* 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.

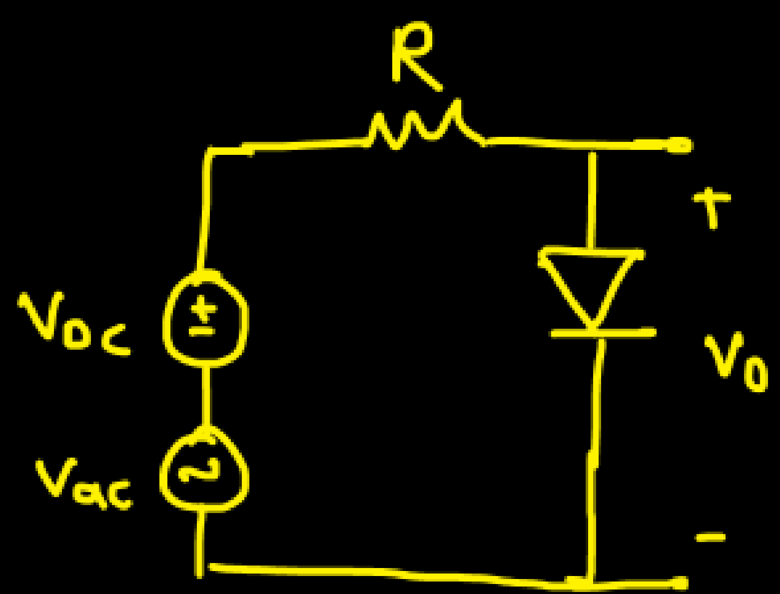
3. Peak detector → detects peak value of i/p and gives dc o/p.

4. Voltage Multipliers → gives the o/p more than the max value of i/p signal (dc o/p)

⑤ Small signal Analysis :-

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

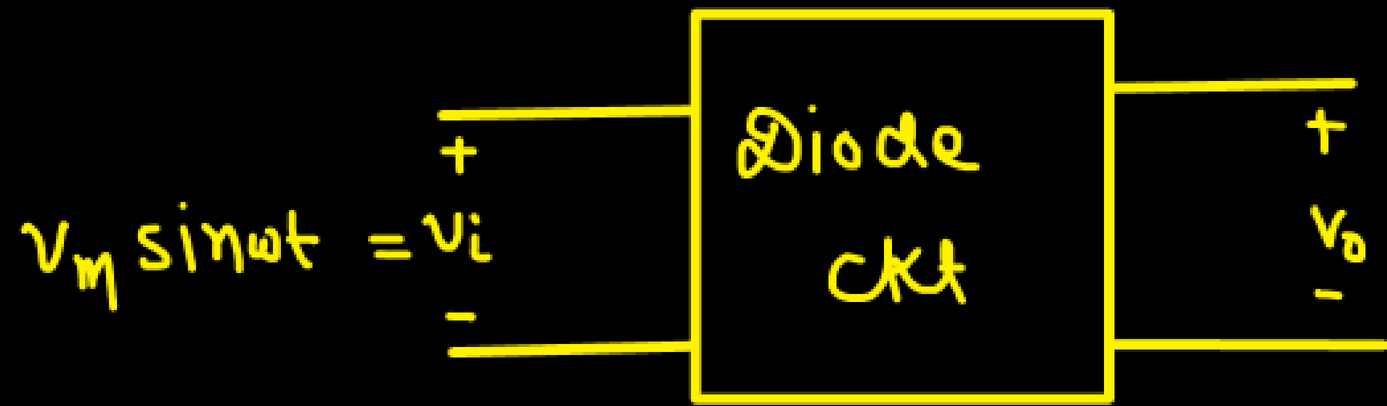
OFF: $r_d = \infty$



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

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

$\Rightarrow$ NOT Getting Amplified o/p.

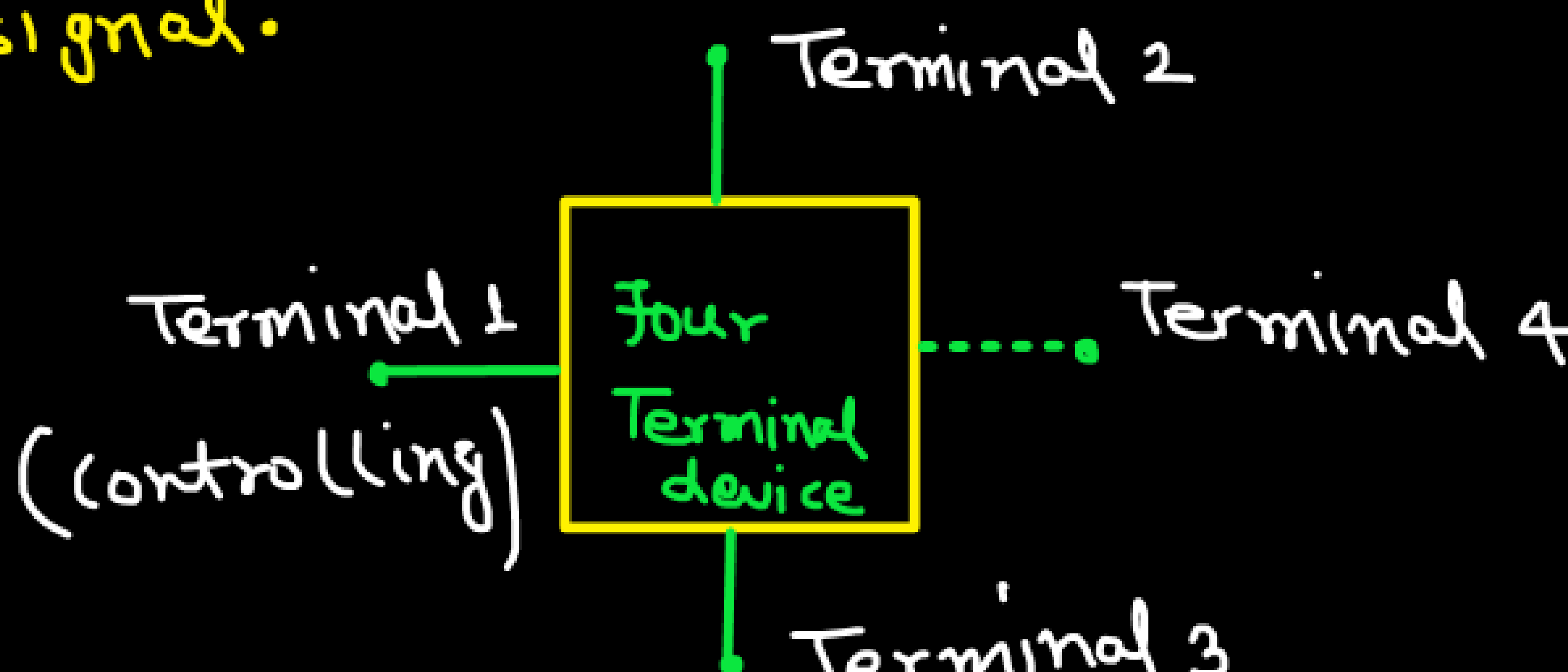


$= K V_m \sin\omega t$

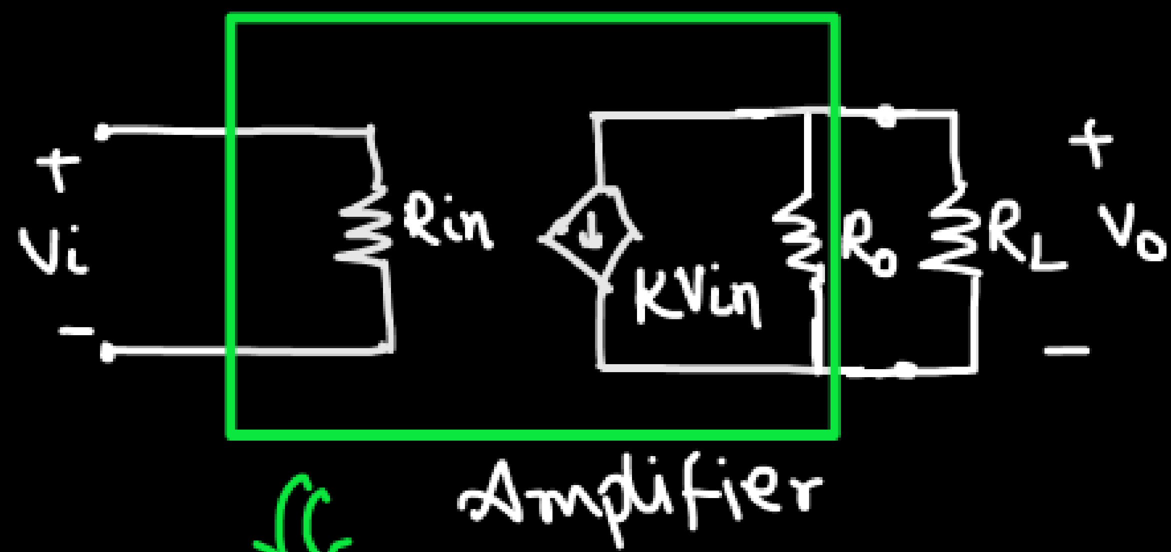
where $|k| > 1$

⇒ NOT POSSIBLE

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



A Basic Amplifier :-



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

$\Downarrow$

Amplification

Gives Rise to Transistors

☆

Field Effect Transistors

(FET)

MOSFETs

(Metal oxide semiconductor)

