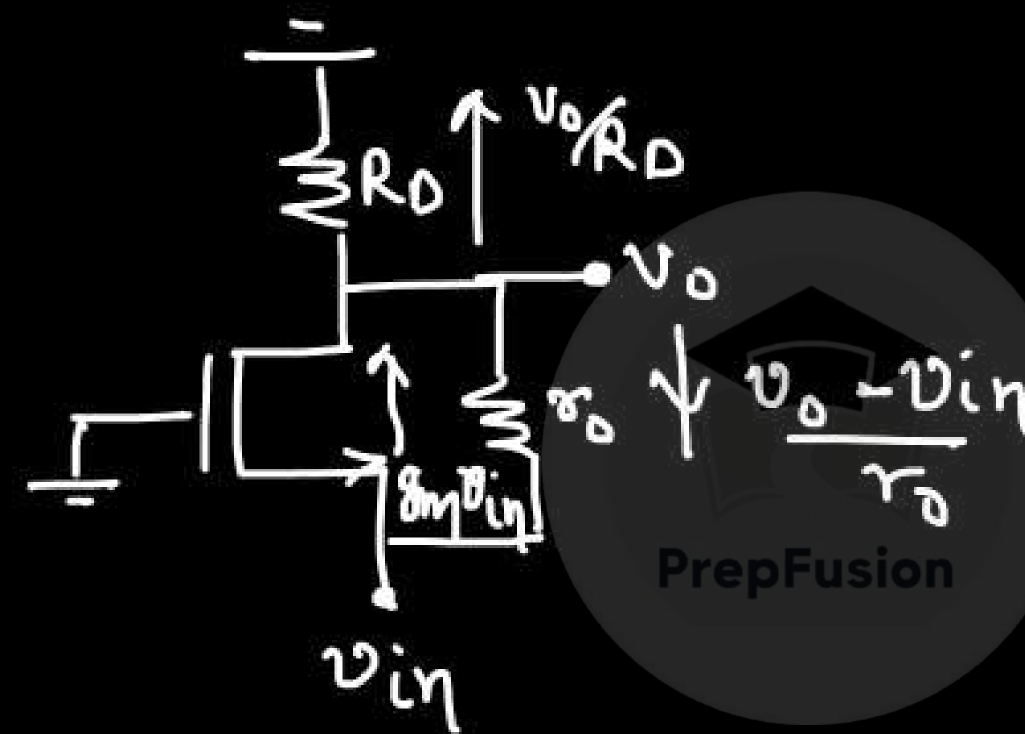
" " o/p → Drain

Small signal model:-



⇒ Voltage gain :-

$(\lambda \neq 0)$ r_o = finite



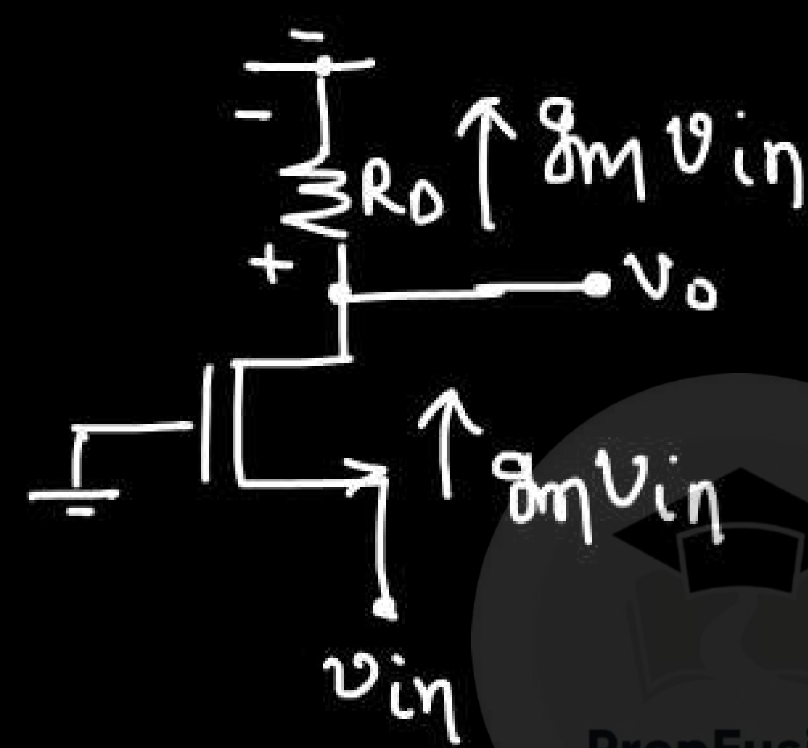
$$g_m v_{in} = \frac{v_o}{R_D} + \frac{v_o - v_{in}}{r_o}$$

$$v_{in}\left[g_m + \frac{1}{r_o}\right] = v_o\left[\frac{1}{R_D} + \frac{1}{r_o}\right]$$

$$v_{in}\left[\frac{g_m r_o + 1}{r_o}\right] = v_o\left[\frac{r_o + R_D}{R_D r_o}\right]$$

$$\boxed{\frac{v_o}{v_{in}} = \frac{R_D\left[g_m r_o + 1\right]}{r_o + R_D}}$$

Voltage gain ($\lambda = 0$) :-



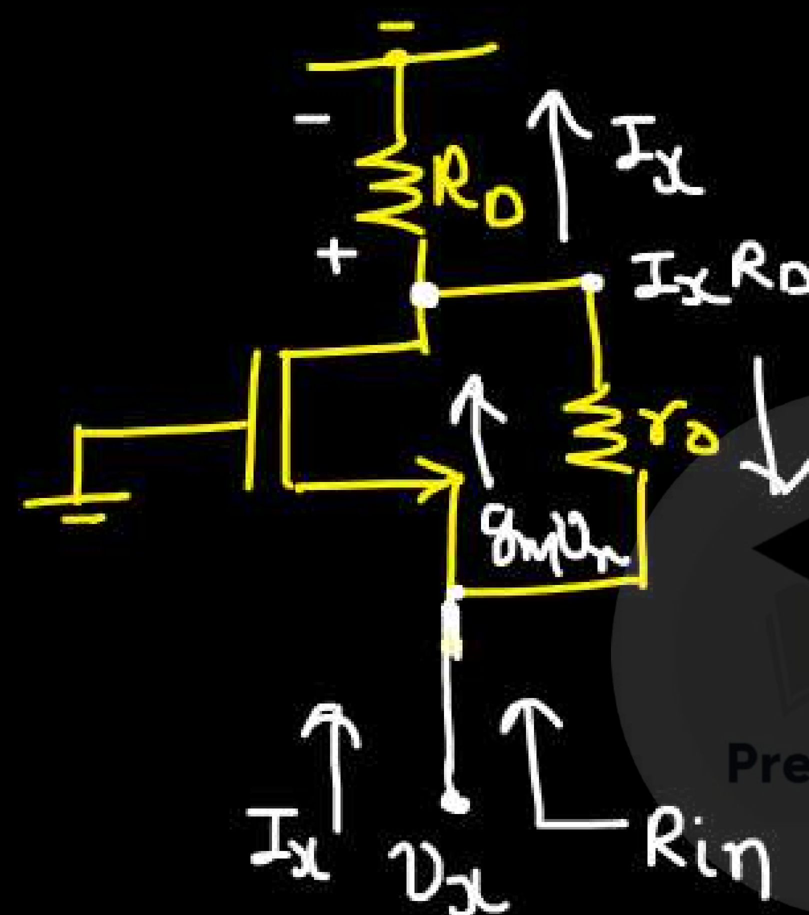
$$v_o = (g_m v_{in}) R_D$$

$$\boxed{\frac{v_o}{v_{in}} = g_m R_D}$$

B/w o/p and i/p there is 0° phase shift.

③ Input Impedance :-

$(\lambda \neq 0)$



Nodal @ $I_x R_D$:-

$$I_x + \frac{I_x R_D - V_x}{r_o} = g_m v_x$$

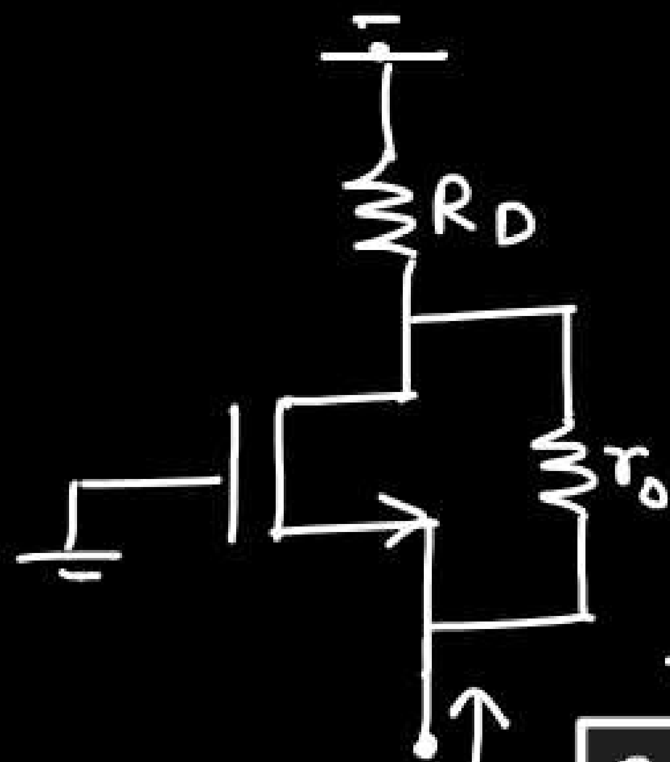
$$I_x\left[\frac{r_o + R_D}{r_o}\right] = v_x\left[g_m + \frac{1}{r_o}\right]$$

$$I_x\left[r_o + R_D\right] = v_x\left[g_m r_o + 1\right]$$

☆☆☆

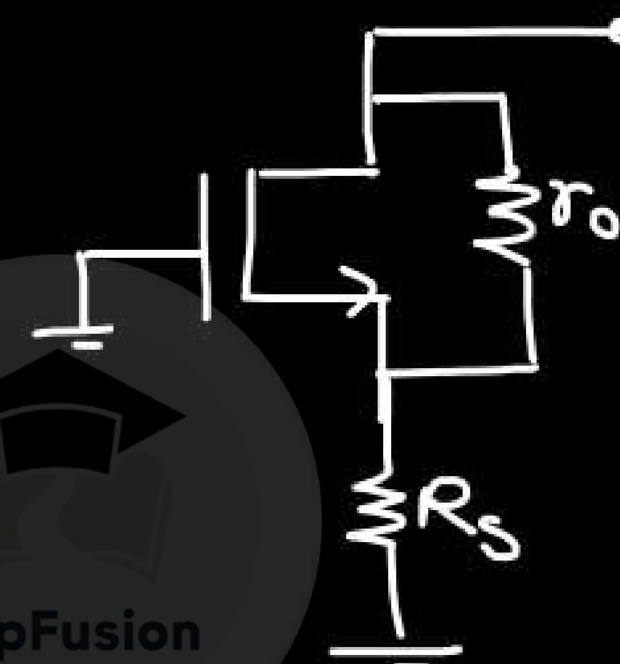
$$\boxed{R_x = \frac{v_x}{I_x} = \frac{r_o + R_D}{1 + g_m r_o}}$$

TO REREMBER :-



★★

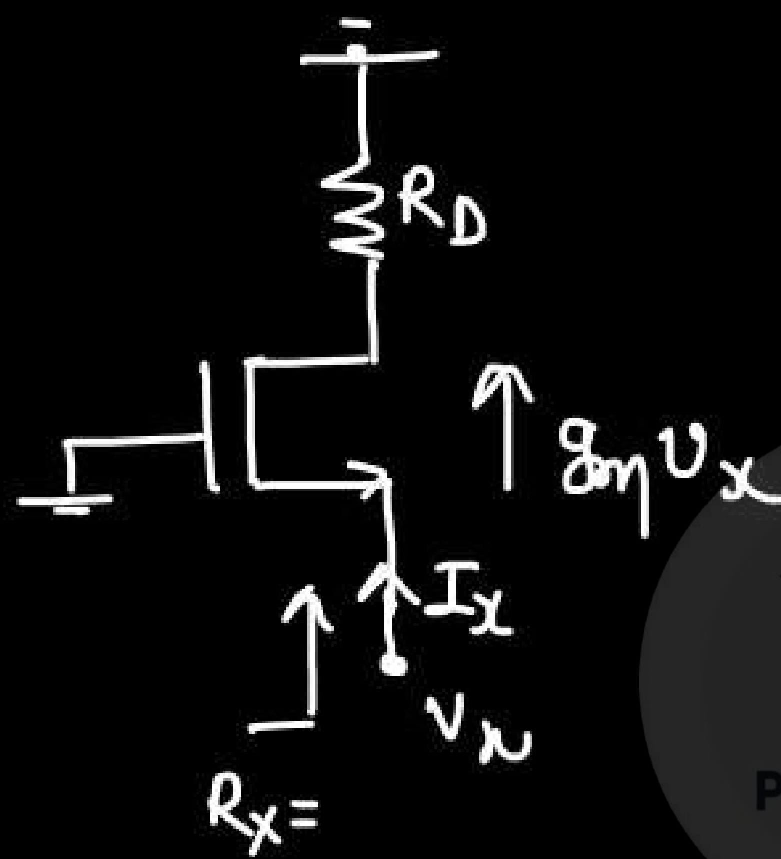
$$\boxed{R_x = \frac{r_o + R_D}{1 + g_m r_o}}$$



★★

$$\boxed{R_x = r_o + R_S + g_m r_o R_S}$$

input impedance ($\lambda = 0$) :-



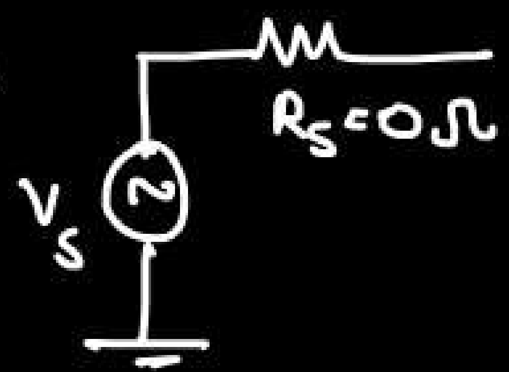
$$g_m v_x = I_x$$

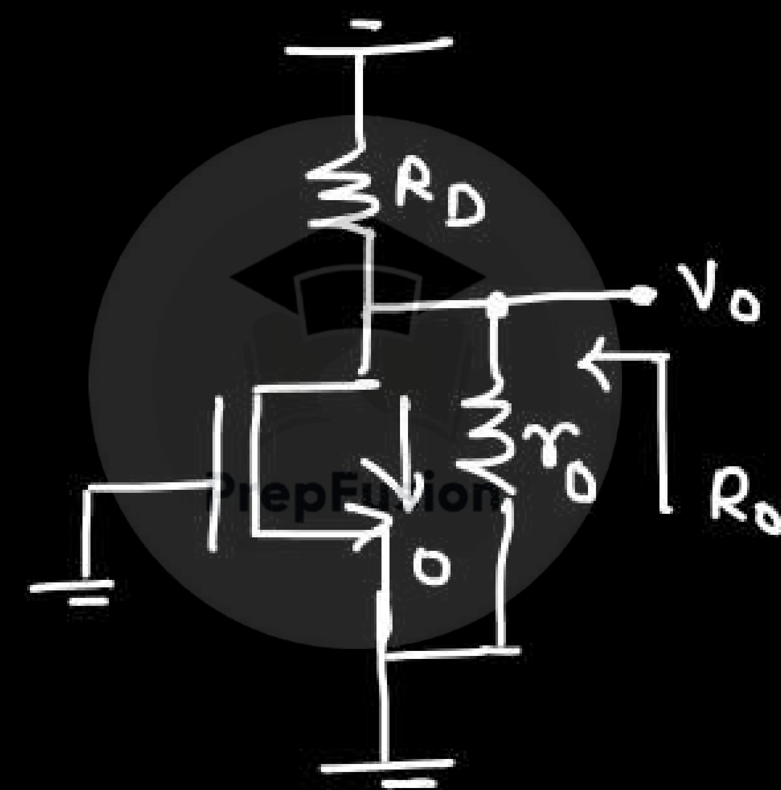
$$\boxed{R_x = \frac{v_x}{I_x} = \frac{1}{g_m}}$$

Output impedance:-

(input source doesn't have any internal resistance)

$v_i \Rightarrow$

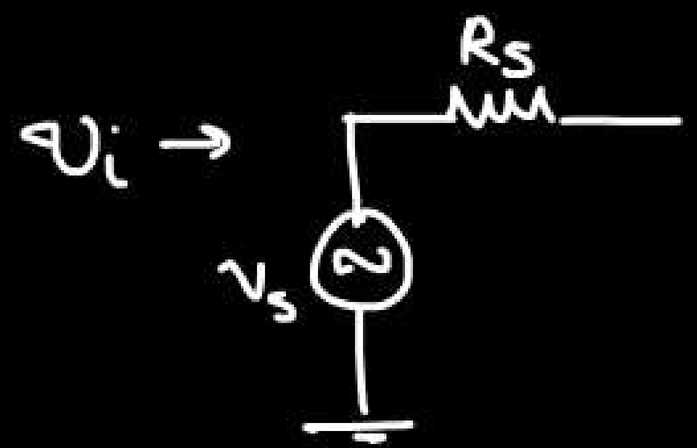


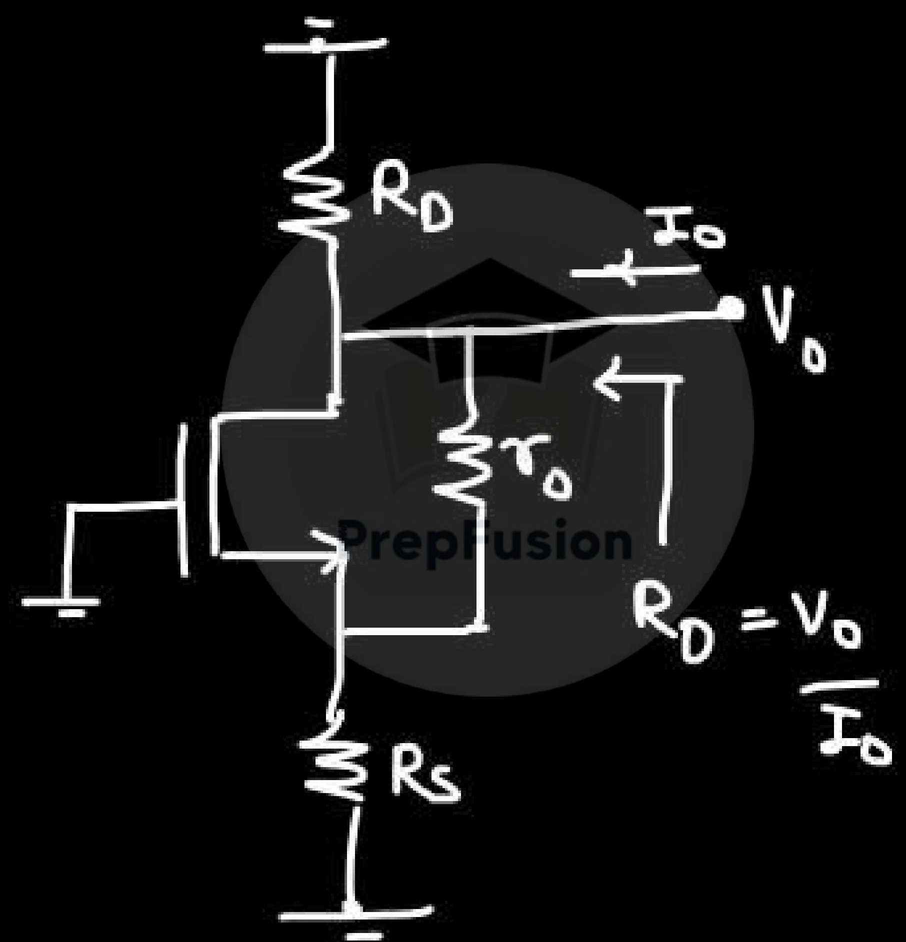


$$\boxed{R_0 = R_D \parallel r_0}$$

Output resistance :-

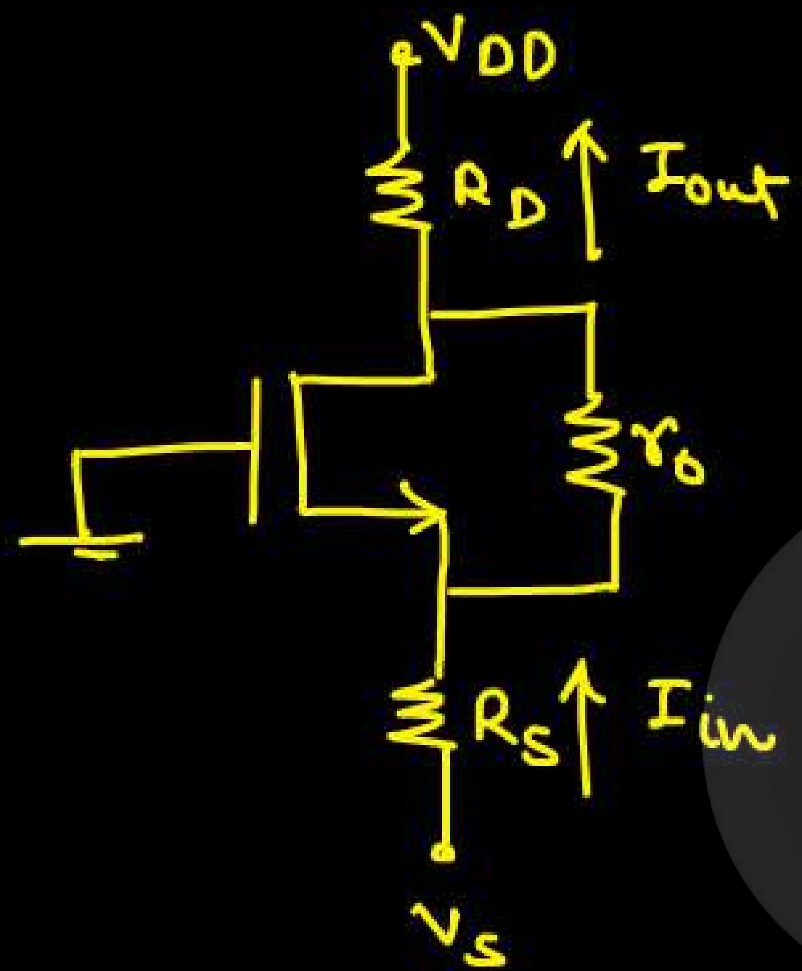
(input source has some internal resistance)





$$\boxed{R_o = R_D \| (r_o + R_S + g_m r_o R_S)}$$

Current - gain:-

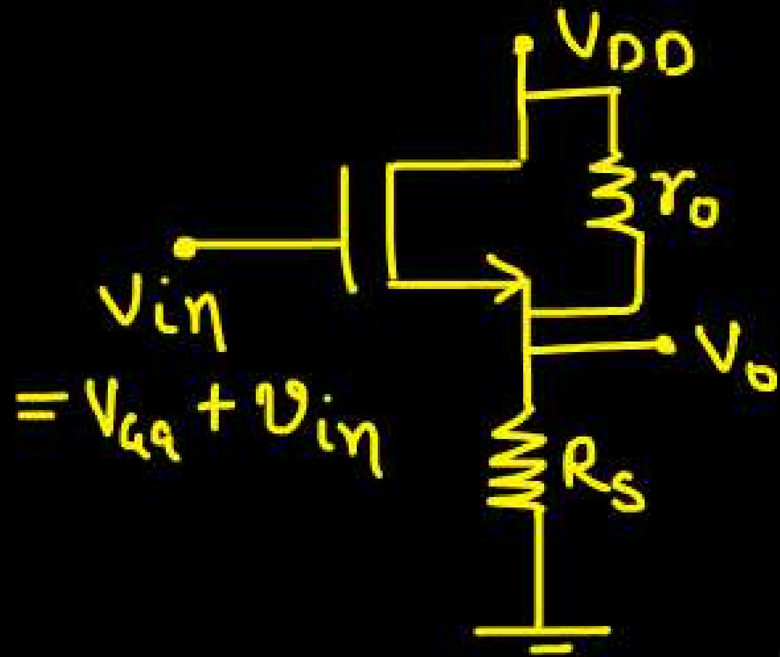


$I_{in} = I_{out}$

$$\boxed{\frac{I_{out}}{I_{in}} = 1} \Rightarrow \text{CURRENT - BUFFER}$$

$$\boxed{\text{COMMON GATE AMPLIFIER} = \text{C - BUFFER}}$$

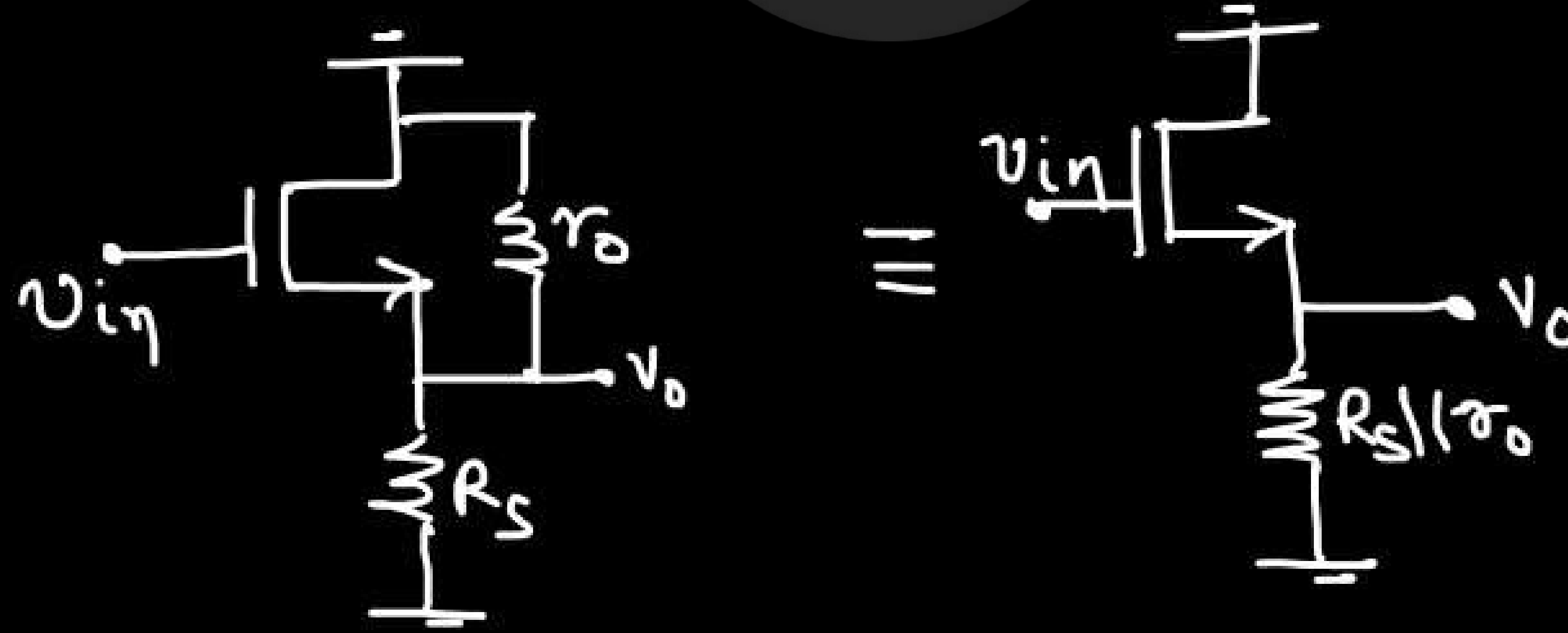
★ Common-drain Amplifier :-



small signal i/p → Gate

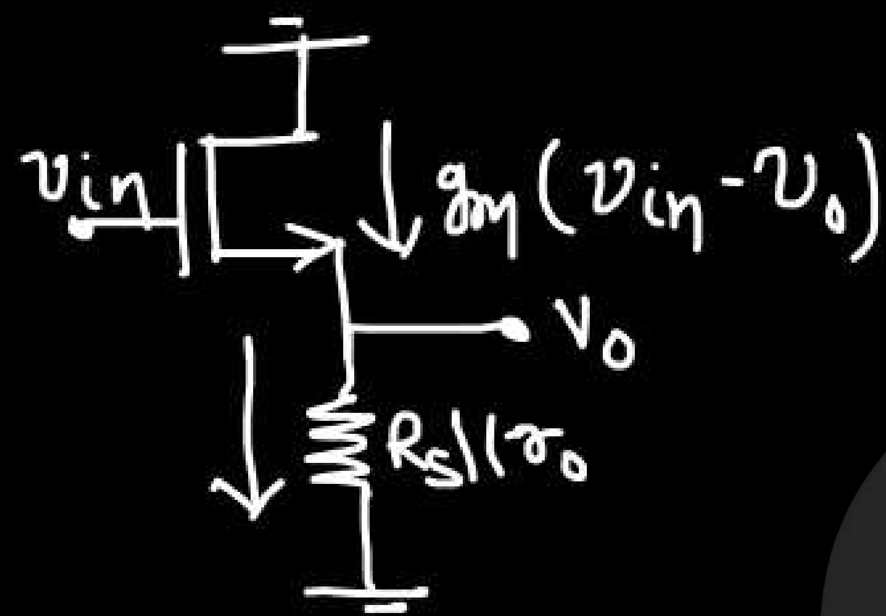
" " o/p → Source

small signal Model :-



Voltage gain:-

M-I



$$g_m(v_{in}-V_o)\times(R_s\|r_o) = v_o$$

$$g_m(R_s\|r_o)\,v_{in} = \left[1+g_m(R_s\|r_o)\right]v_o$$

$$\boxed{\frac{v_o}{v_{in}} = \frac{g_m(R_s\|r_o)}{1+g_m(R_s\|r_o)}}$$

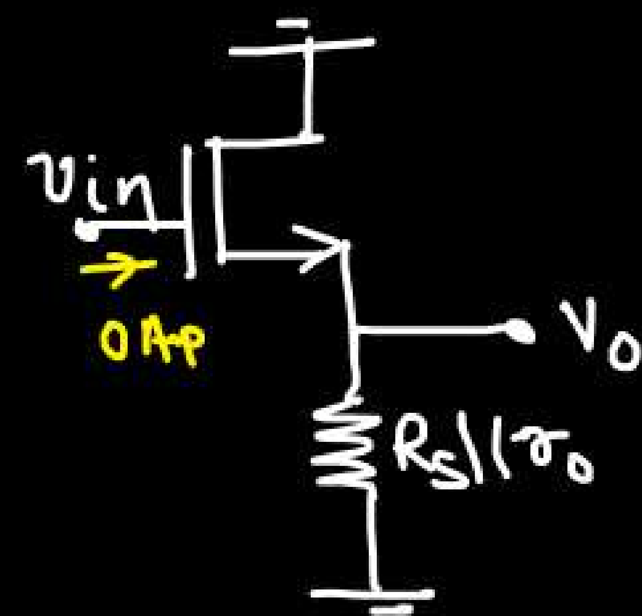
$$g_m(R_s\|r_o) >>> 1$$

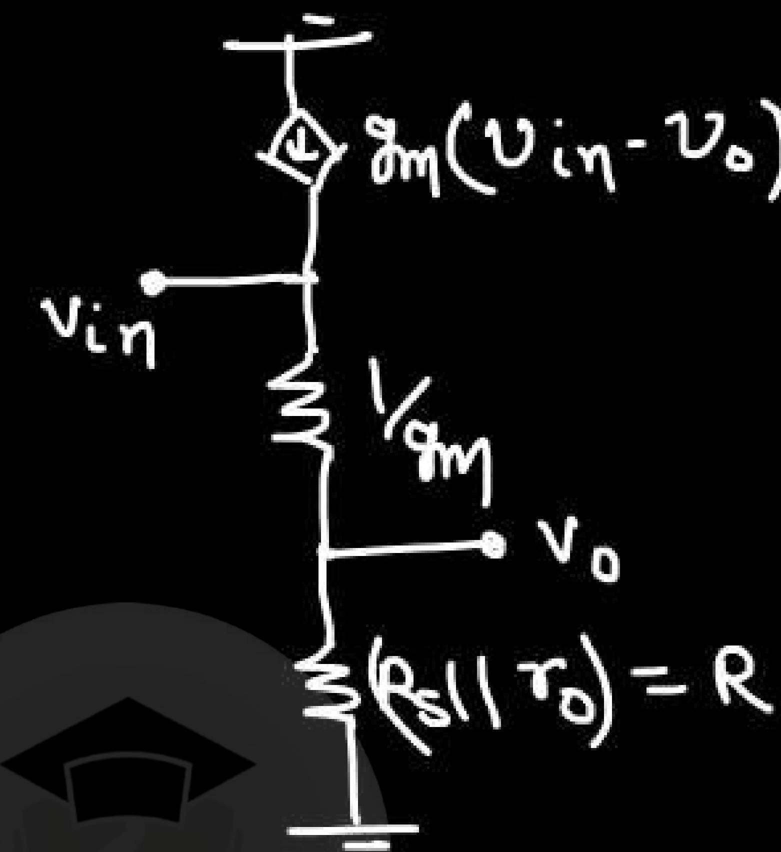
$$\boxed{\frac{v_o}{v_{in}} = 1} \rightarrow \text{source-follower}$$

**

$$\boxed{\text{common-drain} \equiv \text{source-follower}}$$

M - II :-





$$v_o = \frac{R}{R + \frac{1}{g_m}} v_i$$

$$\boxed{\frac{v_o}{v_i} = \frac{g_m R}{1 + g_m R}}$$

$$\boxed{R = R_S \| r_o}$$

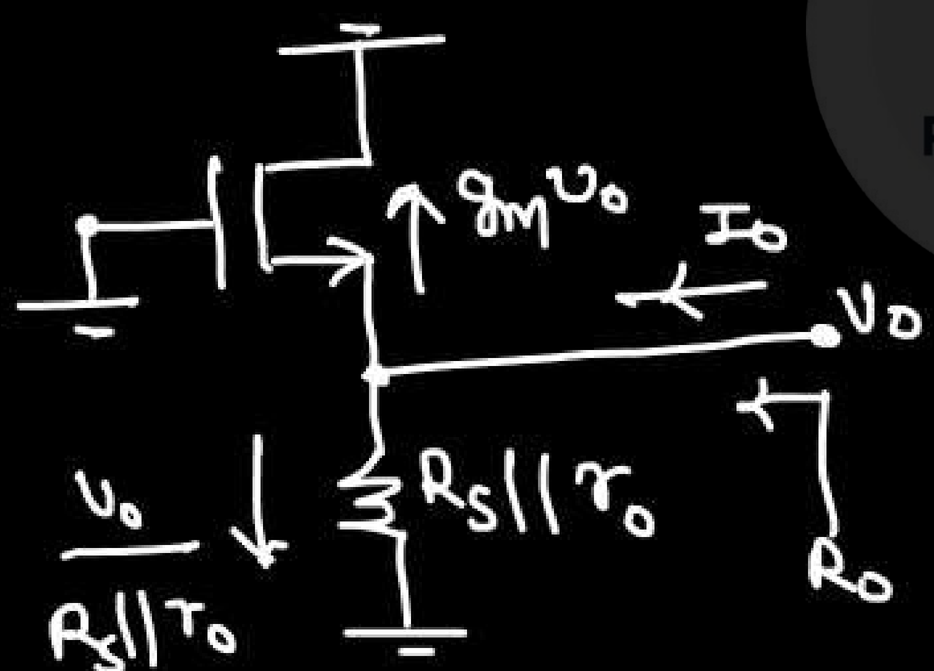
Current gain :-

$$\boxed{A_I = \frac{I_o}{I_{in}} = \frac{I_o}{0} = \infty}$$

Input Impedance :-

$$\boxed{R_i = \frac{V_i}{I_i} = \frac{V_i}{0} = \infty}$$

Output Impedance :-

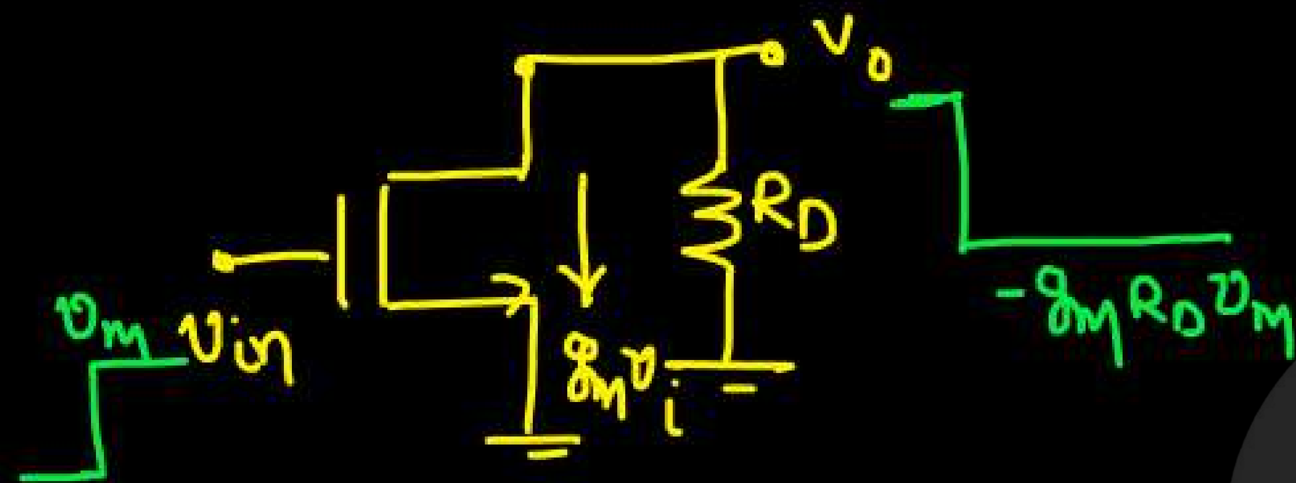


$$\boxed{R_o = R_S \| r_o \| \frac{1}{g_m}}$$

$$\boxed{g_m v_o + \frac{v_o}{R_S \| r_o} = I_o}$$

☆ Summary:-

① Common Source Amplifier:-

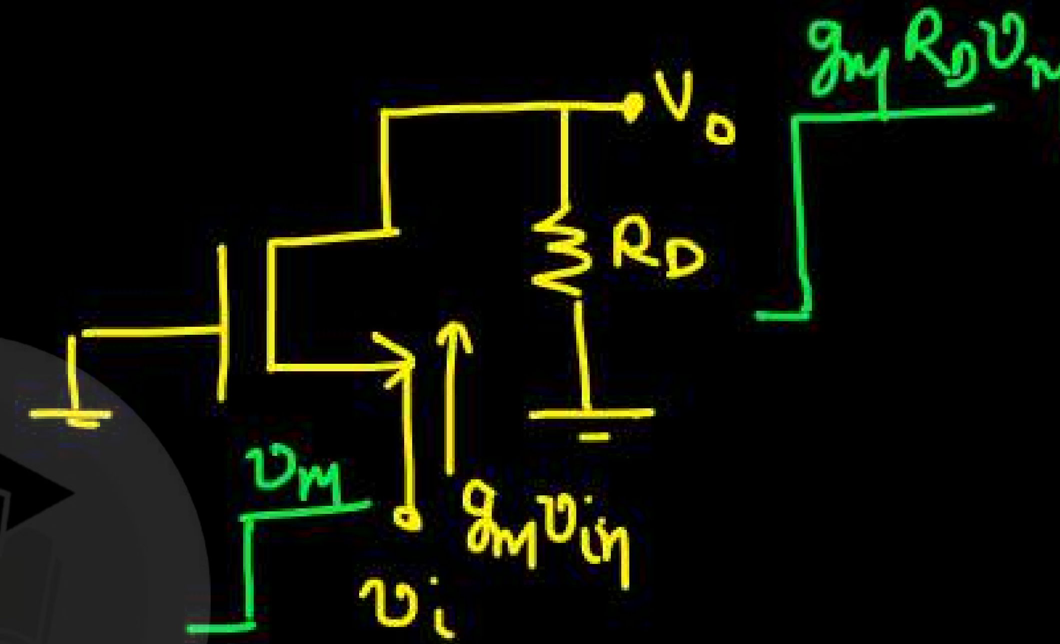


$\boxed{A_V = -g_m R_D}$

⇒ There is 180° phase shift b/w i/p and o/p

$\boxed{R_o = R_D \| r_o}$

② Common GATE Amplifier:-



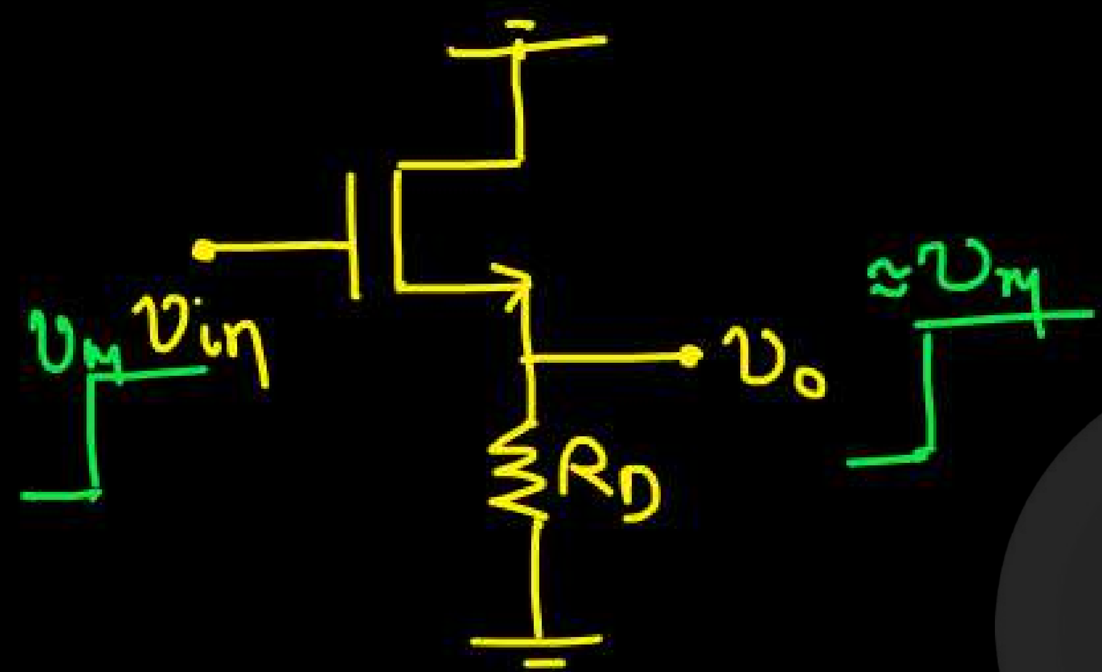
$\boxed{A_V = g_m R_D}$

⇒ B/w i/p and o/p there is zero degree phase shift

$\boxed{R_o = R_D \| r_o}$

$\boxed{A_I = 1}$ ⇒ C-Buffer

③ Common-Drain Amplifier:-

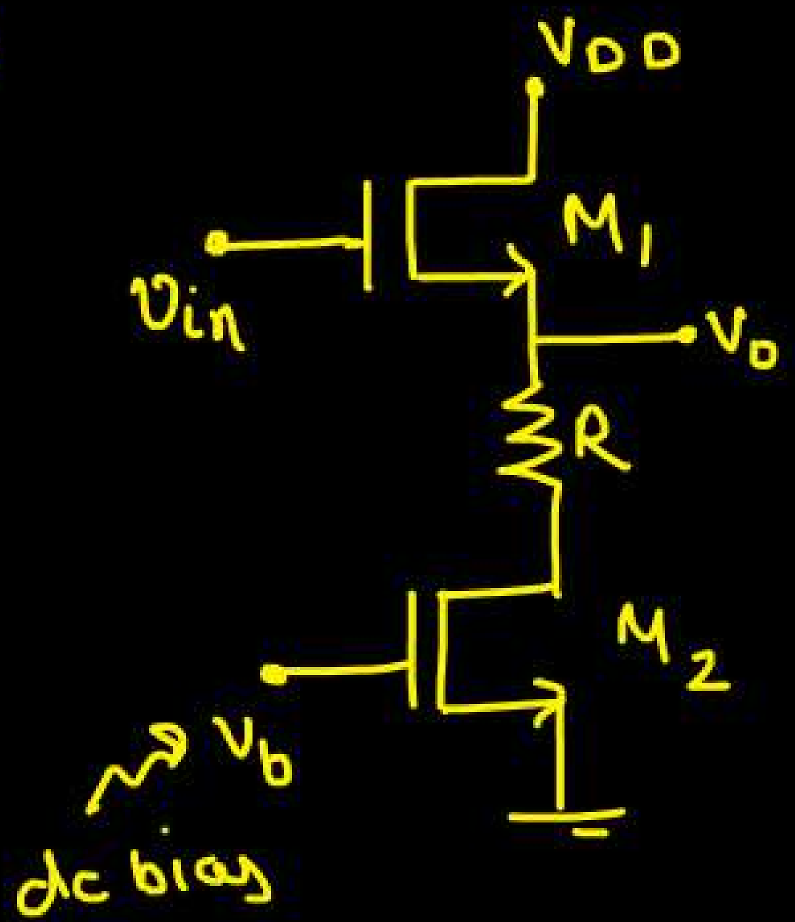


$$\boxed{A_V = \frac{g_m R_D}{1+g_m R_D} \approx 1}$$ ⇒ source-follower

⇒ $\boxed{\text{There is zero degree phase shift b/w i/p and o/p}}$

⇒ $\boxed{R_o = R_D \| r_o \| 1/g_m}$

Q.



$g_{m_1} = 1.92\ mS$

$g_{m_2} = 1.8\ mS$

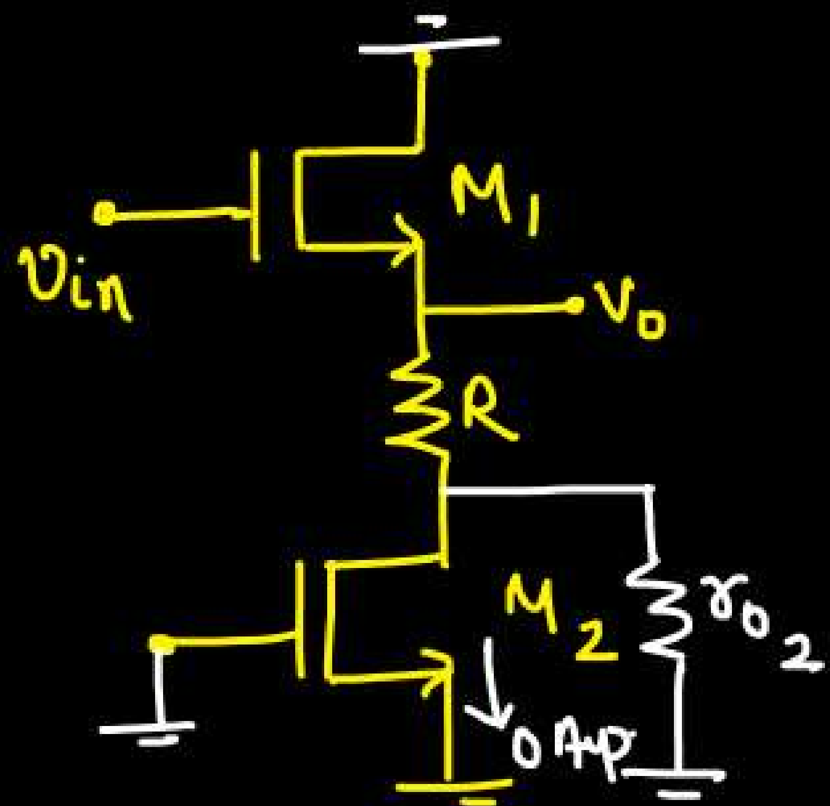
$r_{ds_1} = 20.69\ k\Omega = r_{o_1}$

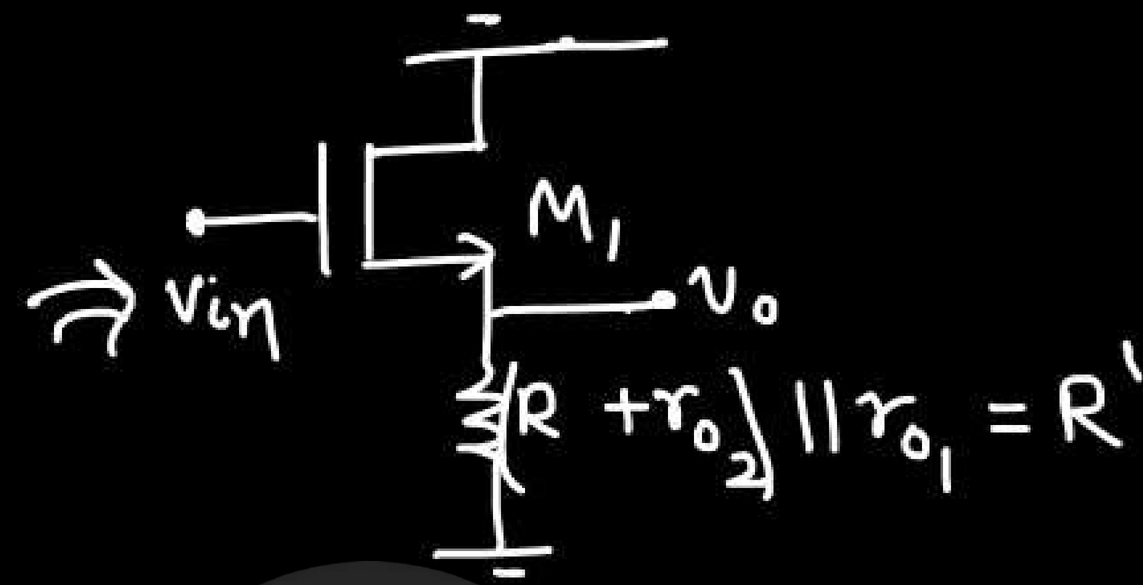
$r_{ds_2} = 23.89\ k\Omega = r_{o_2}$

$R = 4.6\ k\Omega$

Find small signal voltage gain $\frac{v_o}{v_{in}}$.

$\rightarrow$





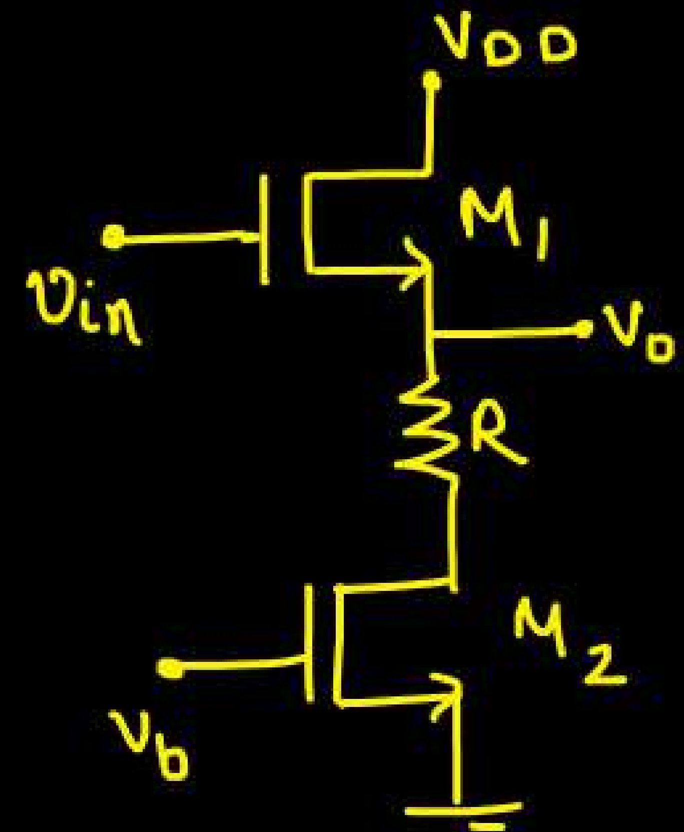
$$\boxed{\frac{v_o}{v_{in}} = \frac{R'}{R' + 1/g_{m_1}} = \frac{g_{m_1}R'}{1 + g_{m_1}R'}}$$

$$R' = 28.49\,\text{K}\Omega \,||\, 20.63\,\text{K}\Omega = 11.96\,\text{K}\Omega$$

$$g_{m_1}R' = 1.92\text{m} \times 11.96\text{K} = 22.97$$

$$\boxed{\frac{v_o}{v_i} = \frac{22.97}{23.97} \approx 0.96}$$

Q.



$g_{m_1} = 1.92\ mS$

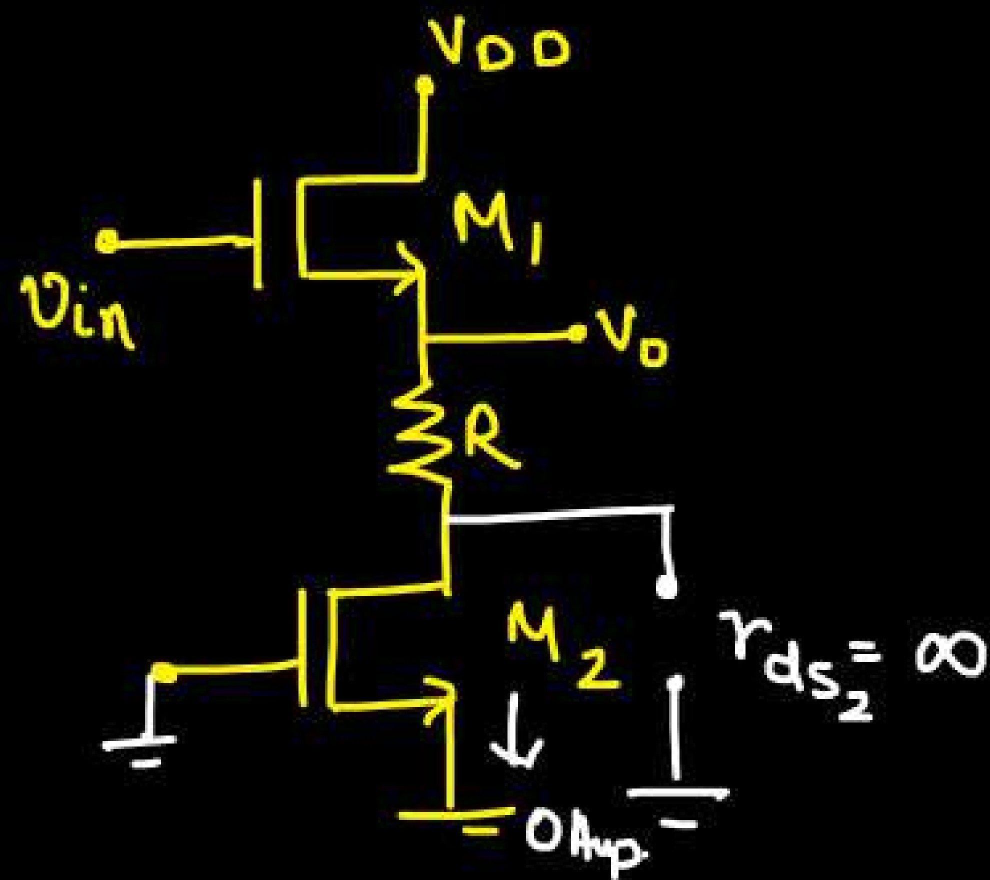
$g_{m_2} = 1.8\ mS$

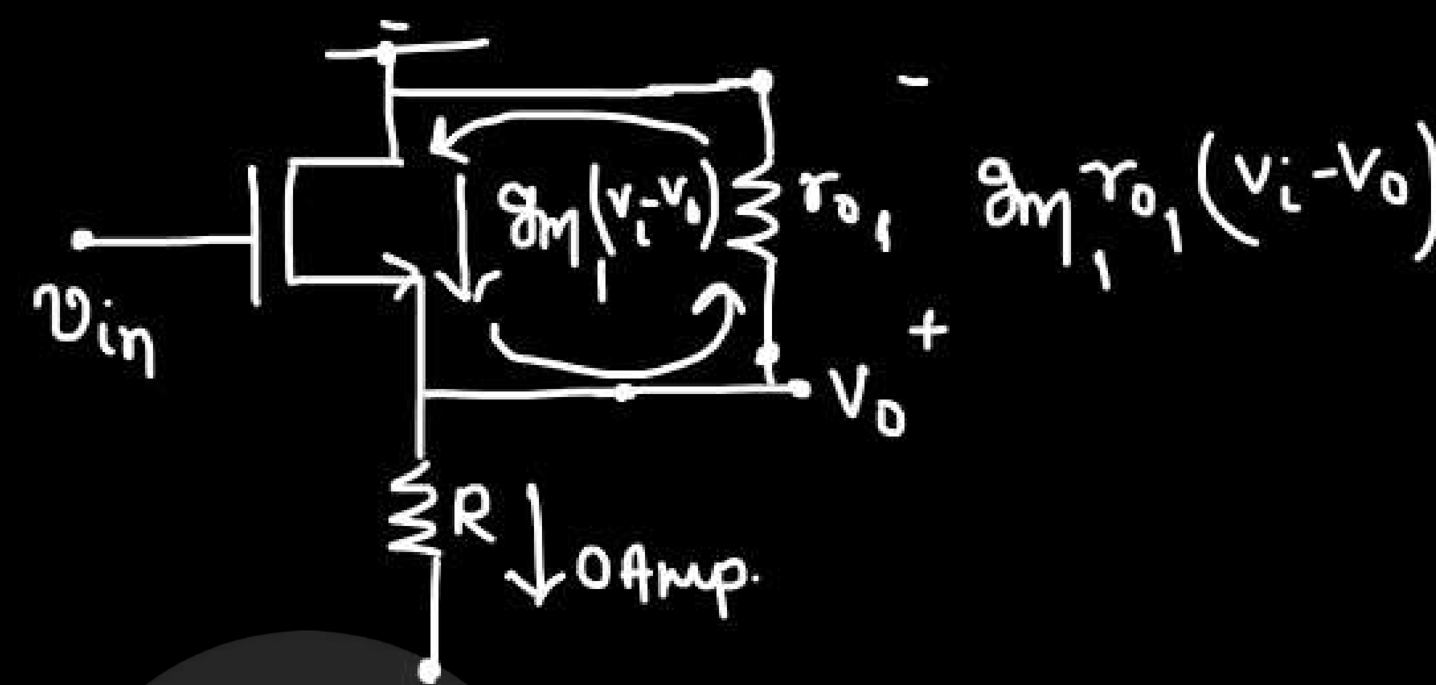
$r_{ds_1} = 20.63\ k\Omega$

$r_{ds_2} = \infty$

$R = 4.6\ k\Omega$

small signal voltage gain $\dfrac{v_o}{v_{in}} = ?$





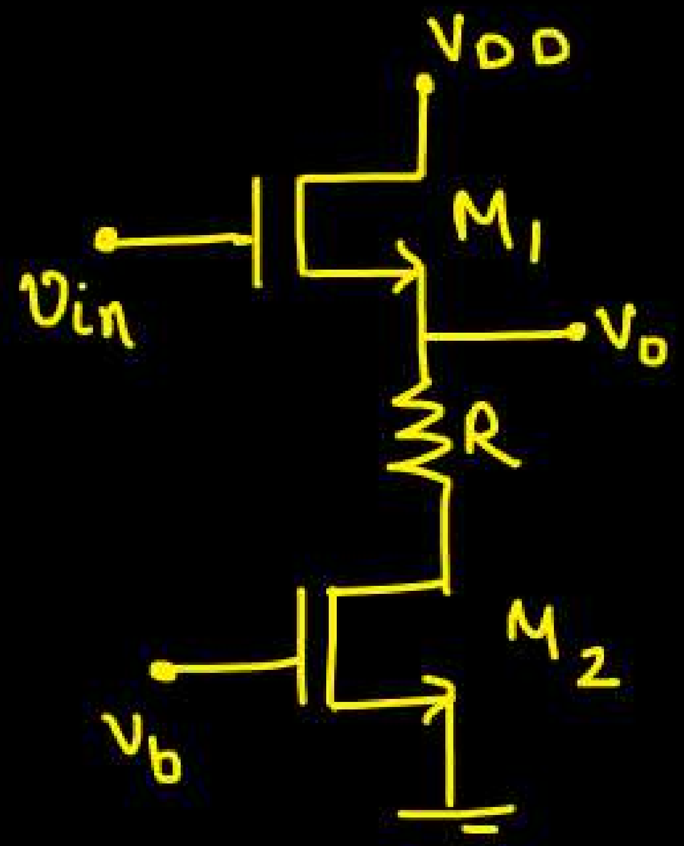
$$g_{m_1} r_{o_1}(v_i - v_0) = v_0$$

$$g_{m_1} r_{o_1} v_i = (1 + g_{m_1} r_{o_1}) v_0$$

$$\boxed{\frac{v_0}{v_i} = \frac{g_{m_1} r_{o_1}}{1 + g_{m_1} r_{o_1}}}$$

$$\boxed{\frac{v_0}{v_i} = \frac{39.6096}{40.6096} = 0.975}$$

Q.



$g_{m_1} = 1.92\ mS$

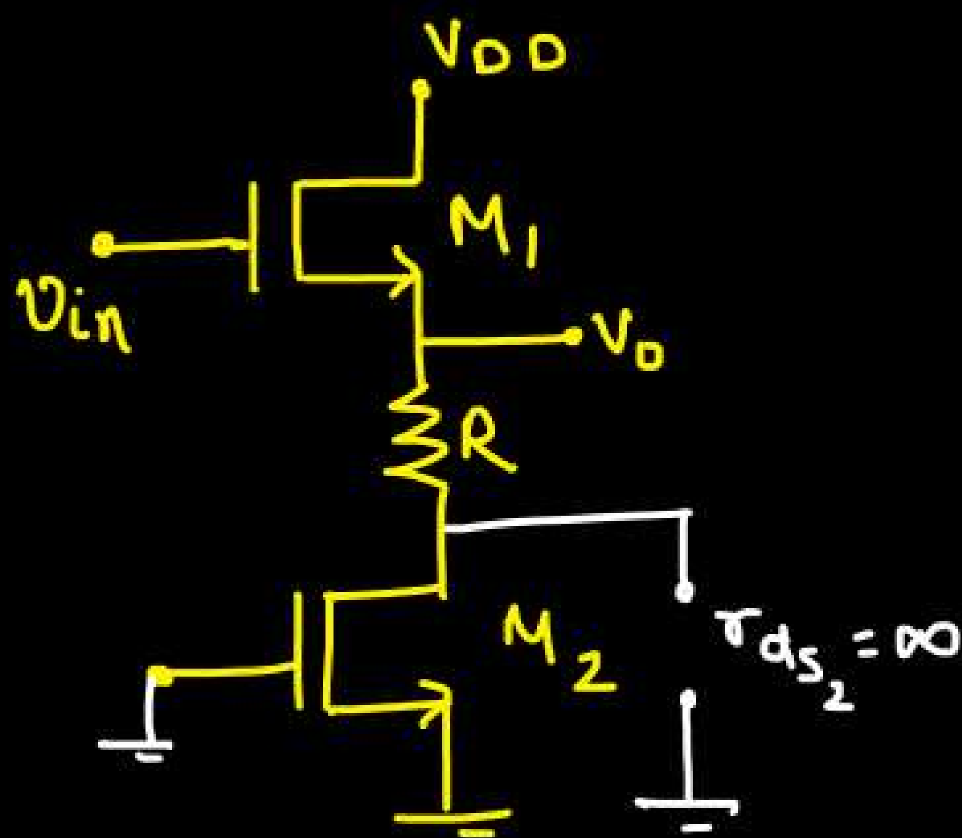
$g_{m_2} = 1.8\ mS$

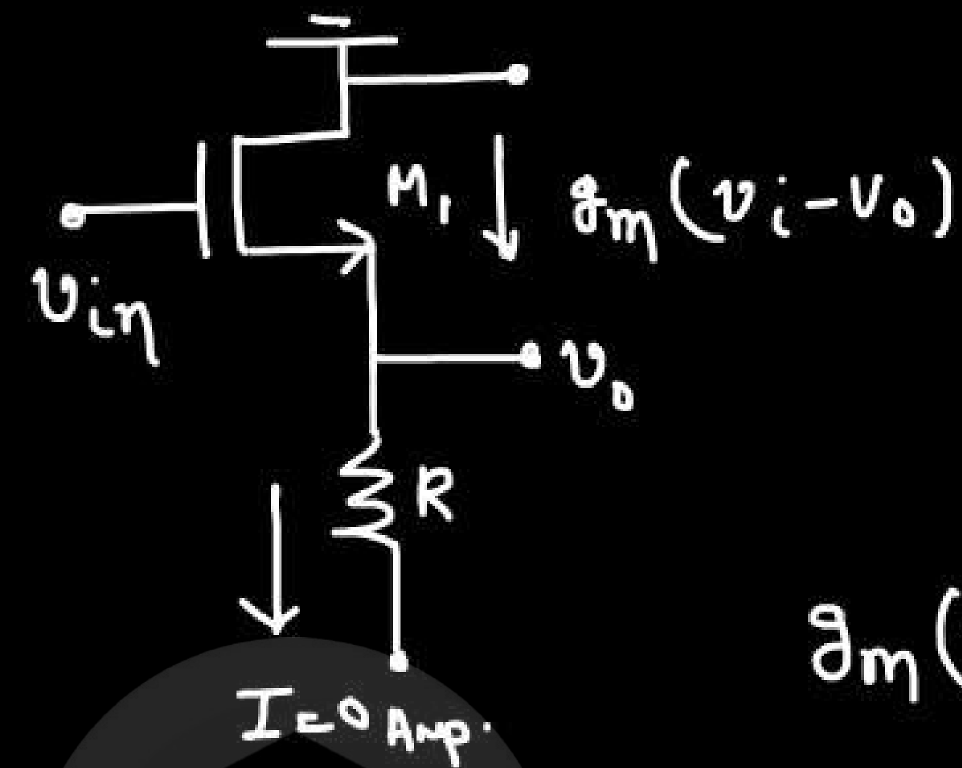
$r_{ds_1} = \infty$

$r_{ds_2} = \infty$

$R = 4.6\ k\Omega$

small signal voltage gain $\frac{v_o}{v_{in}} = ?$





$$g_m(v_i - v_o) = 0$$

$$v_i = v_o$$

**

$$\boxed{\frac{v_o}{v_i} = 1}$$

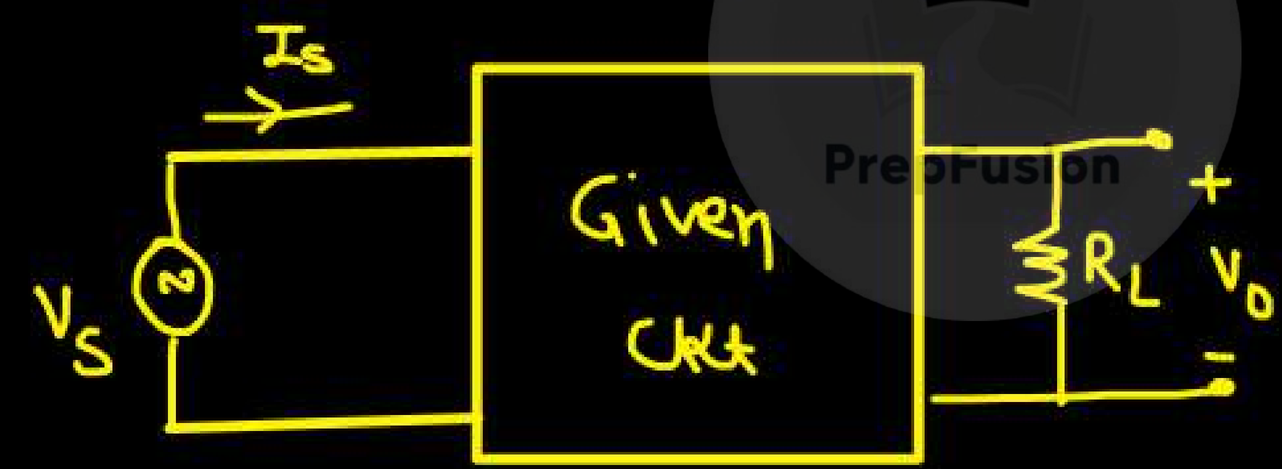
☆ Interesting Method of Finding voltage gain :

($G_m R_{out}$ Method)

☆ Small signal voltage gain of any configuration

$$A_v = G_m R_{out}$$

$$\boxed{G_m \neq g_m}$$



$$\boxed{A_v = \frac{V_o}{V_s} = G_m R_{out}}$$

① $G_m \rightarrow$

Short ckt the o/p and find out the relation b/w i_{out} and V_s.

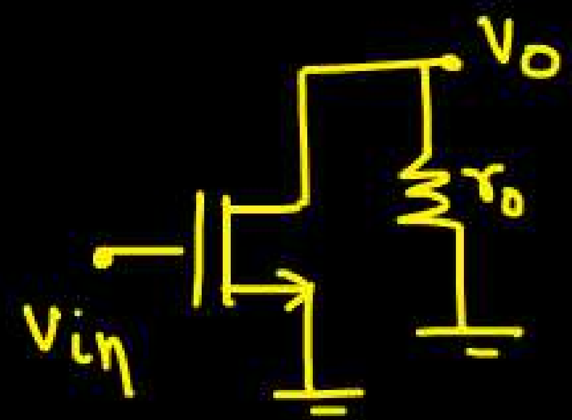
$$\boxed{G_m = \frac{I_{out}}{V_s}}$$

② Find small signal out resistance :-

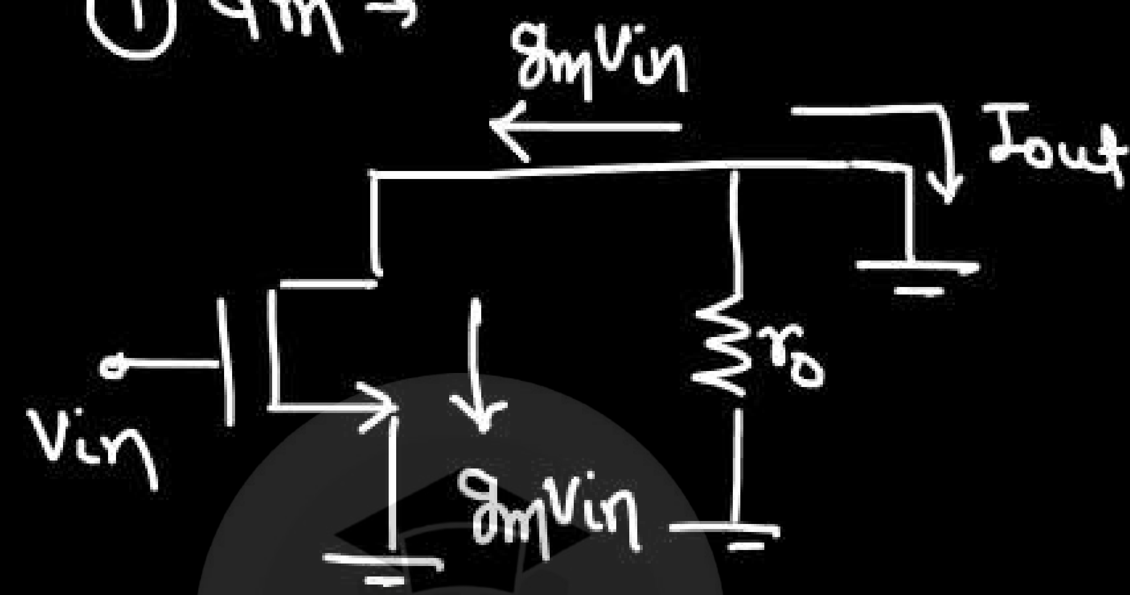
$$R_{out} = \frac{V_o}{I_o}$$

Eg → Find small signal gain.

(1)



(1) G_m →

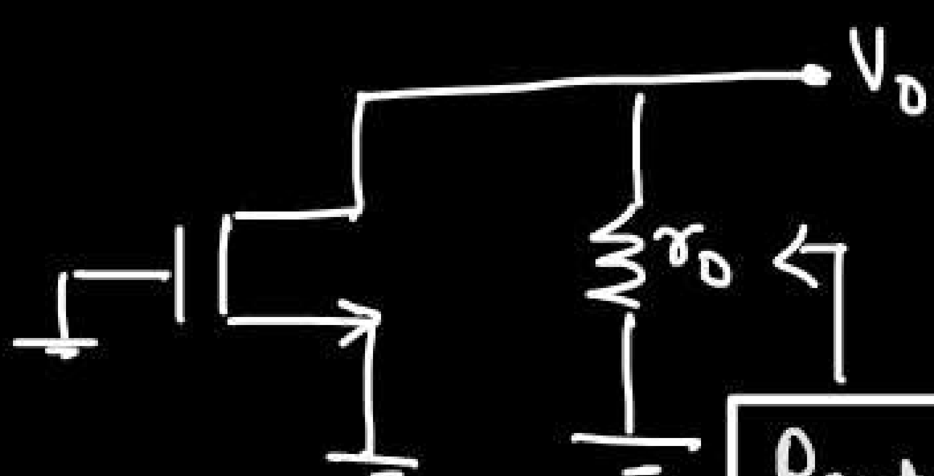


$$I_{out} = -g_m V_{in}$$

$$\boxed{G_m = \frac{I_{out}}{V_{in}} = -g_m}$$

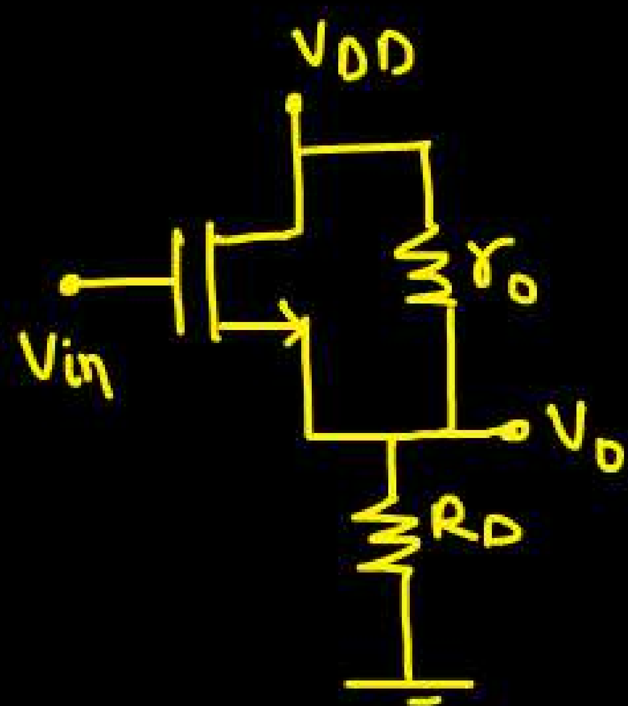
$$\boxed{\text{Gain} = -g_m r_o}$$

(2) R_{out} →

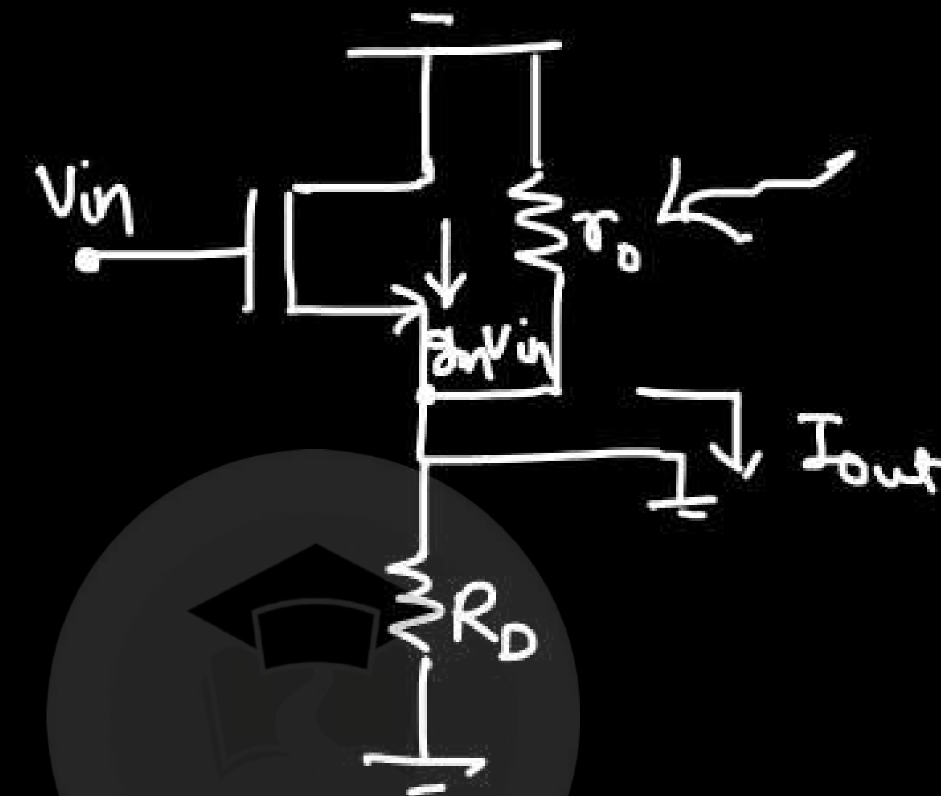


$$\boxed{R_{out} = r_o}$$

(2)



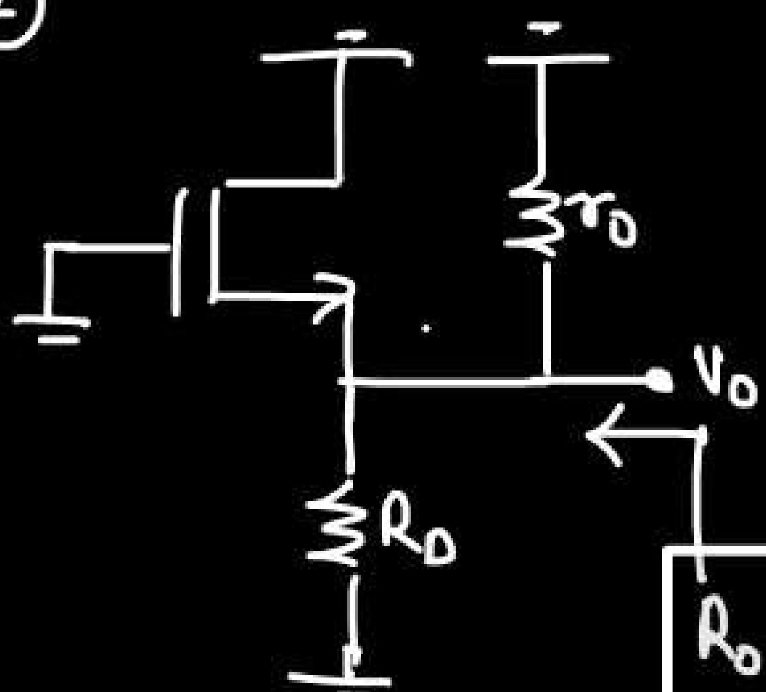
→ (1) G_m →



$$\Rightarrow I_{out} = g_m v_{in}$$

$$\boxed{G_m = g_m}$$

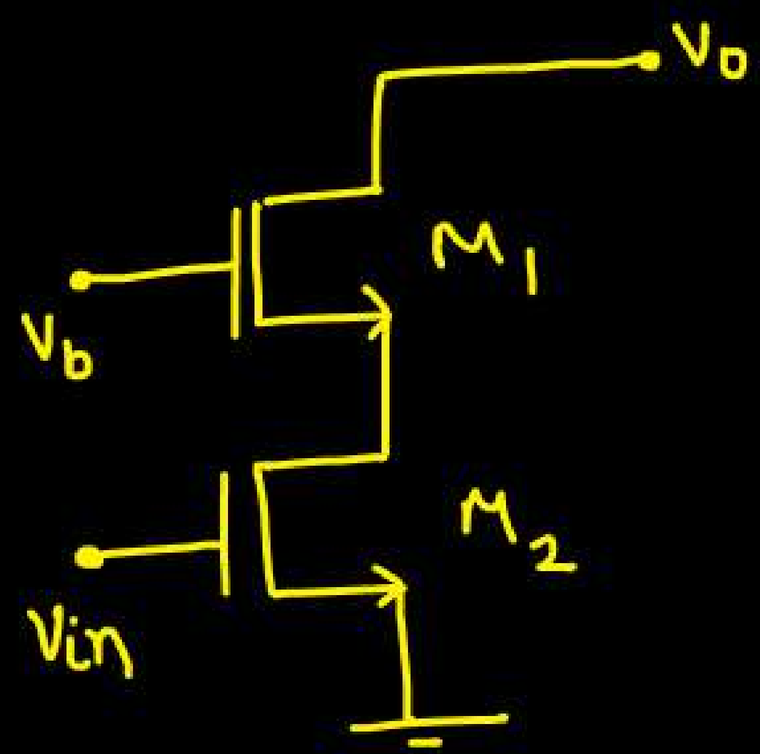
(2)



$$\boxed{R_o = R_D || r_o || 1/g_m}$$

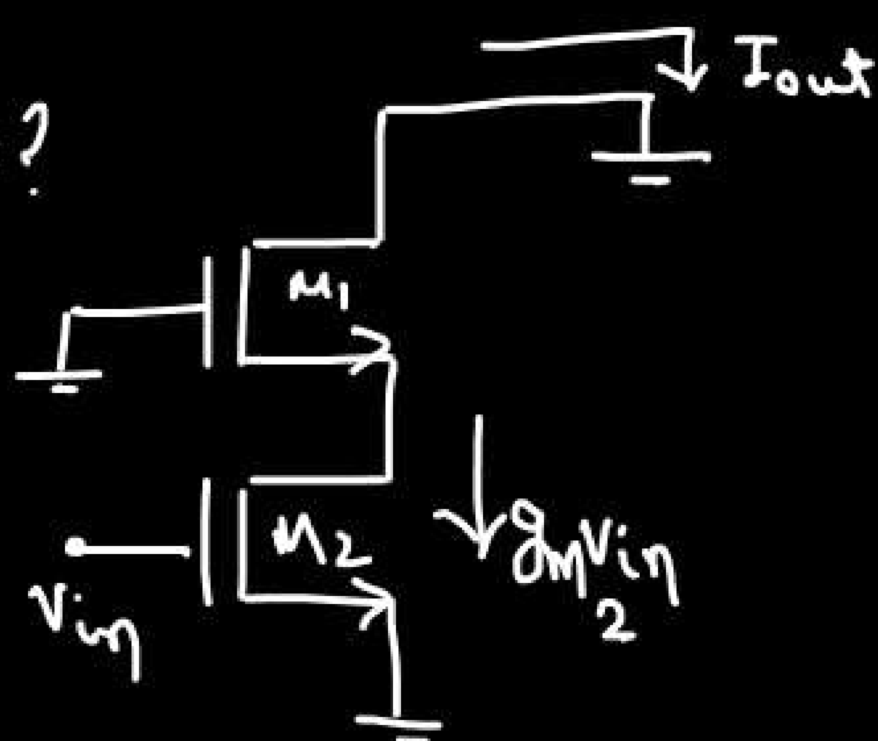
$$\Rightarrow \boxed{A_v = g_m [R_D || r_o || 1/g_m]}$$

3



r_{o1} and r_{o2} are very high.

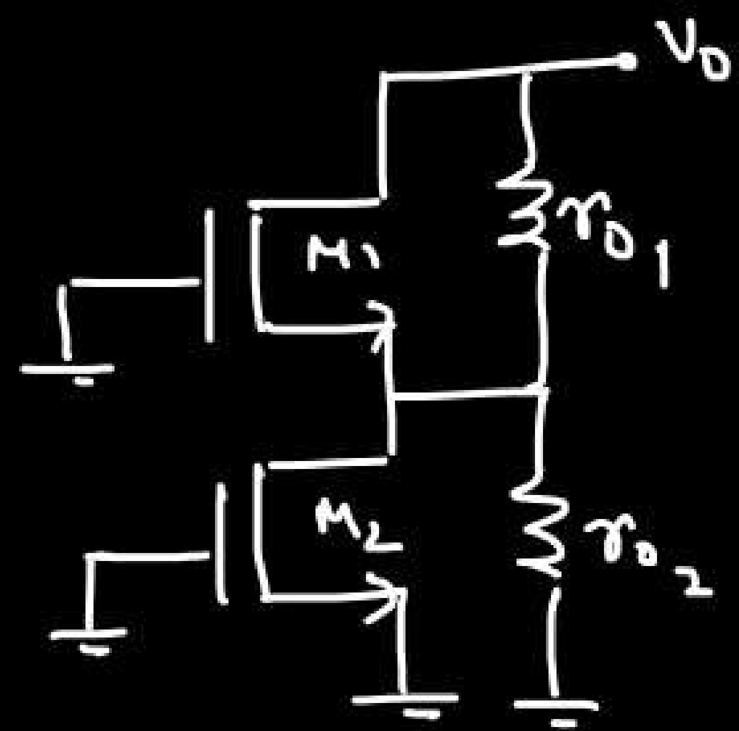
$\Rightarrow$ $G_m = ?$



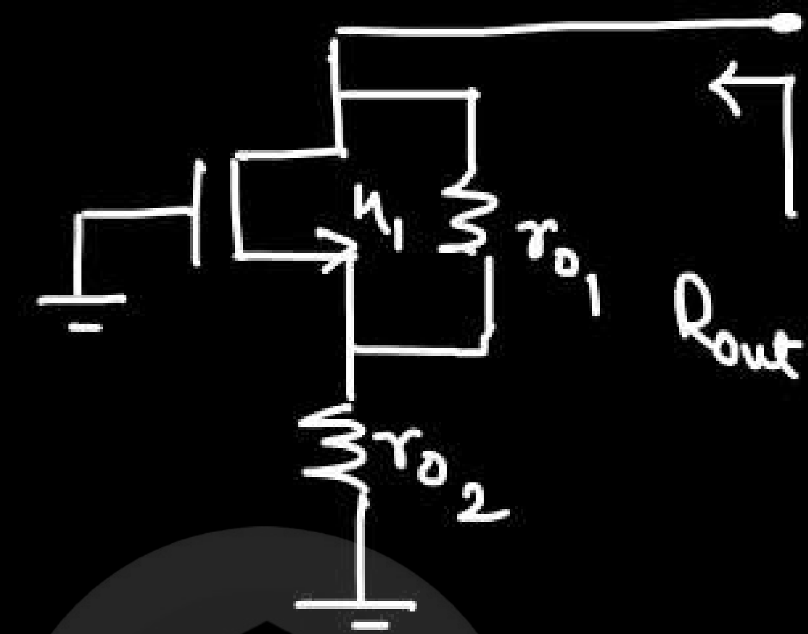
$I_{out} = -g_{m2} V_{in}$

$$\boxed{G_m = -g_{m2}}$$

R_{out}



$\Rightarrow$



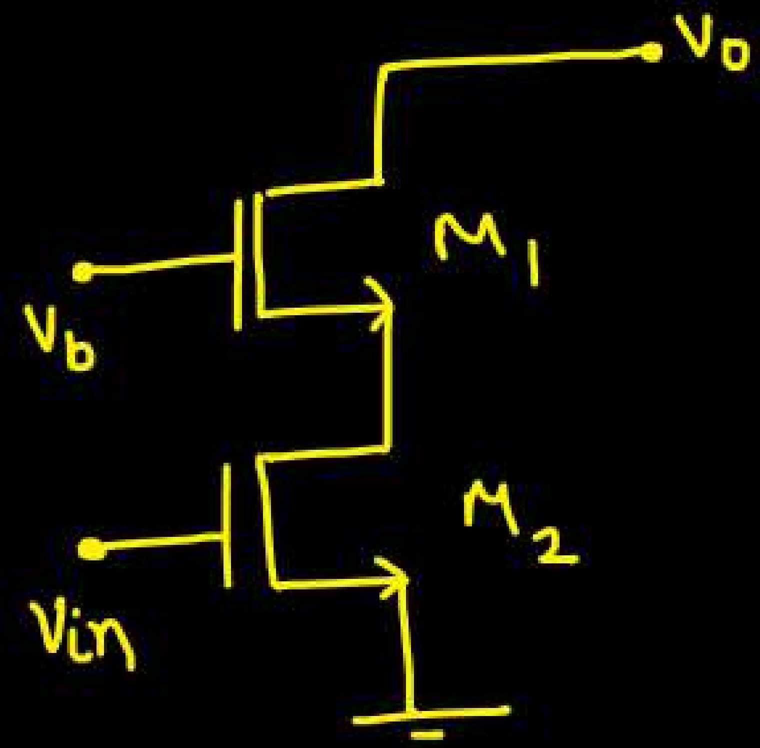
$$R_{out} = r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2}$$

$$\approx g_{m_1} r_{o_1} r_{o_2}$$

$$\Rightarrow \text{Gain} \approx -g_{m_2}\left[r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2}\right]$$

$$\boxed{\text{Gain} \approx -g_{m_2} g_{m_1} r_{o_1} r_{o_2}}$$

Q.



Let's assume,

$$\frac{1}{g_{m_1}} = r_{o_1} = r_{o_2} = 2\,k\Omega$$

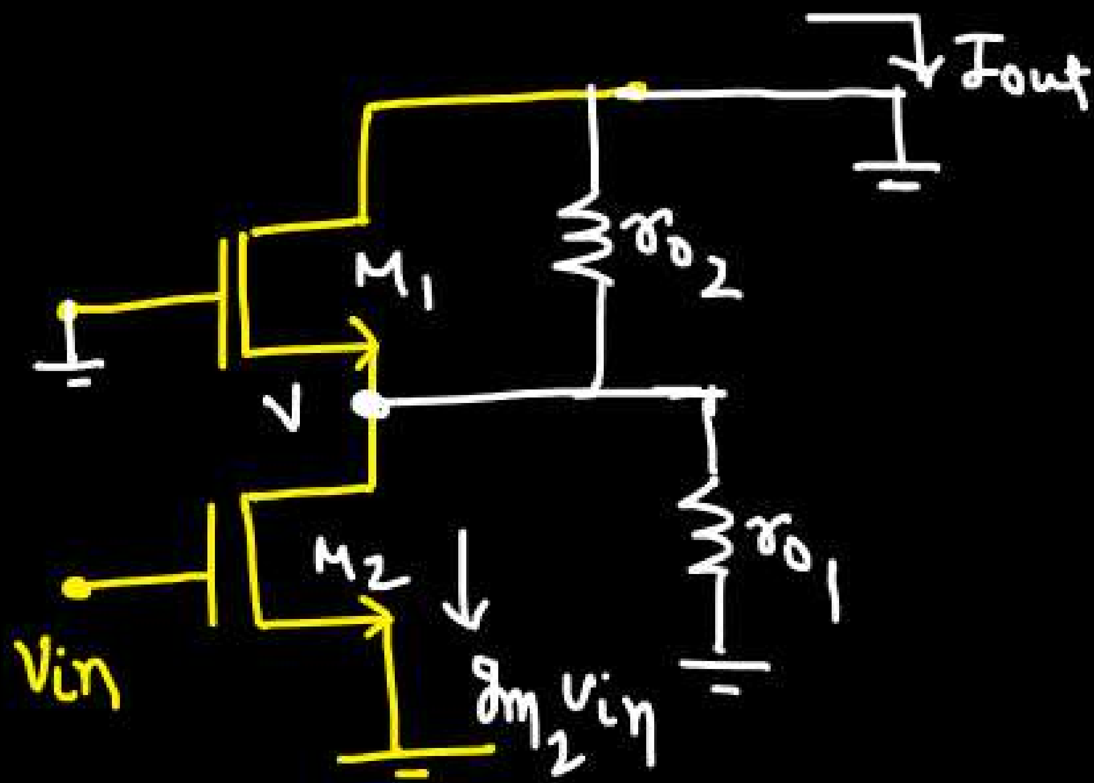
$$g_{m_2} = 3\,mS$$

Find $\frac{v_o}{v_{in}} = ?$

NOTE-

Generally g_m values are in mS and r_o values are in $M\Omega$. We took such values only for understanding purpose.