Depletion Type

n-channel

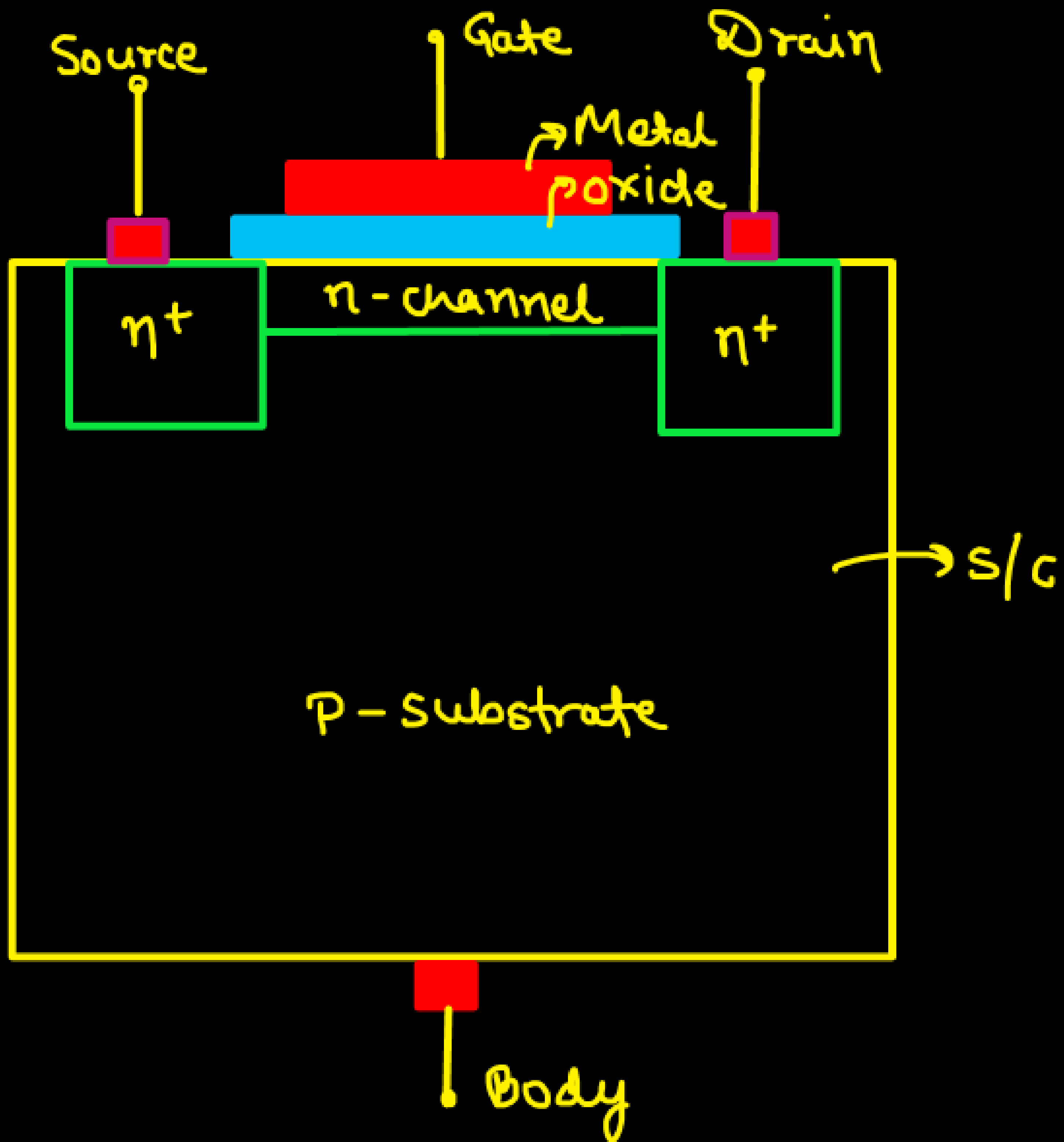
P-channel

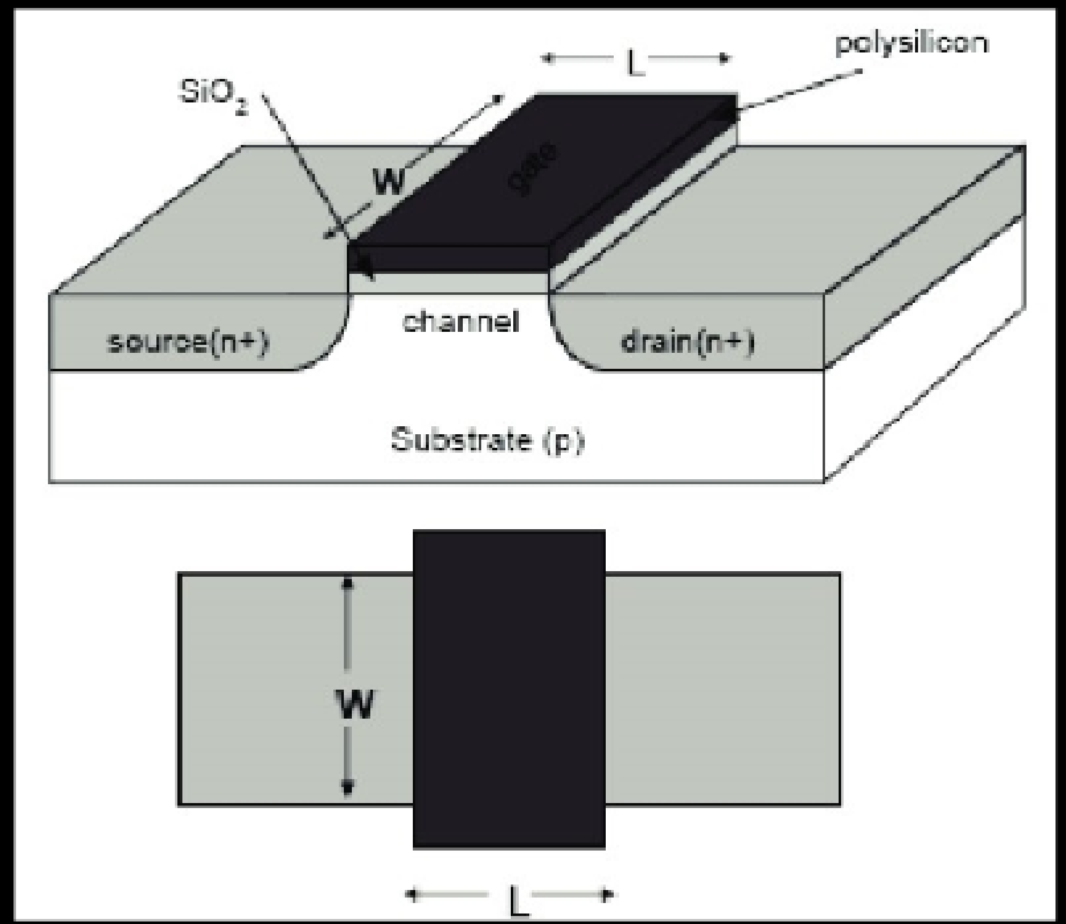
Enhancement type

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.

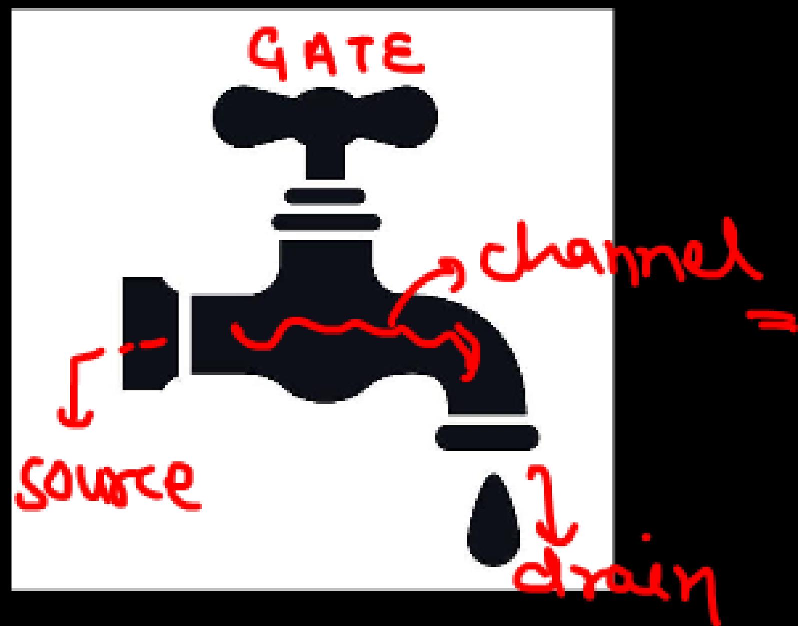
2. **Drain** :- Collects the charge carrier from the channel.