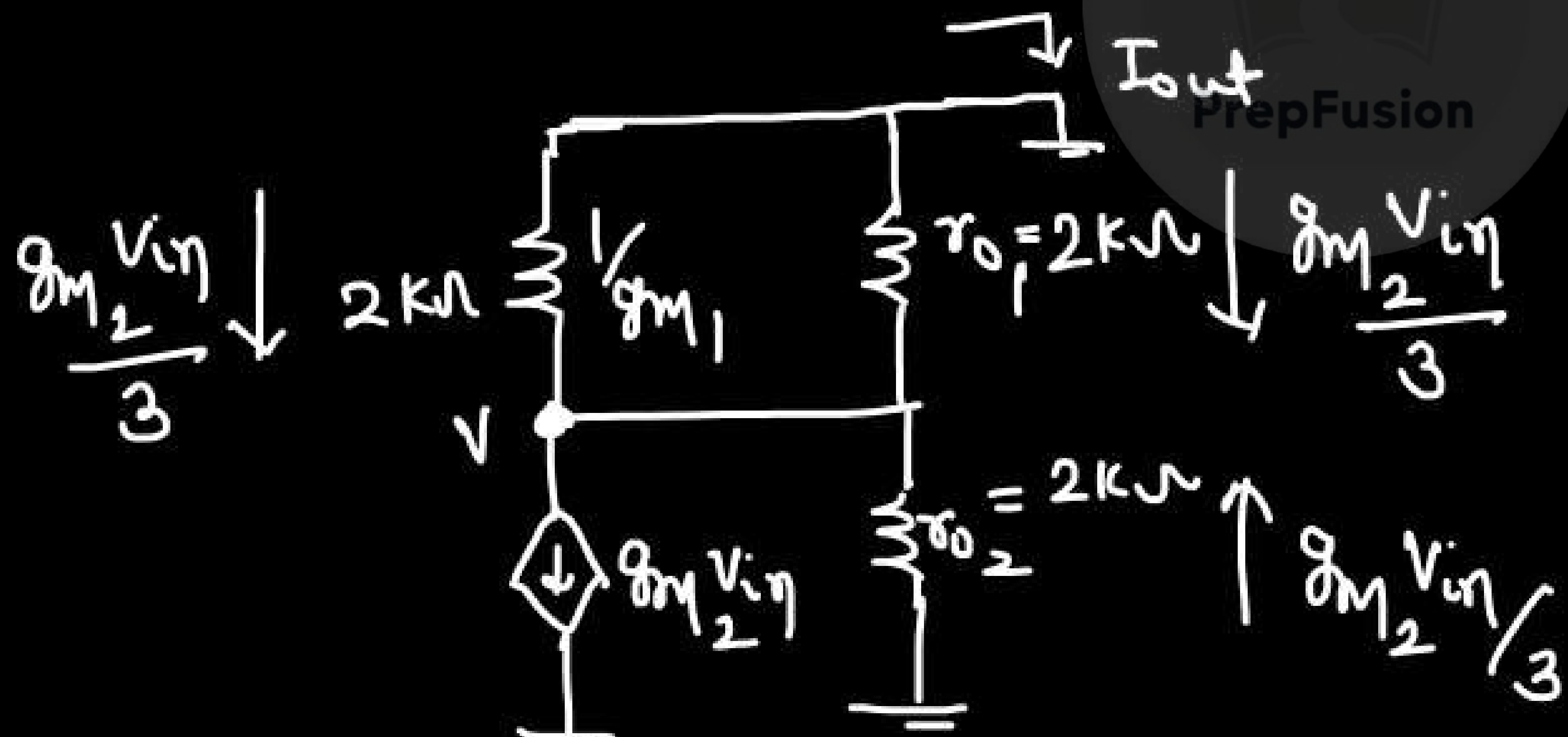
① $G_m \rightarrow$



$$I_{out} = -\left[\frac{g_{m_2} V_{in}}{3} + \frac{g_{m_2} V_{in}}{3}\right]$$

$$I_{out} = \frac{-2 g_{m_2}}{3} v_{in}$$

$$\boxed{G_m = \frac{-2 g_{m_2}}{3}}$$



$$R_{out} = r_{o1} + r_{o2} + g_{m1} r_{o1} r_{o2}$$

$$= 2K + 2K + \frac{1}{2k} \times 2K \times 2K$$

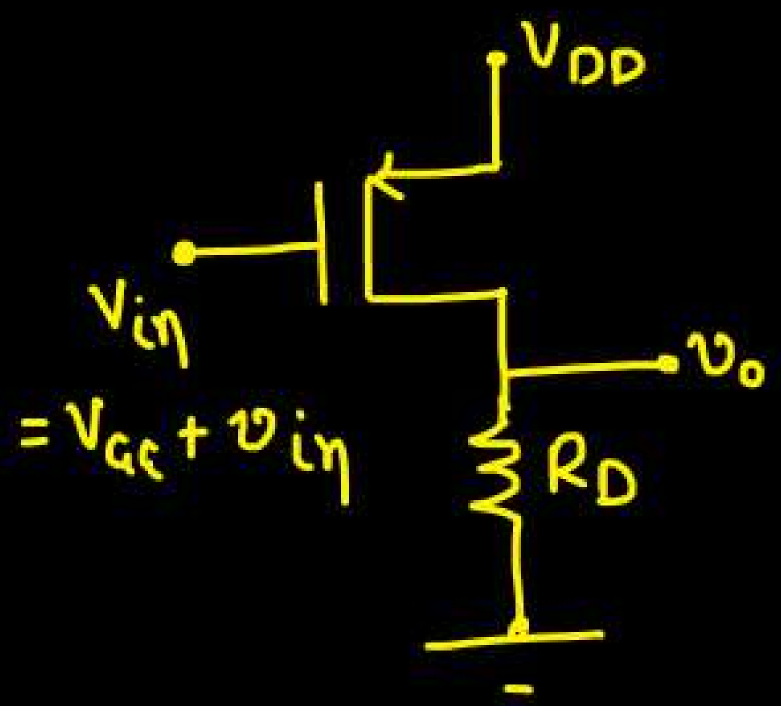
$$\boxed{R_{out} = 6\,k\Omega}$$

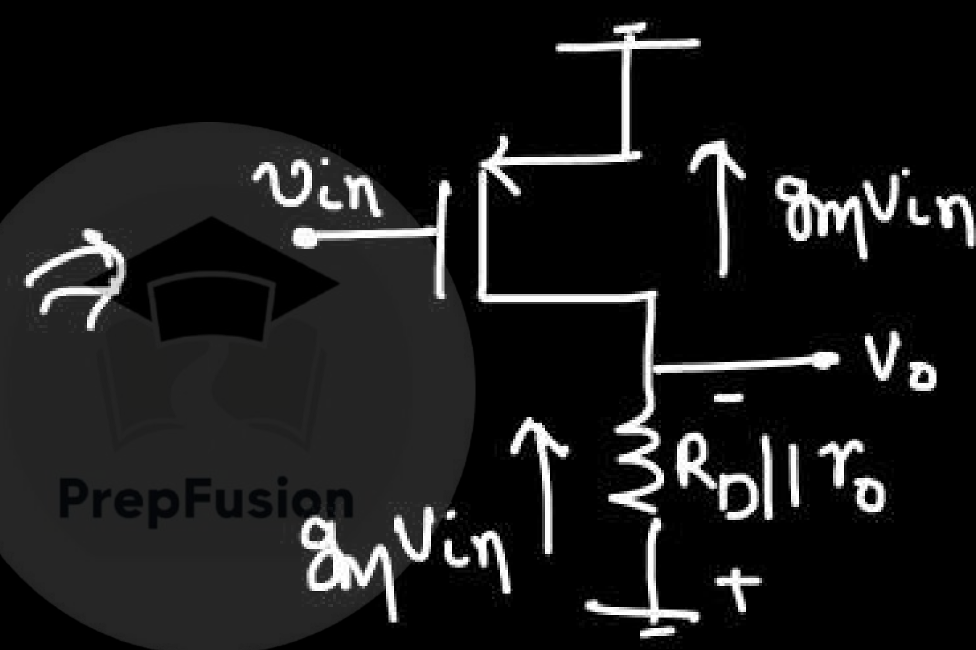
$$A_v = -\frac{2}{3} \times 3\,mS \times 6\,k\Omega$$

$$\boxed{A_v = -12\,V/V}$$

MOS Amplifiers using PMOS:-

① Common Source Amplifier:-

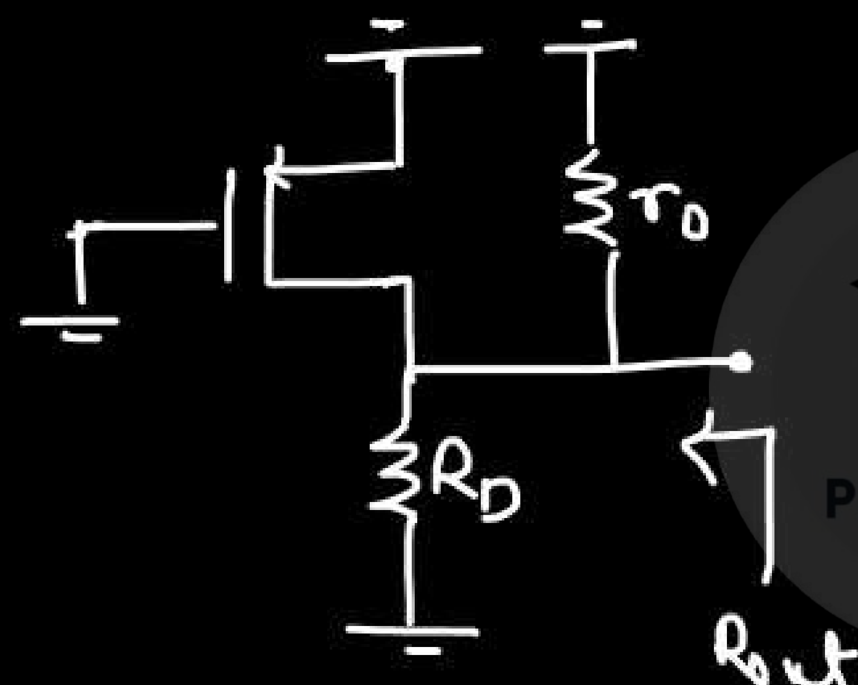




$$\boxed{\frac{v_o}{v_{in}} = -g_m (R_D \| r_o)}$$

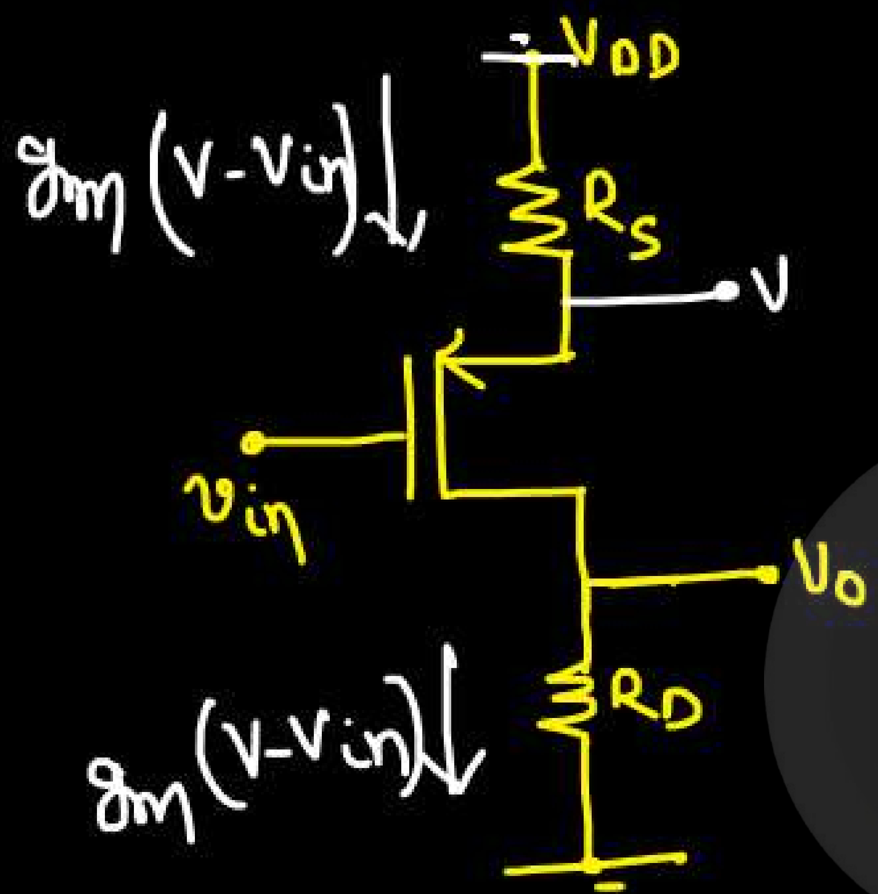
$\Rightarrow$ $\boxed{\text{Current gain} = \text{I/P resistance} = \infty}$ (I/P current = 0)

$\Rightarrow$ <u>o/p impedance:-</u>



$$\boxed{R_o = r_o \,||\, R_D}$$

Common source Amplifier with degeneration:-



$\boxed{\lambda = 0}$

$$\boxed{A_V = \frac{-g_m R_D}{1+g_m R_S}}$$

$$\Rightarrow \frac{V}{R_S} = \frac{-V_o}{R_D}$$

$$V = -\frac{R_S}{R_D} V_o$$

$$V_o = g_m R_D\left[-\frac{R_S}{R_D} V_o - V_{in}\right]$$

$$V_o\left[1+g_m R_S\right] = -g_m R_D V_{in}$$

$$\Rightarrow \boxed{\frac{V_o}{V_{in}} = \frac{-g_m R_D}{1+g_m R_S}}$$

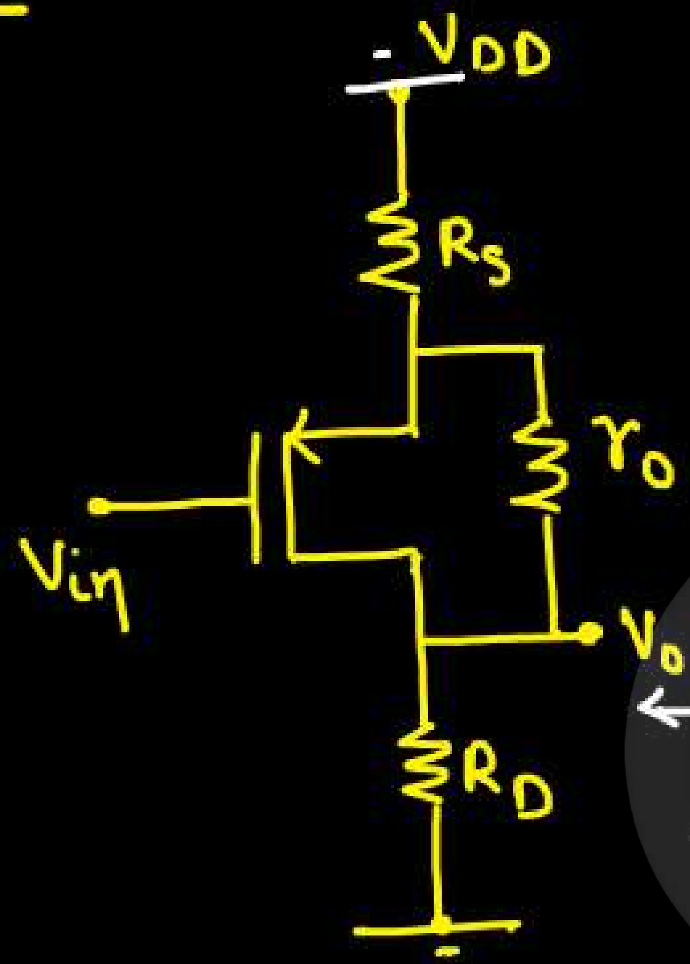
$$A_V = \frac{-g_m R_D}{1 + g_m R_S}$$

$$g_m R_S >> 1$$

$$A_V = \frac{-g_m R_D}{g_m R_S}$$

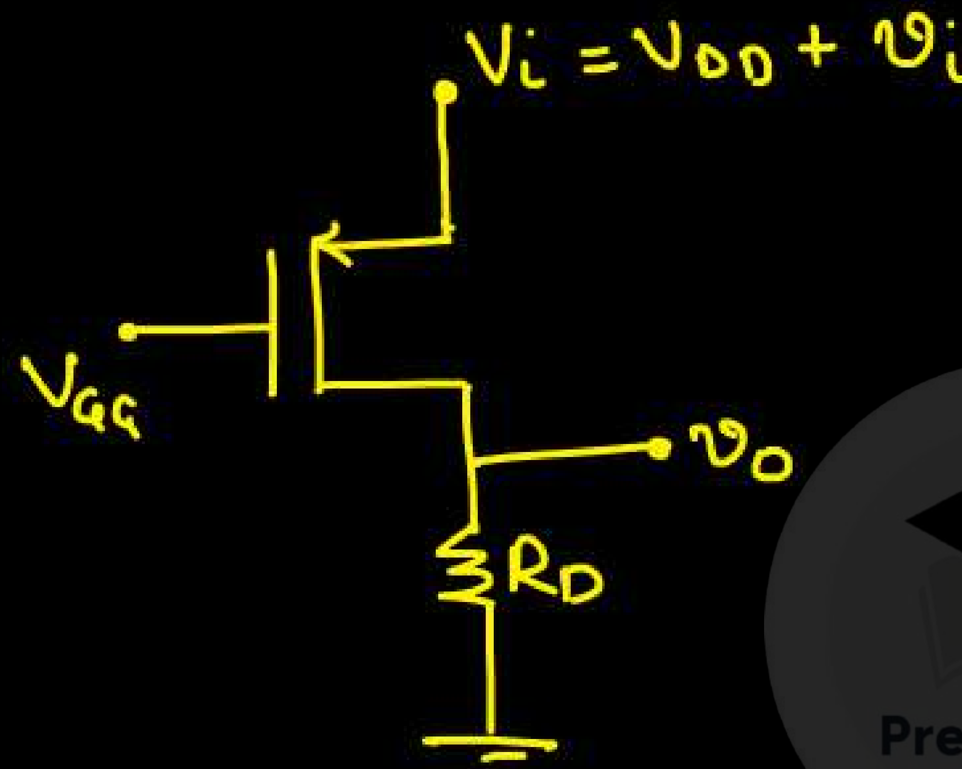
$$\boxed{A_V = \frac{-R_D}{R_S}}$$ → constant gain (very stable)

O/p impedance :-

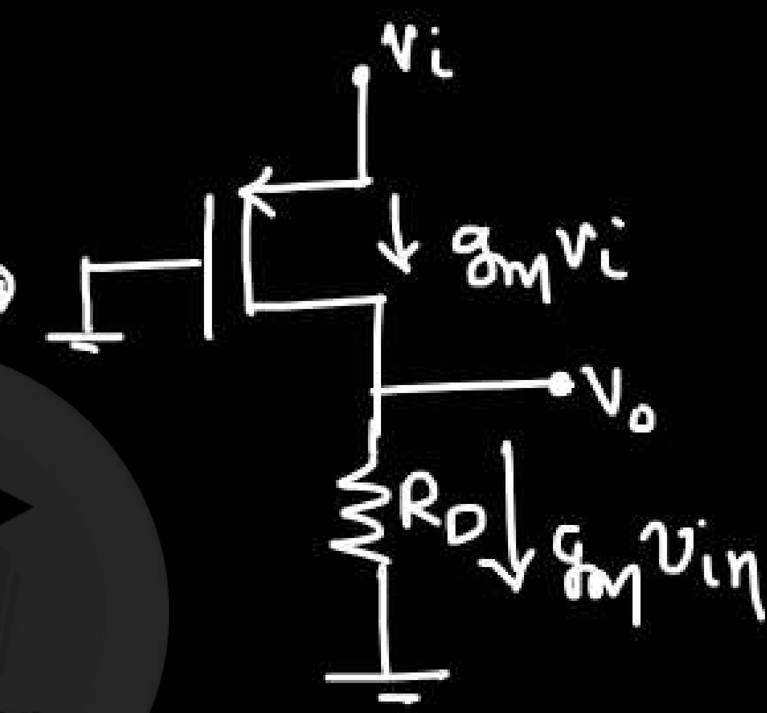


$$\boxed{R_{out} = R_D \| \left(r_o + R_S + g_m r_o R_S\right)}$$

② Common Gate Amplifier :-



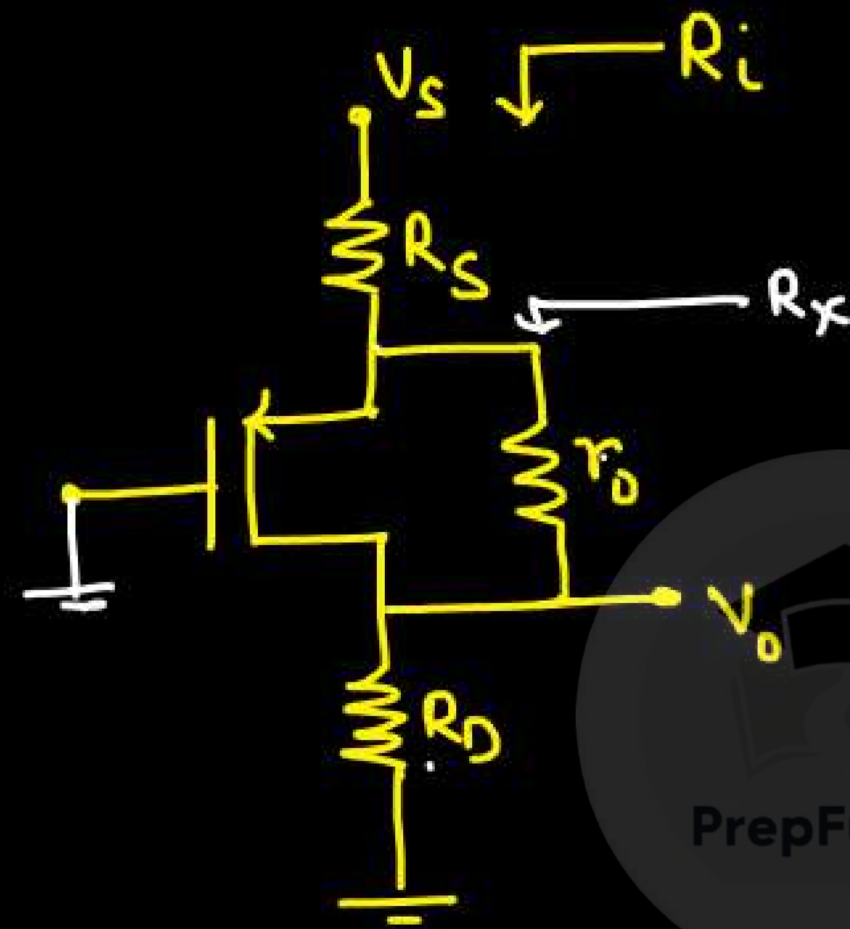
⇒



$\lambda = 0$

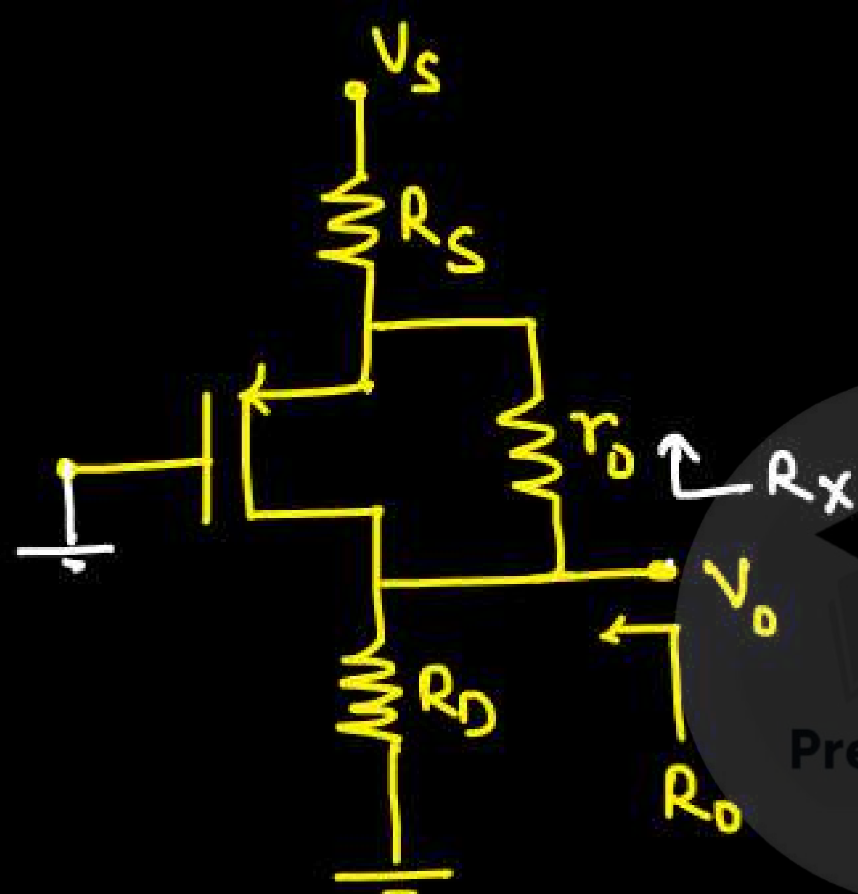
$$\boxed{\frac{v_o}{v_i} = g_m R_D}$$

Input Impedance:-



$$\boxed{R_i = R_S + \frac{R_D + r_0}{1 + g_m r_0}}$$

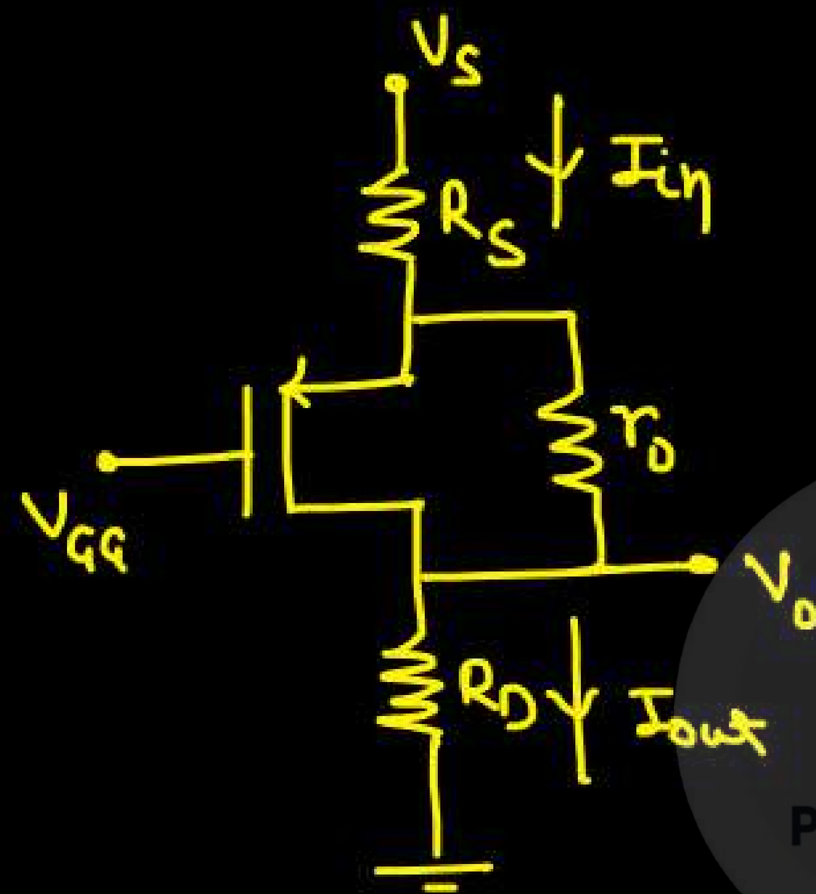
Output Impedance:-



$$R_0 = R_D \| R_x$$

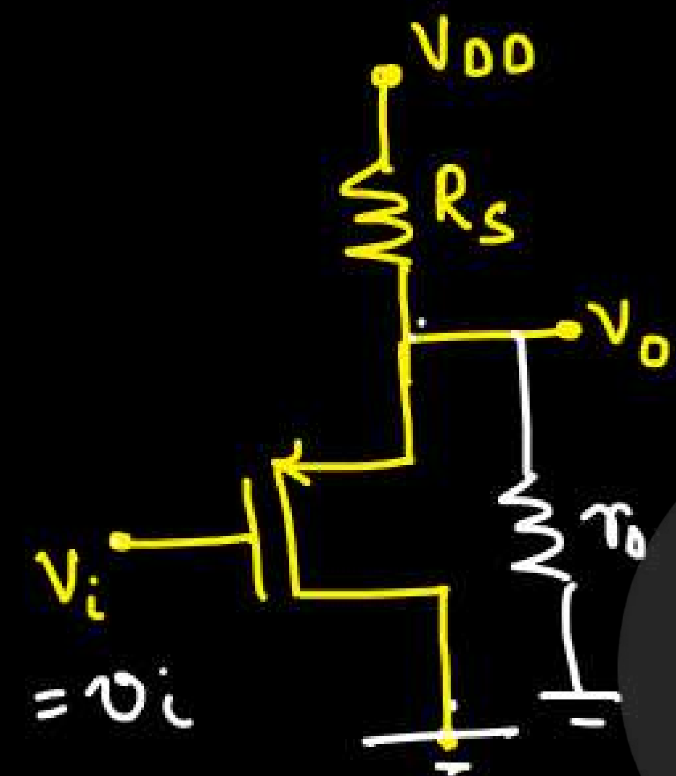
$$\boxed{R_0 = R_D \| r_0 + R_S + g_m r_0 R_S}$$

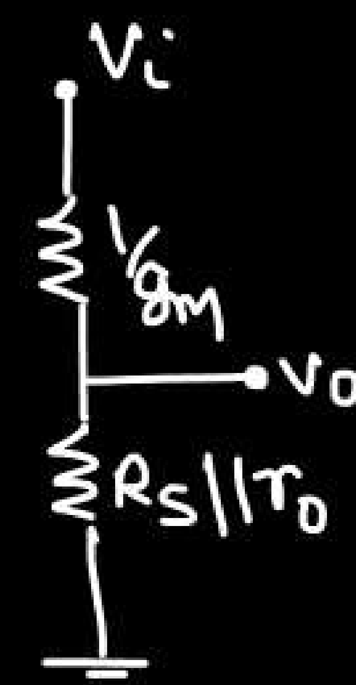
Current gain:-



$$\boxed{\frac{I_o}{I_{in}} = 1}$$

③ Common-Drain Amplifiers:-





$$\frac{v_o}{v_i} = \frac{R_S}{R_S + 1/g_m}$$

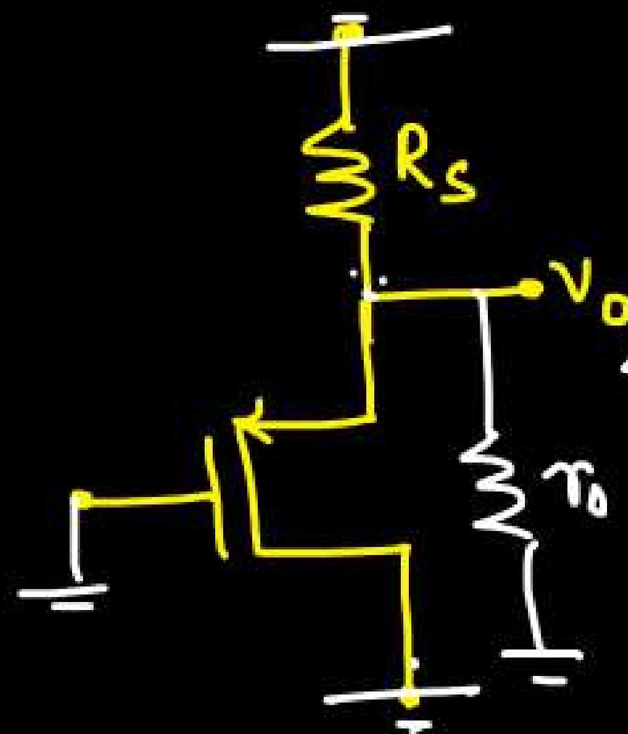
$\lambda = 0$

$$\boxed{\frac{v_o}{v_i} = \frac{g_m R_S}{1 + g_m R_S}}$$

$\lambda \neq 0$

$$\boxed{\frac{v_o}{v_i} = \frac{g_m (R_S \| r_o)}{1 + g_m (R_S \| r_o)}}$$

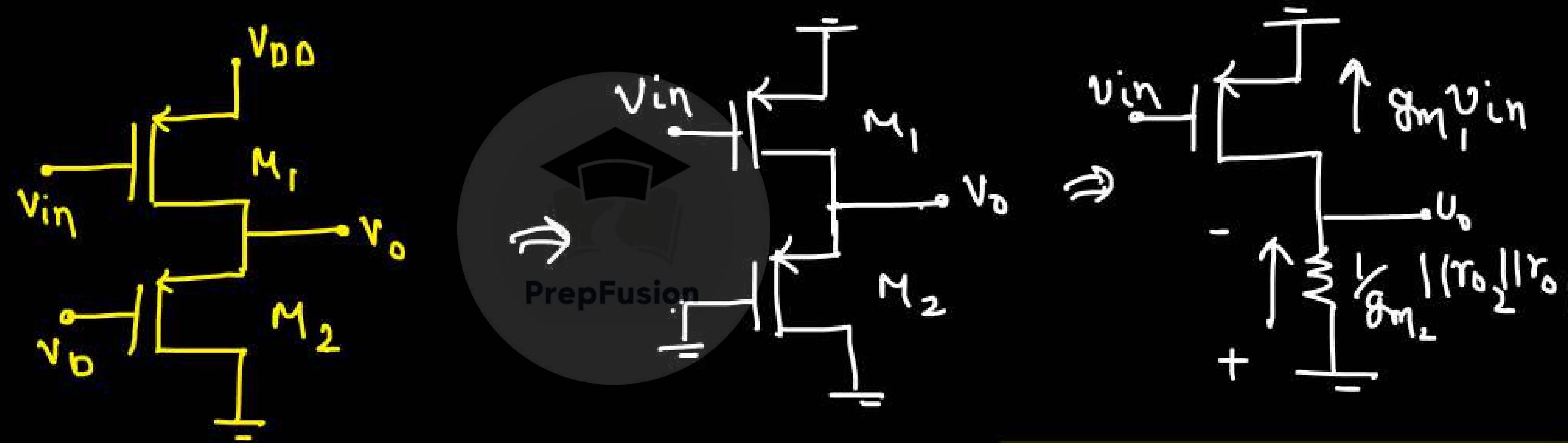
Output Impedance :



$$\boxed{R_{out} = r_o \,||\, R_S \,||\, \frac{1}{g_m}}$$

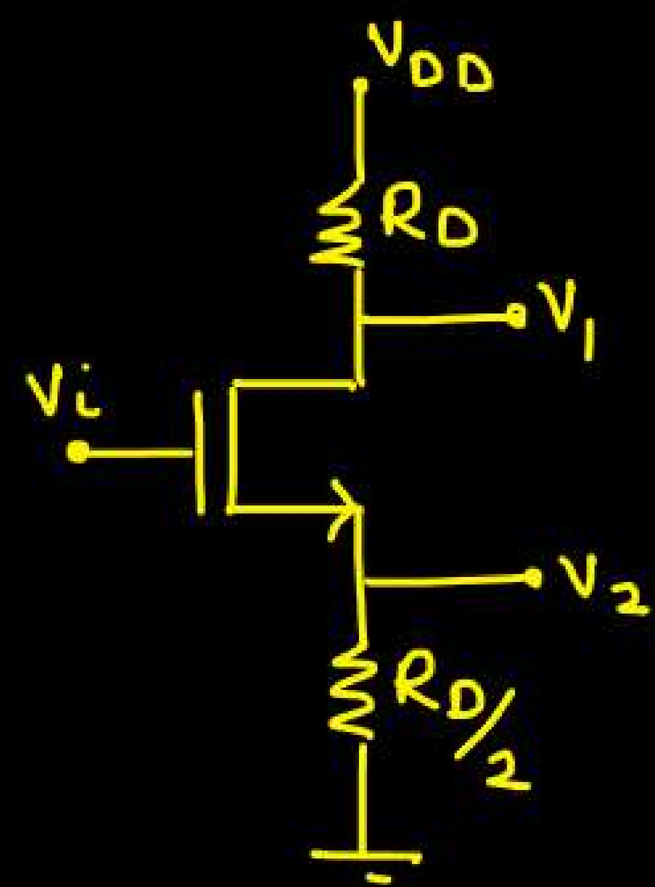
Assignment - 7

Q. Find small signal voltage gain.
$(\lambda \neq 0)$



$$\boxed{\frac{v_o}{v_i} = -g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2} \| r_{o_1}\right]}$$

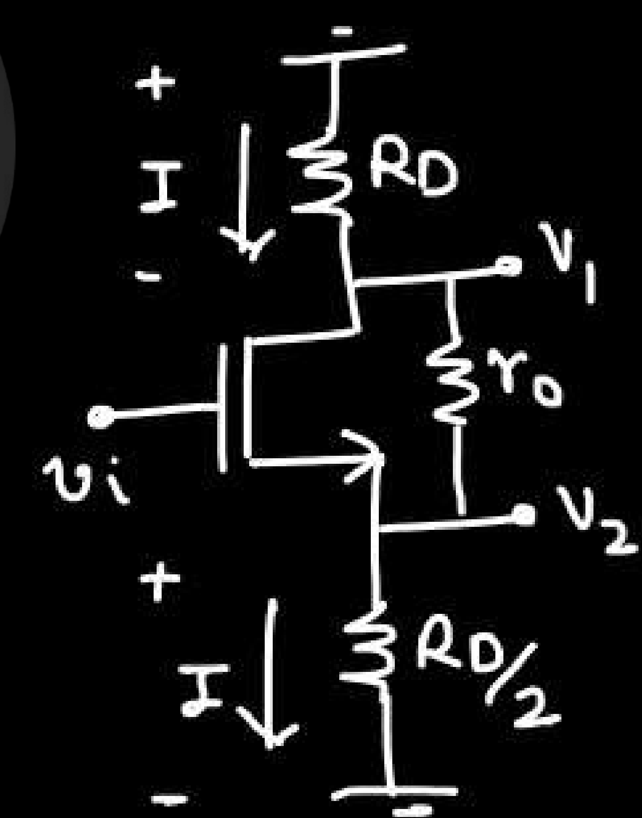
Q.



Find $\frac{V_1}{V_2} = ?$ [small signal]

$(\lambda \neq 0)$

$\Rightarrow$

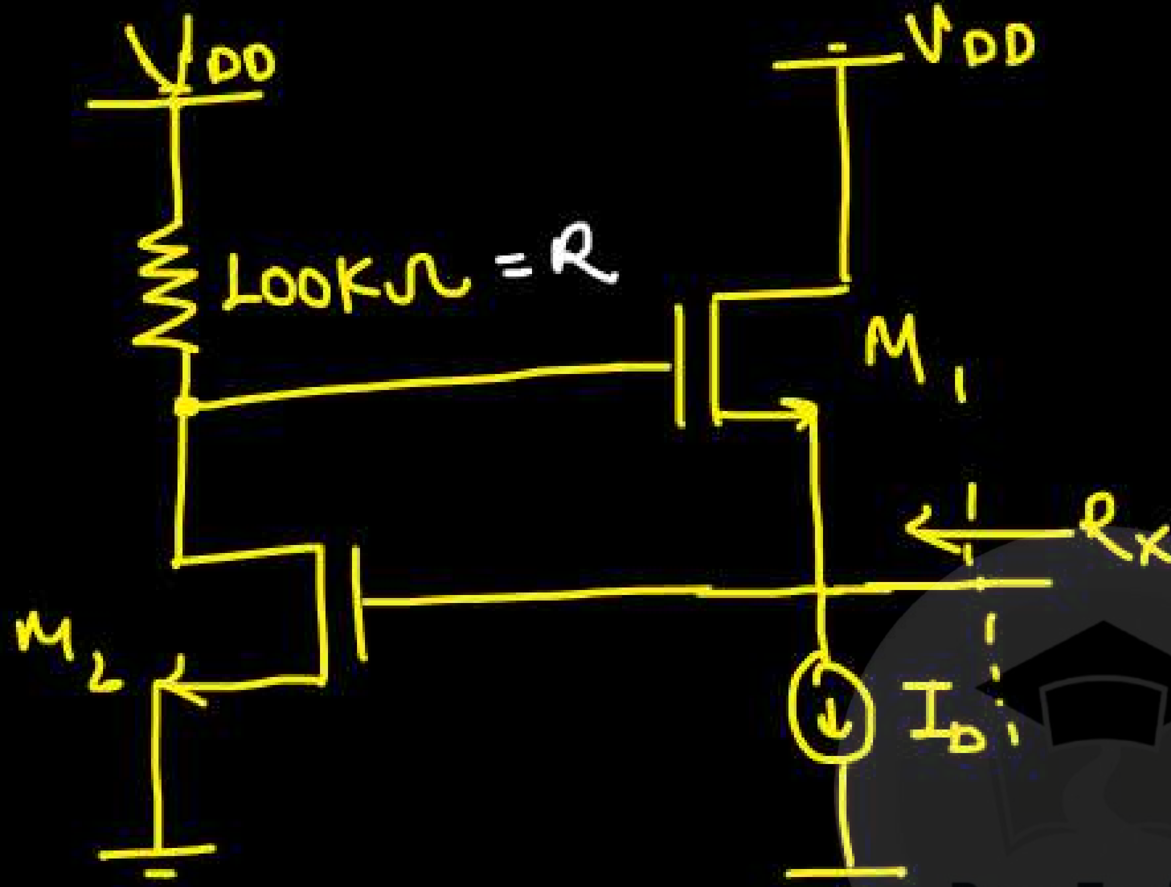


$V_1 = -IR_D$

$V_2 = -IR_D/2$

$$\boxed{\frac{V_1}{V_2} = 2}$$

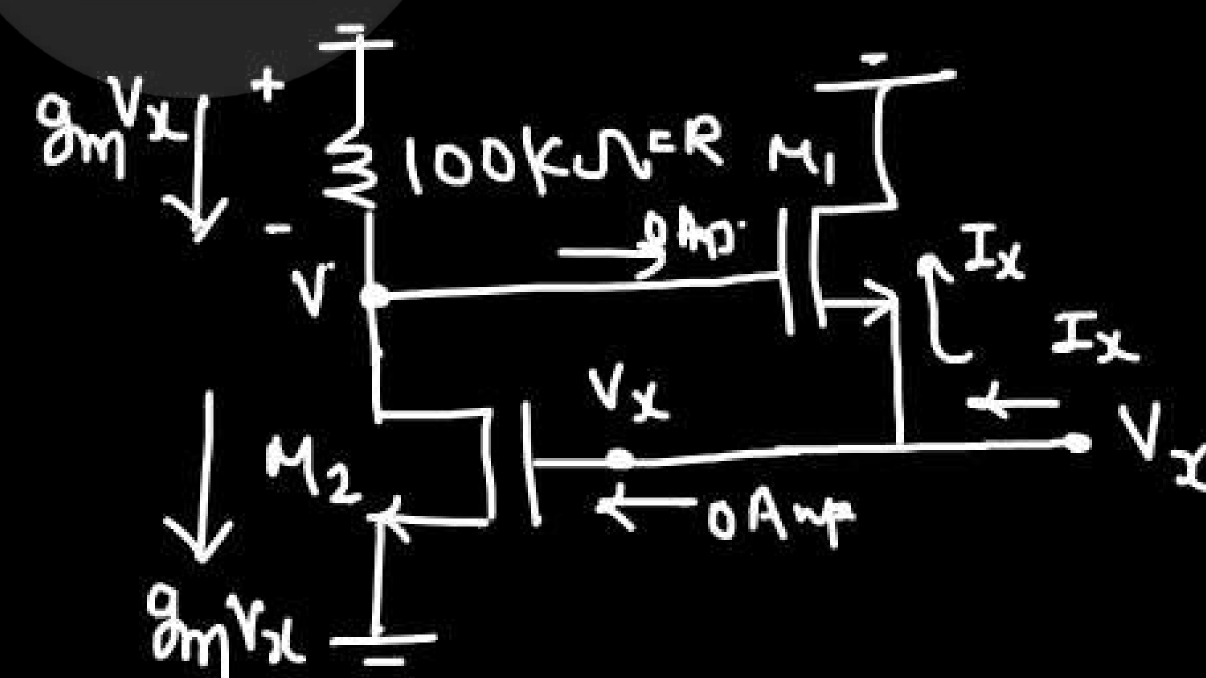
Q.



$g_m = g_{m_1} = g_{m_2} = 100\mu S$

Determine small signal R_x = ?

$R = 100k\Omega$



$R_x = \frac{V_x}{I_x}$

$I_x = g_m(V_x - V) \longrightarrow ①$

$V = -g_m V_x R \longrightarrow ②$

$I_x = g_m(V_x + g_m V_x R)$

$$I_x = g_m [1 + g_m R] V_x$$

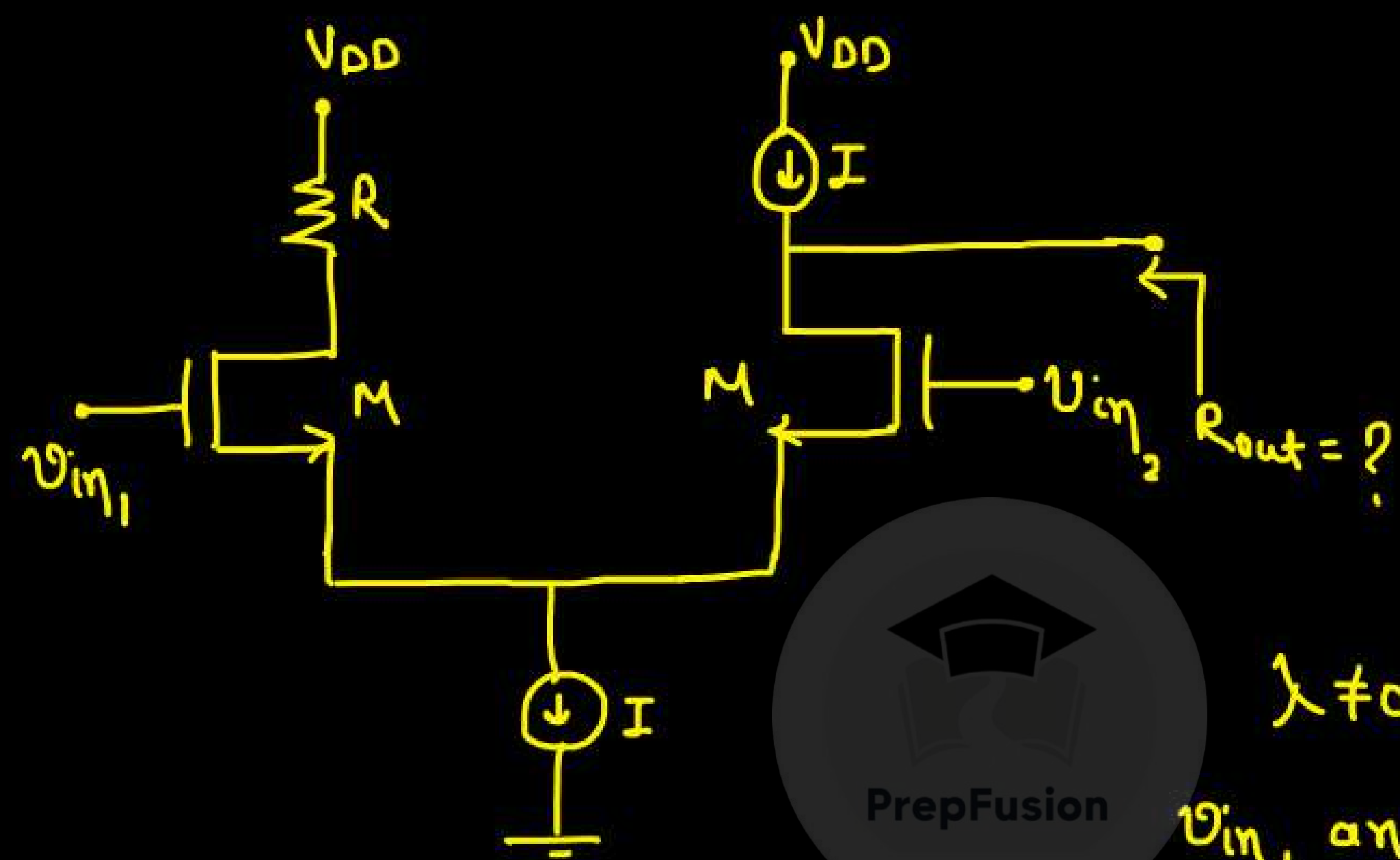
$$R_x = \frac{V_x}{I_x} = \frac{1}{g_m [1 + g_m R]}$$

$$= \frac{1}{10^{-4} [1 + 10^{-4} \times 10^5]}$$

$$R_x = \frac{1}{11} \times 10^4$$

$$\boxed{R_x = 909.09\ \Omega}$$

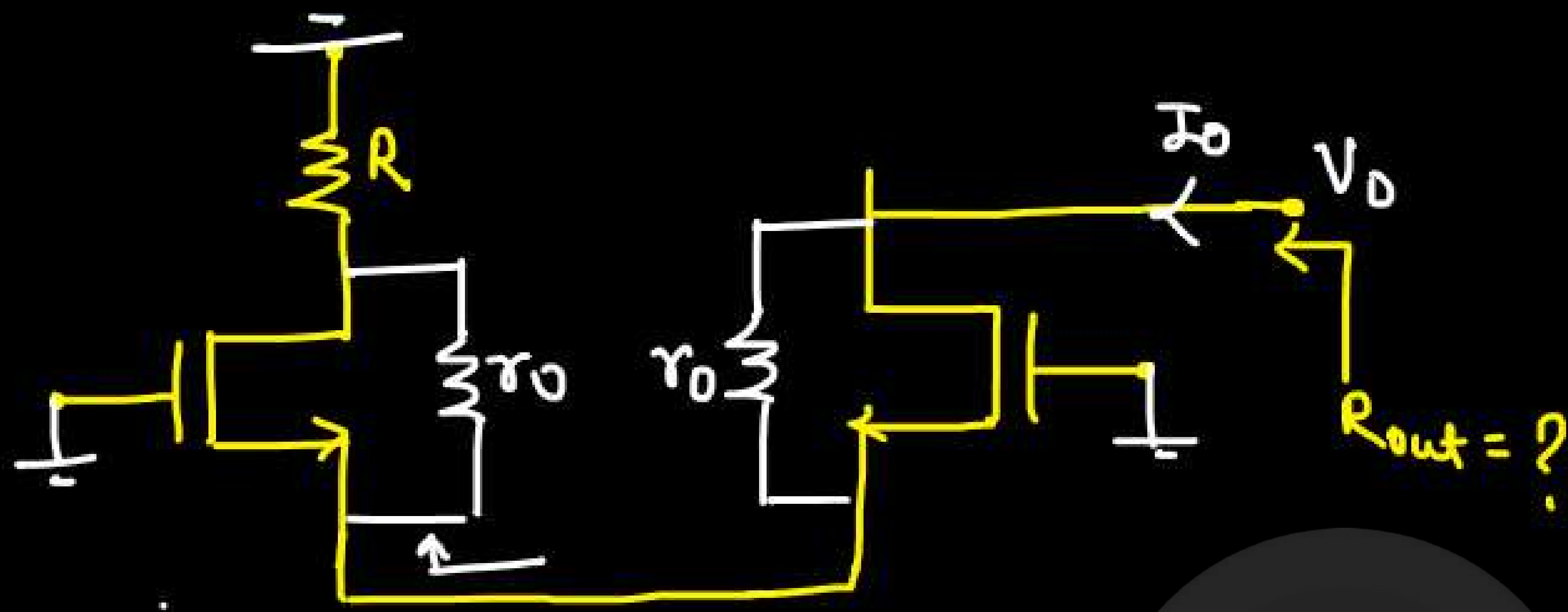
Q.



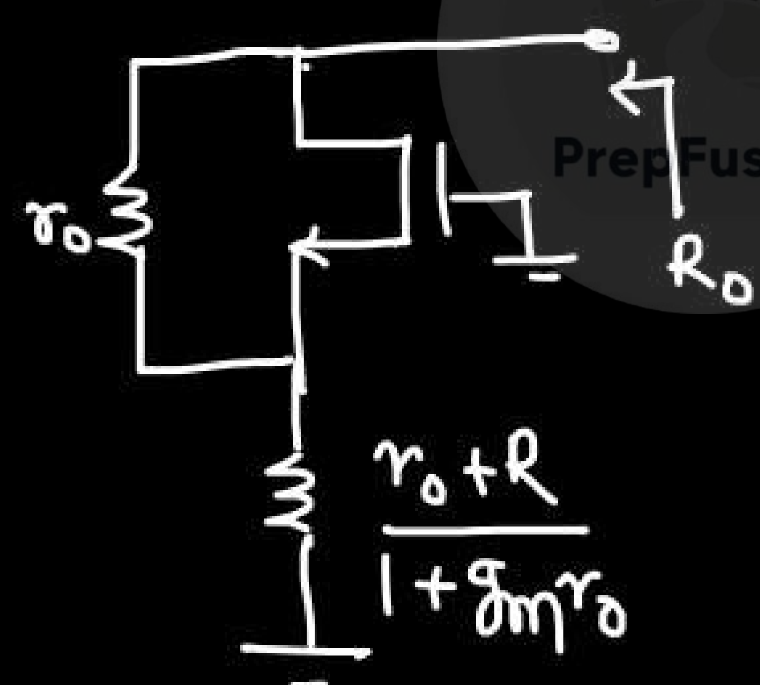
$\lambda \neq 0$

v_{in_1} and v_{in_2} are small signal i/p.

Find small signal $R_{out} = ?$



$$R_{out} = \frac{V_0}{I_0}$$

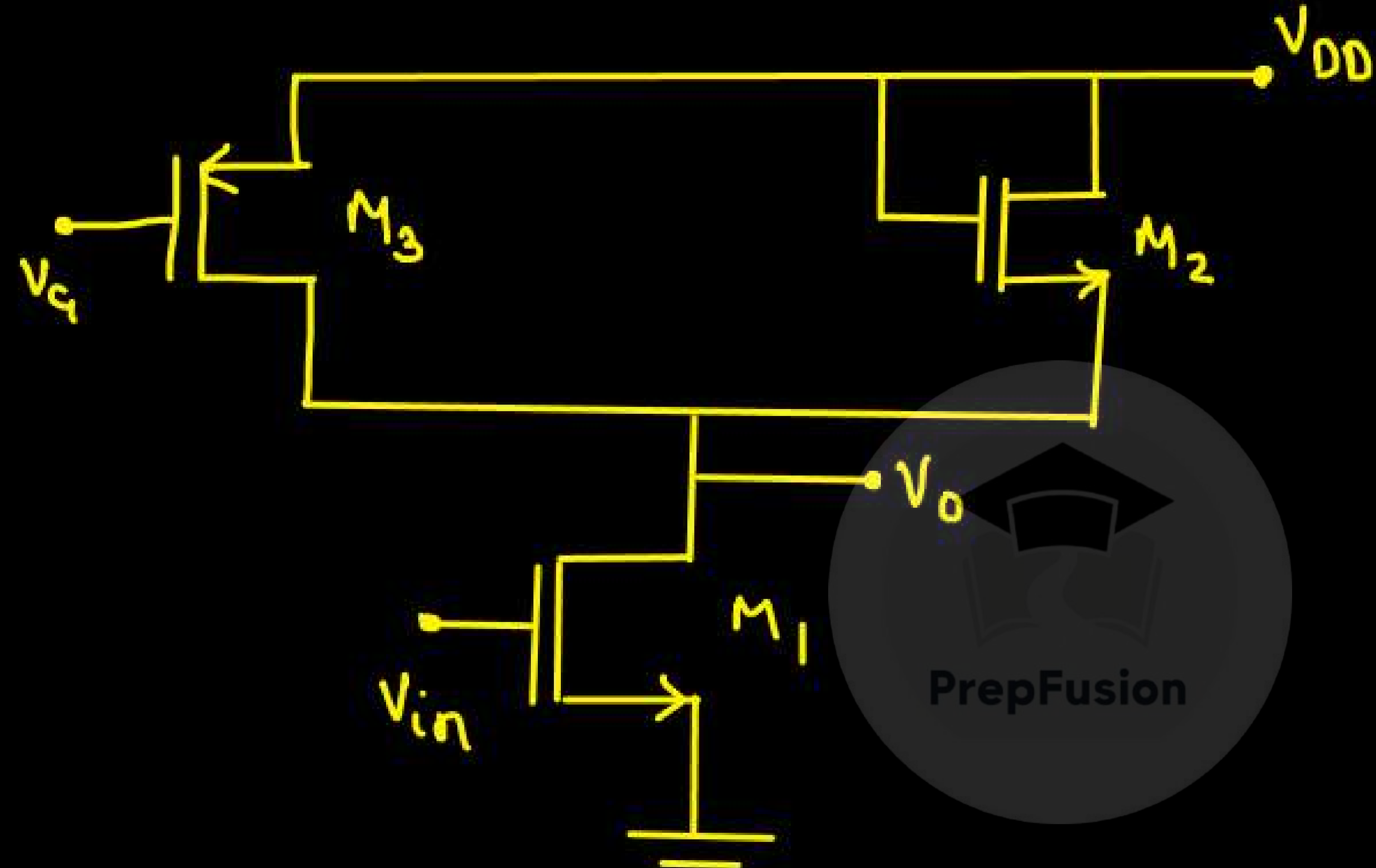


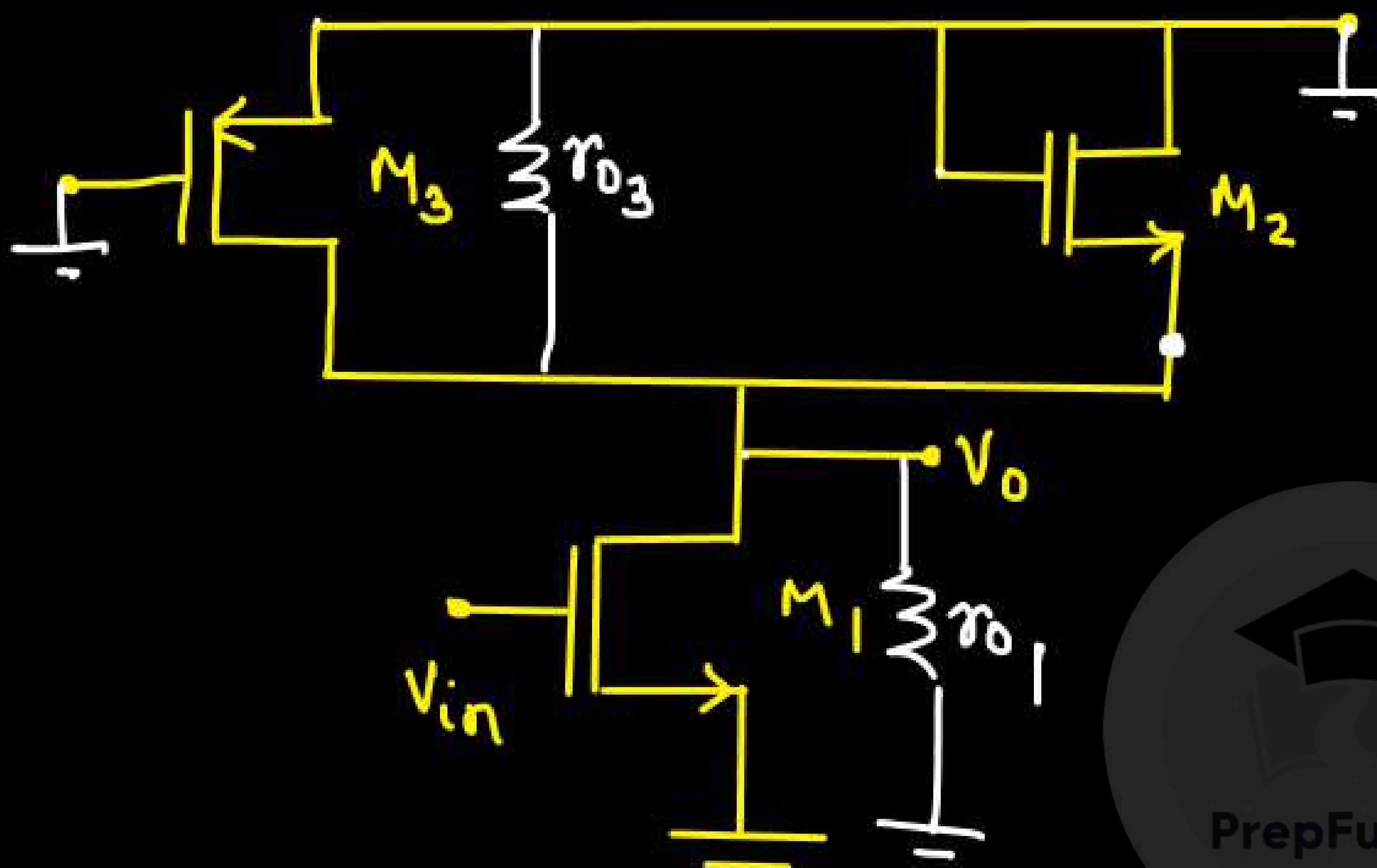
$$R_0 = r_0 + \frac{r_0+R}{1+g_m r_0} + g_m r_0\left[\frac{r_0+R}{1+g_m r_0}\right]$$

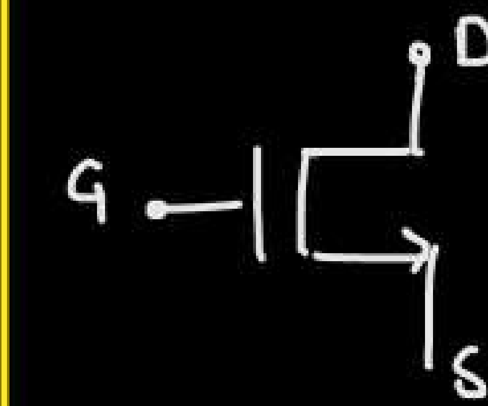
$$= r_0 + \left(\frac{r_0+R}{1+g_m r_0}\right)\left[1+g_m r_0\right]$$

$$\boxed{R_{out} = 2r_0 + R}$$

Q. Find small signal voltage gain. $(\lambda \neq 0)$

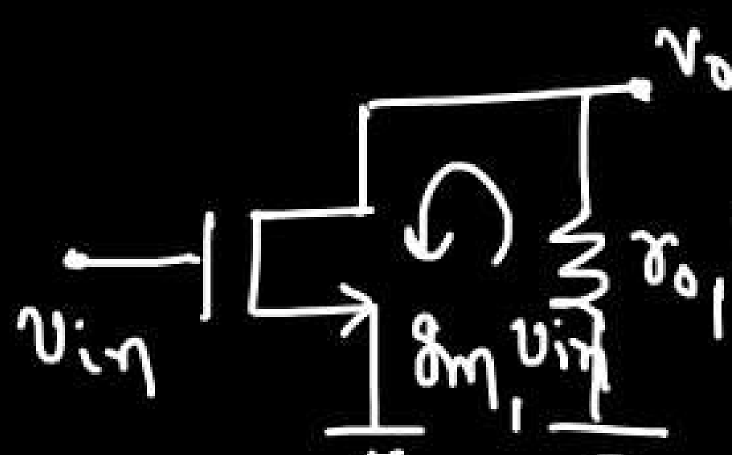






$S \rightarrow G \Rightarrow 1/g_m$

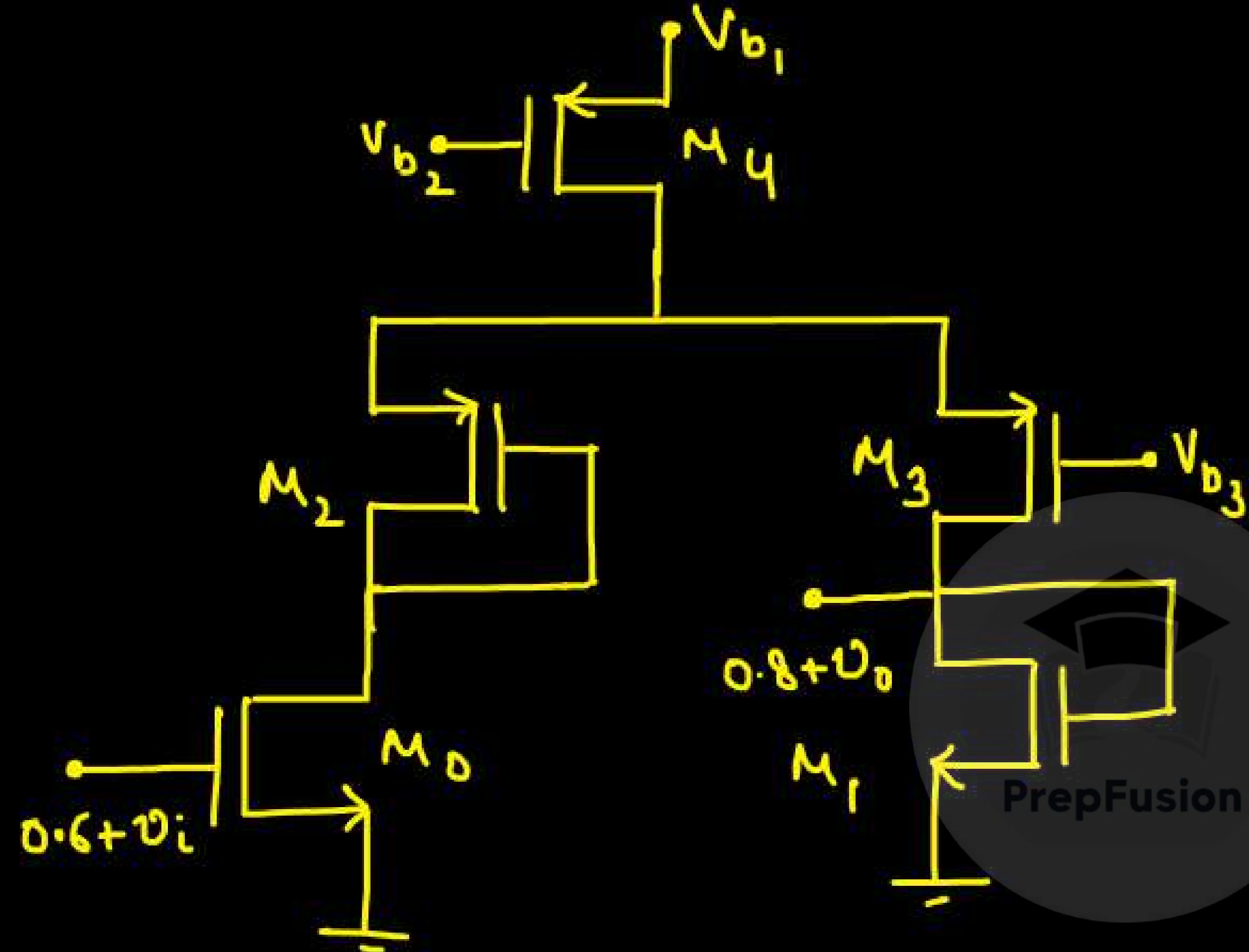
$S \rightarrow D \rightarrow r_o$



$r_{o1} \| r_{o3} \| \frac{1}{g_{m2}} \| r_{o2}$

$$\boxed{\frac{v_o}{v_i} = -g_{m1}\left[\frac{1}{g_{m2}} \| r_{o2} \| r_{o1} \| r_{o3}\right]}$$

Q.

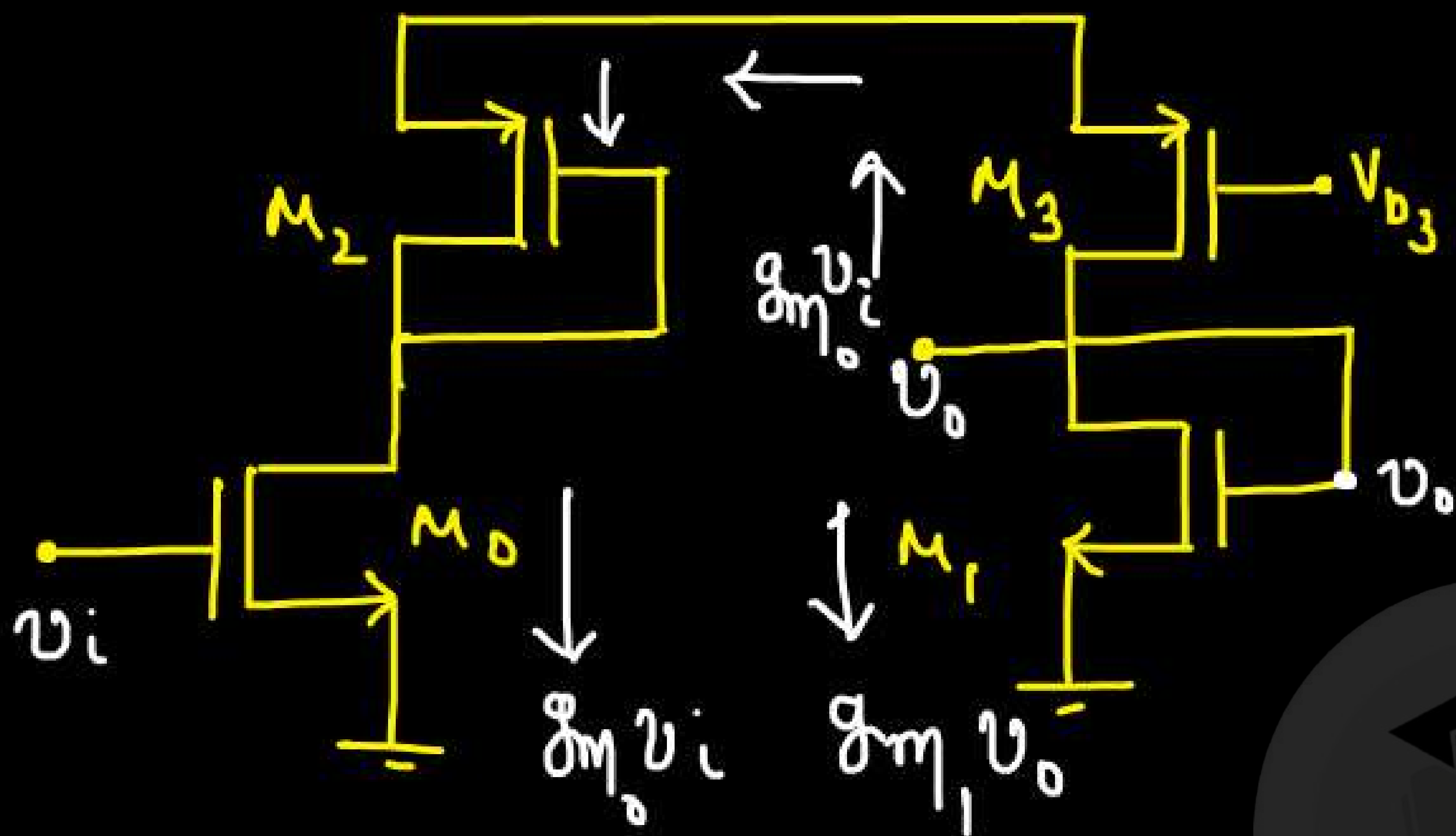


$\lambda = 0$

$$g_m = \frac{2I_{DC}}{V_{GS}-V_T}$$

Transistors are biased such that all transistors are working in sat. region. $M_0 - M_3$ are biased with 5mA current. V_T value for all the transistors is 0.4V.

Find small signal voltage gain v_o/v_i ?



$$g_{m0} v_i = -g_{m1} v_o$$

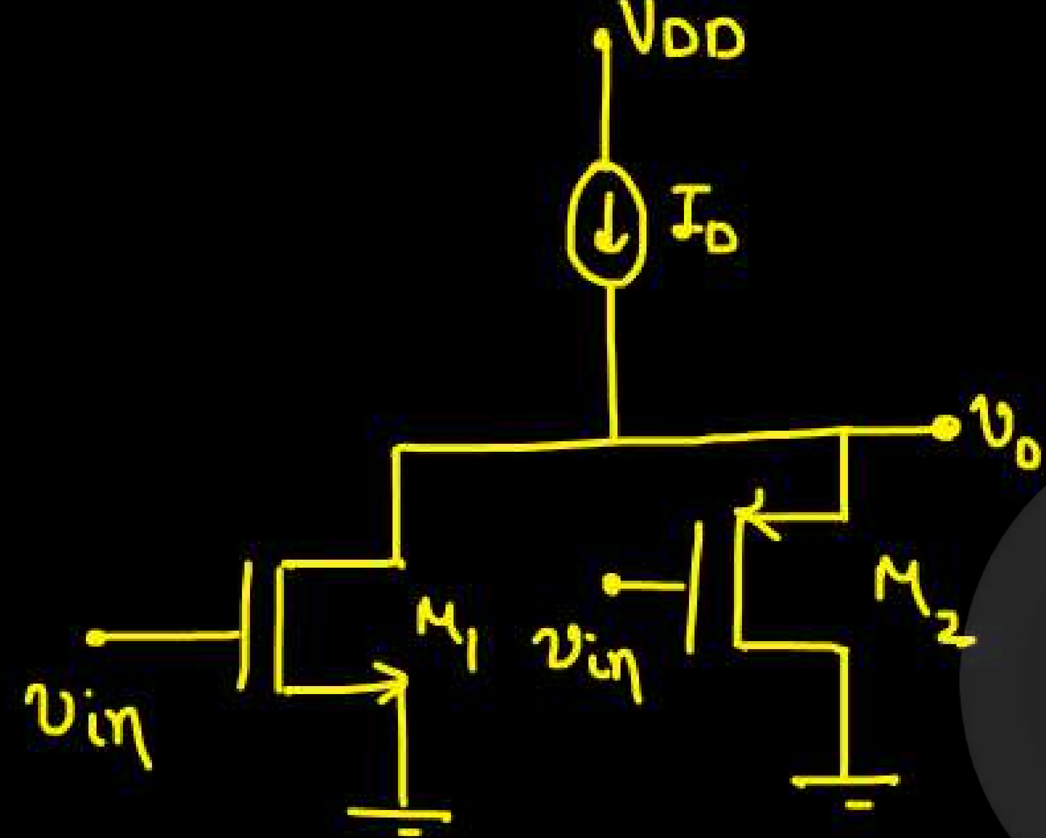
$$\boxed{\frac{v_o}{v_i} = \frac{-g_{m0}}{g_{m1}}}$$

$$g_{m0} = \frac{(2 I_D)_{M_0}}{(V_{GS})_{M_0} - V_T} = \frac{2 \times 5\,\text{mA}}{0.6 - 0.4} = 50\,\text{mS}$$

$$g_{m1} = \frac{2 \times 5\,\text{mA}}{0.8 - 0.4} = 25\,\text{mS}$$

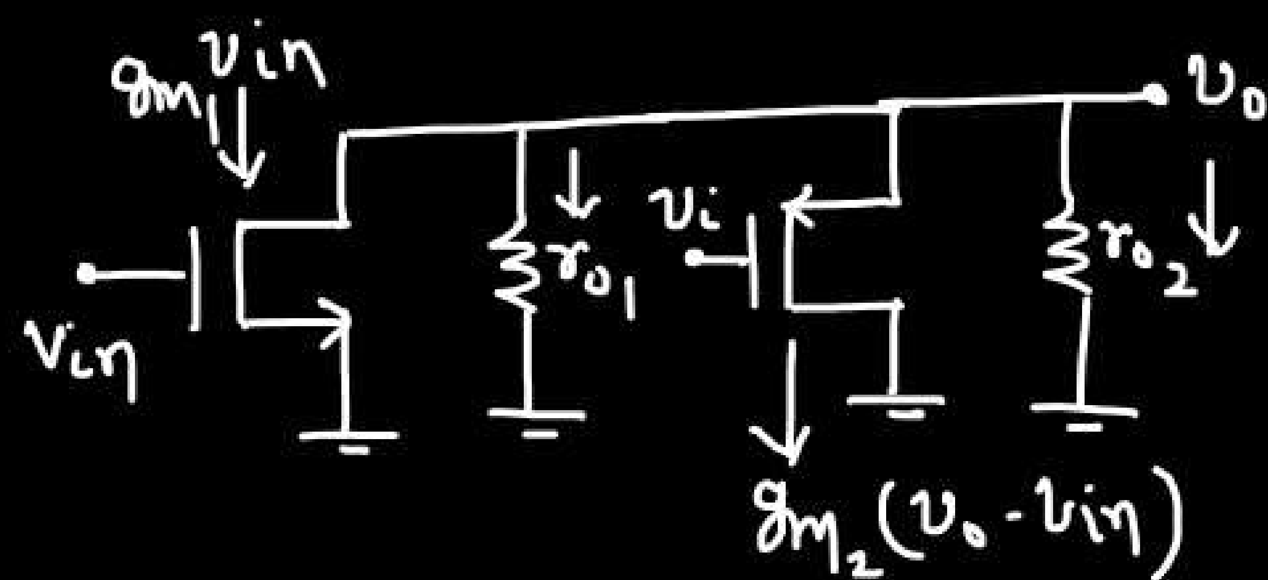
$$\boxed{\frac{v_o}{v_i} = -\frac{50\text{m}}{25\text{m}} = -2\ \text{V/V}}$$

Q. Find small signal voltage gain.



$\lambda \neq 0$

$\Rightarrow$



$$g_{m_1} v_{in} + \frac{v_0}{r_{0_1}} + g_{m_2}(v_0 - v_{in}) + \frac{v_0}{r_{0_2}} = 0$$

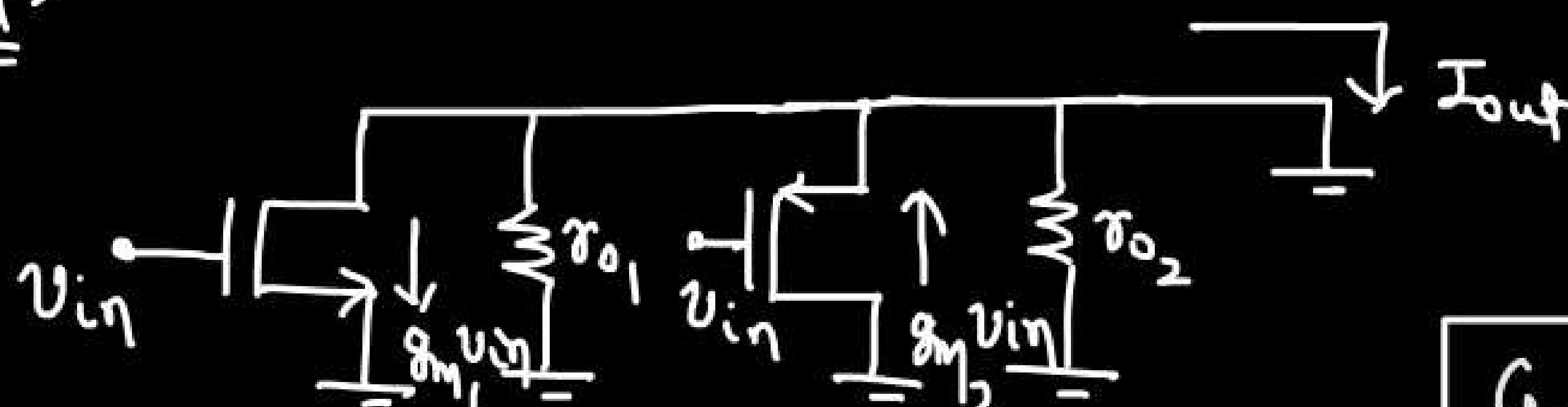
$$\frac{v_0}{r_{0_1}} + g_{m_2} v_0 + \frac{v_0}{r_{0_2}} = (g_{m_2} - g_{m_1}) v_{in}$$

$$\frac{v_0}{r_{o_1} \| r_{o_2} \| \frac{1}{g_{m_2}}} = (g_{m_2} - g_{m_1}) v_{in}$$

$$\boxed{\frac{v_0}{v_{in}} = (g_{m_2} - g_{m_1}) \left(r_{o_1} \| r_{o_2} \| \frac{1}{g_{m_2}} \right)}$$

M-II $G_m R_{out}$ Mtd:-

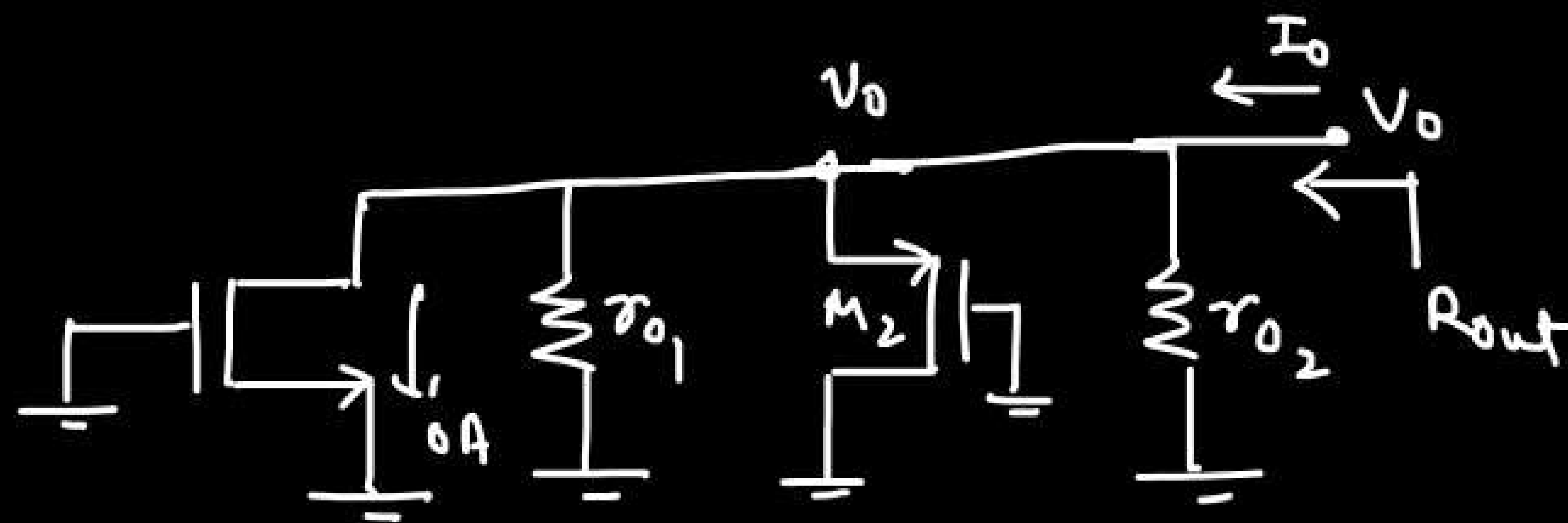
$G_m \rightarrow$



$$g_{m_1} v_{in} + I_{out} = g_{m_2} v_{in}$$

$$\boxed{G_m = \frac{I_{out}}{v_{in}} = g_{m_2} - g_{m_1}}$$

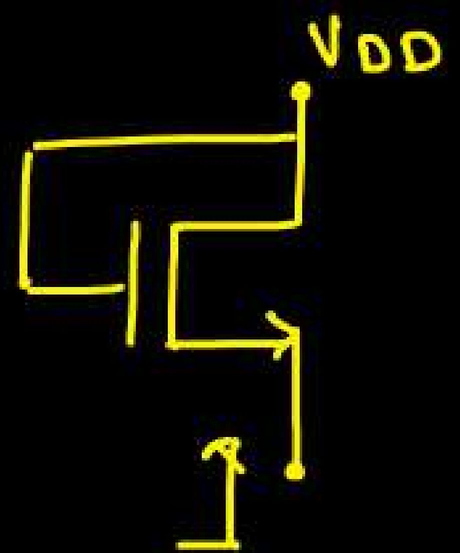
$R_{out} \rightarrow$



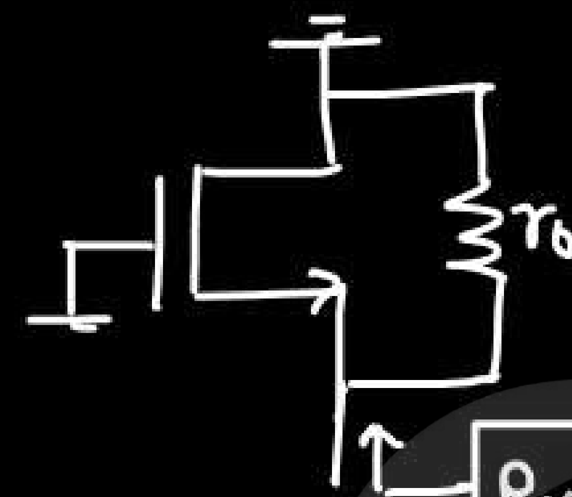
$$\boxed{R_{out} = r_{o_1} \parallel r_{o_2} \parallel 1/g_{m_2}}$$

$$\boxed{A_V = (g_{m_2} - g_{m_1})\left(r_{o_1} \parallel r_{o_2} \parallel \frac{1}{g_{m_2}}\right)}$$

Q.



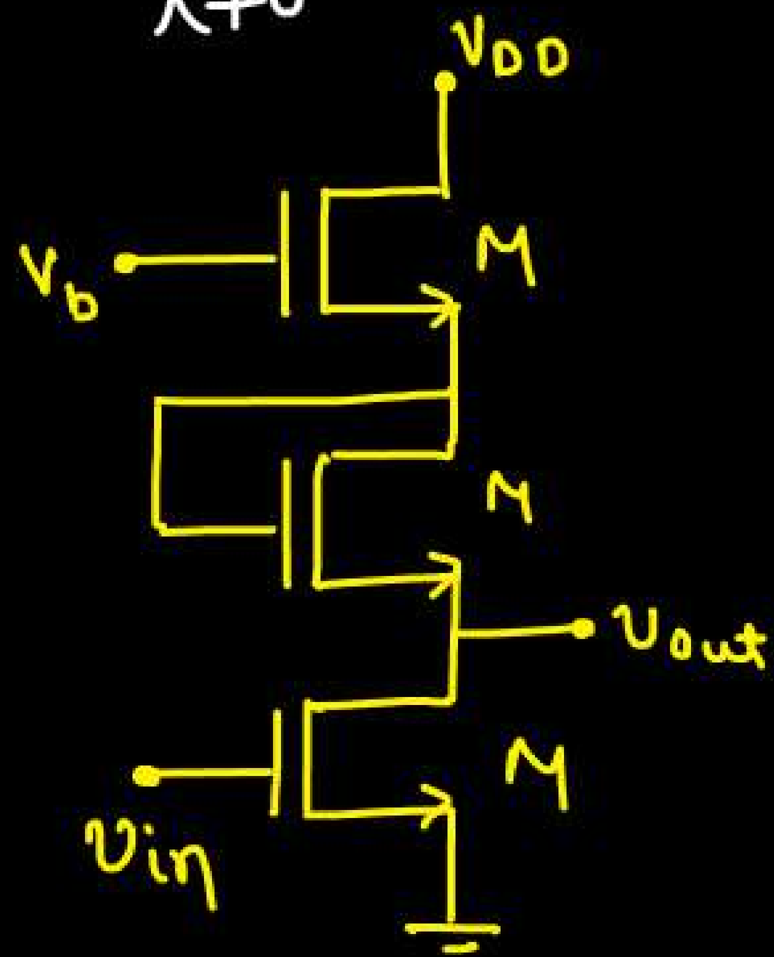
$\Rightarrow$

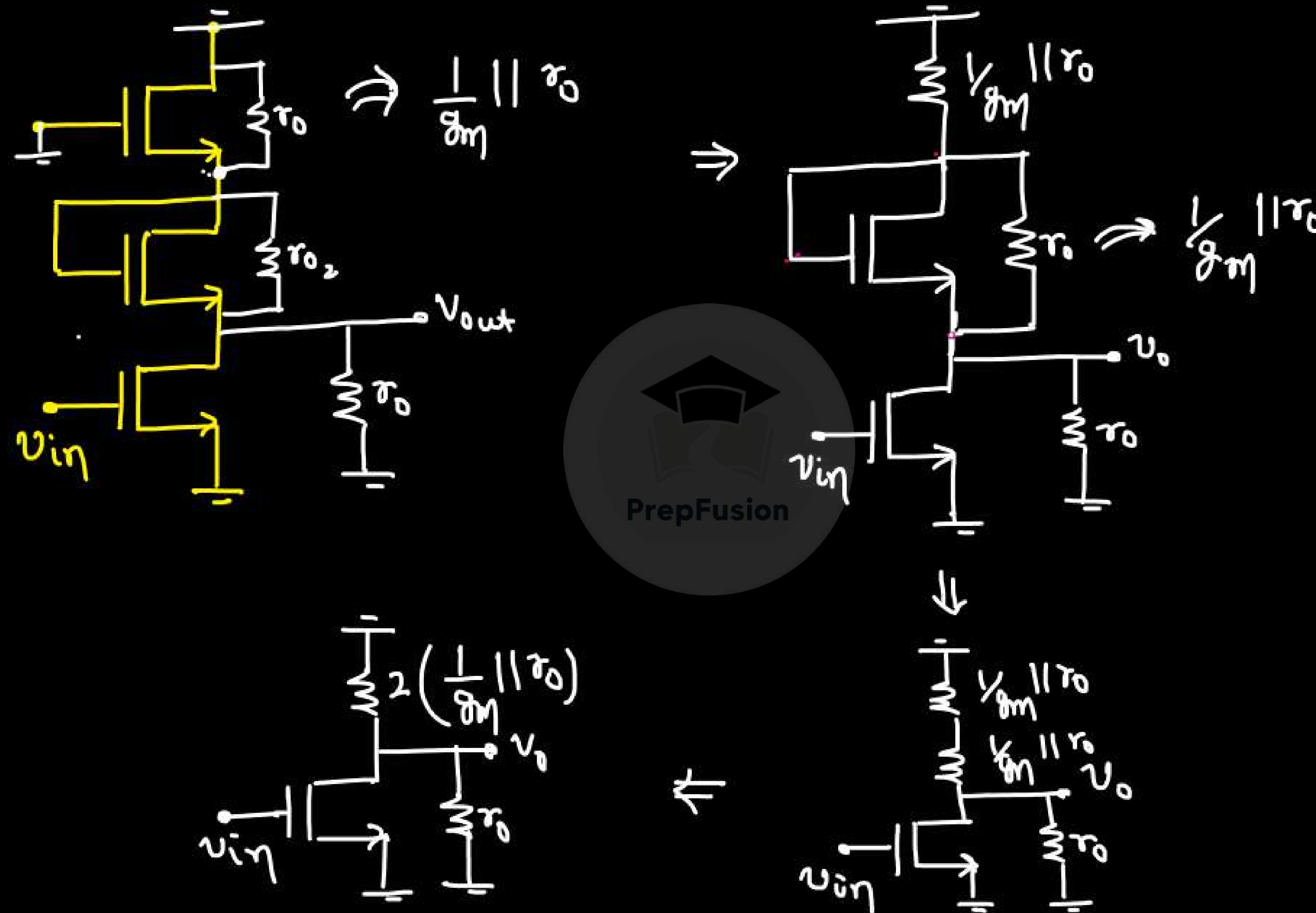


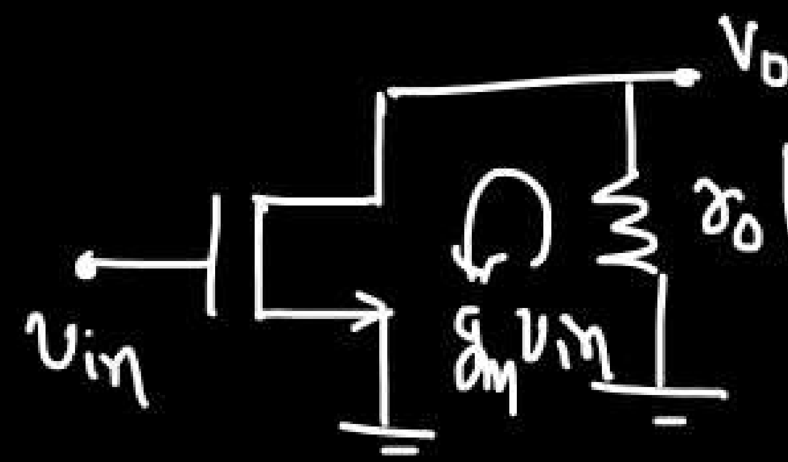
$$\boxed{R_x = \frac{1}{g_m} \parallel r_0}$$

Q.

$\lambda \neq 0$



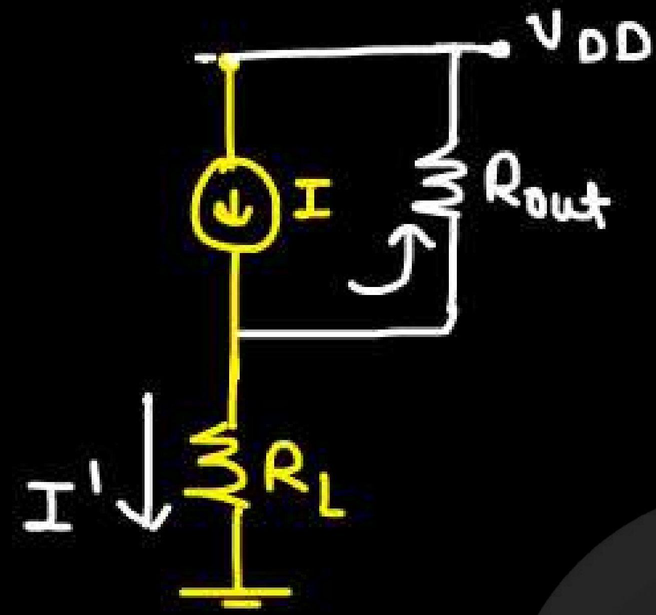

r_0
$\frac{1}{g_m} \| r_0$
r_{o_2}
V_{out}
v_{in}
$1/g_m \| r_0$
r_0
$1/g_m \| r_0$
v_0
v_{in}
$1/g_m \| r_0$
$1/g_m \| r_0$
v_0
r_0
v_{in}
$2\left(\frac{1}{g_m} \| r_0\right)$
v_0
r_0
v_{in}



$$r_o \| 2\left(r_o \| \tfrac{1}{g_m}\right) = r_o \| 2r_o \| 2/g_m$$

$$\boxed{\frac{v_o}{v_{in}} = -g_m\left[\frac{2}{g_m} \| \frac{2r_o}{3}\right]}$$

⇒ Current Source:-



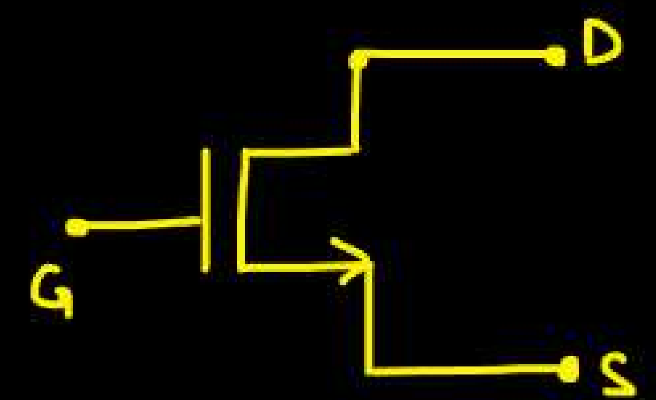
$\boxed{I' < I}$

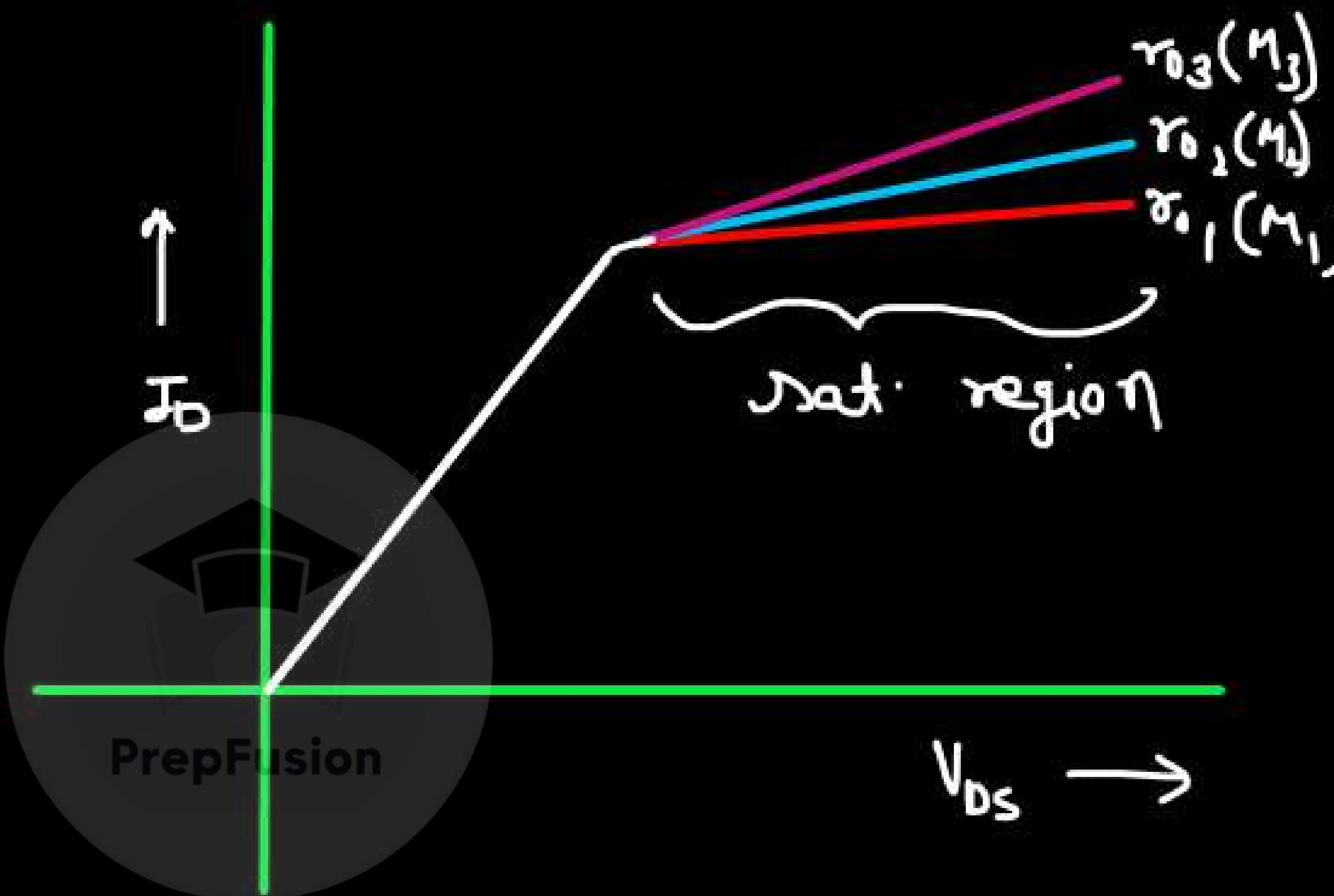
if $R_{out} \to \infty$

$\boxed{I' \to I}$

More R_{out} ⇒ Better current source

Making current source from MOS:-





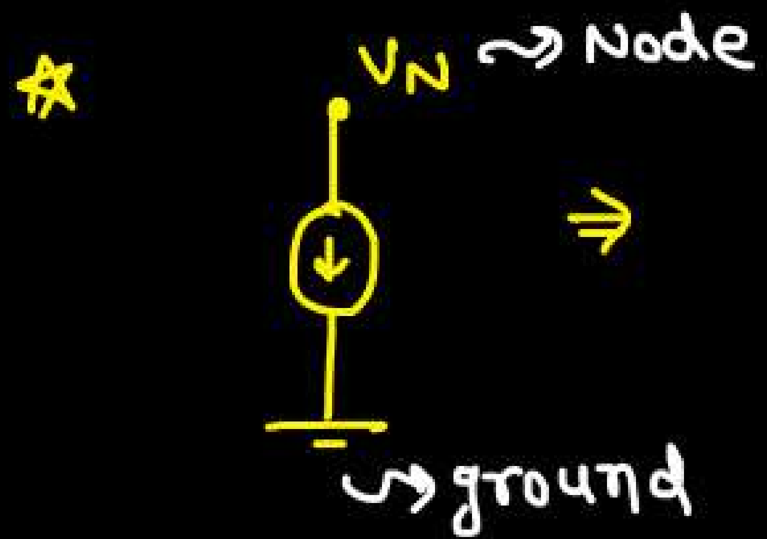
$r_{o1} > r_{o2} > r_{o3}$

$\Downarrow$

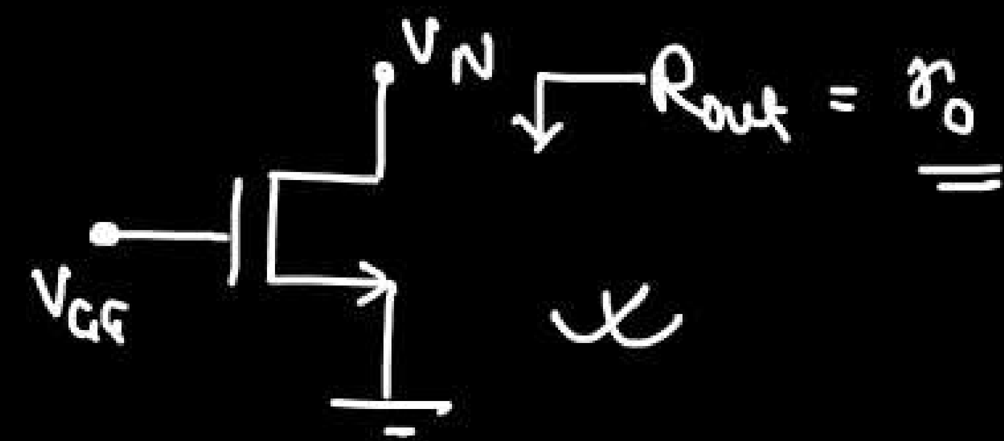
Best current source

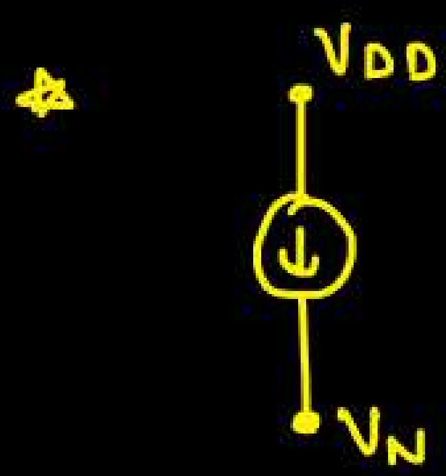
$M_1 \rightarrow$ Best current source

For using MOS as a current source, it should be biased in sat. region.

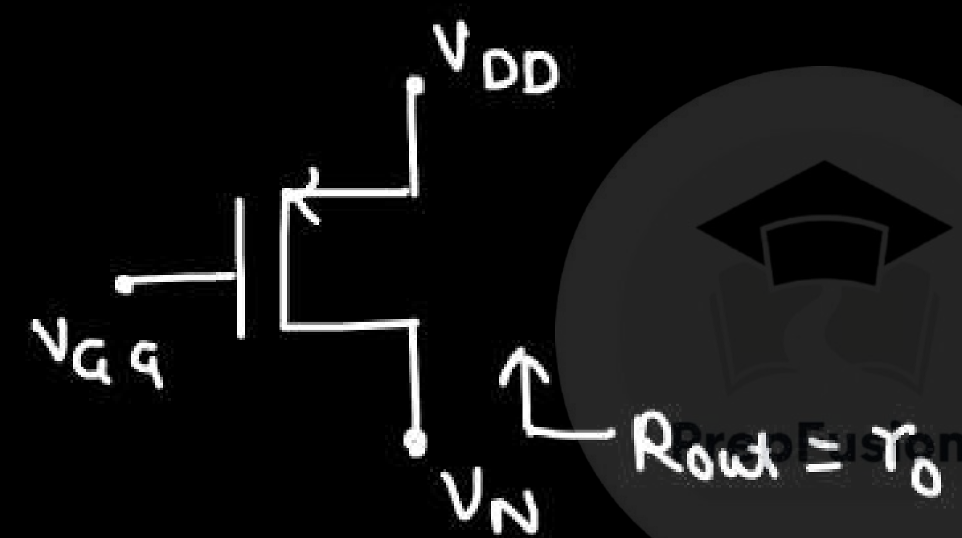


⇒





⇒

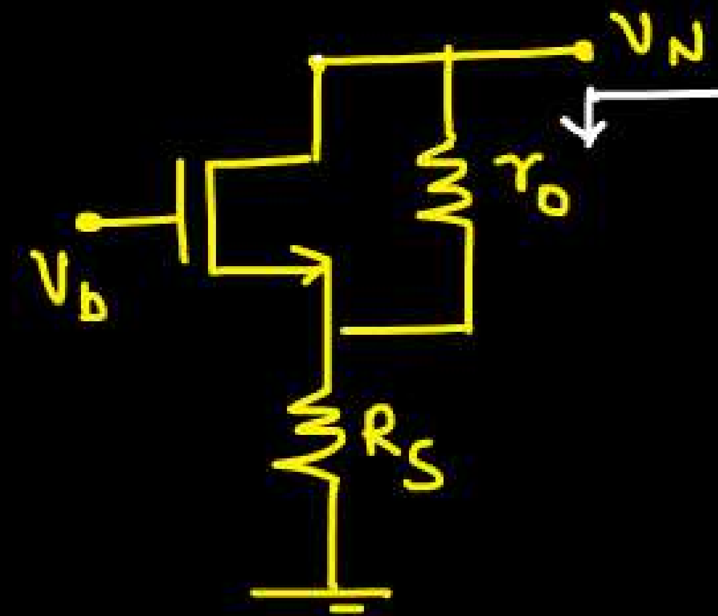


Node to ground → NMOS

Supply to Node → PMOS

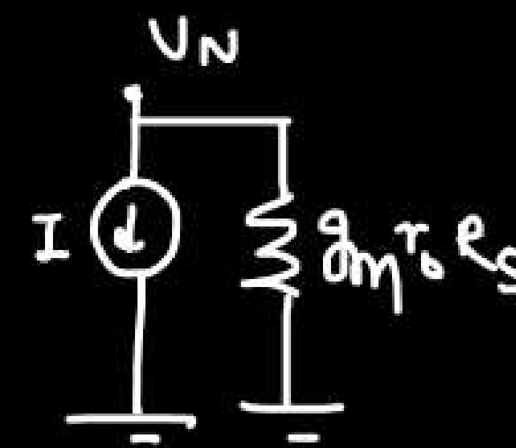
⇒ what if I need a Higher o/p impedance?

★

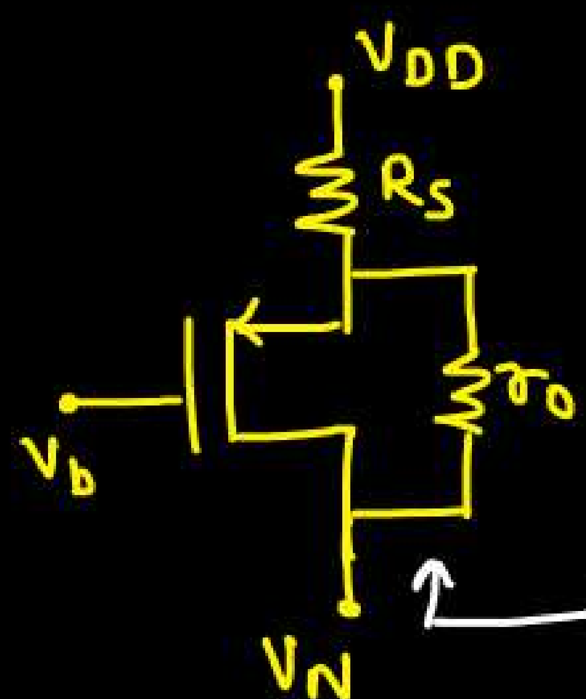


$$R_{out} = r_o + R_S + g_m r_o R_S$$
$$\approx g_m r_o R_S$$

$\Rightarrow$

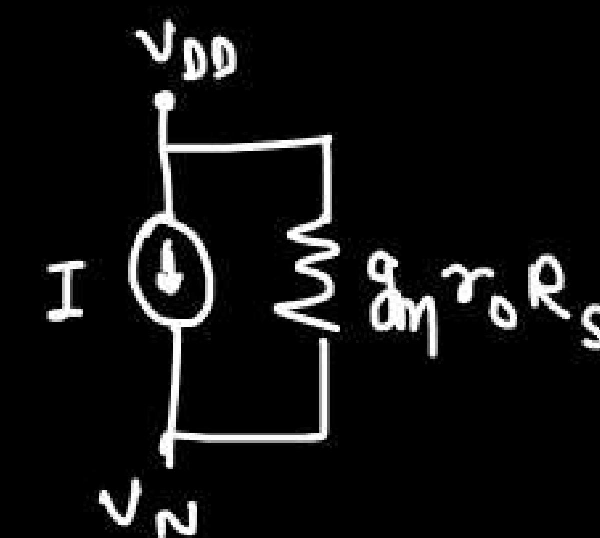


★



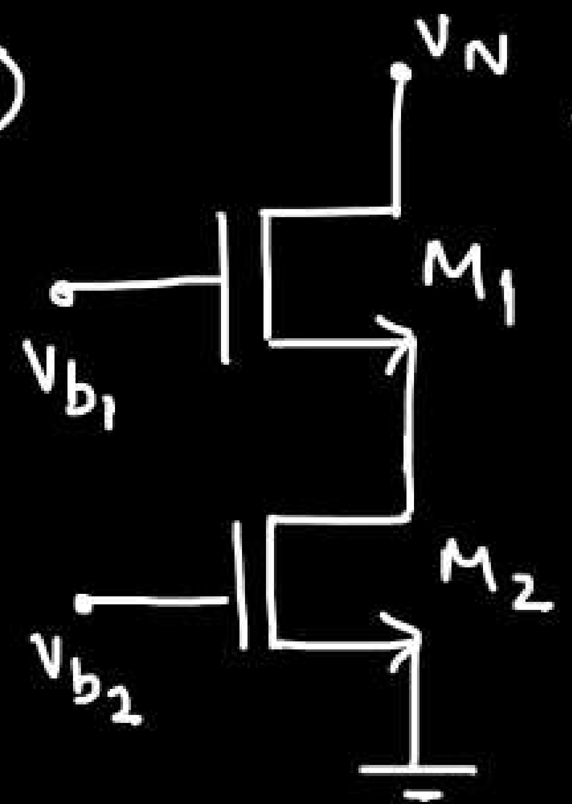
$$R_{out} = r_o + R_S + g_m r_o R_S$$
$$\approx g_m r_o R_S$$

$\Rightarrow$



Cascode Current Source:-

(1)

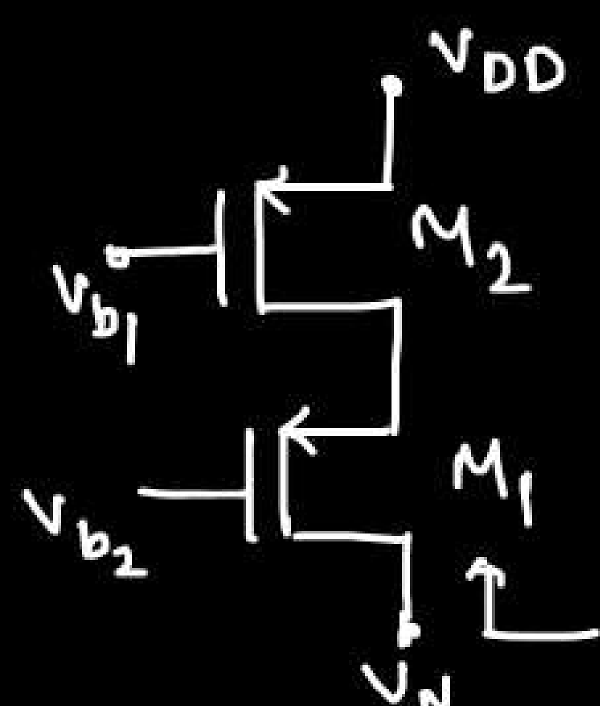


$$R_{out} = r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2}$$

$$\approx g_{m_1} r_{o_1} r_{o_2}$$

(using NMOS)

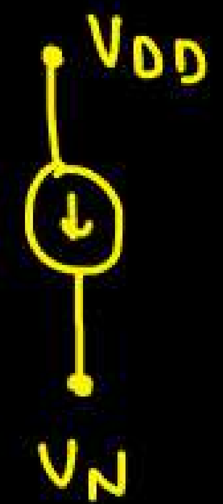
(2)



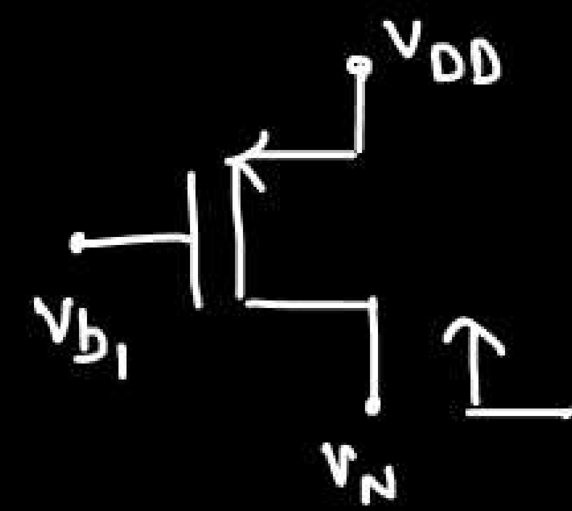
$$R_{out} = r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2} \approx g_{m_1} r_{o_1} r_{o_2}$$

Summary:-

①

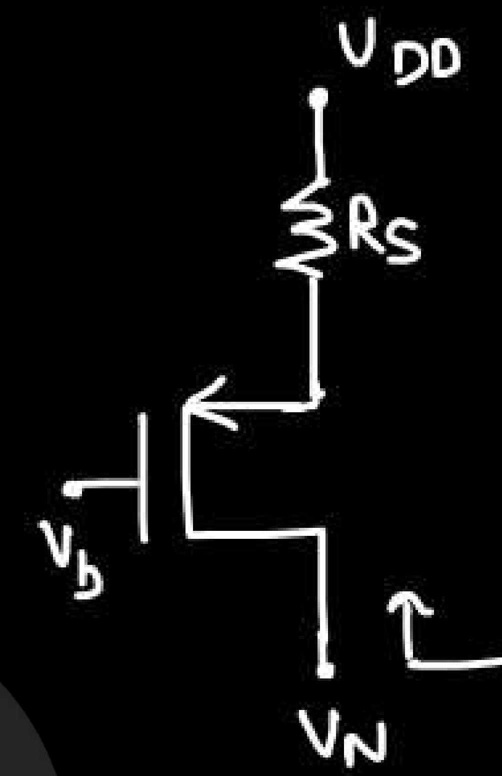


$\Rightarrow$



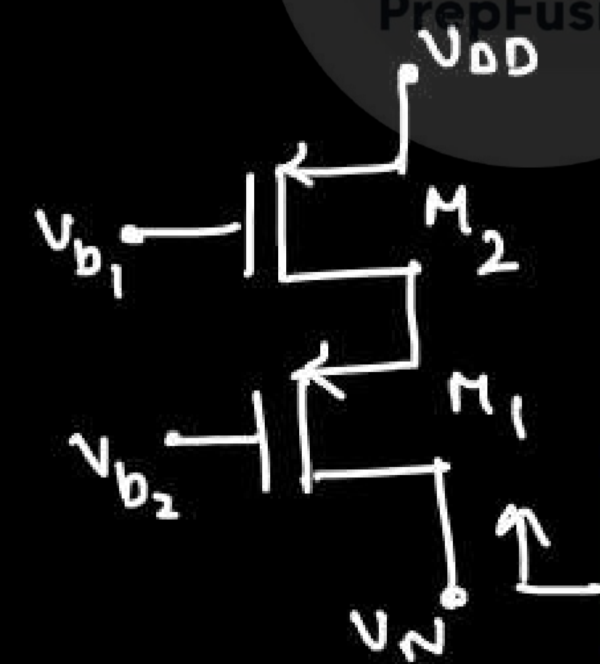
$R_{out} = r_o$

①



$$\boxed{R_{out} \approx g_m r_o R_S}$$

②

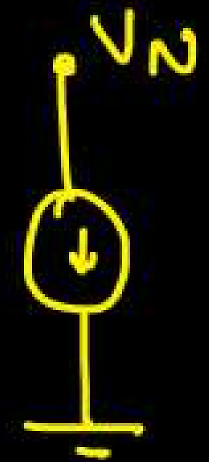


$\rightsquigarrow$ cascode current source

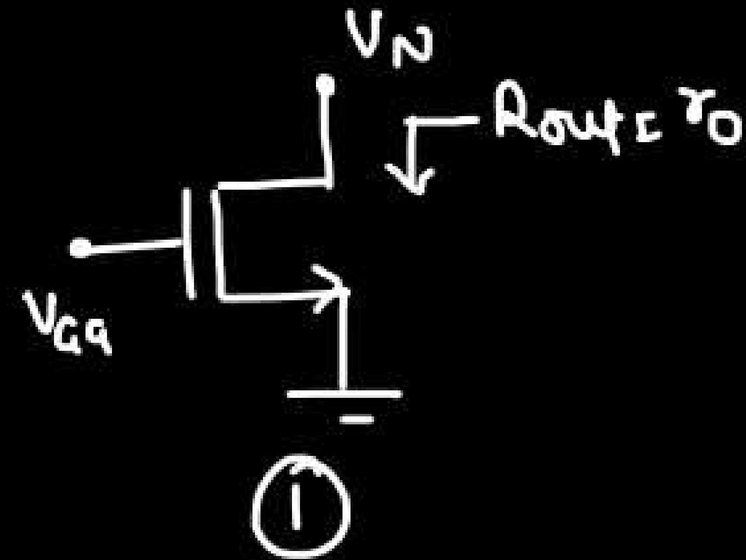
$$\boxed{R_{out} \approx g_{m_1} r_{o_1} r_{o_2}}$$

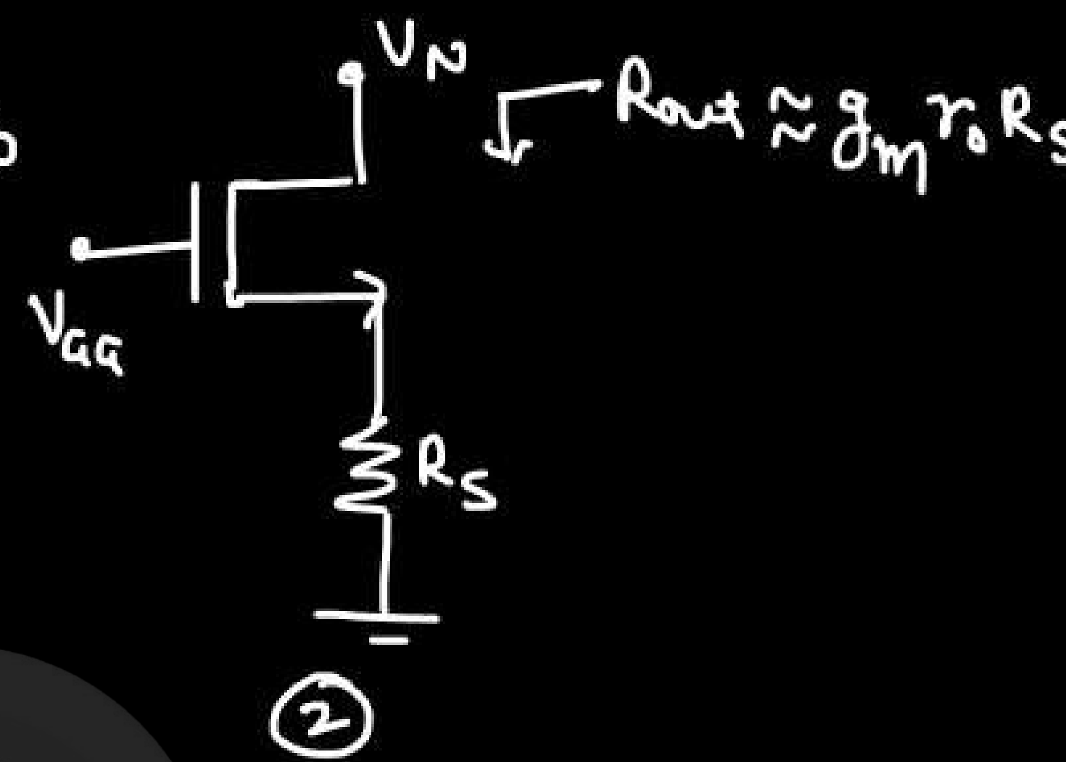
③

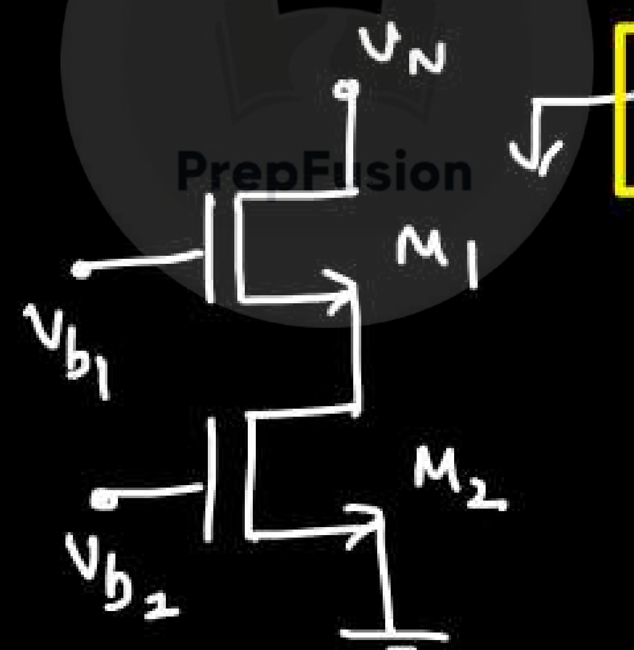
2



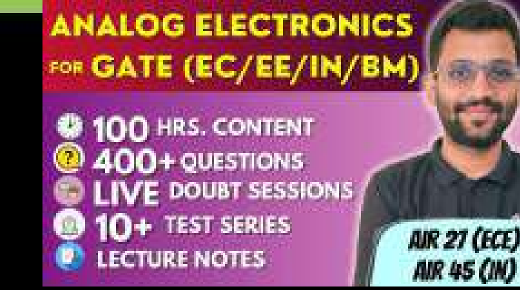
$\Rightarrow$





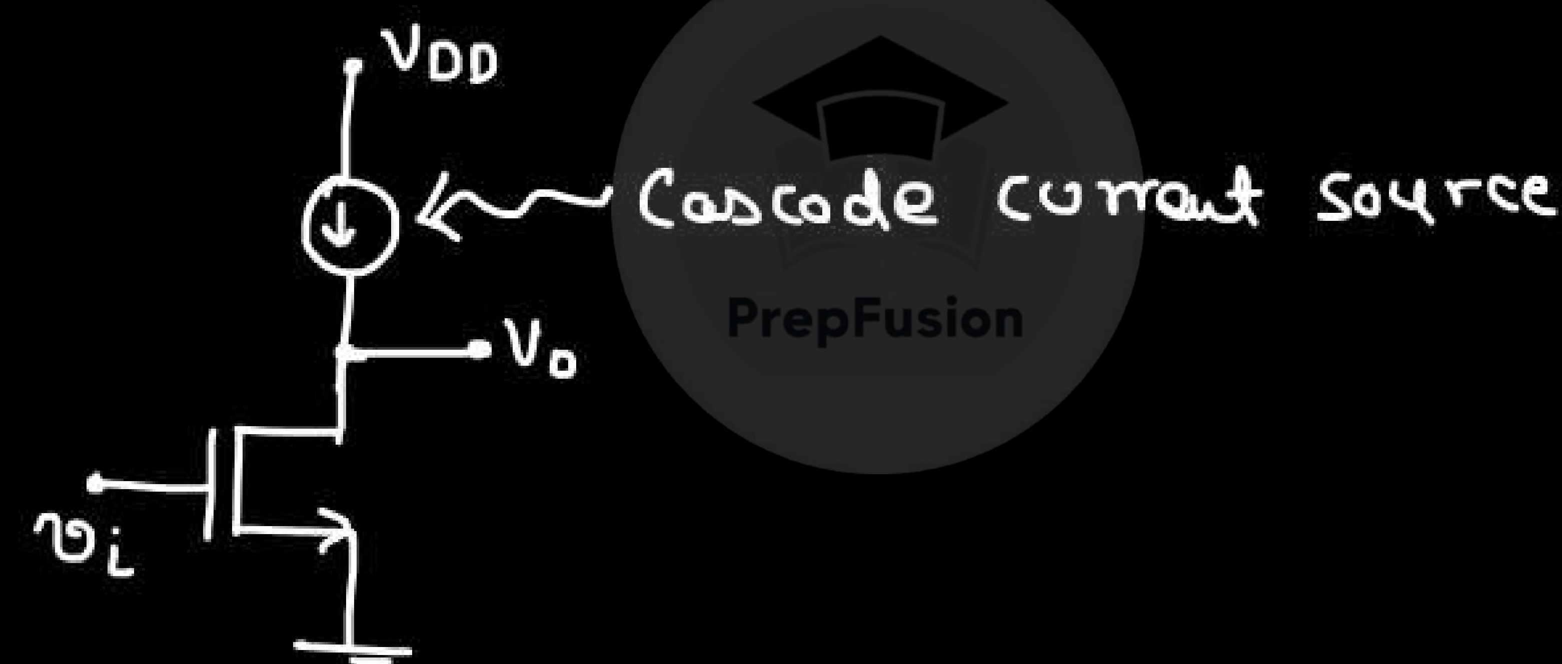


$$\boxed{R_{out} \approx g_{m_1} r_{o_1} r_{o_2}}$$



Q. Design a common source Amplifier with Cascode current source in load. Write the small signal gain. [Using both PMOS & NMOS]

→ CS Amplifier using NMOS, with current source in load:-



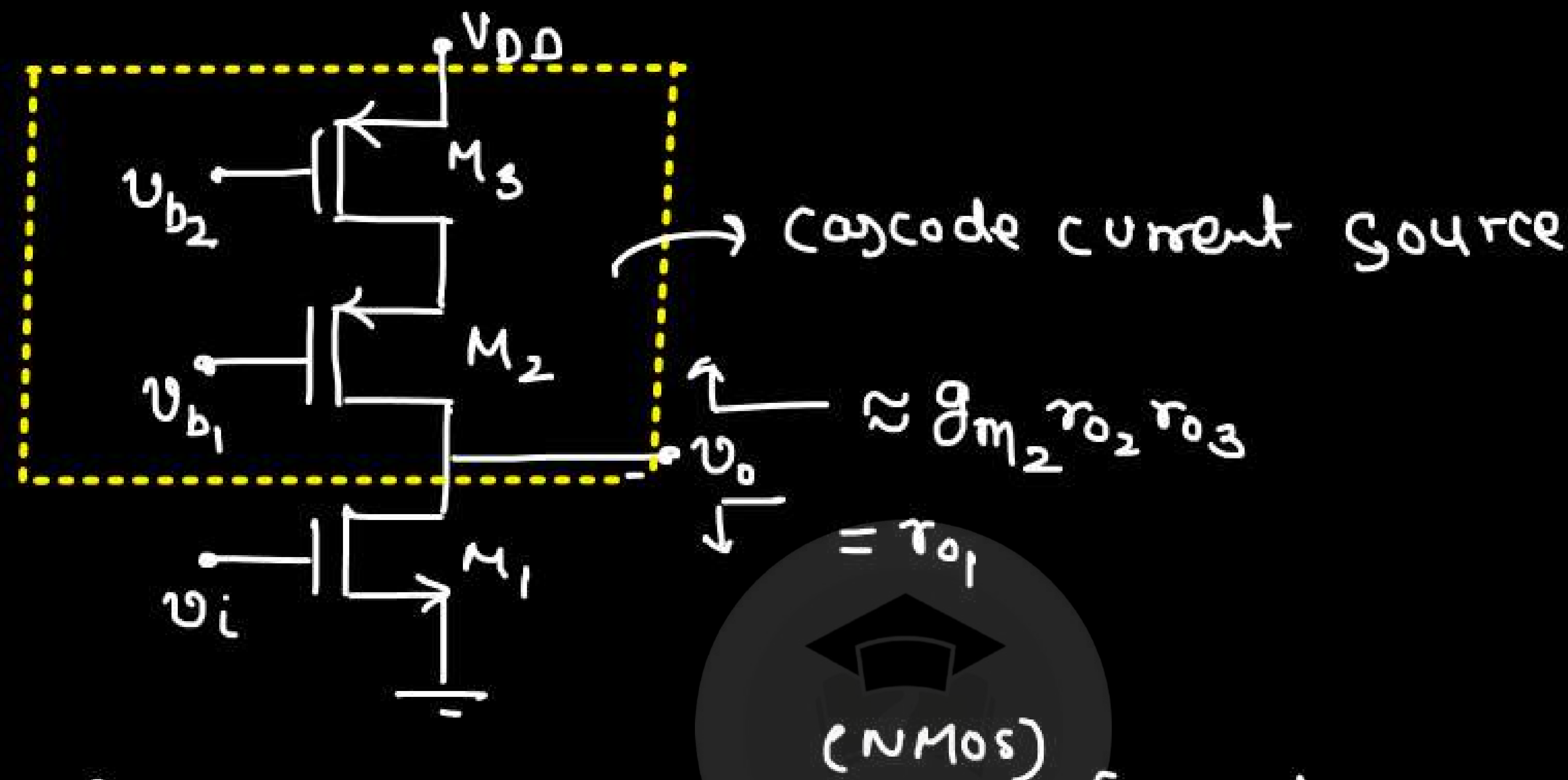
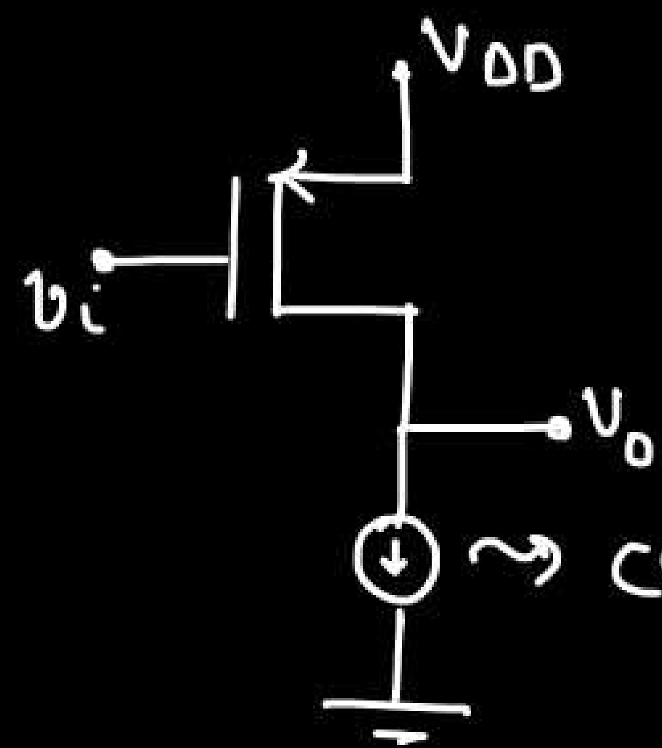


fig → common source amplifier with cascode current source in load. (PMOS)

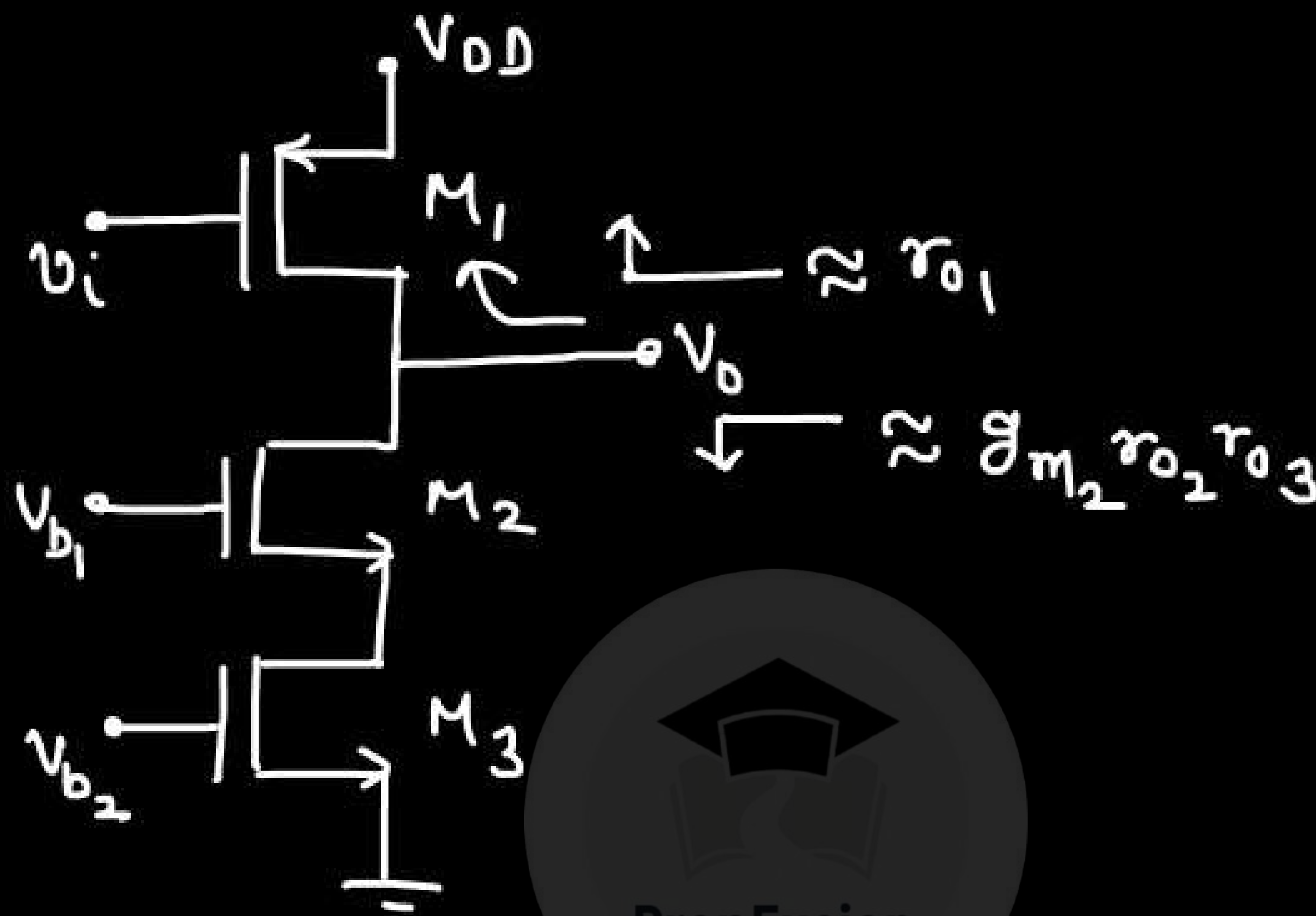
$$\boxed{A_v \approx -g_{m_1}\left[r_{o_1} \,||\, g_{m_2} r_{o_2} r_{o_3} \right]}$$

$$\approx -g_{m_1} r_{o_1}$$

⇒ CS amplifier using PMOS with current source in load.



⇝ cascode current source



$$\boxed{A_V = -g_{m_1}\left[r_{o_1} \,\|\, g_{m_2} r_{o_2} r_{o_3}\right]} \approx -g_{m_1} r_{o_1}$$

fig → common source amplifier (PMOS) with cascode current source (NMOS) in load.

Target :-

Building a High gain Amplifier.

$$\boxed{A_V = G_m R_{out}}$$

keeping G_m constant, increase R_{out}

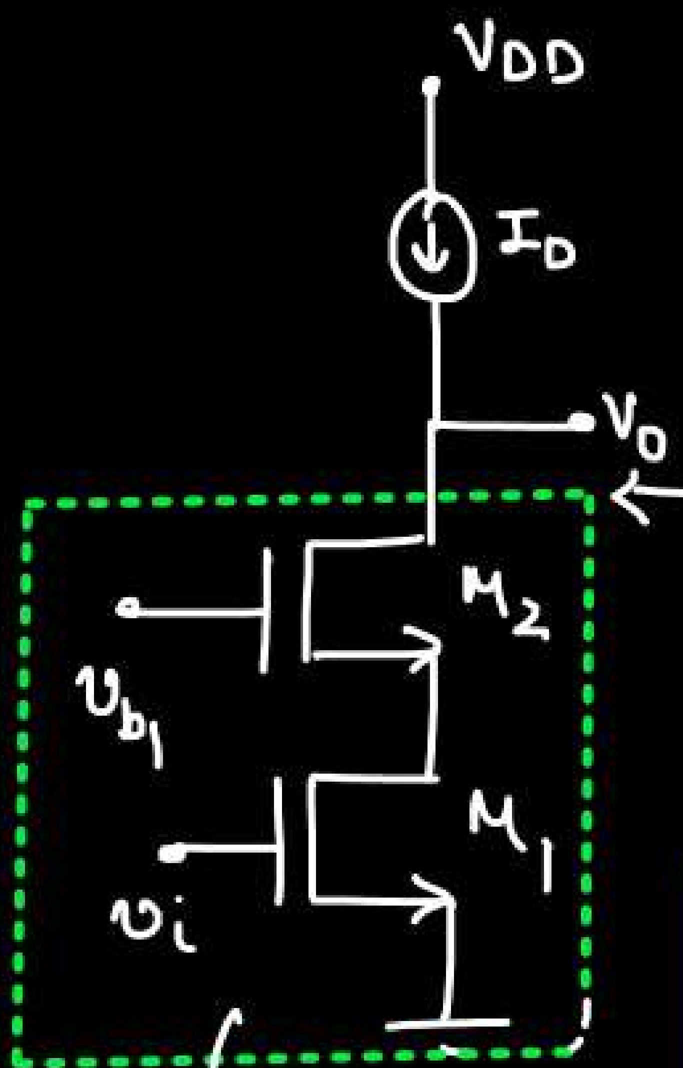
⇒ The design we made in the previous problem.

$$\boxed{R_{out} = r_{o_1} \parallel g_{m_2} r_{o_2} r_{o_3}}$$

$\Downarrow$

increase R_{out}

Cascode Amplifier :-

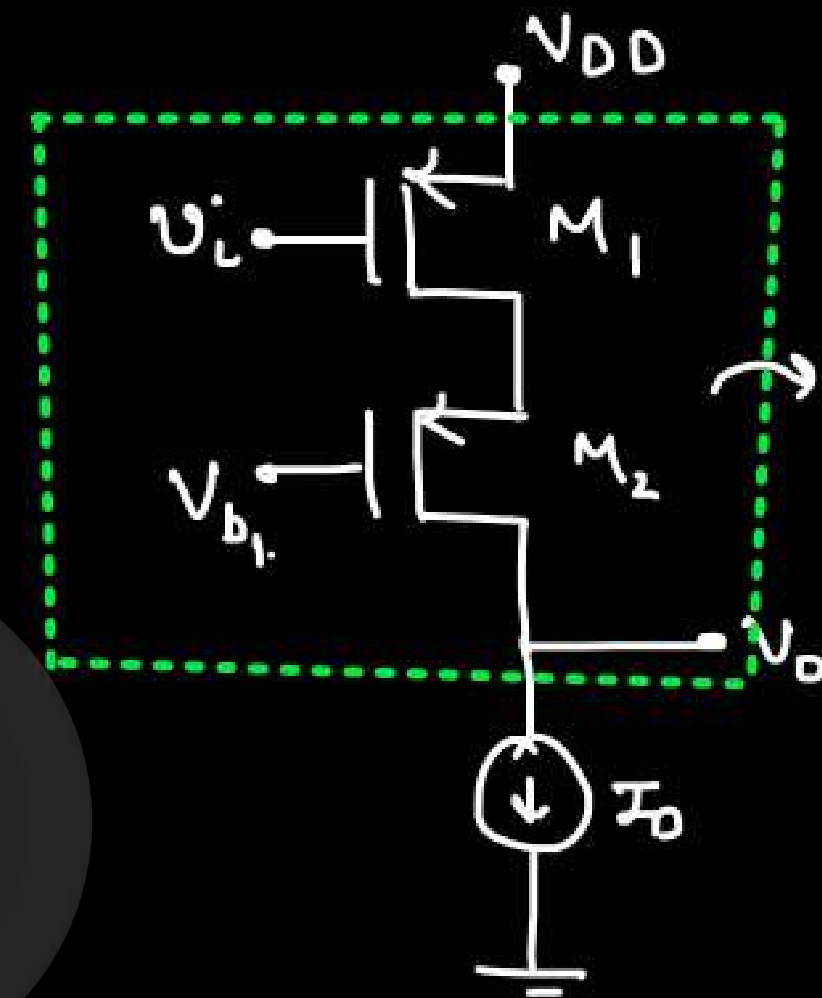


Cascode Amplifier (NMOS)

$R_{out} \approx g_{m_2} r_{o_2} r_{o_1}$

$G_m \approx -g_{m_1}$

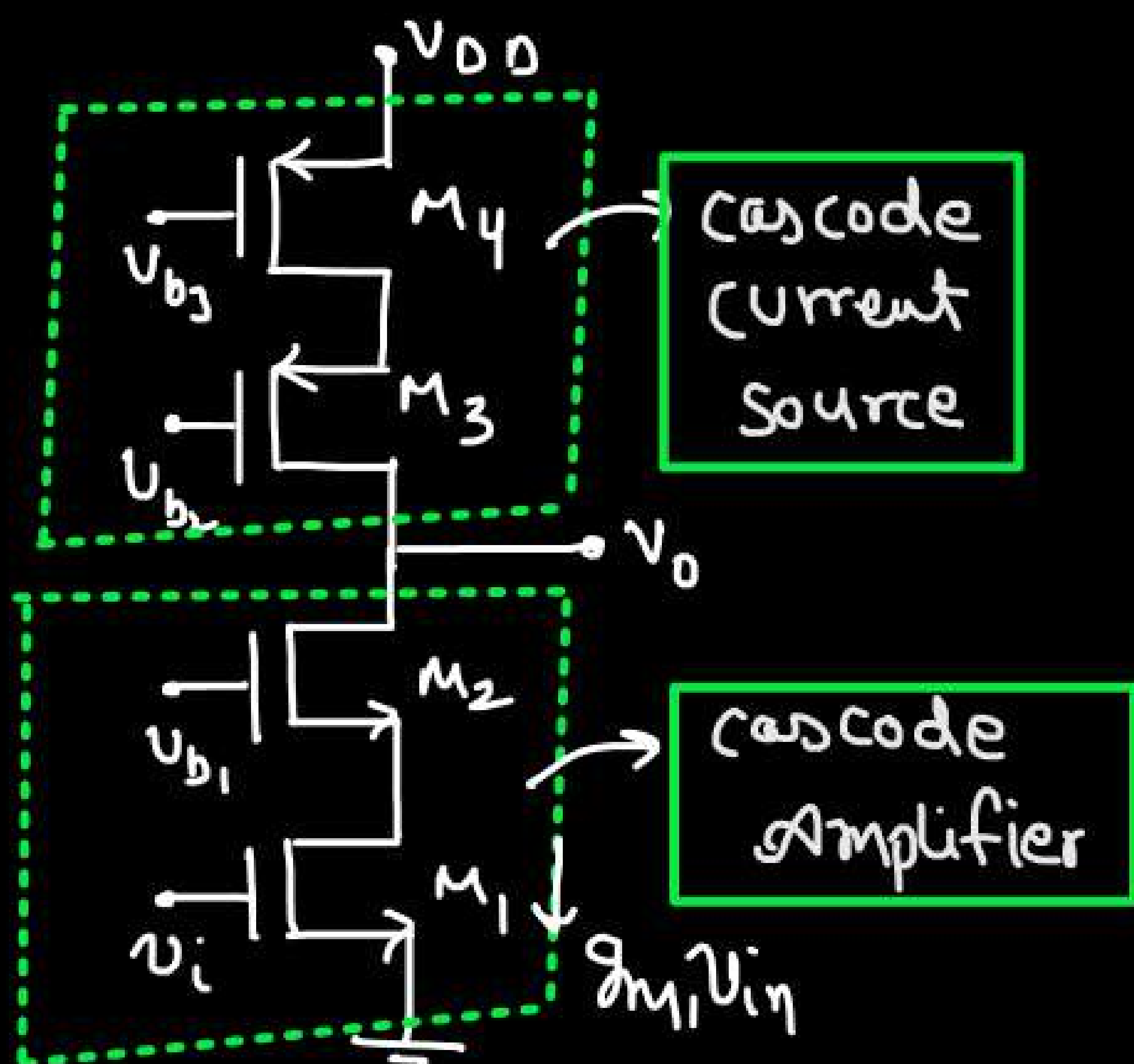
$$\boxed{A_V \approx -g_{m_1} g_{m_2} r_{o_2} r_{o_1}}$$

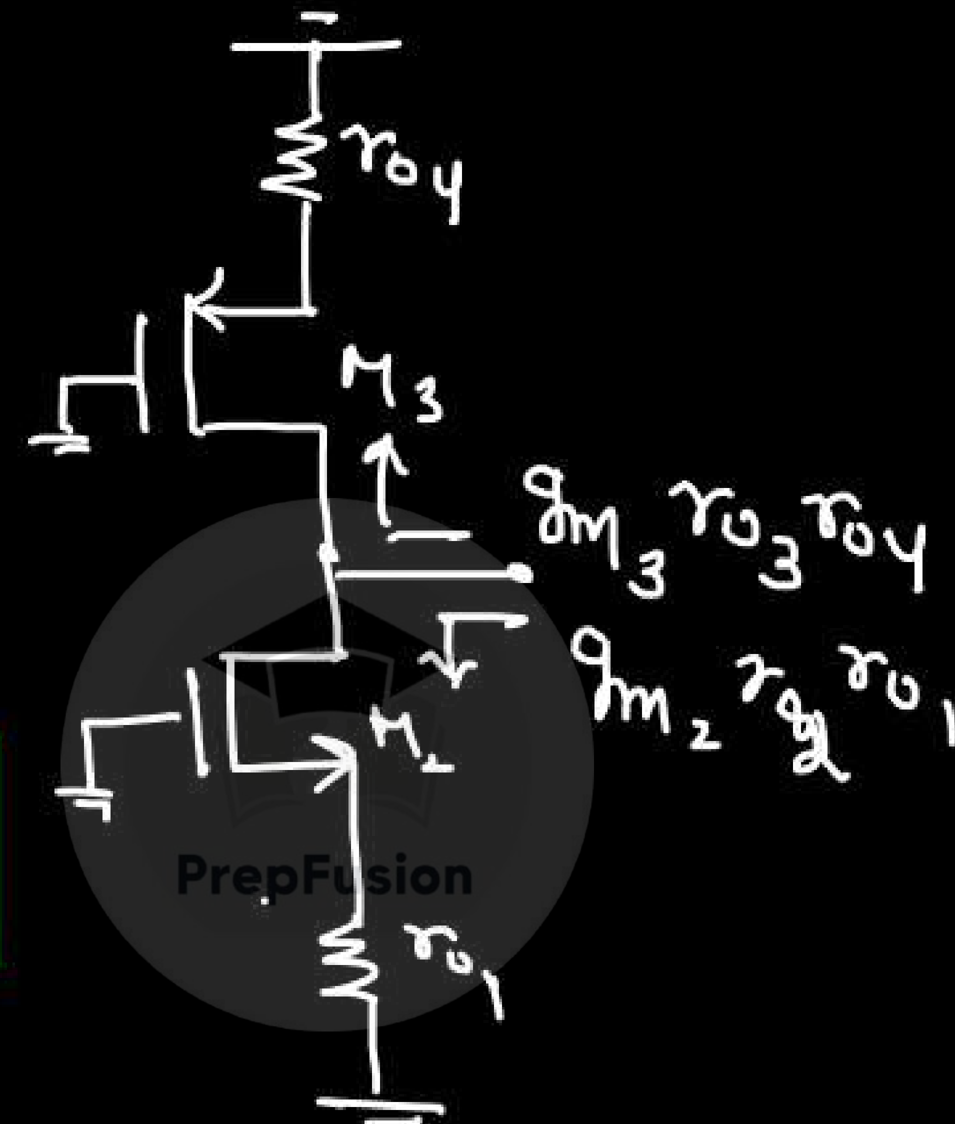


Cascode Amplifier (PMOS)

$$\boxed{A_V \approx -g_{m_1} g_{m_2} r_{o_2} r_{o_1}}$$

Cascode Amplifier with cascode current source:-

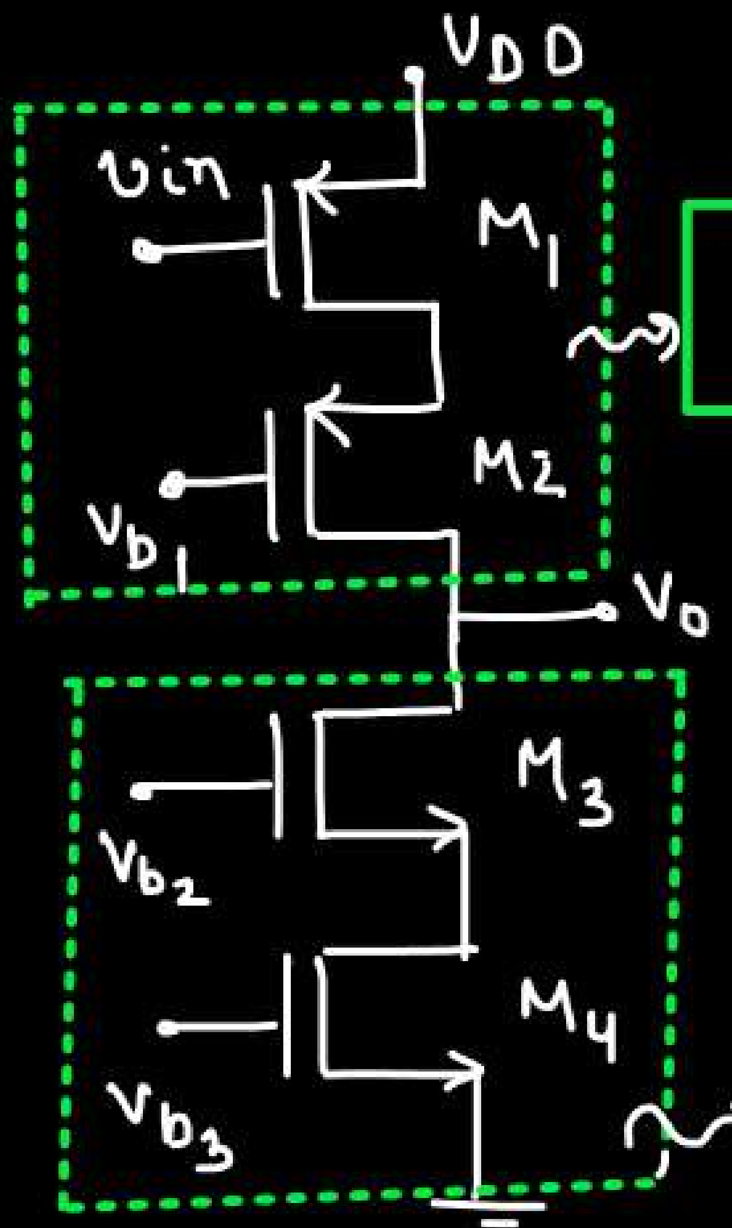




$G_m \approx -g_{m1}$

$R_{out} \approx g_{m3}r_{o3}r_{o4} \,||\, g_{m2}r_{o2}r_{o1}$

$$\boxed{A_V \approx -g_{m1}\left[g_{m3}r_{o3}r_{o4} \,||\, g_{m2}r_{o2}r_{o1}\right]}$$



cascode amplifier

cascode current source

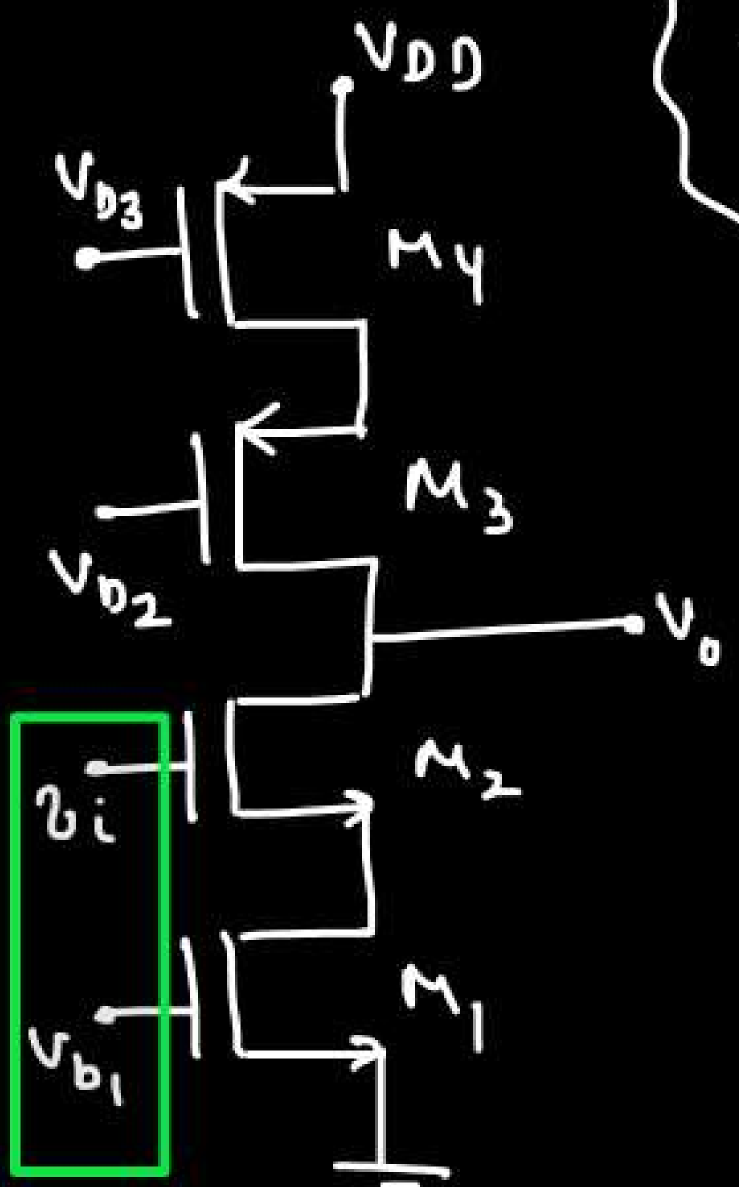
$G_m \approx -g_{m_1}$

$R_{out} \approx g_{m_2} r_{o_2} r_{o_1} \,||\, g_{m_3} r_{o_3} r_{o_4}$

$$\boxed{A_v = -g_{m_1}\left[g_{m_2} r_{o_2} r_{o_1} \,||\, g_{m_3} r_{o_3} r_{o_4}\right]}$$

What if :-

$$\frac{-g_m R_D}{1+g_m R_S}$$

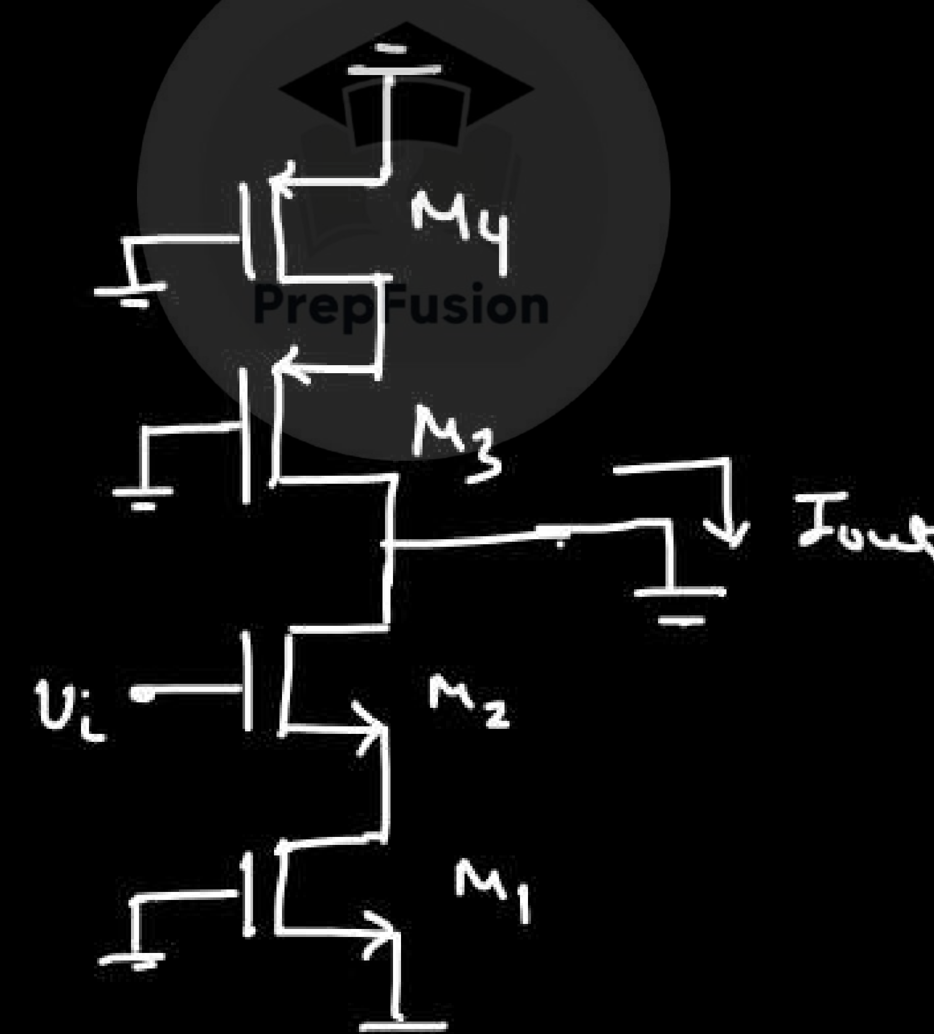


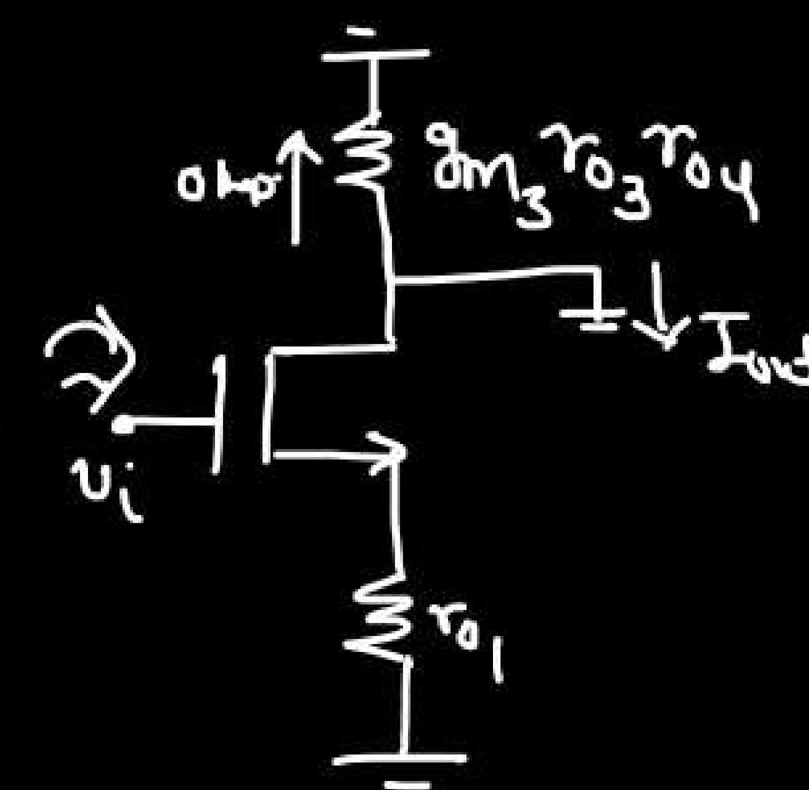
$$\boxed{R_{out} \approx g_{m_3} r_{o_3} r_{o_4} \,||\, g_{m_2} r_{o_2} r_{o_1}}$$

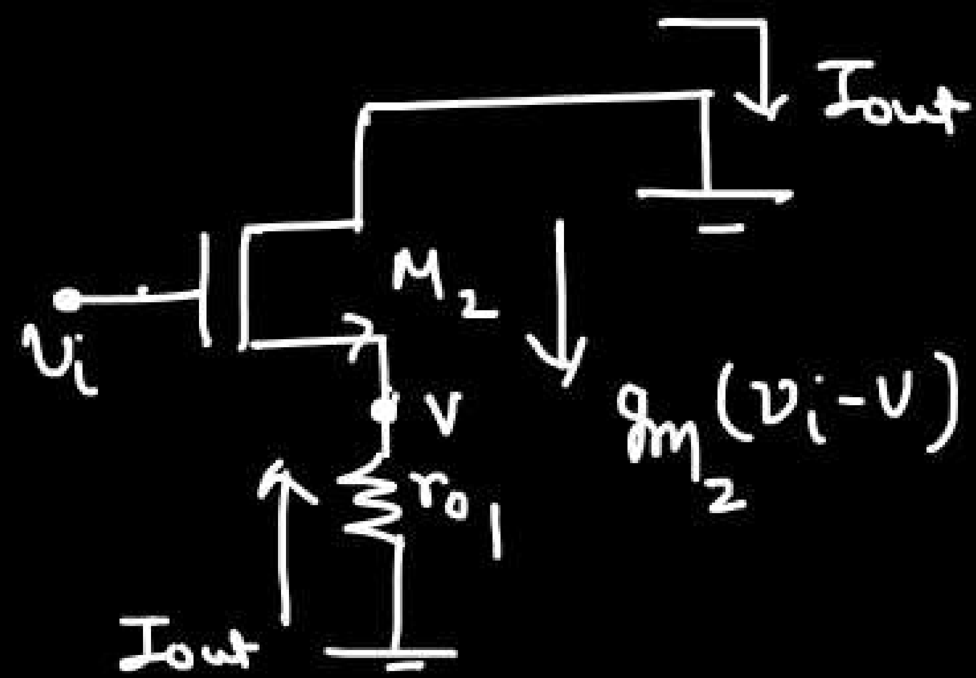
$\Downarrow$

Same as before

$G_m = ?$







$$I_{out} = -g_{m2}(v_i - V)$$

$$\frac{V}{r_{o1}} = -I_{out}$$

$$V = -I_{out} r_{o1}$$

$$I_{out} = -g_{m2}(v_i + I_{out} r_{o1})$$

$$I_{out} = -g_{m2} v_i - g_{m2} r_{o1} I_{out}$$

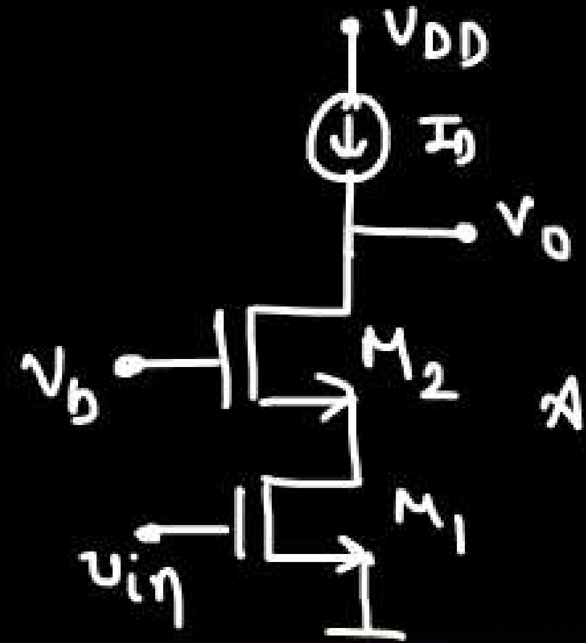
$$\boxed{\text{gain} \approx -\frac{g_{m2}}{1 + g_{m2} r_{o1}} \left[g_{m3} r_{o3} r_{o4} \,||\, g_{m2} r_{o2} r_{o1} \right]}$$

$$\boxed{\frac{I_{out}}{v_i} = \underline{\underline{G_m}} = \frac{-g_{m2}}{1 + g_{m2} r_{o1}}} \rightsquigarrow G_m \text{ is reduce}$$

Gain is reduced [than cascode amplifier]

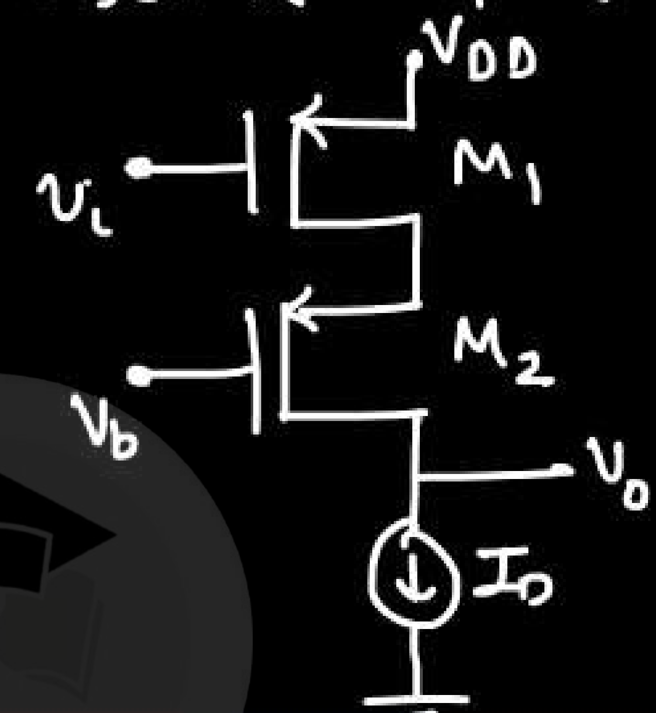
Cascode Amp. v/s Common Source Amp. with degeneration:-

① Cascode Amp. (NMOS)

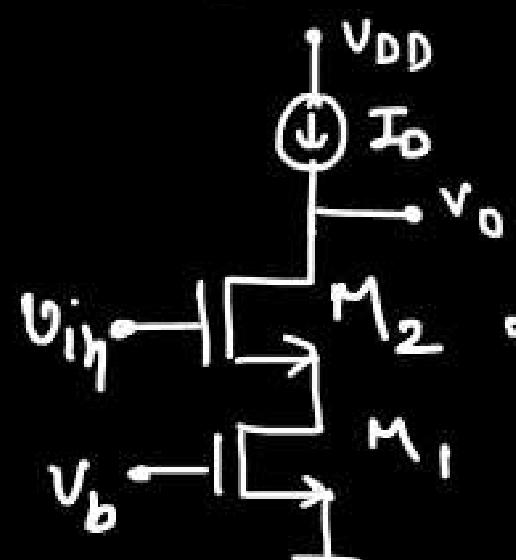


$$A_V = -g_{m_1}\left[g_{m_2} r_{o_2} r_{o_1}\right]$$

③ Cascode Amp. (PMOS)

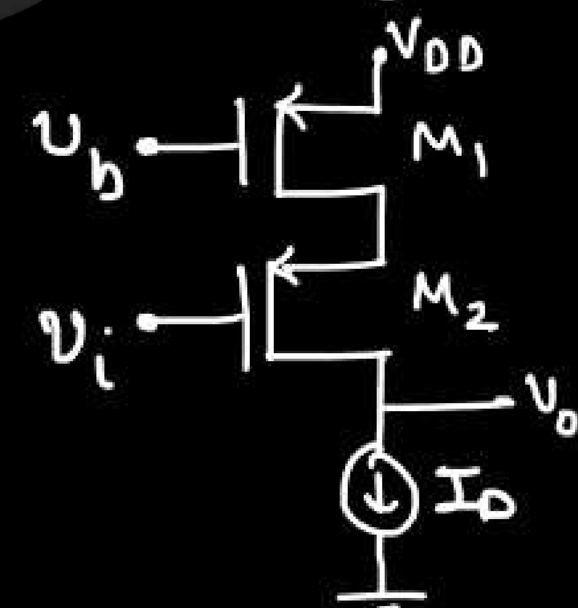


② CS with degen. Amp. (NMOS)



$$A_V = \frac{-g_{m_2}\left[g_{m_2} r_{o_2} r_{o_1}\right]}{1 + g_{m_2} r_{o_1}}$$

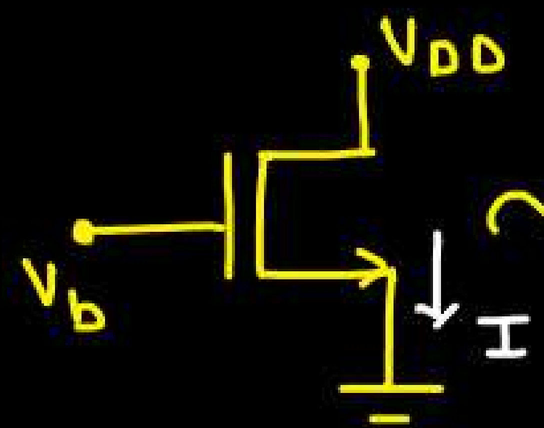
④ CS with degen. Amp. (PMOS)



N.B. -

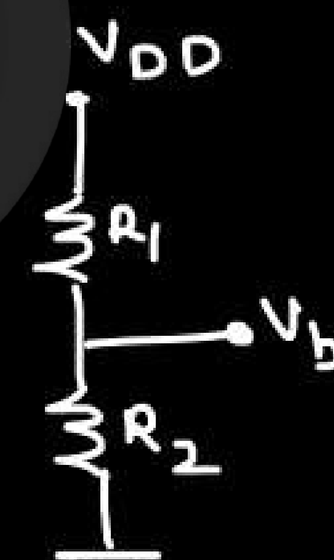
Cascode Amplifier :- Common Source Amp. in series with Common Gate Amp.

⇒ Using MOS as a current Source:-



⇝ Saturation

$$I = \frac{\mu_n C_{ox} W}{2L}(V_b - V_T)^2$$



$$V_b = \frac{R_2}{R_2+R_1} V_{DD}$$

$$I = \frac{\mu_n C_{ox} W}{2L}\left[\underbrace{\frac{R_2}{R_2+R_1} V_{DD}}_{\text{Supply dependent}} - V_T\right]^2$$

μ_n → Temp. dependent

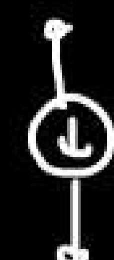
V_T → Temp. dependent

$$\Rightarrow \boxed{I \neq \text{constant}}$$

⇒ For making a current source which is independent of supply and Temp. variation, we need to use "Bandgap" circuit.

[OUT OF The Scope of this course]

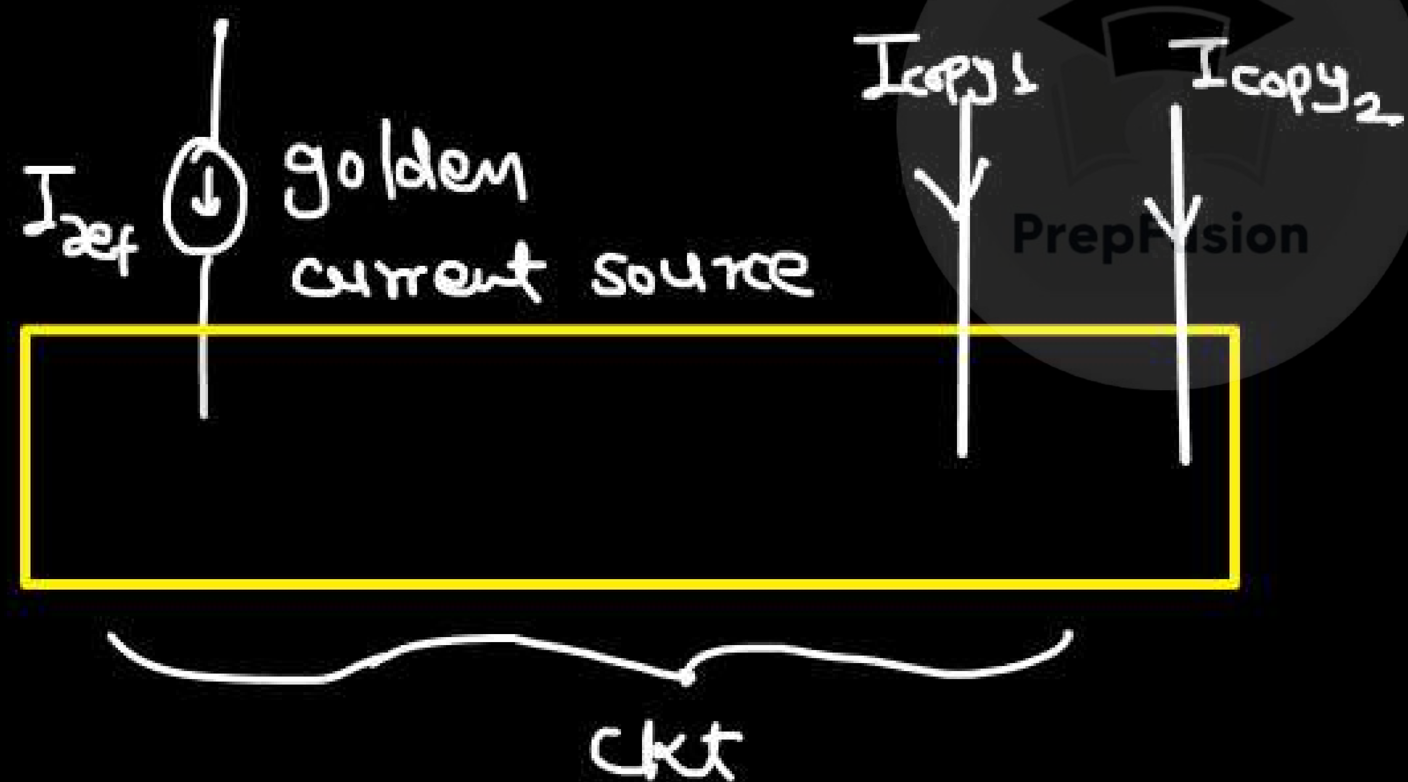
$$\boxed{\text{Golden current source} \Rightarrow \text{Constant current source}}$$



$I_{golden} = I_{ref}$

Current Mirror ckt :-

with the help of golden current source, we will generate other current sources which are identical to golden current source.

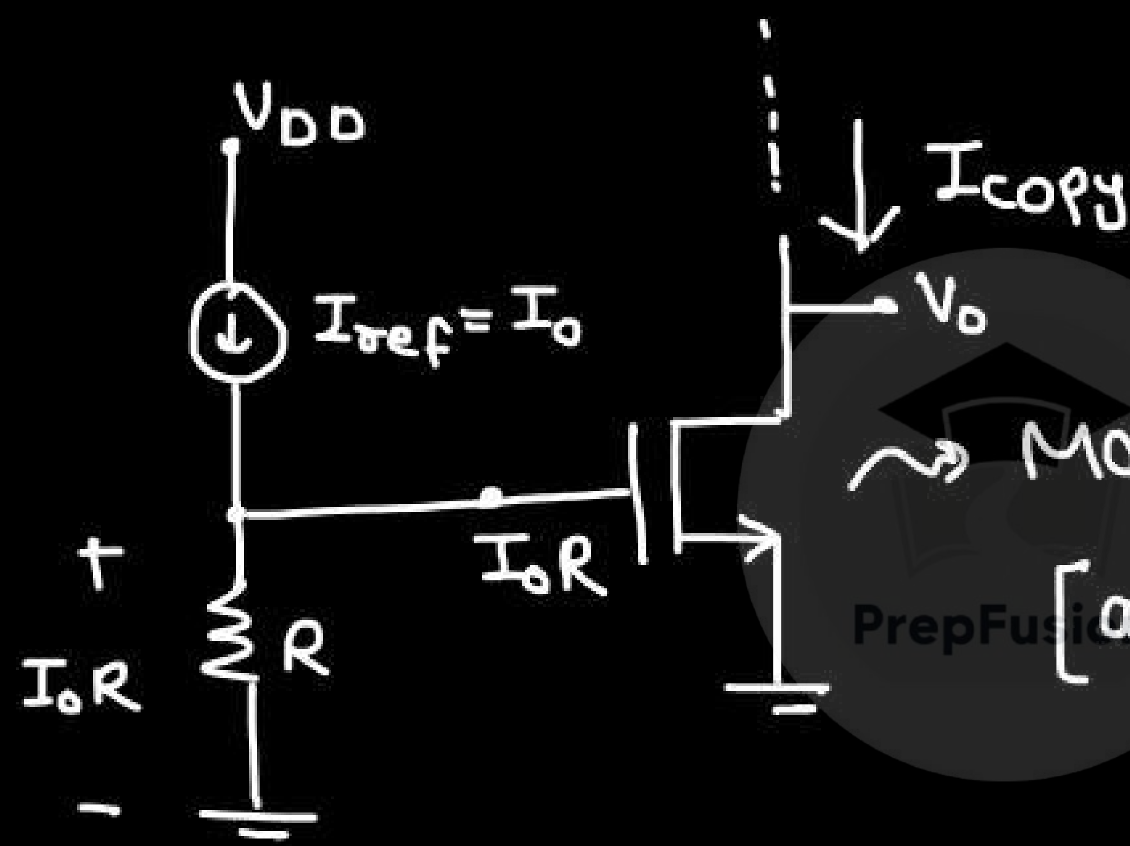


$$I_{copy_1} \propto I_{ref}$$

$$I_{copy_2} \propto I_{ref}$$

Try-1 :-

Using a resistor :-



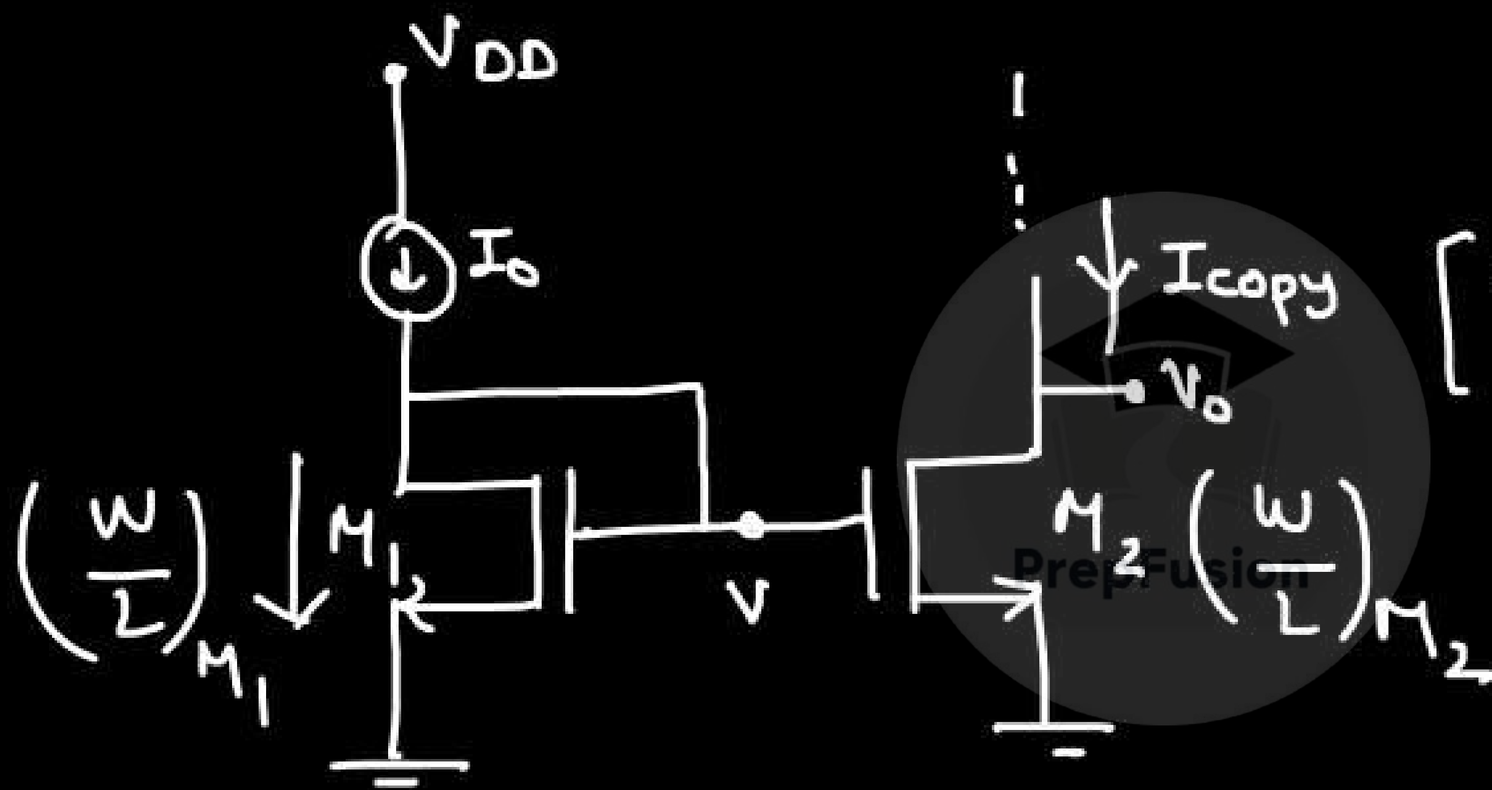
→ MOS is sat. region
[adjust V_o such that MOS is working in sat.]

$$I_{copy} = \frac{\mu_n C_{ox} W}{2L}\left[I_0R - V_T\right]^2$$

Temp. dependent

Try-2 :-

Using diode connected Transistor :-



[adjust V_o such that M_2 is in sat. region]

$$I_o = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{M_1}(V - V_T)^2$$

$$V = \sqrt{\frac{2I_o}{\mu_n C_{ox}(W/L)_{M_1}}} + V_T \quad \text{—— (1)}$$

$$I_{copy} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{M_2}\left[V - V_T\right]^3$$

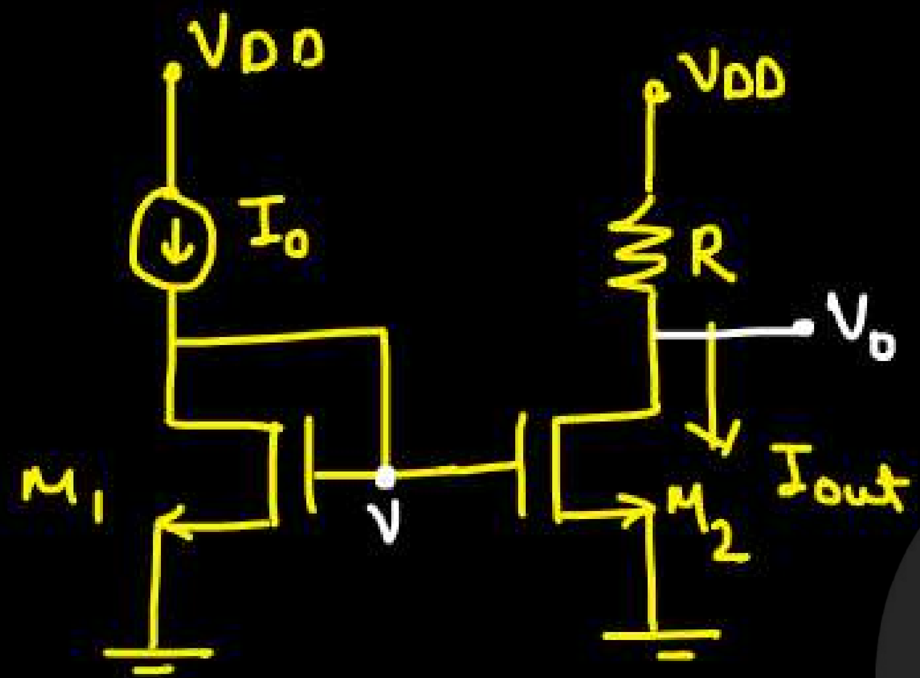
$$= \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{M_2}\left[\sqrt{\frac{2I_0}{\mu_n C_{ox}\left(\frac{W}{L}\right)_{M_1}}} + V_T - V_T\right]^2$$

$$\boxed{I_{copy} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0} \qquad \boxed{I_{copy} \propto I_0}$$

$\Downarrow$

independent of supply and Temp. variation.

Alternative Analysis of current Mirror Ckts:-



$\Rightarrow$ Both M_1 and M_2 are in sat. region.

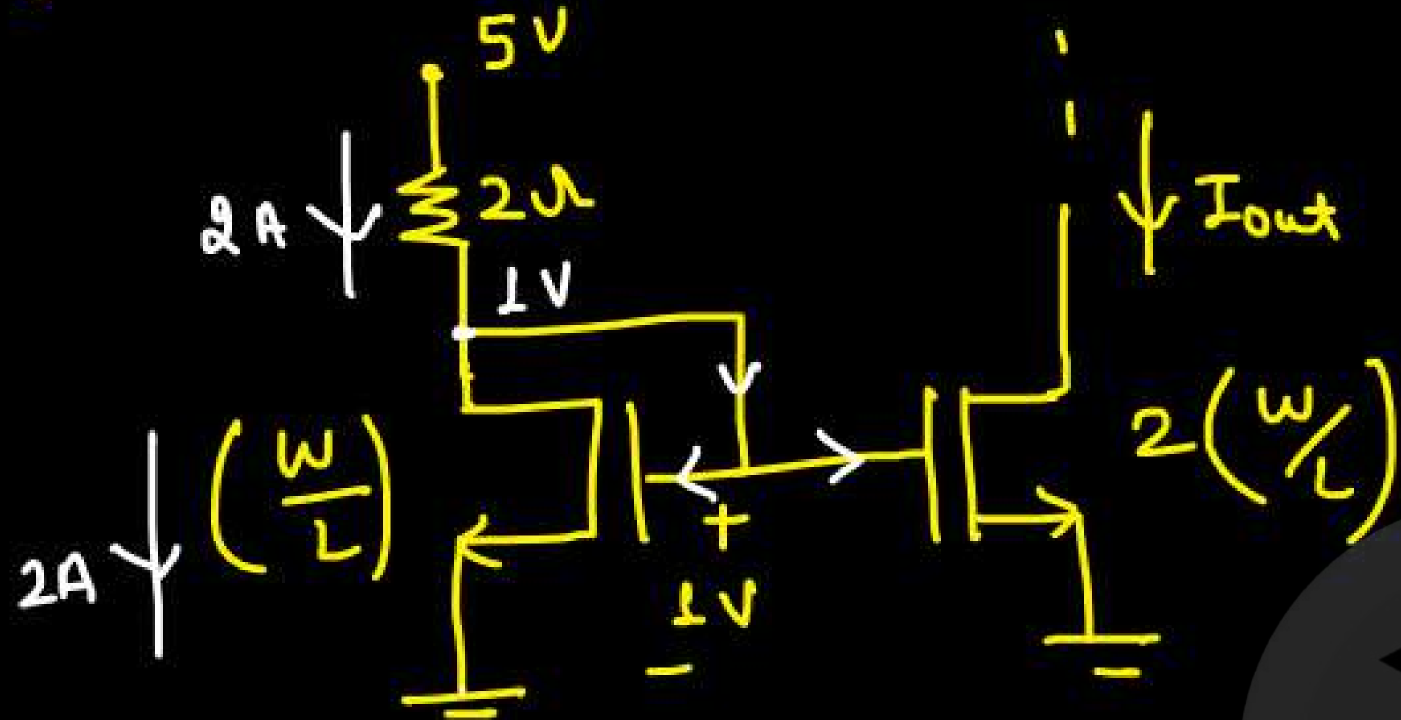
$$(V_{GS})_{M_1} = (V_{GS})_{M_2} = V$$

$$I_0 = \mu_n C_{ox} \left(\frac{W}{L}\right)_{M_1} (V - V_T)^2 \quad \text{—— } ①$$

$$I_{out} = \mu_n C_{ox} \left(\frac{W}{L}\right)_{M_2} (V - V_T)^2 \quad \text{—— } ②$$

$$② \div ① \Rightarrow \frac{I_{out}}{I_0} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} \Rightarrow \boxed{I_{out} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0}$$

Eg.



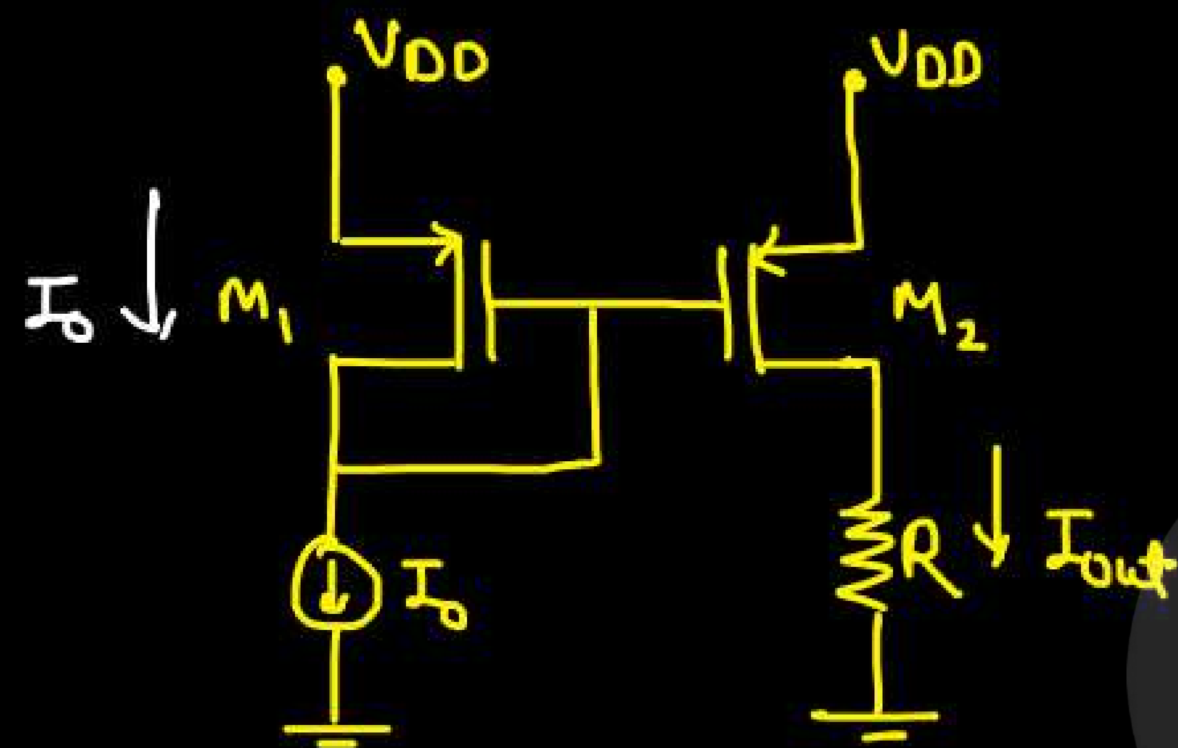
Both Transistors are working in sat. region.

Find $I_{out} = ?$

$$I_{out} = \frac{2(W/L)}{(W/L)} \times 2\text{ Amp.}$$

$$\boxed{I_{out} = 4\text{ Amp.}}$$

Current mirror using PMOS:-



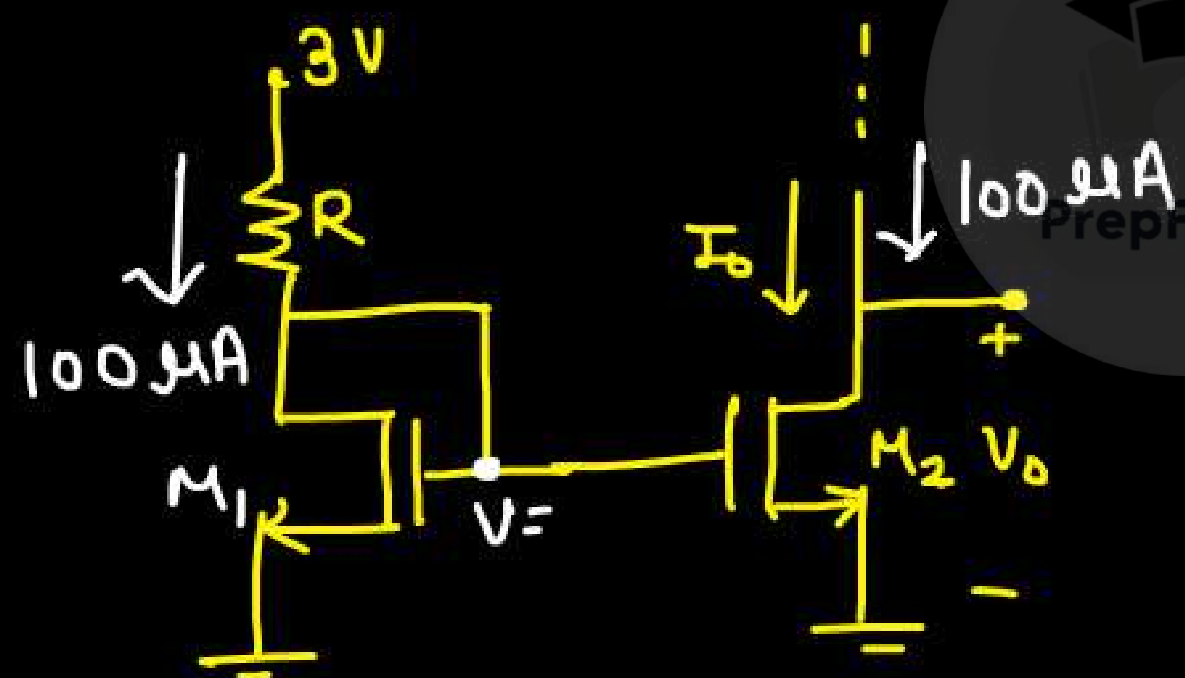
$$\boxed{I_{out} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0}$$

Q. Both Transistors are perfectly matched.

$\mu_n C_{ox} = 200\,\mu A/V^2$, $W/L = 10$, $V_T = 0.7V$, $\lambda = 0$

Find the value of R to get $100\,\mu A$ o/p current.

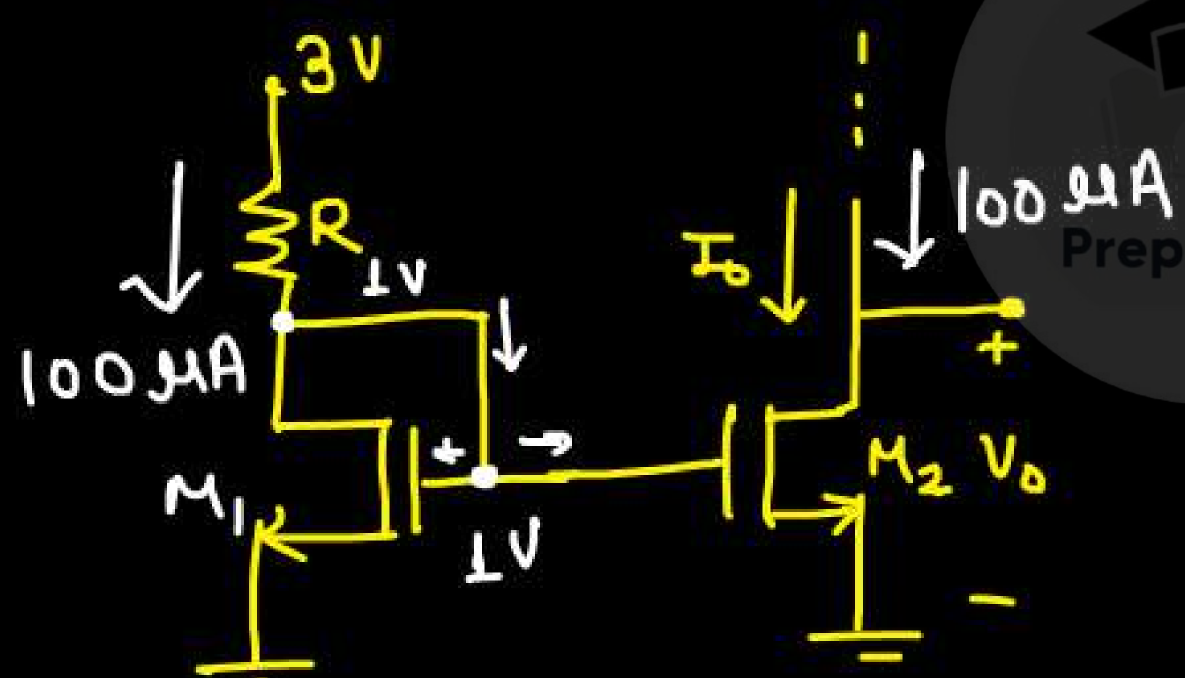
What is the lowest possible value of V_o such that M_2 is working in sat. region.



$$100\mu A = \frac{200\mu \times 10}{2}\left[V-0.7\right]^2$$

$$V - 0.7 = \sqrt{10}$$

$$\boxed{V = 1V}$$



$$\frac{3-1}{R} = 100\mu A$$

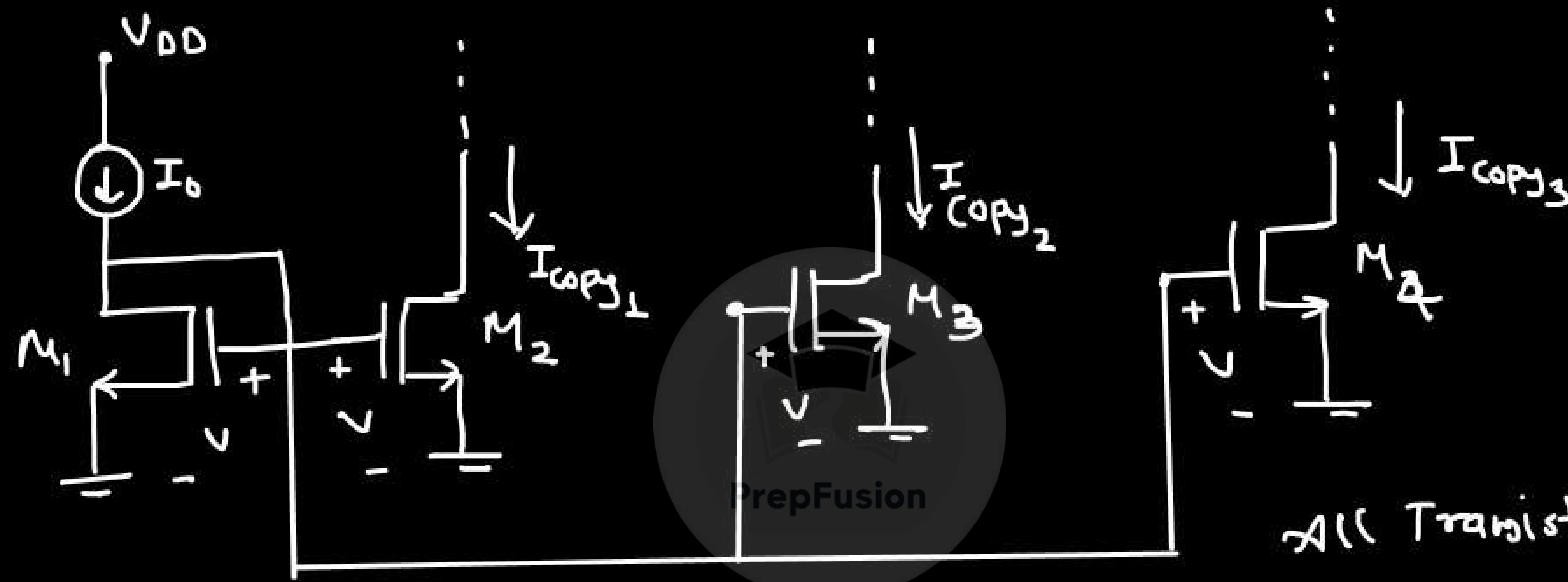
$$\boxed{R = 20k\Omega}$$ ANS.

$\Rightarrow$ For sat. region

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

$$V_o = 1 - 0.7 = 0.3 \Rightarrow \boxed{V_o = 0.3V}$$

⇒ Building Multiple current sources:-

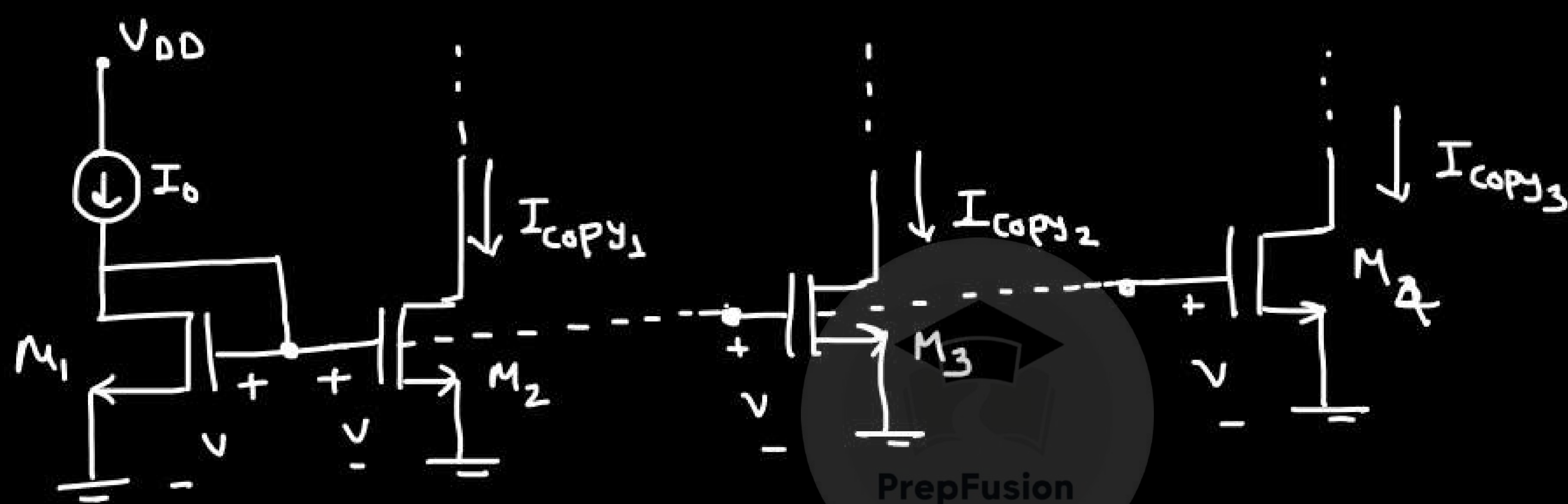


All Transistors are in sat.

$$\boxed{I_{copy_1} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0}$$

$$\boxed{I_{copy_2} = \frac{(W/L)_{M_3}}{(W/L)_{M_1}} I_0}$$

Other way of showing the same ckt :-



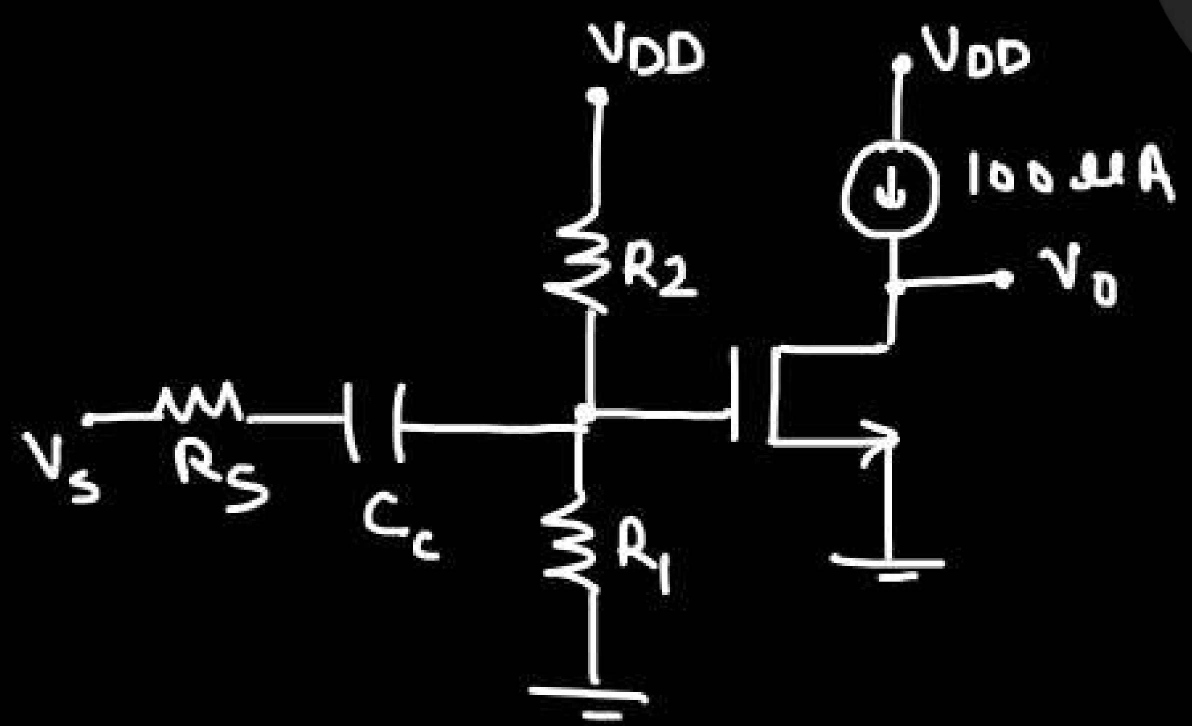
Q. Make a common source Amplifier (using NMOS) with 100 μA current source in load. You have a reference current source of 200 μA.

You only have one supply V_{DD}.

Your small signal i/p V_s has internal resistance R_S.

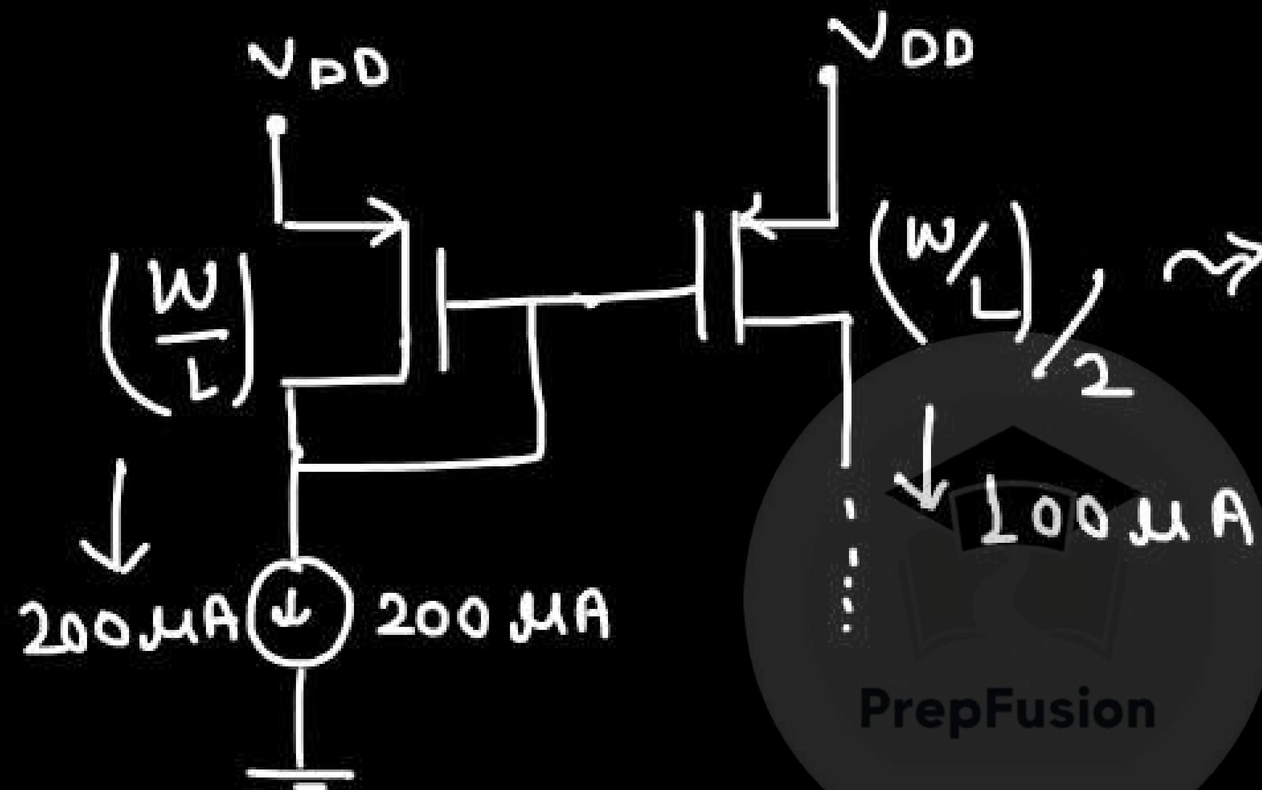
After desiging the ckt, find the small signal voltage gain.