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 :-

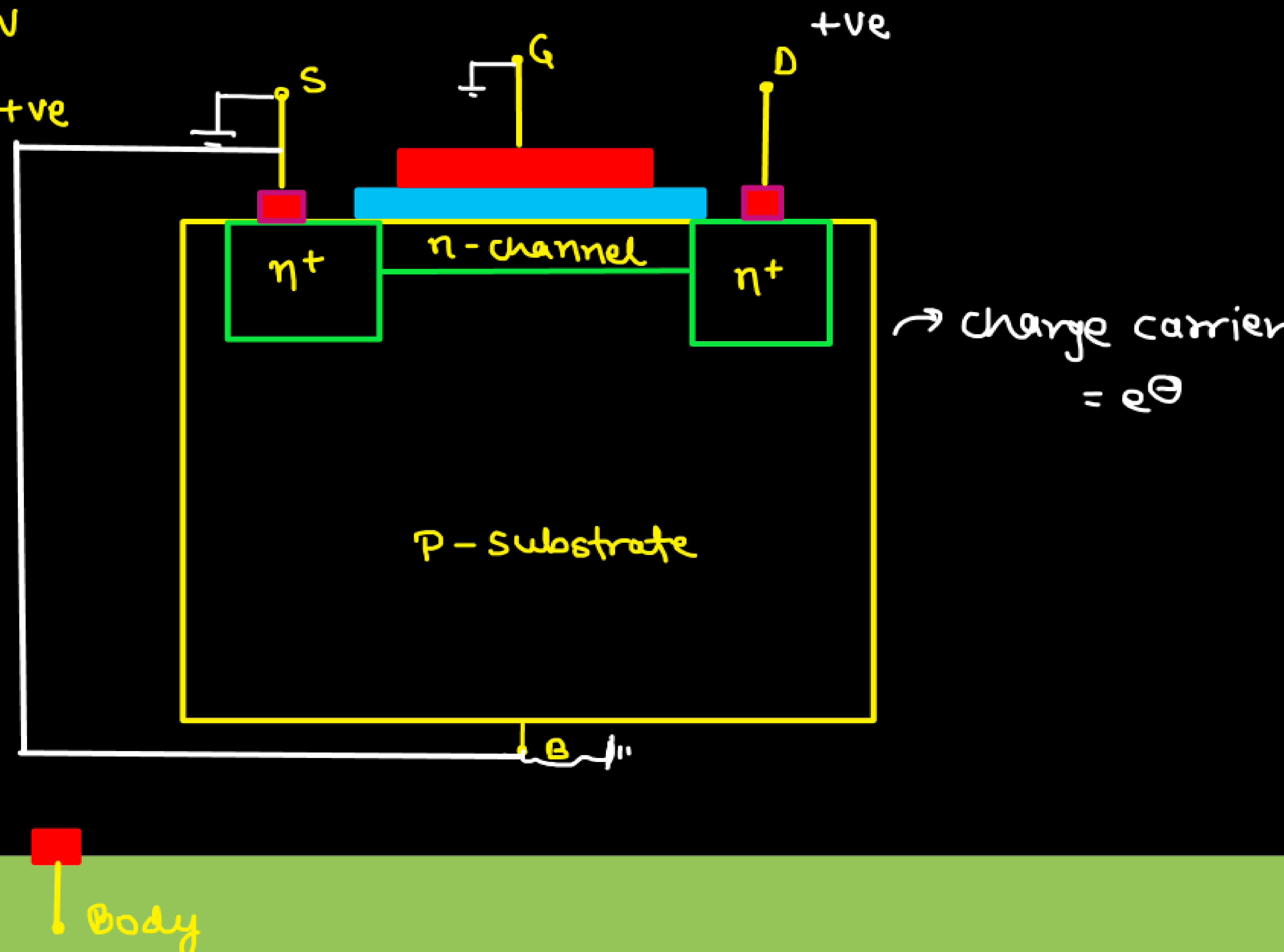


For n-channel depletion type MOSFET :-

Cod^n 1 :-

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

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



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

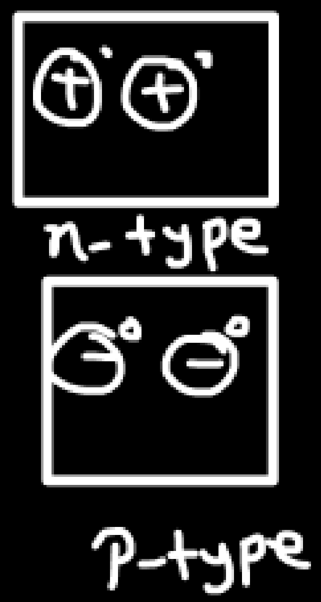
$\Downarrow$

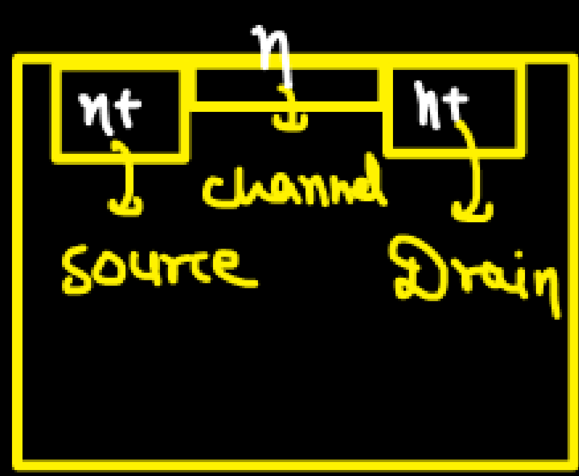
less resistance

$n \to$ Lightly doped $\to$ less conductivity

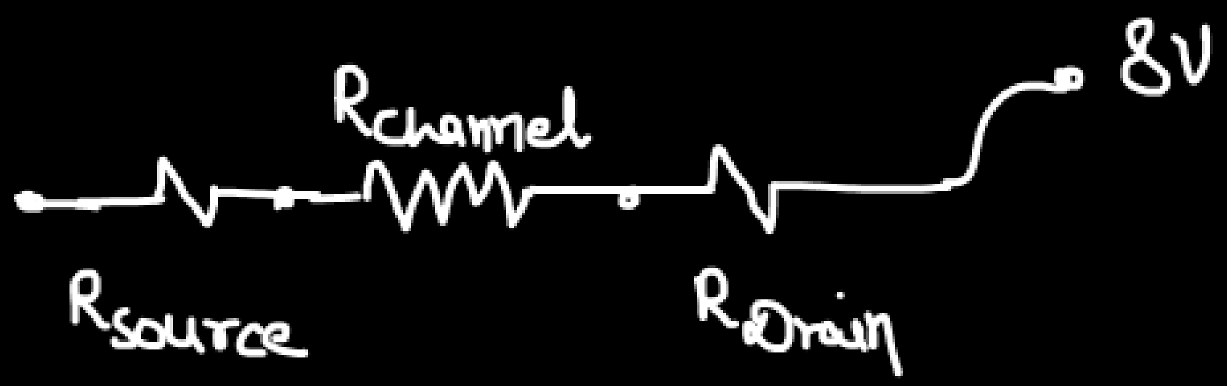
$\Downarrow$

More resistance





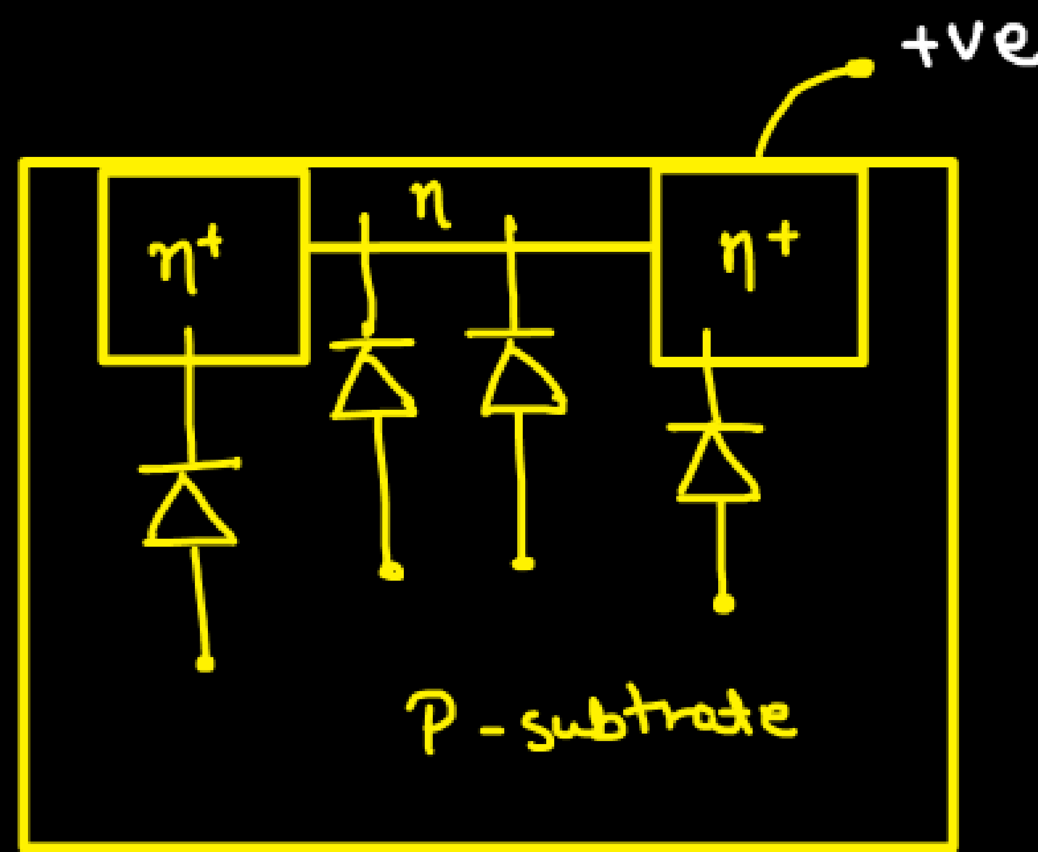
$\equiv$

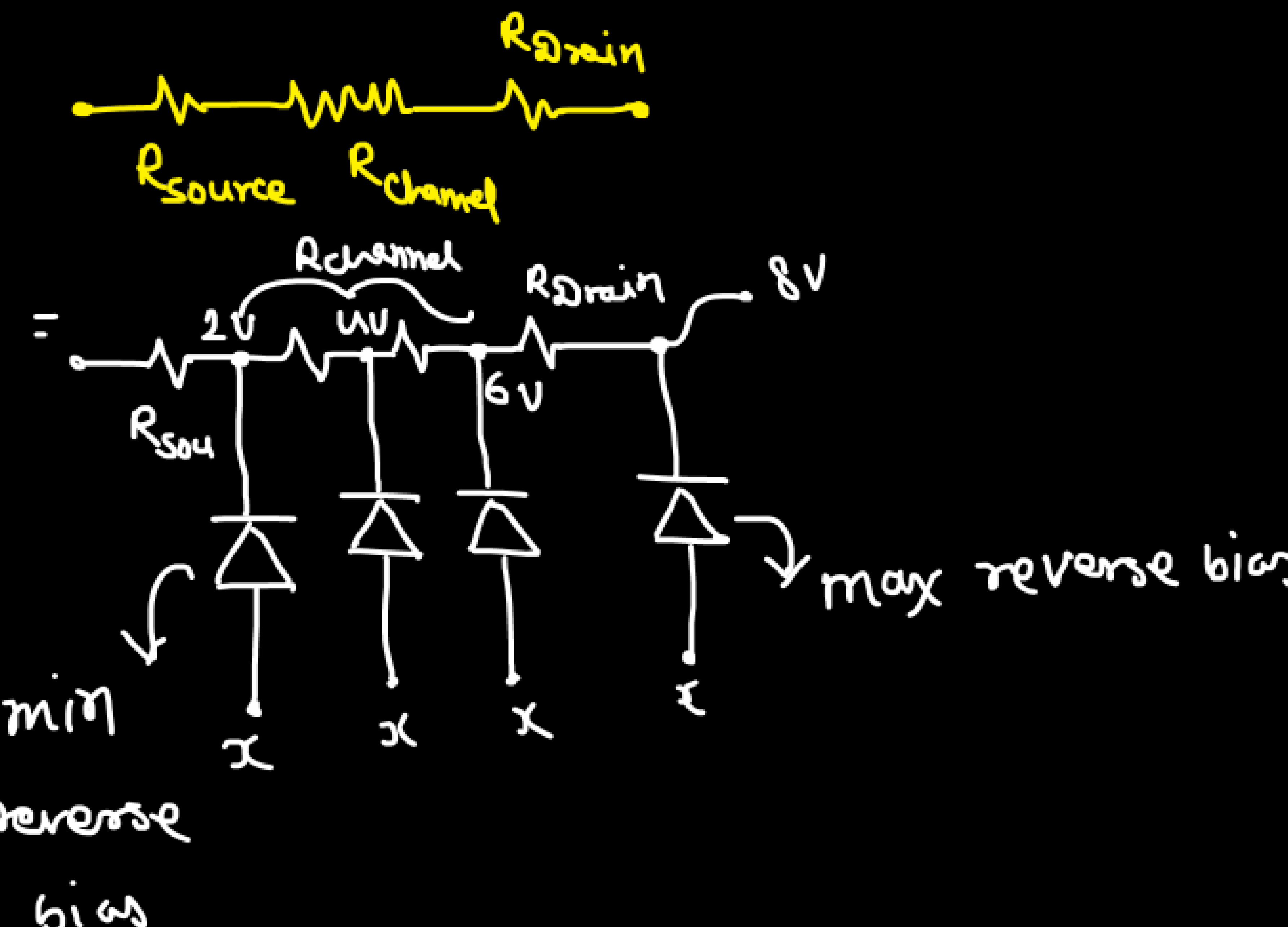


$R_{channel} > R_{Drain}, R_{source}$