→



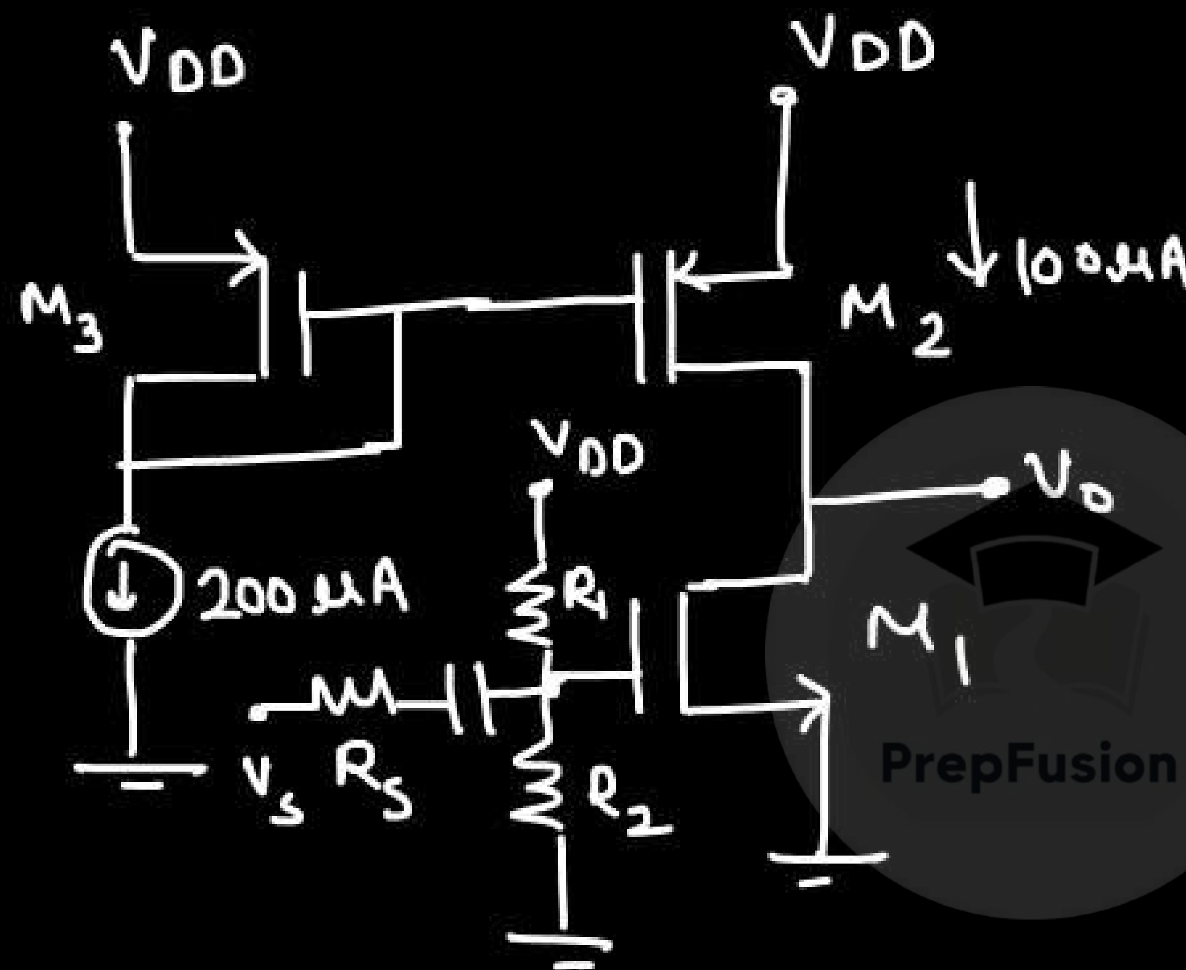
Next task:-

desiging 100 μA current source from 200 μA ref. current.



→ Making sure that this T^r is working in sat.

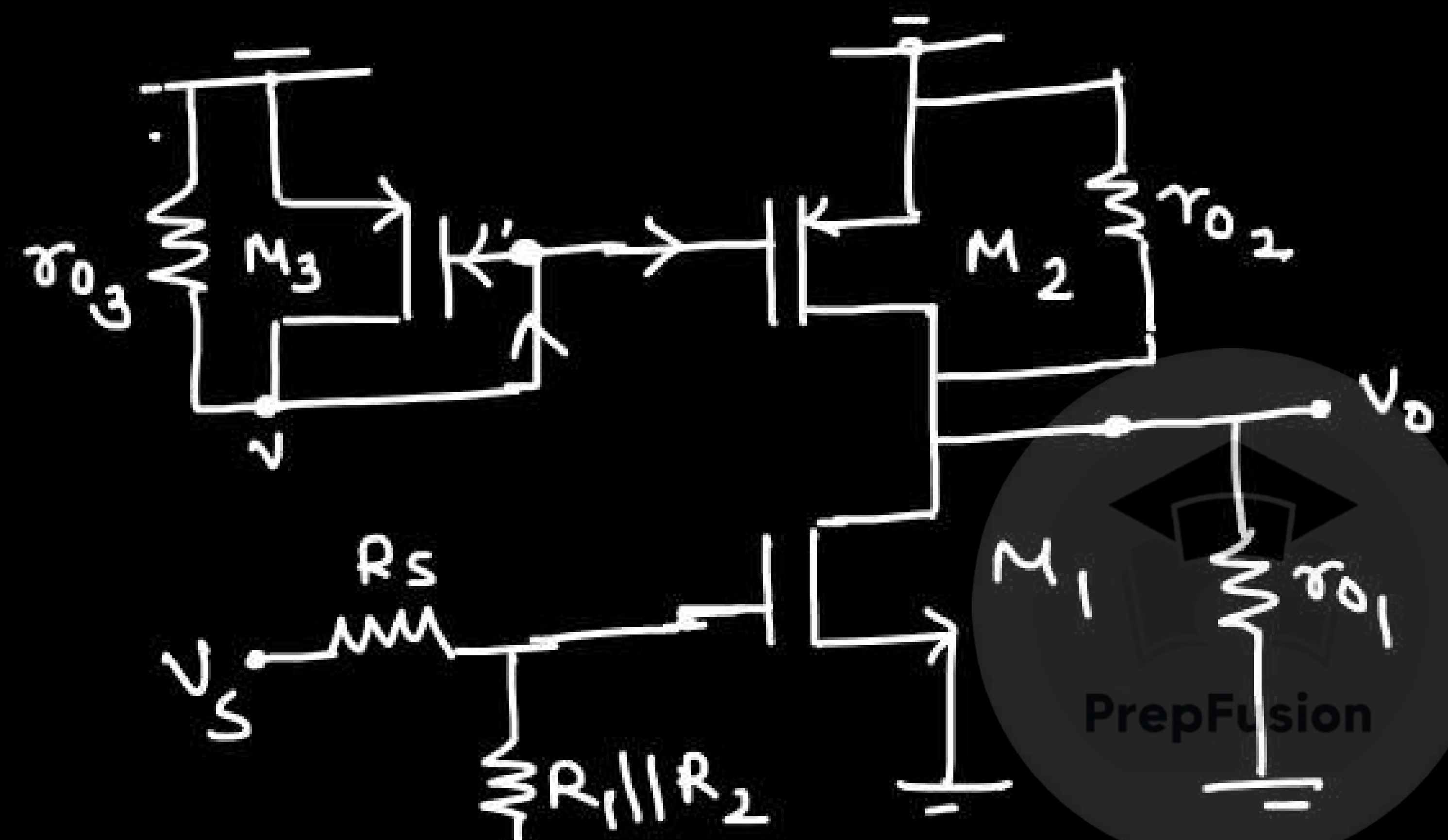
Final design:-



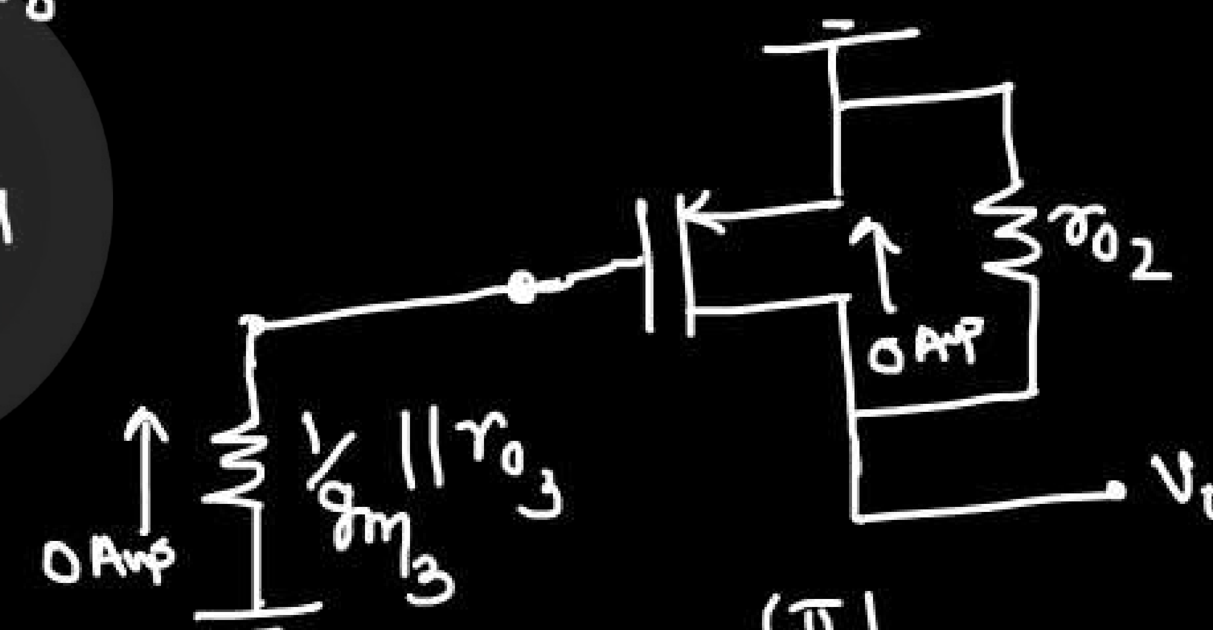
Adjust V_{DD}, R_1, R_2 such that all T^r are working in sat.

$$\left(\frac{W}{L}\right)_3 = 2\left(\frac{W}{L}\right)_2$$

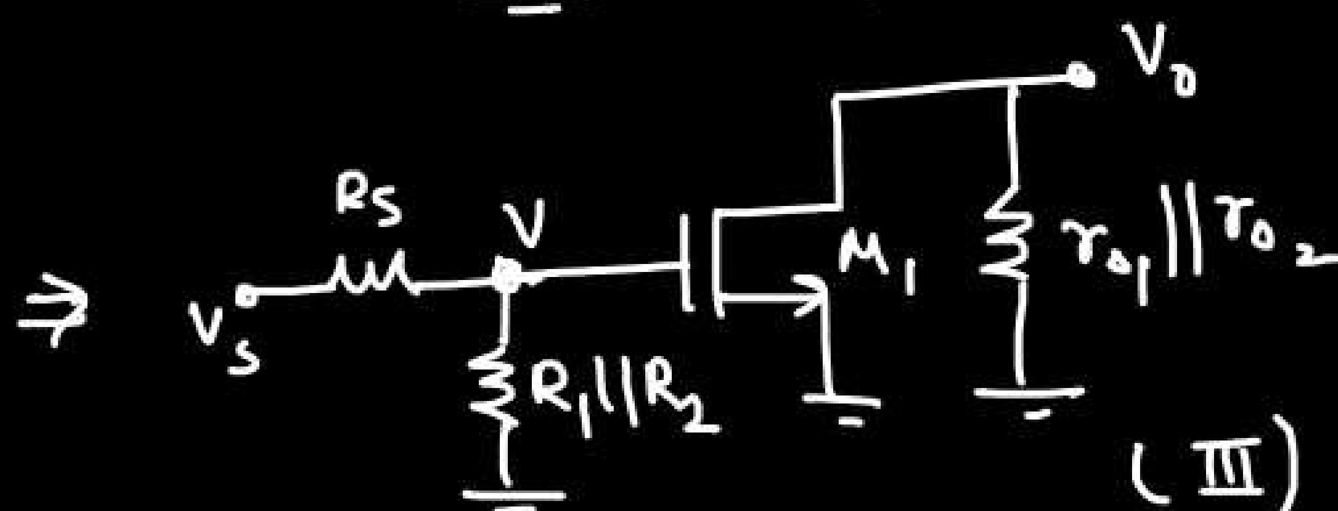
Small signal Voltage gain :-



(I)



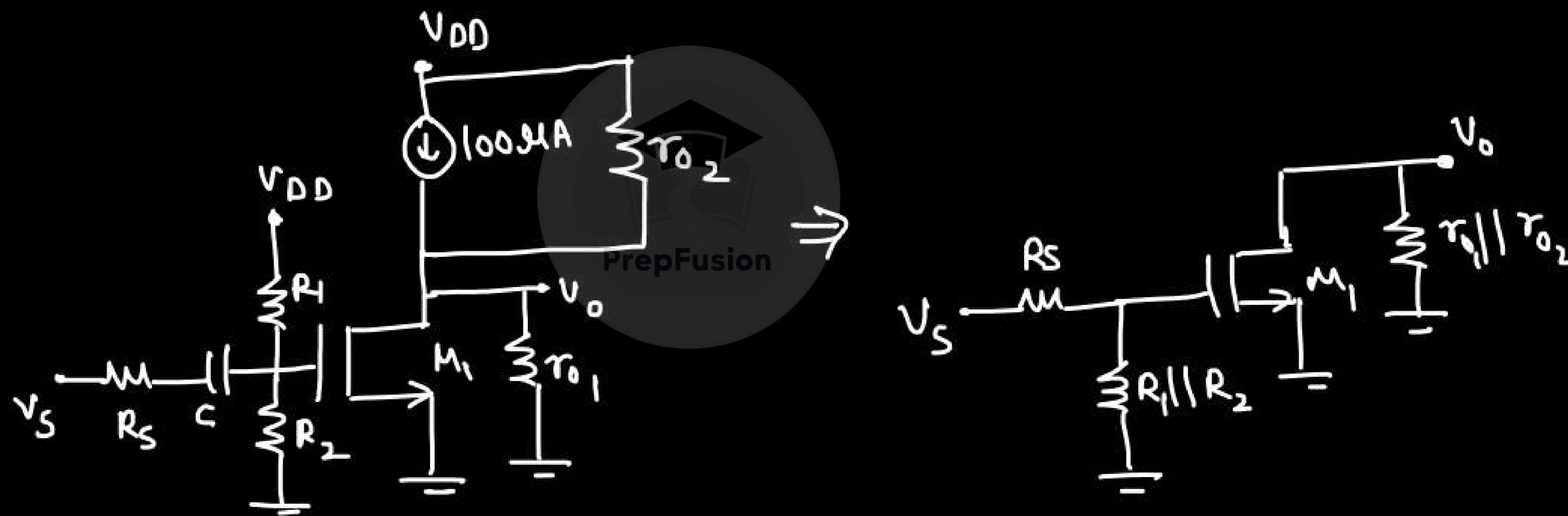
(II)



(III)

$$\boxed{\frac{v_0}{v_s} = -g_{m_1}\left[r_{o_1} \| r_{o_2}\right] \times \frac{(R_1 \| R_2)}{R_s + (R_1 \| R_2)}}$$

M – II

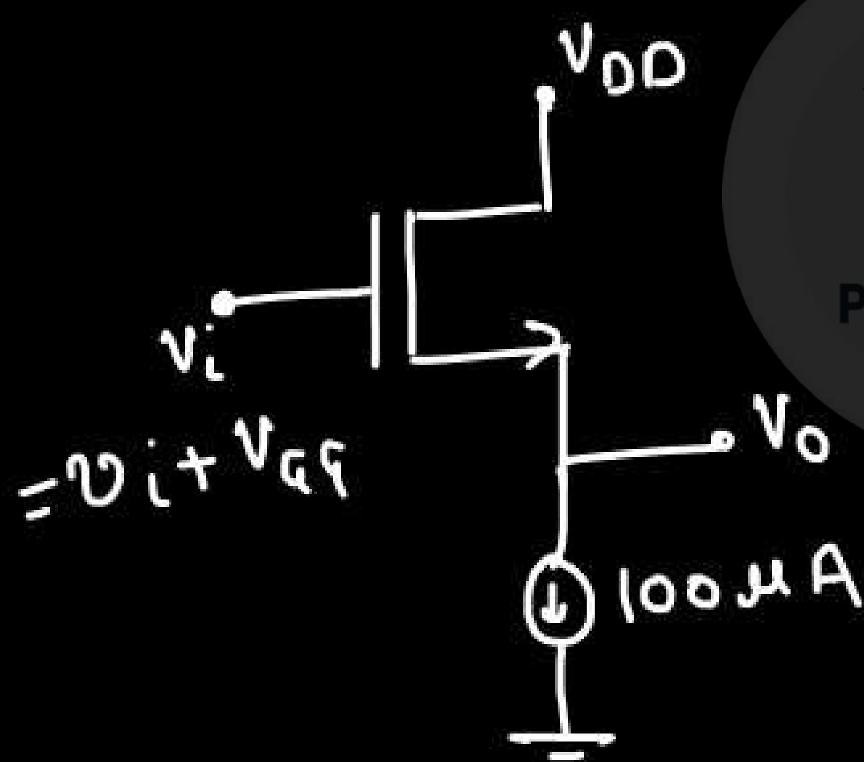


Q. Design a common drain Amplifier (using NMOS) with 100 μA current source in load.

You have a reference current source of 200 μA.

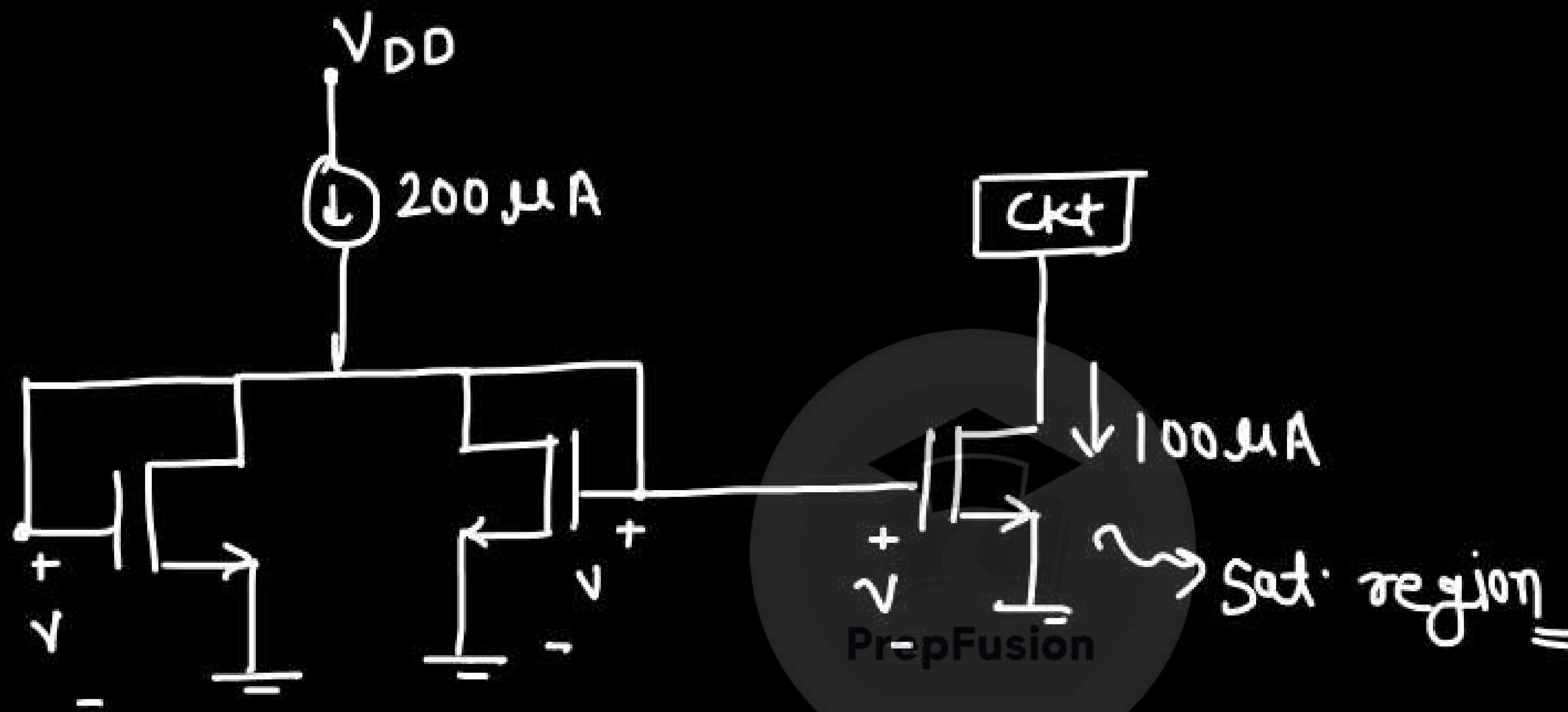
[Note:- All the avaible transistor have same W/L ratios.]

→

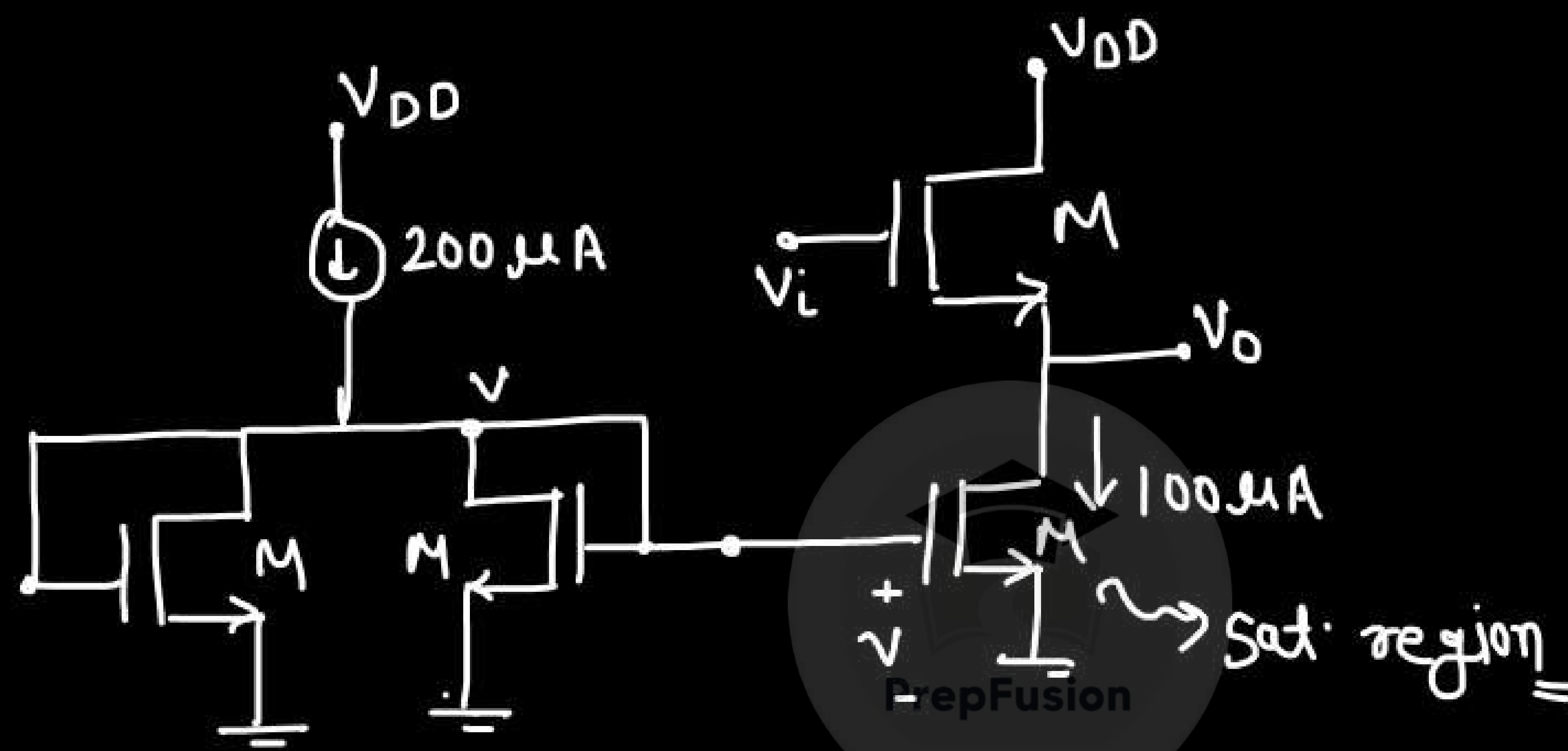


Task:-

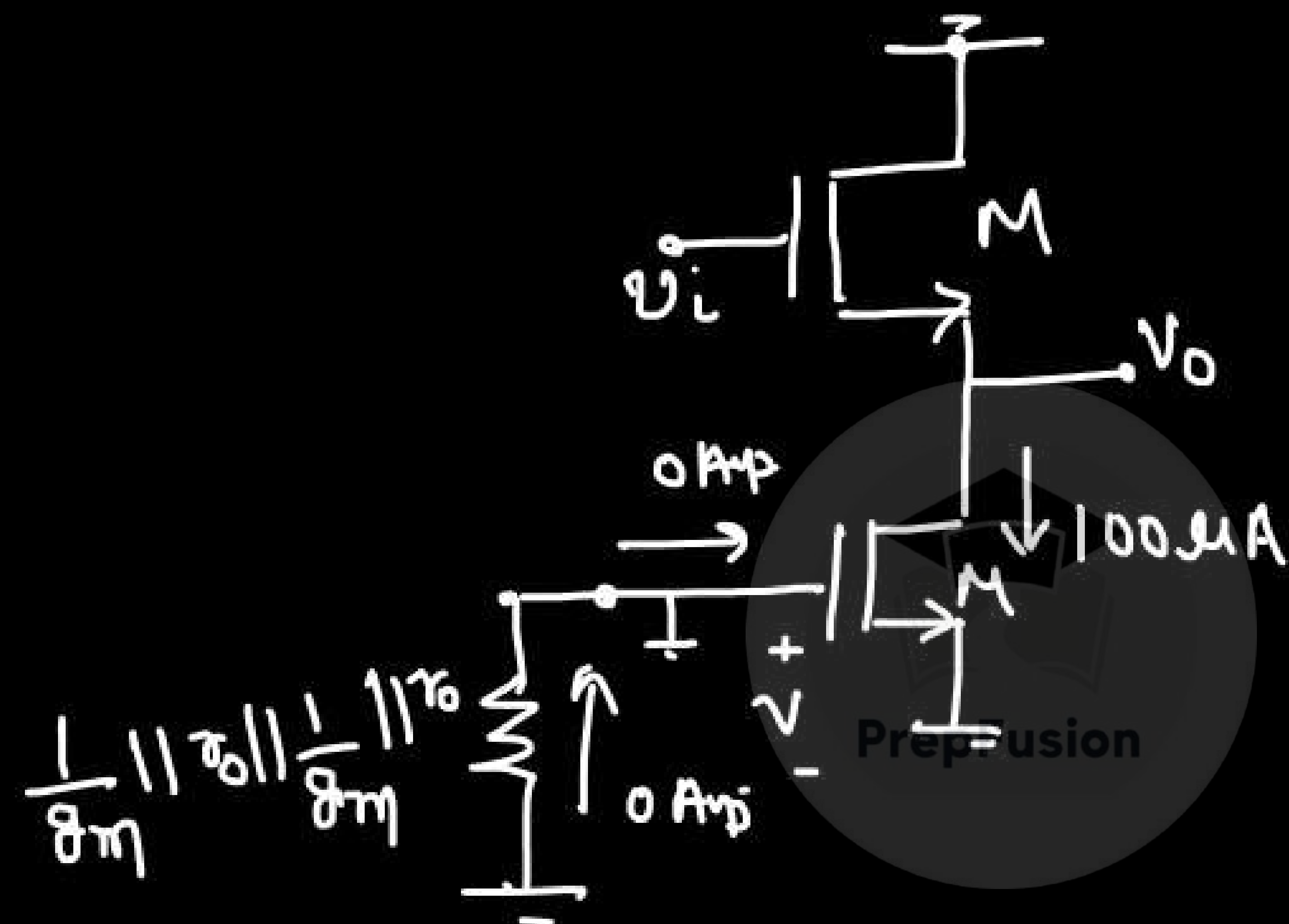
desiging 100 μA current source:-



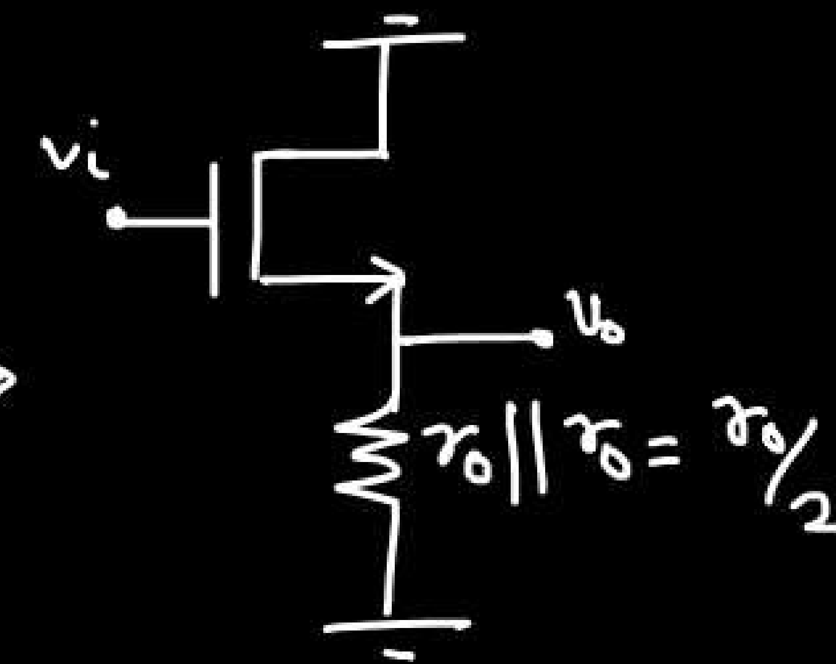
Final design:-



Small signal Analysis :-



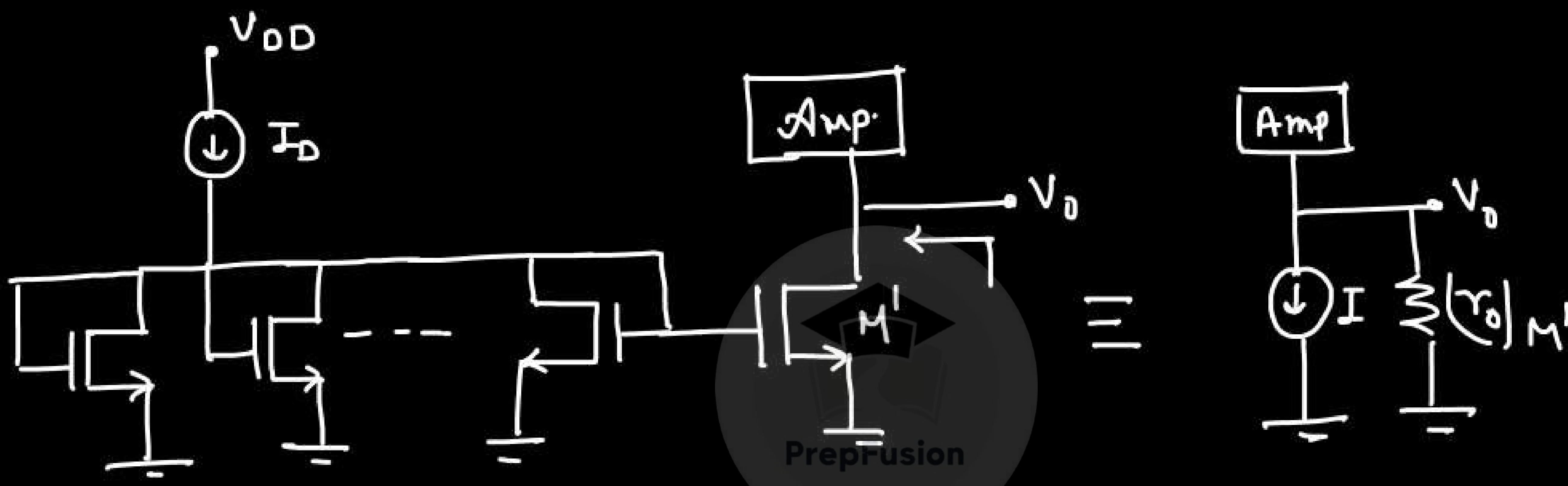
$\Rightarrow$



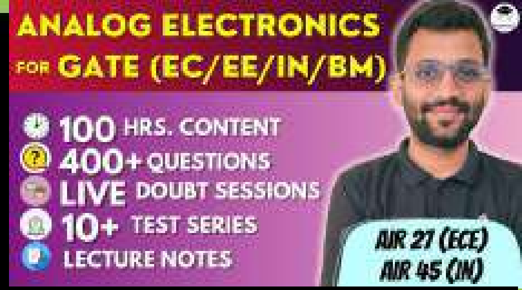
$$\frac{v_o}{v_i} = \frac{r_o/2}{1/g_m + r_o/2}$$

$$\boxed{\frac{v_o}{v_i} = \frac{g_m r_o}{2 + g_m r_o}}$$

Conclusion :-

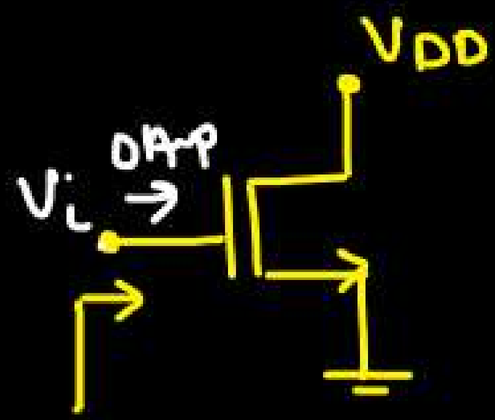


V_{DD}
I_D
Amp.
V_0
M'
≡
Amp
V_0
I
r_0
M'

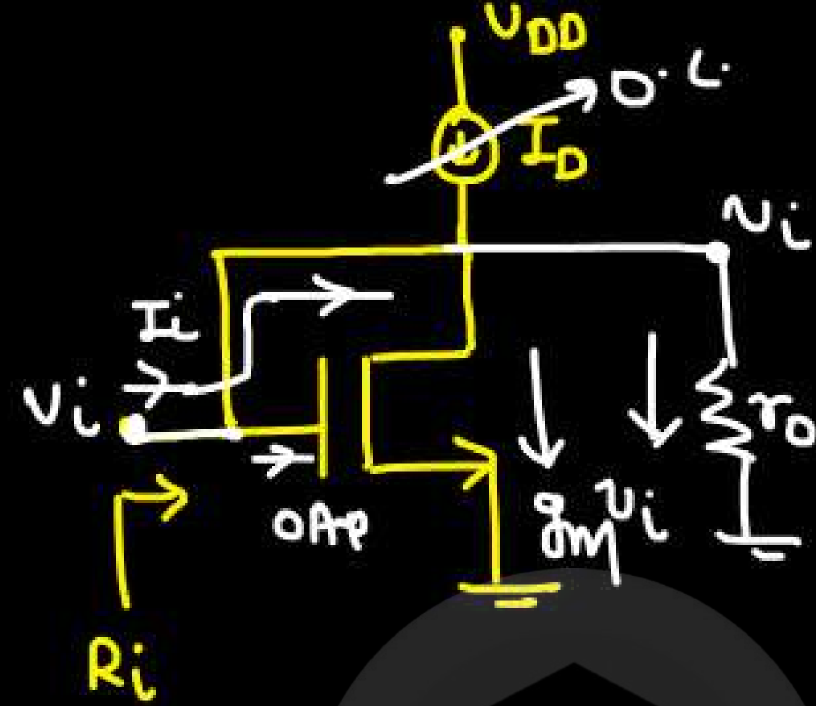


ANALOG ELECTRONICS FOR GATE (EC/EE/IN/BM)
100 HRS. CONTENT
400+ QUESTIONS
LIVE DOUBT SESSIONS
10+ TEST SERIES
LECTURE NOTES
AIR 27 (ECE)
AIR 45 (IN)

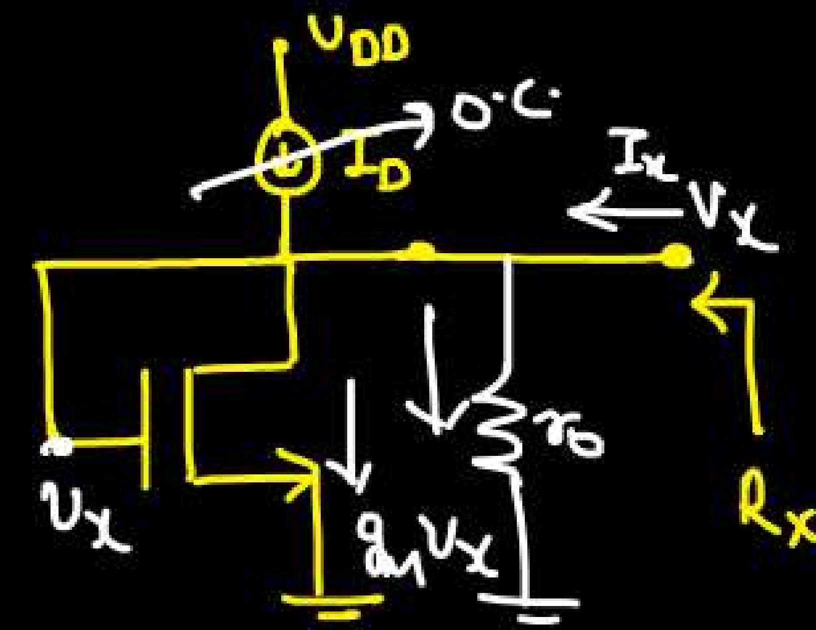
N.B. →



(a)



(b)



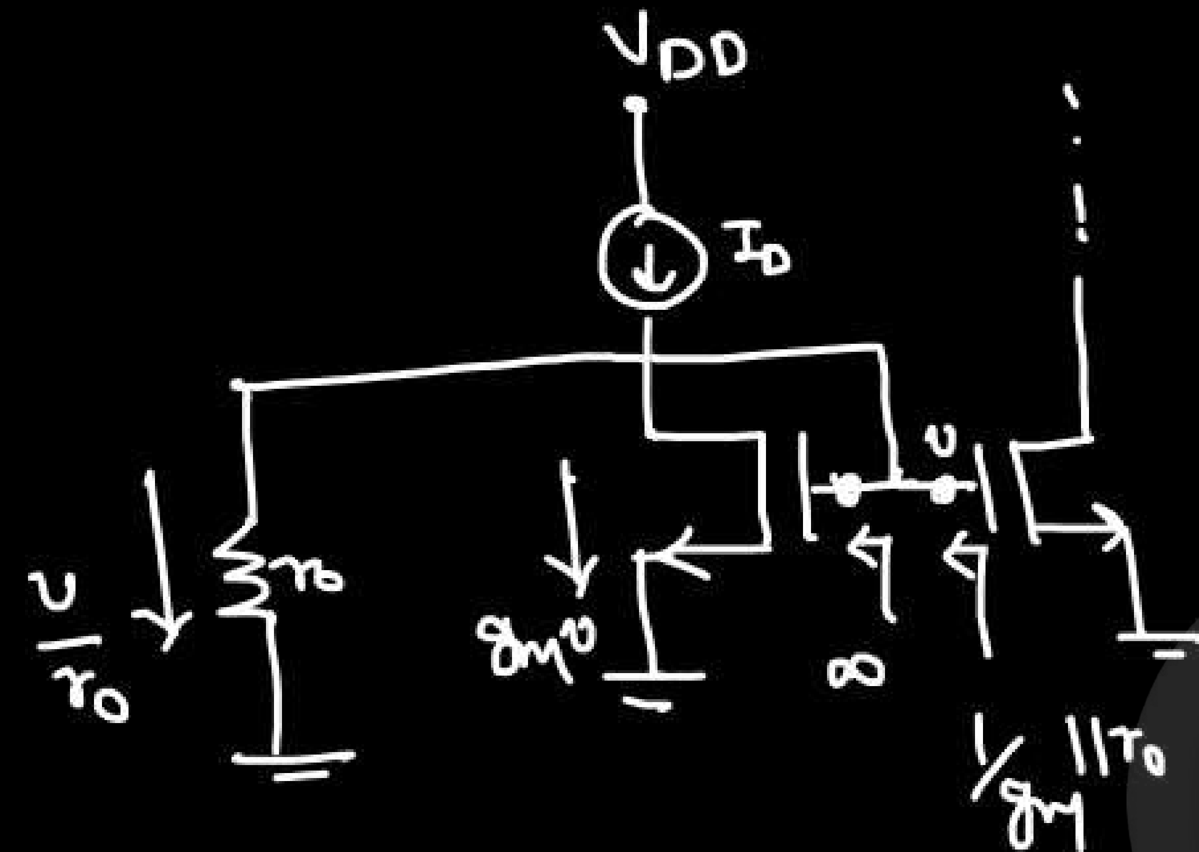
(c)

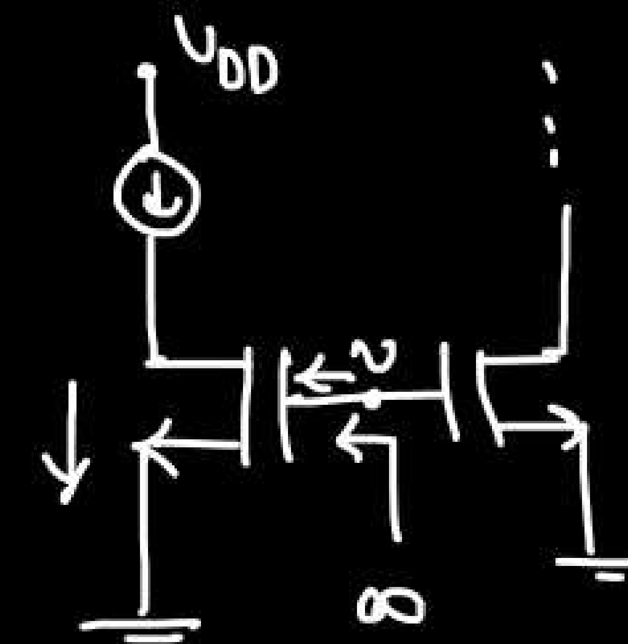
$$I_i = g_m v_i + \frac{v_i}{r_0}$$

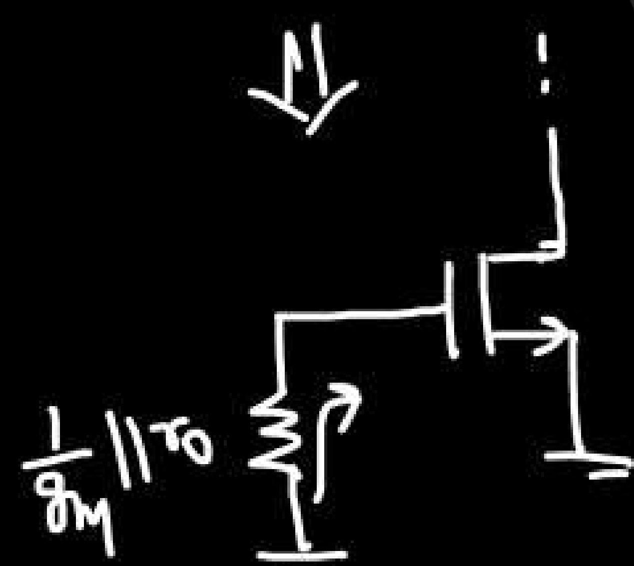
$$\boxed{\frac{v_i}{I_i} = R_i = \frac{1}{g_m} \| r_0}$$

$$\frac{v_x}{r_0} + g_m v_x = I_x$$

$$\boxed{\frac{v_x}{I_x} = R_x = \frac{1}{g_m} \| r_0}$$

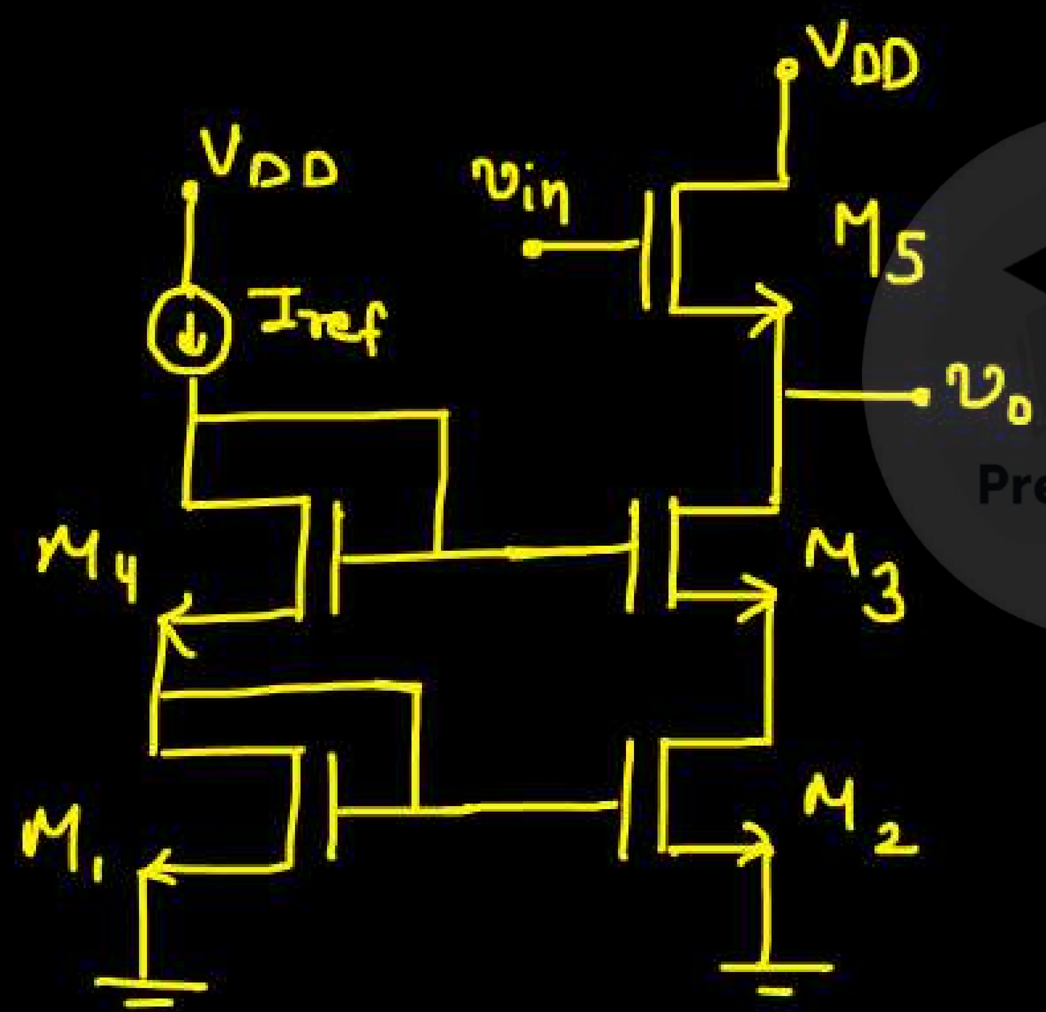

VDD
ID
r0
v/r0
gm v
v
∞
1/gm || r0


VDD
v
∞

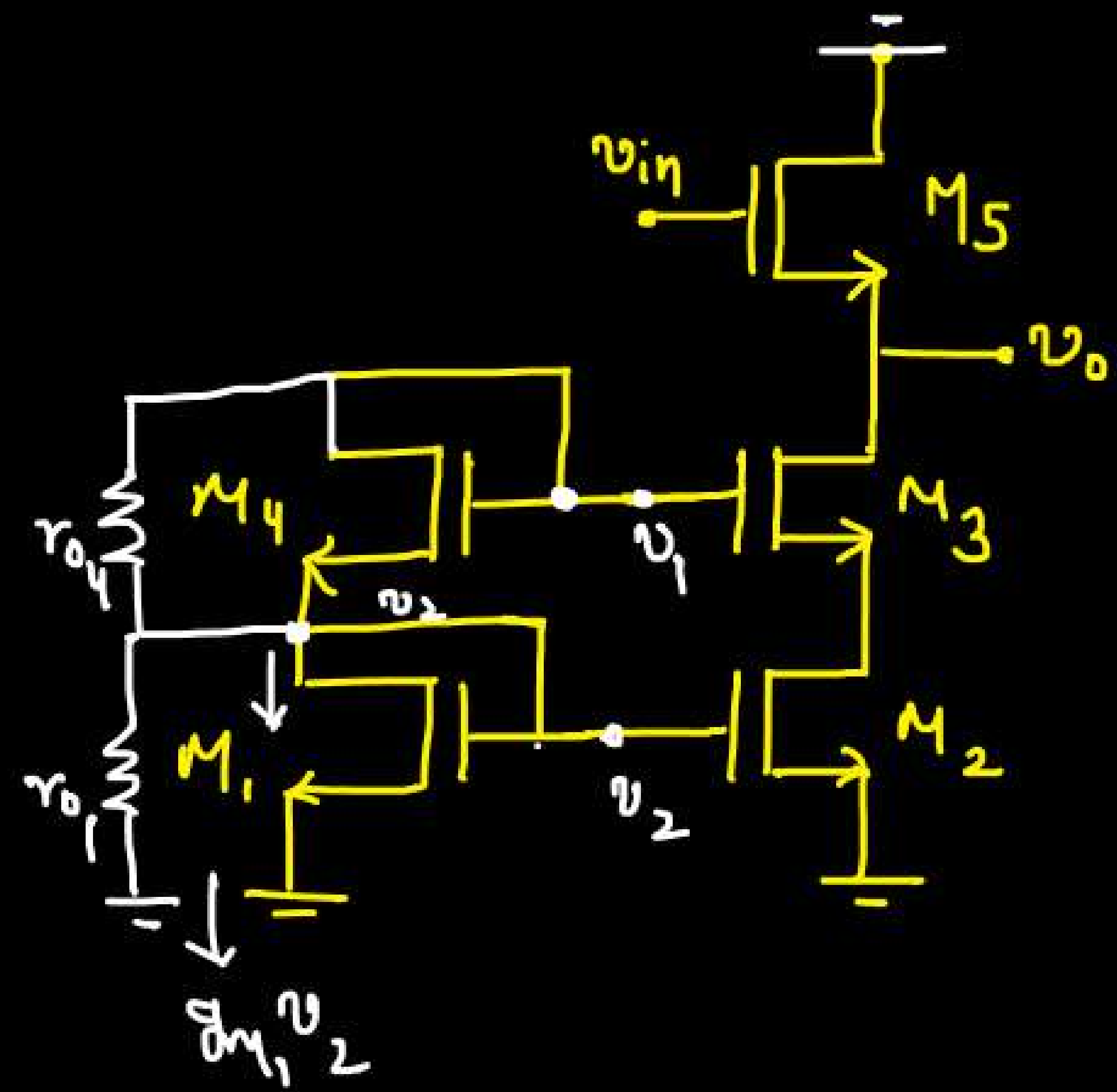

1/gm || r0

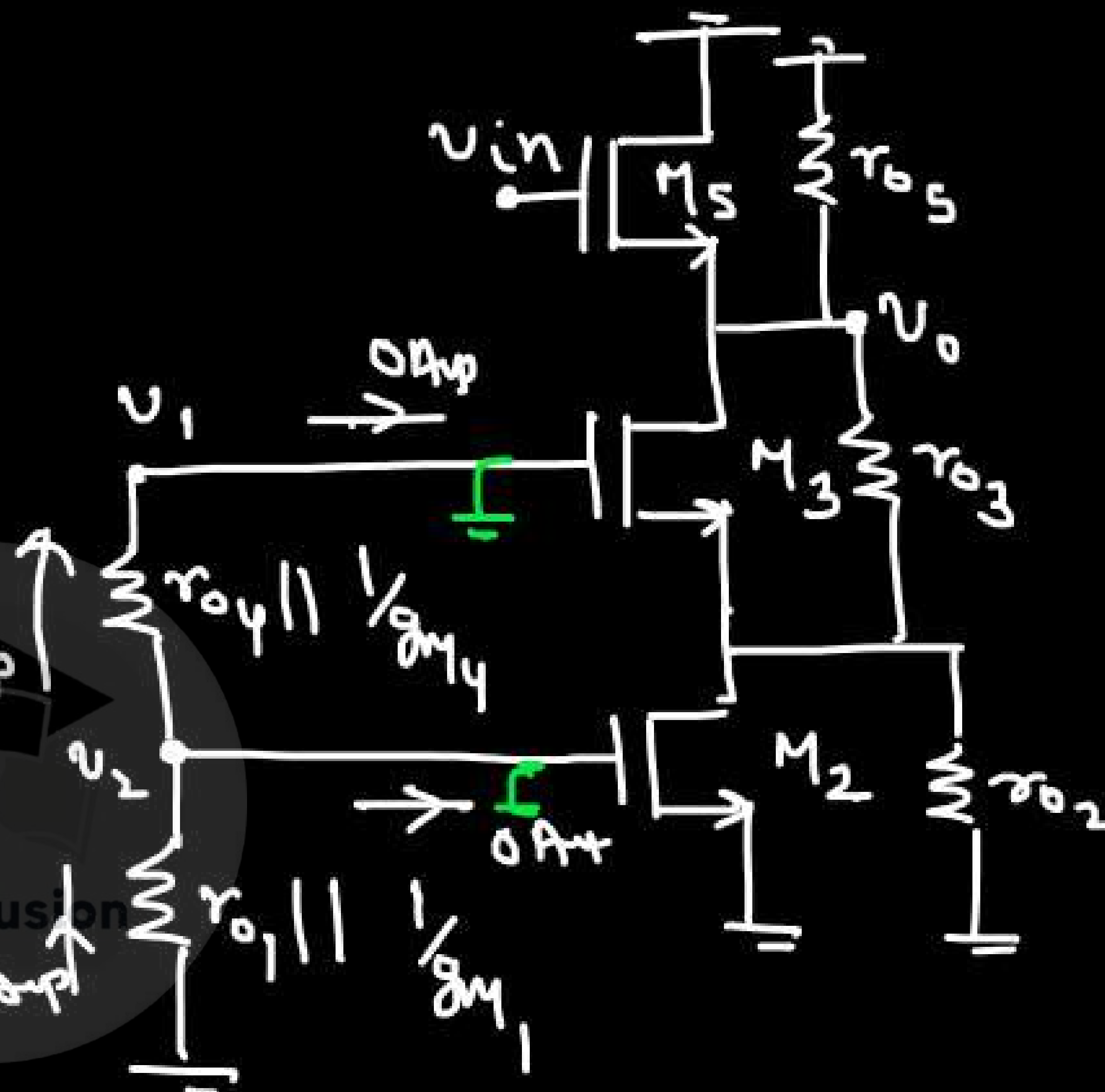
Assignment - 8

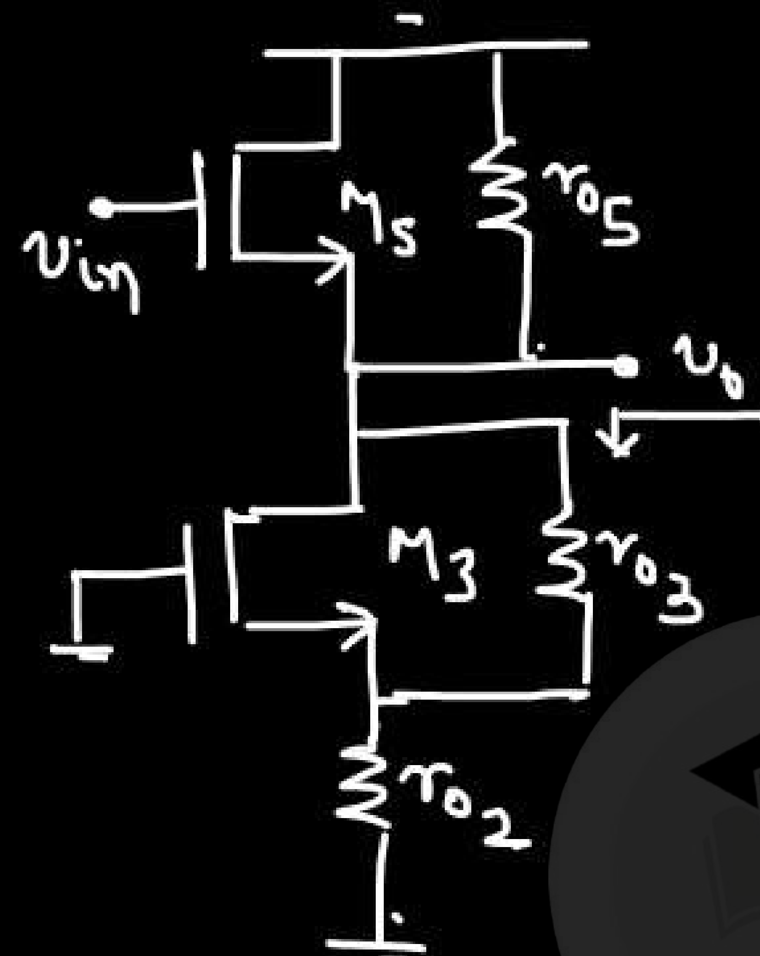
Q.



Find small signal voltage gain $\frac{v_o}{v_i}$?

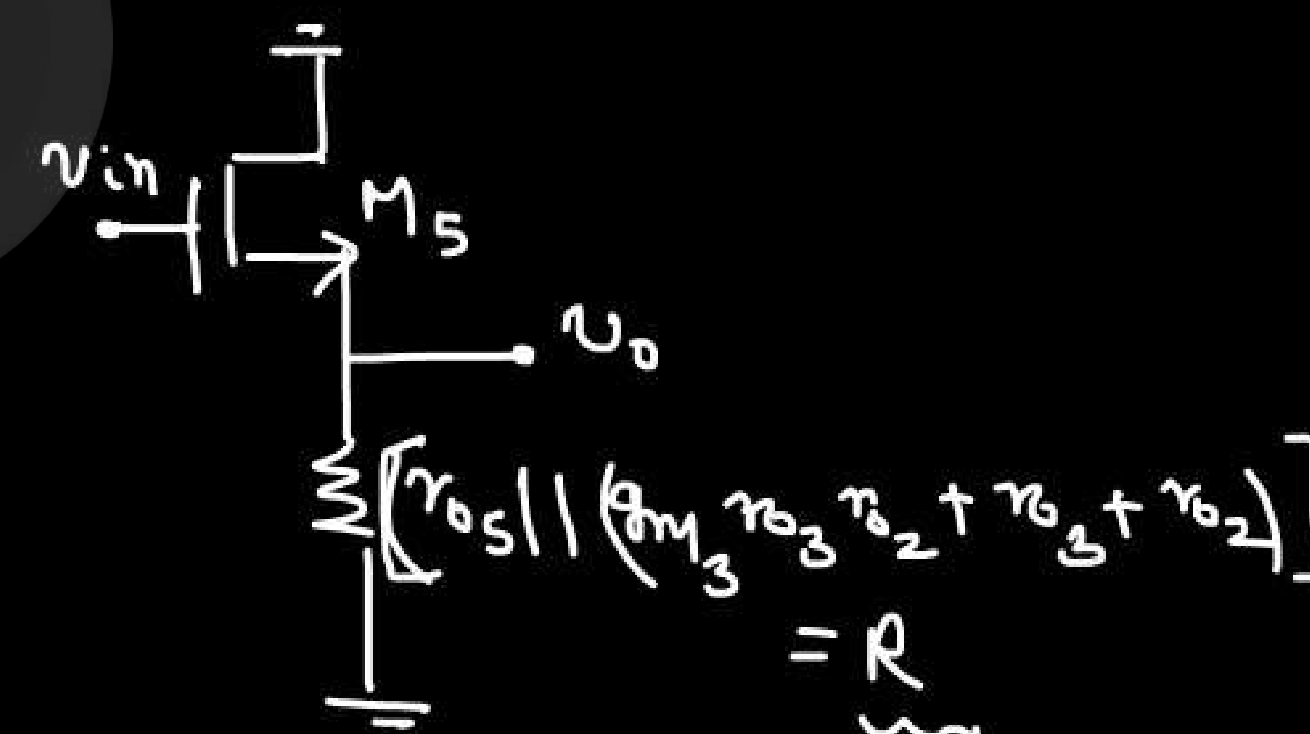

vin
M5
v0
M4
M3
ro4
v1
v2
M1
M2
ro1
v2
gm1v2


vin
M5
ro5
v0
v1
OAmp
M3
ro3
ro4 || 1/gm4
OAmp
v2
M2
ro2
OAmp
ro1 || 1/gm1
OAmp



$$\left[g_{m_3} r_{o3} r_{o2} + r_{o3} + r_{o2}\right]$$

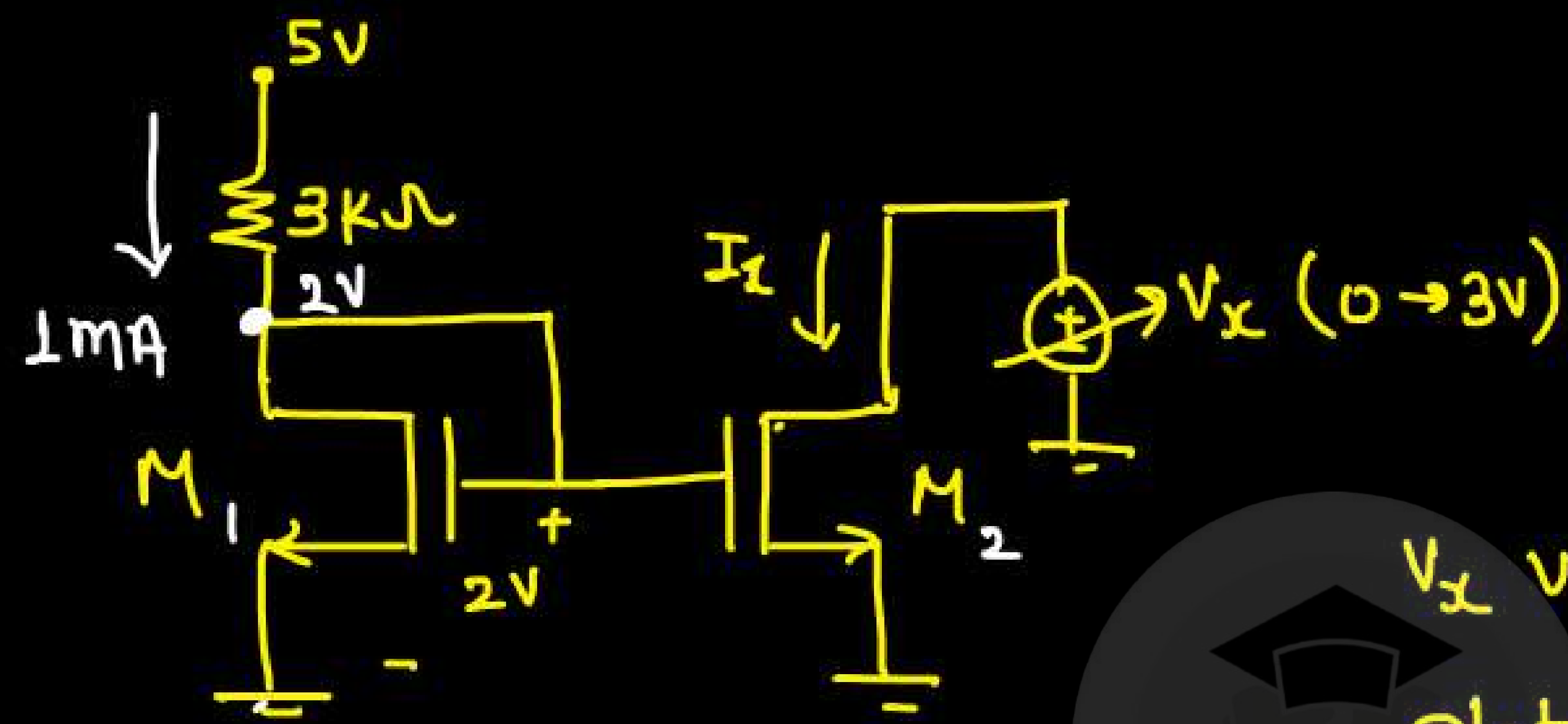
$\Rightarrow$



$$\boxed{\frac{v_o}{v_i} = \frac{g_{m_5} R}{1 + g_{m_5} R}}$$

$$R = r_{o5} \,||\, \left(g_{m_3} r_{o3} r_{o2} + r_{o2} + r_{o3}\right)$$

Q.



$V_T = 1V$

V_x value is swept from $0 \to 3V$.

Plot V_x v/s I_x.

$I_x = 1mA$ [when M_2 is in sat]

$V_x > 2-1 \Rightarrow \boxed{V_x > 1V} \Rightarrow M_2$ is in sat

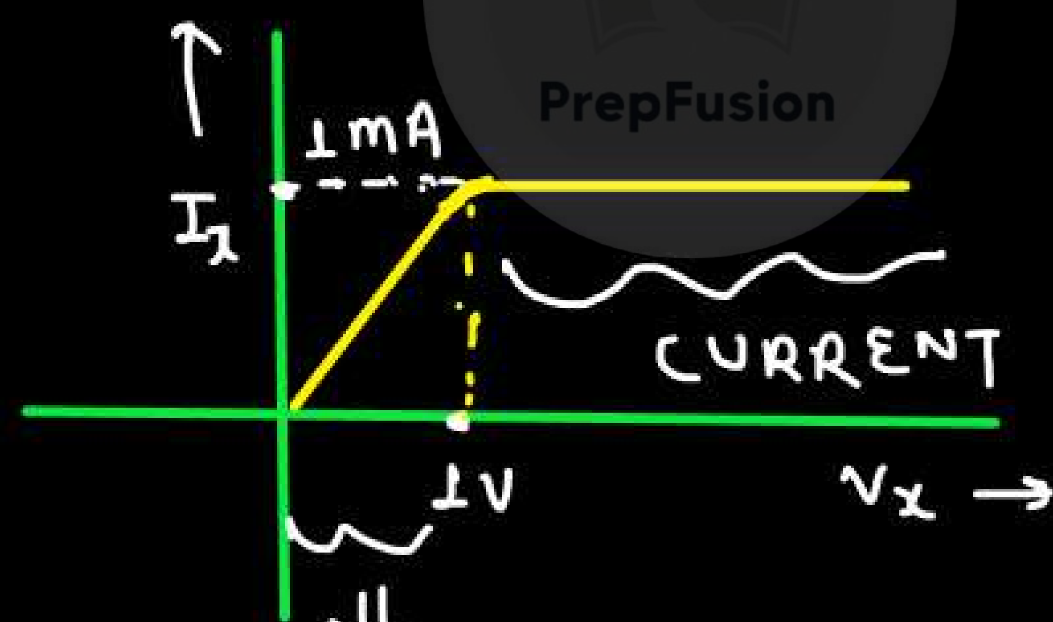
$\Downarrow$

$\boxed{I_x = 1mA} \Leftarrow M_1$ & M_2 are in current mirror

$$\boxed{\text{For } V_x > 1V \Rightarrow I_x = 1mA}$$

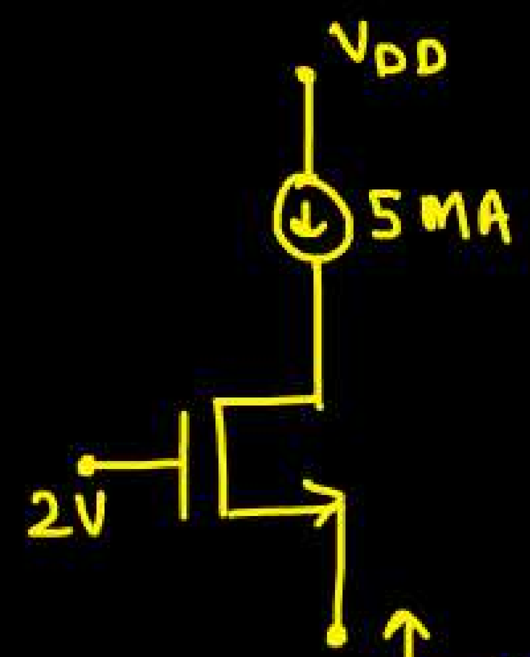
For $V_x < 1V \Rightarrow M_2$ is in linear region

current in linear region < current in sat. region (for fixed V_{GS})



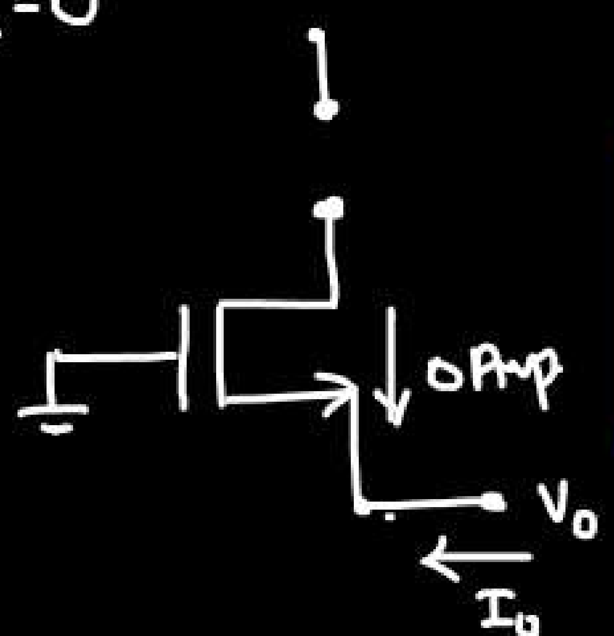
$$I_x = K\left[1 \times V_x - \frac{V_x^2}{2}\right]$$

Q.



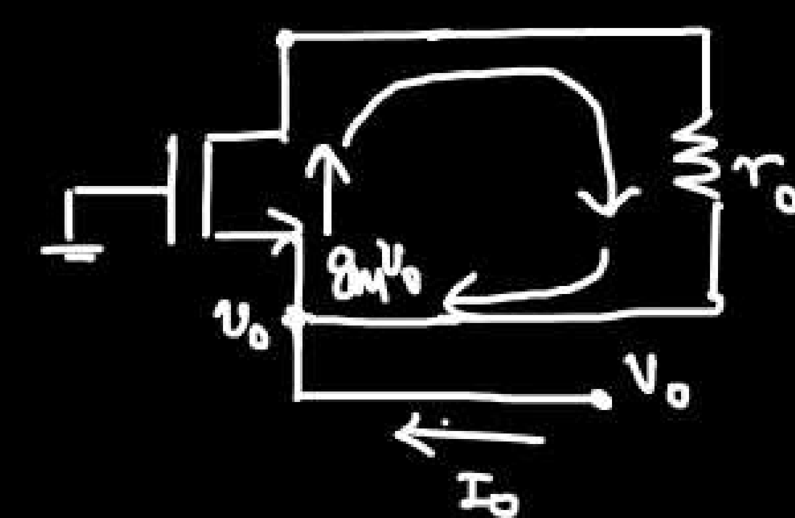
Find R_{out} for $\lambda = 0$, $\lambda \neq 0$

$\Rightarrow$ $\lambda = 0$



$$\boxed{R_{out} = \frac{V_o}{I_o} = \frac{V_o}{0} = \infty}$$

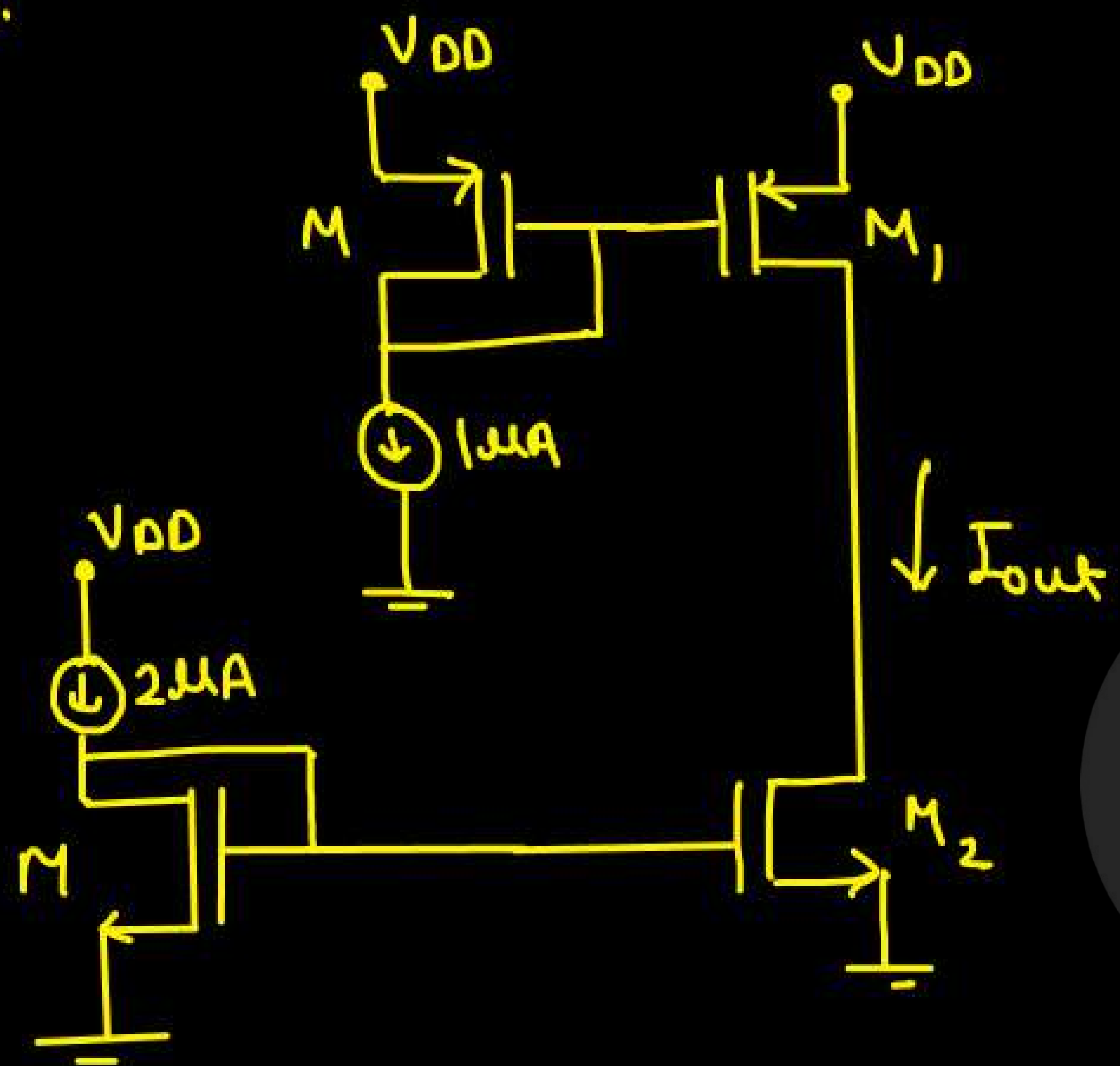
$\lambda \neq 0$



$I_o = 0$ Amp.

$$\boxed{R_o = \infty}$$

Q.



All Tr are identical.

Find I_{out} ?

$\Rightarrow$ if M and M_2 are in C.M. $\Rightarrow I_{out} = 2\mu A$

if M and M_1 are in C.M. $\Rightarrow I_{out} = 1\mu A$

$\boxed{I_{out} = 2\mu A = 1\mu A}$ $\Rightarrow$ NOT POSSIBLE

$\Rightarrow$ There will be only one current mirror working.

$\Rightarrow$ one of M_1 or M_2 will go into triode region and not in sat.

$\boxed{\text{Let } M_2 \text{ is in sat. and } M_1 \text{ is in Triode.}}$

$\underbrace{I_{out} = 2\mu A}$

$\Downarrow$

Same current is flowing through M_1

[if M_1 was in sat., what is the max current it can take? $\rightarrow$ $1\mu A$]

$\Rightarrow$ M_1 can take max $1\mu A$ current, but Here even in Triode region, it's taking $2\mu A$ current $\Rightarrow$ which is not possible

$\Rightarrow$ $\boxed{\text{Assumption is wrong}}$

$\boxed{\text{Let } M_1 \text{ is in sat., } M_2 \text{ is in Triode}}$

$I_{out} = 1\,\mu A$

$\Downarrow$

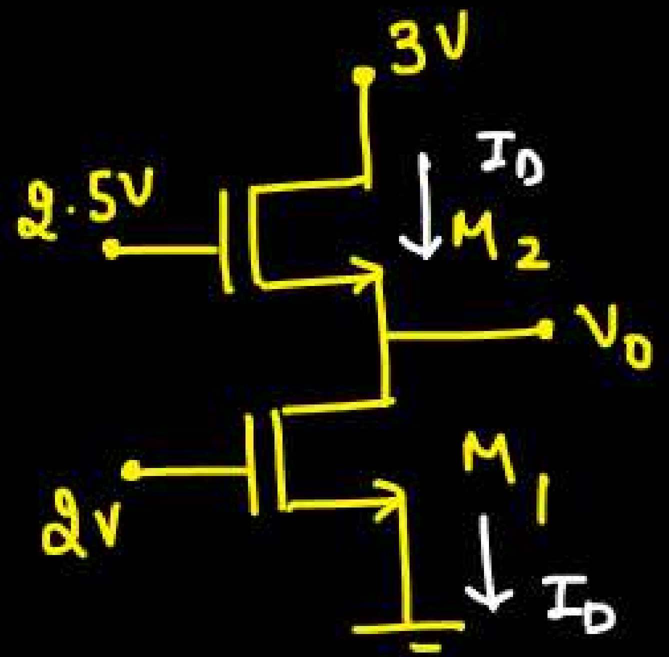
Same current is taken by M_2

[M_2 can drive max^m current of $2\,\mu A$ in sat. So, it can certainly take $1\,\mu A$ current in Triode region]

$\Rightarrow$ Assumption is correct

$$\boxed{I_{out} = 1\,\mu A}$$

Q.



Both Transistors are identical.

$$V_T = 1V$$

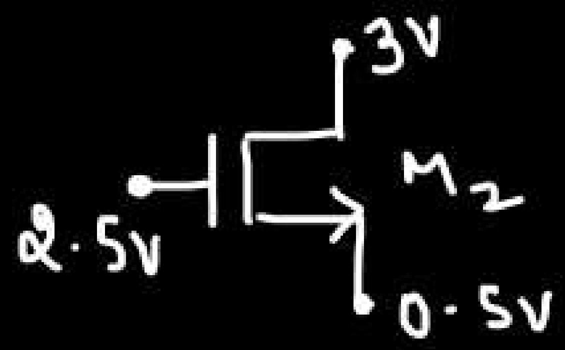
Find operating condⁿ of M_1 & M_2.

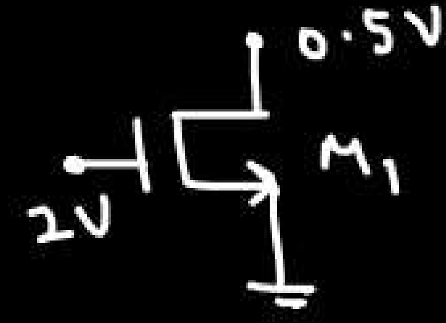
→ Let both M_1 and M_2 are in sat.

$$(I_D)_{M_2} = (I_D)_{M_1}$$

$$\frac{\mu_n \cancel{C_{ox}} W}{\cancel{2L}} (2.5 - V_0 - 1)^2 = \frac{\mu_n \cancel{C_{ox}} W}{\cancel{2L}} (2-1)^2$$

$$\boxed{V_0 = 0.5V} \quad \times$$





$\Downarrow$

$V_{DS} = 2.5V$

$V_{ov} = 2-1 = 1V$

$\boxed{V_{DS} > V_{ov}} \Rightarrow$ sat.

$\Downarrow$

$V_{DS} = 0.5V$

$V_{ov} = 1.5V$

$\boxed{V_{DS} < V_{ov}} \Rightarrow$ linear / Not in sat.

Let M_1 is in linear, M_2 is in sat.

$$(I_D)_{M_1} = (I_D)_{M_2}$$

$$\frac{\mu_n C_{ox} W}{L}\left[(1)(V_0) - \frac{V_0^2}{2}\right] = \frac{\mu_n C_{ox} W}{2L}\left[2.5 - V_0 - 1\right]^2$$

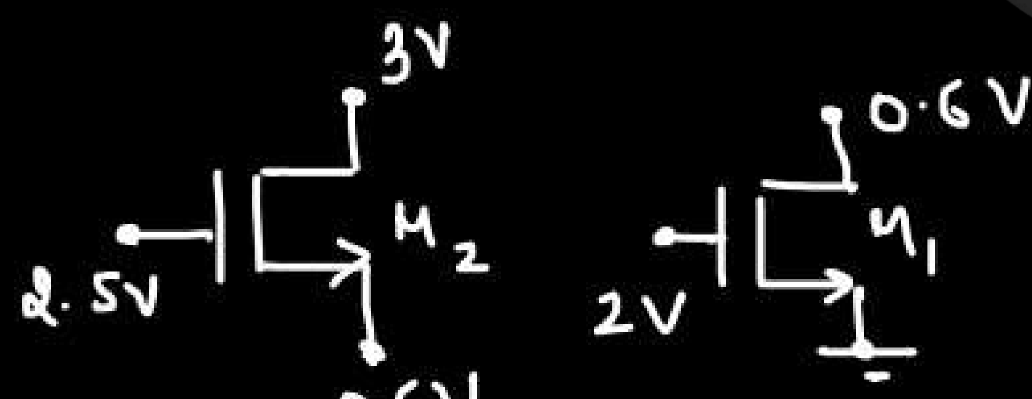
$$2V_0 - V_0^2 = [1.5 - V_0]^2$$

$$2V_0 - V_0^2 = 2.25 + V_0^2 - 3V_0$$

$$2V_0^2 - 5V_0 + 2.25 = 0$$

$$V_0 = \frac{5 \pm 2.64}{4}$$

$$V_0 = 1.9\,\text{V} \text{ OR } \boxed{0.6\,\text{V}} \checkmark$$



$\Downarrow$ sat

$\Downarrow$ linear

$\Rightarrow$

M_2 is sat

M_1 is in linear

$V_0 = 0.6\,\text{V}$

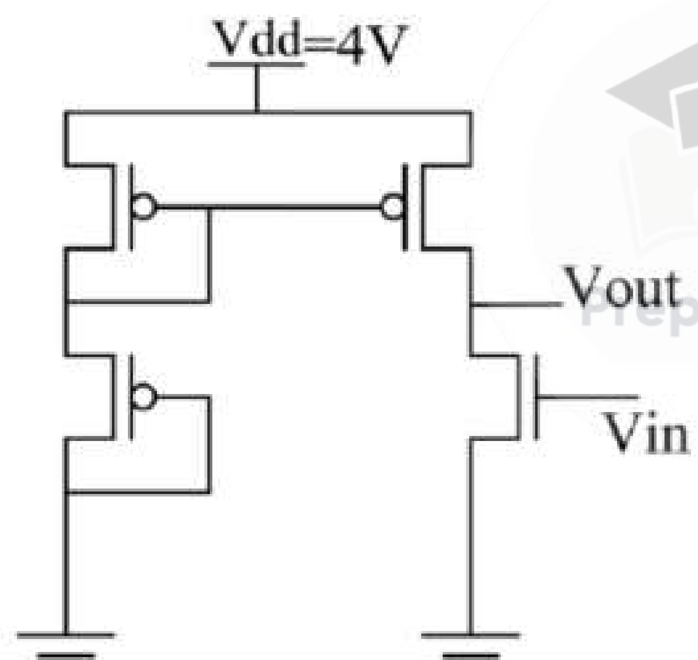
Q.

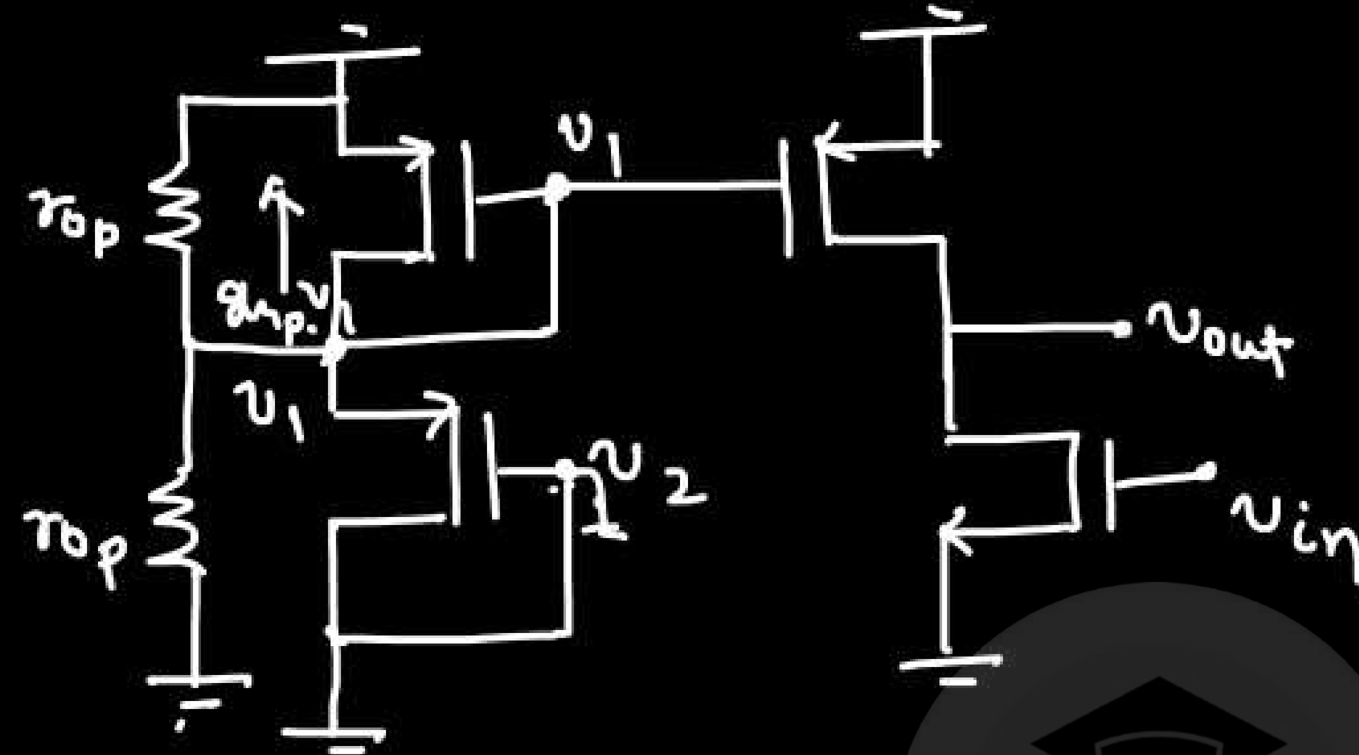
In the circuit shown, the threshold voltages of the pMOS ($|V_{tp}|$) and nMOS (V_{tn}) transistors are both equal to 1 V. All the transistors have the same output resistance r_{ds} of 6 MΩ. The other parameters are listed below:

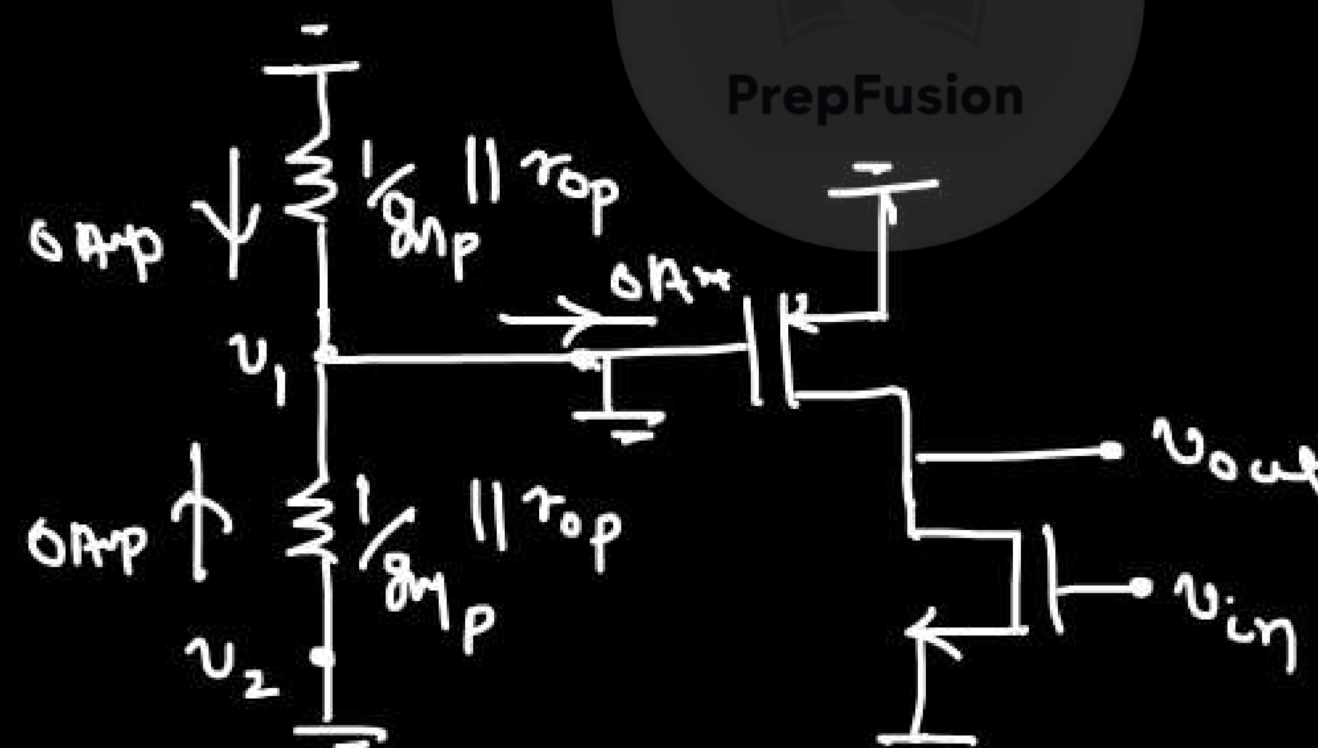
$$\mu_n C_{ox} = 60\ \mu A/V^2 \ ; \left(\frac{W}{L}\right)_{\text{nMOS}} = 5$$

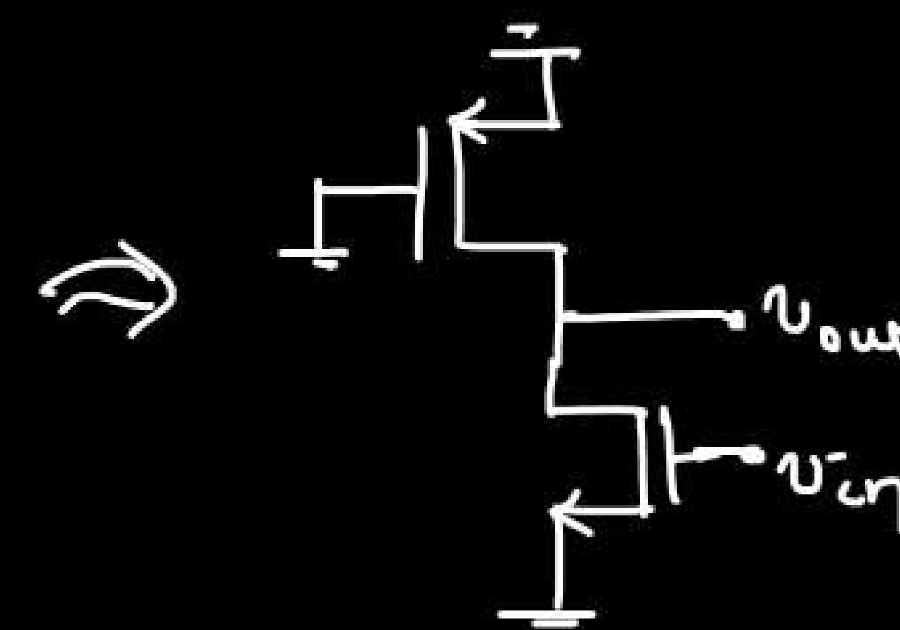
$$\mu_p C_{ox} = 30\ \mu A/V^2 ; \left(\frac{W}{L}\right)_{\text{pMOS}} = 10$$

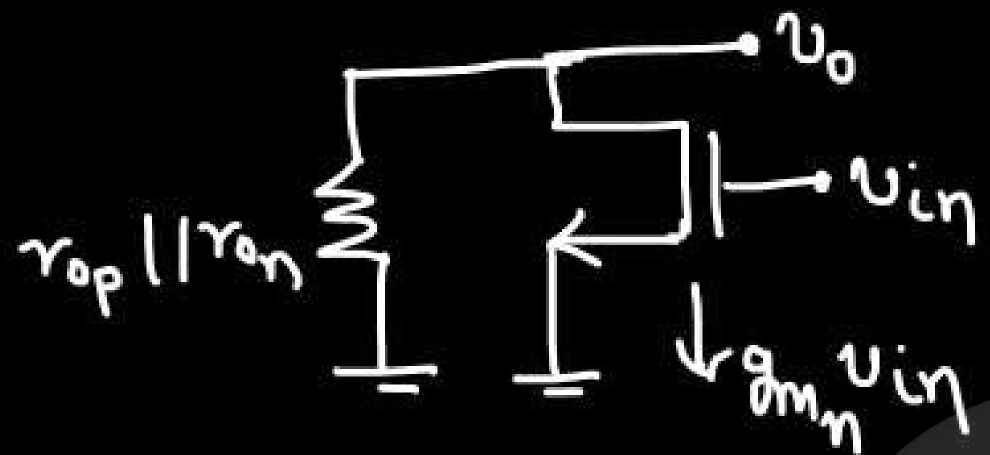
μ_n and μ_p are the carrier mobilities, and C_{ox} is the oxide capacitance per unit area. Ignoring the effect of channel length modulation and body bias, the gain of the circuit is ____ (rounded off to 1 decimal place).




r_{op}
$g_{mp} \cdot v_1$
v_1
r_{op}
v_1
v_2
v_{out}
v_{in}


0 Amp
$\frac{1}{g_{mp}} \| r_{op}$
0 Amp
v_1
0 Amp
$\frac{1}{g_{mp}} \| r_{op}$
v_2
v_{out}
v_{in}


v_{out}
v_{in}



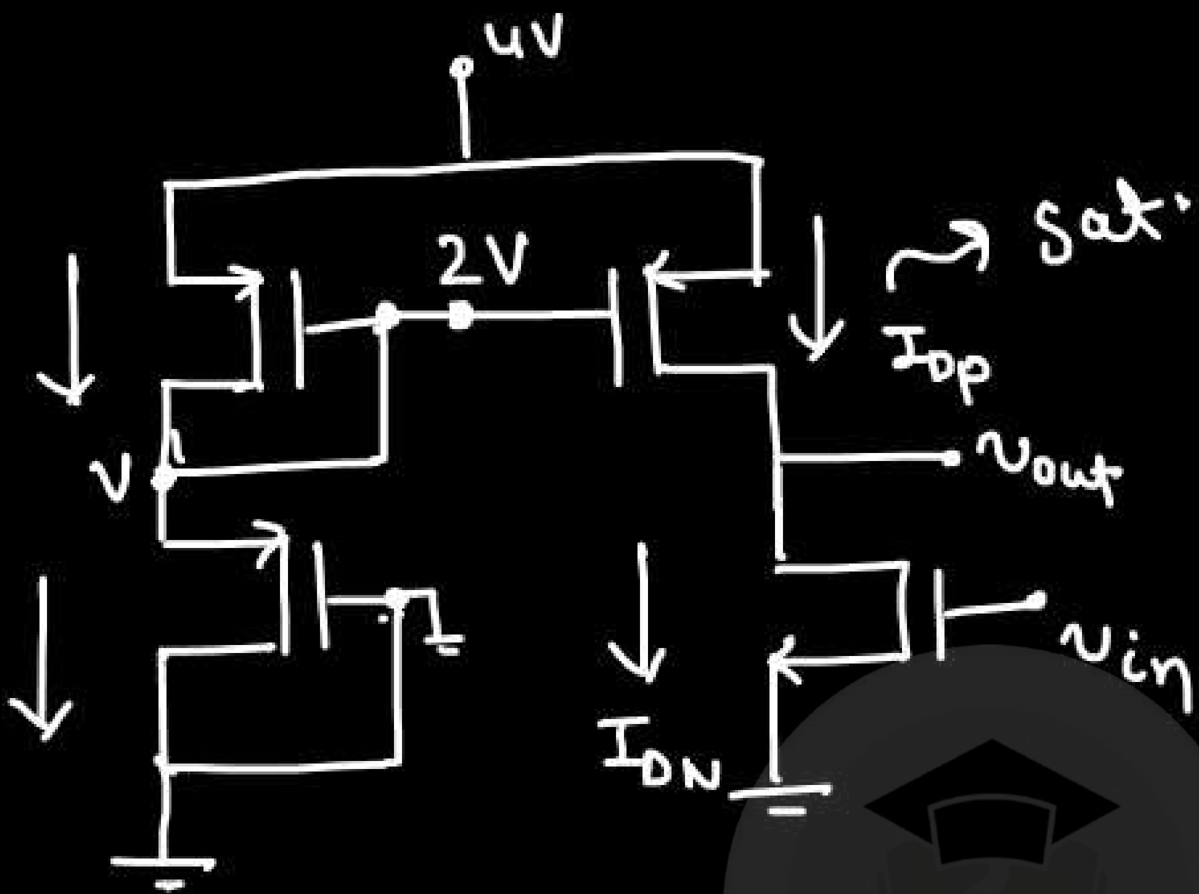
$$\boxed{\frac{v_o}{v_i} = -g_{m_n}\left[r_{op} \| r_{on}\right]}$$

$$r_{op} = r_{on} = 6\,M\Omega$$

$$\boxed{g_{m_n} = ?}$$

$$\boxed{g_{m_n} = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_{D_N}}}$$

$$I_{D_N} = ?$$



$$\frac{\mu_p C_{ox} W}{2L}\left[4 - V_a - 1\right]^2 = \frac{\mu_p C_{ox} W}{2L}\left[V_a - 1\right]^2 \qquad \{\lambda \to \text{very small}\}$$

$$3 - V_a = V_a - 1$$

$$\boxed{V_a = 2V}$$

$$I_{Dp} = \frac{\mu_p C_{ox} W}{2L} (V_{SG} - V_T)^2$$

$$I_{Dp} = \frac{300\mu}{2} (2-1)^2$$

$$I_{Dp} = 150\mu \text{ Amp.} = I_{DN}$$

$$g_{m_n} = \sqrt{2 \times 300\mu \times 150\mu} = 300\mu S$$

$$A_V = -g_{m_p} [r_{op} \| r_{on}] \qquad r_{op} = r_{oN} = 6M\Omega$$

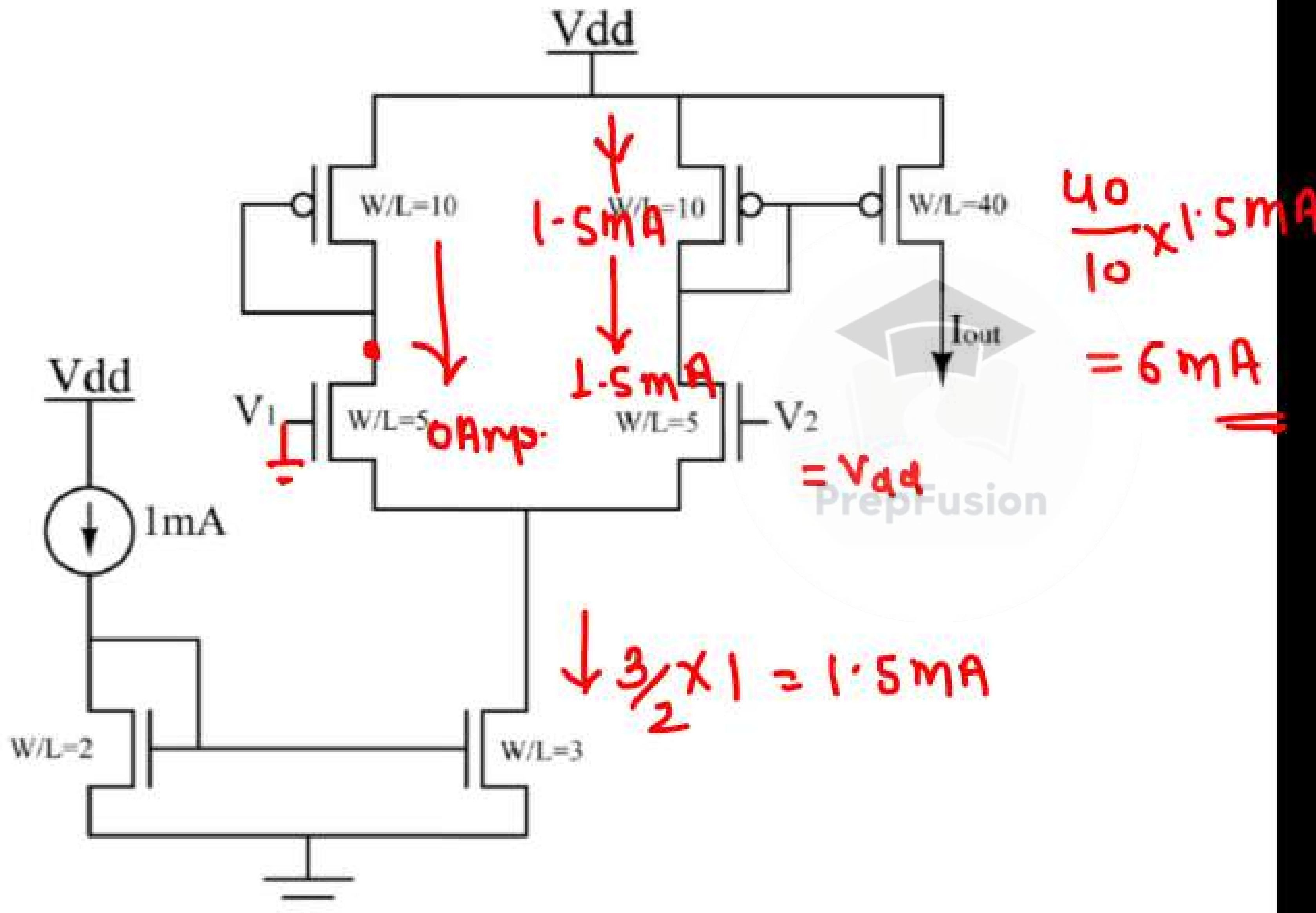
$$= -300\mu \times [6M \| 6M]$$

$$= -3 \times 10^{-4} \times 3 \times 10^6 = -900$$

$$\boxed{A_V = -900 \, V/V}$$

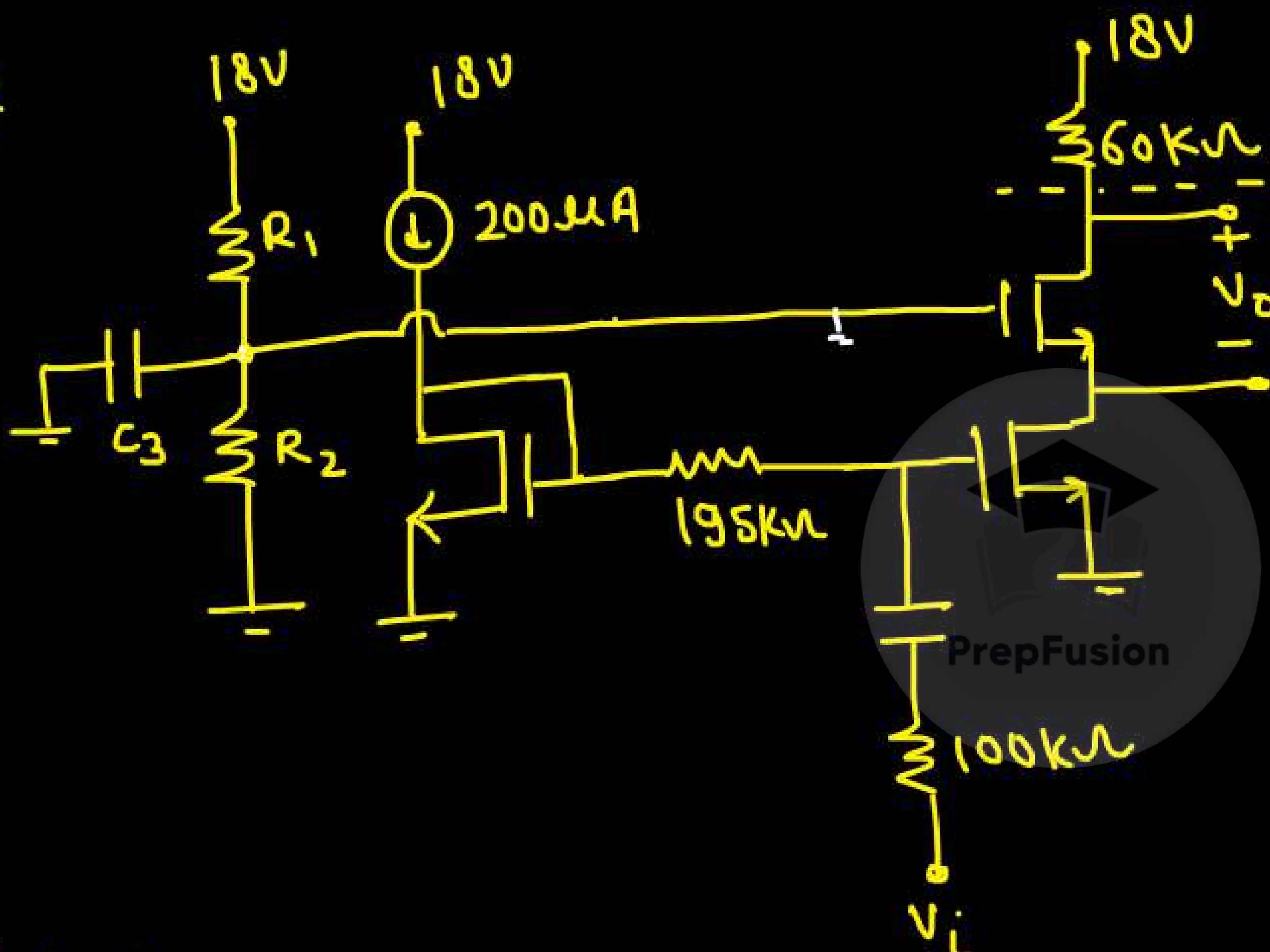
Ans.