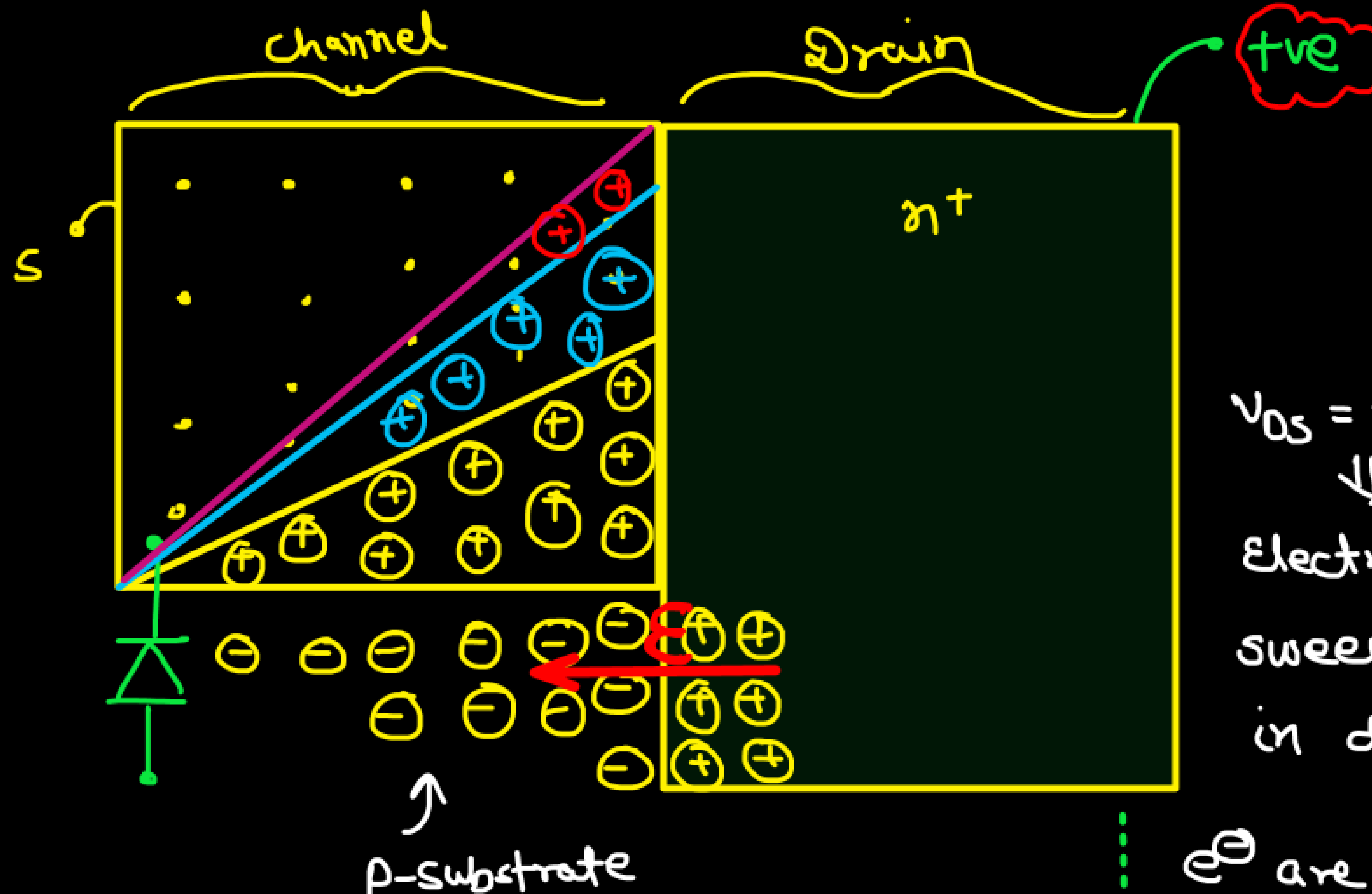
Assumption

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





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



$V_{DS} = +ve$

$\Downarrow$

Electric field ε will sweep away the $e^{\ominus}$ in drain terminal

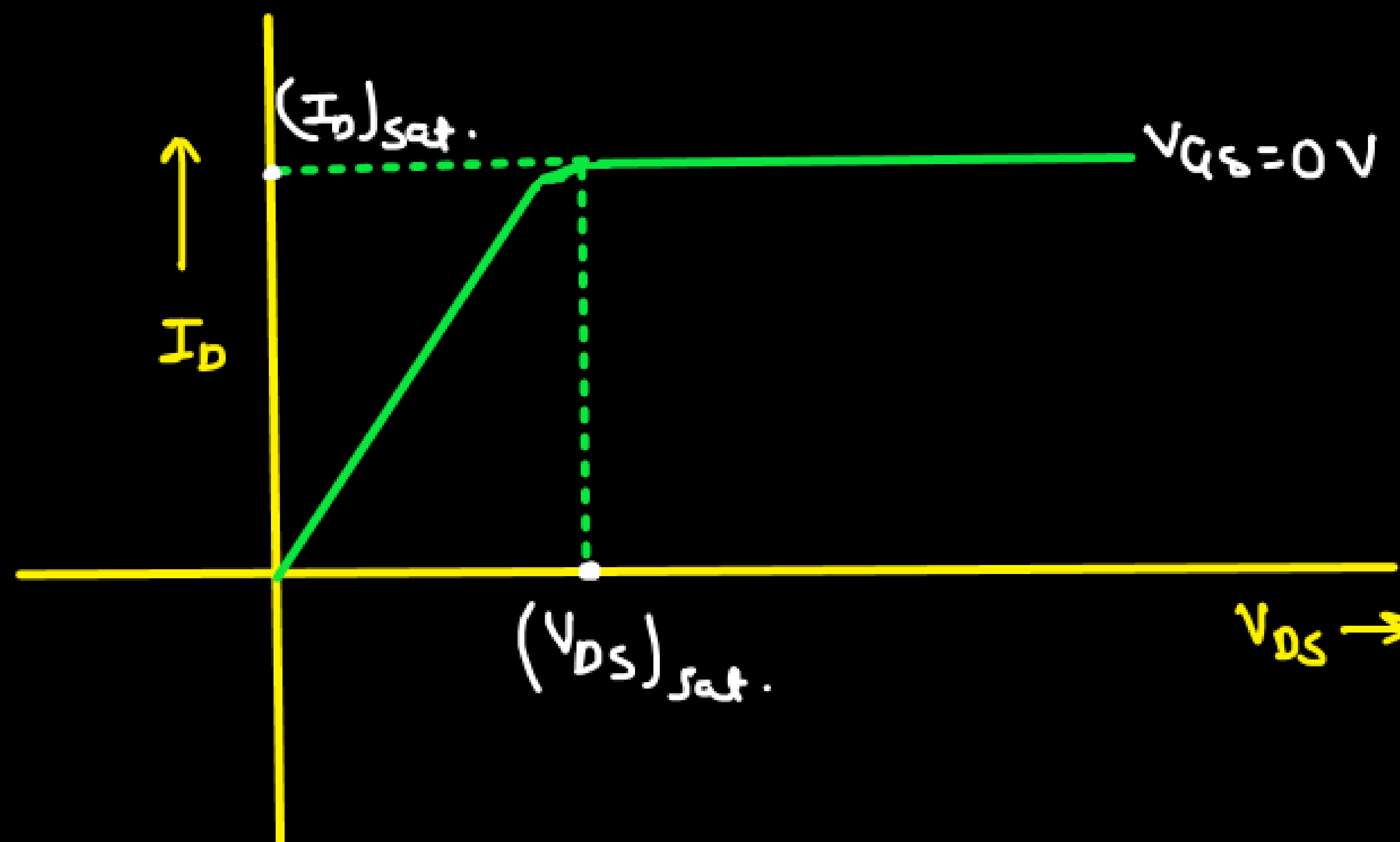
$\Downarrow$

$e^{\ominus}$ are moving from source to drain

$\Downarrow$

current will flow from Drain to source.

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



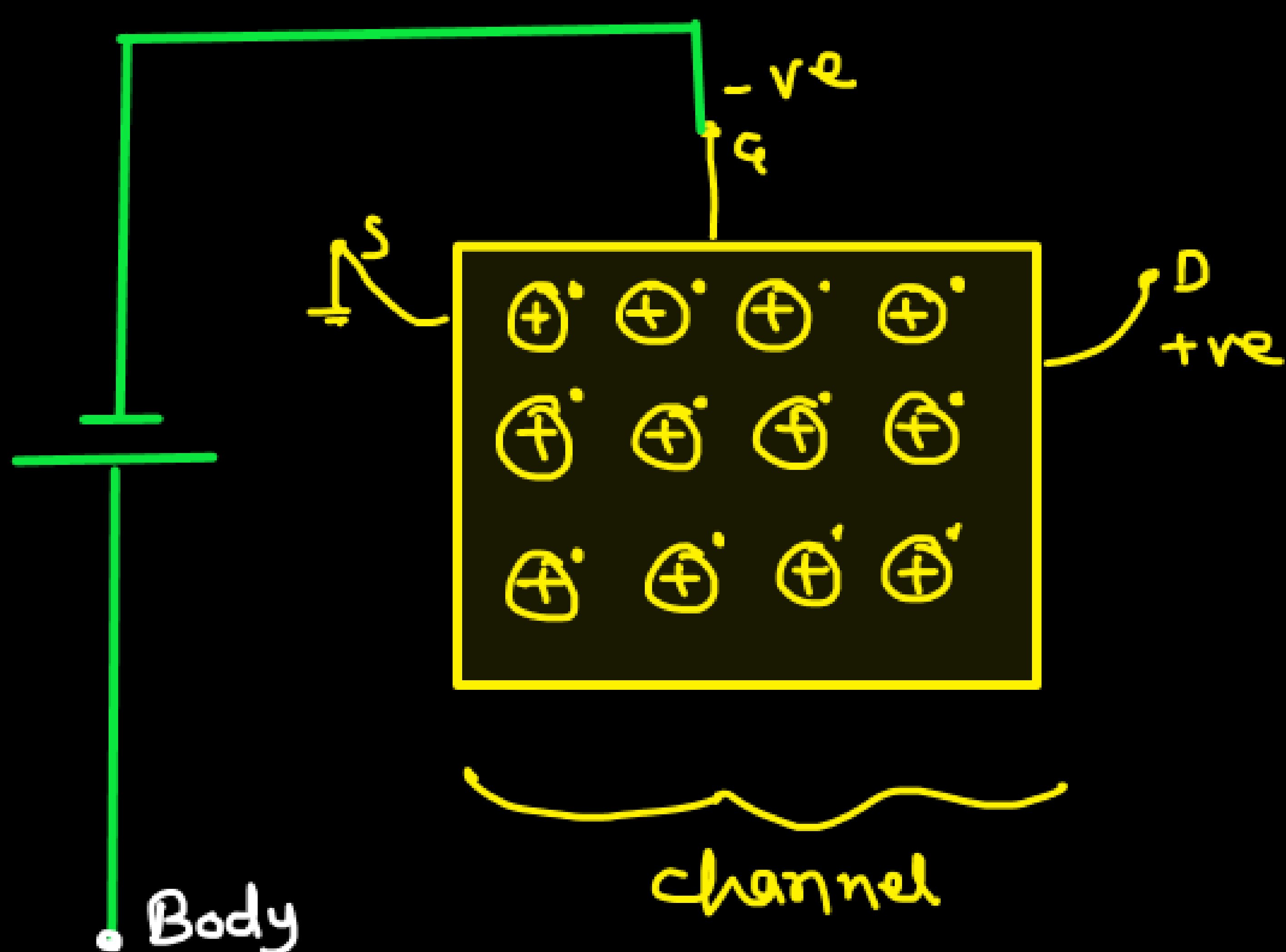
But @ a certain value of V_{DS}, the channel will start having very less charge carriers. Although the "E" field is strong but the charge carriers are less and because of that current saturates.

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

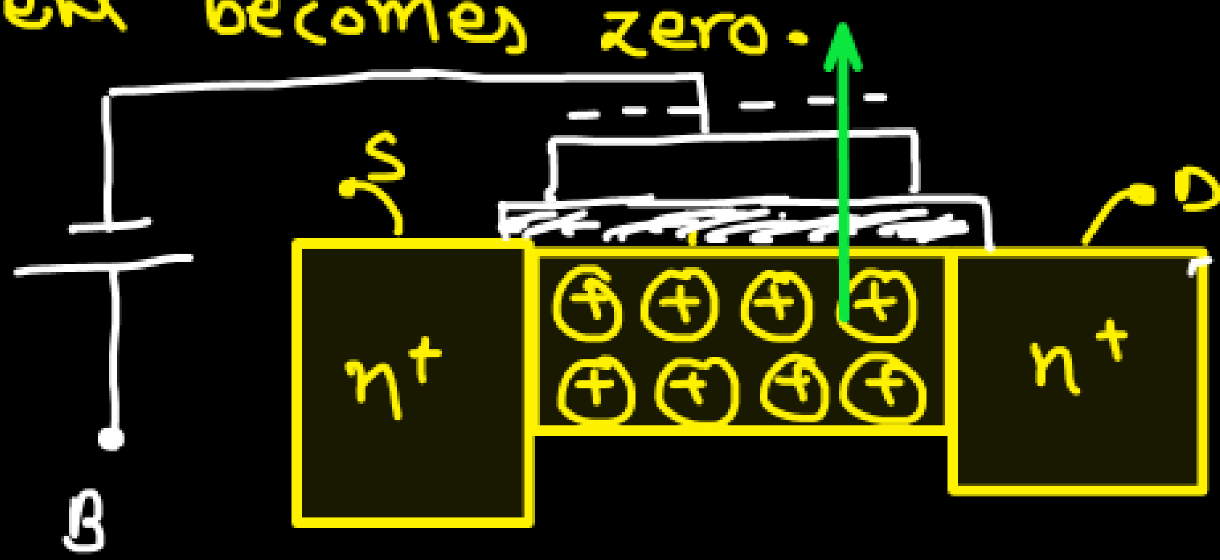
$\Downarrow$

Channel is getting depleted of charge carrier

$\Downarrow$

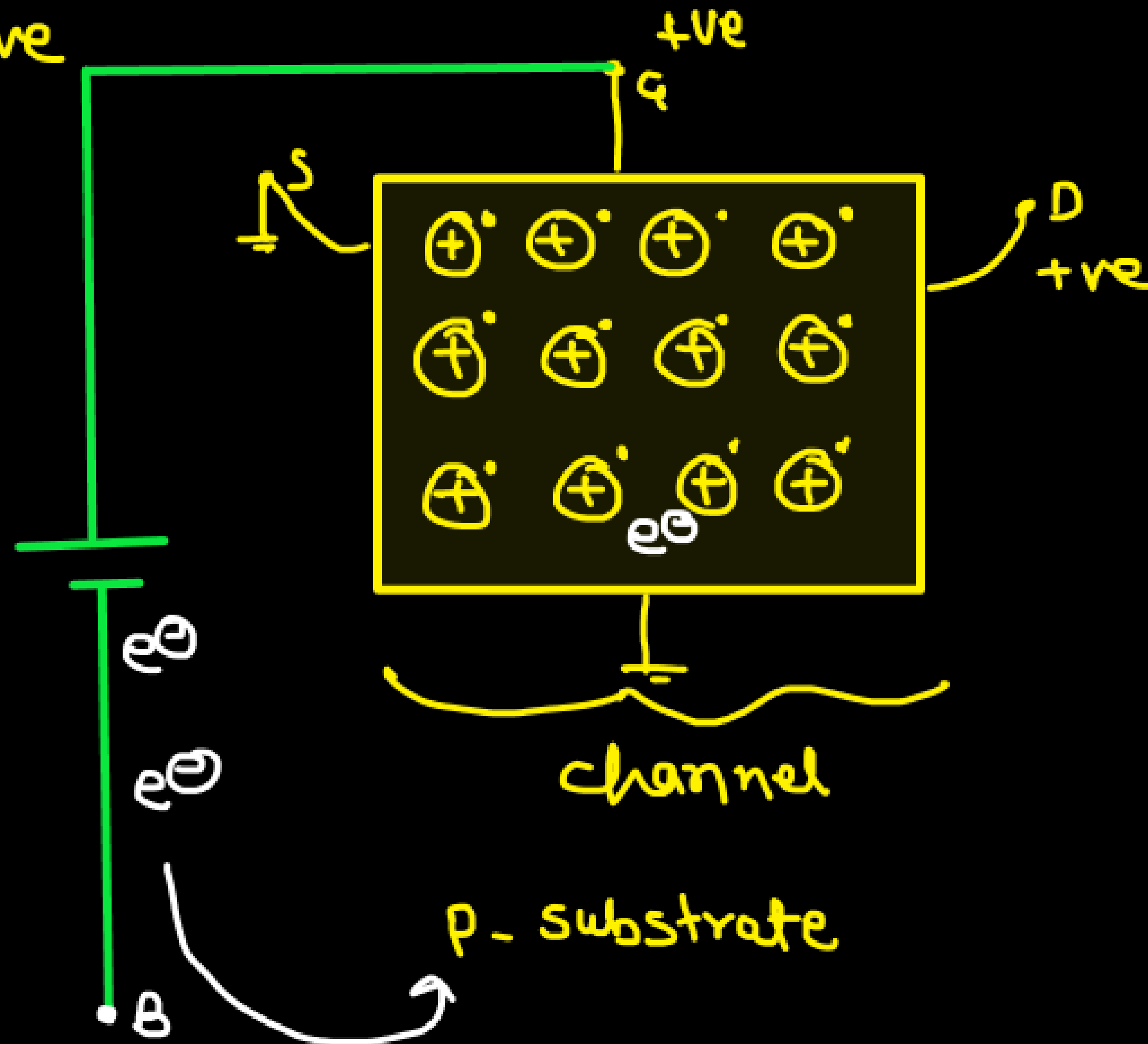
Current is decreasing

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 $e^{\ominus}$ from source side will not be reaching the drain side and the current becomes zero.



$\Rightarrow$ Negative potential is known as pinch-off voltage.