In the circuit shown, $V_1 = 0$ and $V_2 = V_{dd}$. The other relevant parameters are mentioned in the figure. Ignoring the effect of channel length modulation and the body effect, the value of I_{out} is ______mA (rounded off to 1 decimal place).



Assignment-9 [Fusion_Special]

Q.



(a) Find small signal voltage gain $\frac{v_o}{v_i}$. ($\lambda=0$)

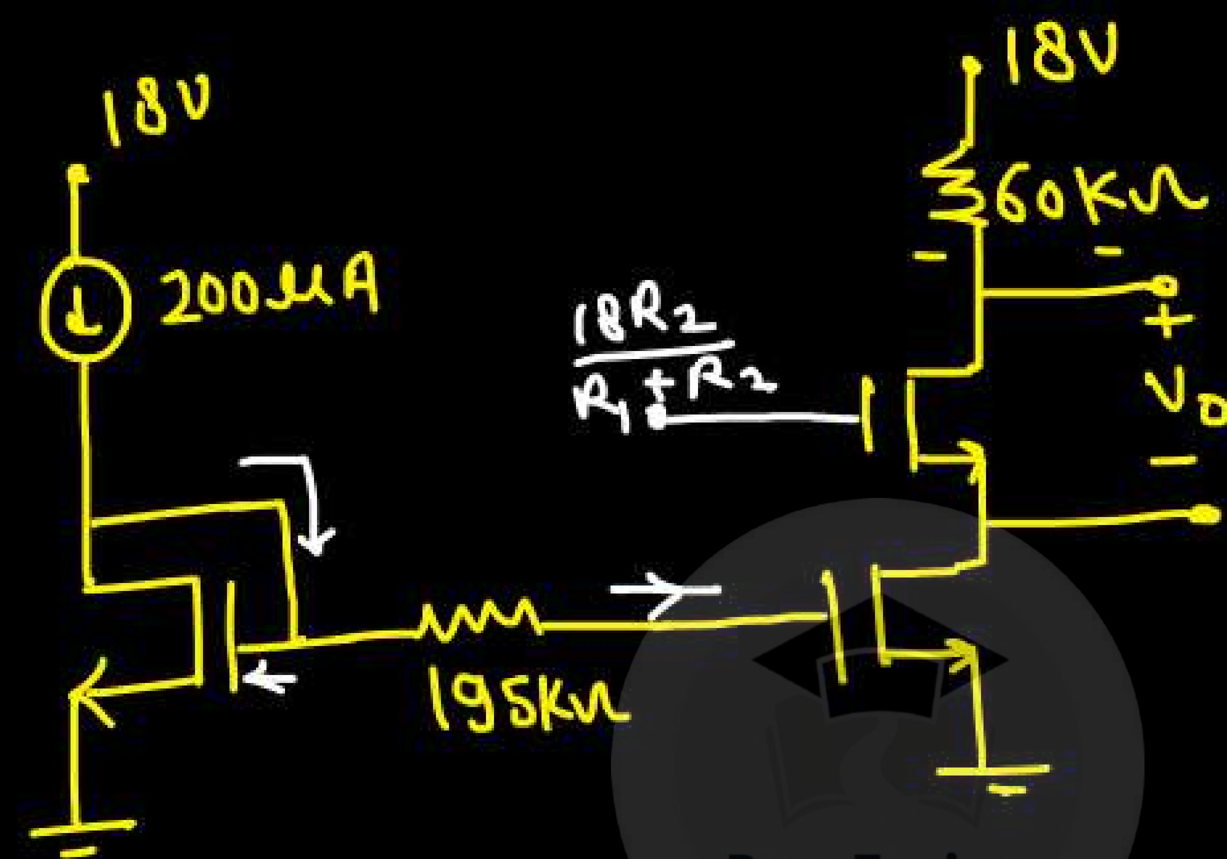
(b) Find small signal R_o. ($\lambda = 0.05\,V^{-1}$)

Given that all Tr are working in sat. region.

$\mu_n C_{ox}\frac{W}{L} = 100\,\mu A/V^2$

$V_T = 1V$

→ DC Analysis:-



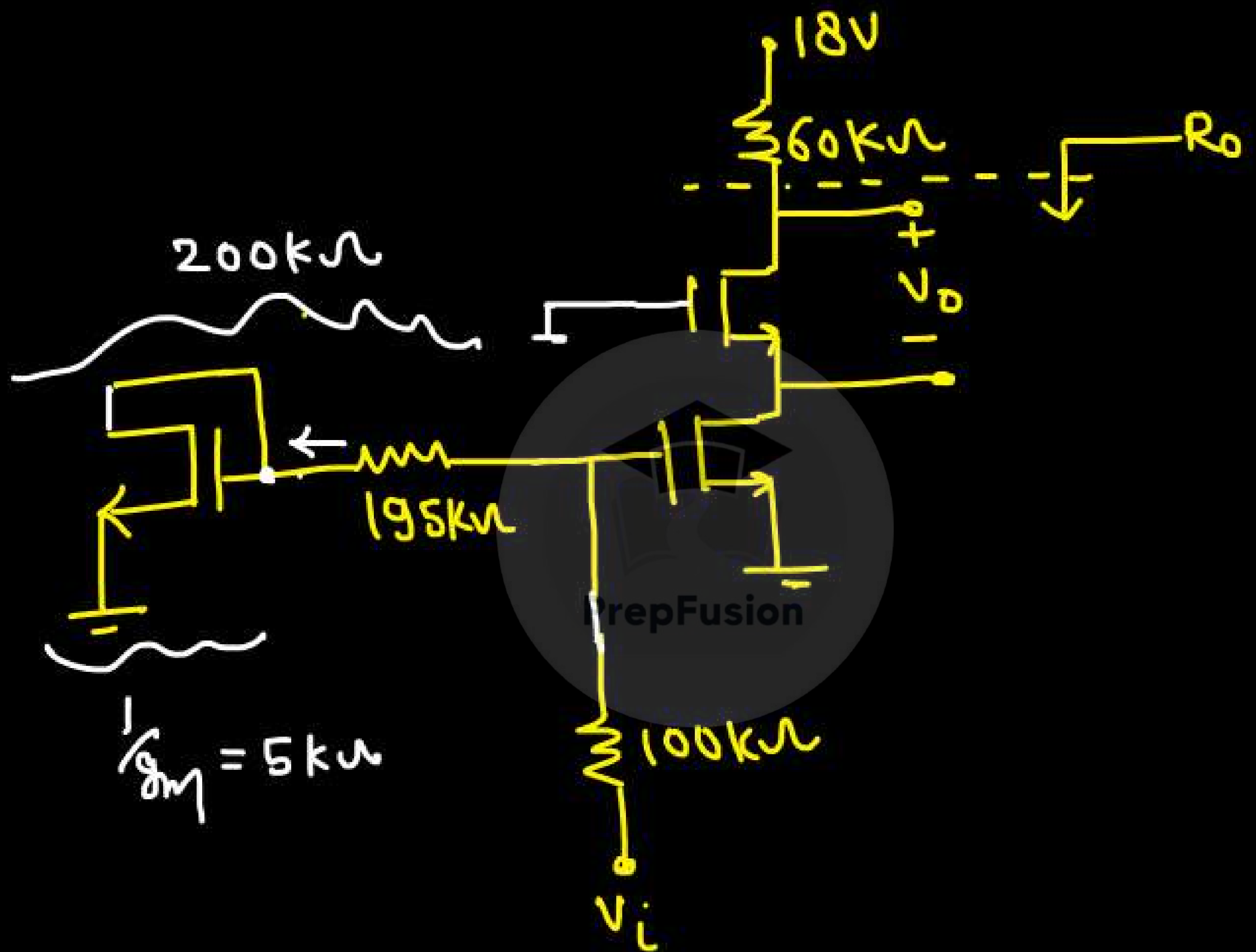
$I_D = 200\,\mu A$

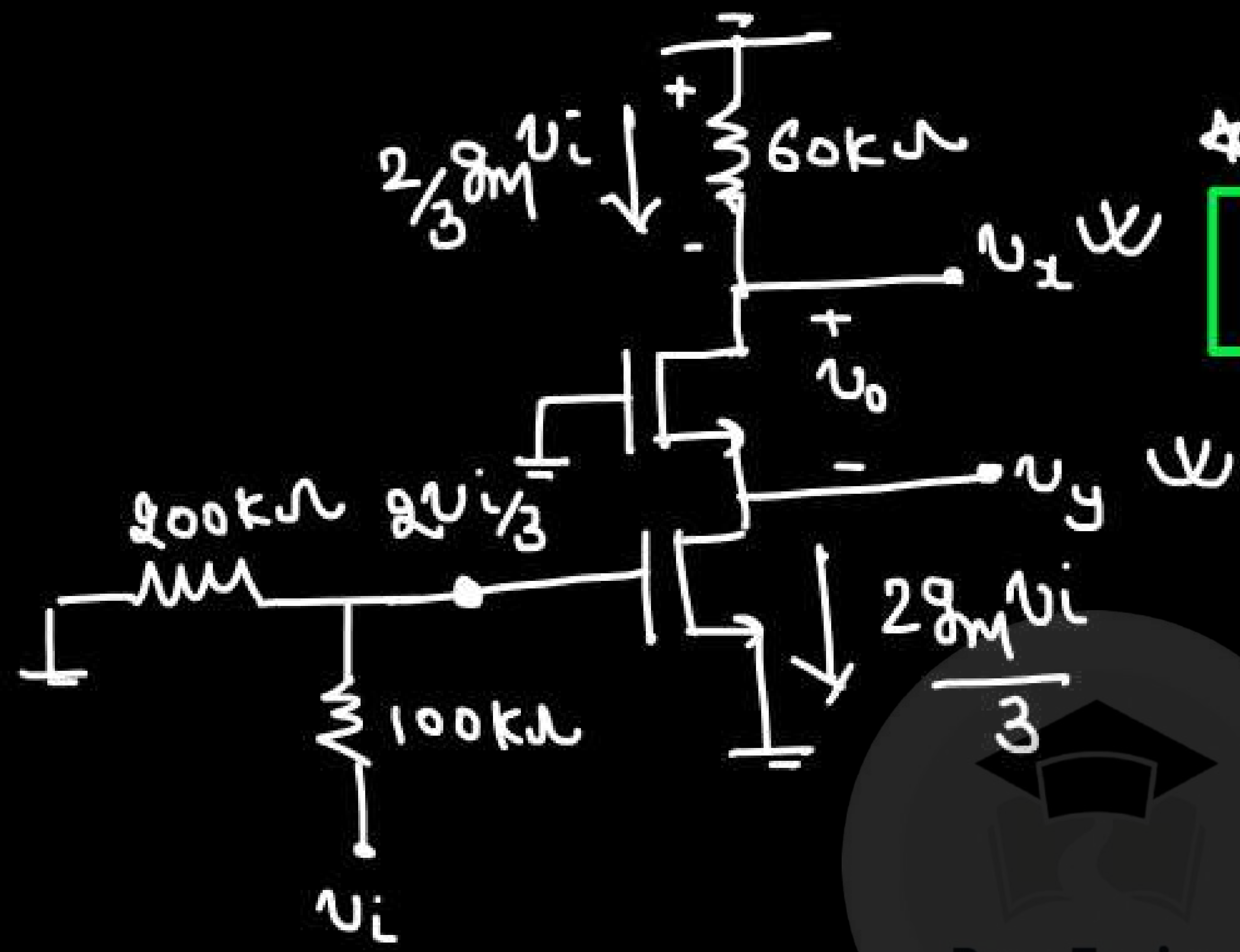
$$g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D} = 200\,\mu S$$

⇒

$$\boxed{\begin{aligned} g_m &= 200\,\mu S \\ 1/g_m &= 5\,k\Omega \end{aligned}}$$

Ac Analysis:-





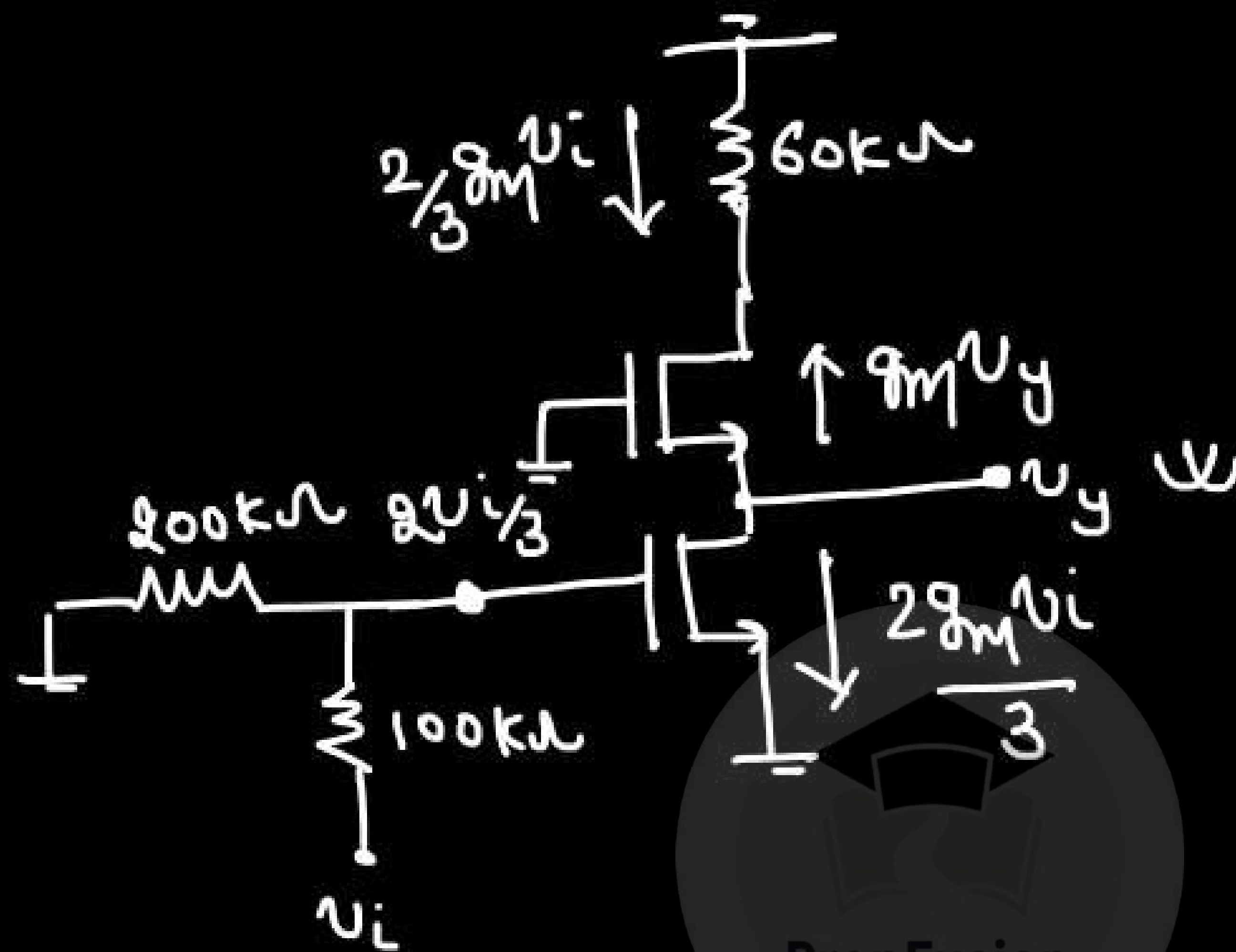
$$\boxed{v_o = v_x - v_y}$$

$$\boxed{v_o = -\frac{2}{3} g_m v_i \times 60k\Omega}$$

$$v_x = -\frac{2}{3} g_m v_i \times 60k\Omega$$

$$= -\frac{2}{3} \times 200\mu \times 60k \times v_i$$

$$\boxed{v_x = -8v_i}$$



$$g_m v_y = -\frac{2}{3} g_m v_i$$

$$\boxed{v_y = -\frac{2}{3} v_i}$$

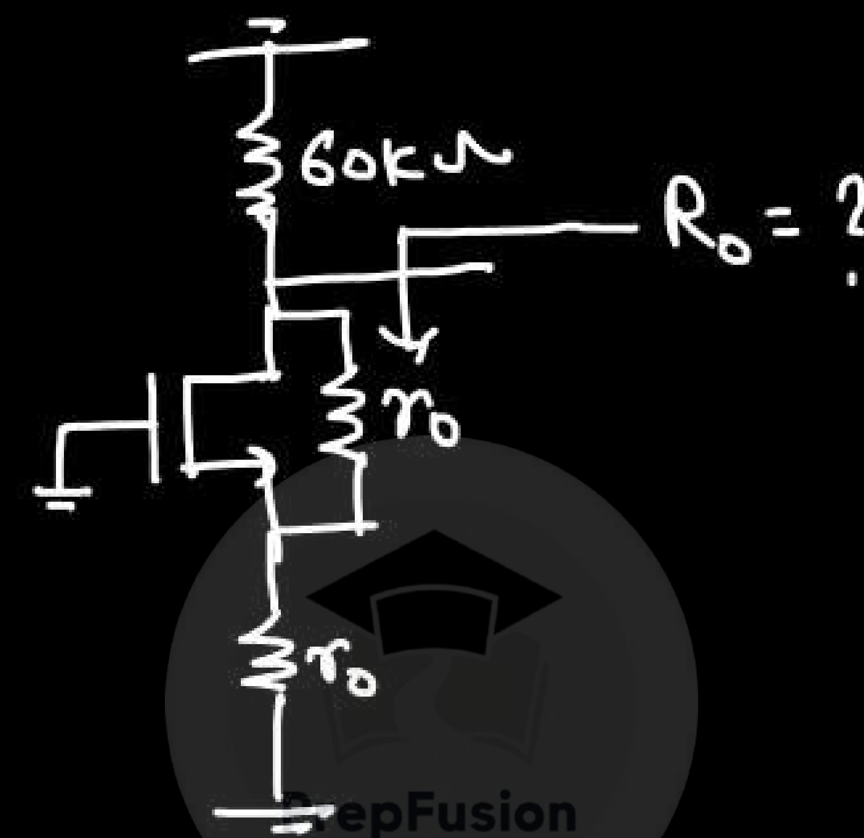
$$v_o = v_x - v_y$$

$$= -8v_i + \frac{2}{3} v_i$$

$$v_o = -7.33 v_i$$

$$\boxed{\frac{v_o}{v_i} = -7.33}$$

R_o :-



$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.05 \times 200\mu}$$

$$\boxed{r_o = 100k\Omega}$$

$$R_o = g_m r_o r_o + r_o + r_o$$

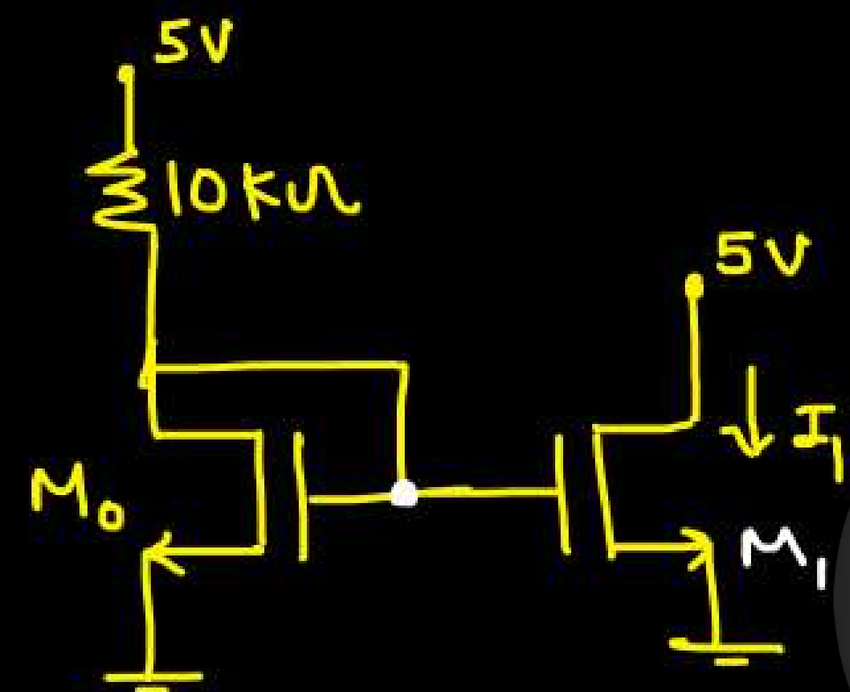
$$= g_m r_o^2 + 2r_o$$

$$= 200\mu \times 10^{10} + 2 \times 10^5$$

$$\boxed{R_o = 2.2\,M\Omega}$$

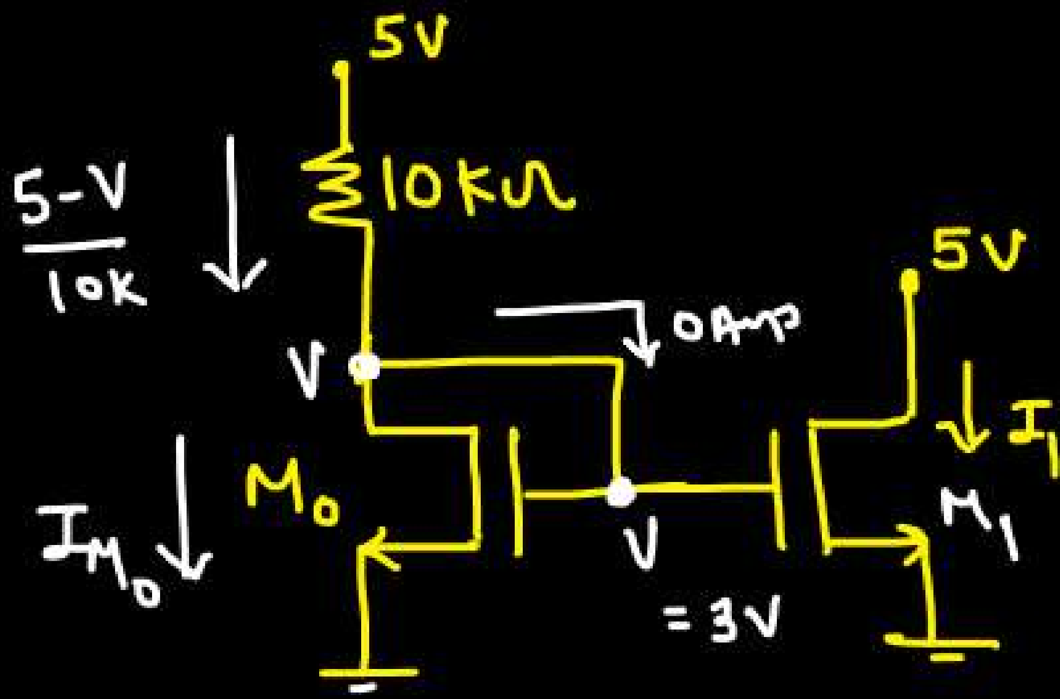
Q. M_0 and M_1 are perfectly Matched.

(a) Determine current I_1



$\mu_n C_{ox} = 100\,\mu A/V^2$, $W/L = 1$, $V_T = 1V$

(b) V_{DD} increases to 5.5V. Determine the increase in I_1.



(a)

$$I_{M_0} = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2$$

$$\frac{5-V}{10k} = \frac{100\mu}{2}(V-1)^2$$

$$5 - V = (V-1)^2/2$$

$$10 - 2V = V^2 + 1 - 2V$$

$$\boxed{V = 3\text{volt}}$$

$$I_{M_0} = \frac{5-3}{10k} = \frac{2}{10k} = 200\,\mu A = I_1$$

$M_1 \rightarrow$

$V_{DS} = 5V$

$V_{GS} = 3V$

$V_{ov} = 2V$

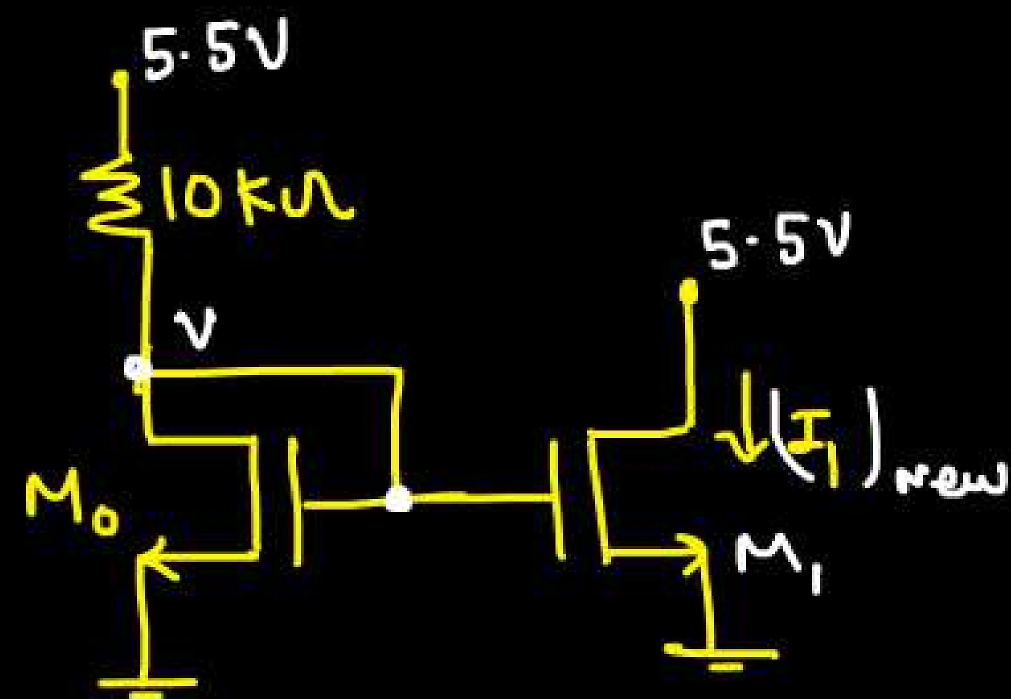
$\Downarrow$

Sat.

$$\boxed{I_1 = 200\,\mu A}$$

Ans

M-I



$$\Rightarrow \frac{5.5 - V}{10K} = \frac{100\mu}{2}(V-1)^2$$

$$11 - 2V = V^2 + 1 - 2V$$

$$V^2 = 10$$

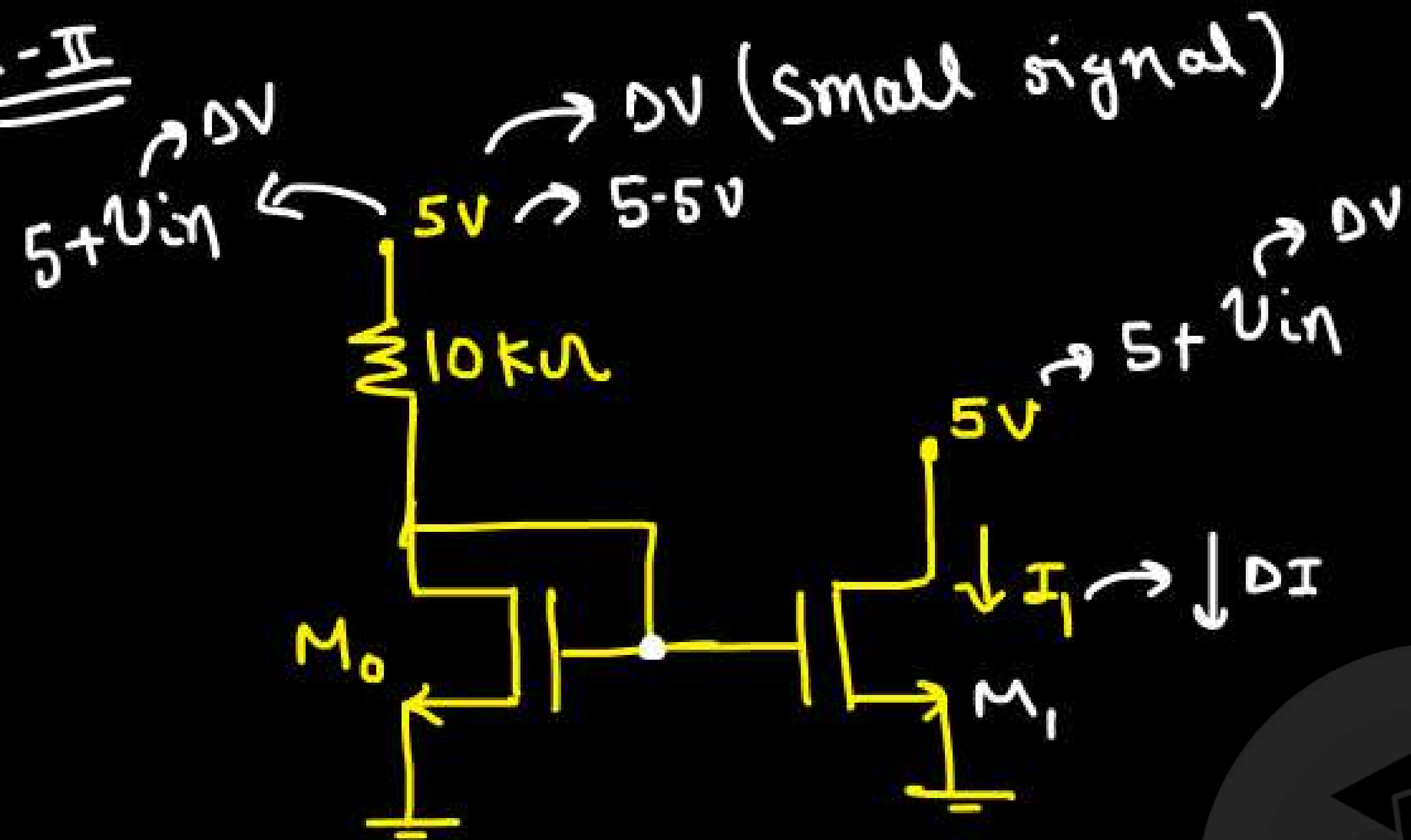
$$V = 3.16 \text{ Volt}$$

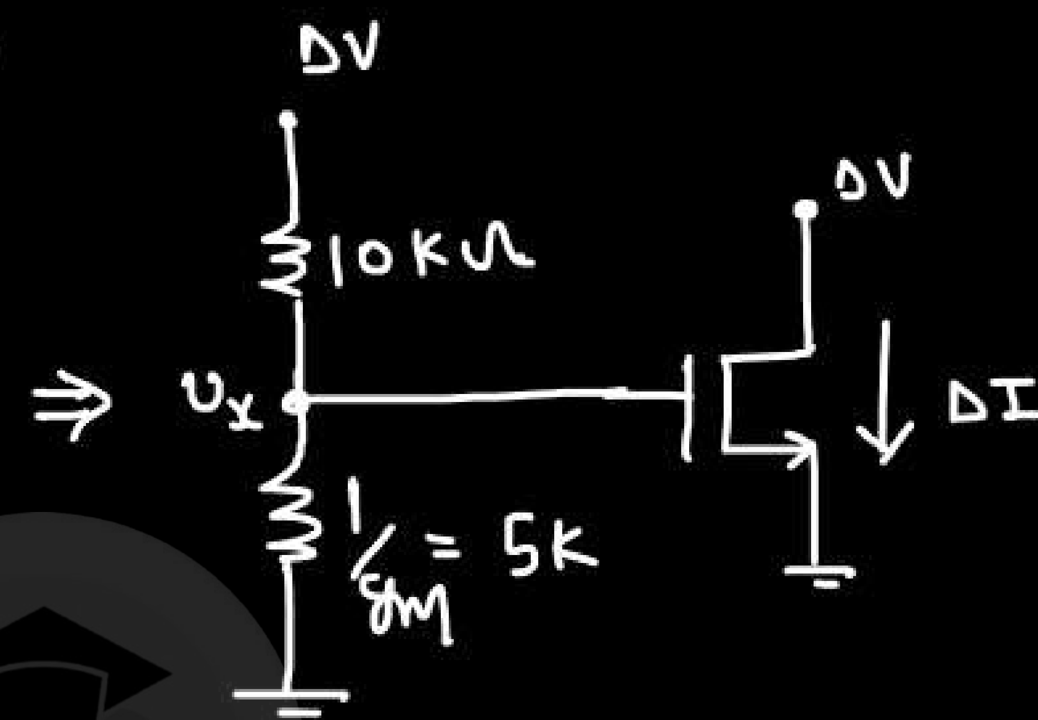
$$(I_{M_0})_{new} = (I_1)_{new} = \frac{5.5 - 3.16}{10K}$$

$$\boxed{(I_1)_{new} = 233\,\mu A}$$

$$\boxed{\Delta I = 233\mu - 200\mu = 33\,\mu Amp}$$

M-II





$$g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D}$$

$$= \sqrt{2 \times 100\mu \times 200\mu}$$

$$g_m = 200\,\mu S$$

$$1/g_m = 5k\Omega$$

$$v_x = \frac{5k}{5k+10k} \times \Delta V = \frac{\Delta v}{3}$$

$$\Delta I = g_m v_x = \frac{g_m \Delta V}{3} = \frac{200\mu}{3}\Delta V$$

A ✗

$$\boxed{\Delta I = \frac{200\mu}{3}\Delta V}$$

Here; $\Delta V = 5.5 - 5 = 0.5V$

$$\Delta I = \frac{200\mu}{3} \times 0.5$$

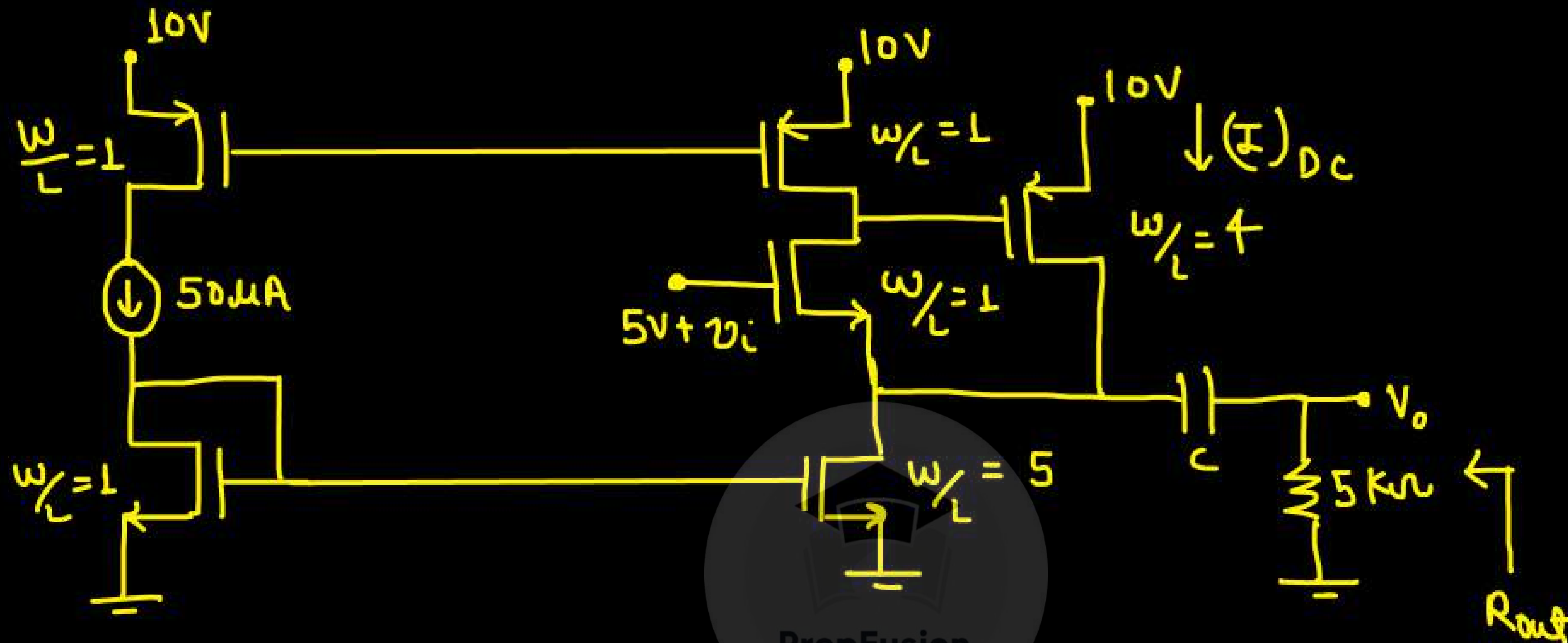
$$\boxed{\Delta I = 33.33 \mu Amp.}$$

For supply,

(i) $5.1V \Rightarrow \Delta I = \frac{200\mu}{3} \times 0.1 = 6.66 \mu Amp.$

(ii) $5.3V \Rightarrow \Delta I = \frac{200\mu}{3} \times 0.3 = 20 \mu Amp.$

Q.



$\mu_n C_{ox} = 100\,\mu A/V^2$, $\mu_p C_{ox} = 25\,\mu A/V^2$

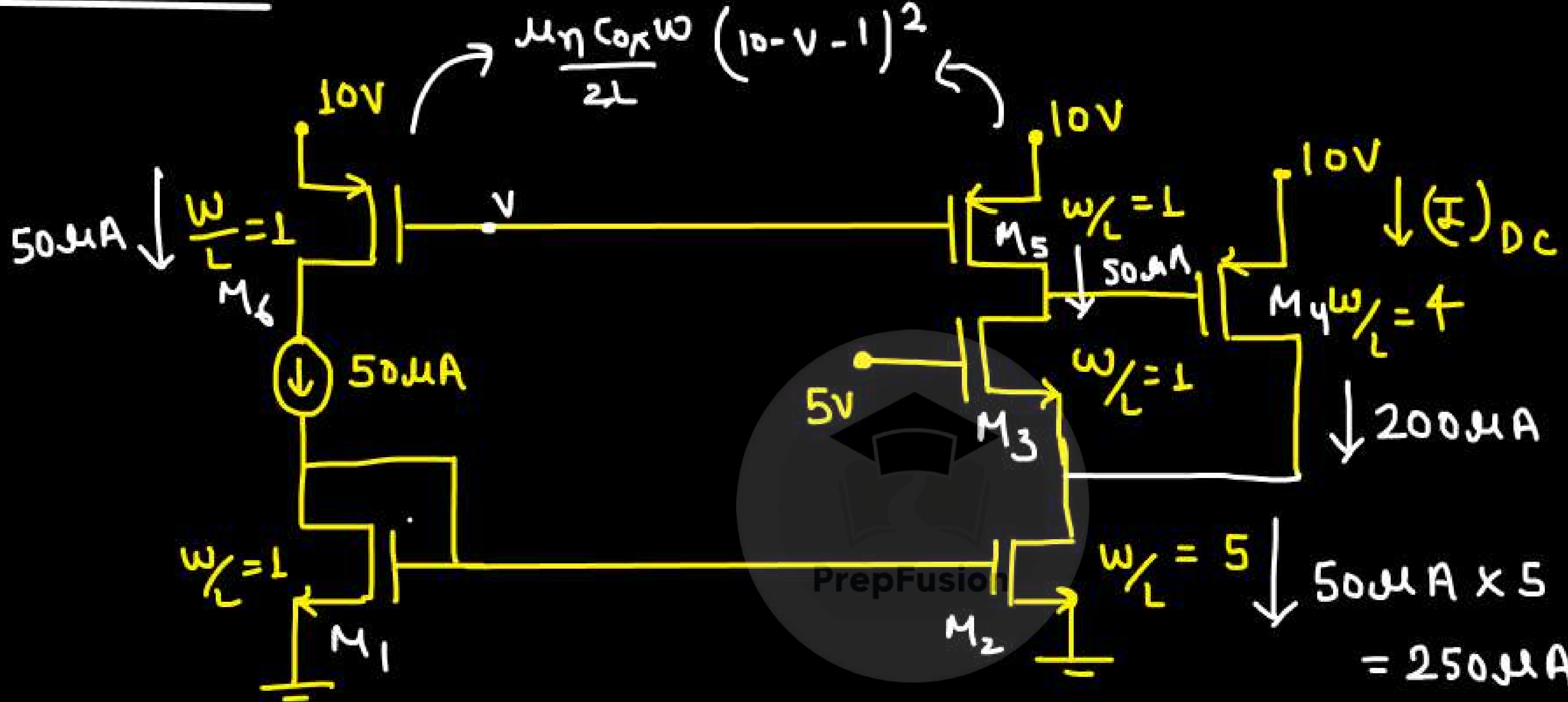
$V_{TH} = 1V$ Given → All Trs are biased in sat.

(a) Determine I_{DC}

(b) Find small signal voltage gain

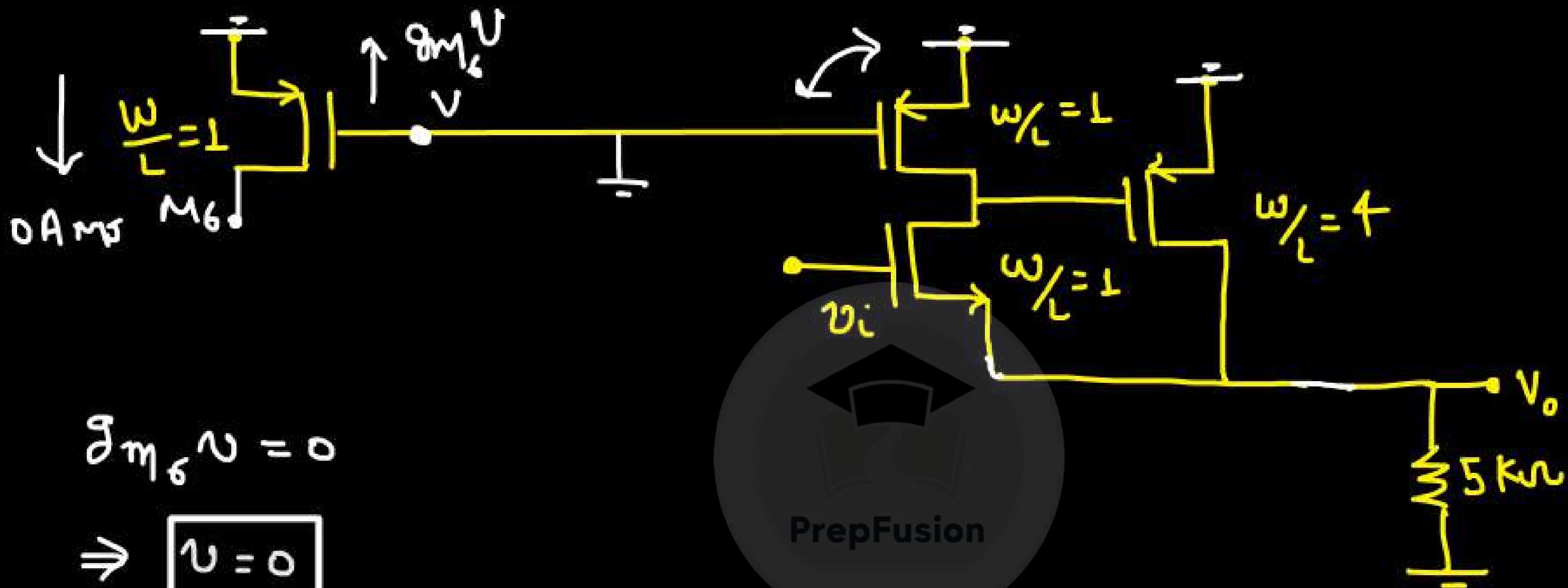
(c) Find small signal R_{out}.

DC Analysis:-



$$\boxed{(I_{DC}) = 200\mu A}$$

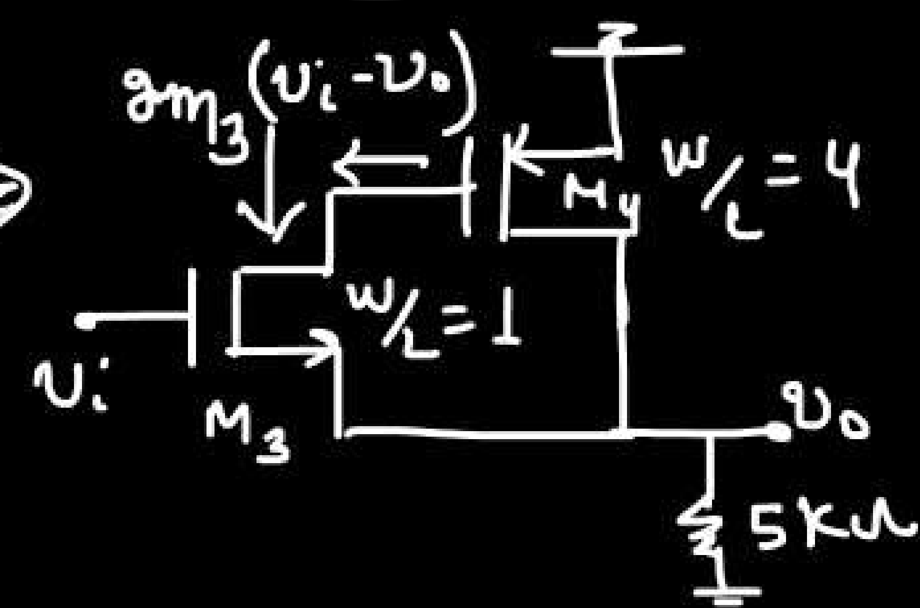
AC Analysis:



$$g_{m_6} v = 0$$

$$\Rightarrow \boxed{v = 0}$$

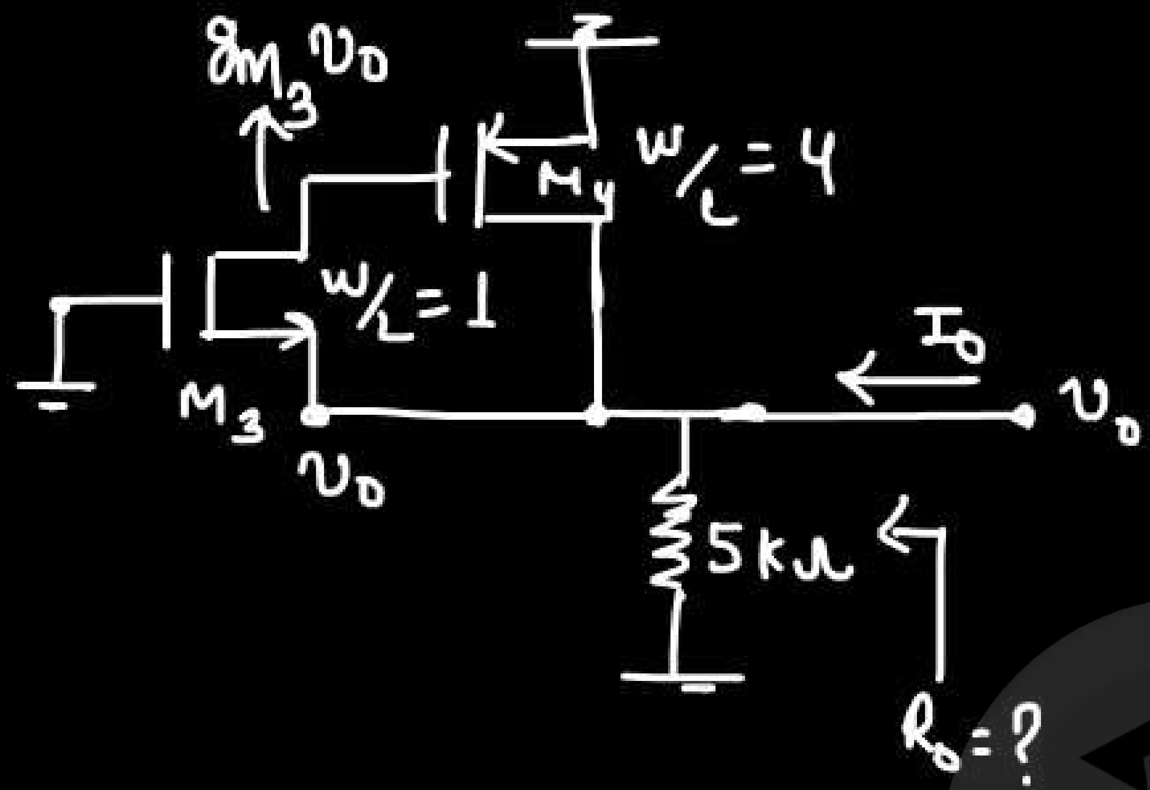
$\Rightarrow$



$$g_{m_3}(v_i - v_o) = 0$$

$$v_o = v_i$$

$$\boxed{\frac{v_o}{v_i} = 1}$$ ANS.



$$\boxed{\frac{v_0}{I_0} = R_0}$$

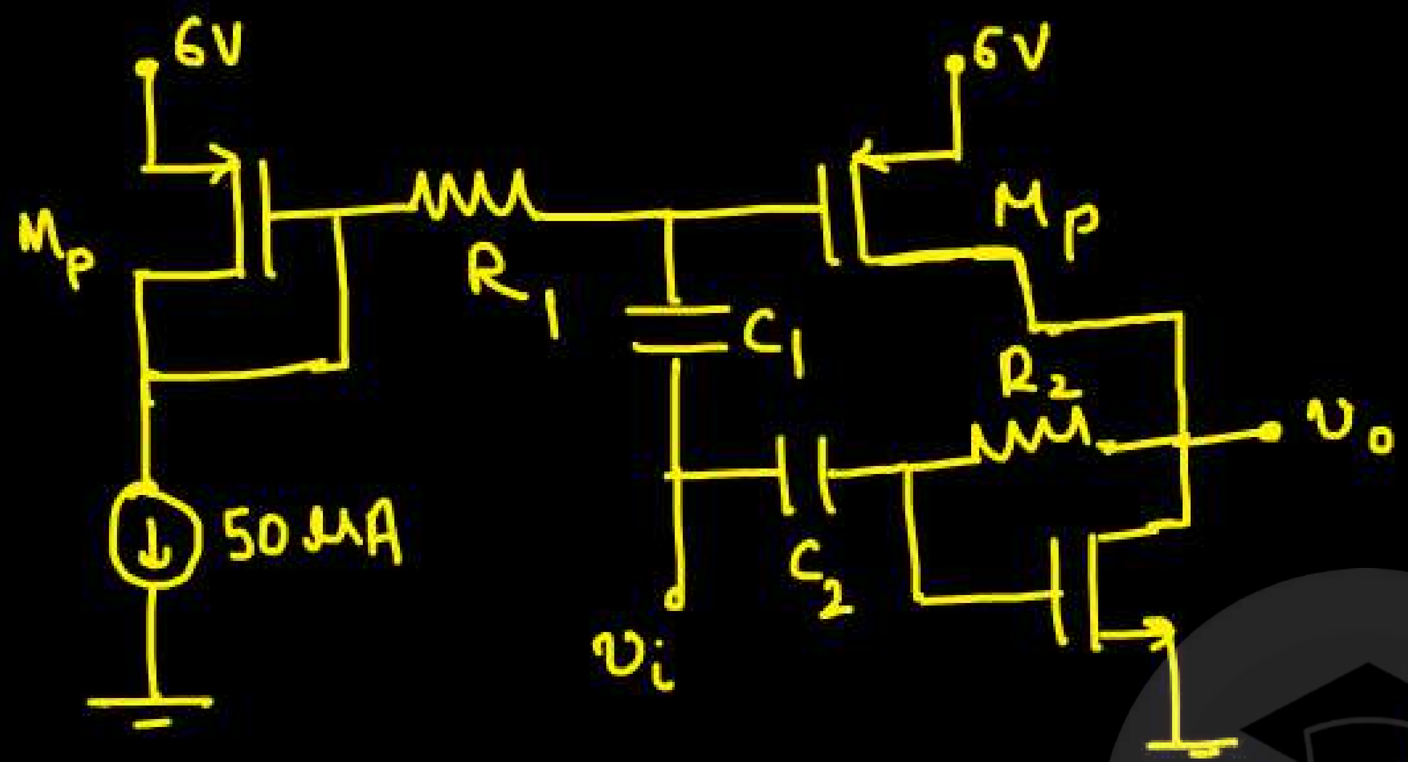
$$g_{m_3} v_0 = 0$$

$$v_0 = 0$$

$$\boxed{R_0 = \frac{0}{I_0} = 0\,\Omega}$$

$5k\Omega$

Q.



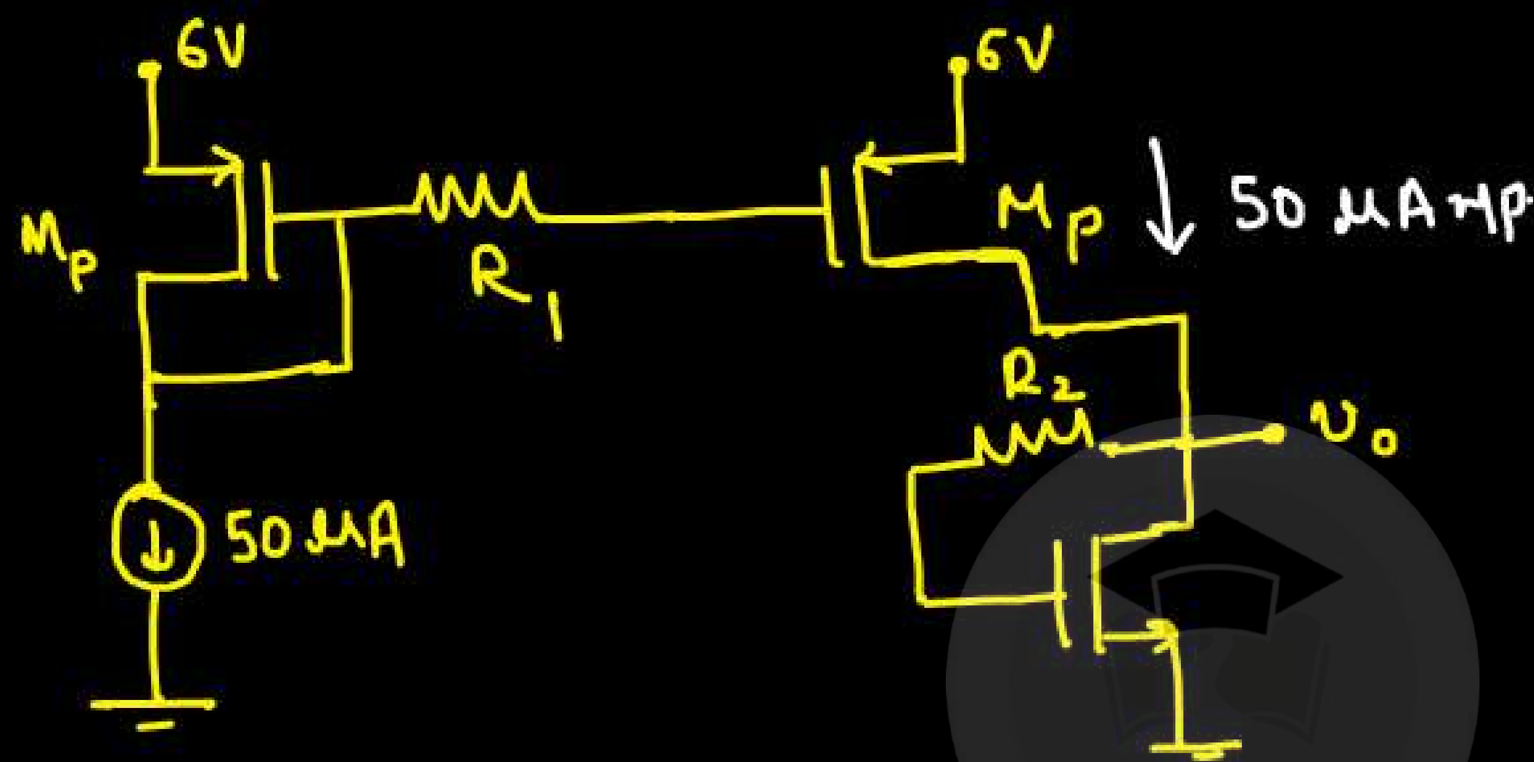
Given → R_1, R_2 values are very large.

M_p: $\mu_p C_{ox} = 100\ \mu A/V^2$, $\frac{W_p}{L_p} = 4$, $V_{Tp} = 0.5V$, $\lambda_p = 0.05\ V^{-1}$

M_n: $\mu_n C_{ox} = 400\ \mu A/V^2$, $\frac{W_n}{L_n} = 1$, $V_{Tn} = 0.5V$, $\lambda_n = 0.05\ V^{-1}$

Determine small signal voltage gain $\frac{v_o}{v_i}$?

DC Analysis:-



$$g_{m_p} = \sqrt{2 \times \mu_p C_{ox} \frac{W}{L} I_D} = \sqrt{2 \times 400\mu \times 50\mu} = 200\,\mu S$$

$$g_{m_n} = \sqrt{2 \times \mu_n C_{ox} \frac{W}{L} I_D} = \sqrt{2 \times 400\mu \times 50\mu} = 200\,\mu S$$

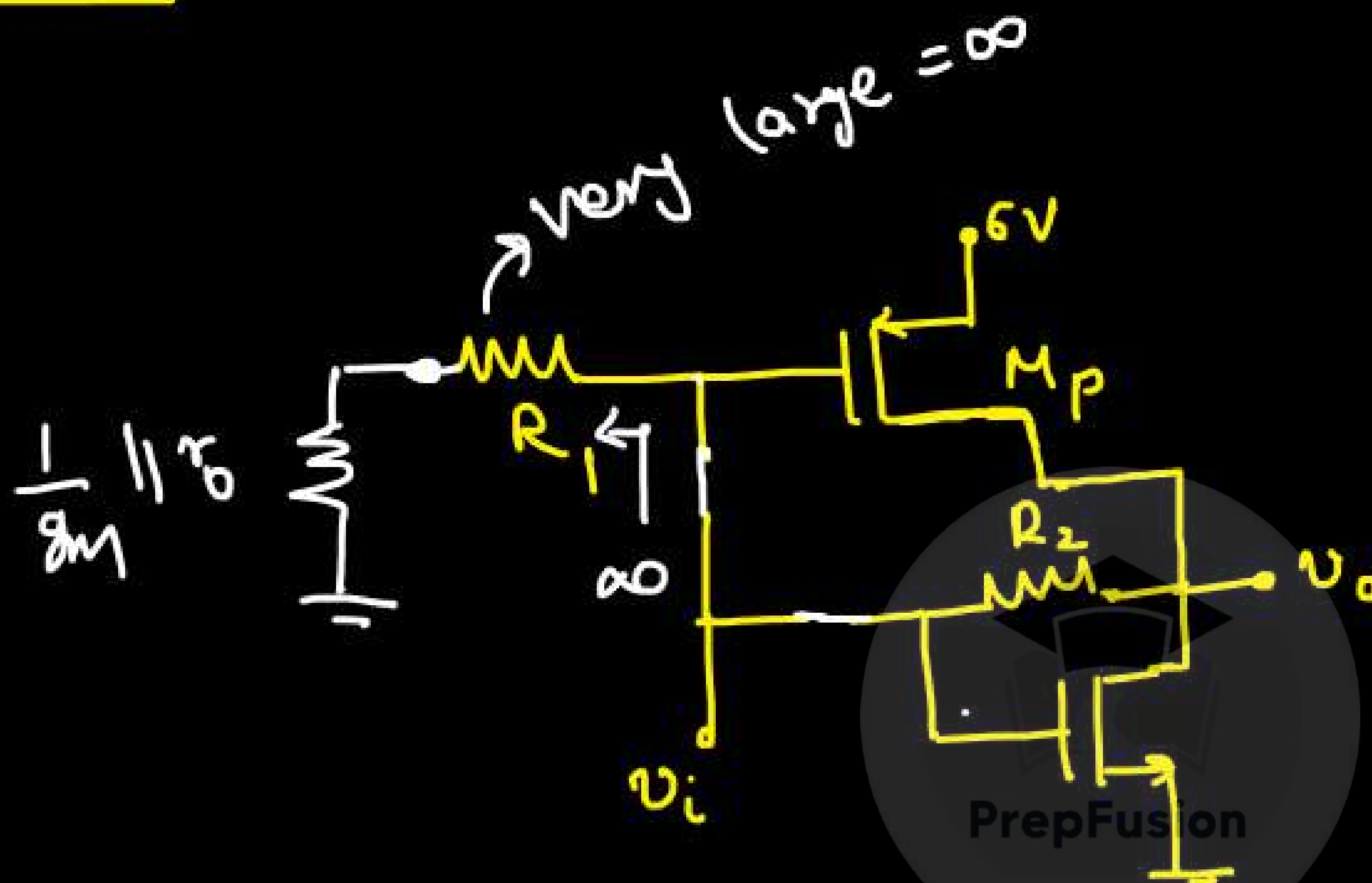
$$\boxed{g_{m_p} = g_{m_n} = g_m = 200\,\mu S}$$

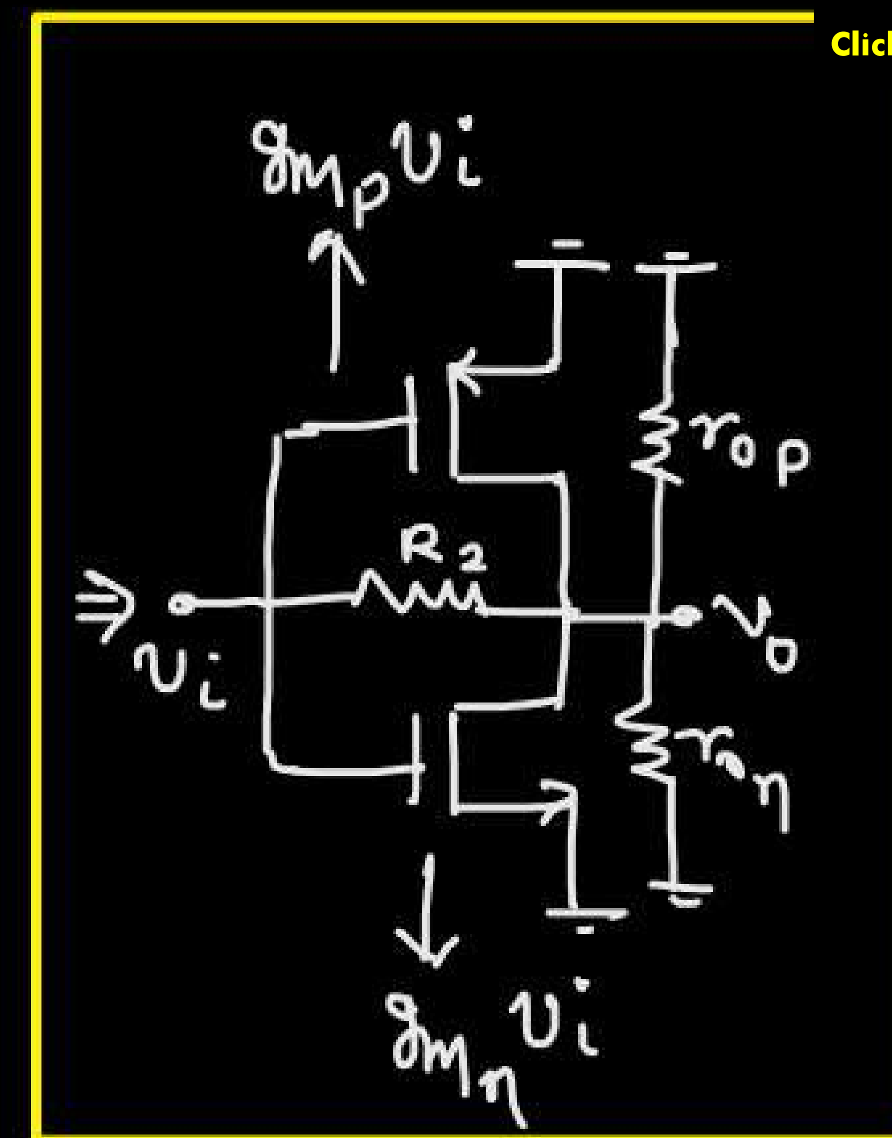
$$r_{op} = \frac{1}{\lambda_p I_D} = \frac{1}{0.05 \times 50\mu} = 400\,k\Omega$$

$$r_{on} = \frac{1}{\lambda_n I_D} = \frac{1}{0.05 \times 50\mu} = 400\,k\Omega$$

$$\boxed{r_{op} = r_{on} = 400\,k\Omega = r_o}$$

AC Analysis:-





$$\frac{v_0}{r_{op}} + \frac{v_0}{r_{on}} + g_{mp} v_i + g_{mn} v_i = 0$$

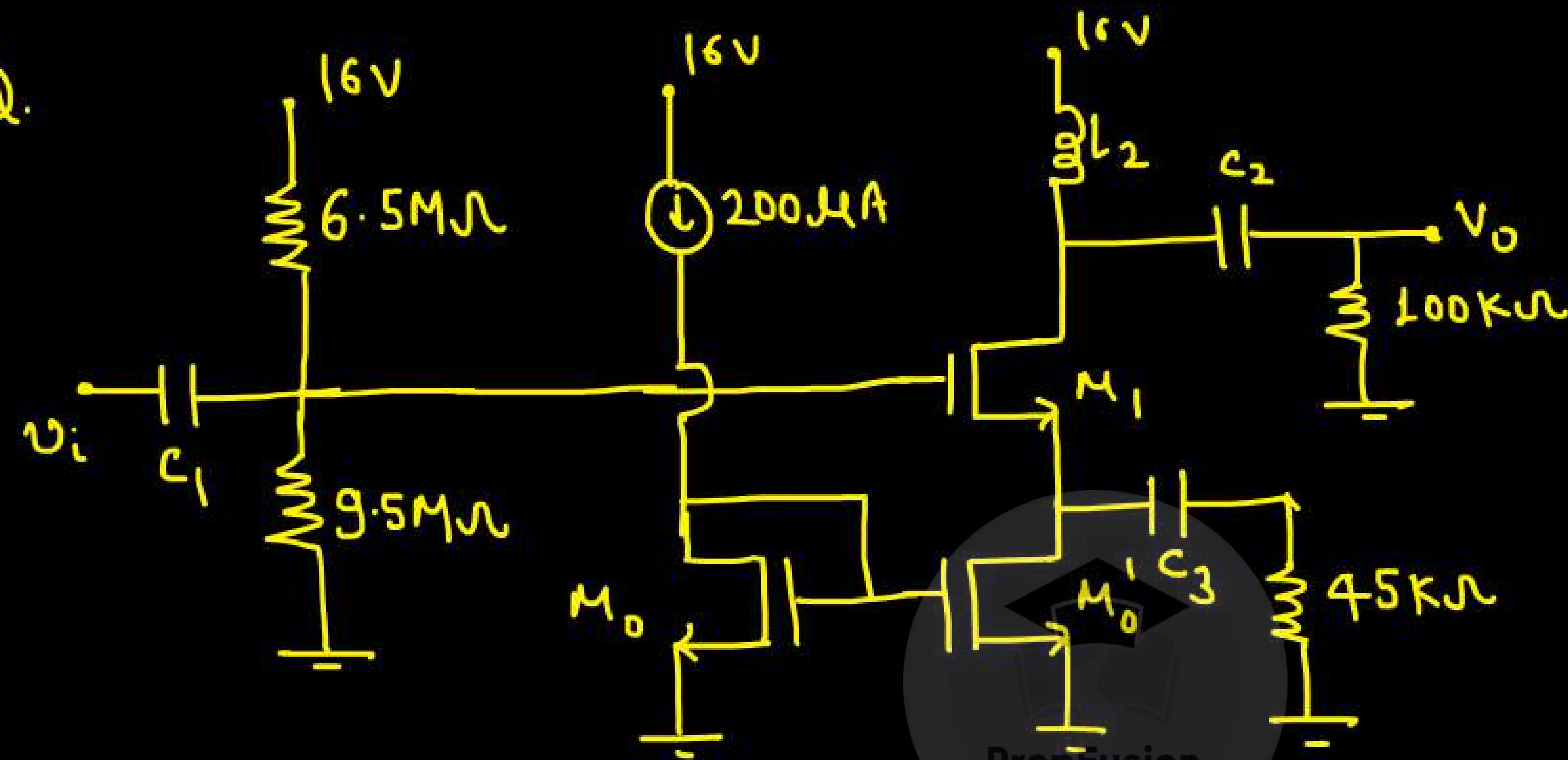
$$\frac{v_0}{r_{op} \| r_{on}} = -(g_{mp} + g_{mn}) v_i$$

$$\frac{v_0}{v_i} = -(g_{mp} + g_{mn})(r_{op} \| r_{on})$$

$$\Rightarrow \frac{v_0}{v_i} = -400 \times 10^{-6} \times 200 \times 10^{3} = -80$$

Ans.

Q.



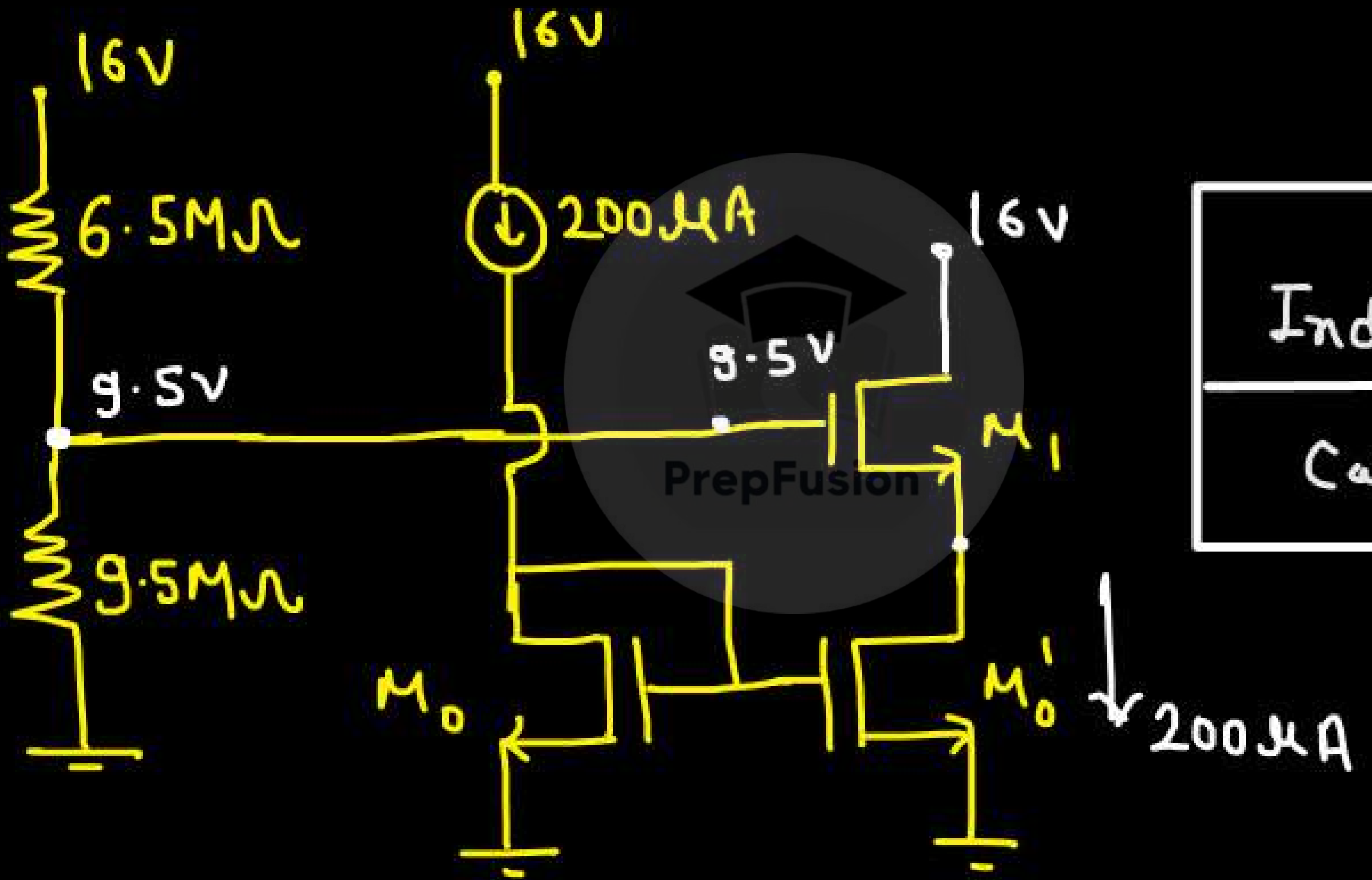
(a) Determine v_i for which M_1 enters into Triode region.

(b) Determine v_i for which M_o' enters into Triode region.

$$\frac{\mu_n C_{ox} W}{L} = 100\,\mu A/V^2 \;,\; V_T = 1V$$

⇒ Considering M_1 and M_0' are working in sat. region based on the given bias.

DC Analysis:-



	DC	AC
Inductor	S.C.	O.C.
Capacitor	O.C.	S.C.

$$I_{M_0'} = I_{M_1} = 200\,\mu$$

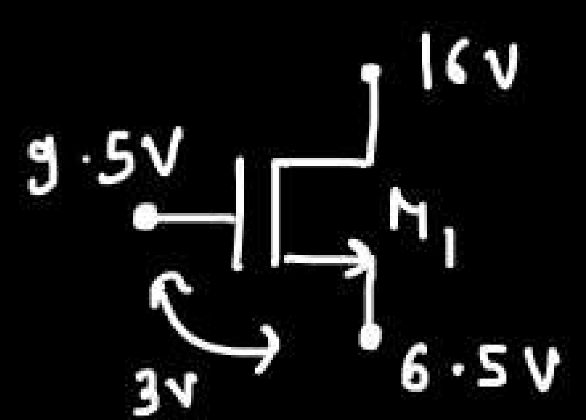
$$200\,\mu = \frac{100\,\mu}{2}\left(V_{GS} - 1\right)^2$$

$$\boxed{V_{GS} = 3V}$$

For M_0' and M_1 $\quad V_{GS} = 3V$

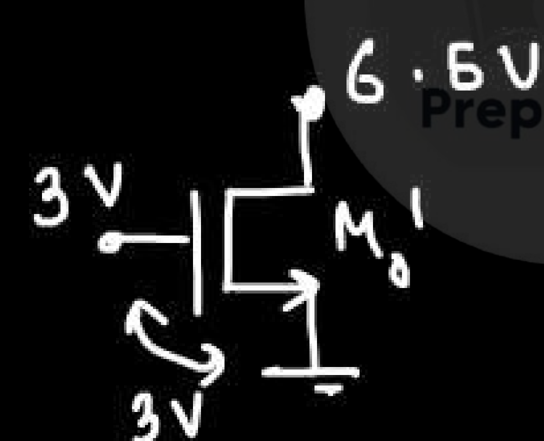
$$g_m = \frac{2I_D}{V_{GS} - V_T} = \frac{2 \times 200\,\mu}{3-1}$$

$$= 200\,\mu S$$



$\Downarrow$

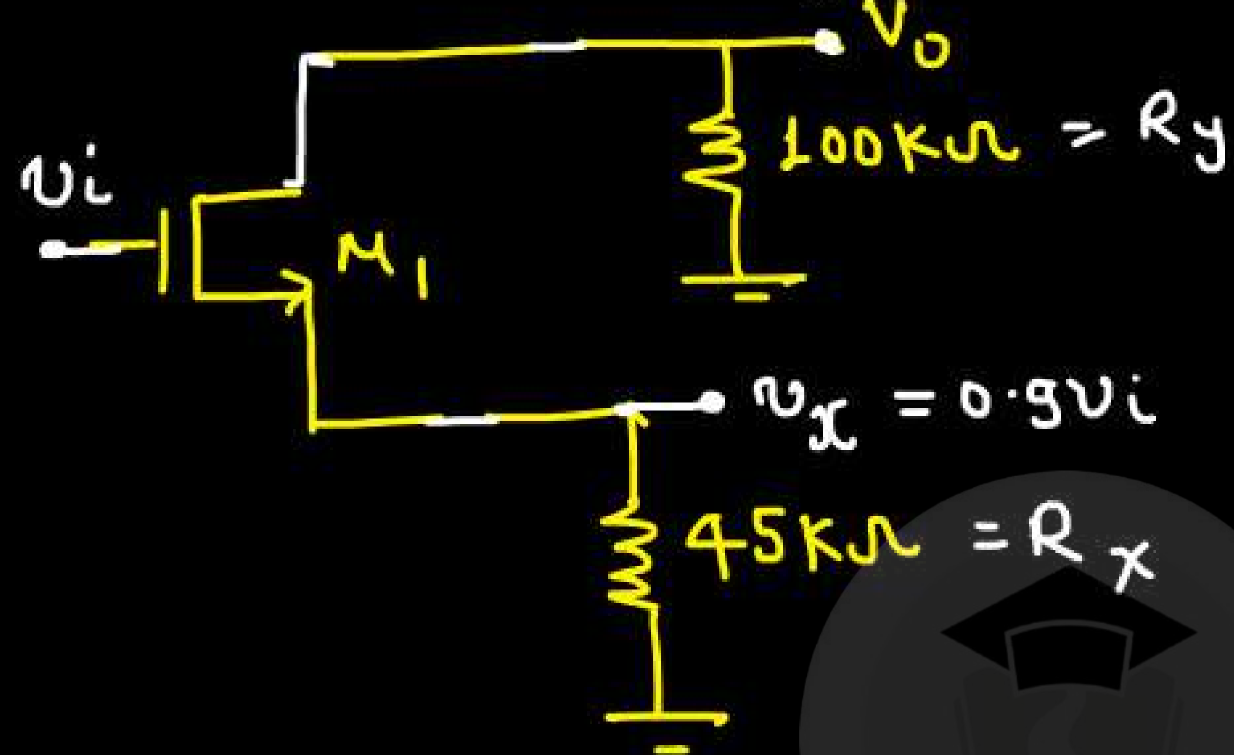
Sat.



$\Downarrow$

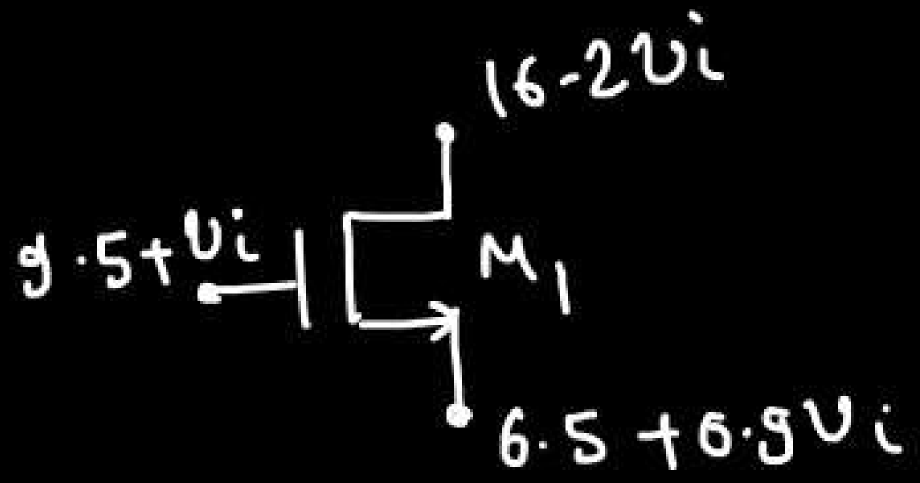
Sat.

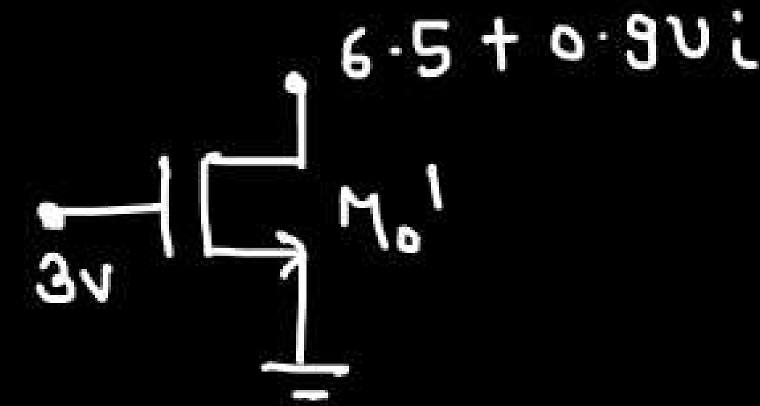
Ac Analysis:-



$$v_x = \frac{R_x}{R_x + 1/g_m} v_i = \frac{g_m R_x}{1 + g_m R_x} v_i = \frac{200\mu \times 45K}{1 + 200\mu \times 45K} v_i = 0.9 v_i$$

$$v_y = \frac{-g_m R_y}{1 + g_m R_x} v_i = \frac{-200\mu \times 100k}{1 + 200\mu \times 45K} v_i = \frac{-20}{10} v_i = -2v_i$$





(a) For M_1 to go into Triode:-

$$V_{DS} \le V_{GS} - V_T$$

$$V_D - \cancel{V_S} \le V_G - \cancel{V_S} - V_T$$

$$V_D \le V_G - V_T$$

$$16 - 2v_i \le 9.5 + v_i - 1$$

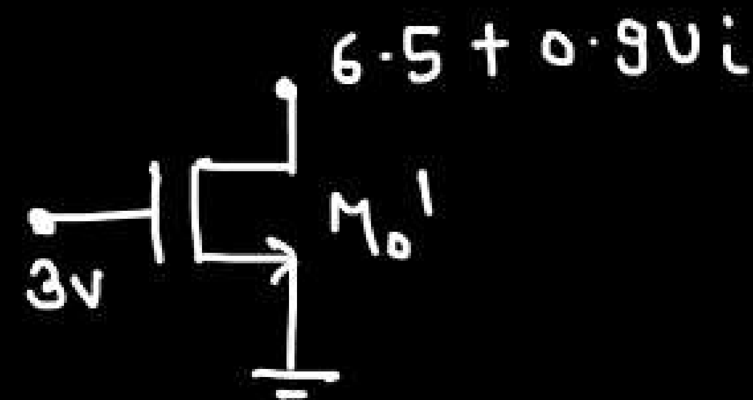
$$16 - 2v_i \le 8.5 + v_i$$

$$\Rightarrow 7.5 \le 3v_i$$

$$\boxed{v_i \ge 2.5V}$$

@ $v_i = 2.5V \Rightarrow$ Tr goes into triode.

(c) For M_0'



For cut off:-

$$V_{DS} \leq 0$$

$$6.5 + 0.9v_i \leq 0$$

$$0.9v_i \leq -6.5$$

$$\boxed{v_i \leq -7.28\,V}$$

For Triode,

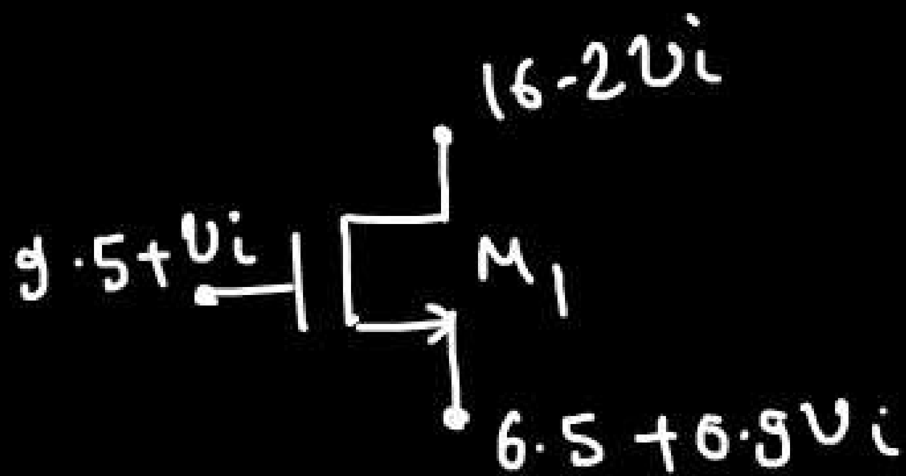
$$6.5 + 0.9v_i \leq 3 - 1$$

$$6.5 + 0.9v_i \leq 2$$

$$0.9v_i \leq -4.5$$

$$\boxed{v_i \leq -5}$$

@ $v_i = -5V \Rightarrow$ Tr M_0' goes into Triode region



for cut off M_1

① $V_{DS} \leq 0$

$$16 - 2v_i - 6.5 - 0.9v_i \leq 0$$

$$9.5 - 2.9v_i \leq 0$$

$$2.9v_i \geq 9.5$$

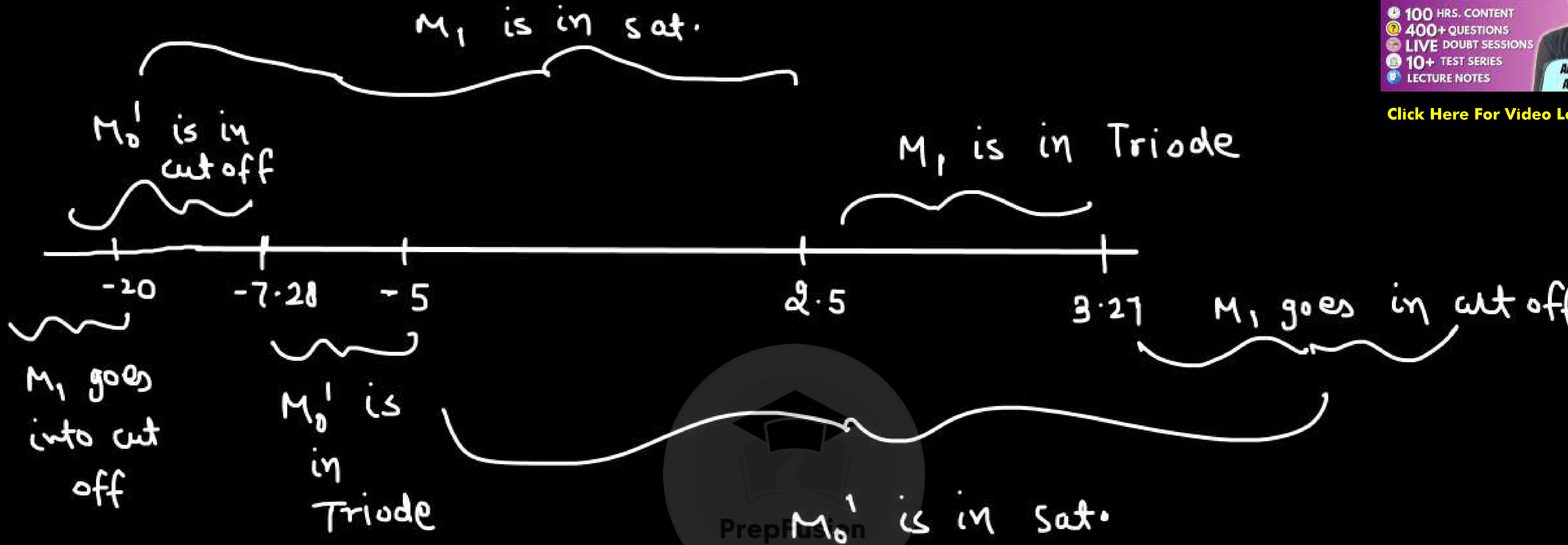
$$v_i \geq 3.27\,V$$

② $V_{GS} \leq V_T$

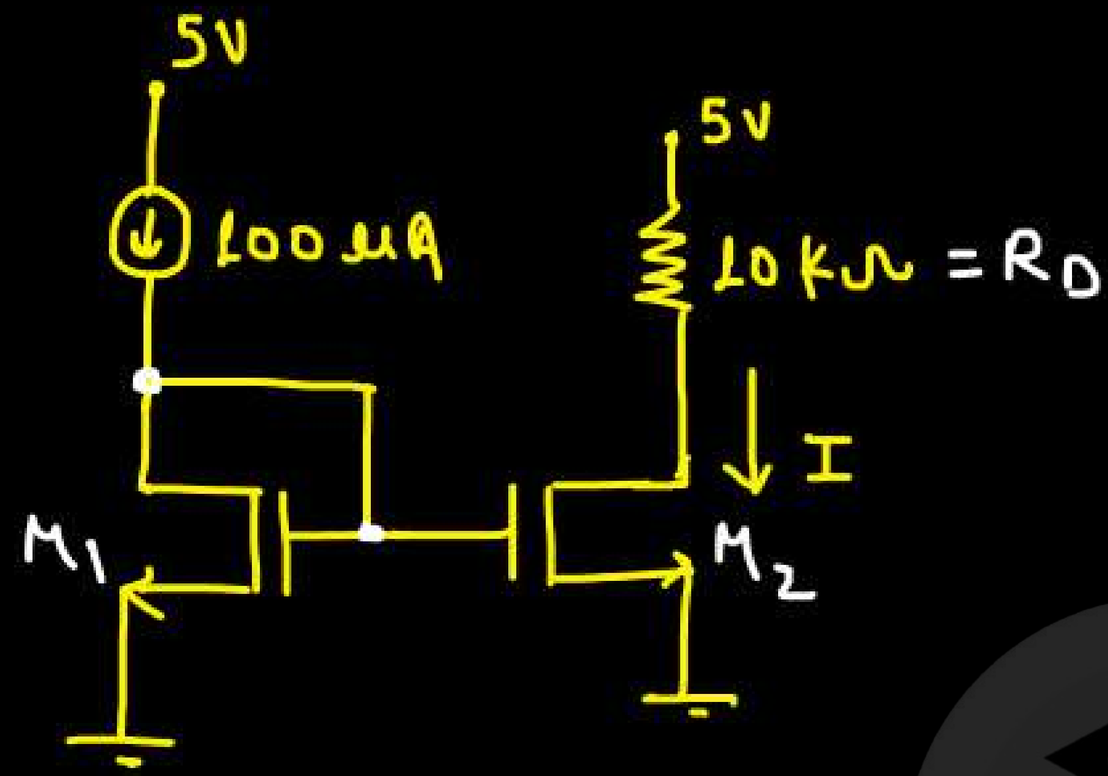
$$9.5 + v_i - 6.5 - 0.9v_i \leq 1$$

$$3 + 0.1v_i \leq 1$$

$$v_i \leq -20\,V$$


M1 is in sat.
Mo' is in cut off
M1 is in Triode
-20
-7.28
-5
2.5
3.27
M1 goes in cut off
M1 goes into cut off
Mo' is in Triode
Mo' is in sat.

Q.



$$\frac{\mu_n C_{ox} W}{L} = 50 \frac{\mu A}{V^2}$$

$$V_T = 1V$$

$$\lambda = 0.01 V^{-1}$$

Find current I ?

(a) 100 µA

(b) 100.96 µAmp.