② $V_{GS} = +ve$

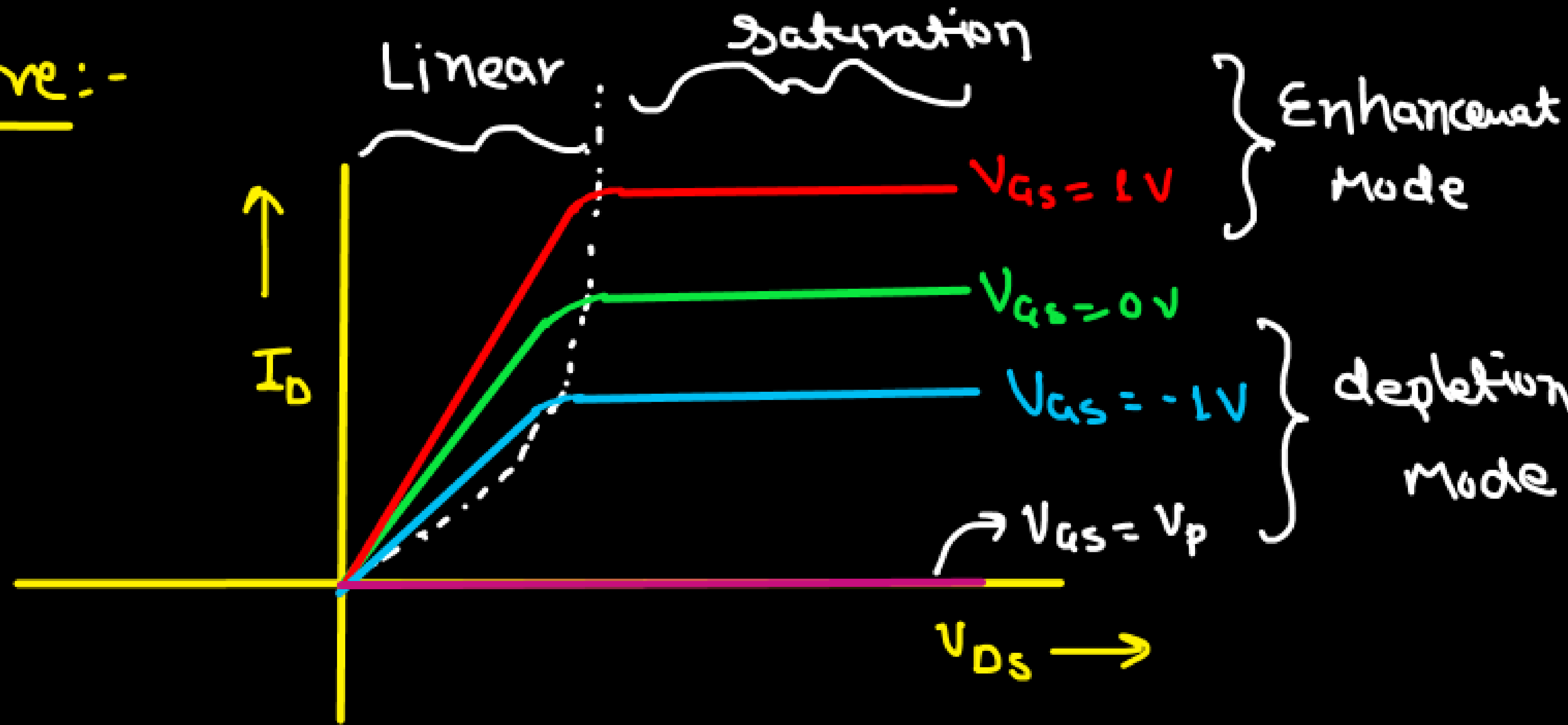


$V_G \uparrow \Rightarrow$ more $e^{\ominus}$ in channel

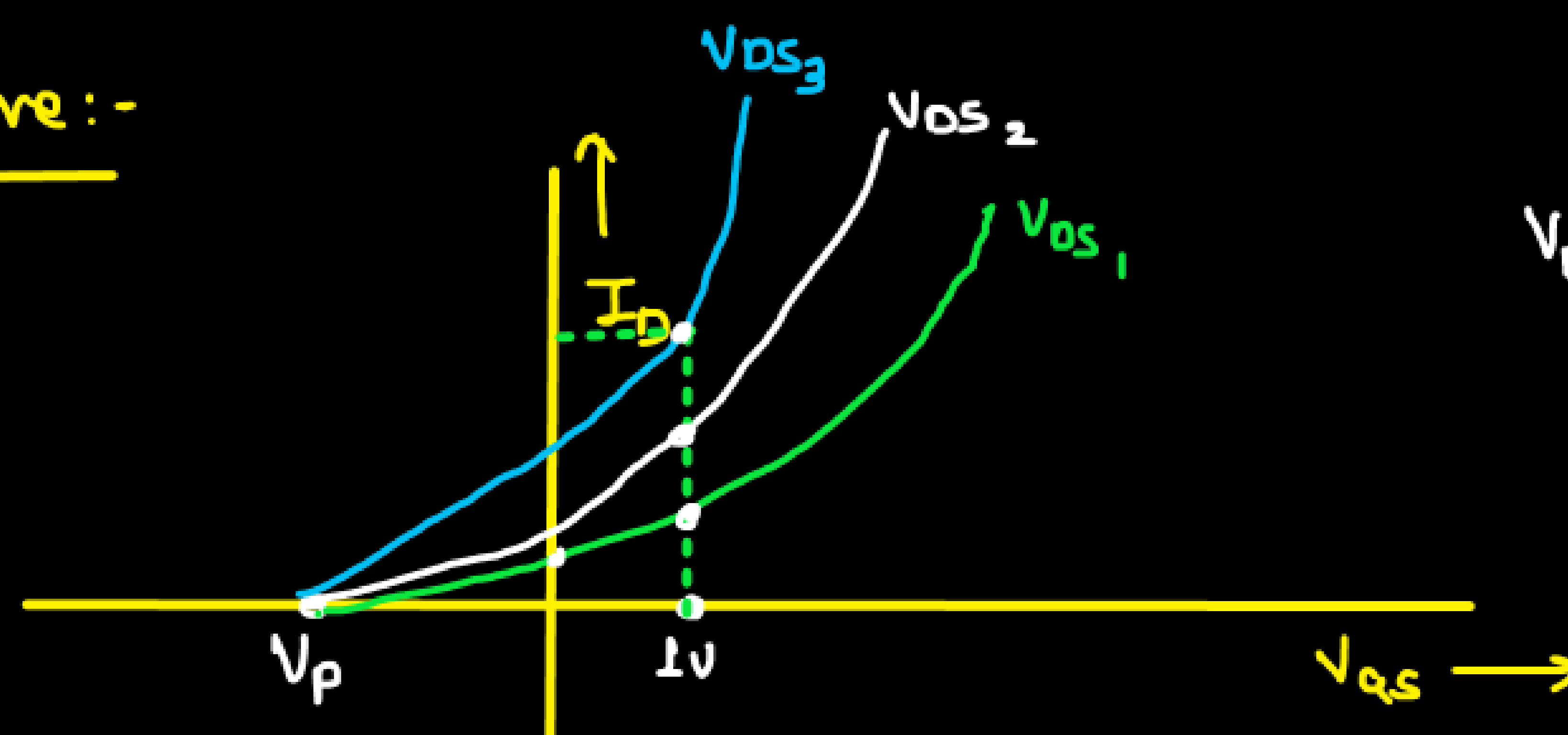
$\Downarrow$

$I_D \uparrow$

I_D v/s V_{DS} curve:-

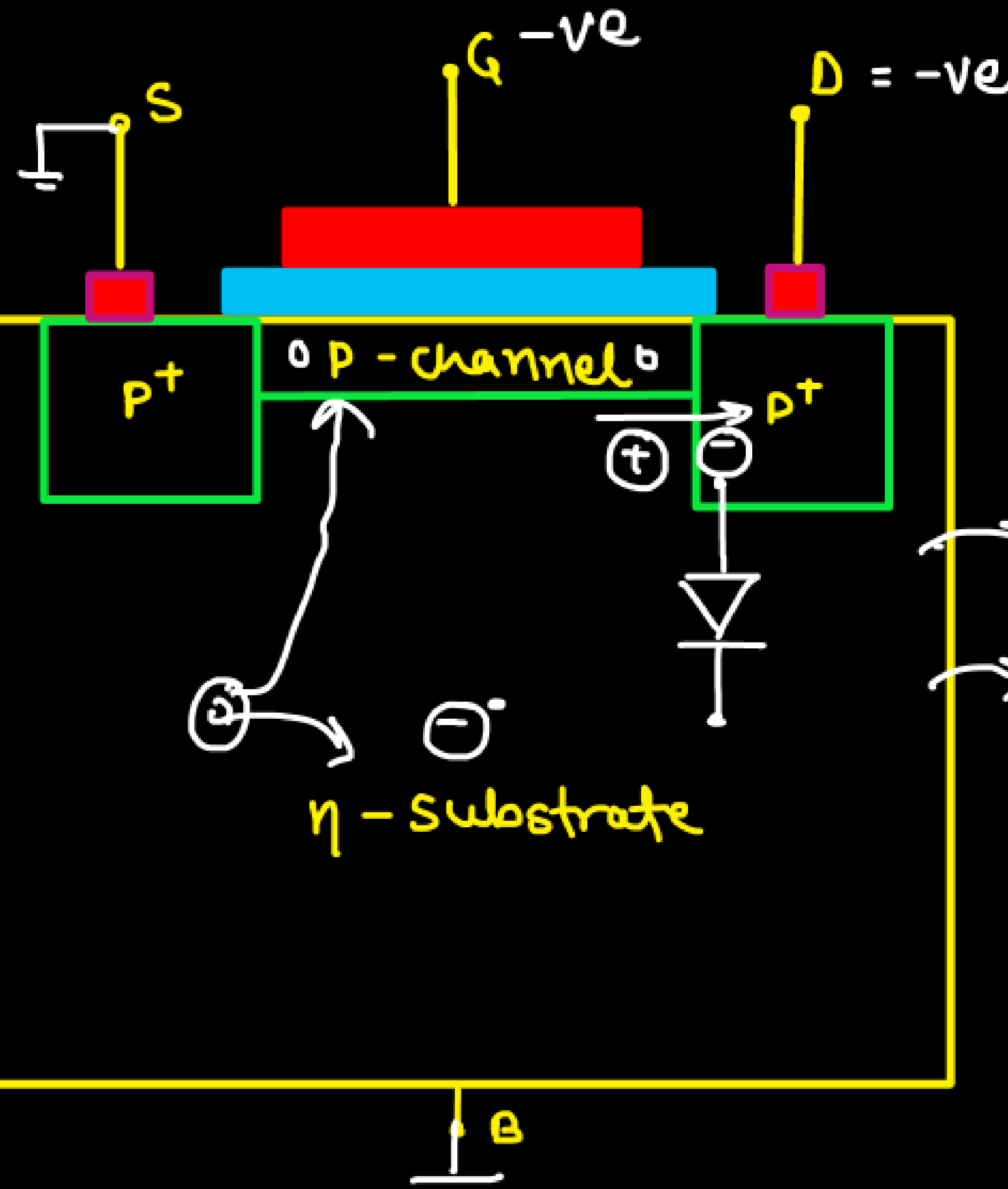


I_D v/s V_{GS} curve:-



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

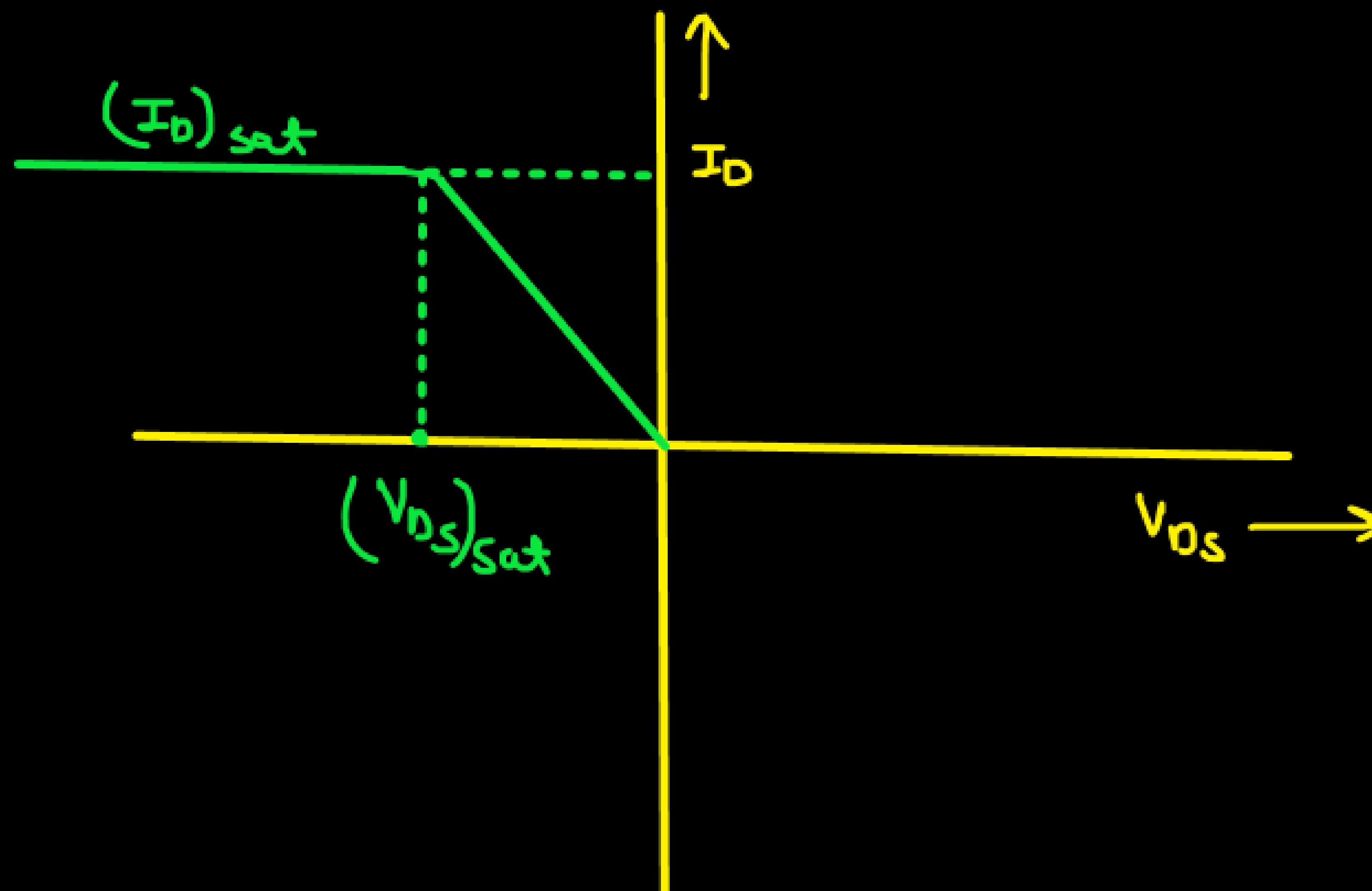
P-channel depletion type MOSFET :-



→ charge carrier = holes

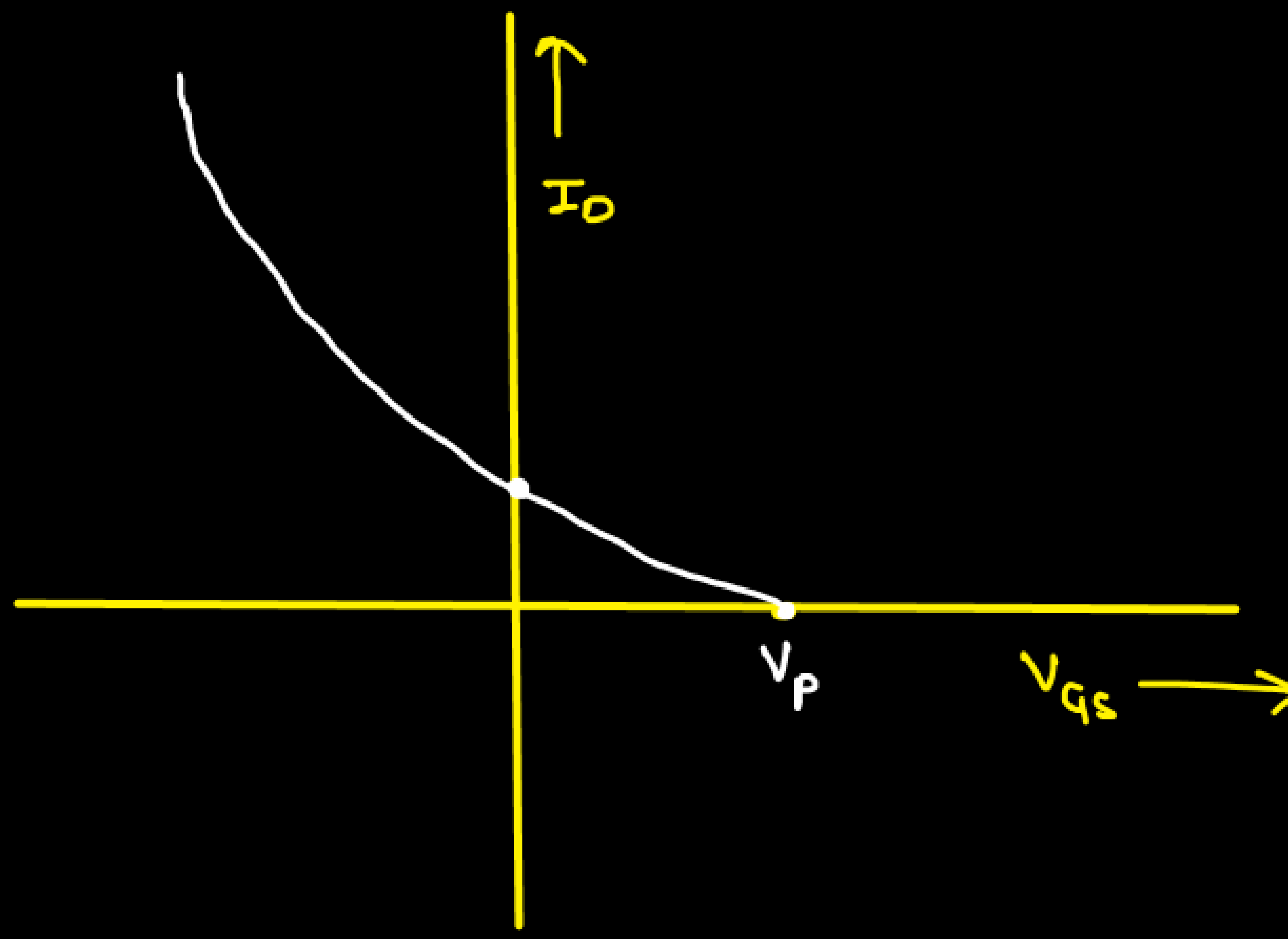
→ current dir^n ⇒ source to drain

I_D v/s V_{DS} curve :-



I_D direction ⇒ source to drain

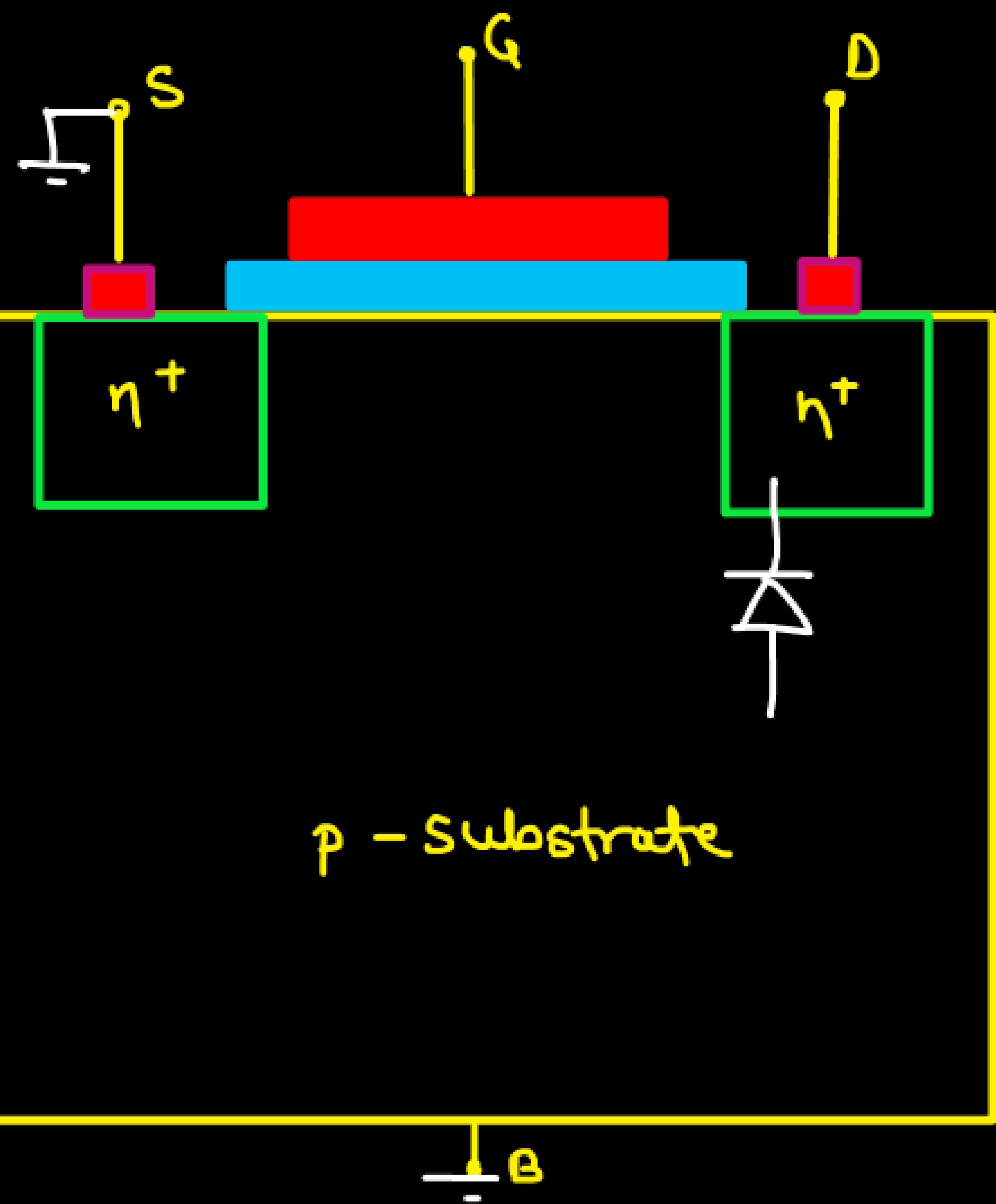
I_D v/s V_{GS} curve:-



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

$V_{GS} = 0V$

$V_{DS} = 0V$

$\Rightarrow I_D = 0$ Amp.

Cod^n - 2

$V_{GS} = 0V$

$V_{DS} = -ve$

$\Rightarrow I_D = 0$ Amp.

Cod^n - 3

$V_{GS} = 0V$

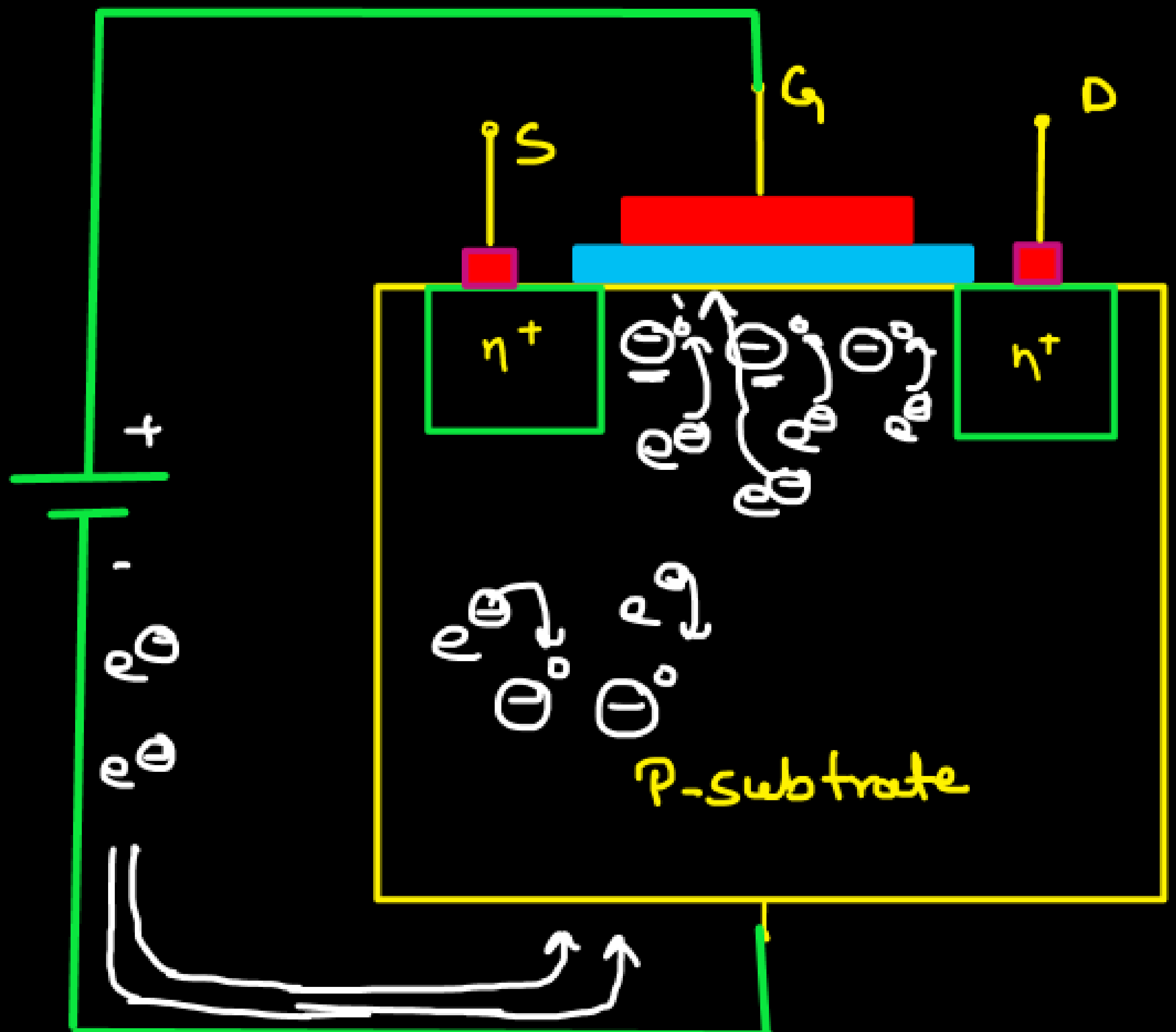
$V_{DS} = +ve$

$\Rightarrow I_D = 0$ Amp

Codⁿ-4

$V_{GS} = +ve$ {very less}

$V_{DS} = +ve$



$V_G \uparrow \Rightarrow$ electron will come into substrate & recombine with Hole

can't conduct current

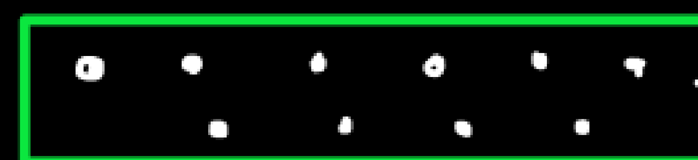
B

still $I_D = 0$ Amp

$\Downarrow$

I have to increase V_G potential

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



→ 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.

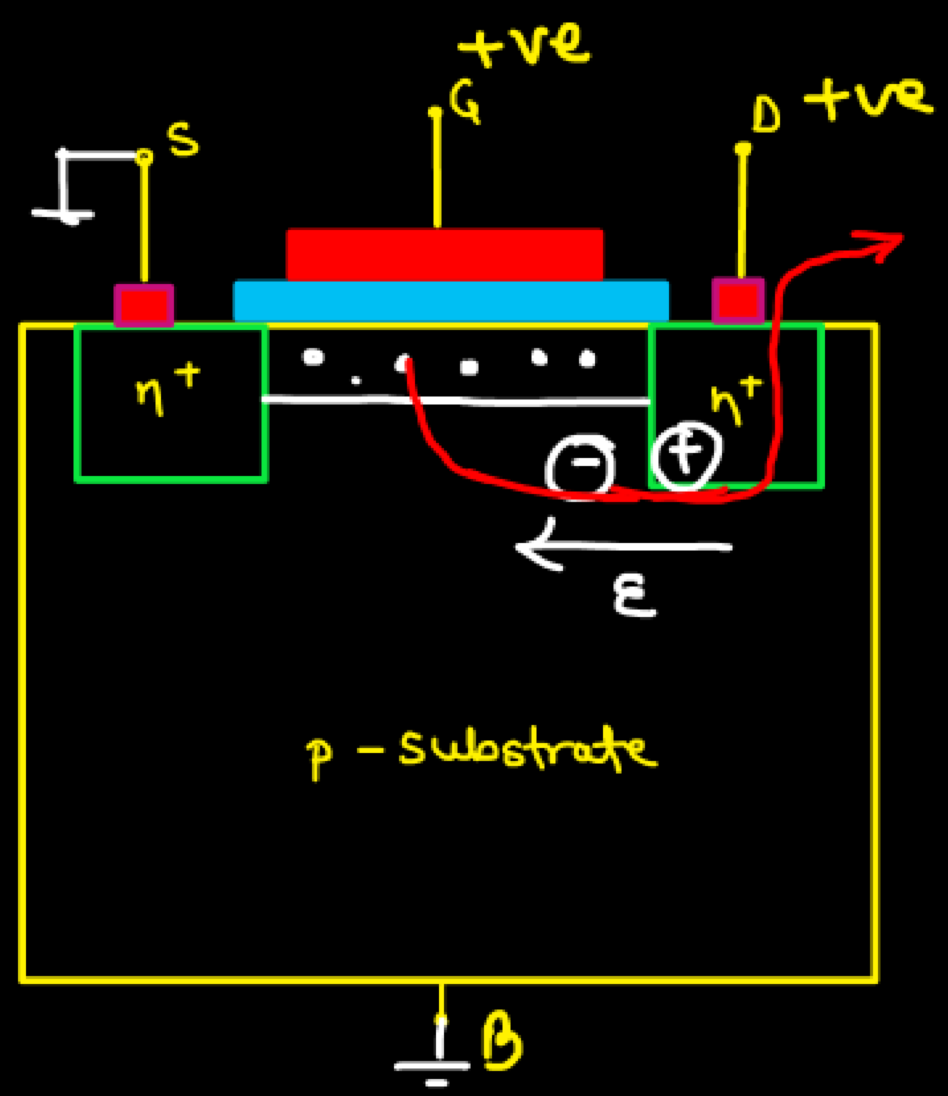
☆ The value of V_{GS} @ which the current flows, is known as threshold voltage (V_T).

Cod^n. 5

$V_{DS} = +ve$

$V_{GS} > V_T$

$\Rightarrow$ I_D flows from drain to source.