(c) 99.04 µAmp

(d) 98.96 µAmp

$$I = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

$$\lambda \neq 0$$

$$I_{M_1} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS_1})$$

$$I_{M_2} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS_2}) \quad \{\text{let } M_2 \text{ is in sat}\}$$

$$\boxed{\frac{I_{M_1}}{I_{M_2}} = \frac{1 + \lambda V_{DS_1}}{1 + \lambda V_{DS_2}}}$$

For M_1

$$100\mu = \frac{50\mu}{2}(V_{GS}-1)^2(1+\lambda V_{DS})$$

since λ is very small, let $\lambda V_{DS} << 1$

$$\boxed{V_{GS} = 3V}$$

Here $V_{GS} = V_{DS} = 3$

$$\lambda V_{DS} = 0.01 \times 3 = 0.03 << \underline{\underline{1}} \Rightarrow \text{considerable}$$

$$\frac{I_{M_1}}{I_{M_2}} = \frac{1+\lambda(3)}{1+\lambda[V_{DS_2}]}$$

$V_{DS_2} = ?$, let $I_{M_2} = x$

$$V_{DS_2} = 5 - 10^4 x$$

$$\frac{100\mu}{x} = \frac{1+3\lambda}{1+\lambda[5-10^4 x]}$$

$$10^{-4}[1+5\lambda - \lambda \times 10^4 x] = x + (3\lambda)x$$

$$10^{-4} + 5\times10^{-4}\lambda - \lambda x = x + (3\lambda)x$$

$$10^{-4} + 0.05\times10^{-4} = x + 0.04x$$

$$1.05\times10^{-4} = 1.04x$$

$$\boxed{x = \frac{1.05\times10^{-4}}{1.04} = 100.96\,\mu\text{Amp.}}$$

if $R_D = 20\,k\Omega \Rightarrow I_{M_2} = 100\,\mu Amp.$

[Perfectly matched V_{DS}]

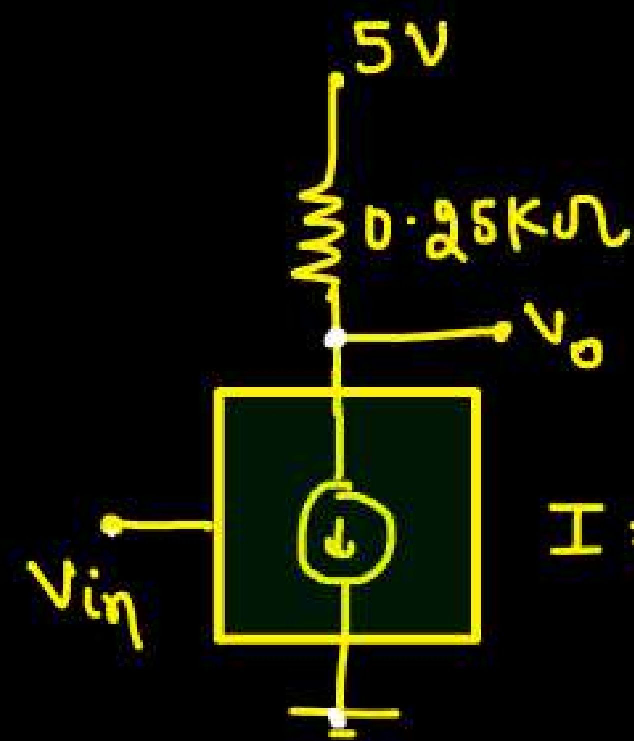
if $R_D = 10\,k\Omega \Rightarrow I_{M_2} > 100\,\mu Amp.$

$[V_{DS_2} > V_{DS_1}]$

if $R_D = 25\,k\Omega \Rightarrow I_{M_2} < 100\,\mu Amp.$

$[V_{DS_2} < V_{DS_1}]$

Q.



$$I = [V_{in}^2 + 2V_{in} + 1][1 + 0.05V_o] \text{ mA}$$

Yellow-box is a three terminal element. $V_{in-Q} = 1V$

Find small signal voltage gain $\frac{v_{in}}{v_o} = ?$ (Approx)

(a) -0.95

(b) -19.5

(c) -49.5

(d) -99.5

→ For MOS :-

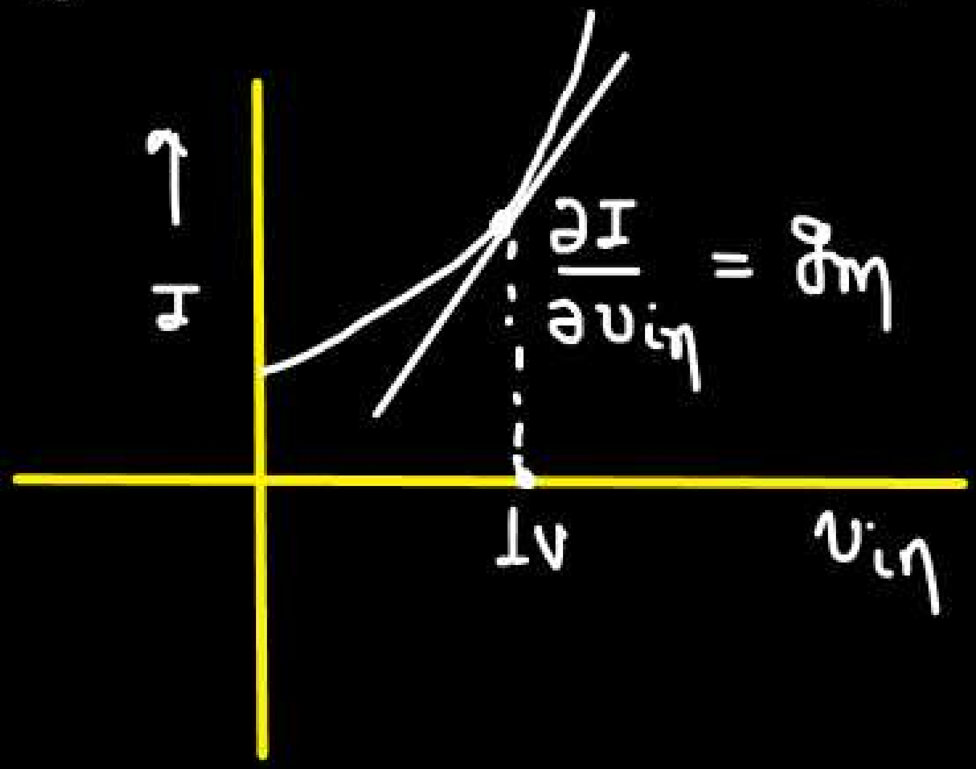
$$I_D = k_n [V_{GS} - V_T]^2 [1 + \lambda V_{DS}]$$

For given problem,

$$I = [V_{in}^2 + 2V_{in} + 1][1 + 0.05 V_0] \text{ mA}$$

$$g_m = \frac{\partial I}{\partial v_{in}} = 2V_{in} + 2 \text{ mA} \quad \{\text{Assuming } 1 + 0.05 V_0 <<< 1\}$$

$$\boxed{(g_m)_{v_{in} = 1V} = 4 \text{ mS}}$$



$$r_0 = \frac{1}{\frac{\partial I}{\partial V_0}} = \frac{10^3}{(V_{in}^2 + 2V_{in} + 1)(0.05)}$$

$$\boxed{(r_o)_{v_{in\text{-}Q}=1} = \frac{10^3}{4\times 0.05} = 5\,K\Omega}$$

Small signal current

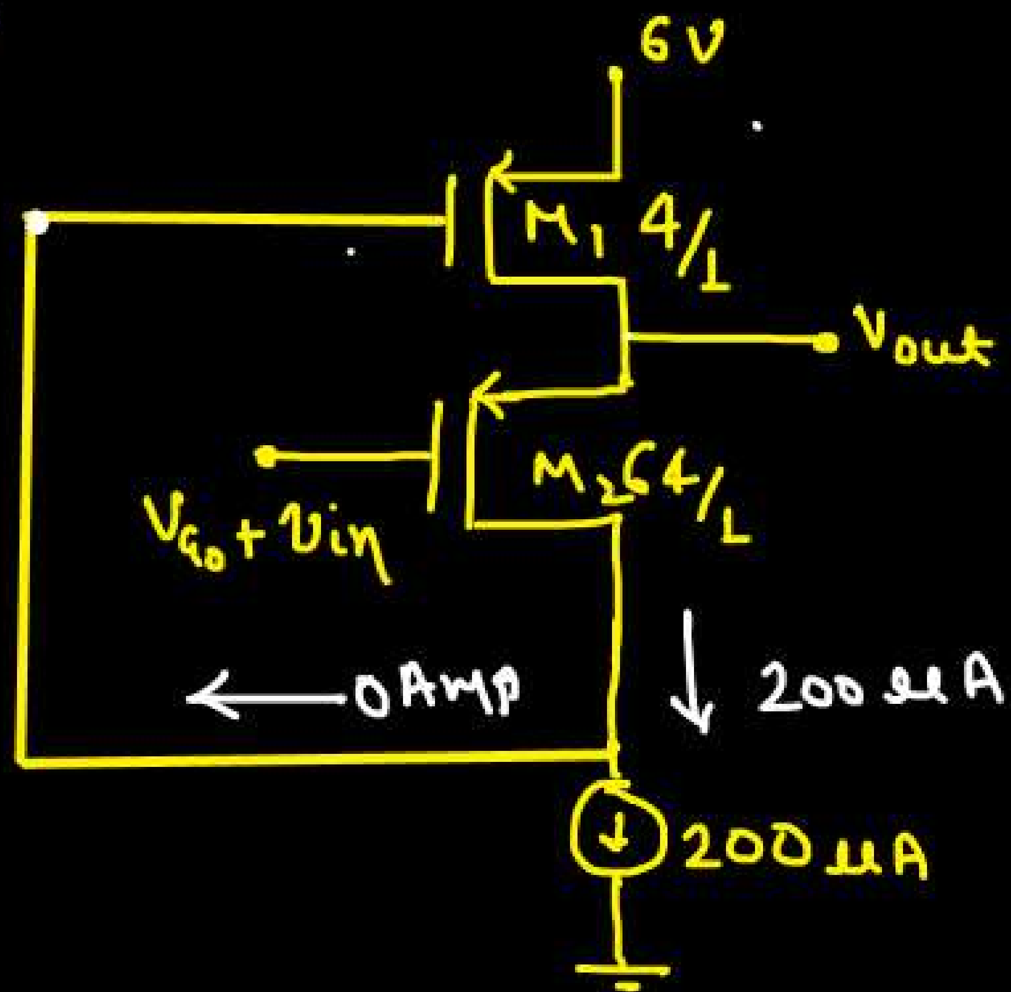
$$v_o = -g_m\,(5K \,\|\, 0.25K)\,v_{in}$$

$$= -4m \times 0.238K \times v_{in}$$

$$\boxed{\frac{v_o}{v_{in}} = -0.95\ V/V}$$

Ans.

Q.



$\mu_p C_{ox} = 25\,\mu A/V^2$

$V_T = 1V$

$v_{in} = V_p \cos(\omega t)$

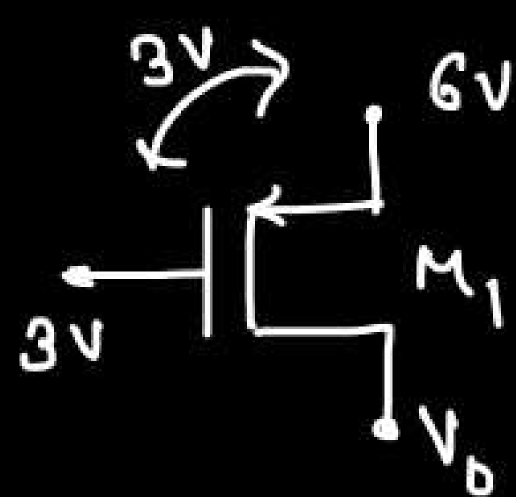
V_{G0} is set such that it maximizes V_p that can be applied while keeping all the Tr. in sat. region.

(a) Find optimum value of V_{G0} (b) Find max value of V_p.

$I_{M_1} = 200\,\mu A$

$$\Rightarrow 200\mu = \frac{25\mu \times 4}{2}\left(V_{SG_{M_1}} - 1\right)^2$$

$$\boxed{V_{SG_{M_1}} = 3V}$$

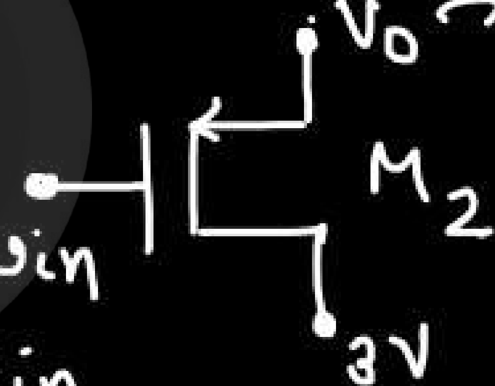


$I_{M_2} = 200\,\mu A$

$$\Rightarrow 200\mu = \frac{25\mu \times 64}{2}\left(V_{SG_{M_2}} - 1\right)^2$$

$$\boxed{V_{SG_{M_2}} = 1.5V}$$

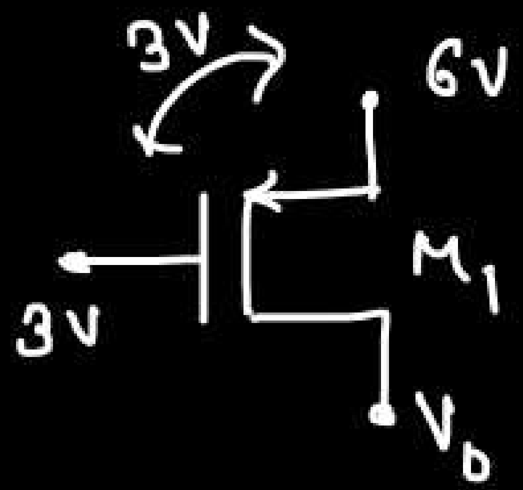
$V_o \rightarrow$ Both dc and ac



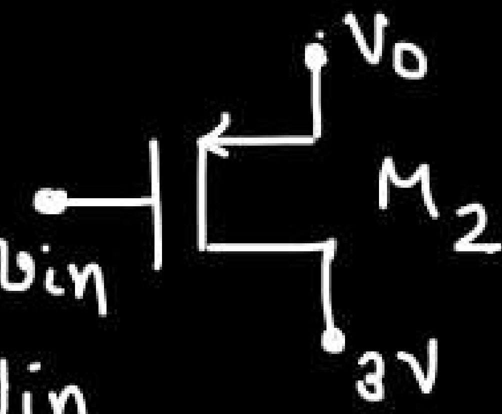
$V_{G0} + v_{in}$
$= V_{in}$

$V_o - V_{in} = 1.5$

$$\boxed{V_o = 1.5 + V_{in}}$$



$V_{G0} + v_{in}$
$= V_{in}$



For sat.

$$6 - V_0 \geq 6 - 3 - 1$$

$$6 - V_0 \geq 2$$

$$V_0 \leq 4$$

$$1.5 + V_{in} \leq 4$$

$$\boxed{V_{in} \leq 2.5\,V}$$

$$V_0 - 3 \geq V_0 - V_{in} - 1$$

$$-3 \geq -V_{in} - 1$$

$$\boxed{V_{in} \geq 2}$$

2.3 0.2

$$V_{in} = V_{G0} + v_{in}$$

$$= V_{G0} + V_p \cos \omega t$$

$$(V_{in})_{max} = V_{G0} + V_p \quad , \quad (V_{in})_{min} = V_{G0} - V_p$$

$$V_{GO} - V_p = 2$$

$$V_{GO} + V_p = 2.5$$

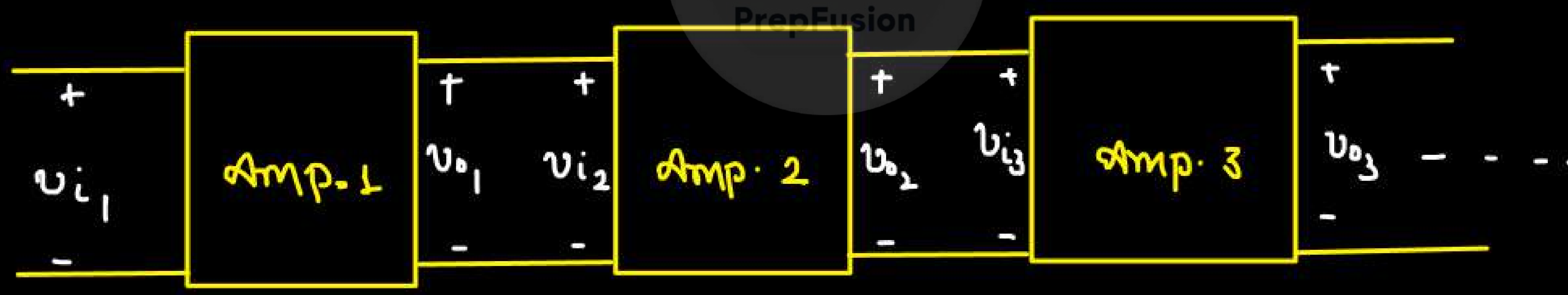
$\boxed{V_{GO} = 2.25\,V}$ Ans, $\boxed{V_p = 0.25\,V}$ Ans.

$$\boxed{\begin{array}{c} 2 < V_{GO} < 2.5 \\ \downarrow \qquad\qquad \downarrow \\ 0.5 > V_p > 0 \end{array}}$$

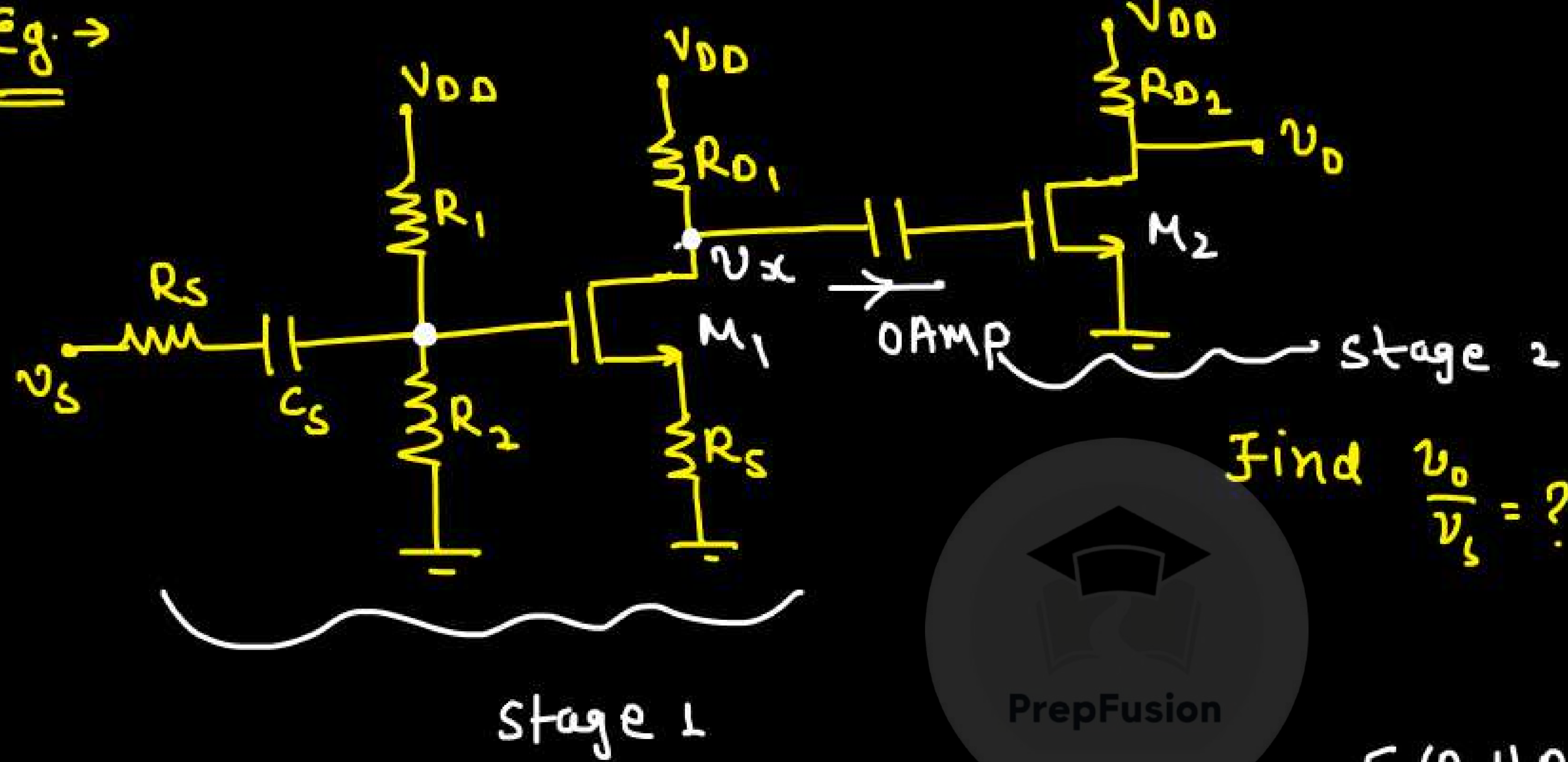
⇒ Some Miscellaneous Topics :-

★ Multi-stage Amplifiers (Cascade Amplifiers) :-

A series of amplifier in which each amplifier connects its o/p to the i/p of next amplifier in the chain.



Eg. →



Find $\frac{v_o}{v_s} = ?$

$$\frac{v_x}{v_s} = \frac{-g_{m_1} R_{D_1}}{1+g_{m_1} R_S}\left[\frac{(R_1 \| R_2)}{(R_1 \| R_2)+R_S}\right] \quad \text{— (1)}$$

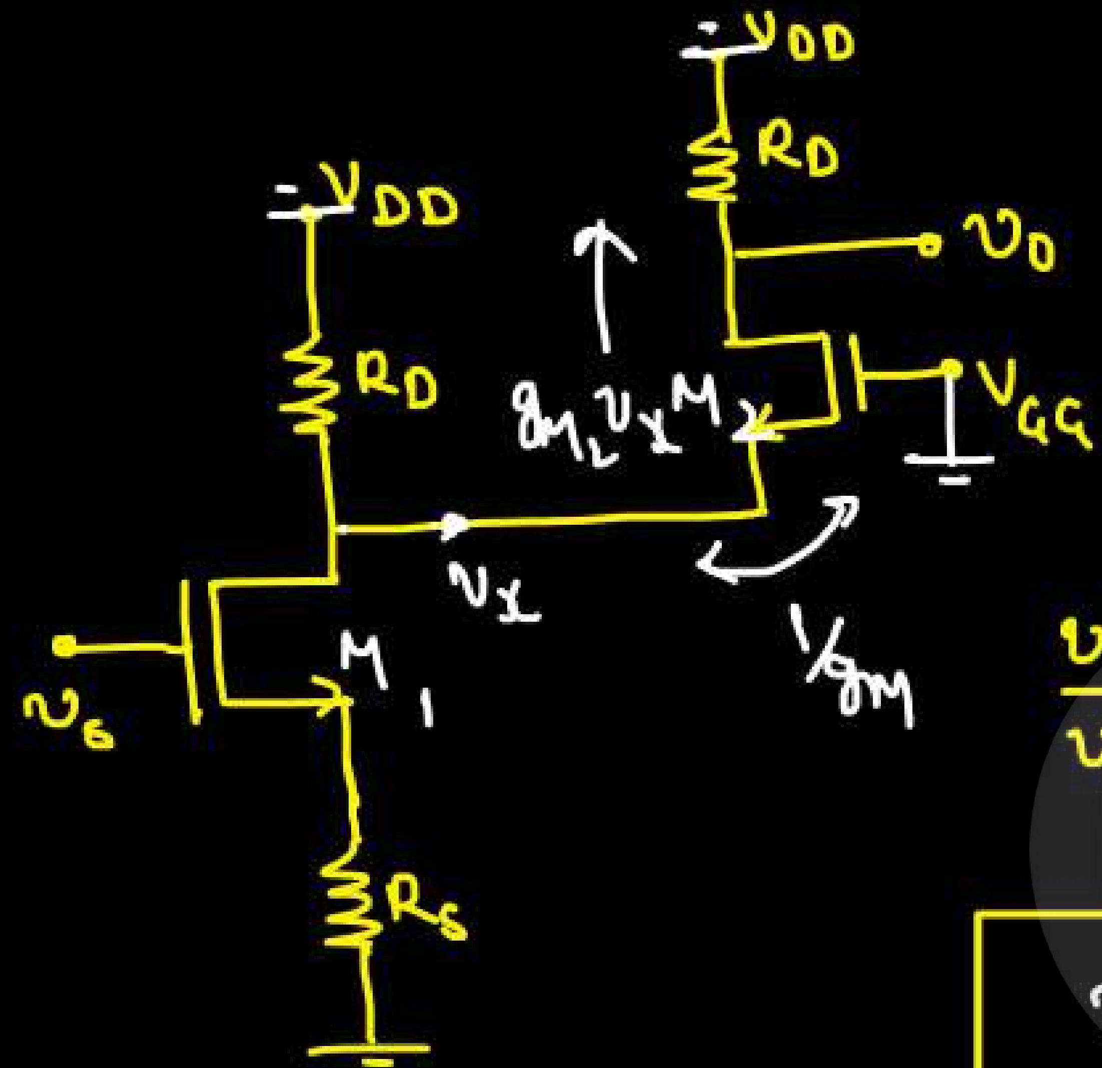
$$\frac{v_o}{v_x} = -g_{m_2} R_{D_2} \quad \text{— (2)}$$

multiply eq^n 1 with eq^n 2

$$\frac{v_x}{v_s} \times \frac{v_o}{v_x} = \boxed{\frac{v_o}{v_s} = \left[g_{m_2} R_{D_2}\right]\left[\frac{g_{m_1} R_{D_1}}{1 + g_{m_1} R_S}\right]\left[\frac{(R_1 || R_2)}{(R_1 || R_2) + R_S}\right]}$$

**

2



$\frac{v_0}{v_s} = ?$ [Small signal voltage gain]

$$\boxed{\frac{v_x}{v_s} = \frac{-g_m R_D}{1 + g_m R_S}}$$

$$\frac{v_x}{v_s} = \frac{-g_{m_1}\left[R_D \,\|\, \frac{1}{g_{m_2}}\right]}{1 + g_{m_1} R_S} \rightarrow (1)$$

$$\frac{v_x}{v_o} = ?$$

$$v_o = g_{m_2} v_x R_D$$

$$\frac{v_o}{v_x} = g_{m_2} R_D \quad \text{—} \quad (2)$$

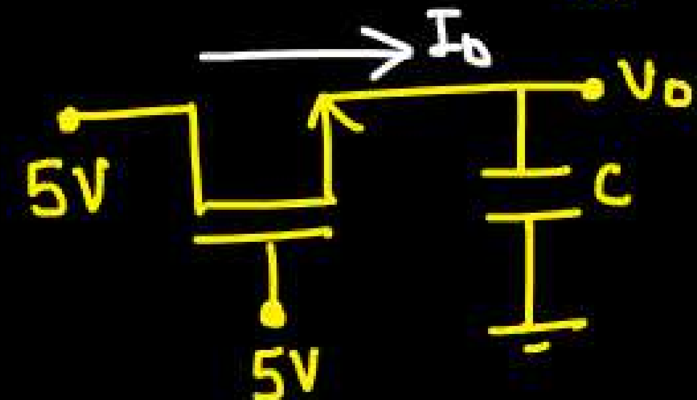
**

$$\boxed{\frac{v_o}{v_s} = -g_{m_2} R_D \times \frac{g_{m_1}\left[R_D \,||\, \frac{1}{g_{m_2}}\right]}{1 + g_{m_1} R_S}}$$

Concept of Pass Transistor Logic:-

Q. Find the steady state value of V_0.

$(V_T = 1V)$



(a)

@ $t = 0^+$, $V_0 = 0V$

$V_{DS} = 5V$

$V_{GS} = 5V$ $\Rightarrow$ Tr is ON

$V_T = 1V$

if Tr is ON $\Rightarrow$ 5V from drain will charge the capacitor

When $I_D = 0$ Amp $\Rightarrow$ No charging ON cap.

$\Downarrow$

Steady state

$\underbrace{I_D > 0}$ $\Rightarrow$ cap will be charging

$\Downarrow$

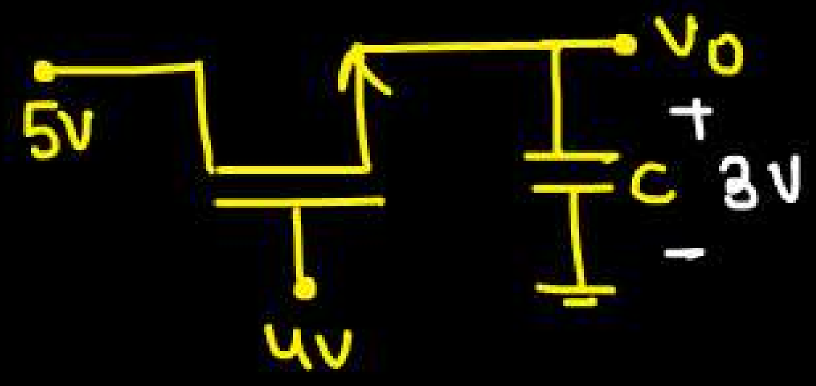
① $V_{GS} \geq V_T \Rightarrow 5 - V_0 \geq 1 \Rightarrow \boxed{V_0 \leq 4}$

② $V_{DS} \geq 0 \Rightarrow 5 - V_0 \geq 0 \Rightarrow \boxed{V_0 \leq 5}$

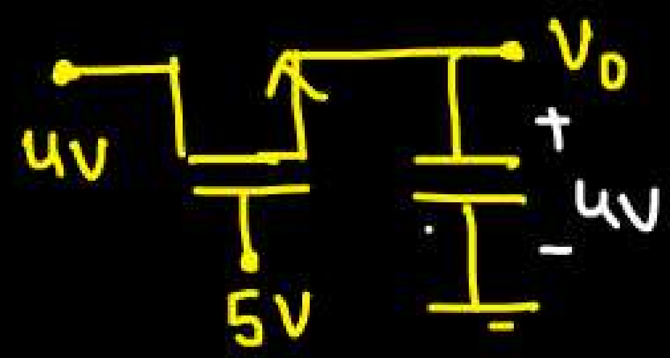
$\Rightarrow \boxed{V_0 \leq 4V}$

$\Downarrow$

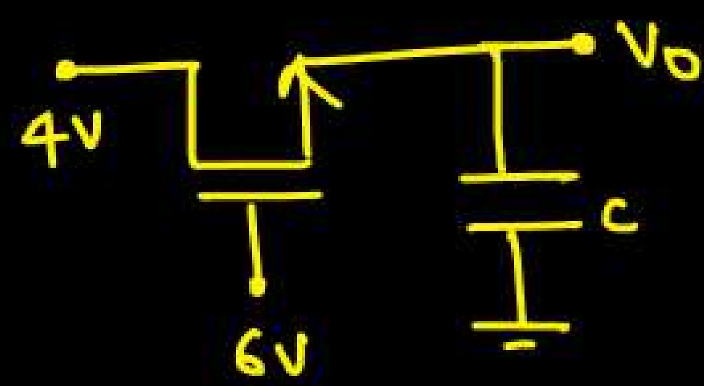
$$\boxed{(V_0)_{s.s.} = 4V}$$



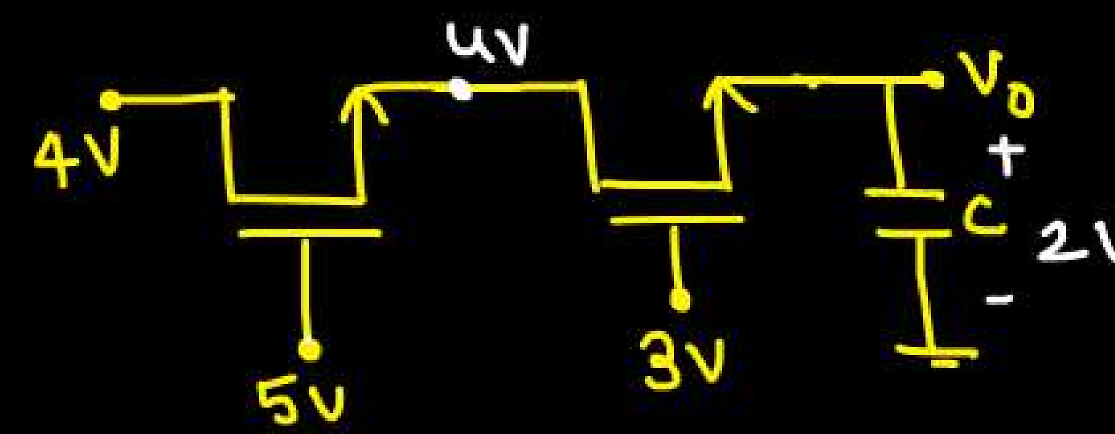
(b)



(c)



(D)



(E)

$$V_{GS} \geq V_T \quad — \quad (1)$$

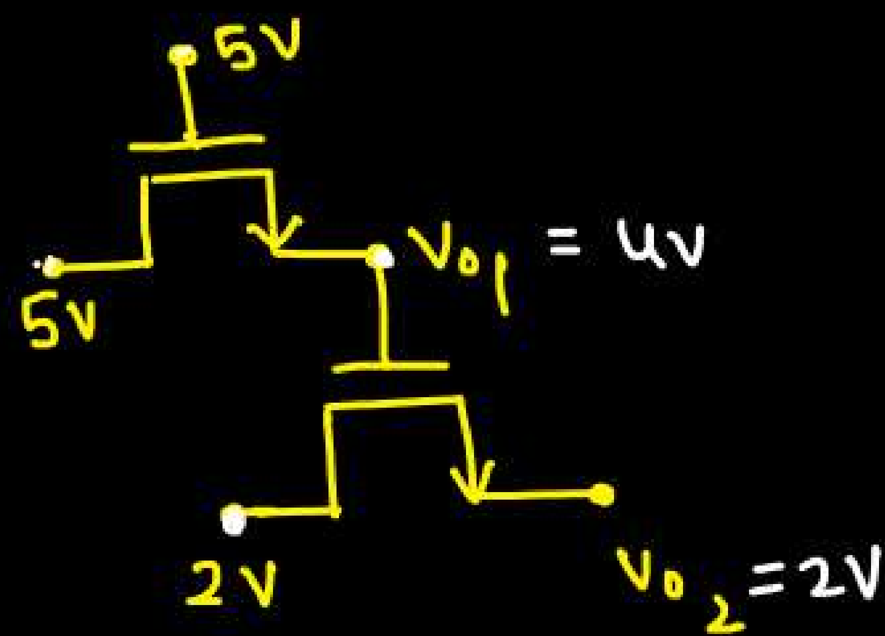
$$6 - V_0 \geq 1$$

$$\boxed{V_0 \leq 5V}$$

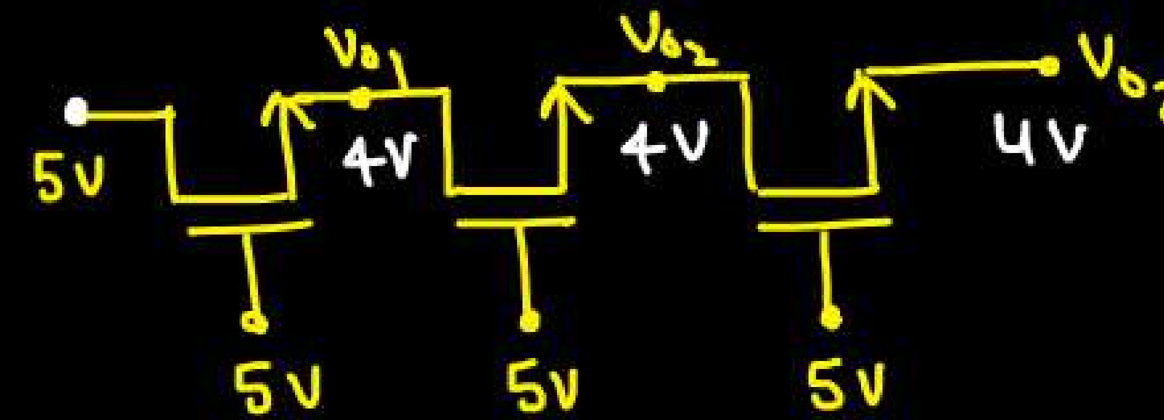
$$V_{DS} \geq 0 \quad — \quad (2) \quad \Rightarrow \quad \boxed{V_0 = 4V}$$

$$4 - V_0 \geq 0$$

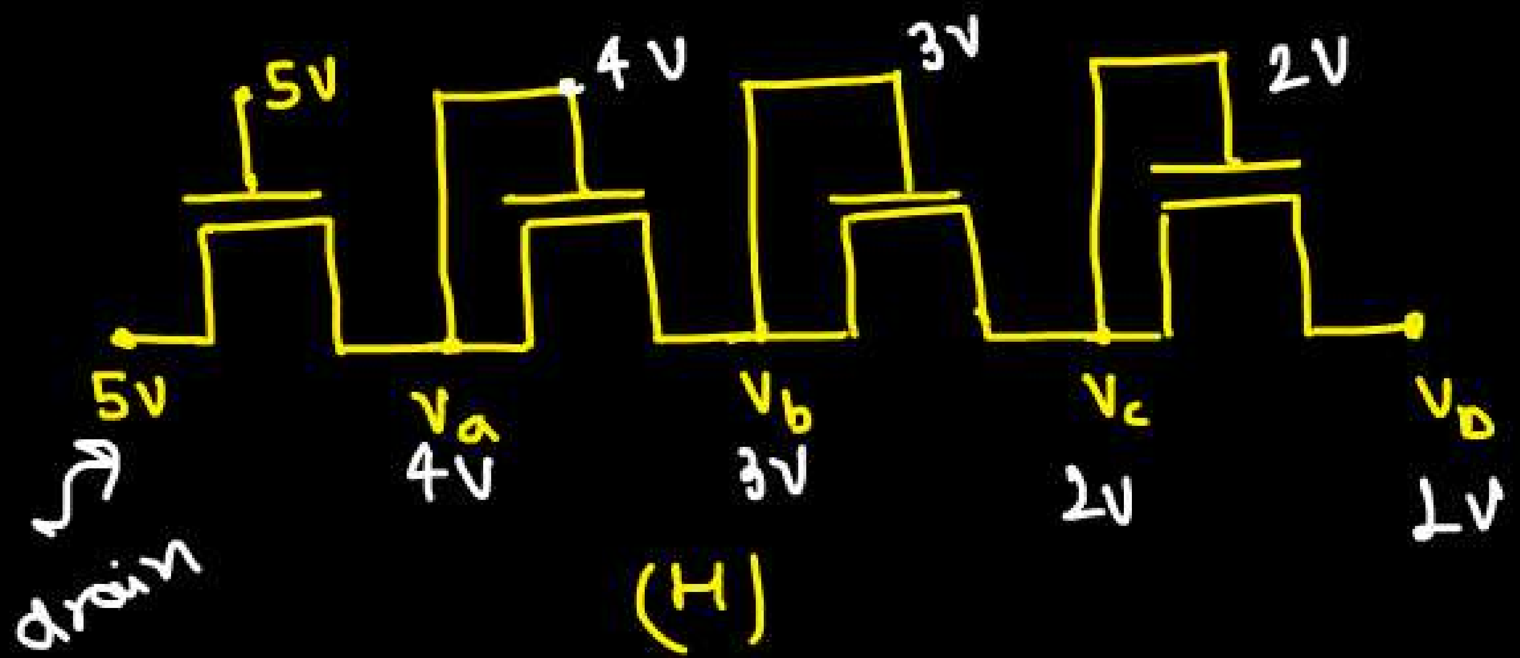
$$\boxed{V_0 \leq 4V}$$

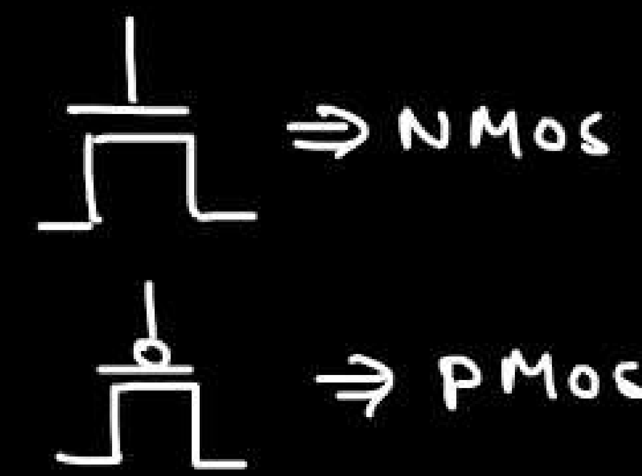


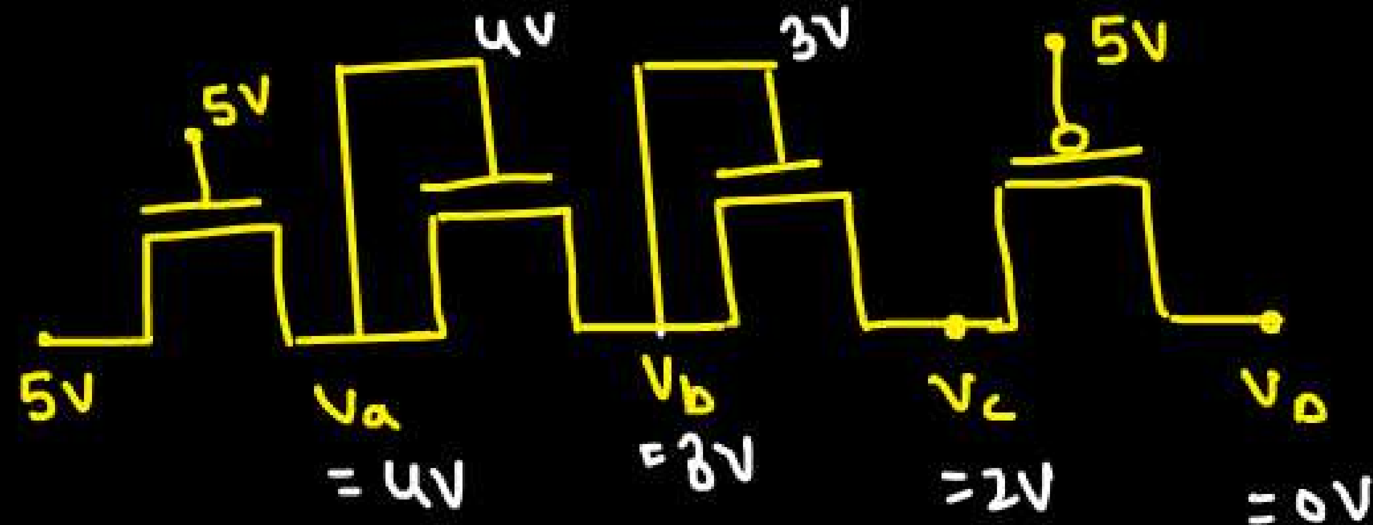
(F)

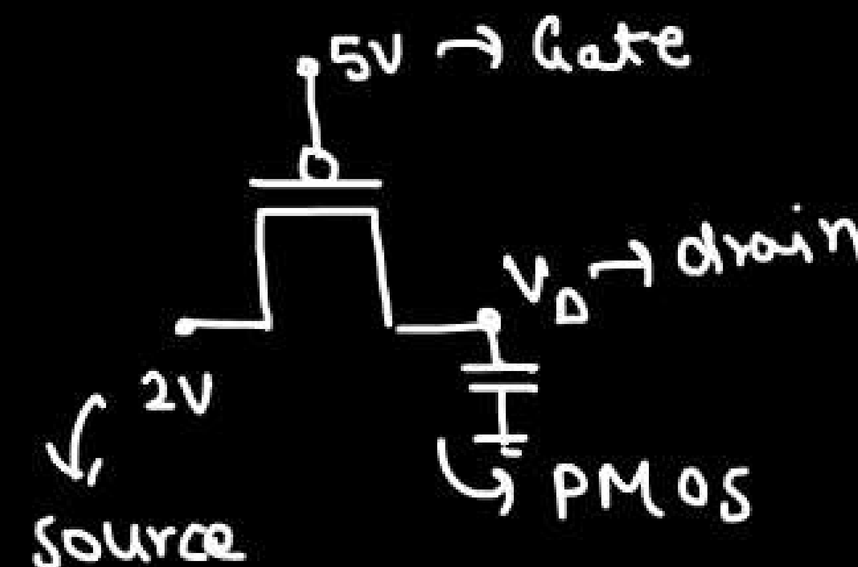


(G)


5V
4V
3V
2V
5V
drain
Va
4V
Vb
3V
Vc
2V
VD
1V
(H)


⇒ NMos
⇒ PMos





H.P → source

L.P → Drain

⇓

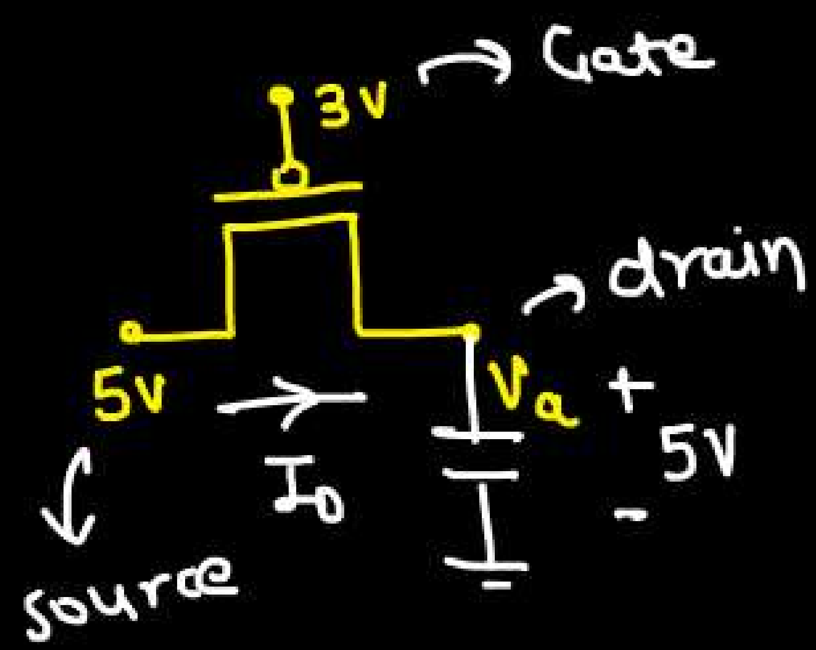
$V_{sg} = 2 - 5 = \underline{\underline{-3V}}$

⇓

MOS is off

⇓

No charging for V_D



$V_{SG} = 5 - 3 = 2V > V_T \Rightarrow$ always

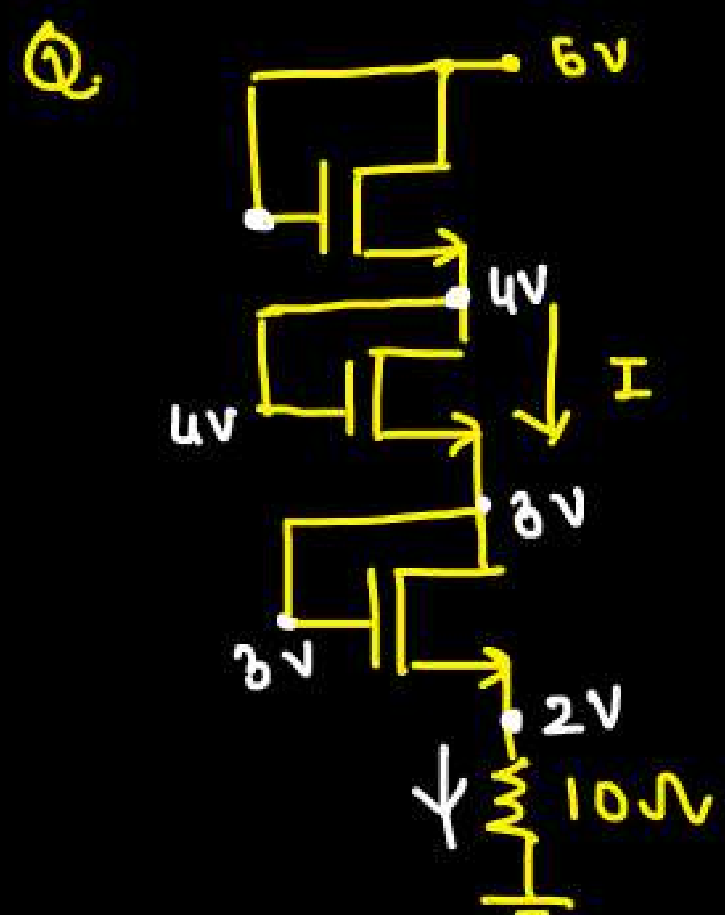
Tr can turn off only when

$$V_{SD} = 0$$

$$5 - V_0 = 0$$

$$\boxed{(V_0)_{s.s} = 5V}$$

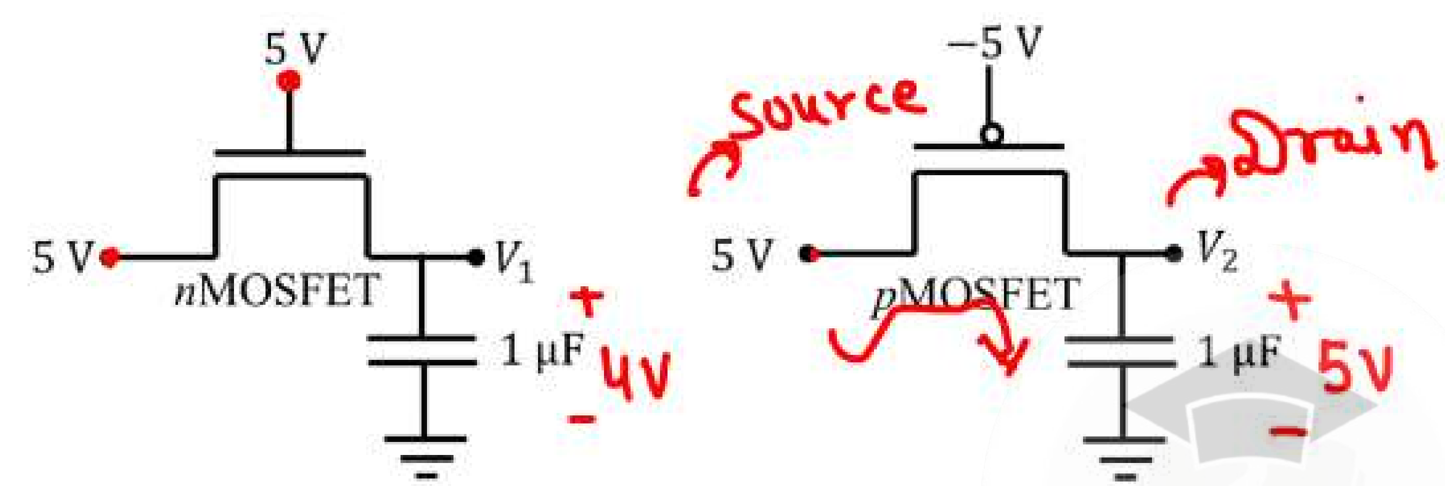
Q



steady state I = ?

$$\boxed{I = \frac{2}{10} = 0.2 \text{ Amp.}}$$

Q.20 The ideal long channel nMOSFET and pMOSFET devices shown in the circuits have threshold voltages of 1 V and −1 V, respectively. The MOSFET substrates are connected to their respective sources. Ignore leakage currents and assume that the capacitors are initially discharged. For the applied voltages as shown, the steady state voltages are __________________.



(A)	$V_1 = 5$ V, $V_2 = 5$ V
(B)	$V_1 = 5$ V, $V_2 = 4$ V
(C)	$V_1 = 4$ V, $V_2 = 5$ V
(D)	$V_1 = 4$ V, $V_2 = -5$ V

$V_{sg} = 5 - (-5) = 10V$

$\Downarrow$

Tr ON

Frequency Response of MOS

Pre-requisites:-

Transfer f^n, pole, zero, Bode plot.

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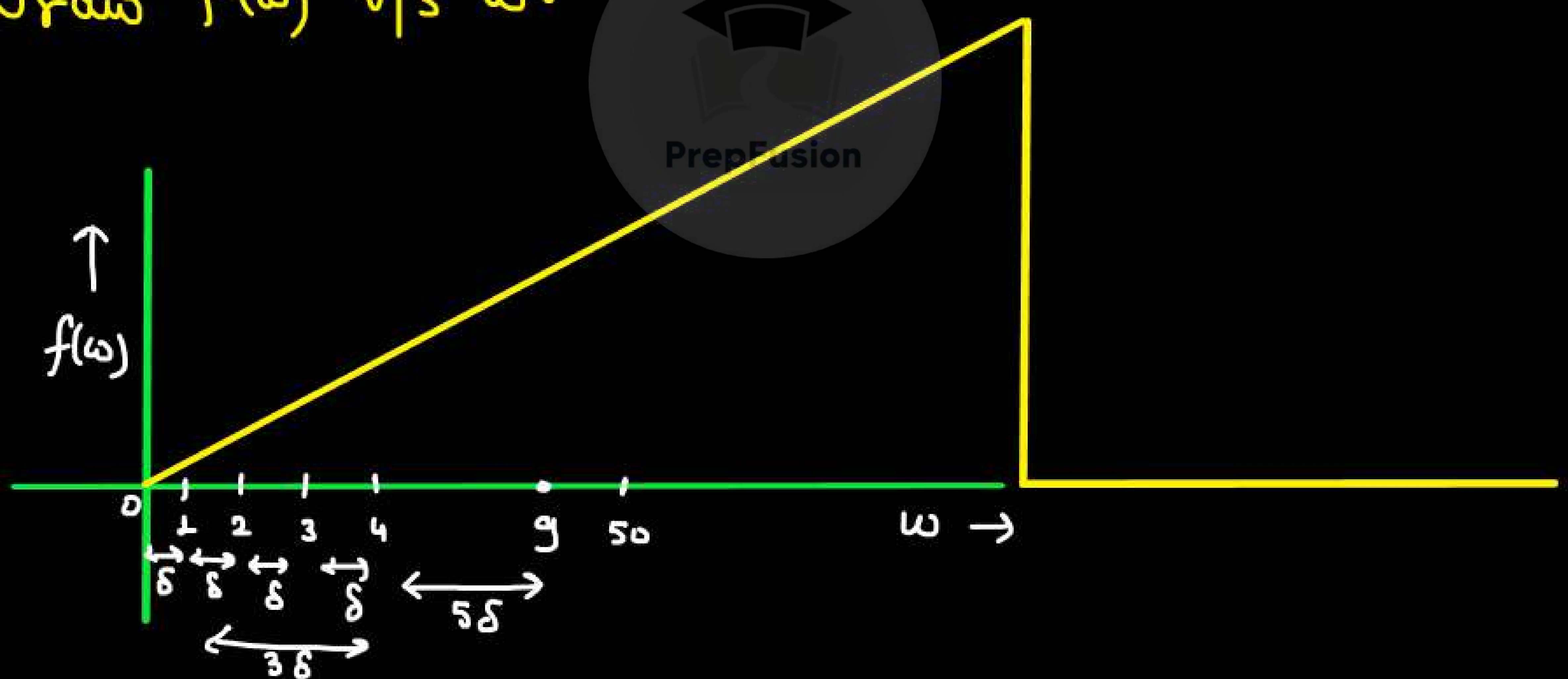
Concepts of Frequency response & Bode plot.

Q. $$f(\omega) = \begin{cases} \omega, & 0 \le \omega \le 100 \\ 0, & o/\omega \end{cases}$$

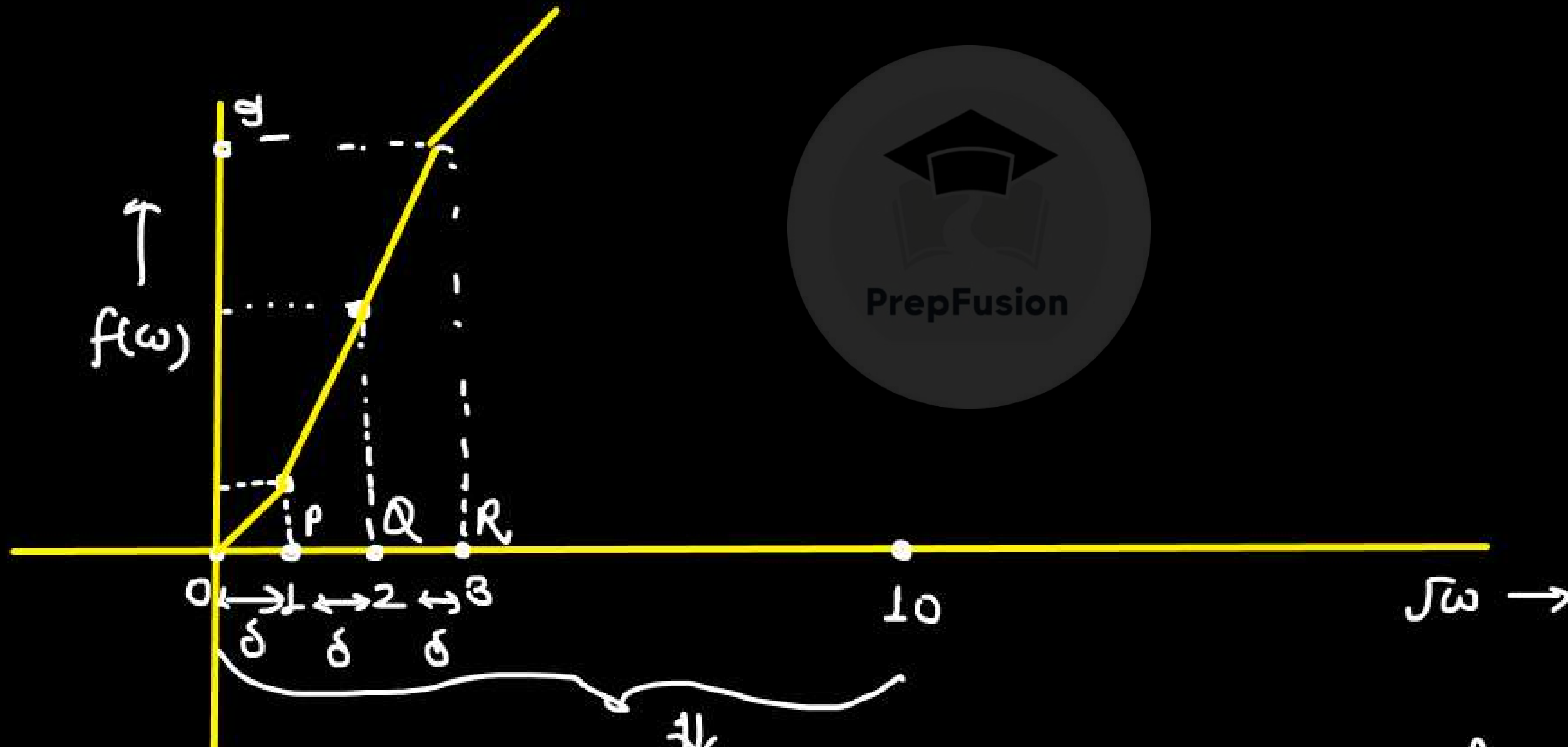
Draw $f(\omega)$ v/s ω.

→



Q. $$f(\omega) = \begin{cases} \omega, & 0 \le \omega \le 100 \\ 0, & o/\omega \end{cases}$$

Draw $f(\omega)$ v/s $\sqrt{\omega}$.



Have covered all the values of ω

Q. $$f(\omega) = \begin{cases} \omega, & 0 \le \omega \le 100 \\ 0, & o/w \end{cases}$$

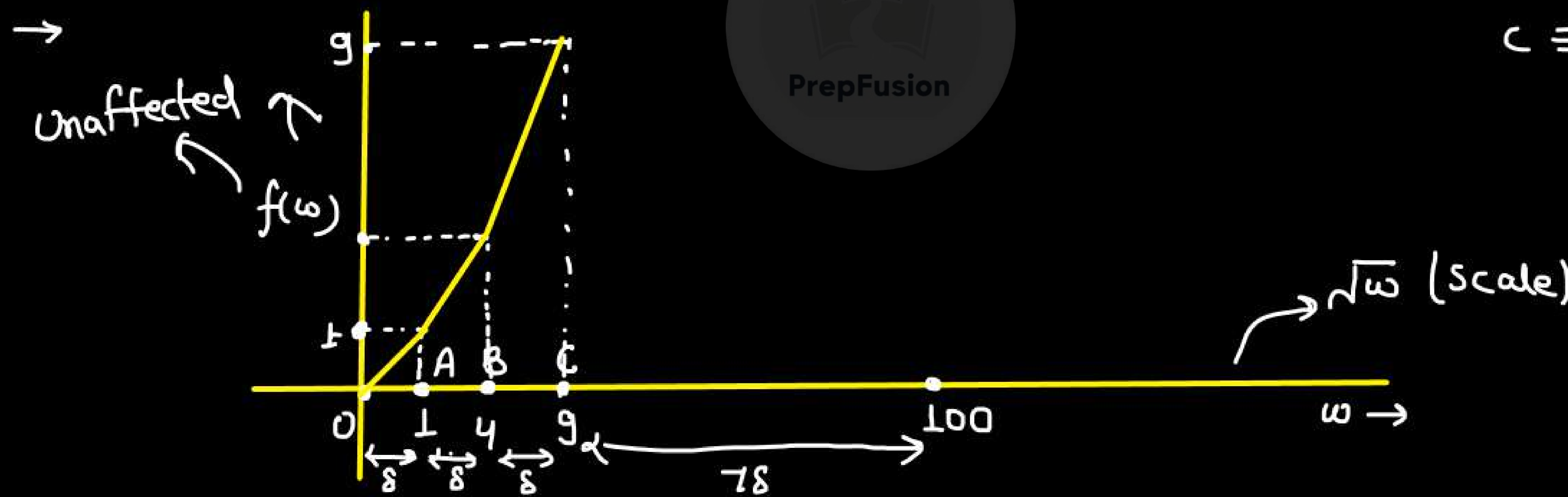
Draw $f(\omega)$ v/s ω.

But x-axis is in square root scale.

$A \equiv P$

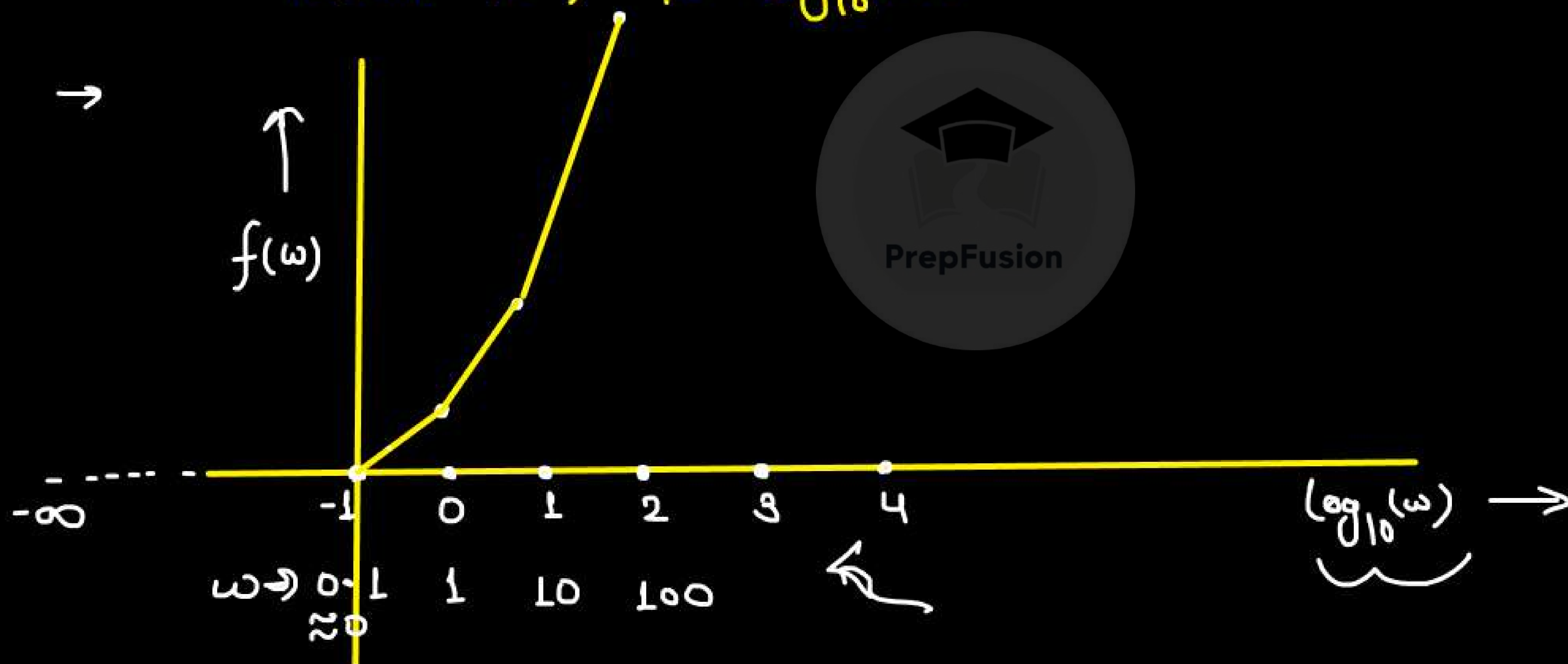
$B \equiv Q$

$C \equiv R$



Q. $f(\omega) = \begin{cases} \omega, & 0 \le \omega \le 100 \\ 0, & \text{o/w} \end{cases}$

Draw $f(\omega)$ v/s $\log_{10}\omega$.

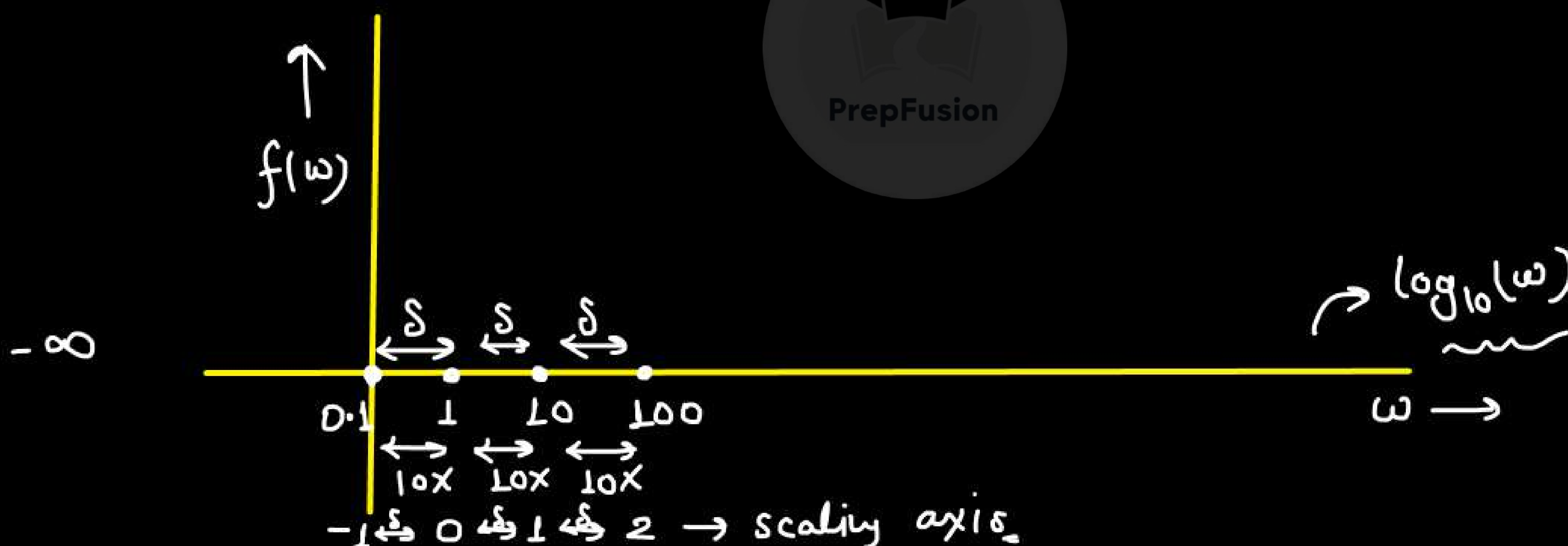


Q. ★ ★ ★

$$f(\omega) = \begin{cases} \omega, & 0 \le \omega \le 100 \\ 0, & o/w \end{cases}$$

Draw $f(\omega)$ v/s ω.

↳ But the x-axis is in log scale.



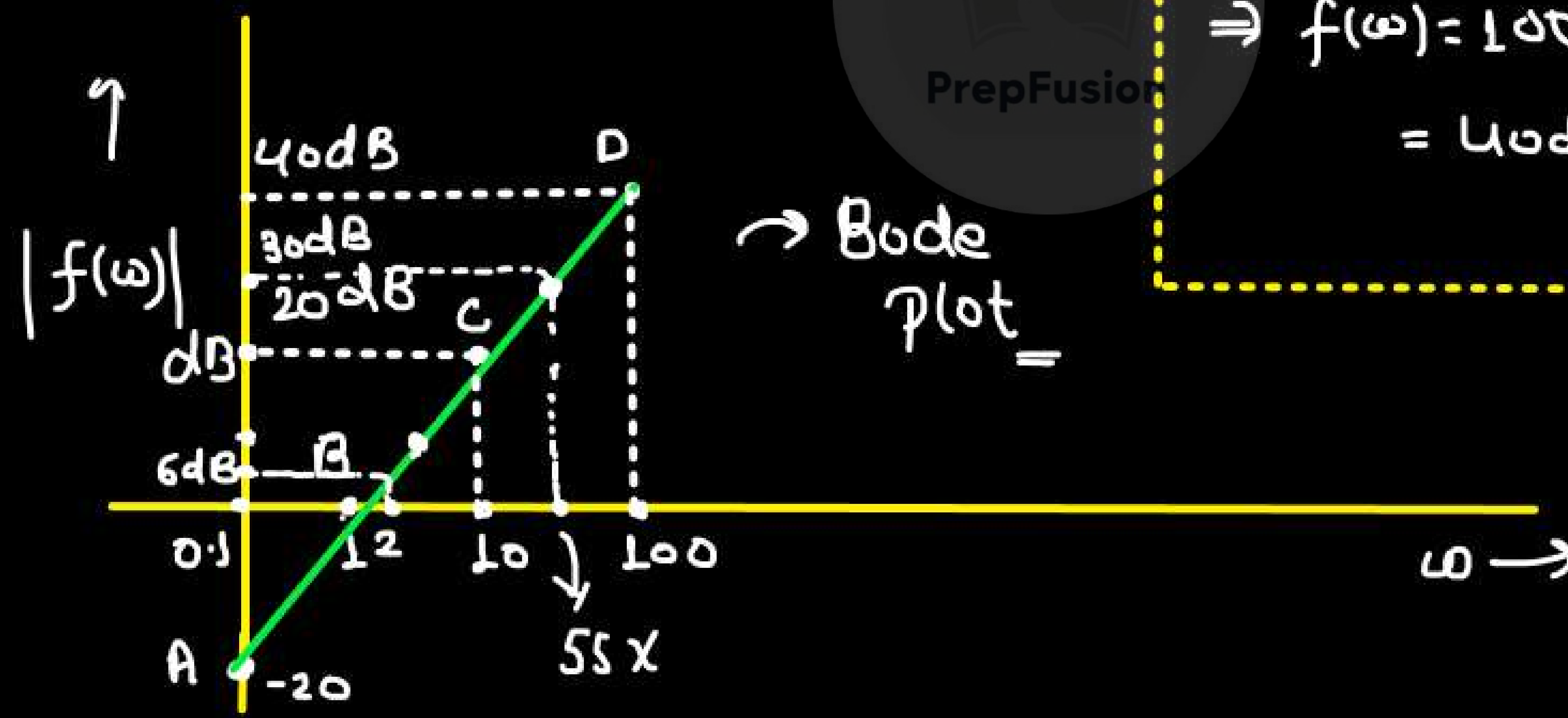
Q. ★★★★

$$f(\omega) = \begin{cases} \omega, & 0 \le \omega \le 100 \\ 0, & o/\omega \end{cases}$$

Draw $|f(\omega)|_{dB}$ v/s ω.

considering x-axis in log-scale.

→



→ Bode plot

★ Decimal to dB conversion

$$\underbrace{x}_{\text{decimal}} = \underbrace{20\log_{10} x}_{\text{dB}}$$

Q. Convert 10 in dB

→ $20\log_{10} 10 = 20\,dB$

$\omega = 100$

$\Rightarrow f(\omega) = 100$

$= 40\,dB$

$\omega = 0.1 \Rightarrow f(\omega) = 0.1$

$= -20\,dB$

$\omega = 1 \Rightarrow f(\omega) = 1$

$= 0\,dB$

$\omega = 2 \Rightarrow f(\omega) = 2$

$= 6\,dB$

$\omega = 10 \Rightarrow f(\omega) = 10$

$= 20\,dB$

Slope of AB = Slope of BC = Slope of CD

= Slope of AD

★ Slope of AD $= \dfrac{40-(-20)}{\log_{10}100 - \log_{10}0.1}$

$= \dfrac{60}{\log_{10}\left(\frac{100}{0.1}\right)}$

$$\boxed{\text{Slope of AD} = 20\ \text{dB/dec.}}$$

* Frequency Response :-

↳ Magnitude + Phase

Q. Draw the frequency response of the following Transfer function.

$$T(s) = \frac{1}{2s+1}$$

→

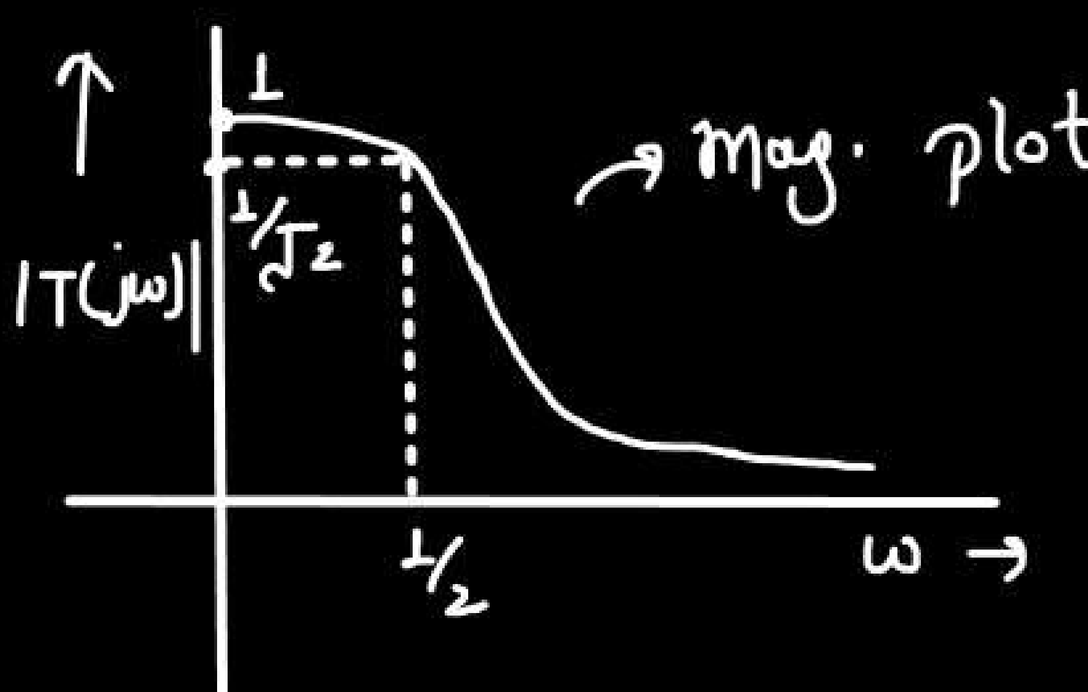
$$s = j\omega$$

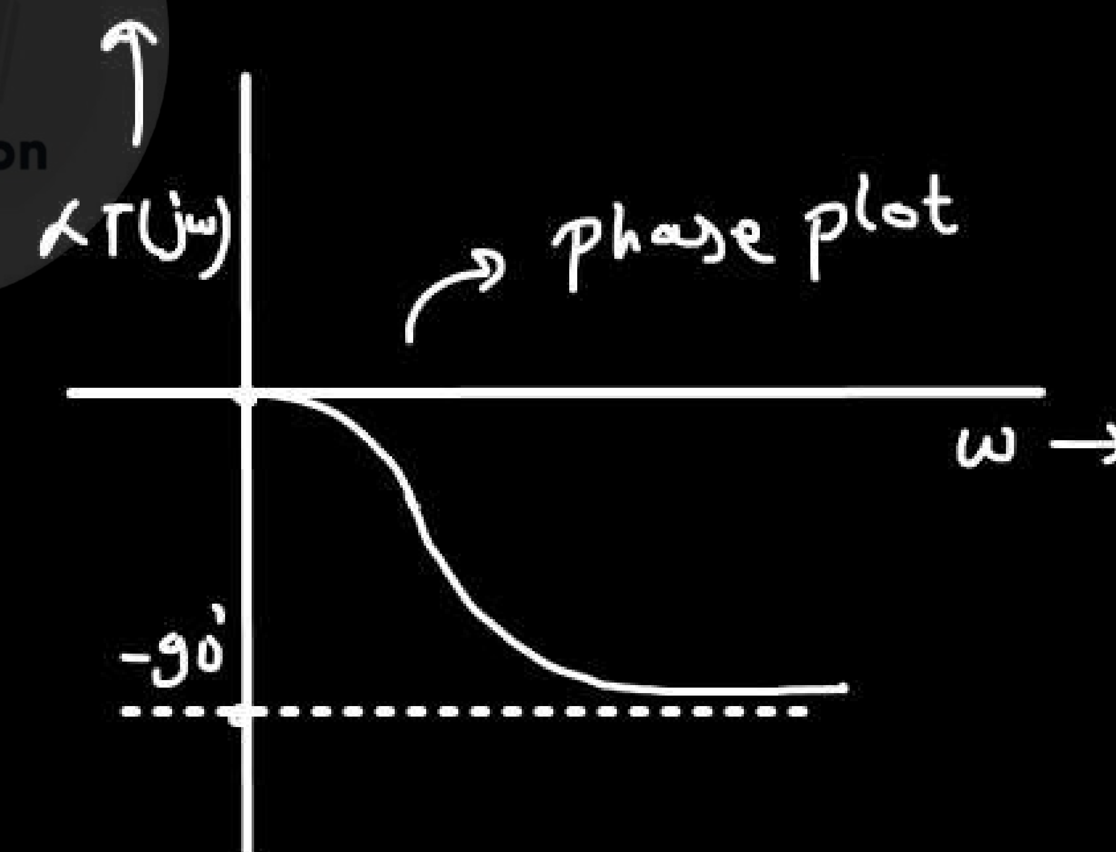
$$T(j\omega) = \frac{1}{2j\omega + 1}$$

$$|T(j\omega)| = \frac{1}{\sqrt{1+4\omega^2}} \qquad \angle T(j\omega) = -\tan^{-1}(2\omega)$$

$$|T(j\omega)| = \frac{1}{\sqrt{1+4\omega^2}} \qquad \angle T(j\omega) = -\tan^{-1}(2\omega)$$

ω	$\lvert T(j\omega)\rvert$	$\angle T(j\omega)$
0	1	0°
$1/2$	$1/\sqrt{2}$	-45°
∞	0	-90°





Q. Draw the frequency response of the following Transfer function.

$$T(s) = \frac{1}{2s}$$

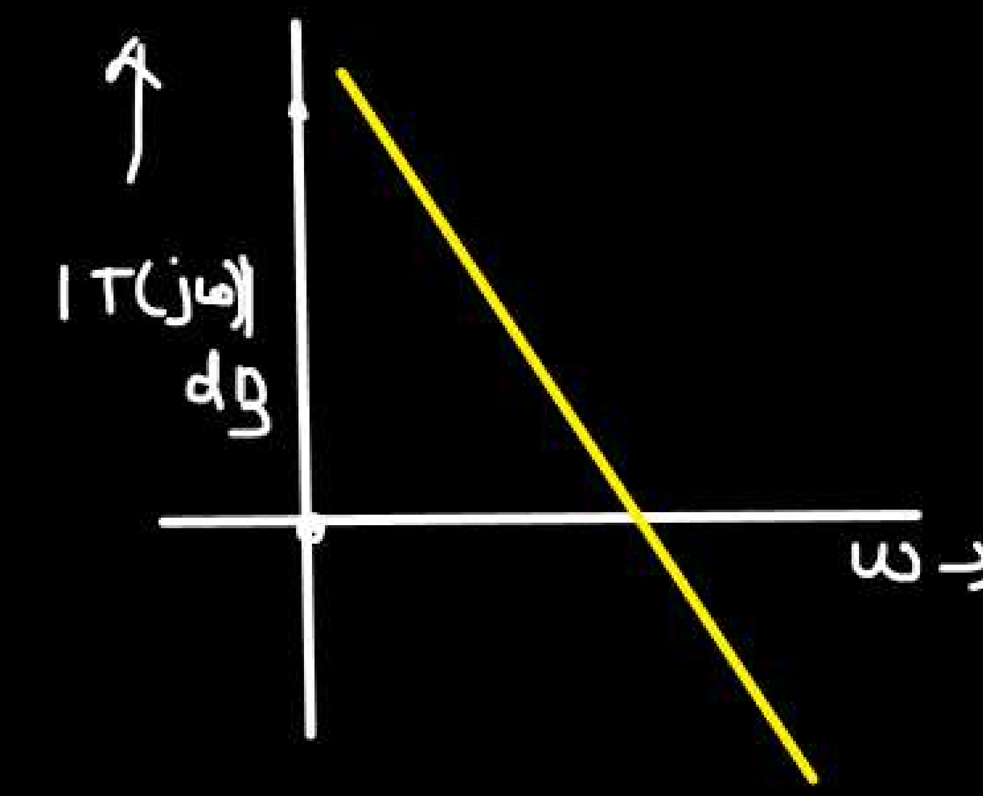
take gain in dB.

→

$$T(j\omega) = \frac{1}{2j\omega}$$

$$|T(j\omega)| = \frac{1}{2\omega}$$

ω	$\lvert T(j\omega)\rvert$	$\lvert T(j\omega)\rvert$ dB
0	∞	∞
1	1/2	-6
∞	0	$-\infty$



Q. Draw the frequency response of the following Transfer function.

$$T(s) = \frac{1}{2s}$$

take gain in dB. Take x-axis in log-scale.

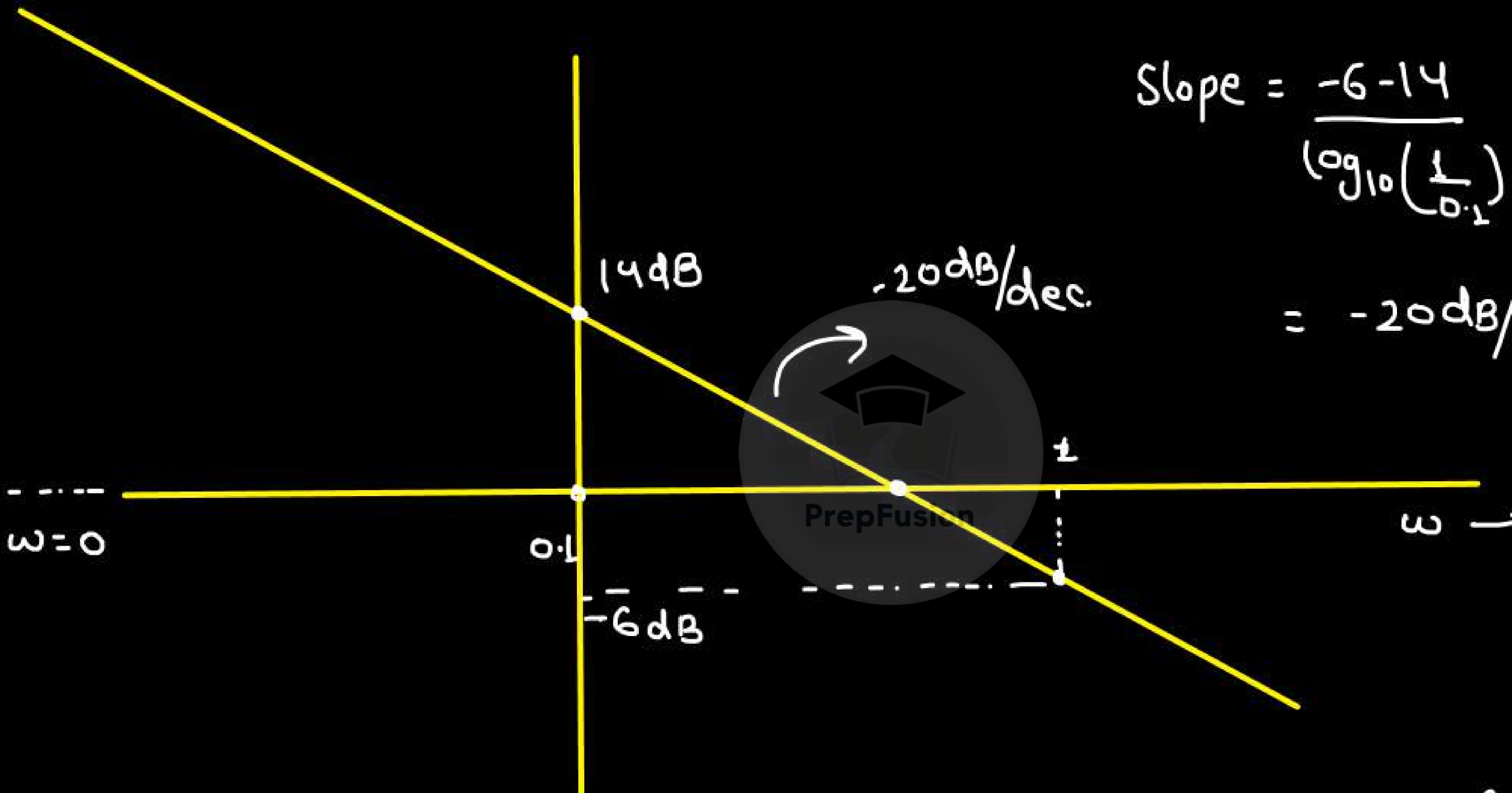
→ (i) you have a pole @ $\omega = 0$

$$T(j\omega) = \frac{1}{2j\omega}$$

$$|T(j\omega)| = \frac{1}{2\omega}$$

ω	$\lvert T(j\omega)\rvert$	$\lvert T(j\omega)\rvert_{dB}$
0	∞	∞
0.1	5	13.97
1	1/2	-6
∞	0	$-\infty$

when $\omega = 0 \Rightarrow$ log scale will take $\underline{\underline{\log_{10}(0) = -\infty}}$



$$\text{Slope} = \frac{-6-14}{\log_{10}\left(\frac{1}{0.1}\right)}$$

$$= -20\,\text{dB/dec.}$$

<u>Imp.</u> $\boxed{\text{N.B.} \rightarrow \text{A pole gives you a slope of } -20\,\text{dB/dec.}}$

n poles give $-20n$ dB/dec. slope.

Q. Draw the frequency response of the following Transfer function.

$$T(s) = 2s$$

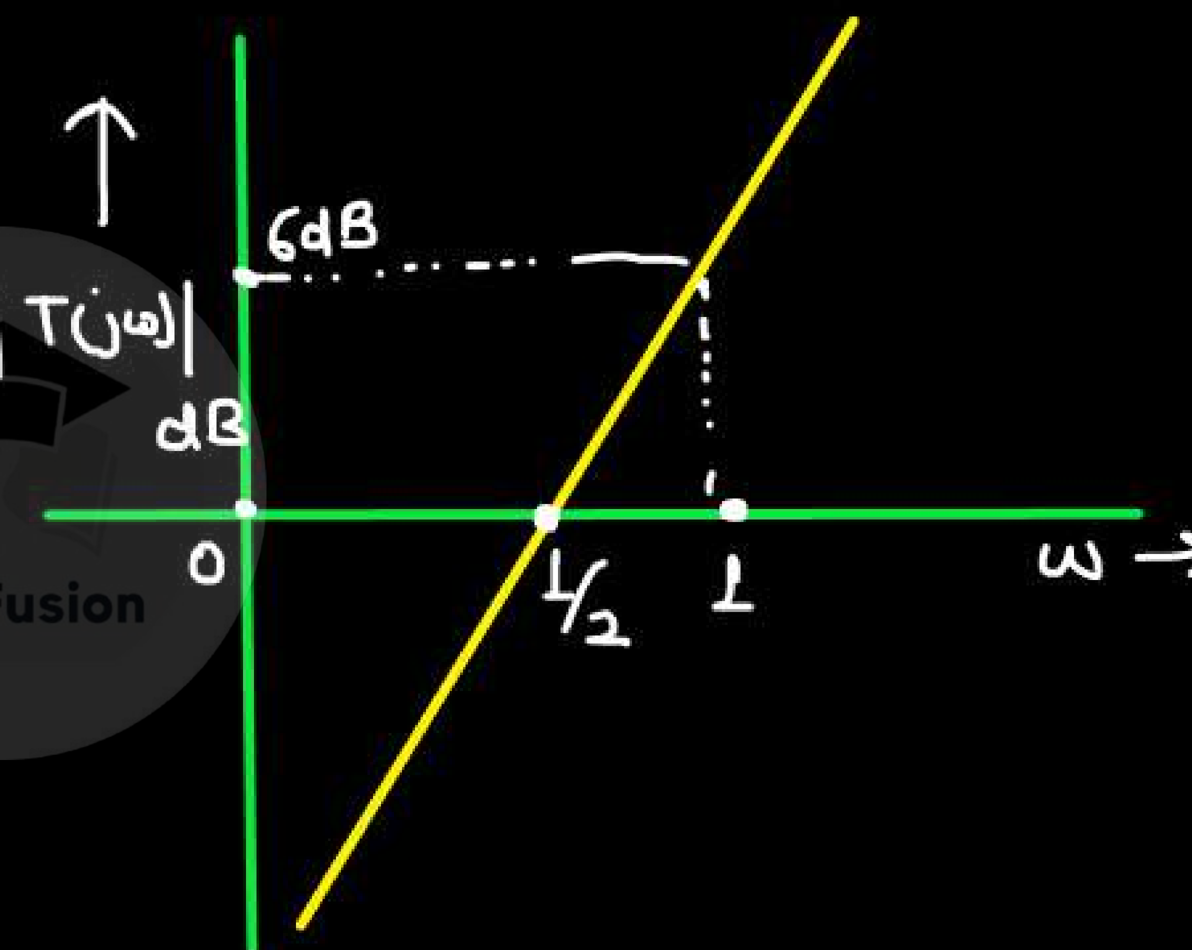
take gain in dB.

→

$$T(j\omega) = 2j\omega$$

$$|T(j\omega)| = 2\omega$$

ω	$\lvert T(j\omega)\rvert_{dB}$	
0	$-\infty$	
1	6	
∞	∞	
$1/2$	0	



Q. Draw the frequency response of the following Transfer function.

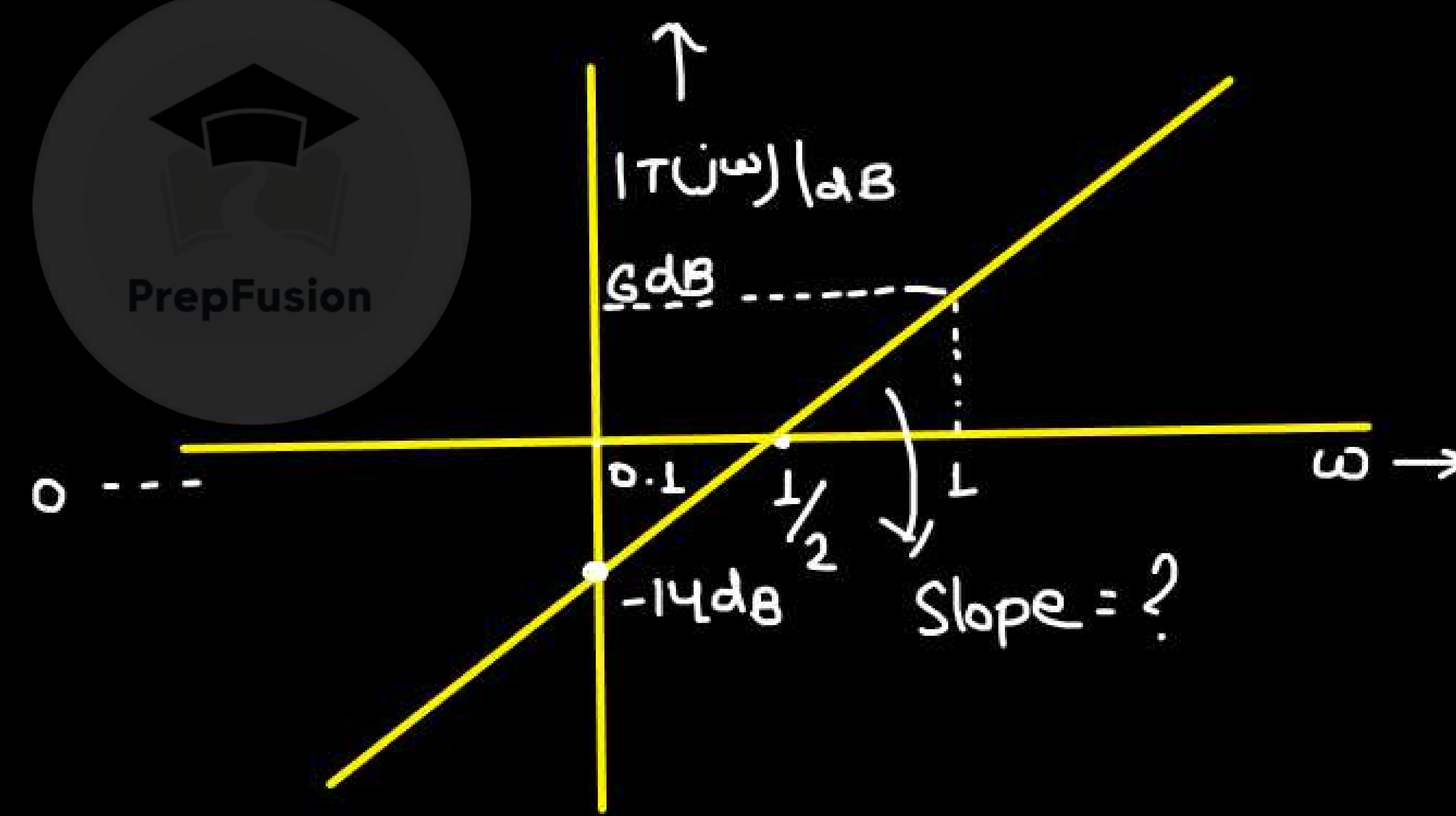
$$T(s) = 2s$$

take gain in dB. Take x-axis in log scale.

→ $T(j\omega) = 2j\omega$

$|T(j\omega)| = 2\omega$

ω	$\lvert T(j\omega)\rvert_{dB}$
0	$-\infty$
0.1	-14
$1/2$	0
1	6
∞	∞



$1/2$

$$\text{Slope} = \frac{6-(-14)}{\log_{10}(1/0.1)}$$

$$\boxed{\text{Slope} = 20\,\text{dB/dec.}}$$

Here, you had a zero @ $\omega = 0$

Imp, $\boxed{\text{A zero will give you a } 20\,\text{dB/dec slope.}}$

n zero will give you $20n$ dB/dec. slope.

* Bode plot:-

Important points:-

1. A pole gives a slope of -20 dB/dec.
2. A zero gives a slope of 20 dB/dec.
3. Assumption made in bode plot-

Let $T(S) = S\tau + 1$

$\Rightarrow$ For $S\tau < 1$

$T(S) \approx 1$

For $S\tau > 1$

$T(S) \approx S\tau$

* For bode plot
  - ↳ gain will be in dB
  - ↳ x-axis will be in log scale

$\underbrace{\qquad\qquad}_{\text{Semi-log graph paper}}$

Q. Draw the bode plot for the T.F.

$$T(s) = \frac{3}{2s+1}$$

→ ① Find the dc gain in dB

$$(\omega = 0)$$

$$T(j\omega) = \frac{3}{2j\omega + 1}$$

$$T(j0) = 3$$

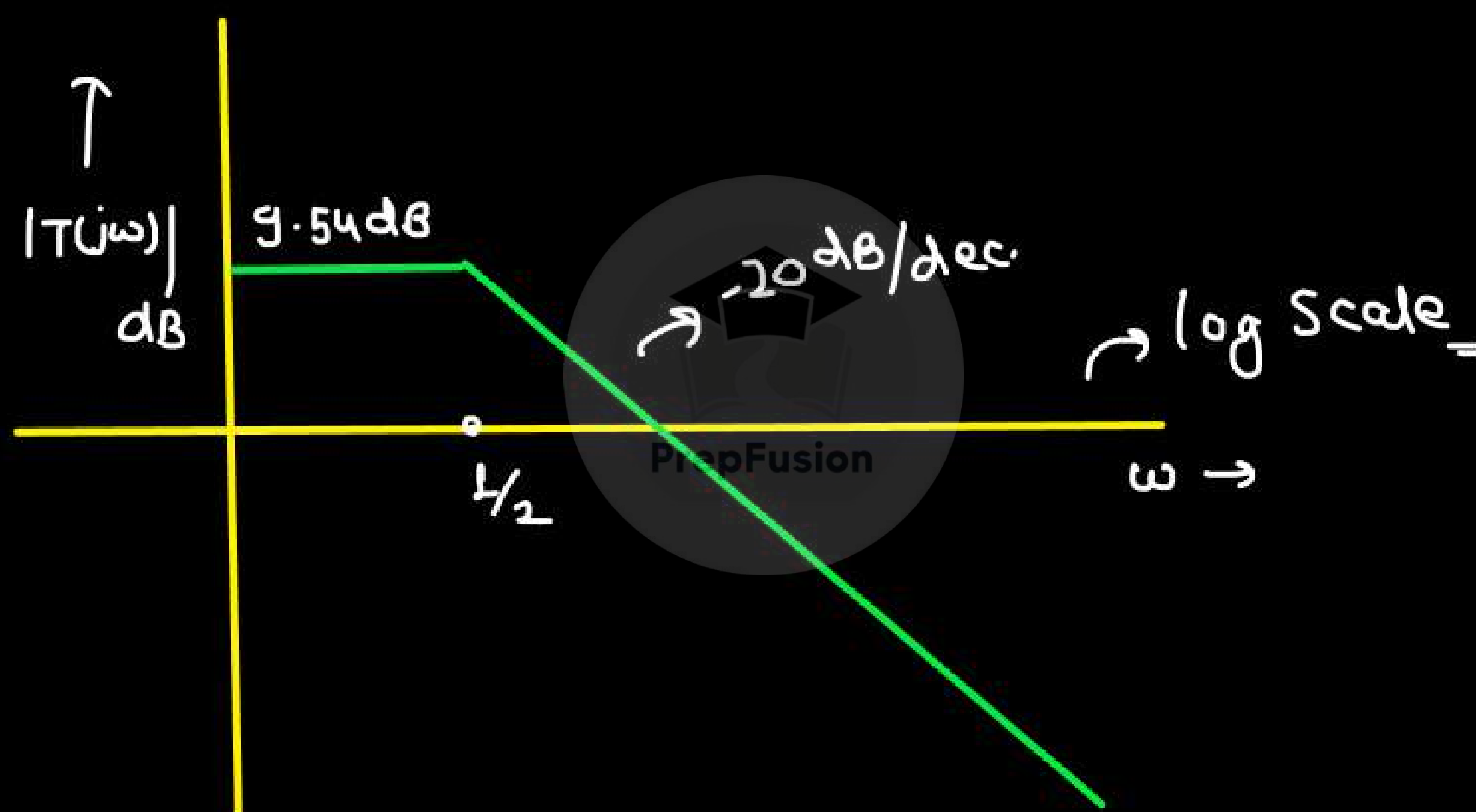
$$|T(j0)| = 20\log_{10} 3 = \underline{\underline{9.54\,dB}} \rightarrow \text{dc gain}$$

② Find location of poles and zero

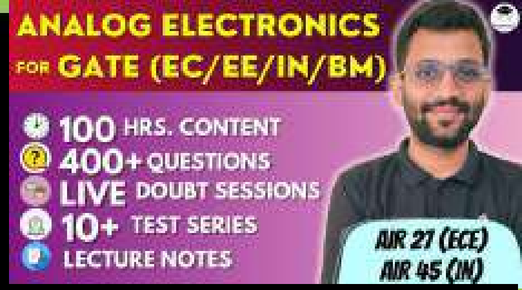
$\omega_p = -1/2$, no zeros

③ @ pole, -20 dB/dec slope.

@ zero, 20 dB/dec slope.



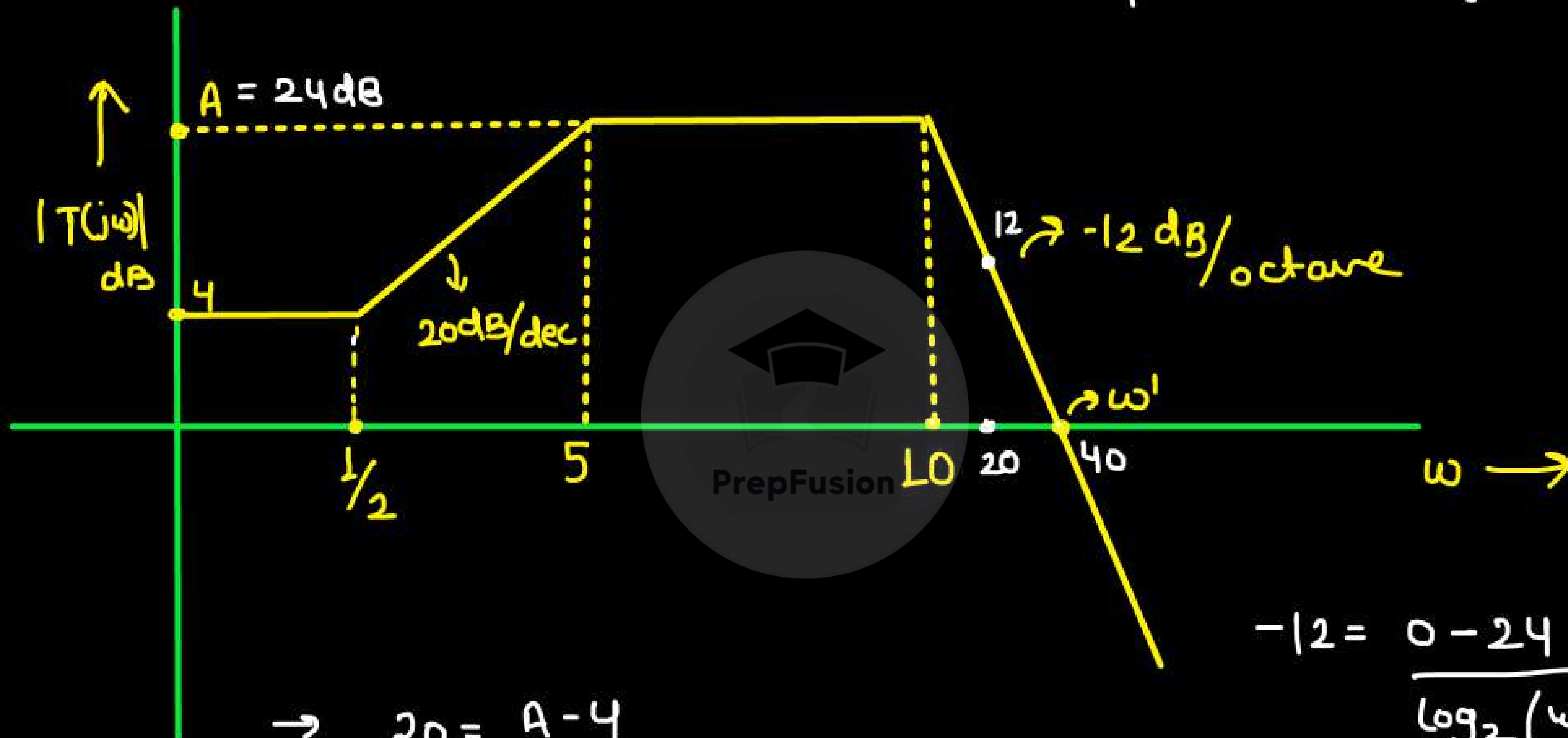
Bode Mag. Plot



Q. Find the value of A and ω'.

Freq. 2X ⇒ ±6n dB

Freq. 10X ⇒ ±20n dB



$$\rightarrow \quad 20 = \frac{A-4}{\log_{10}\left(\frac{5}{1/2}\right)}$$

$$\boxed{A = 24\,\text{dB}}$$

$$-12 = \frac{0-24}{\log_2\left(\frac{\omega'}{10}\right)}$$

$$\boxed{\omega' = 40\ \text{rad/sec.}}$$

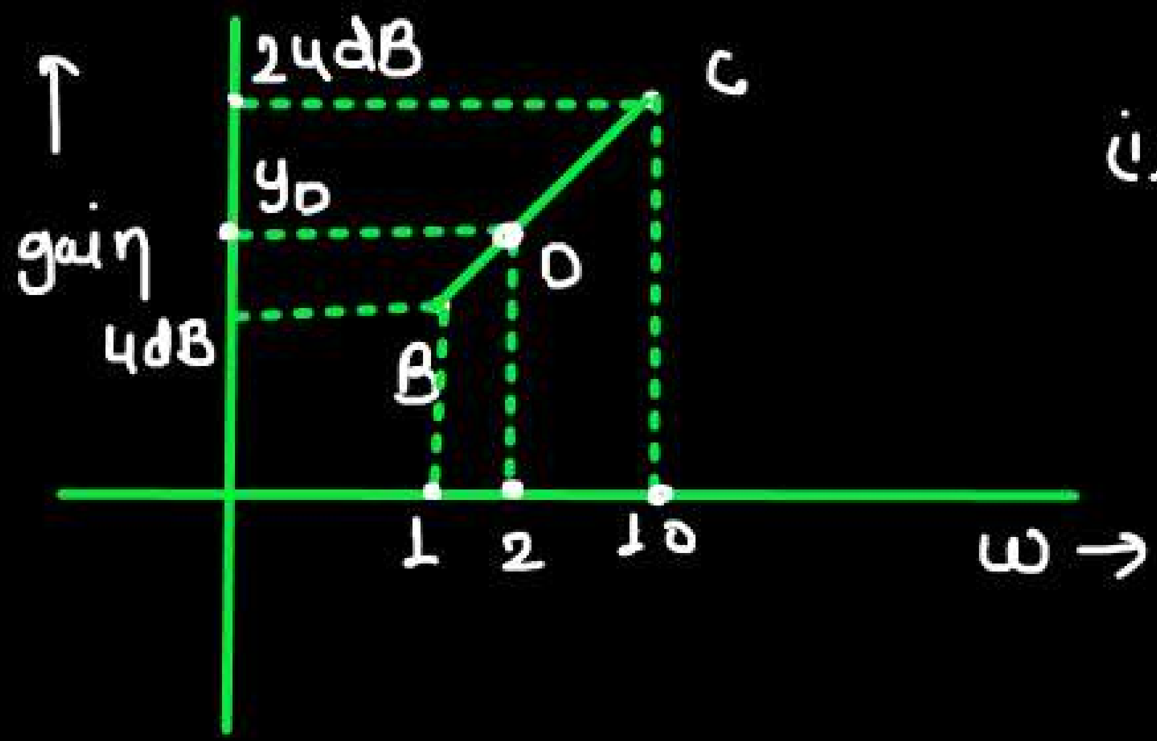
$dB/dec.$

$$\text{Slope} = \frac{[y_2 - y_1]\ dB}{\log_{10}\left(\frac{x_2}{x_1}\right)}$$

$dB/octave$

$$\text{Slope} = \frac{[y_2 - y_1]\ dB}{\log_2\left(x_2/x_1\right)}$$

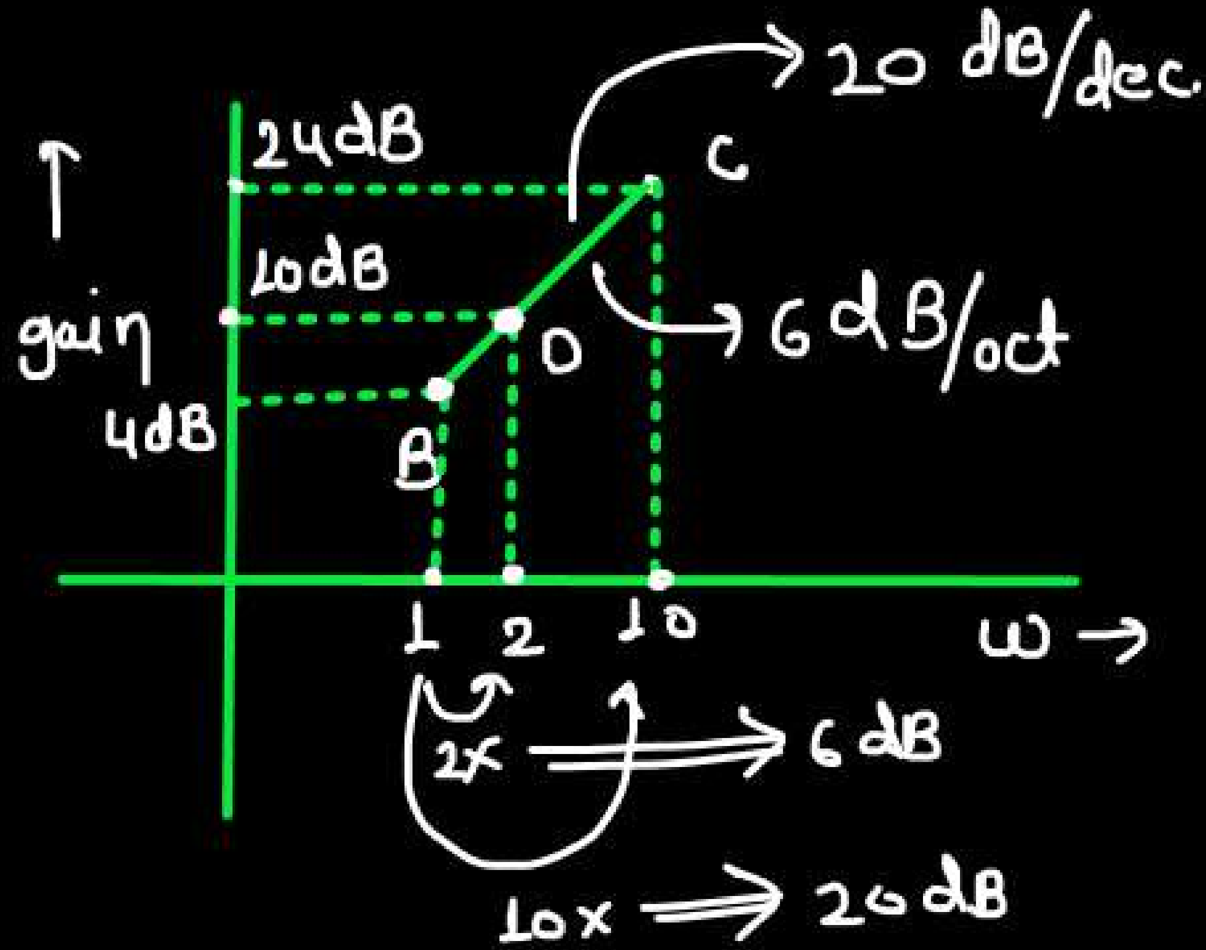
$$\boxed{20\ dB/dec = 6\ dB/oct}$$



(i) $\text{slope of } BC = \dfrac{20}{\log_{10}(10)} = 20\ dB/dec.$

(ii) $20 = \dfrac{y_D - 4}{\log_{10}(2)} \Rightarrow y_D = 4 + 20\log_{10}(2)$

$$\boxed{y_D = 10\,dB}$$



dB/oct

$$\text{Slope} = \frac{24-4}{\log_2(10)}$$

$$\boxed{\text{Slope} = 6\ \text{dB/oct}}$$

* $20\ \text{dB/dec} = 6\ \text{dB/oct}$

$40\ \text{dB/dec} = 12\ \text{dB/oct}$

** $\boxed{\pm 20n\ \text{dB/dec} = \pm 6n\ \text{dB/oct}}$

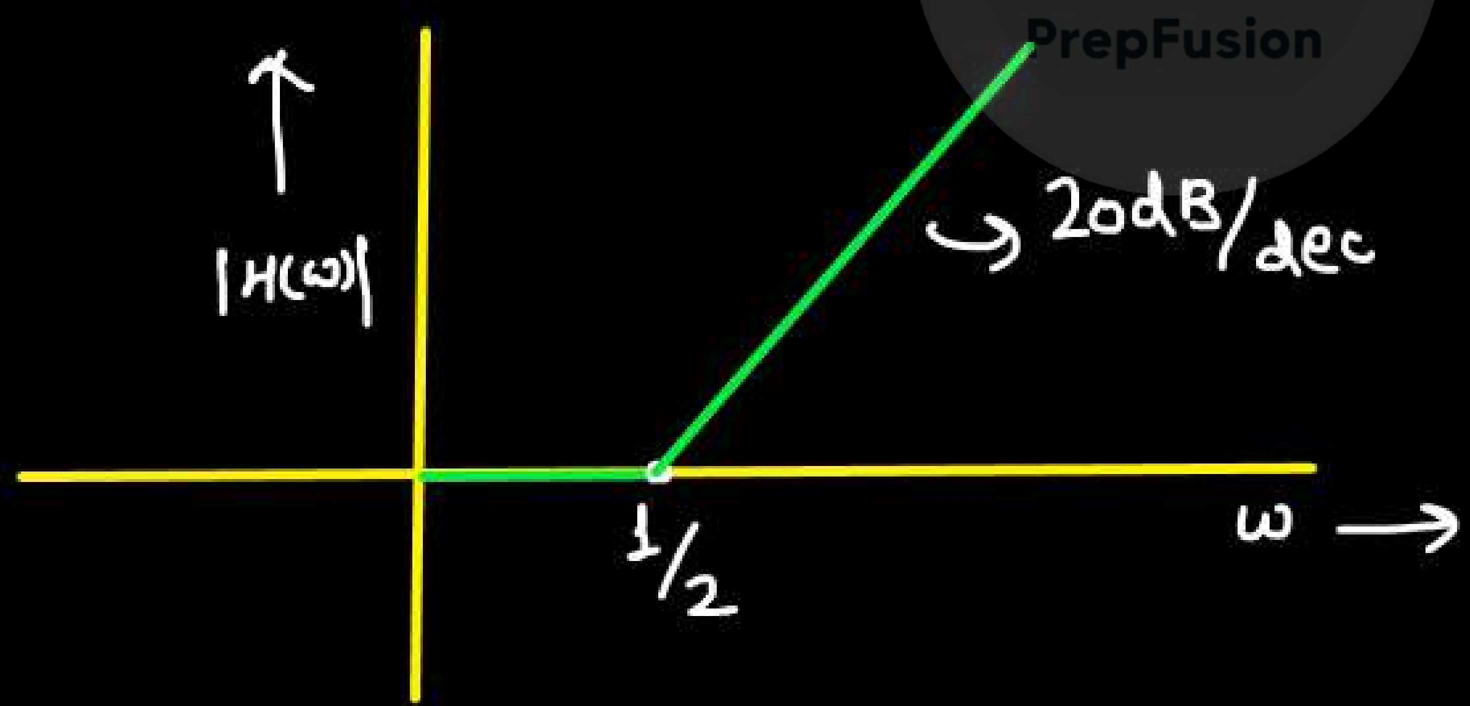
Q. Draw bode plot for

$$T(s) = 2s + 1$$

→ Dc gain ($\omega = 0$)

$$|T(j\omega)| = 1 = 0\ dB$$

$\omega_z = -1/2 \rightarrow$ zero will give $+20\ dB/dec$ slope.



Q. Draw bode plot for

$$T(s) = \frac{10(s+4)}{(s+2)(s+10)}$$

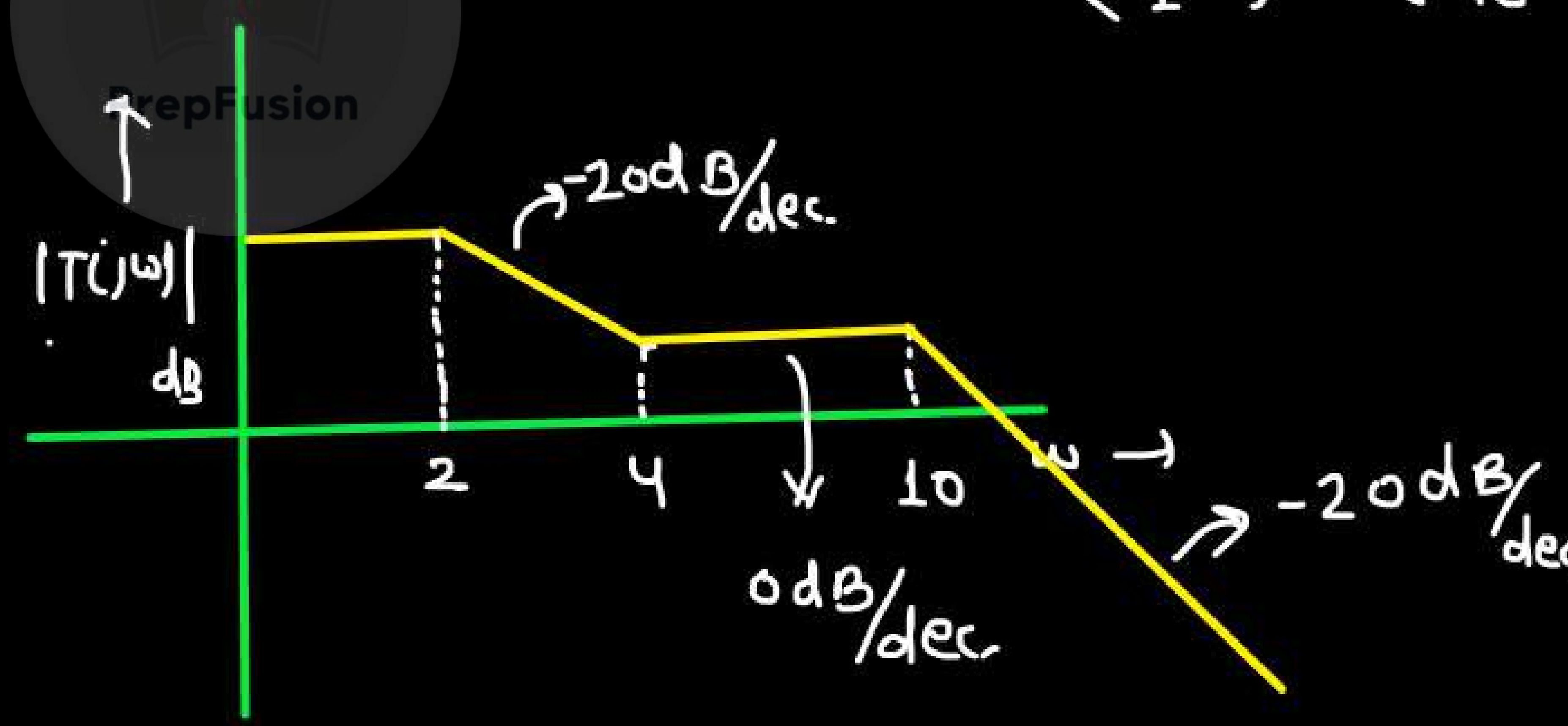
→ Dc gain $= \frac{10\times4}{10\times2} = 2 \Rightarrow 20\log 2 = 6\,dB$

$>1 \Rightarrow +ve\ dB$

$<1 \Rightarrow -ve\ dB$

$\omega_p = -2, -10$

$\omega_z = -4$



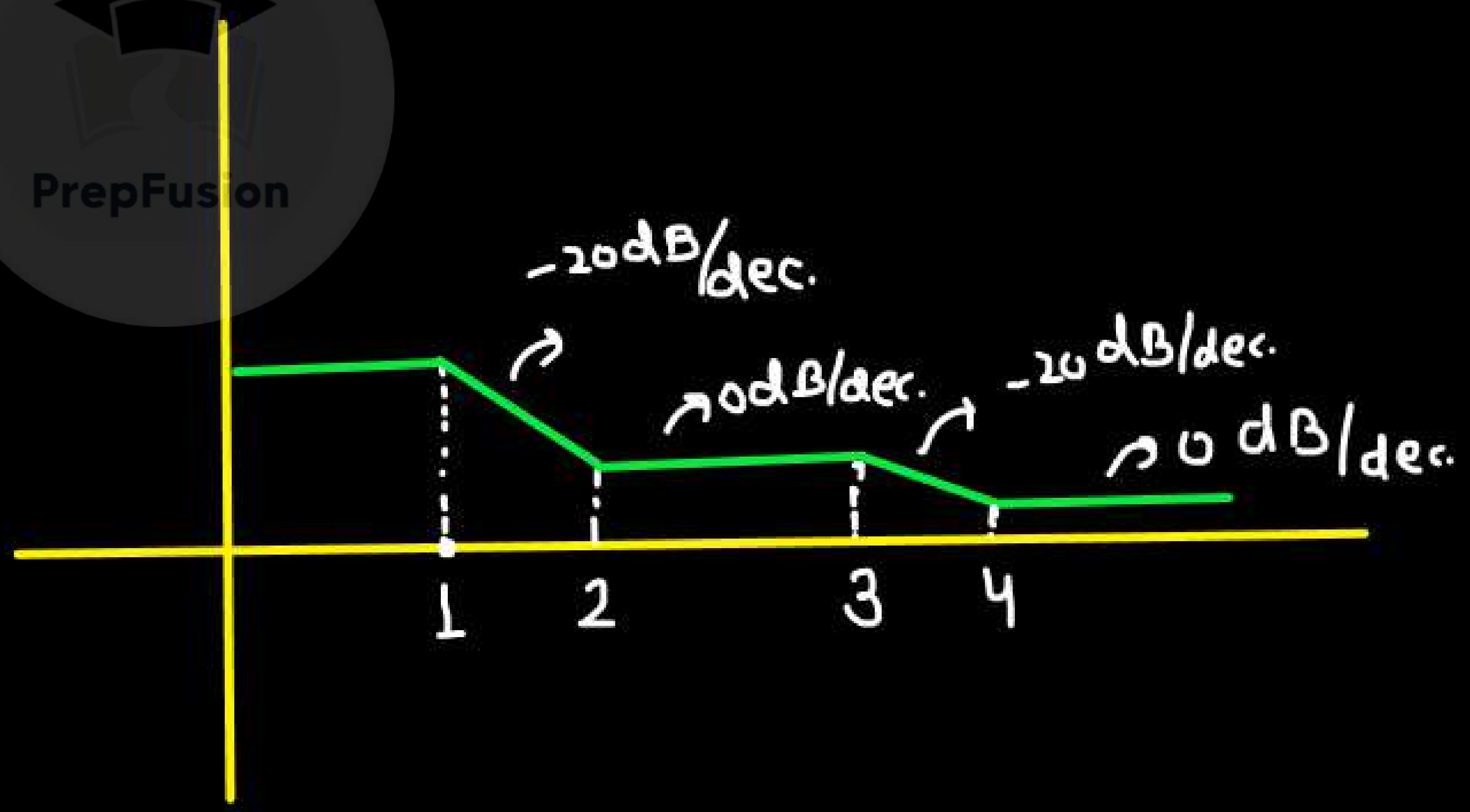
Q. Draw bode magnitude plot for

$$T(s) = \frac{10(s+2)(s+4)}{(s+1)(s+3)}$$

→ dc gain $= 80/3 = 28.5\,dB$

$\omega_p = -1, -3$

$\omega_z = -2, -4$



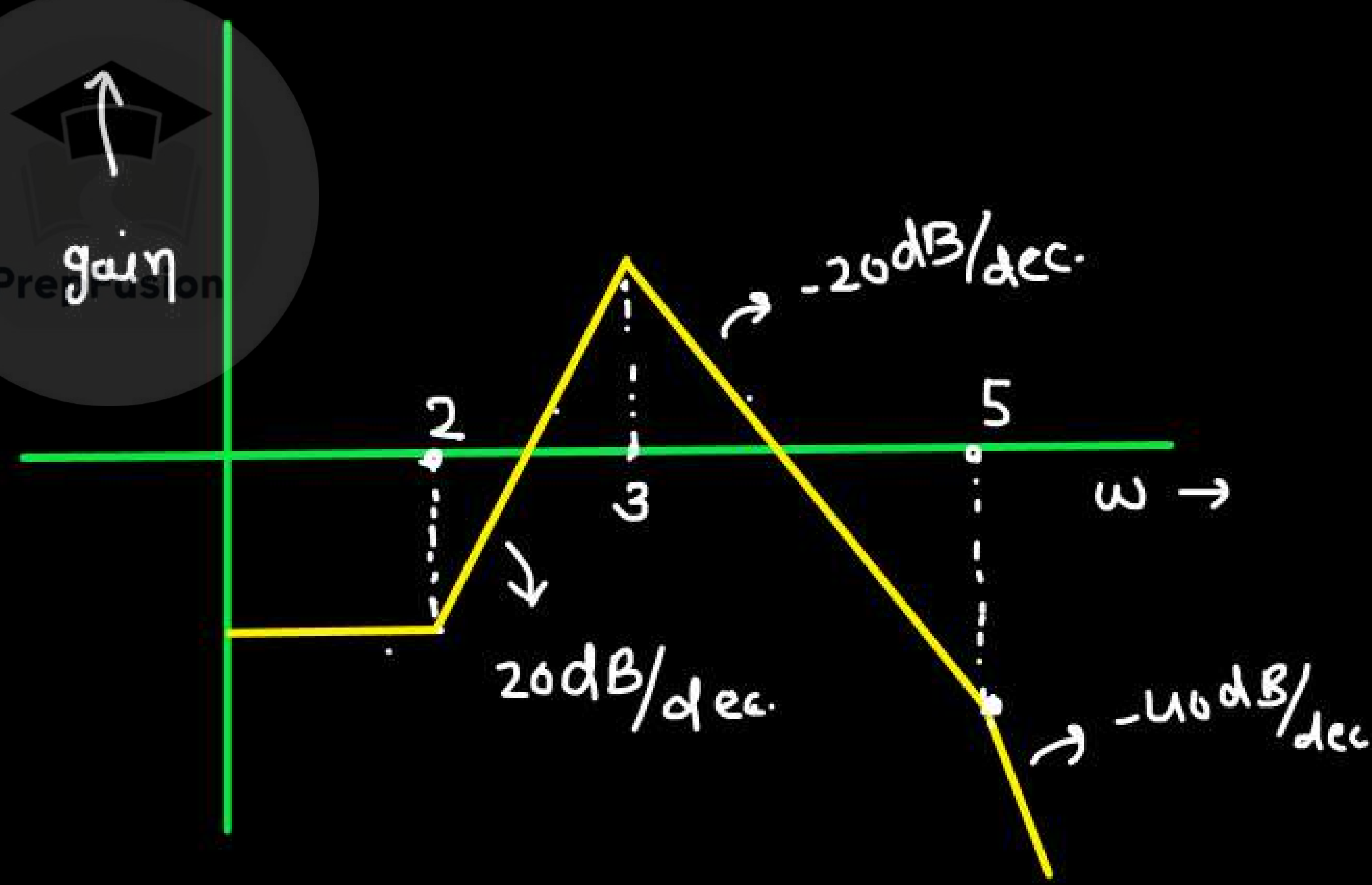
Q. Draw bode-plot for

$$T(s) = \frac{10(s+2)}{(s+3)^2(s+5)}$$

→ dc gain = -7

$\omega_p = -3, -3, -5$

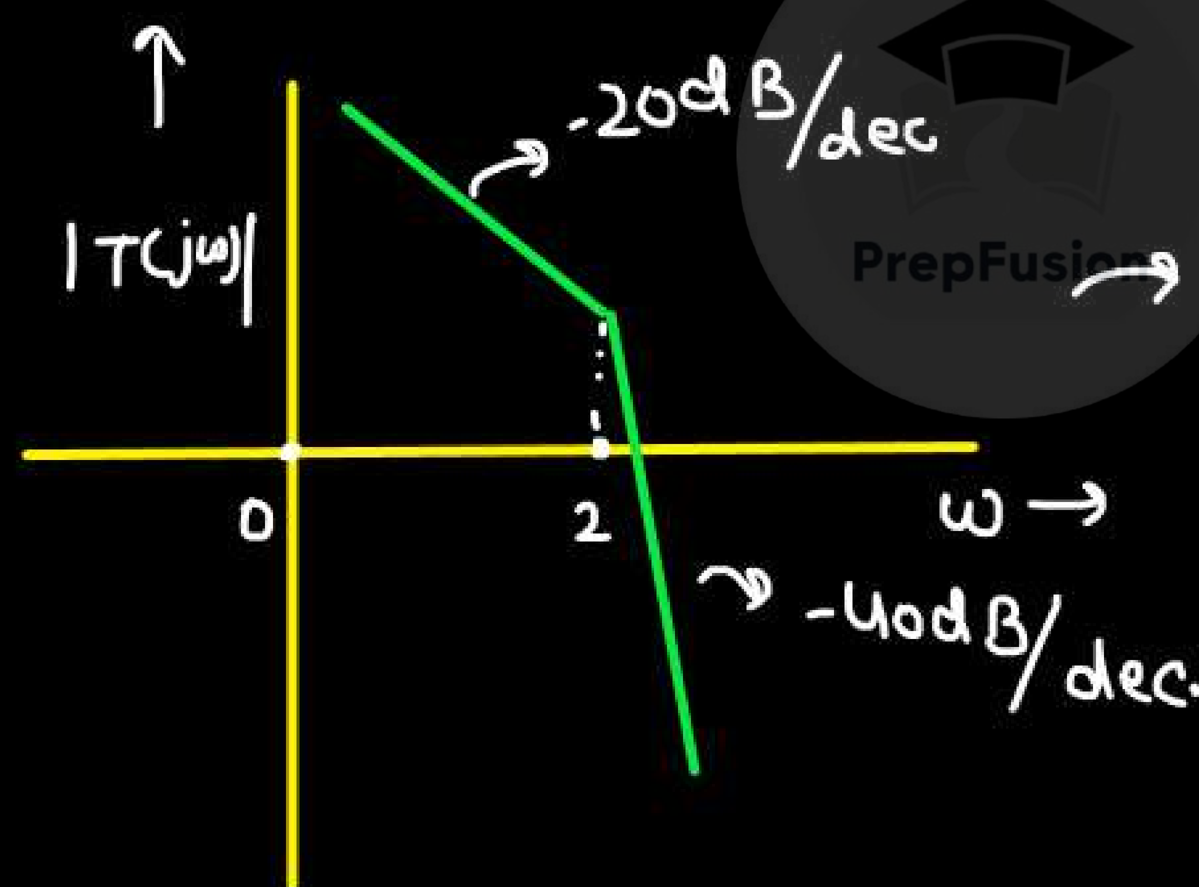
$\omega_z = -2$



Q. Draw bode plot for:-

$$T(s) = \frac{2}{s(s+2)}$$

→ dc gain $= \infty = \infty$ dB , poles $= 0, -2$

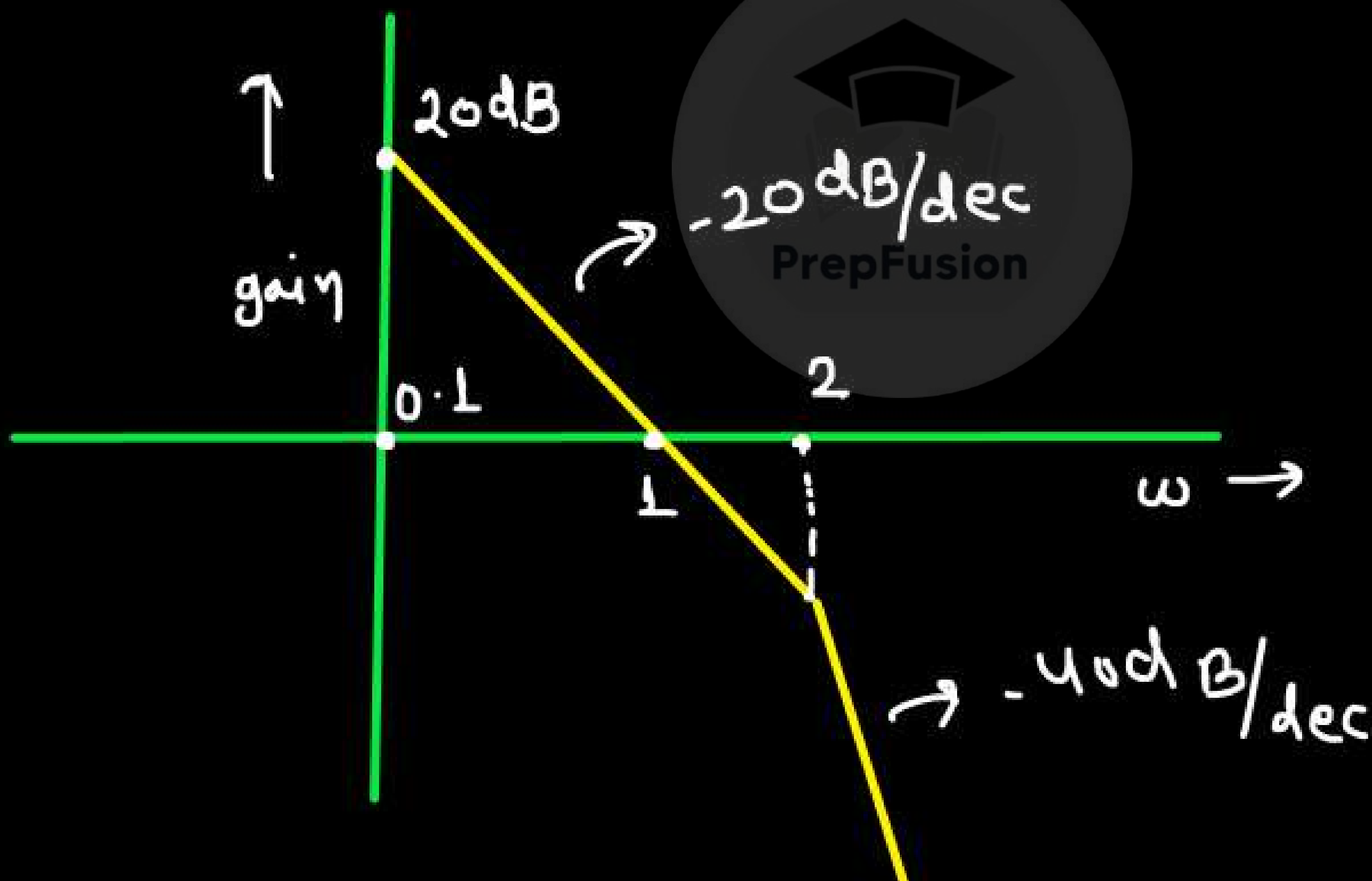


→ not correct

gain $\omega = 0.1$

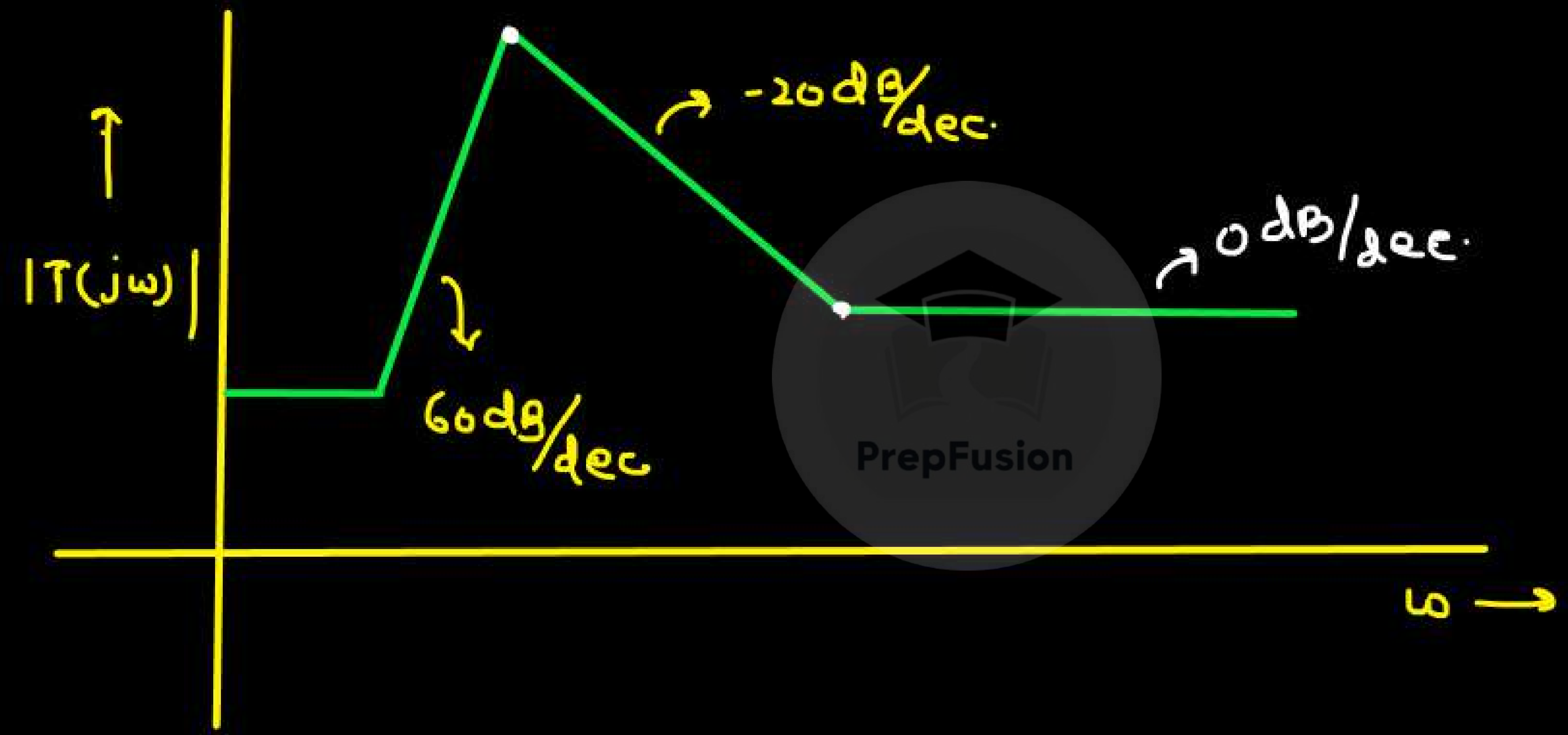
Here, we have pole @ $\omega = 0$ [Type-1 s/s]

$$T(j0.1) = \frac{2}{(0.1)(2)} = 10 \Rightarrow 20\,dB$$



Q. Find the number of poles and zero of the Transfer f^n.

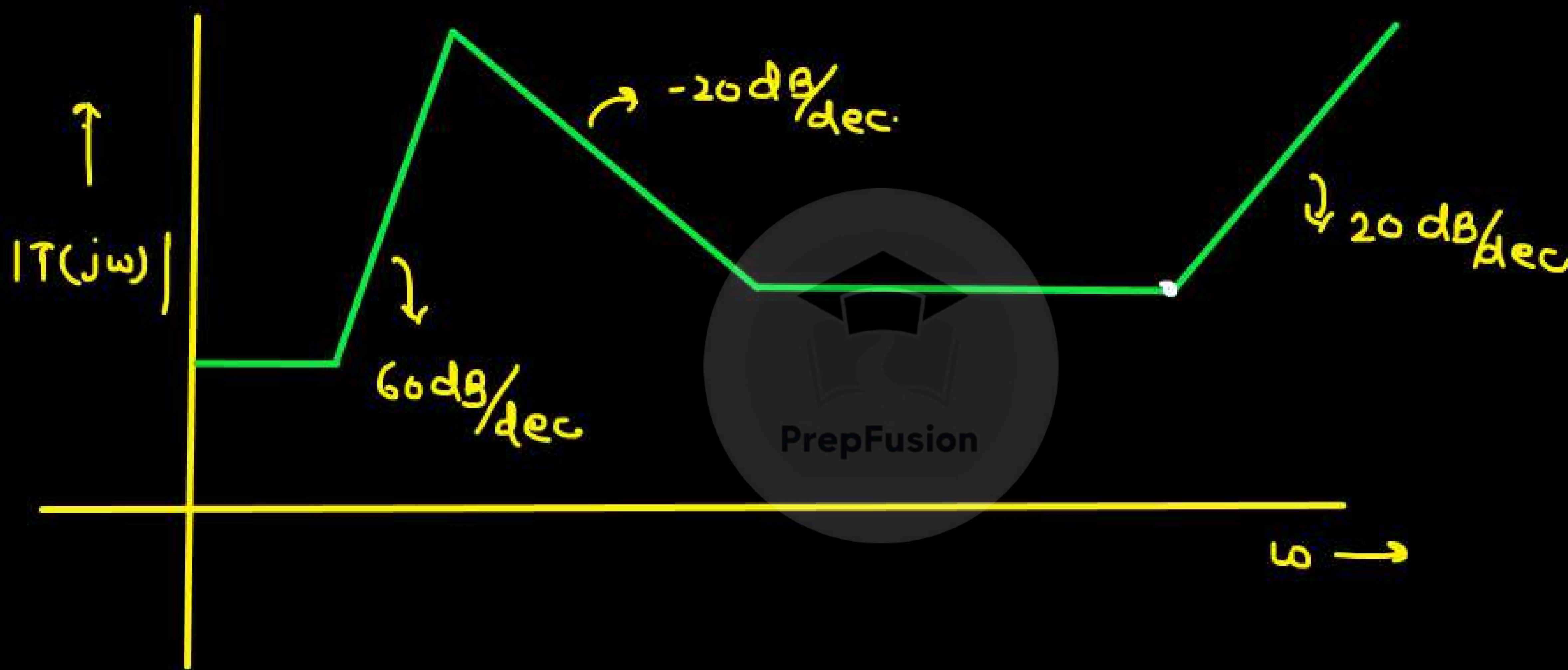
→



→ 3 zero + 4 poles + 1 zero ⇒ 4z + 4p

Q. Find the number of poles and zero of the Transfer f^n.

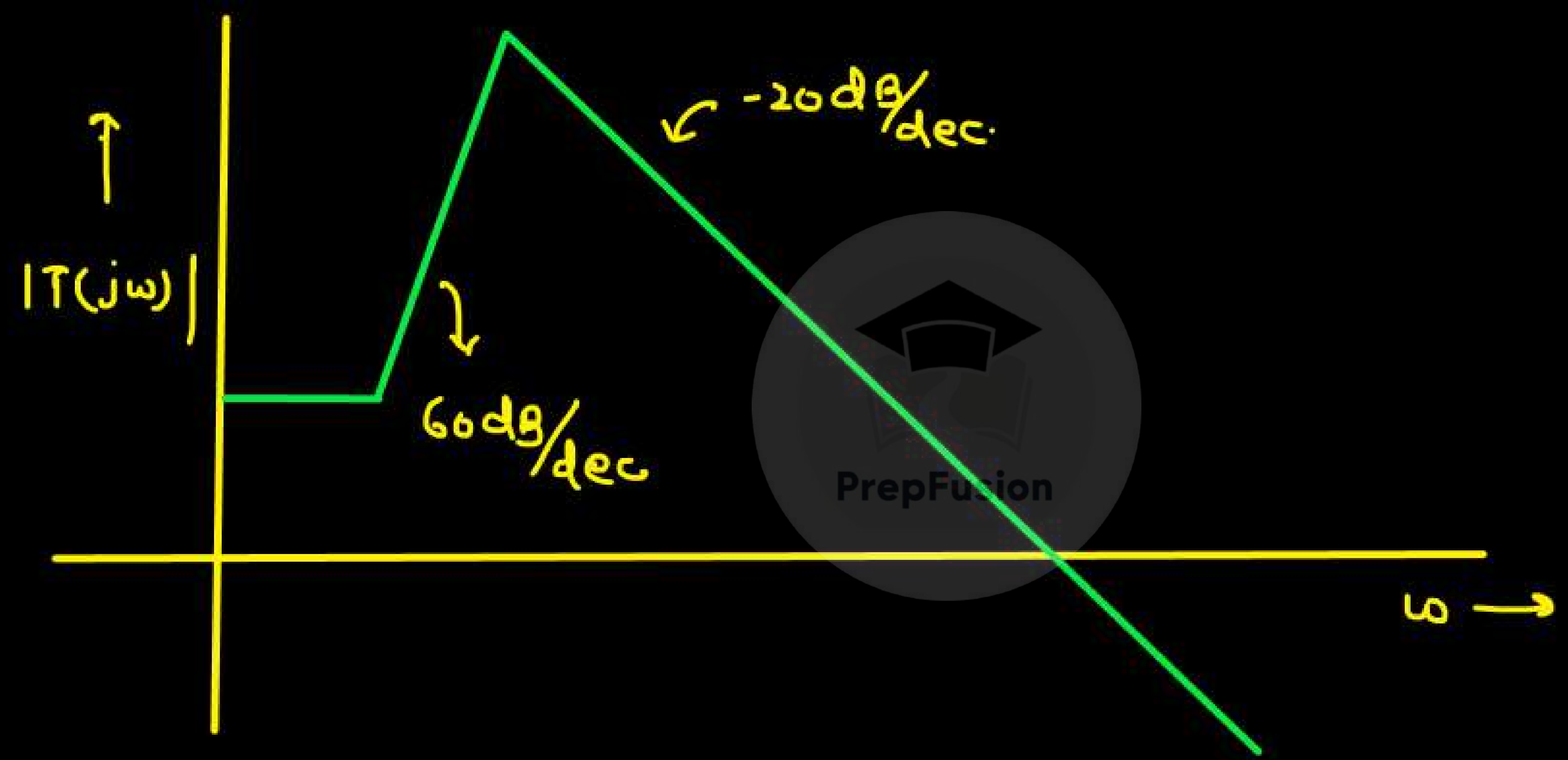
→



→ $4z + 4p + 1z \Rightarrow 5z + 4p$

Q. Find the number of poles and zero of the Transfer f^n.

→



$3Z + 4P$

N.B.:-

1. For $\omega = \infty \Rightarrow$ if the slope is 0 dB/dec

$\Downarrow$

no. of poles = no of zeros

2. For $\omega = \infty \Rightarrow$ if the slope is negative

$\Downarrow$

no. of poles > no. of zeros

3. For $\omega = \infty \Rightarrow$ if the slope is positive

$\Downarrow$

no. of poles < no. of zeros

★ Bode phase plot :-

Q. Draw phase plot for

$$T(s) = s\tau + 1$$

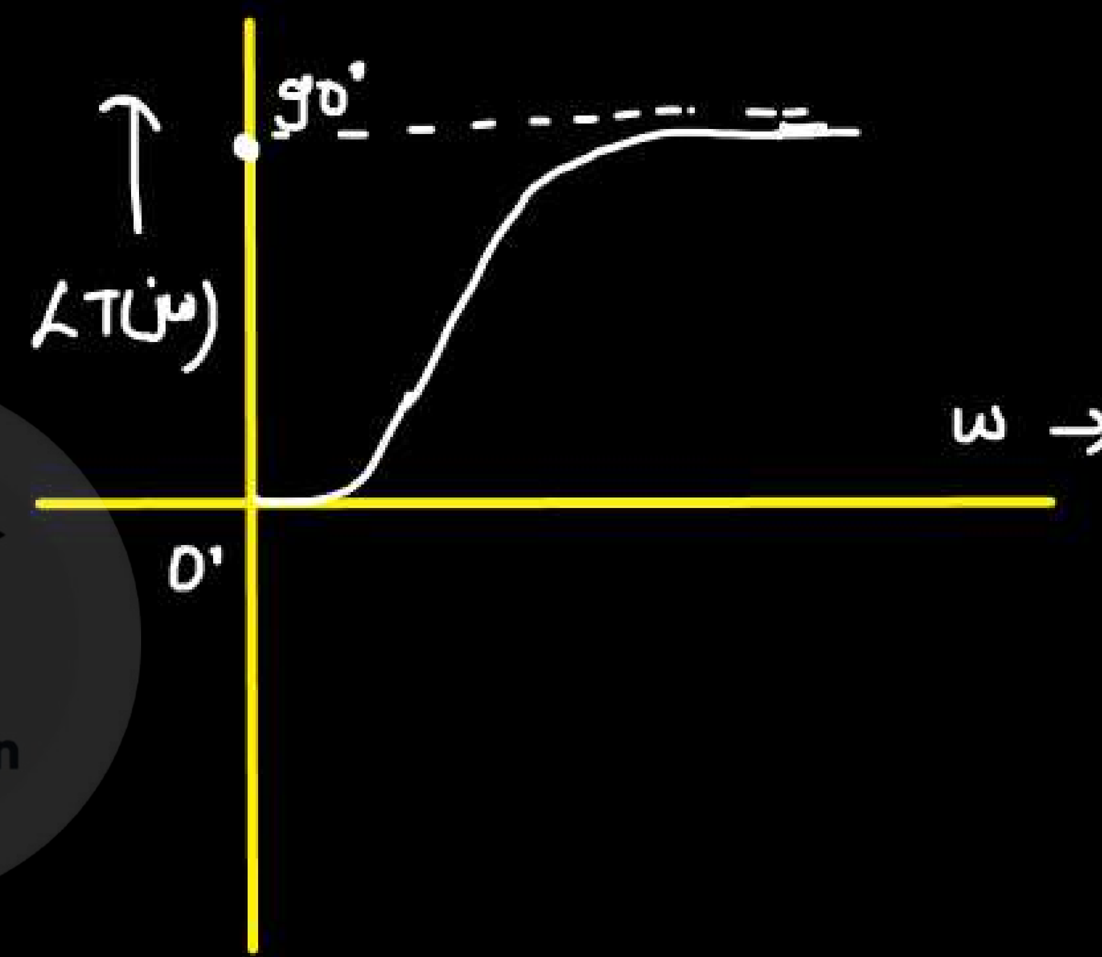
→

$$T(j\omega) = j\omega\tau + 1$$

$$\angle T(j\omega) = \tan^{-1}(\omega\tau)$$

$$\omega = 0 \Rightarrow \angle T(j0) = 0°$$

$$\omega = \infty \Rightarrow \angle T(j\infty) = 90°$$



Q. Draw Bode phase plot for

$$T(s) = 2s + 1$$

→ zero → $\omega_z = -1/2$

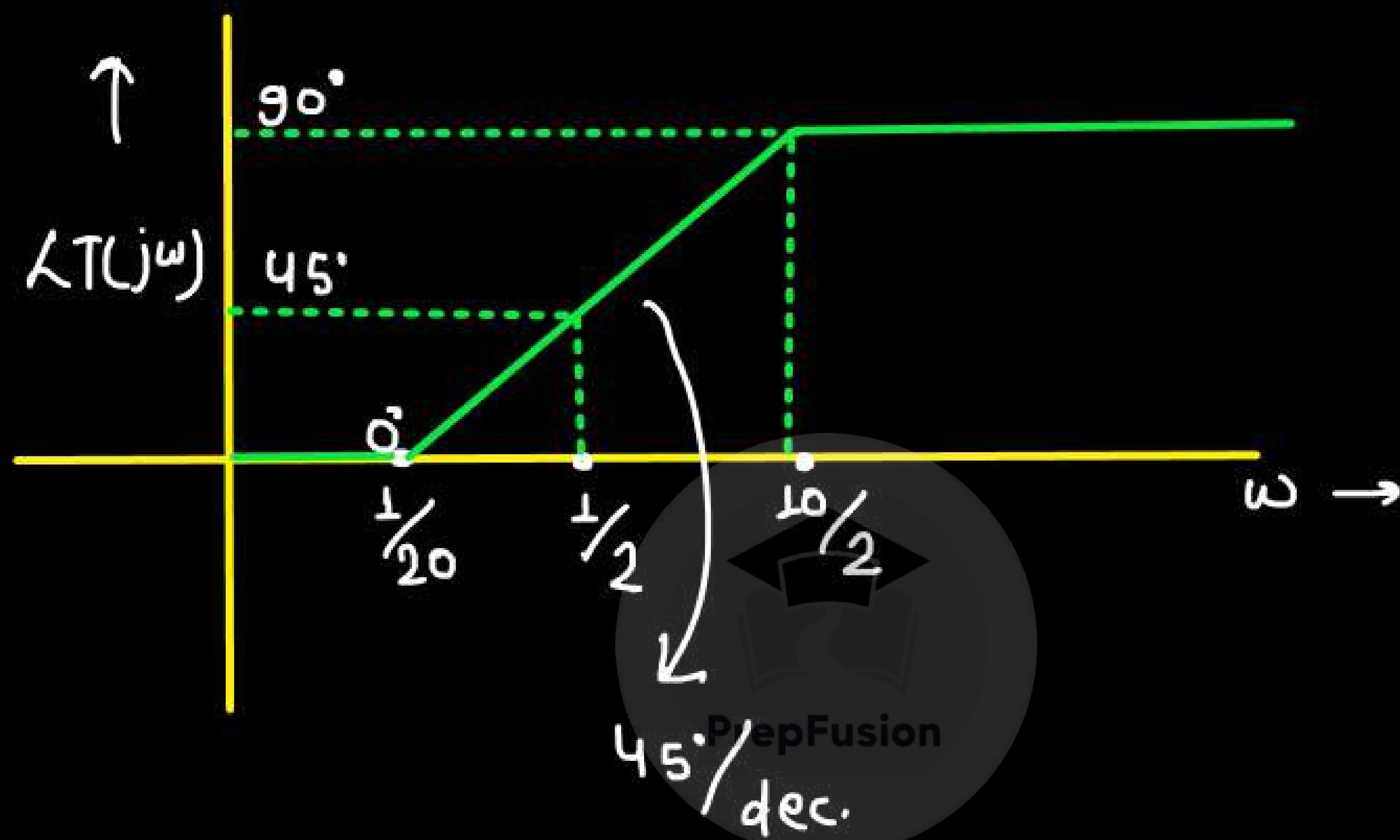
$\tan^{-1}(2 \times 1/2)$

$$\angle T(j\omega) = \tan^{-1}(2\omega)$$

ω	$\angle T(j\omega)$
$1/20$	$2.86°$ → very low ≈ $0°$ (Bode plot)
$1/2$	$45°$
$10/2$	84.28 ≈ $90°$ (Bode plot)

$\frac{1}{10} \times$

$10 \times$



$$\boxed{n \text{ zeros will give } 45°n/\text{dec. slope}}$$

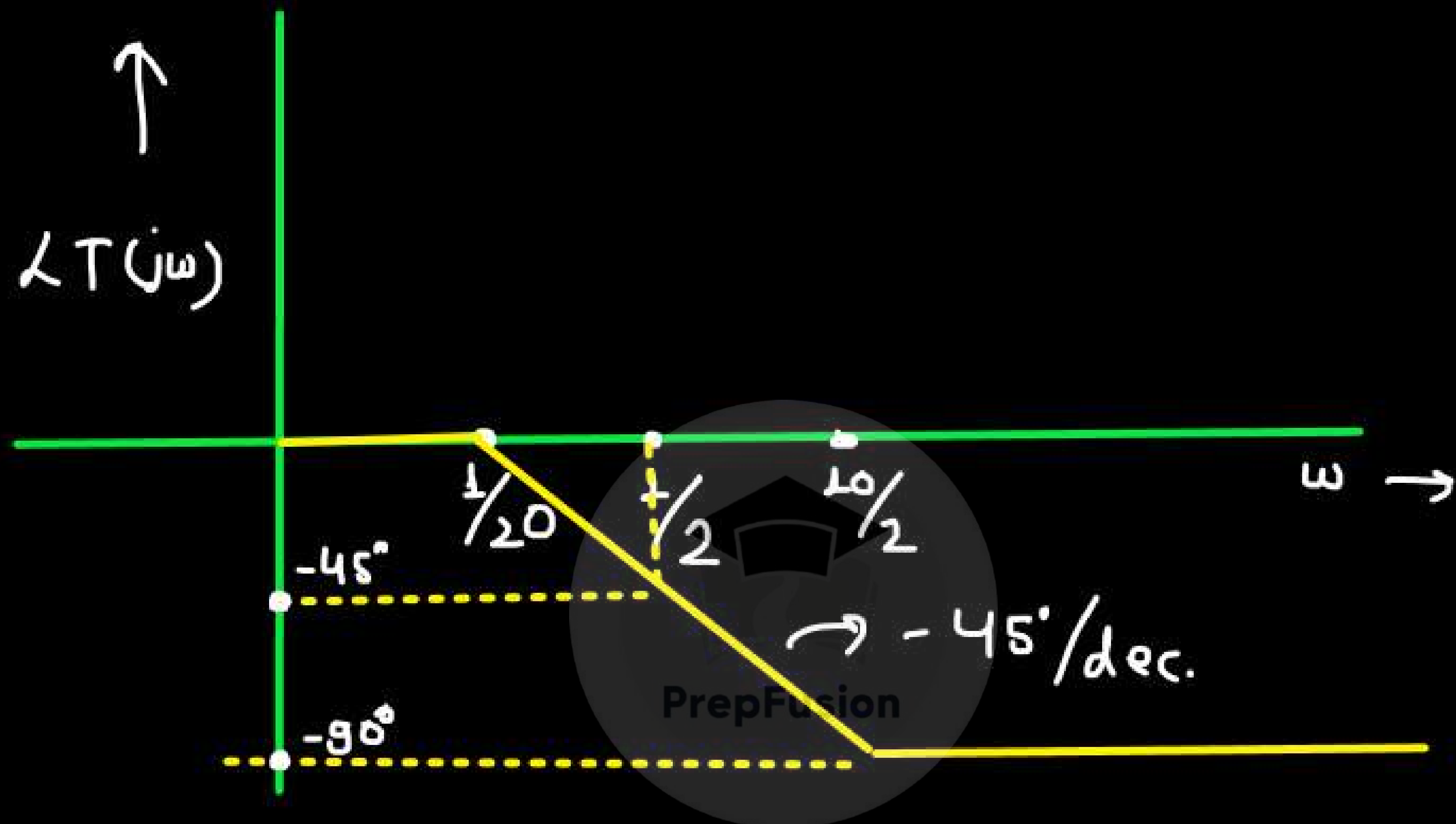
Q. Draw bode phase plot for

$$T(s) = \frac{1}{2s+1}$$

→

$$s_p = -\tfrac{1}{2} \qquad \angle T(j\omega) = -\tan^{-1}(2\omega)$$

s	$\angle T(j\omega)$
$1/20$	$-2.86^\circ \approx 0^\circ$
$1/2$	$-45^\circ \approx -45^\circ$
$10/2$	$-84.28^\circ \approx -90^\circ$



n poles will give you $-45n°/_{dec}$ slope.

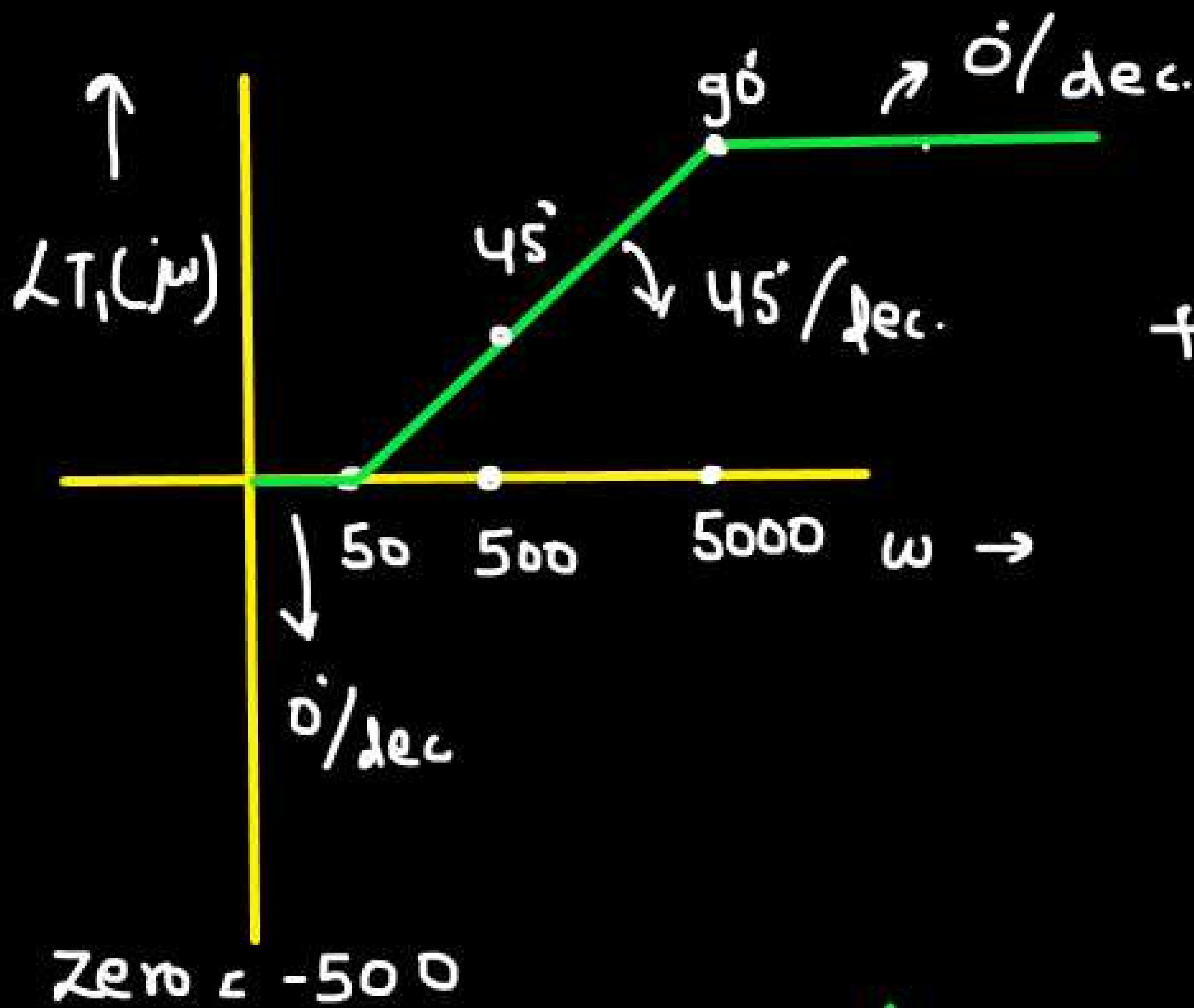
Q. Draw the bode phase plot for

$$T(s) = \frac{\left(1 + s/500\right)}{\left(1 + s/5\right)}$$

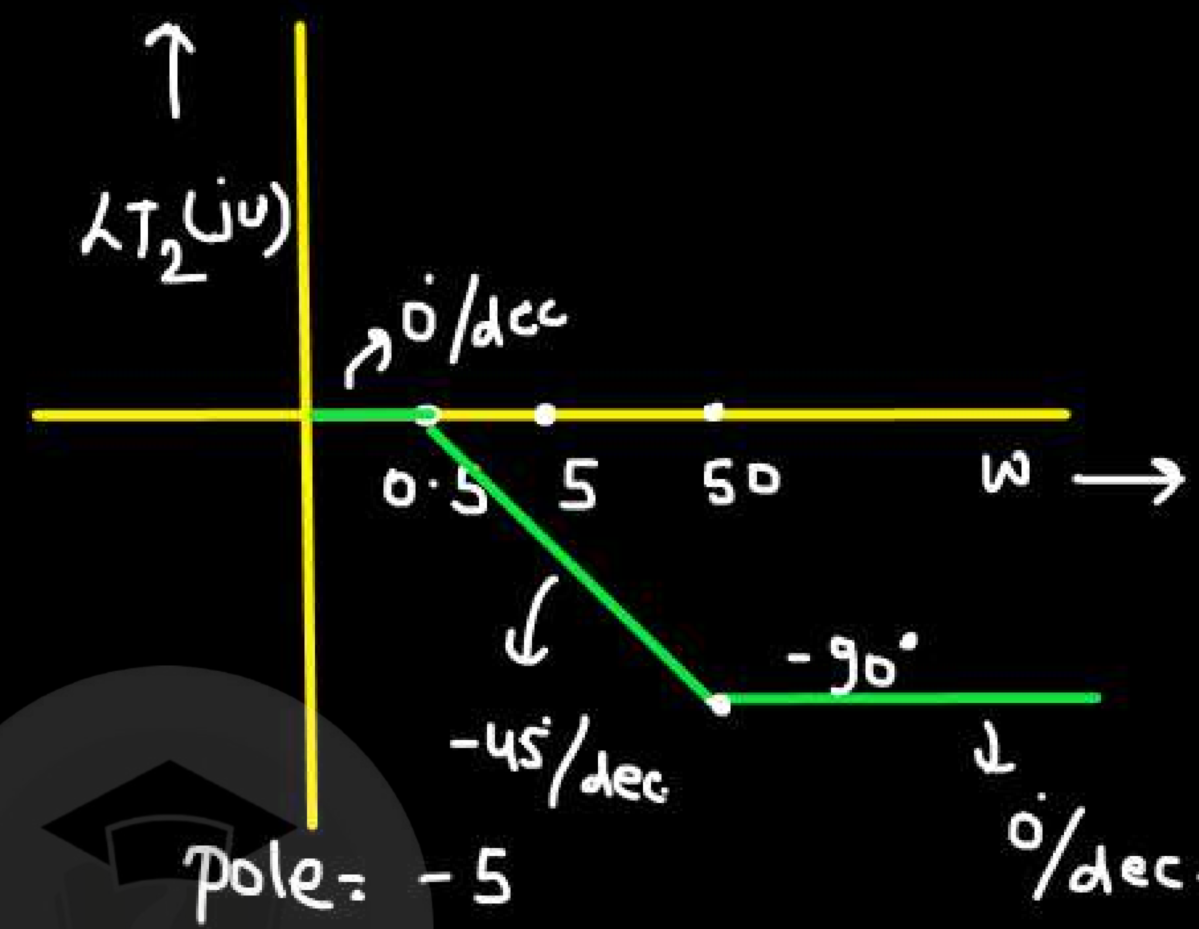
$\rightarrow$ $T(s) = T_1(s) \times T_2(s)$

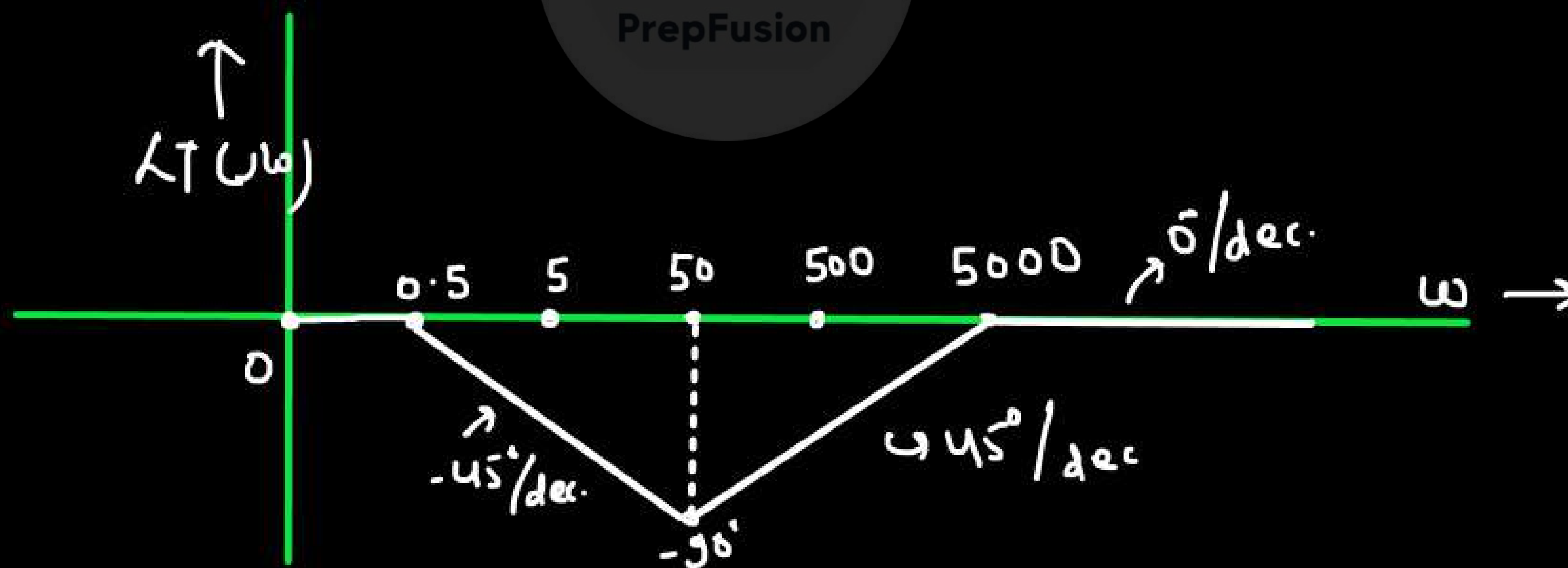
$T_1(s) = 1 + s/500$ $\quad$ $T_2(s) = \dfrac{1}{1 + s/5}$

$$\angle T(j\omega) = \angle T_1(j\omega) + \angle T_2(j\omega)$$


∠T₁(jω)
90°
0°/dec.
45°
45°/dec.
0°/dec
50
500
5000
ω →
Zero = -500

+


∠T₂(jω)
0°/dec
0.5
5
50
ω →
-45°/dec
-90°
0°/dec.
Pole = -5


∠T(jω)
0.5
5
50
500
5000
0°/dec.
ω →
0
-45°/dec.
45°/dec
-90°

Q. Draw bode phase plot for

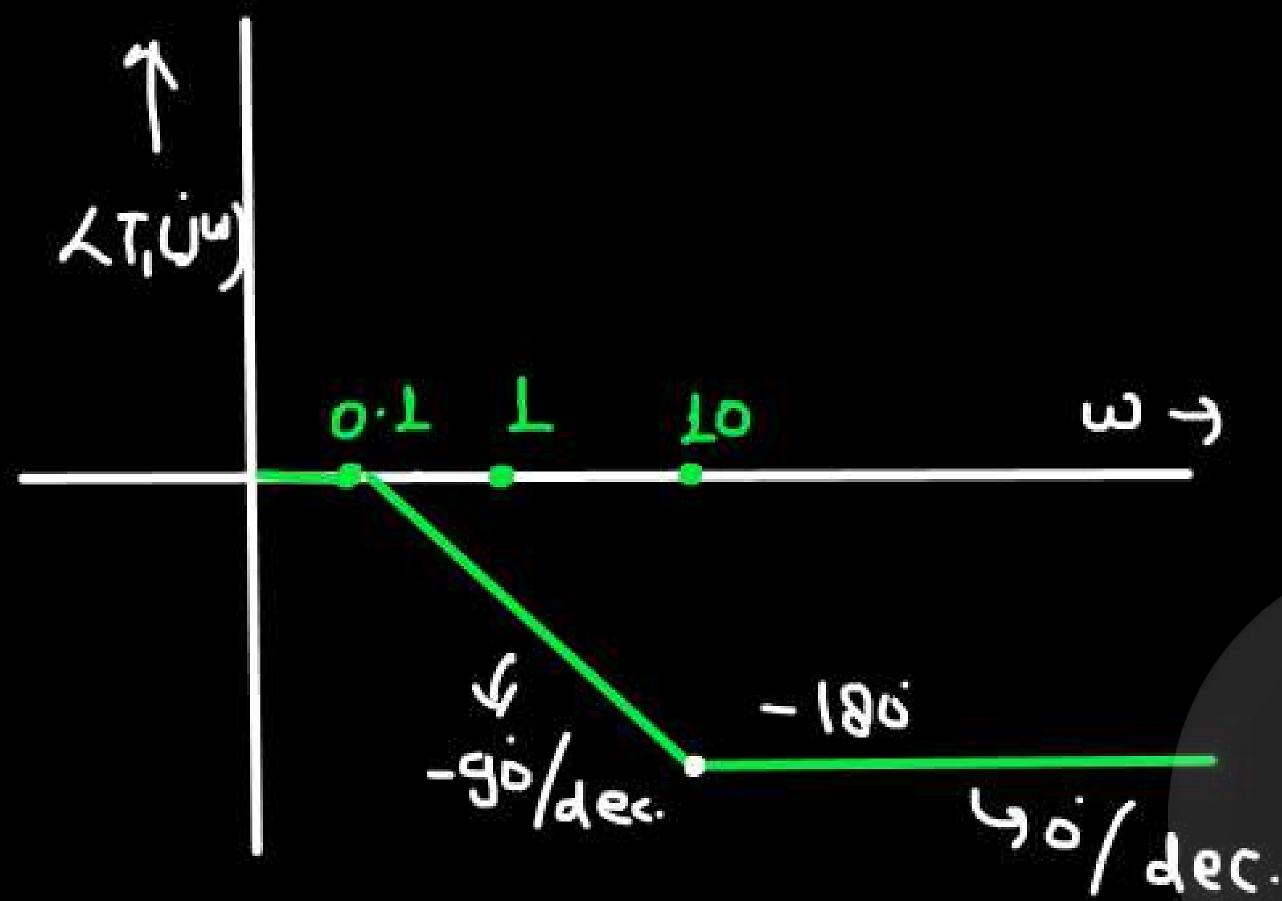
$$T(s) = \frac{A}{(s+1)^2(s+5)}$$

→

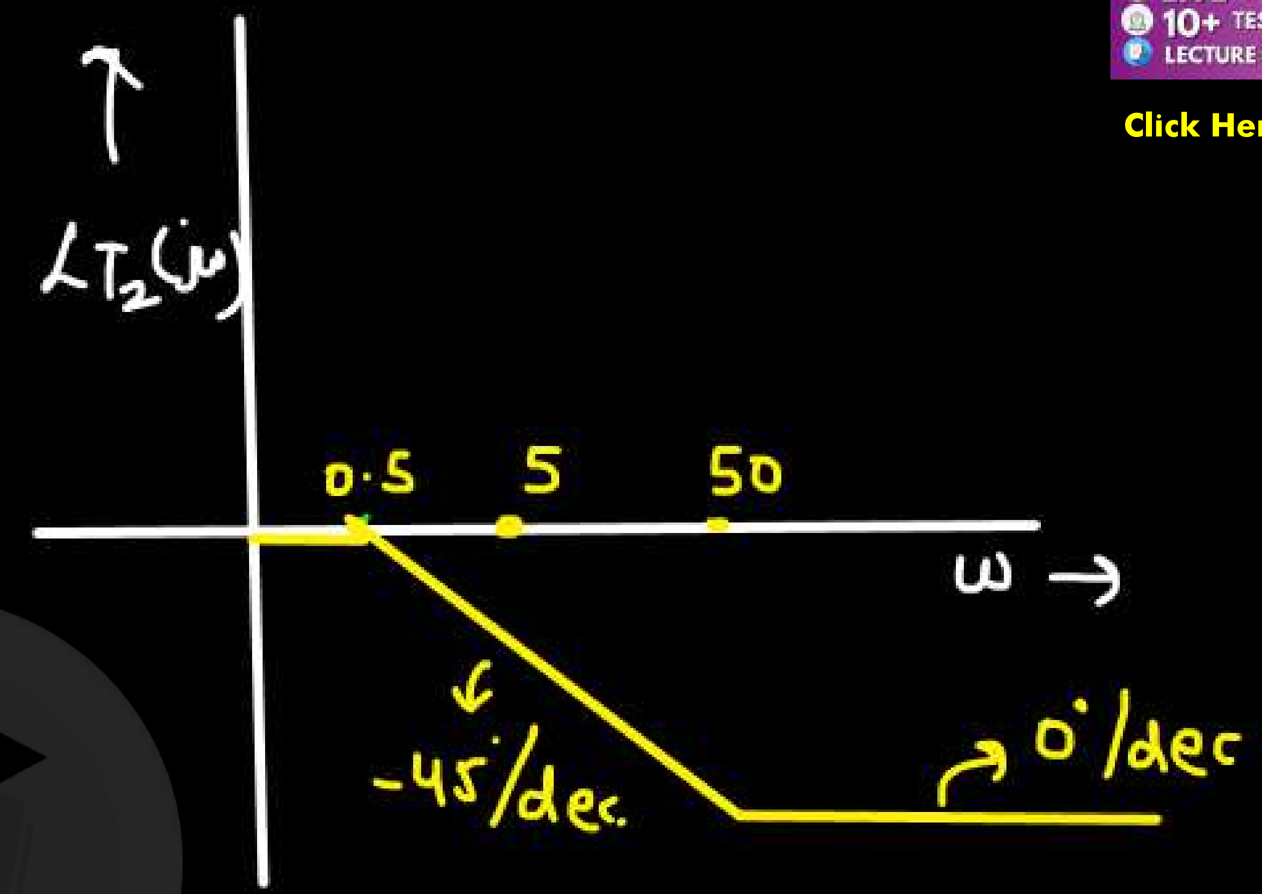
$$\angle T(j\omega) = -2\tan^{-1}(\omega) - \tan^{-1}(5)$$

$$T(s) = \frac{A_1}{s+1} \times \frac{A_2}{s+5}$$

$$= \angle T_1(j\omega) + \angle T_2(j\omega)$$

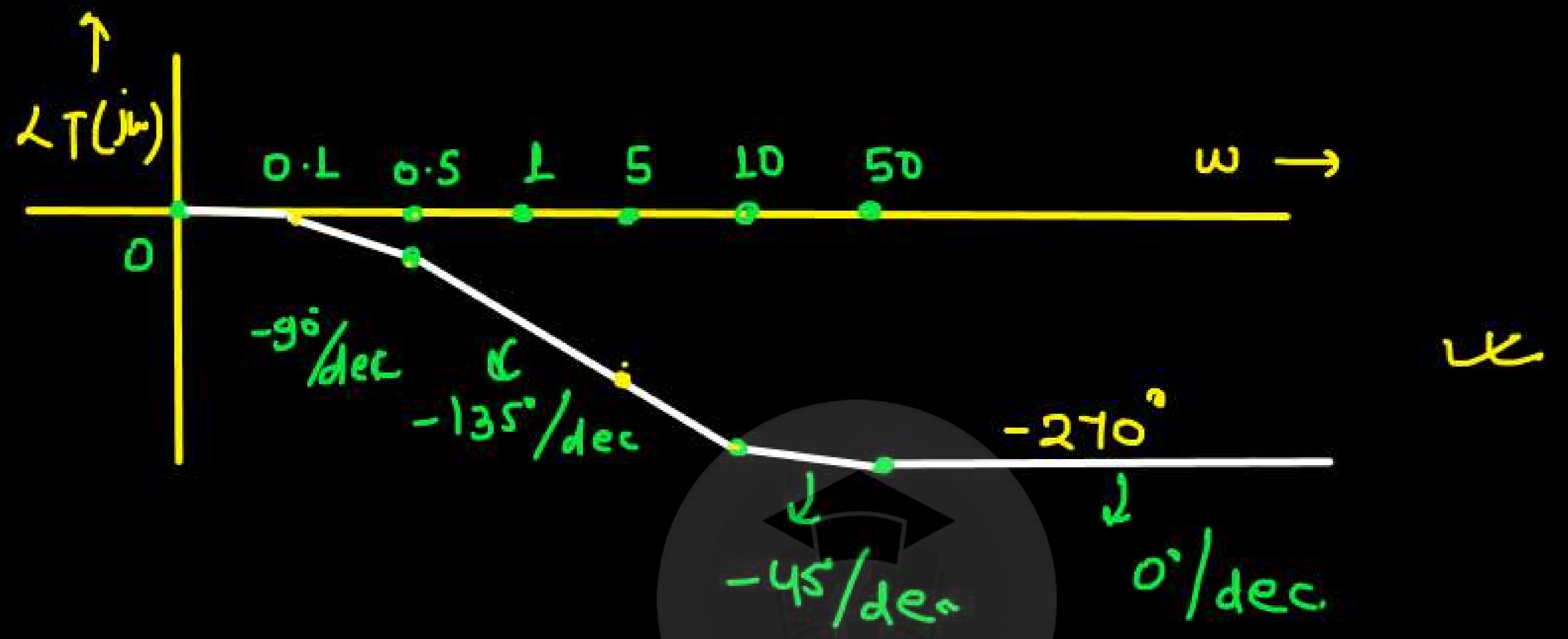


+



⇒ Two poles @ $\omega = 1$

⇒ one pole @ $\omega = .5$


∠T(jω)
0.1
0.5
1
5
10
50
ω
0
-90°/dec
-135°/dec
-45°/dec
-270°
0°/dec

★ Analog Filters :-

The ckt which passes some particular frequency components and rejects all other components.

Analog Filters

Active Filters	Passive Filters
⇓	⇓
Filters which have an active component like OP-Amp.	Filters which have only passive components like resistors, capacitors and inductors.

[In active filters cap., resistor or inductor can be there]

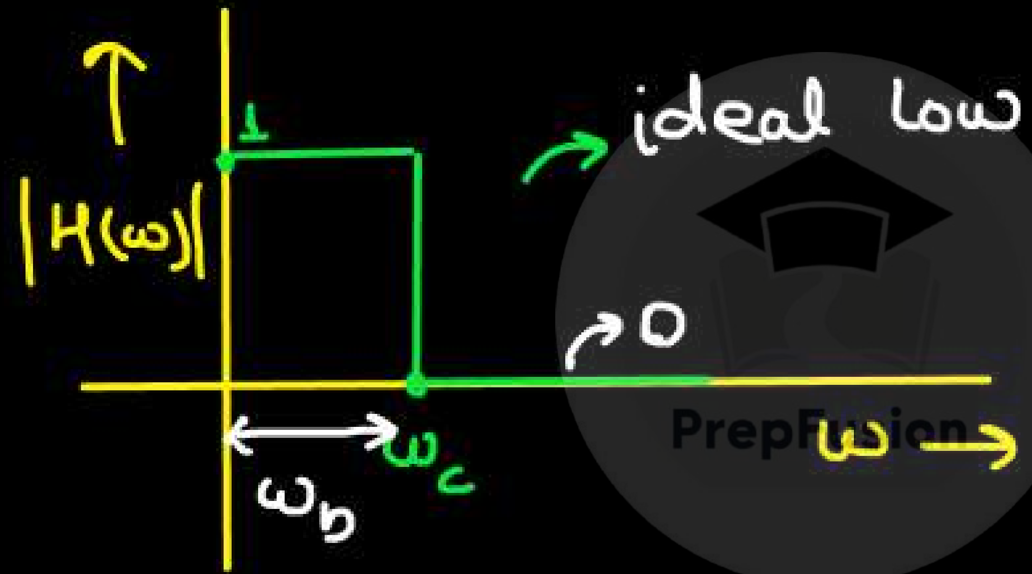
Analog Filters

- → Low Pass Filter (LPF)
- → High pass Filter (HPF)
- → Band pass Filter (BPF)
- → Band Reject Filter / Band stop filter / Notch filter (BSF)
- → All pass Filter (APF)

1. Low Pass Filter (LPF) :-

Low Frequency component → passes

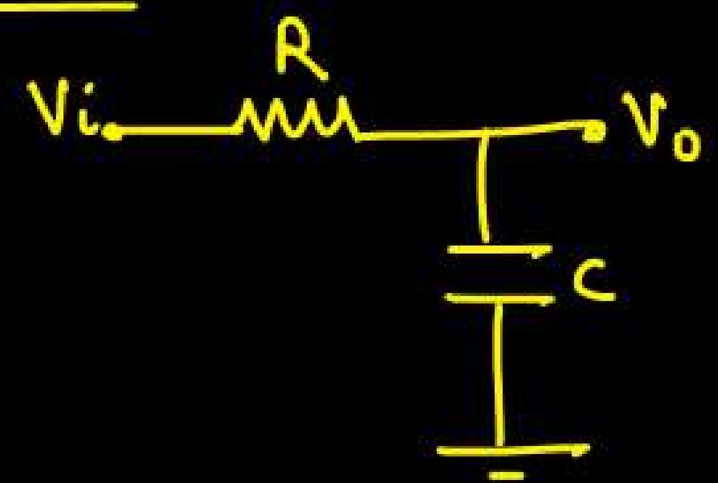
High Frequency component → attenuates



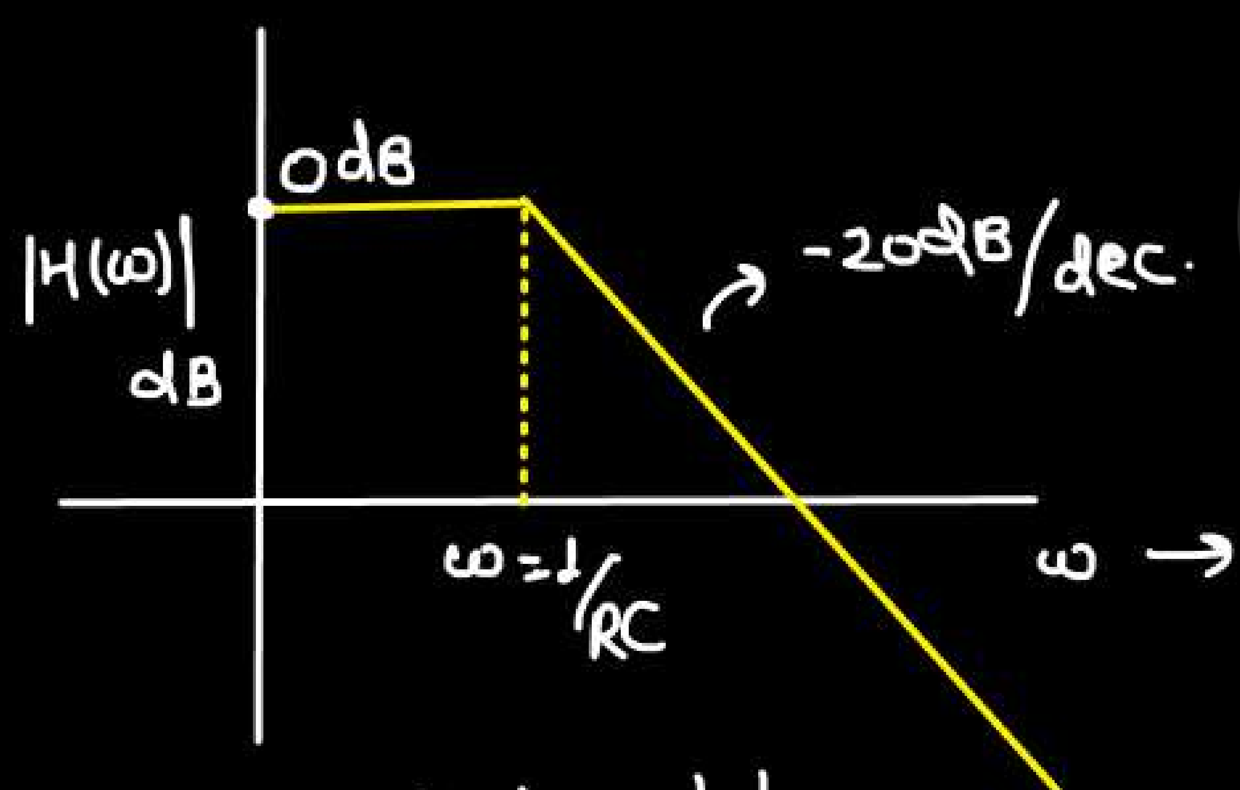
$\omega_c \rightarrow$ cut-off freq.

$(\omega_b)_{LPF} = \omega_c =$ 3-dB Bandwidth

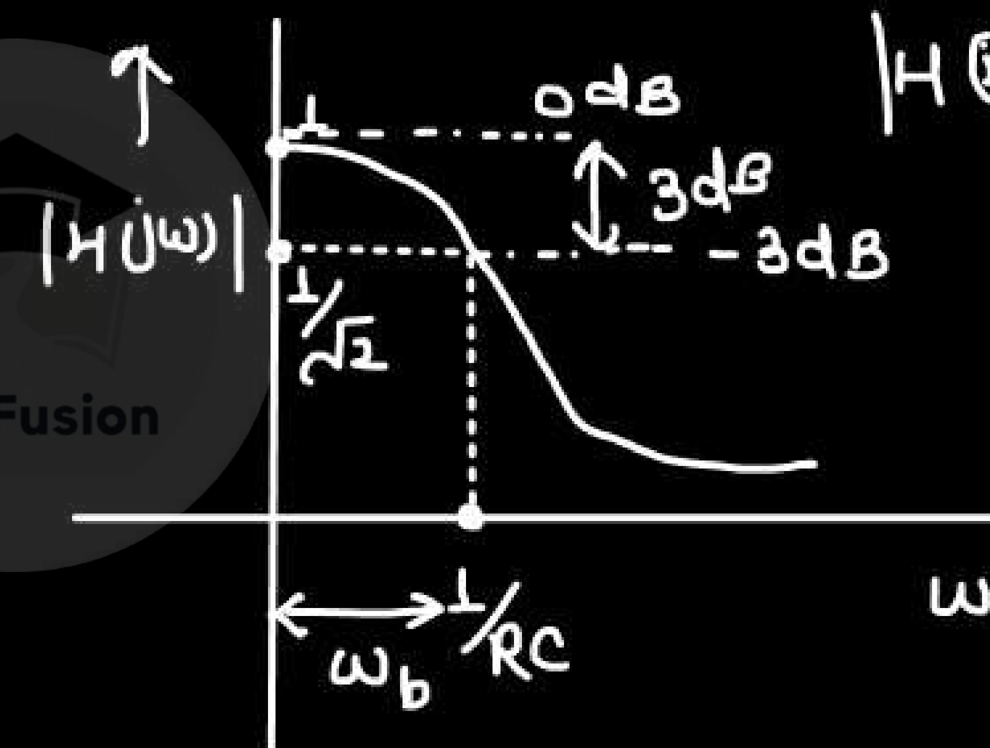
Practical LPF :-



$$\frac{V_o(s)}{V_i(s)} = \frac{1}{sRC+1}$$



Bode plot
(Approx plot)



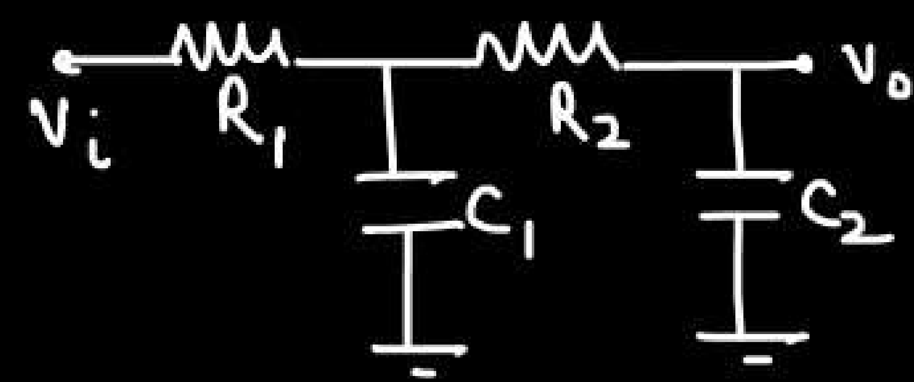
$$|H(j\omega)| = \frac{1}{\sqrt{1+\omega^2R^2C^2}}$$

gain @ $\omega = \frac{1}{RC}$

$= \frac{1}{\sqrt{2}}$

$\omega = 0 \Rightarrow$ gain $= 1$
$\omega = 0.0001 \Rightarrow$ gain < 1
$\omega > \frac{1}{RC} \Rightarrow$ gain $\neq 0$
→ Pratical LPF

How to check the type of filter in complex circuits?



@ $\omega = 0$ $\Rightarrow$ $V_o = V_i$ $\Rightarrow$ some o/p is observed $\Rightarrow$ low freq. passed

@ $\omega = \infty$ $\Rightarrow$ $V_o = 0$ $\Rightarrow$ no o/p $\Rightarrow$ High freq. doesn't pass

$\Downarrow$

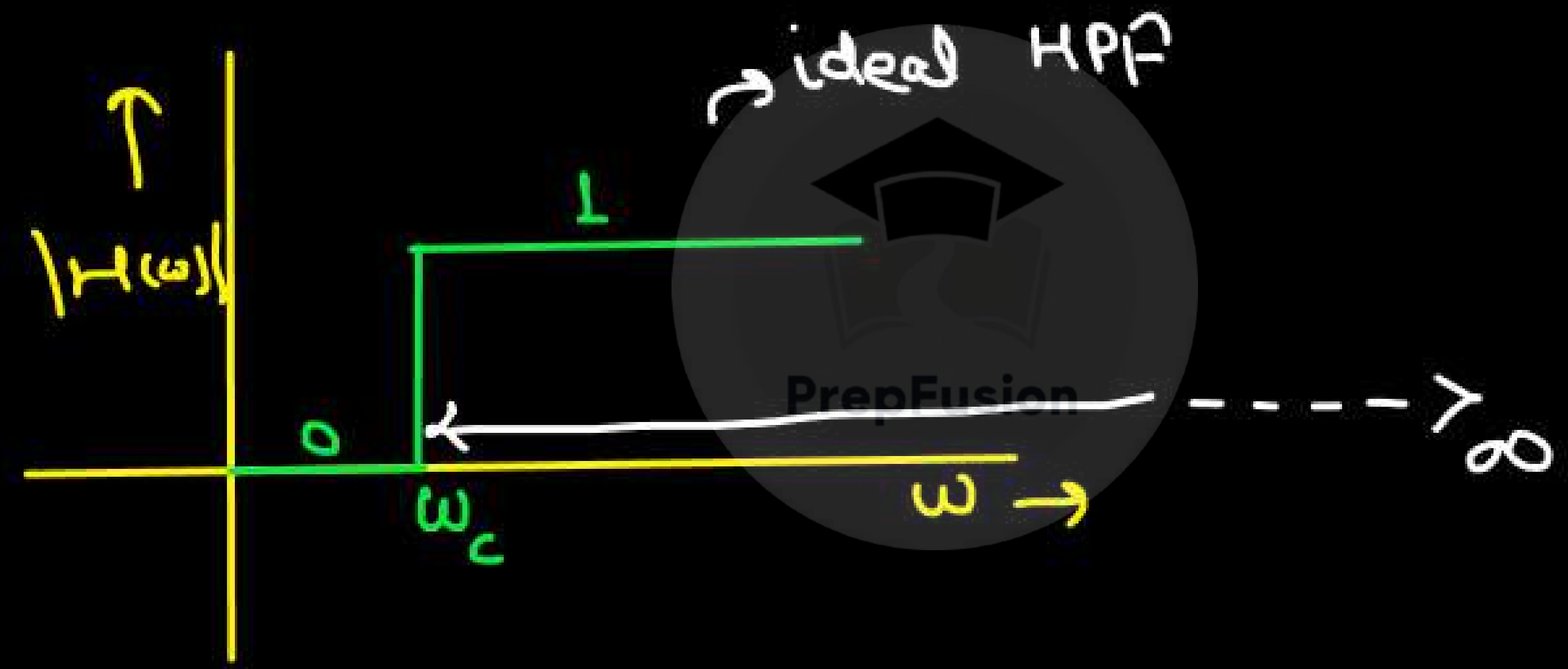
L.P.F.

(2) High Pass Filter (HPF):-

High freq. component → passes

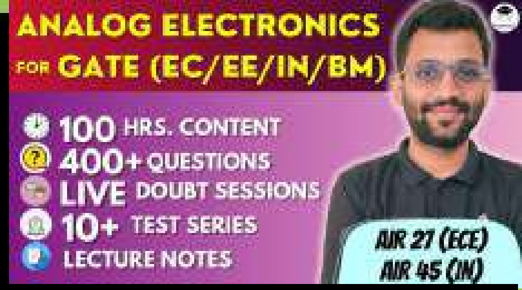
Low freq. component → attenuates

ideal HPF:-

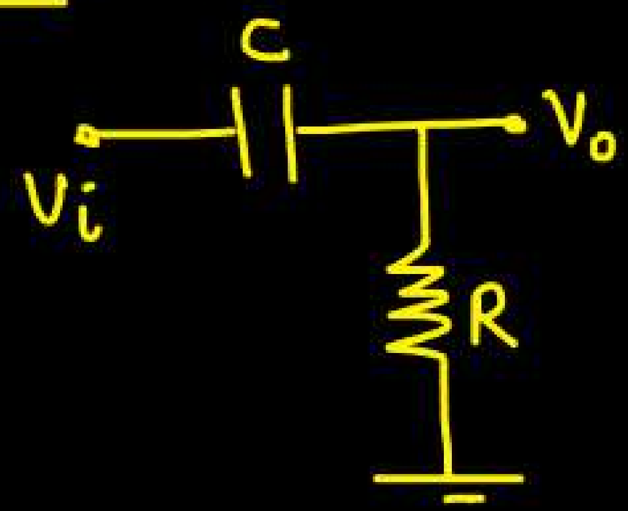


ω_c → cut-off High pass filter

3-dB Bandwidth → ∞

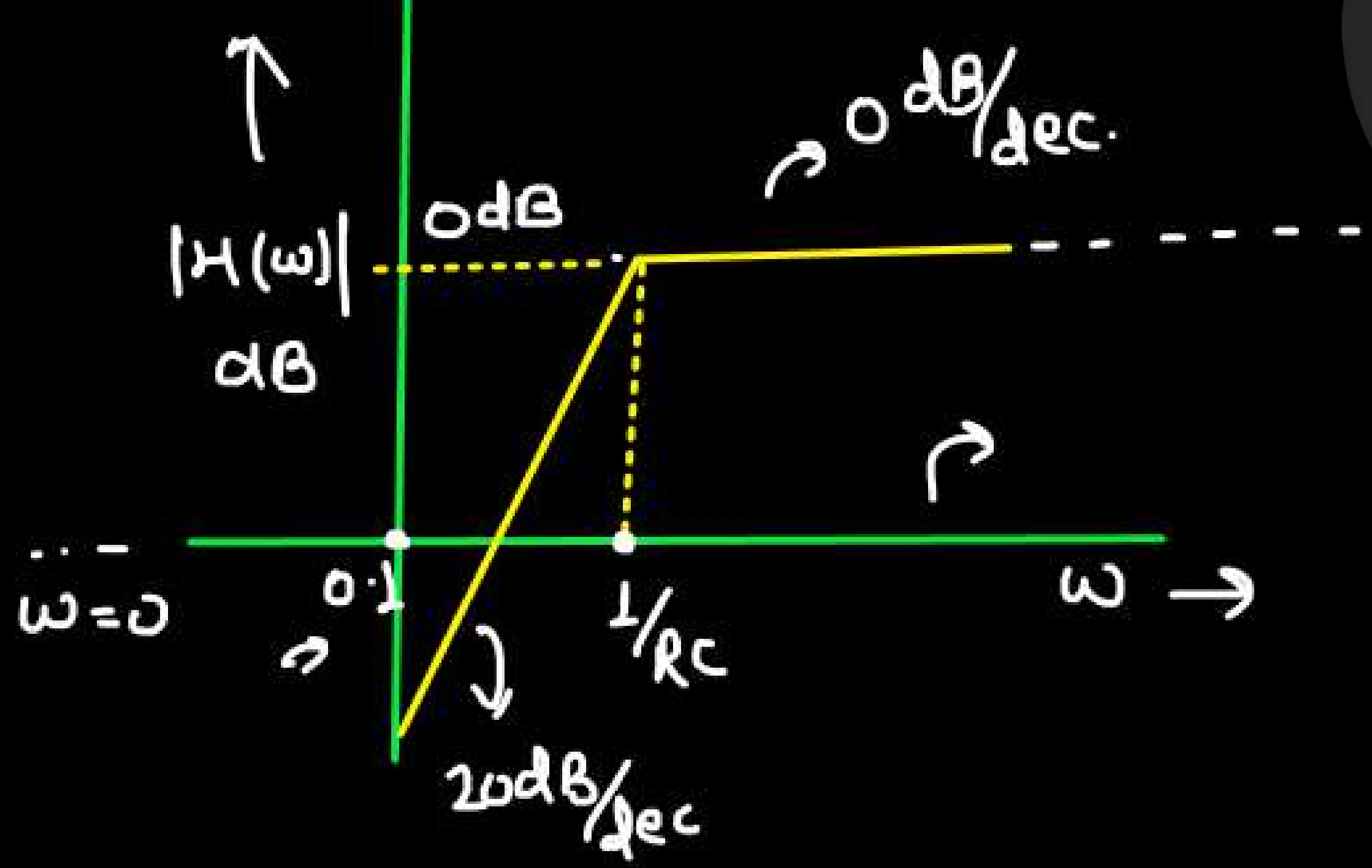


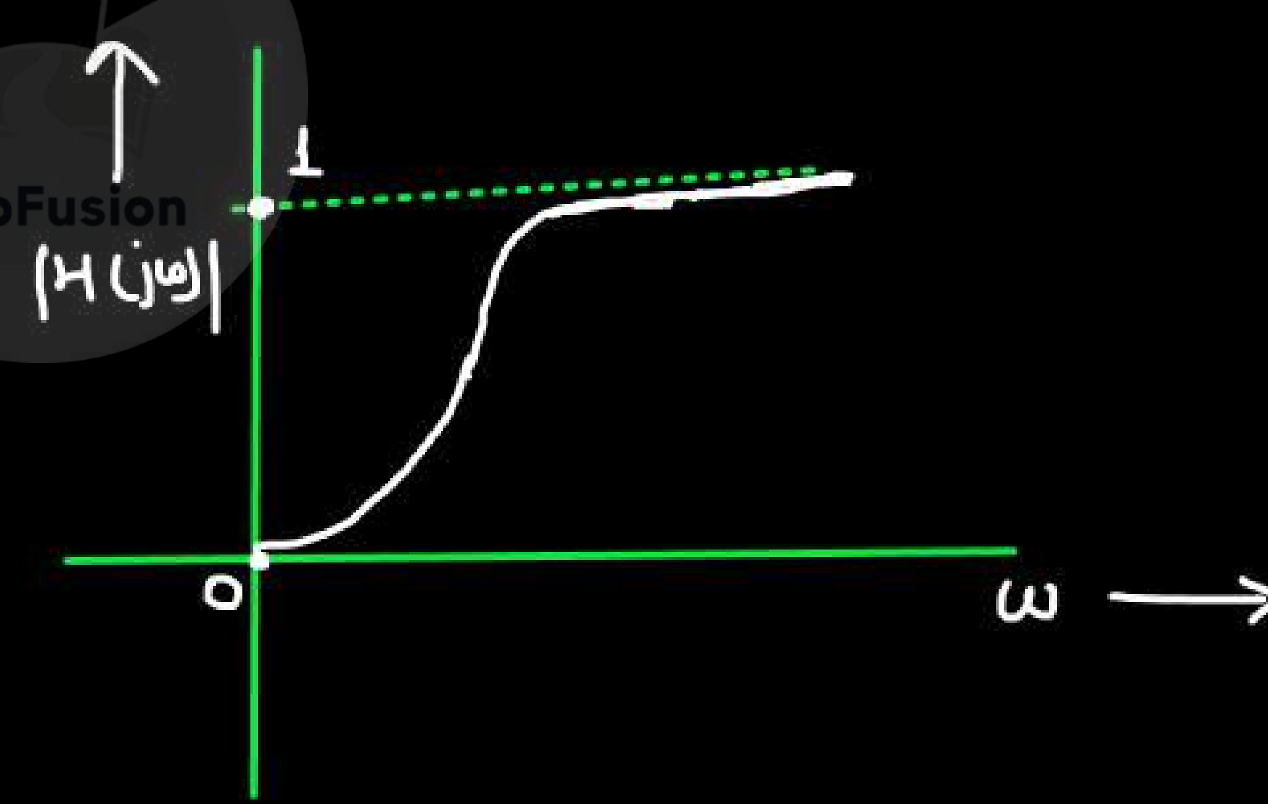
* Practical HPF :-



$$\frac{V_o(s)}{V_i(s)} = \frac{RCs}{RCs+1}$$

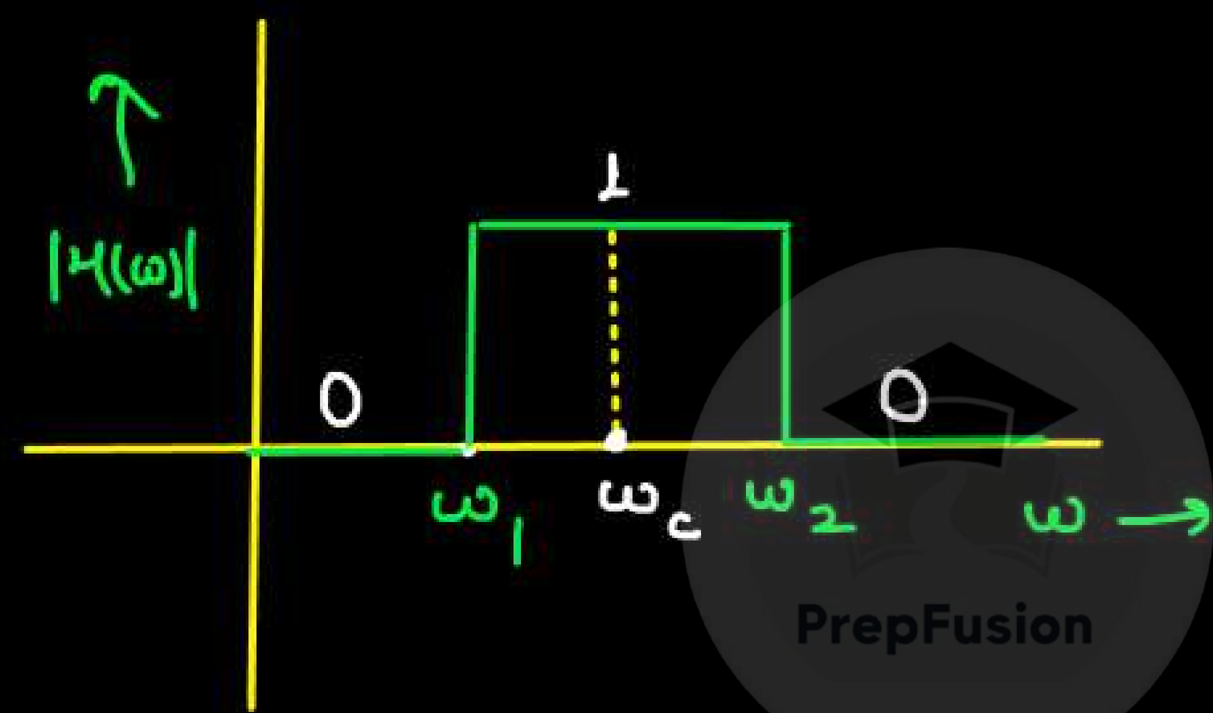
$$|H(j\omega)| = \frac{\omega RC}{\sqrt{\omega^2R^2C^2+1}}$$





③ Band Pass Filter :-

Passes a particular range of frequencies.

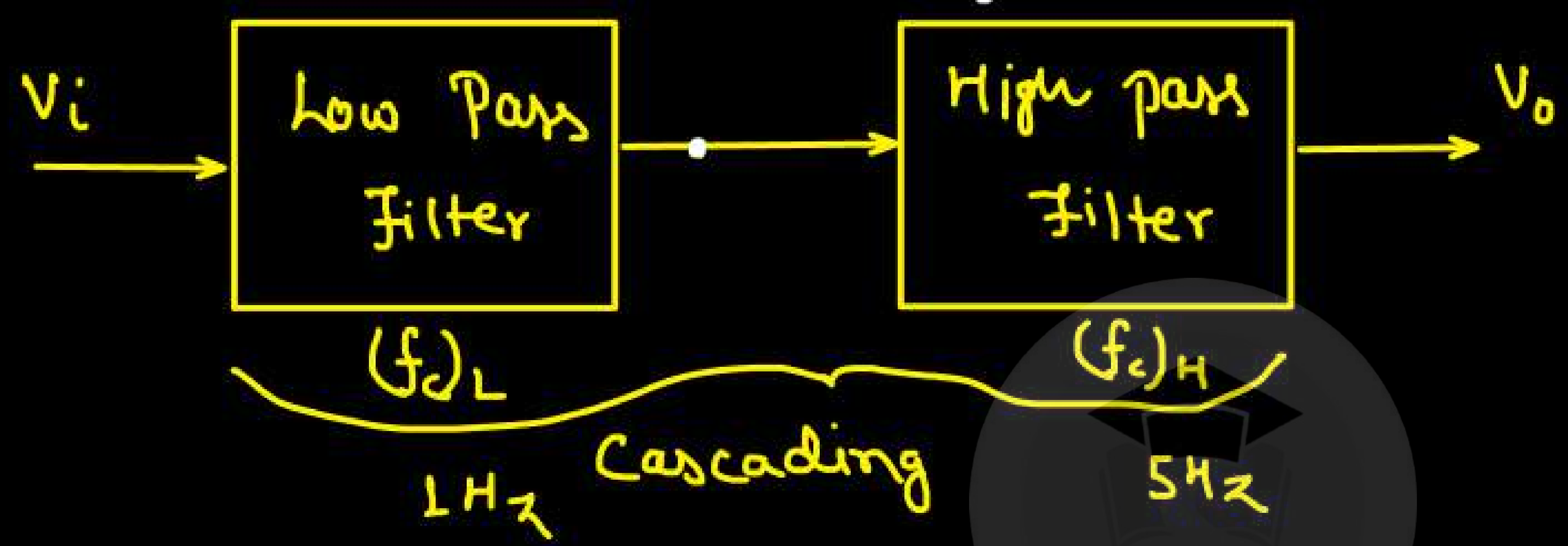


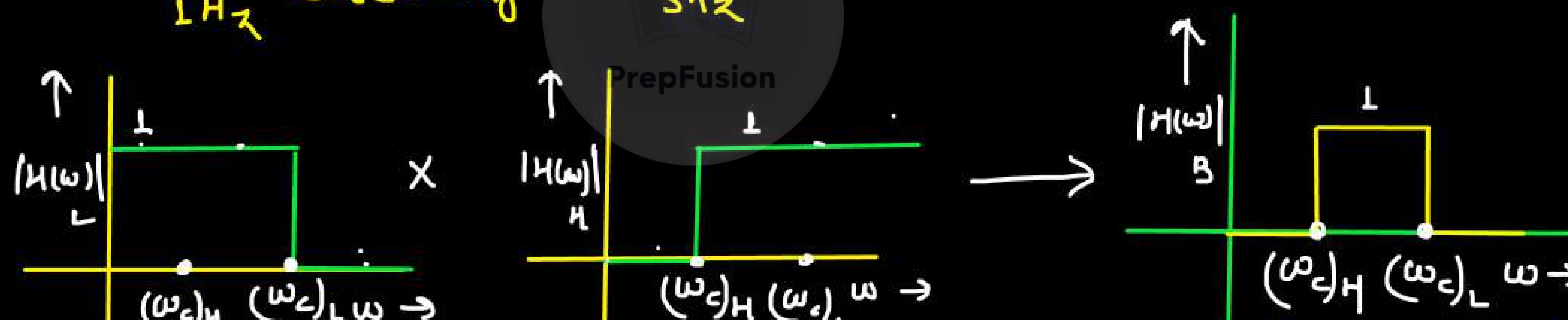
3-dB Bandwith = $\omega_2 - \omega_1$

ω_c = centre freq. = $\sqrt{\omega_1 \omega_2}$

How to make a band pass filter :-

Cascading :- o/p of first stage in connected to the i/p of 2nd stage.

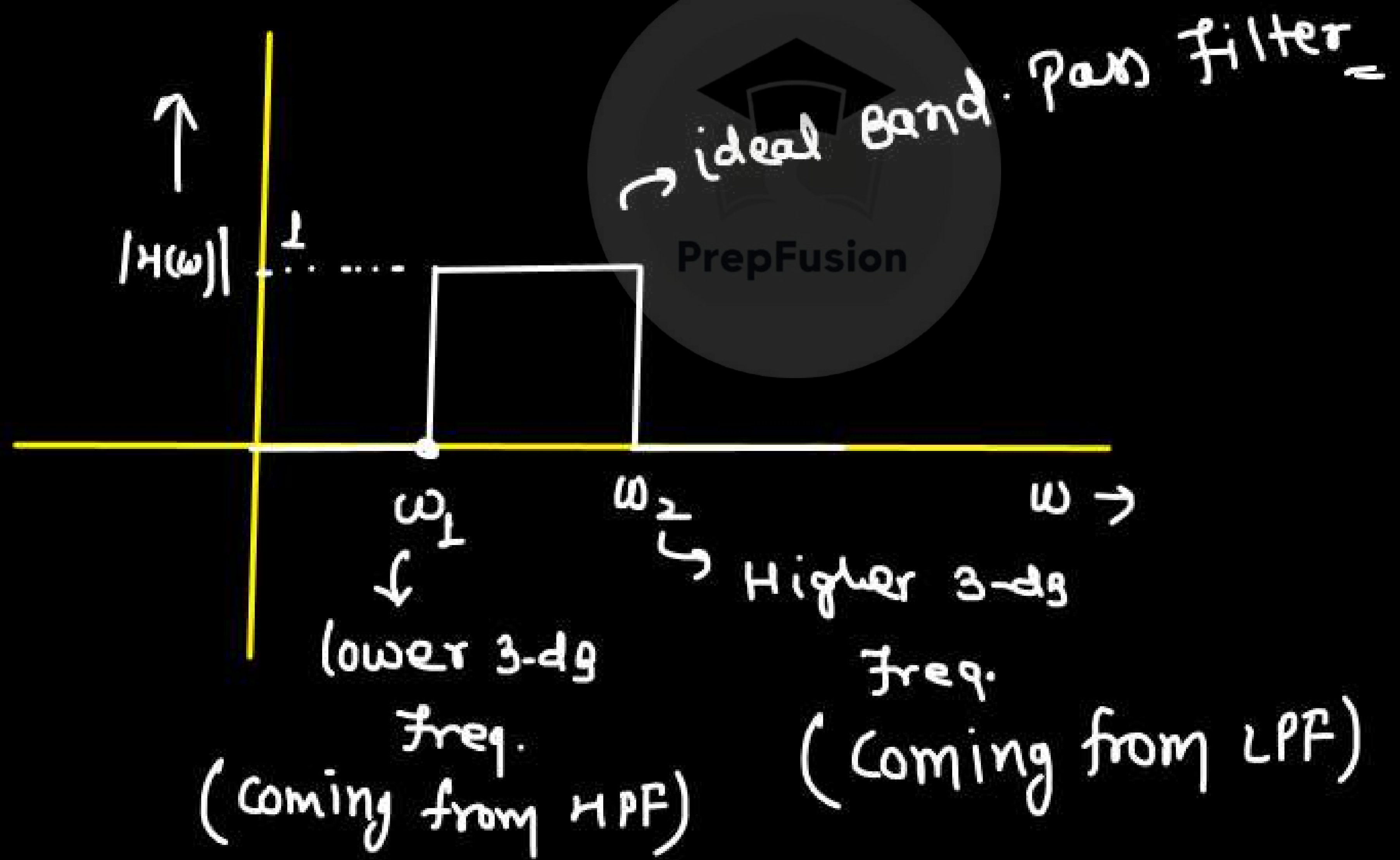




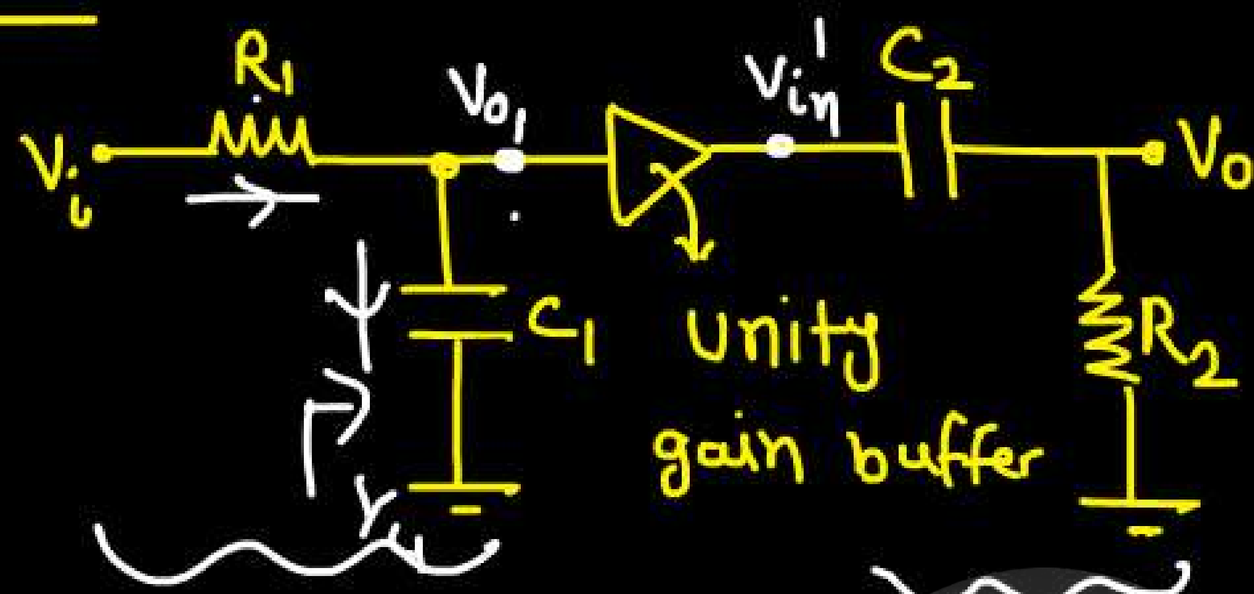
** $\boxed{(\omega_c)_L > (\omega_c)_H}$

[** N.B. → in cascade, freq. response are multiplied]

⇒ To make a BPF from LPF and HPF, you should connect both LPF and HPF in cascaded with the condition that the cut-off freq. of low pass filter is higher than the cut-off freq. of High pass filter.



Practical BPF :-



LPF

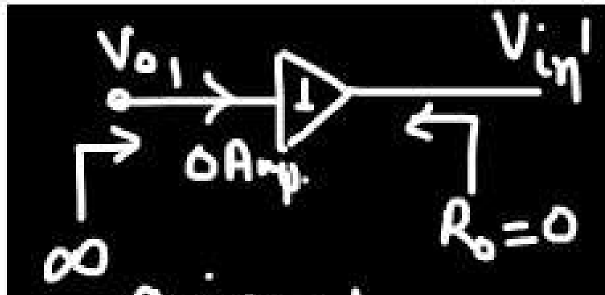
$\Downarrow$

$$\frac{1}{R_1C_1s+1}$$

HPF

$\Downarrow$

$$\frac{sR_2C_2}{1+sR_2C_2}$$



gain = 1

$I_{in} = 0$

$R_{in} = \infty$

$R_o = 0$

$V_{in}' = V_{o_1}$

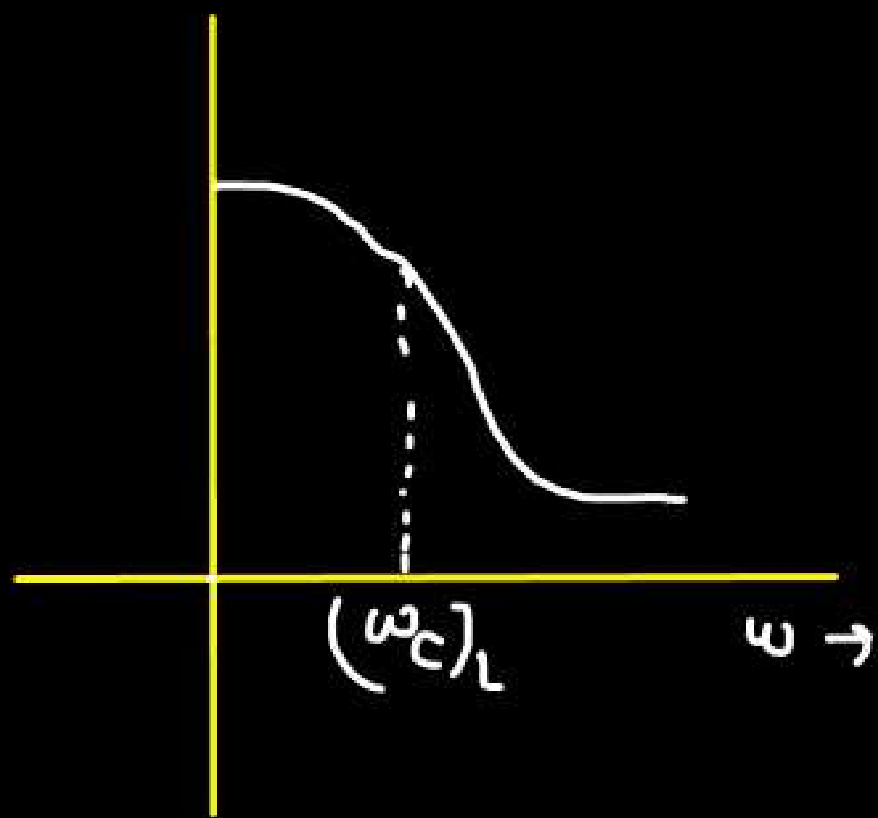
$$\frac{V_o(s)}{V_i(s)} = \frac{sR_2C_2}{(R_1C_1s+1)(1+sR_2C_2)}$$

$\Rightarrow$

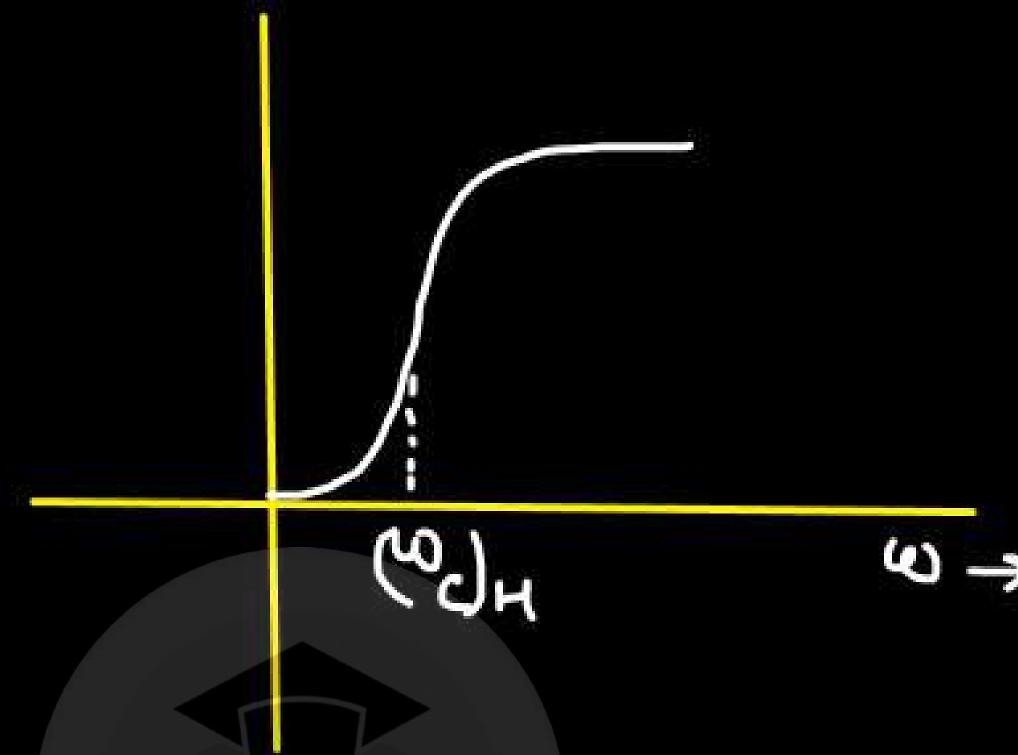
$$(\omega_c)_L > (\omega_c)_H$$

$$\frac{1}{R_1C_1} > \frac{1}{R_2C_2}$$

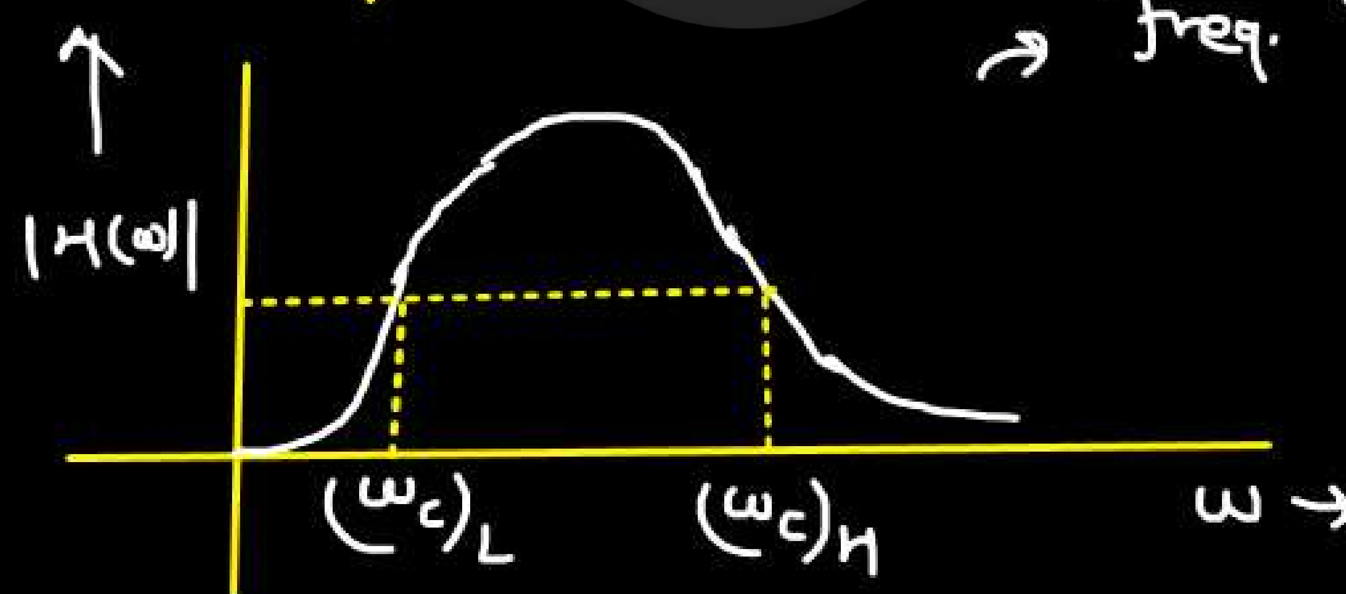
$$\boxed{R_2C_2 > R_1C_1}$$



×



→ Freq. response

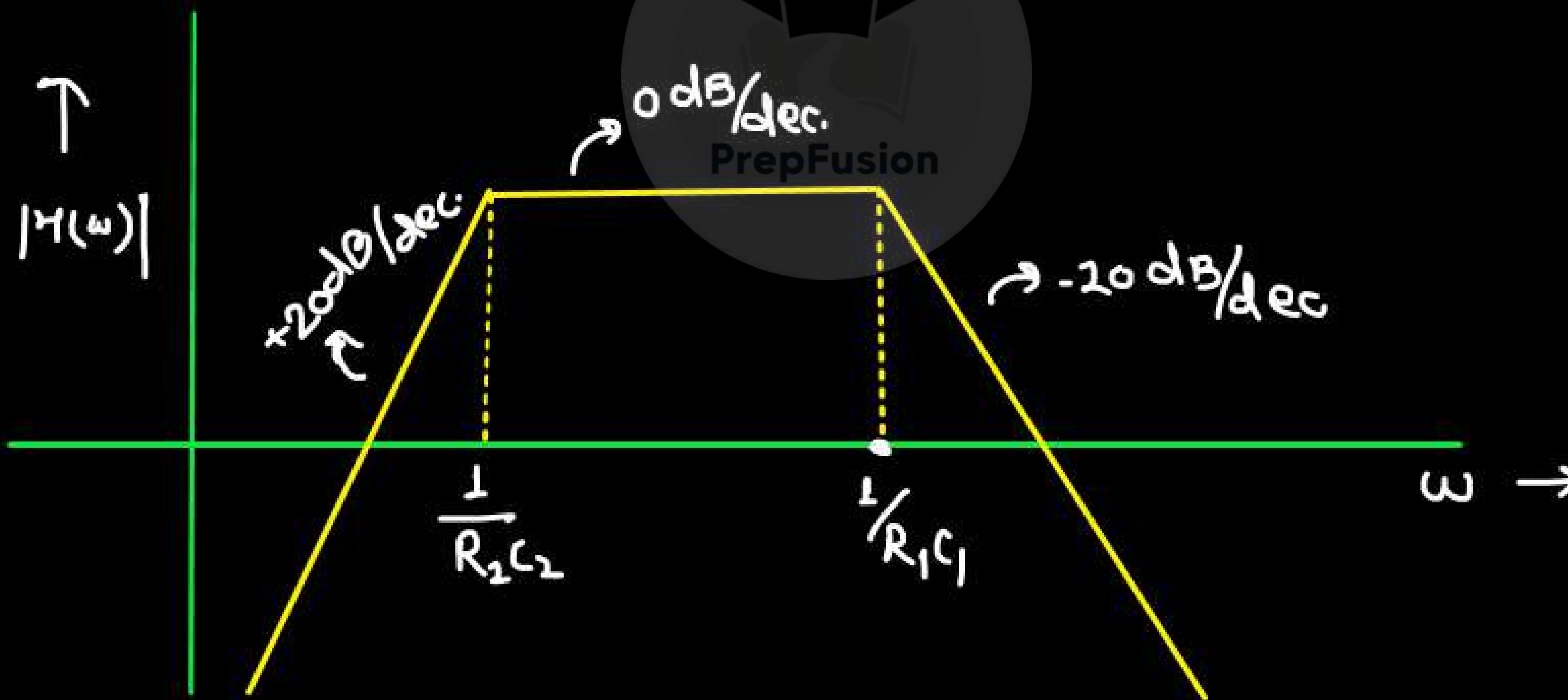


$$H(s) = \frac{sR_2C_2}{(sR_1C_1+1)(sR_2C_2+1)}$$

Zero $\rightarrow$ $\omega_z = 0$

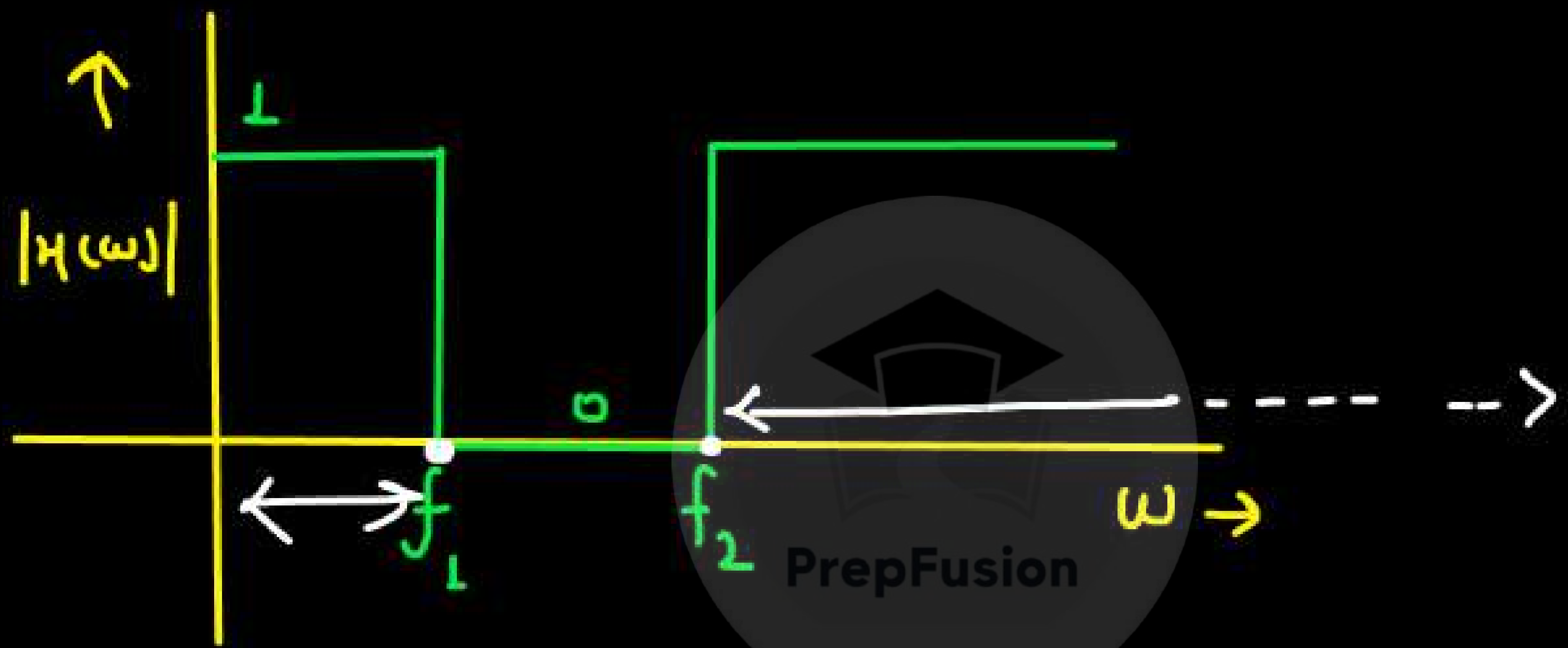
Poles $\rightarrow$ $\omega_p = \frac{1}{R_1C_1}, \frac{1}{R_2C_2}$

$$\frac{1}{R_2C_2} < \frac{1}{R_1C_1}$$



④ Band reject Filter | Band stop Filter | Notch Filter :-

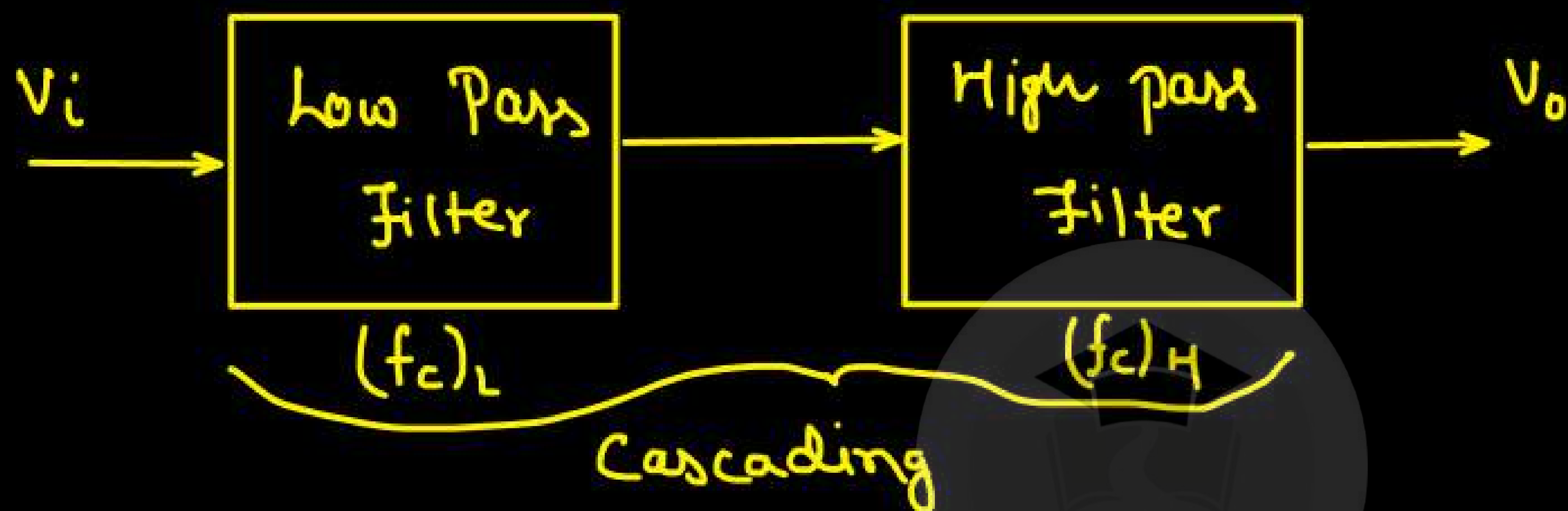
Rejects a particular range of freq.



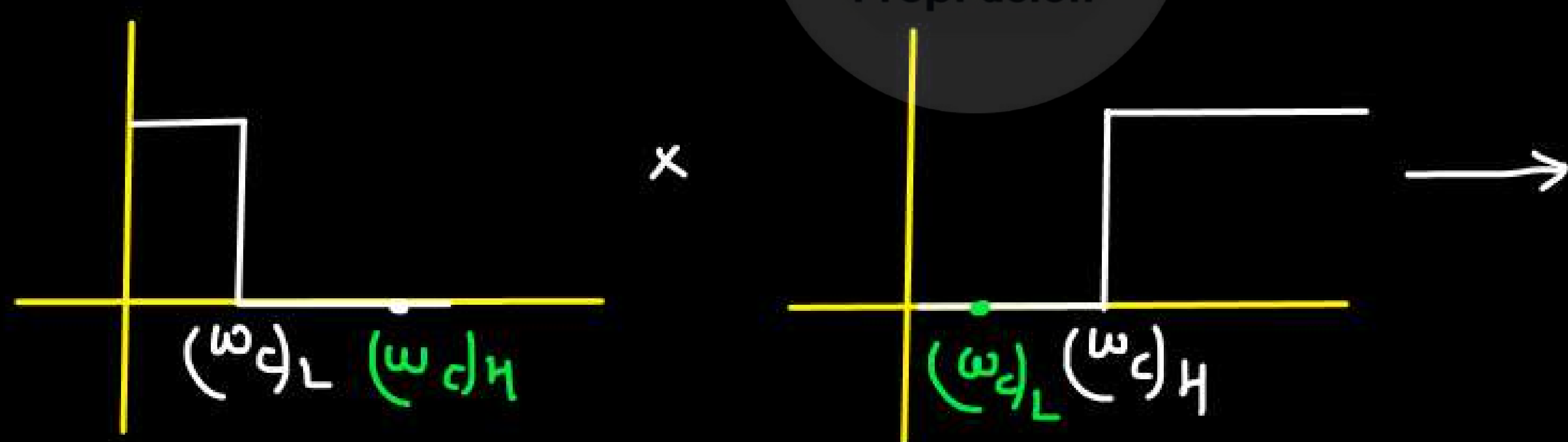
Bandwidth of BSF = ∞

How to make band reject filter :-

Cascade ?

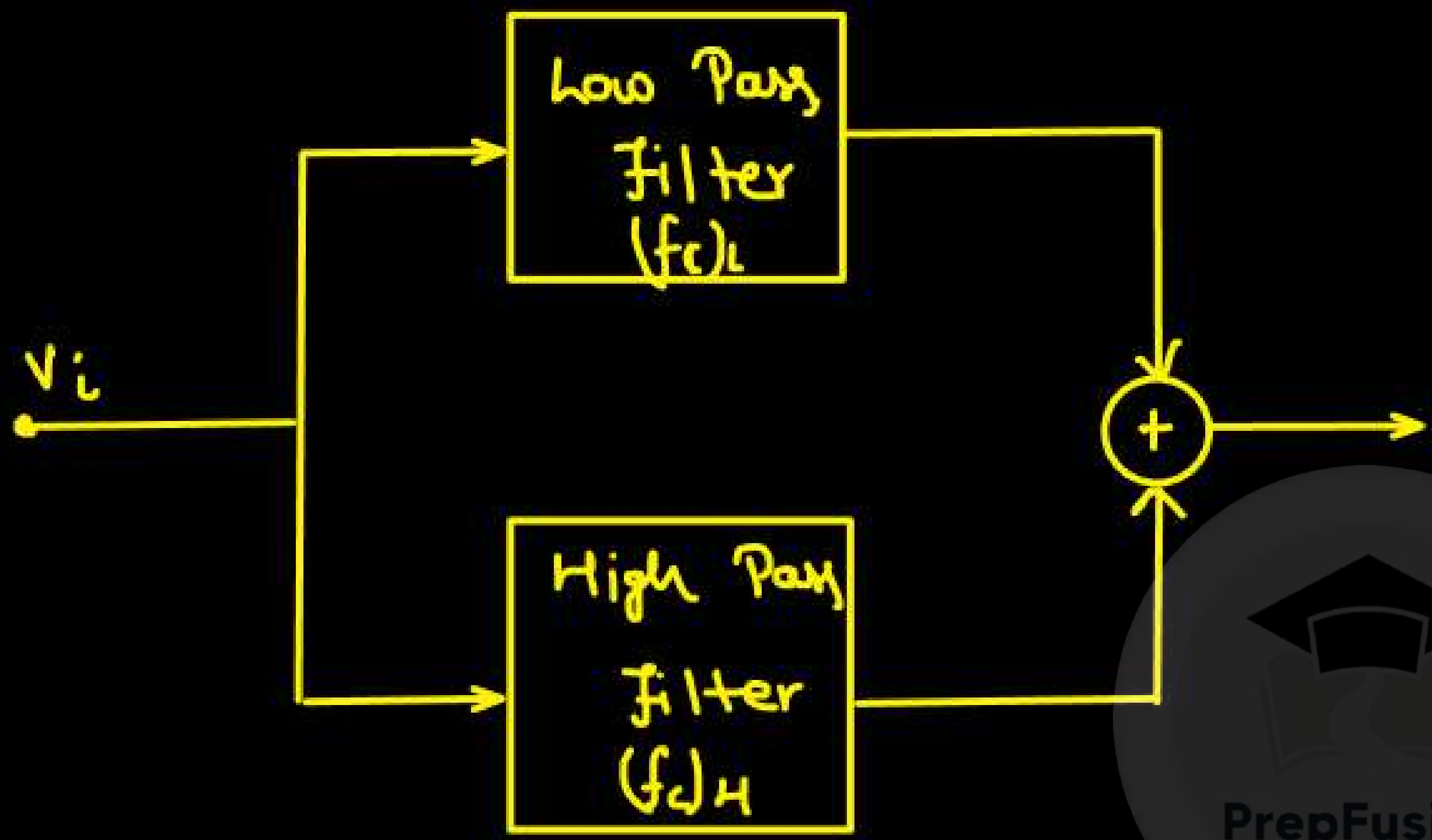


consider $(\omega_c)_L < (\omega_c)_H$

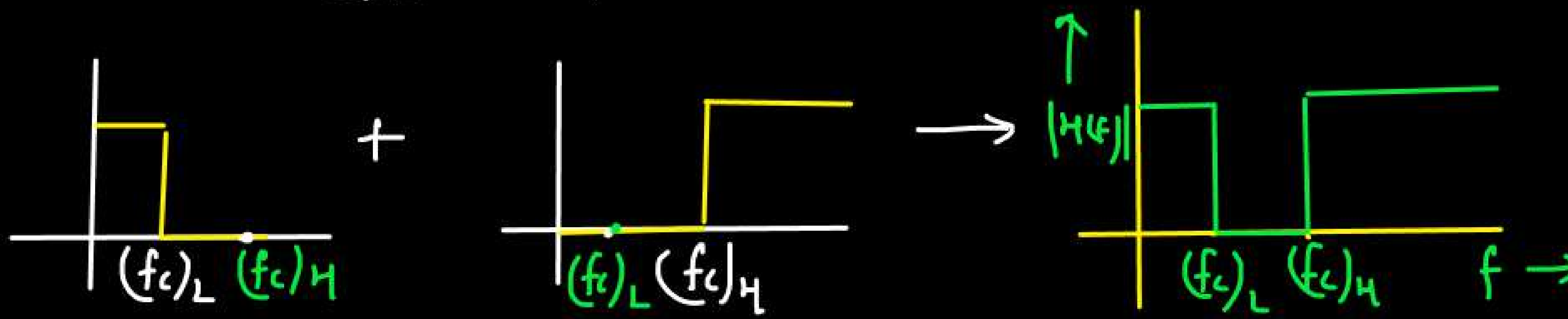


⇒ cascading doesn't give you Band Reject Filter.

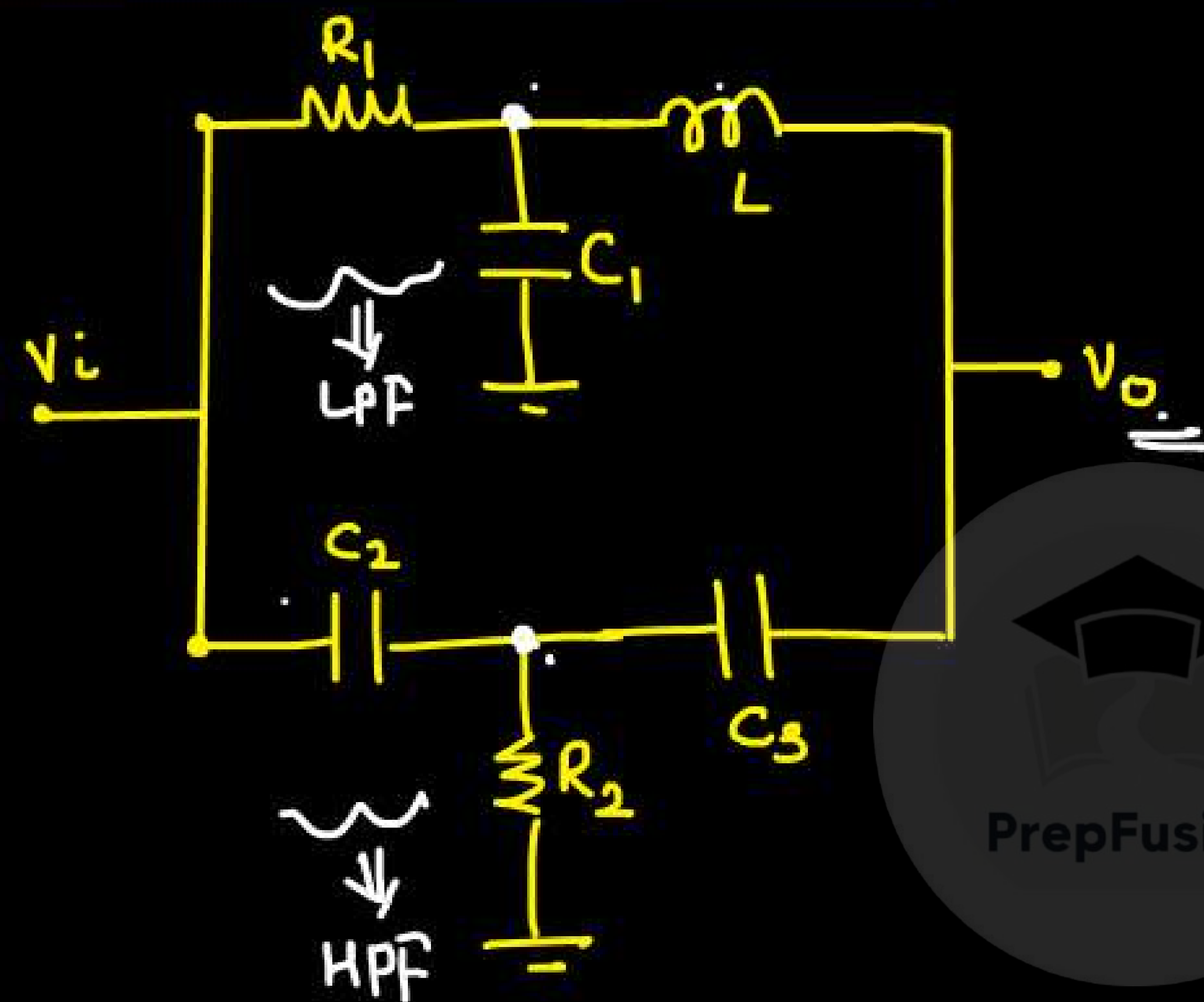
Connect in parallel :-



Cond^n $\rightarrow$ $(f_c)_L < (f_c)_H$



Practical Band reject filter :-



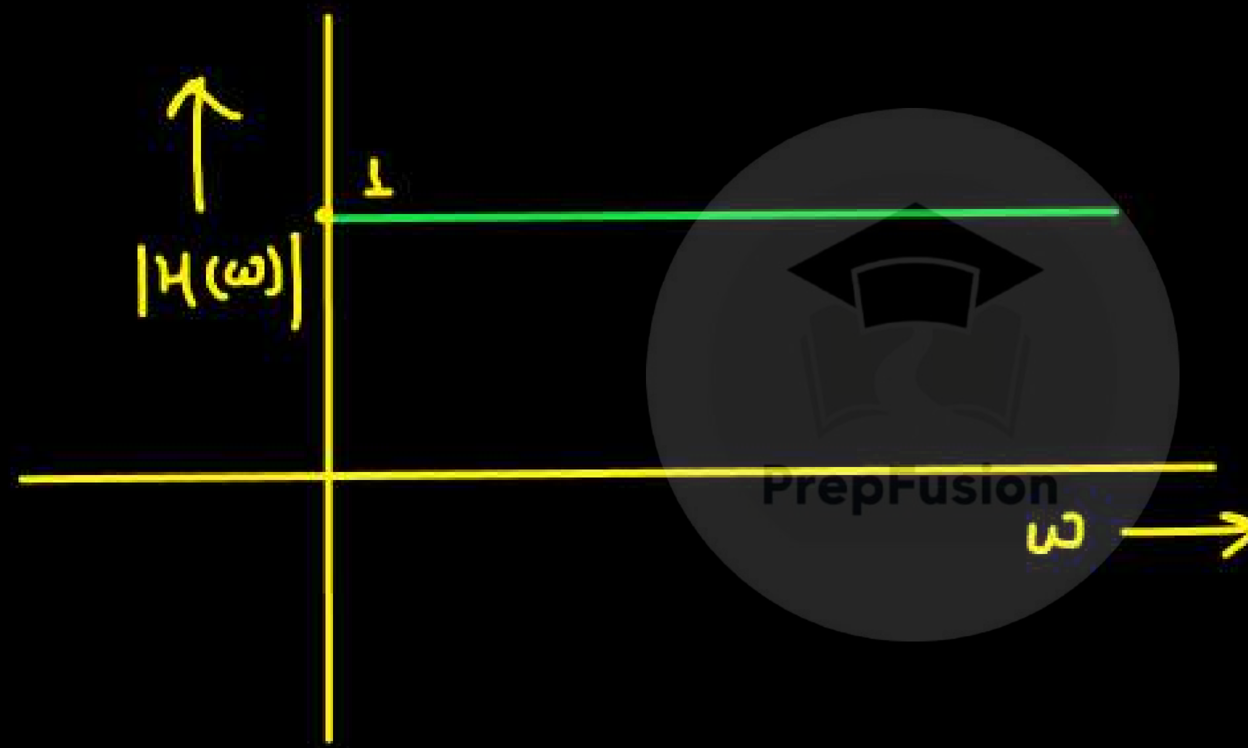
$$\omega = 0 \Rightarrow V_0 = V_i$$

$$\omega = \infty \Rightarrow V_0 = V_i$$

⑤ All Pass filter:-

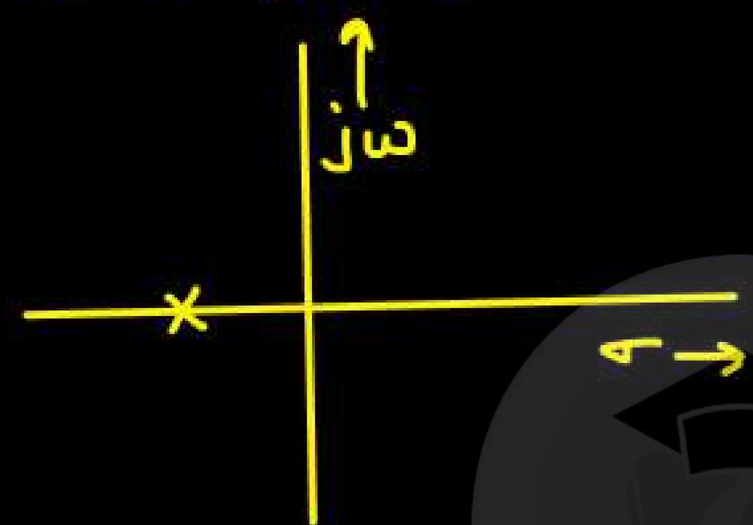
Passes all the freq. component but provides some phase shift

ideal APF:-



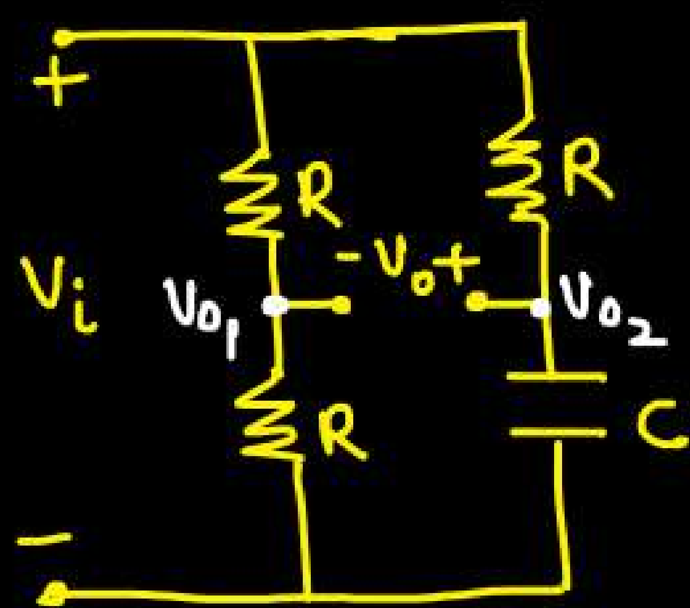
N.B. -

(i) For a stable s/s the poles should always be on the left Half of s-plane.



(ii) For APF, poles and zero are symmetric about jω axis.

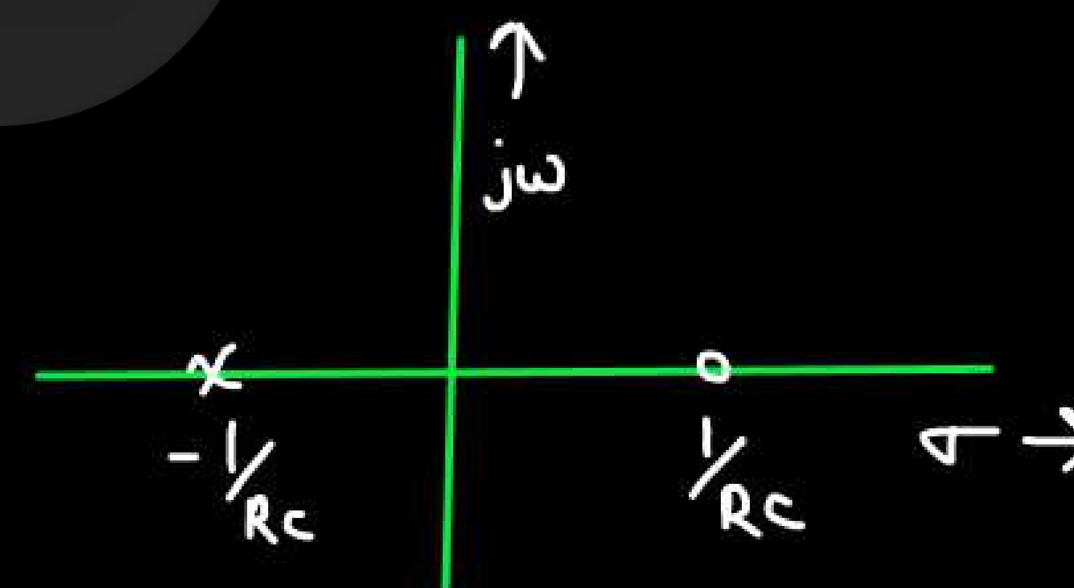
Practical APF:-



$$V_o = V_{o_2} - V_{o_1}$$

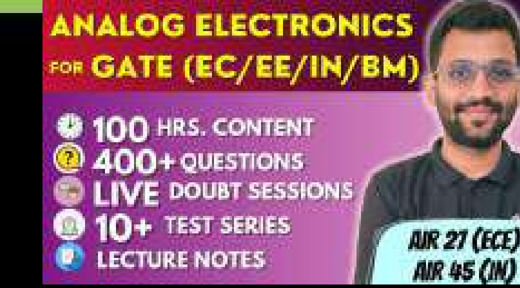
$$V_o(s) = \frac{1}{1+RCs} V_i(s) - \frac{V_i(s)}{2}$$

$$\boxed{\frac{V_o(s)}{V_i(s)} = \frac{1}{2}\left[\frac{1-sRC}{1+sRC}\right]}$$



$\omega = 0 \Rightarrow V_o = V_i/2$

$\omega \to \infty \Rightarrow V_o = V_i/2$

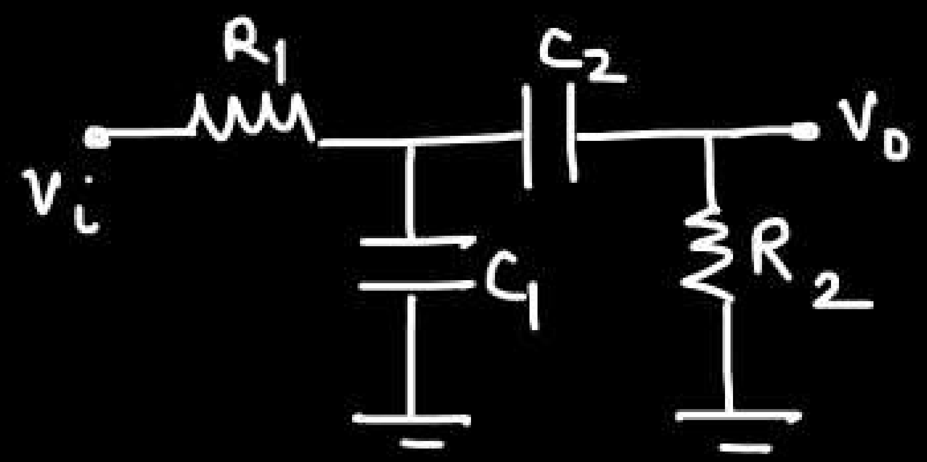


Both BSF and APF will give some o/p @ $\omega = 0$ and @ $\omega = \infty$

but incase of APF, poles and zero will be of symmetric nature.

Q. Find the types of filter.

(a)



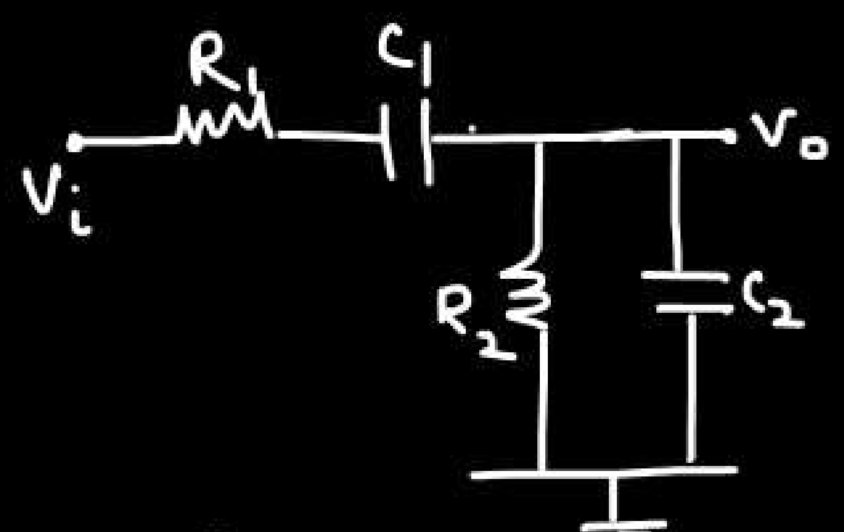
$\rightarrow \omega = 0 \Rightarrow V_0 = 0$ Volt

$\omega = \infty \Rightarrow V_0 = 0$ Volt

$\Downarrow$

BPF

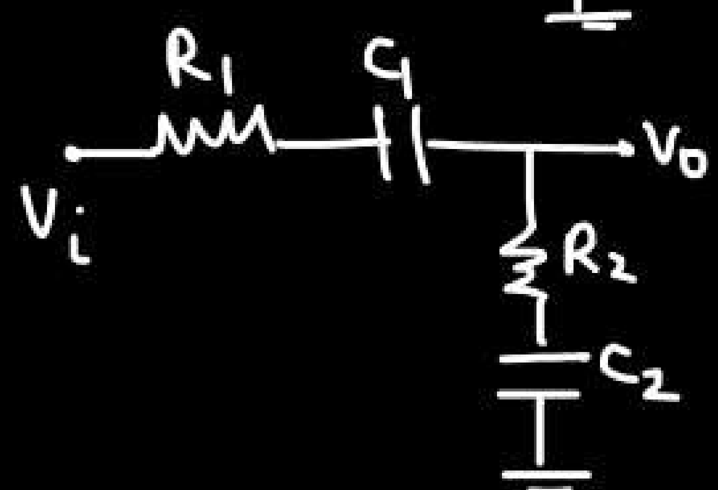
(b)



$\rightarrow \omega = 0 \Rightarrow V_0 = 0$ Volt $\Rightarrow$ BPF

$\omega = \infty \Rightarrow V_0 = 0$ volt

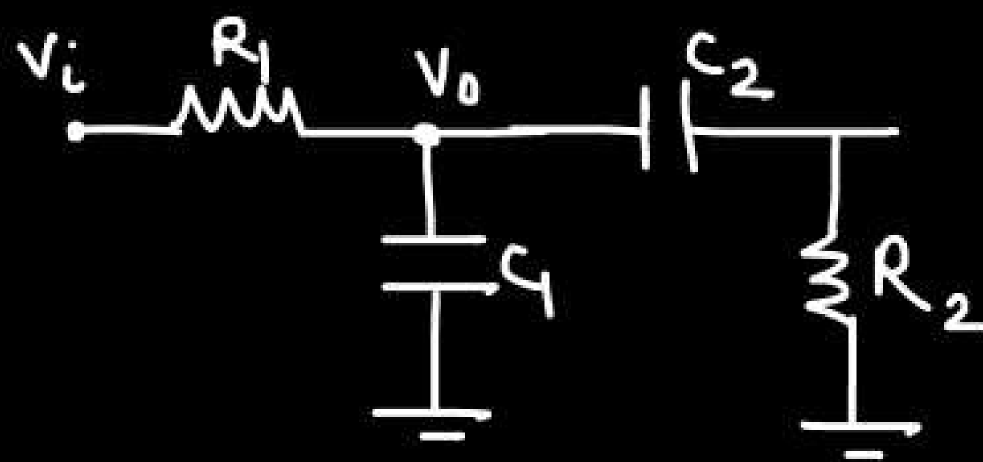
(c)



$\rightarrow \omega = 0 \Rightarrow V_0 = \dfrac{C_1}{C_1 + C_2} V_i$ $\Rightarrow$ BSF

$\omega = \infty \Rightarrow V_0 = \dfrac{R_2}{R_2 + R_1} V_i$

(c)

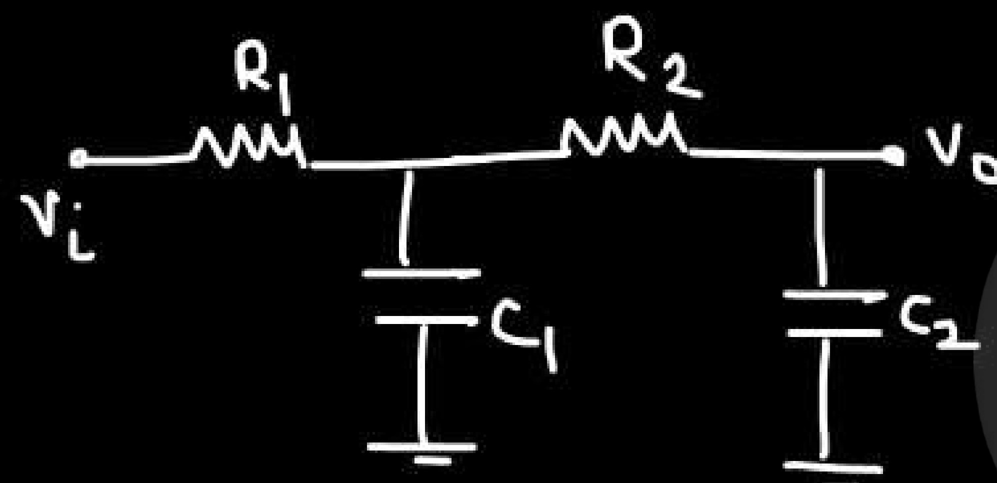


$\omega = 0, \; V_0 = V_i$

$\omega = \infty, \; V_0 = 0$

$\Rightarrow$ LPF

(d)

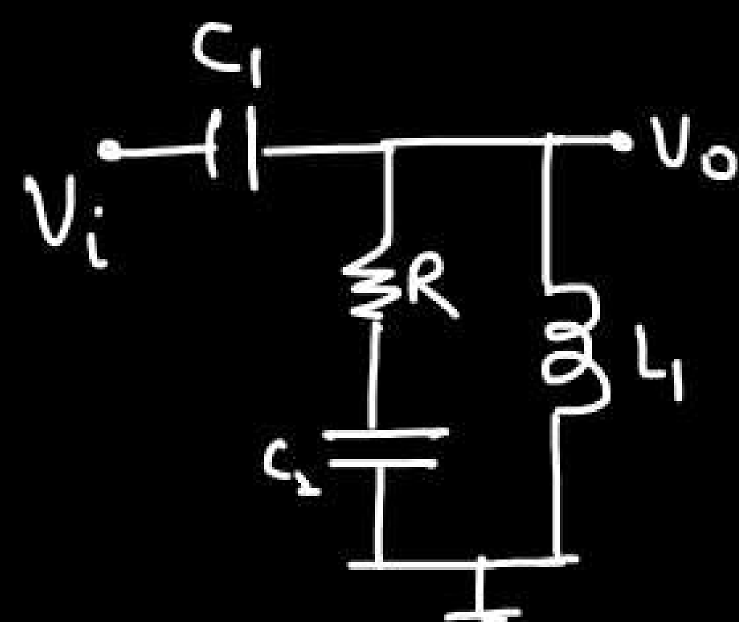


$\omega = 0, \; V_0 = V_i$

$\omega = \infty, \; V_0 = 0$

$\Rightarrow$ LPF

(e)



$\omega = 0, \; V_0 = 0$

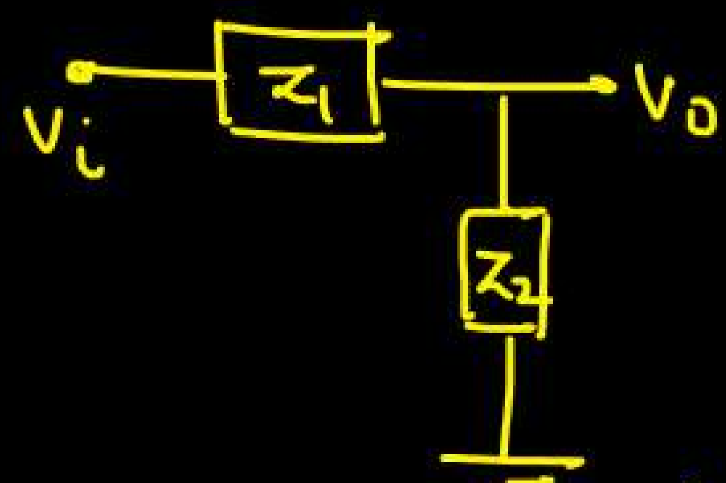
$\omega = \infty, \; V_0 = V_i$

$\Rightarrow$ HPF

Finding poles and zeros intuitively :-

$$\frac{V_0(s)}{V_i(s)} = H(s)$$

$$H(s)\Big|_{s=s_z} \to 0 \quad , \quad H(s)\Big|_{s=s_p} \to \infty$$



$$H(s) = \frac{V_0(s)}{V_i(s)} = \frac{Z_2}{Z_2+Z_1}$$

For poles :-

$$Z_2 = -Z_1 \quad (Z_1 = Z_2 \neq 0)$$

For zeros:-

(i) Break the link b/w o/p & i/p

$$Z_1 \to \infty \quad (Z_2 \neq \infty)$$

(ii) $Z_2 \to 0 \quad (Z_1 \neq 0)$

↳ Some more imp. Points:-

(i) For any T.F., no. of poles and no. of zeros are equal.

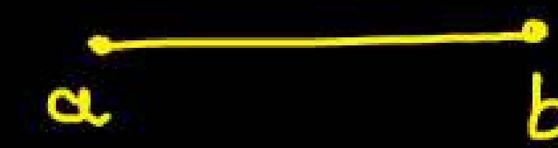
$$H(s) = \frac{s+a}{(s+b)(s+c)}$$

Poles ⇒ $-b, -c$

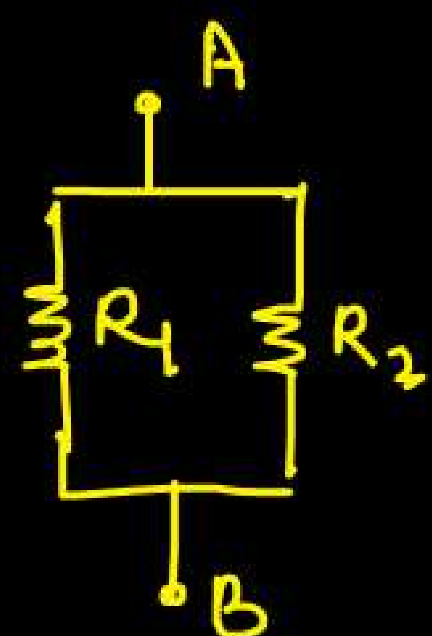
Zeros ⇒ $-a, \infty$ → not finite

(ii)

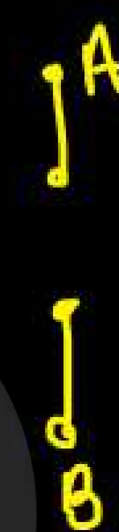
$Z_{eq} = R_1 + R_2$



$R_2 = -R_1$



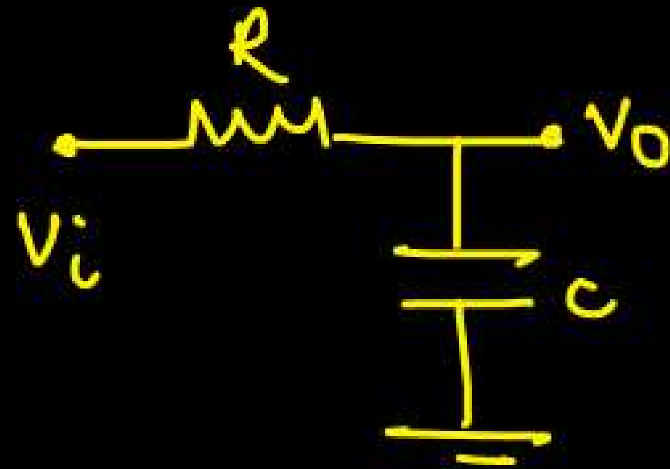
$Z_{eq} = \frac{R_1 R_2}{R_1 + R_2}$



$R_1 = -R_2$

$= \infty$

Eg. - 1



for zero's

(i) $Z_1 = R \rightarrow$ fixed

$\Rightarrow Z_1$ can never go to ∞.

(ii) $S = \infty \Rightarrow \frac{1}{sC} = 0 \Rightarrow V_0 = 0$

$\Downarrow$

we have a zero at $S_z = \infty$

for poles:-

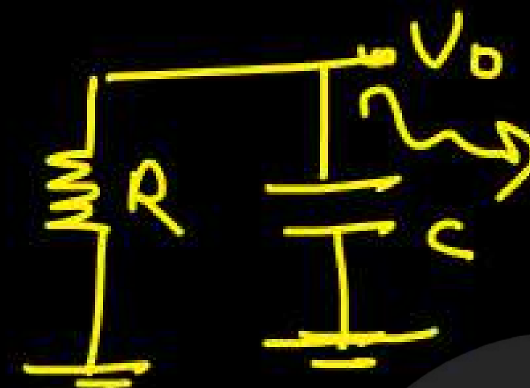
$Z_2 = -Z_1$

$\frac{1}{sC} = -R$

$S_p = \frac{-1}{RC}$ //

Alternative mtd for finding pole :-

Put $V_i \to 0$



make ∞ impedance here

$$\frac{1}{sC} = -R$$

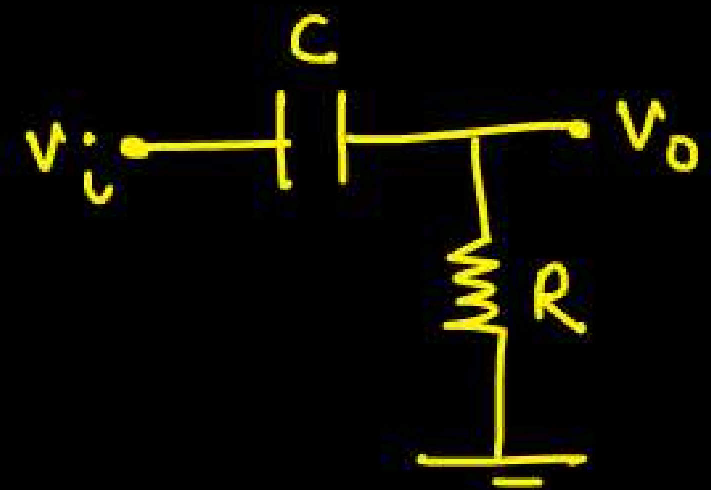
$$S_p = \frac{-1}{RC}$$

$$H(s) = \frac{A}{sRC+1}$$

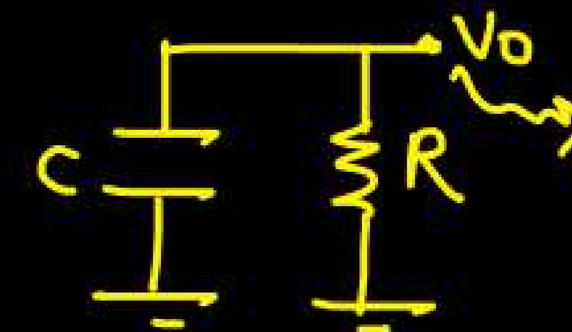
$H(0) = A \Rightarrow V_0 = V_i \Rightarrow H(0) = 1$

$A = 1 \Rightarrow H(s) = \dfrac{1}{sRC+1}$

(2)



For pole:-



$\rightsquigarrow$ ∞ impedance

$R = -\dfrac{1}{SC}$

$S_p = -\dfrac{1}{RC}$

For zero:-

(i) $Z_1 \to \infty \Rightarrow \dfrac{1}{SC} = \infty \Rightarrow S_Z = 0$

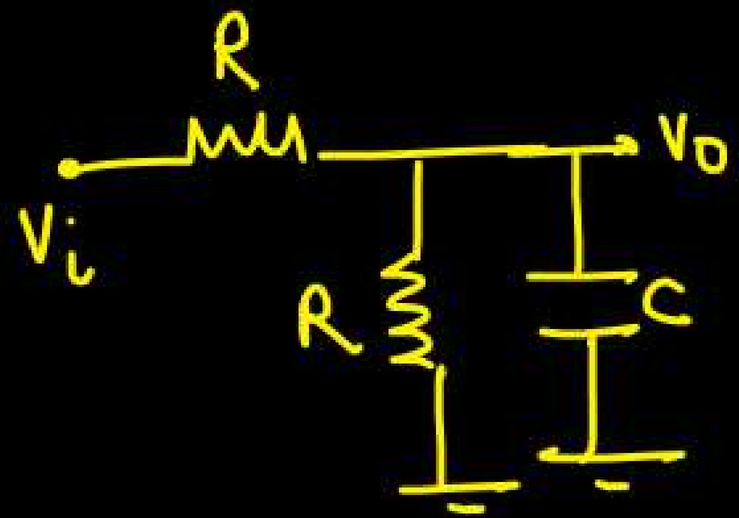
(ii) $Z_2 \to 0 \Rightarrow$ Not possible

$$H(S) = A\left(\frac{S}{SRC+1}\right)$$

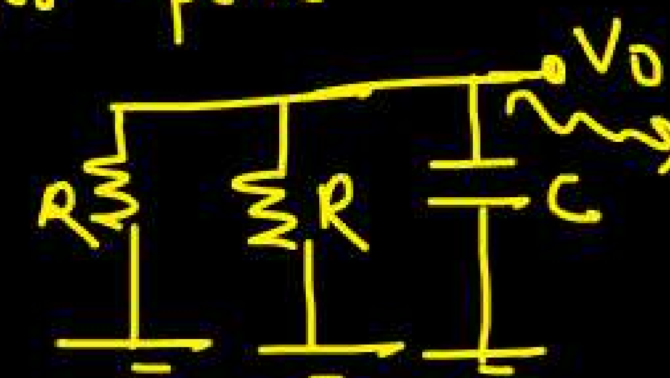
$$H(\infty) = \frac{A}{RC} = 1 \Rightarrow A = RC$$

$$H(S) = \frac{SRC}{SRC+1}$$

3

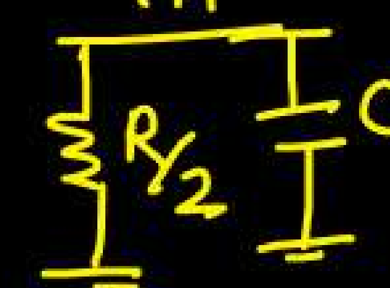


for pole



∞ impedance

|||



$\Rightarrow S_p = \dfrac{-2}{RC}$

for zero

(i) $Z_1 \to \infty \Rightarrow$ not possible

(ii) $S = \infty \Rightarrow Z_2 = 0$

$\hookrightarrow S_z = \infty$

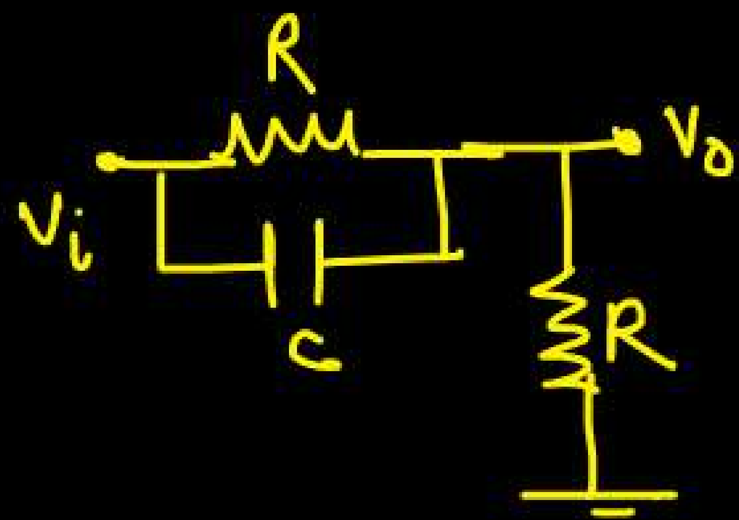
$$H(s) = \frac{A}{\frac{SRC}{2} + 1}$$

$H(0) = A = \frac{1}{2}$

$$H(s) = \frac{1/2}{\frac{SRC}{2} + 1}$$

$$H(s) = \frac{1}{SRC + 1}$$

(4)



For pole:-

$$S_p = \frac{-2}{RC}$$

For zero:-

(i) $Z_1 \to \infty$

$$\frac{1}{sC} = -R$$

$$S_z = \frac{-1}{RC}$$

(ii) $Z_2 \to 0 \Rightarrow$ Not possible

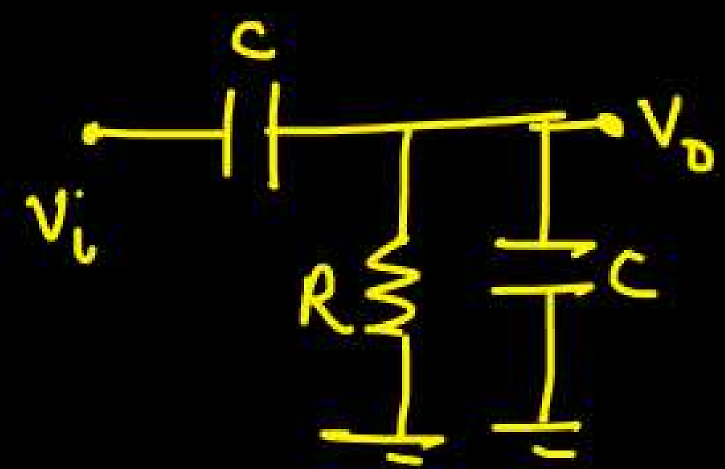
$$H(s) = A\left[\frac{sRC+1}{\frac{sRC}{2}+1}\right]$$

$$H(0) = A = 1/2$$

$$\Downarrow$$

$$\boxed{H(\omega) = \frac{sRC+1}{sRC+2}}$$

⑤



$$H(s) = \frac{A \cdot S}{2SRC + 1}$$

$$H(\infty) = \frac{A}{2RC} = \frac{1}{2}$$

$$A = RC$$

$$H(s) = \frac{SRC}{2SRC + 1}$$

for pole:-

$$S_p = \frac{-1}{2RC}$$

for zero:-

(i) $S = 0 \Rightarrow Z_1 = \infty \Rightarrow S_z = 0$ ✓

↳ $Z_2 = R$

(ii) $S = \infty \Rightarrow Z_2 = 0$ ✓

↳ zero at $S = \infty$ ✗

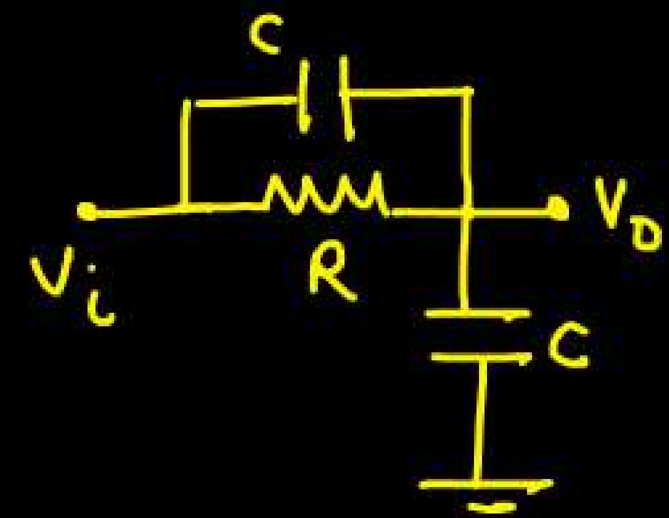
because

$S = \infty \Rightarrow Z_1 = 0$

both Z_1 & $Z_2 = 0$

Not acceptable

6



For pole :-

$$S_p = -\frac{1}{2RC}$$

For zero -

(i) $S_z = \frac{-1}{RC}$

(ii) $S = \infty \Rightarrow \frac{1}{CS} = 0 \Rightarrow Z_2 = 0$

$\Downarrow$

also, $Z_1 = 0$

$\downarrow$

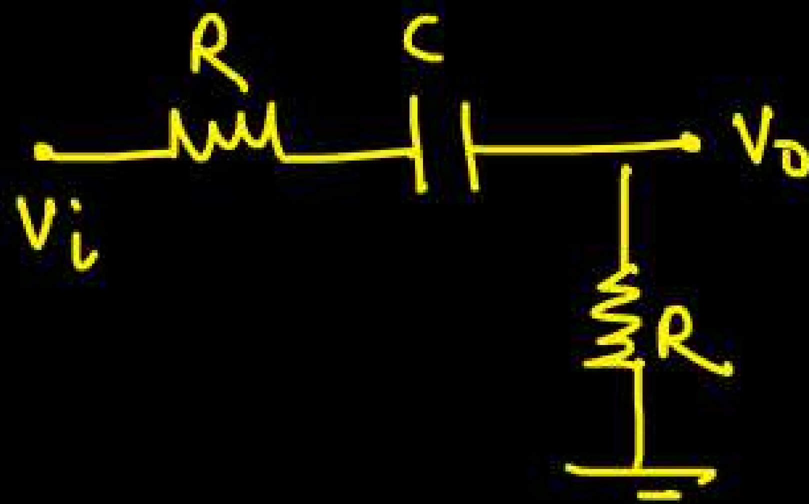
not acceptable

$$H(s) = A\left[\frac{sRC + 1}{2sRC + 1}\right]$$

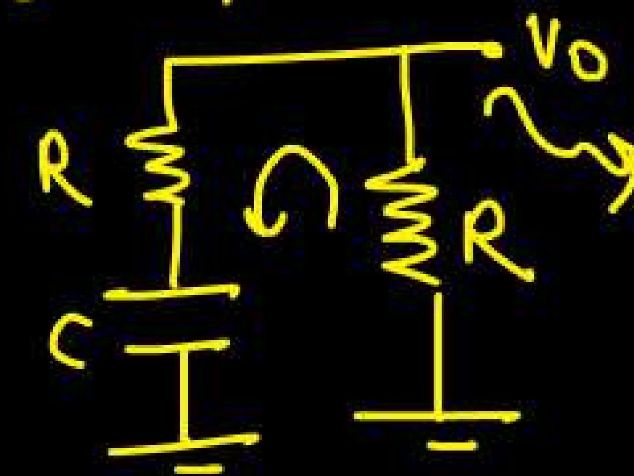
$$H(0) = A = 1$$

$$H(s) = \frac{sRC + 1}{2sRC + 1}$$ Ans

(7)



For pole:-



$$-R = R + \frac{1}{C\omega}$$

$$S_p = \frac{-1}{2RC}$$

For zero:-

(i) $s = 0 \Rightarrow \frac{1}{C\omega} = \infty \Rightarrow Z_1 = \infty \Rightarrow S_z = 0$

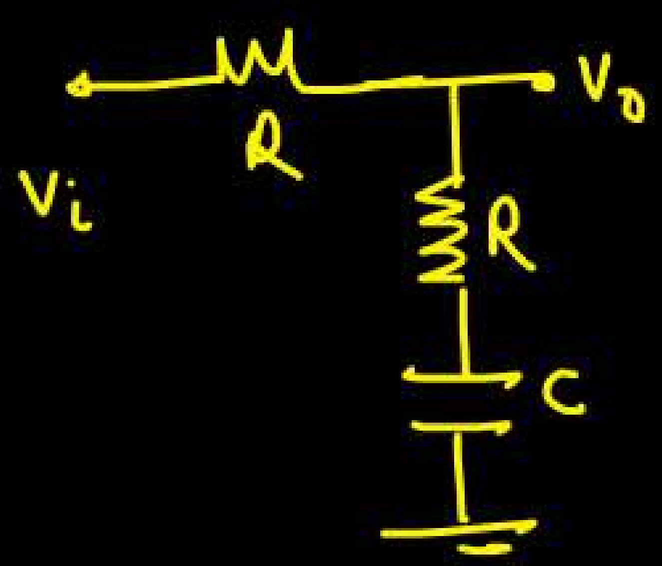
(ii) $Z_2 \to 0 \Rightarrow$ Not possible

$$H(s) = \frac{As}{2sRC + 1} \qquad H(s) = \frac{sRC}{2sRC+1}$$

$\Uparrow$

$$H(\infty) = \frac{A}{2RC} = \frac{1}{2} \Rightarrow A = RC$$

8



For poles:-

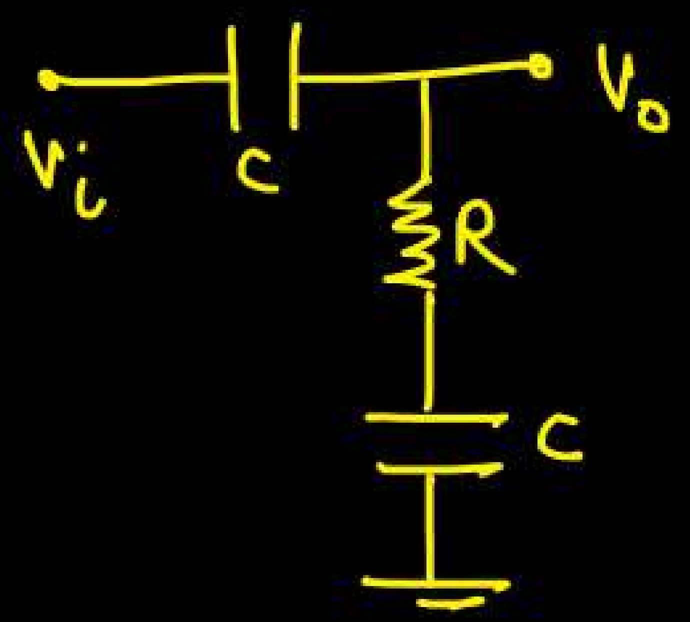
$$S_p = \frac{-1}{2RC}$$

For zero's:-

$$Z_2 \to 0 \Rightarrow R + \frac{1}{SC} = 0 \Rightarrow S_z = \frac{-1}{RC}$$

$$H(s) = \frac{SRC+1}{2SRC+1}$$

9



$$H(s) = \frac{sRC + 1}{sRC + 2}$$

For poles:-

$$S_p = -\frac{2}{RC}$$

For zero:-

(i) $Z_1 \to \infty \Rightarrow S_z = 0 \to$ zero ✗

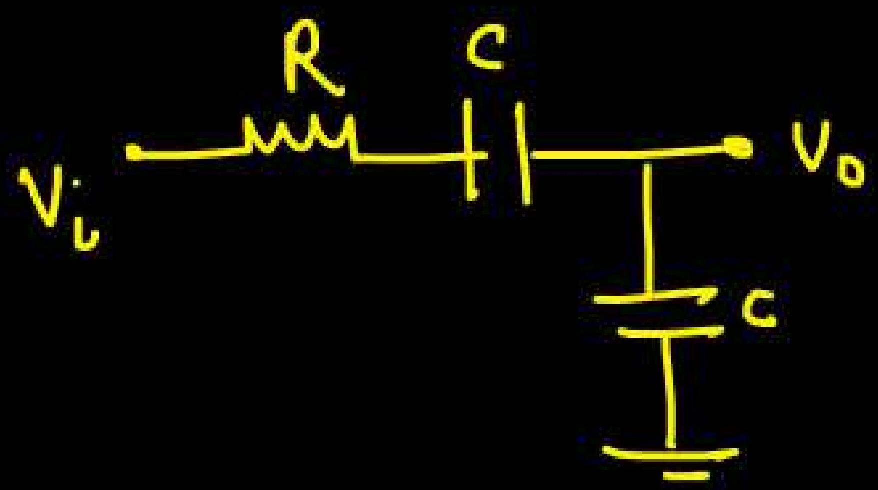
Because, $S = 0 \to Z_2 = 0$

$\therefore S = 0 \Rightarrow Z_1 = Z_2 = \infty \to$ NOT acceptable

(ii) $Z_2 = 0$

$$S_z = -\frac{1}{RC}$$

10



$$H(s) = \frac{1}{sRC + 2} =$$

For poles

$$S_p = \frac{-2}{RC}$$

For zero:-

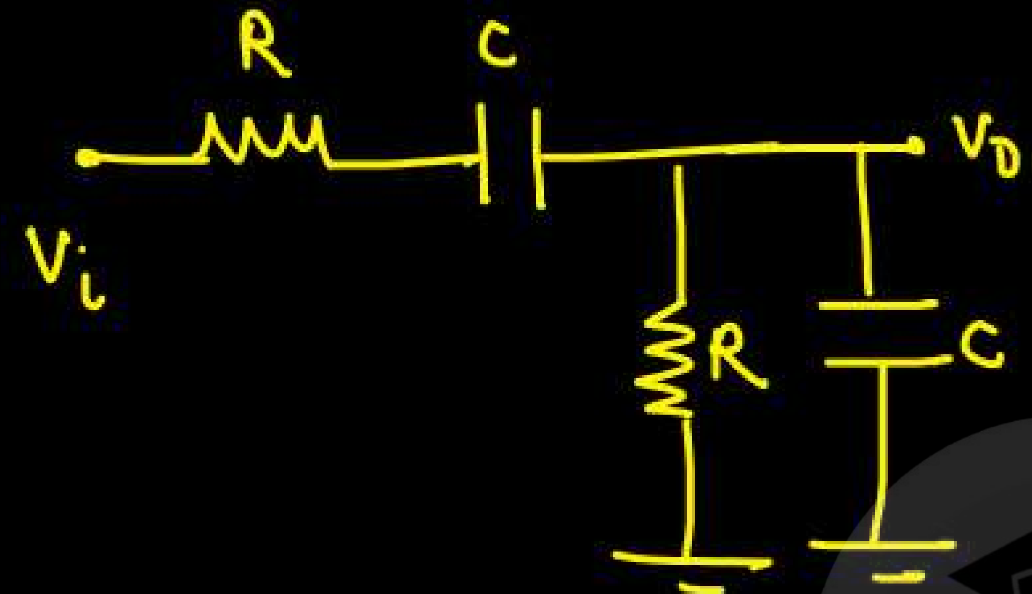
$S = 0 \Rightarrow Z_1 \to \infty$

$Z_2 \to \infty \Rightarrow$ Not accepted

$S = \infty \Rightarrow Z_2 = 0$

$Z_1 = R$

2^{nd} order ckt:-



Two storing element

$\Downarrow$

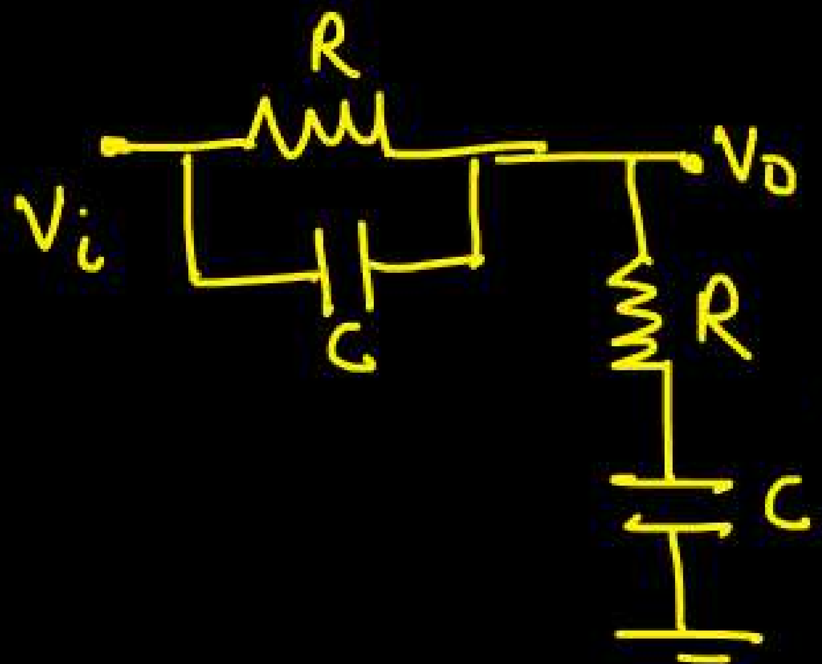
Two poles

for zeros:--

$S=0 \Rightarrow Z_1=\infty,\ Z_2=R \rightarrow$ Acceptable $(S_z=0)$

$S=\infty \Rightarrow Z_2=0,\ Z_1=R \rightarrow$ Acceptable

$$H(S)=\frac{AS}{S^2+bS+C}$$



① Two poles :-

② for zeros

(i) $R + \frac{1}{C\omega} = 0 \Rightarrow S_z = \frac{-1}{RC}$ = acceptable

$\Downarrow$

$z_1 = \infty, \quad z_2 = 0$

$$H(s) = \frac{A(SRC+1)^2}{s^2 + bs + c}$$

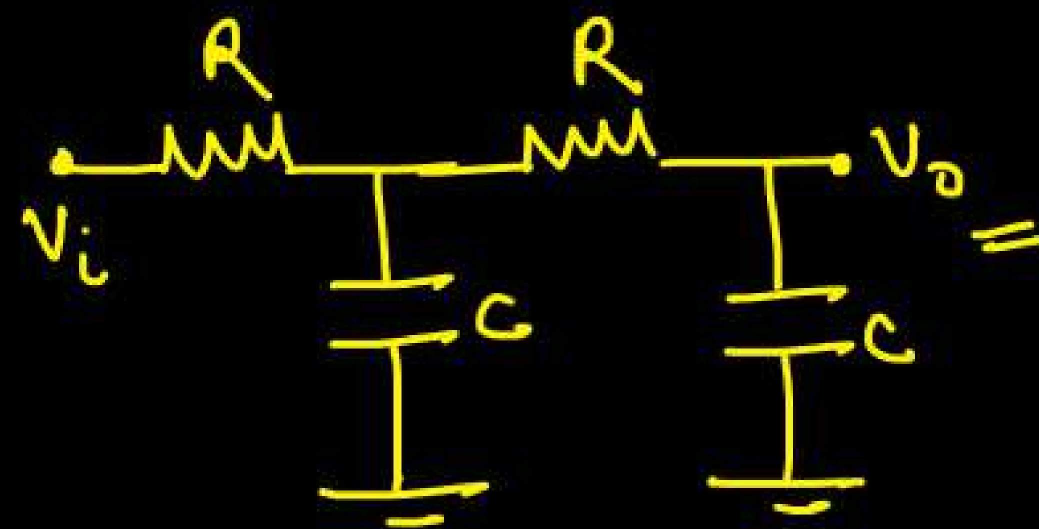
(ii) $R + \frac{1}{C\omega} = 0$

$\hookrightarrow S_z = \frac{-1}{RC}$

[$s \to \infty, \quad z_1 = 0, \quad z_2 = R$

Not a zero at $s = \infty$]

3



① Two poles:-

② for zeros:-

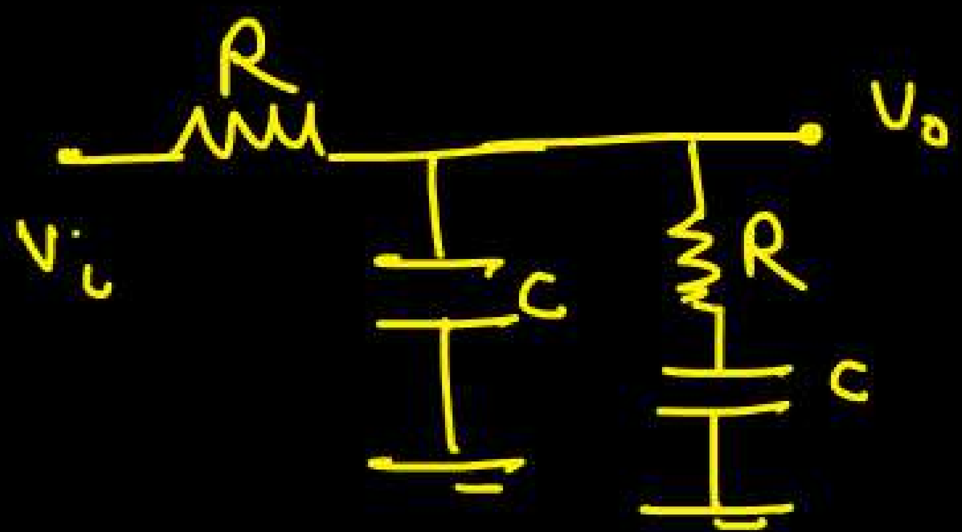
$s = \infty \Rightarrow V_0 = 0 \Rightarrow$ zero at $s = \infty$

$s_z = \infty$

Two zero's at $s = \infty$

$$H(s) = \frac{A}{s^2 + bs + c}$$

4



Two poles

(ii) Zeros

$R + \frac{1}{Cs} = 0 \Rightarrow S_z = -\frac{1}{RC}$

$s = \infty \Rightarrow \frac{1}{Cs} = 0$

$\hookrightarrow V_0 = 0 \Rightarrow S_z = \infty$

$$H(s) = A\frac{(sRC + 1)}{(s^2 + as + b)} =$$

Drawing bode plots of first order RC circuits :-

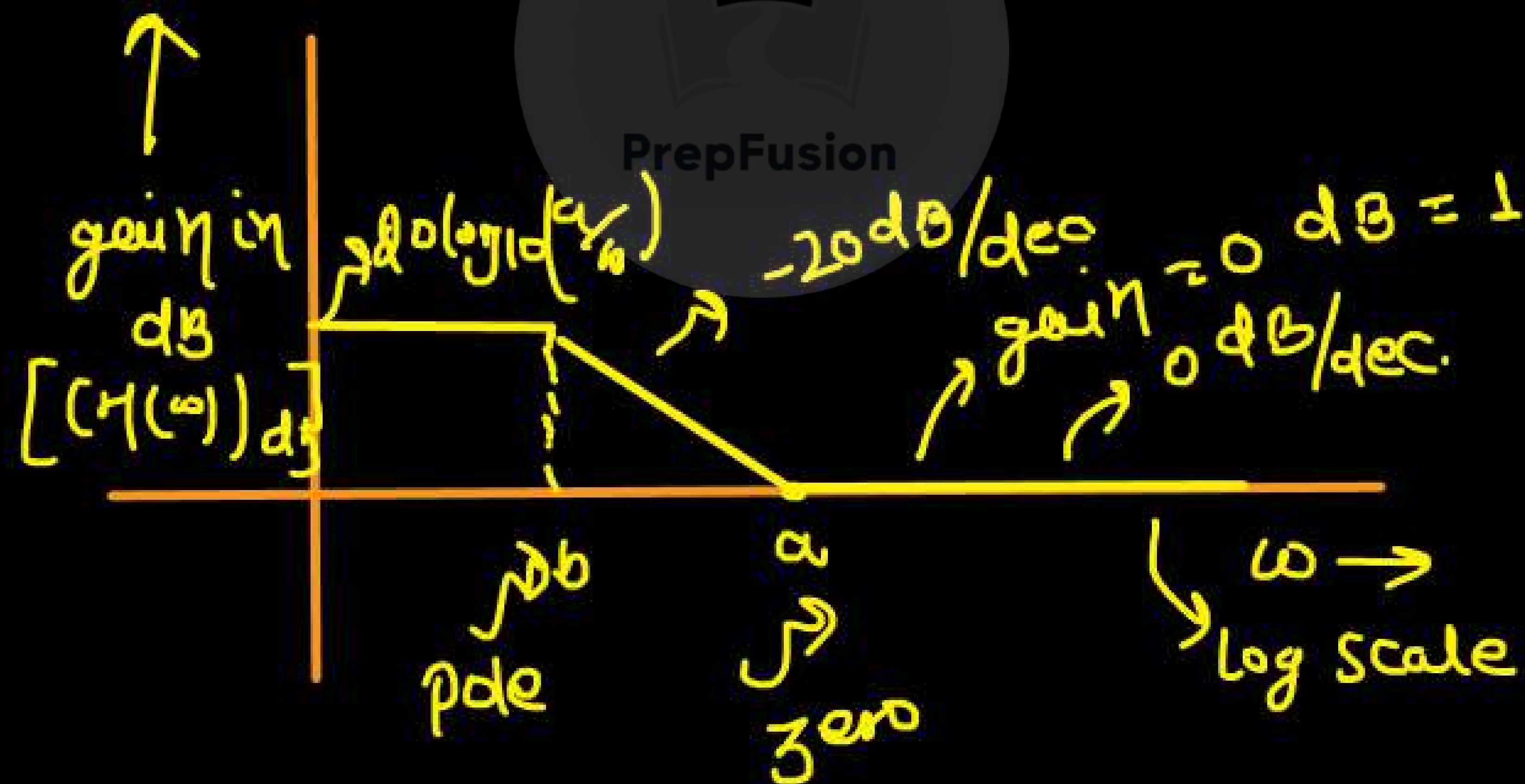
$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{s+a}{s+b} \quad ; \quad a > b$$

pole

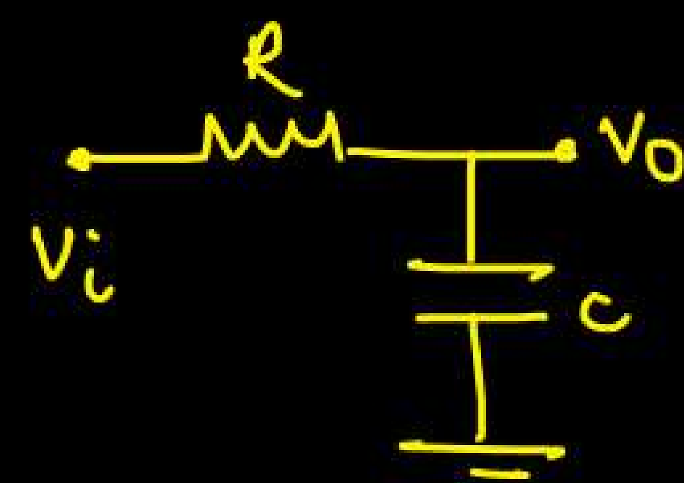
$$H(0) = a/b \qquad H(\infty) = 1 = 0\,dB$$

pole → -20 dB/dec.

zero → +20 dB/dec



Eg. - 1



$$S_p = -\frac{1}{RC}$$

$$H(s) = \frac{1}{sRC+1} \longrightarrow \text{pole} = -1/RC$$

$$H(0) = 0\,\text{dB}$$
$$H(\infty) = 0 = -\infty\,\text{dB}$$