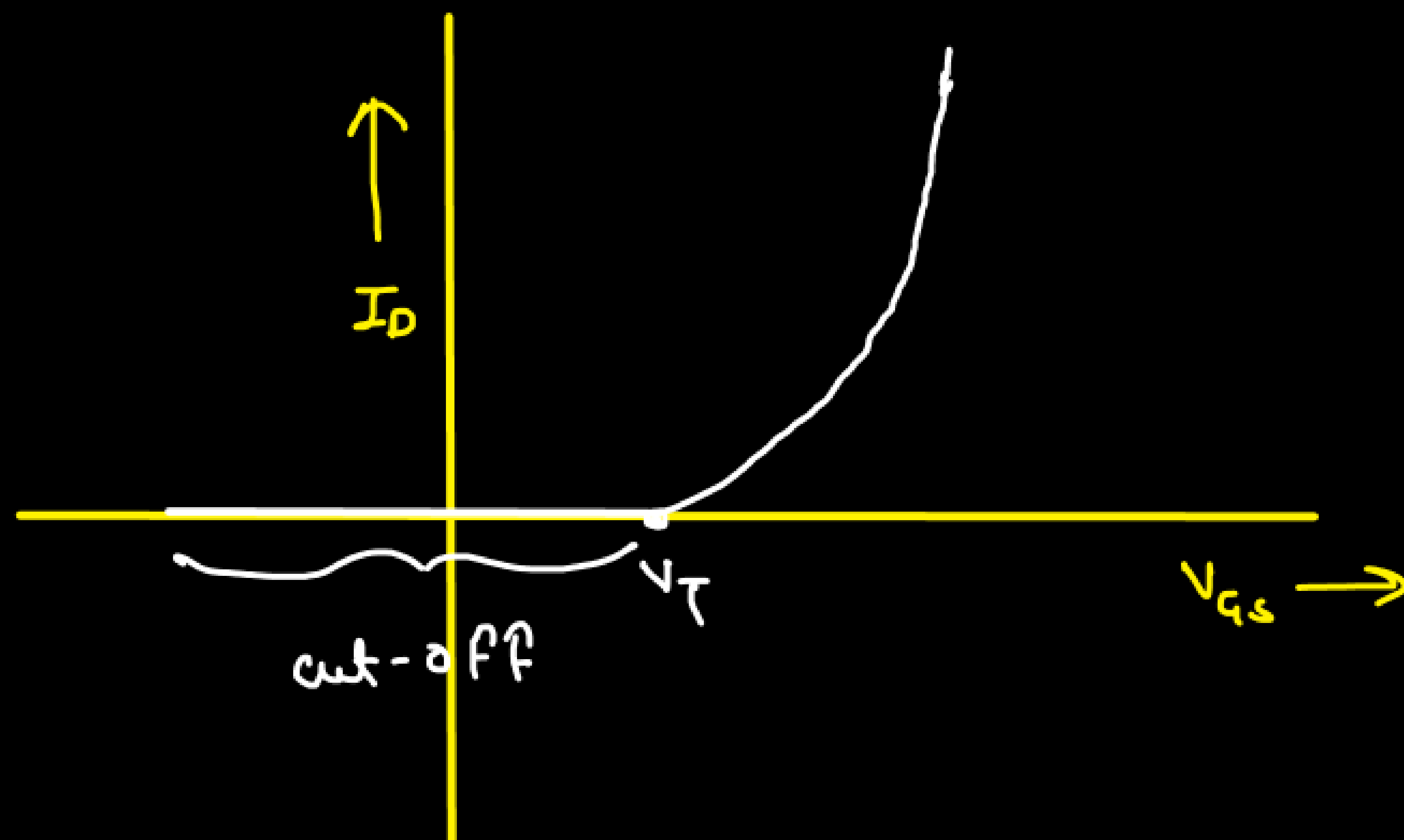


After V_{TH}, Increasing V_{GS} ↑ ⇒ more $e^{\ominus}$ in channel

⇓

I_D ↑

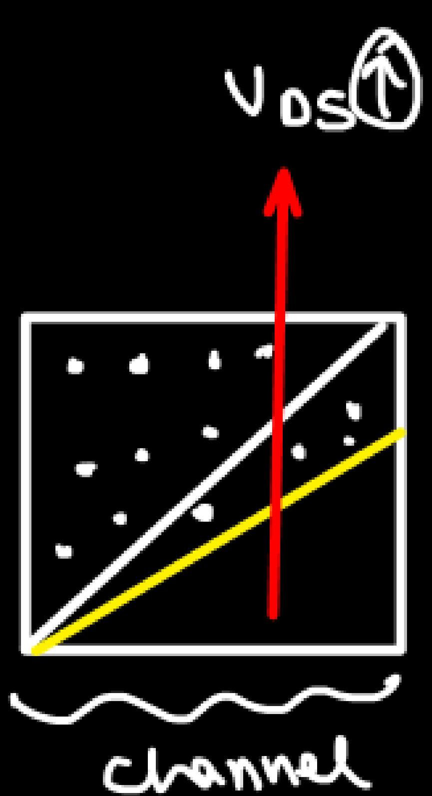
*** I_D v/s V_{GS} curve :-

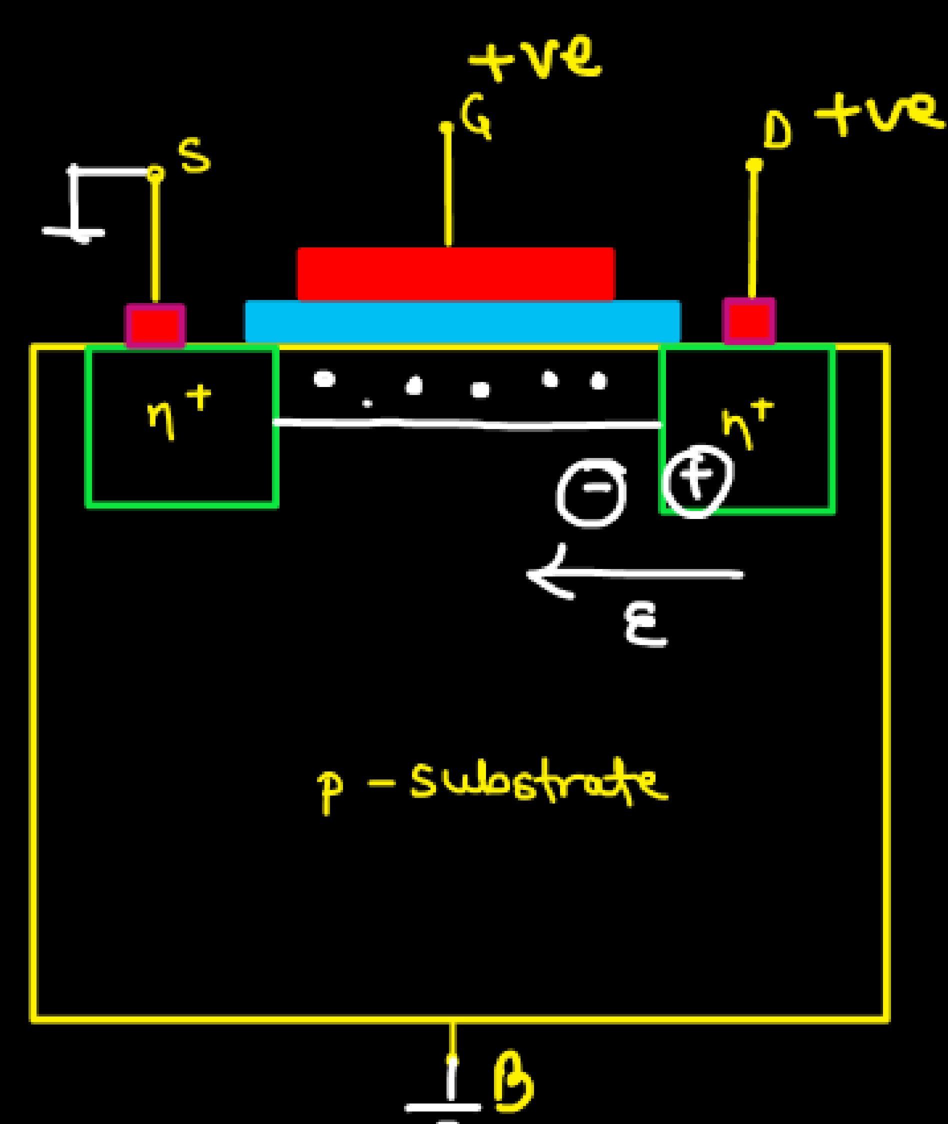


Cod^n-6

$V_{GS} > V_T$ {Fixed}

V_{DS} = +ve {Increasing}





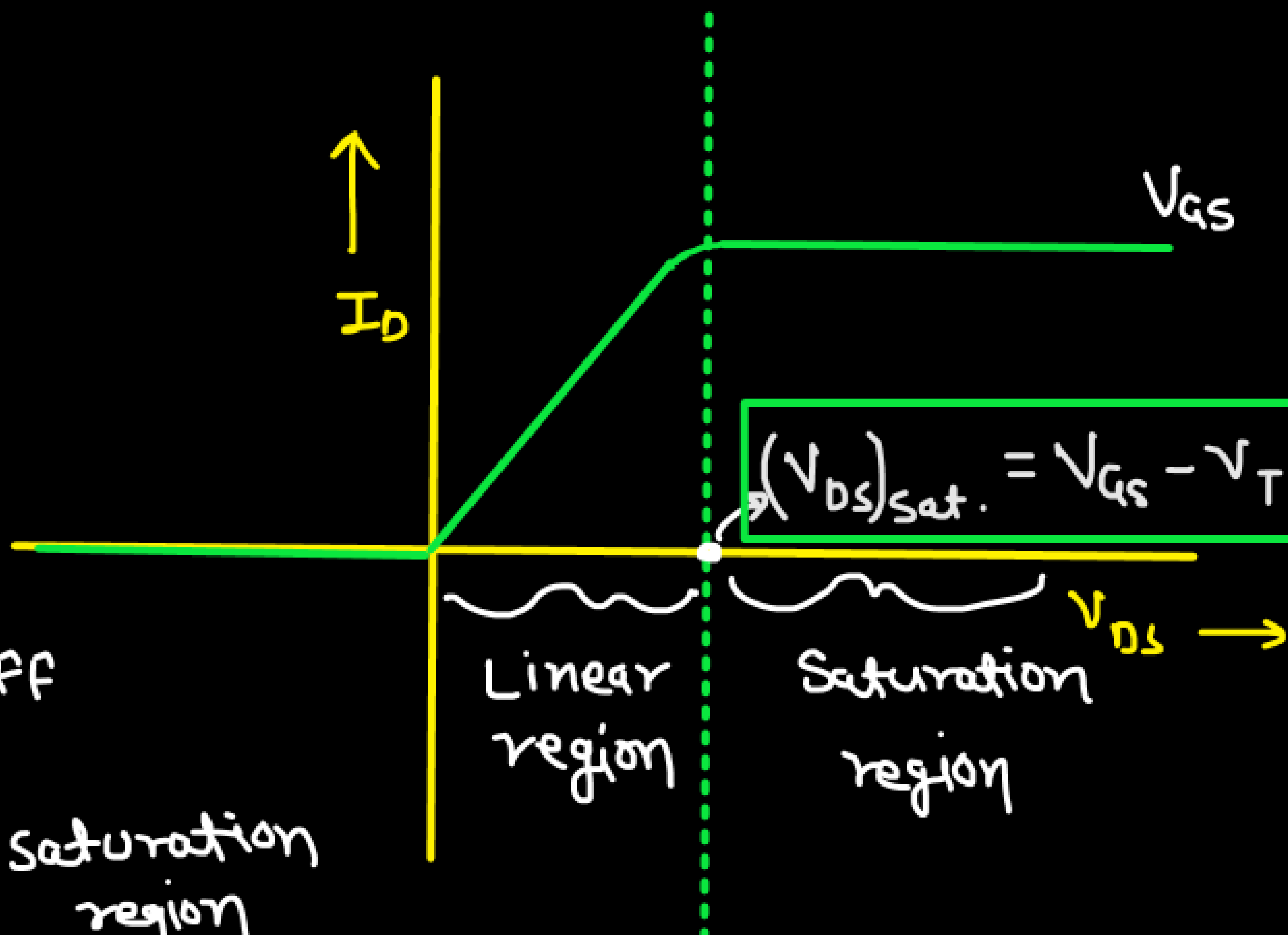
$V_{DS} \uparrow \Rightarrow \varepsilon \uparrow \Rightarrow e^{\ominus}$ gets more force

$\Downarrow$

more current

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

I_D v/s V_{DS} curve :-

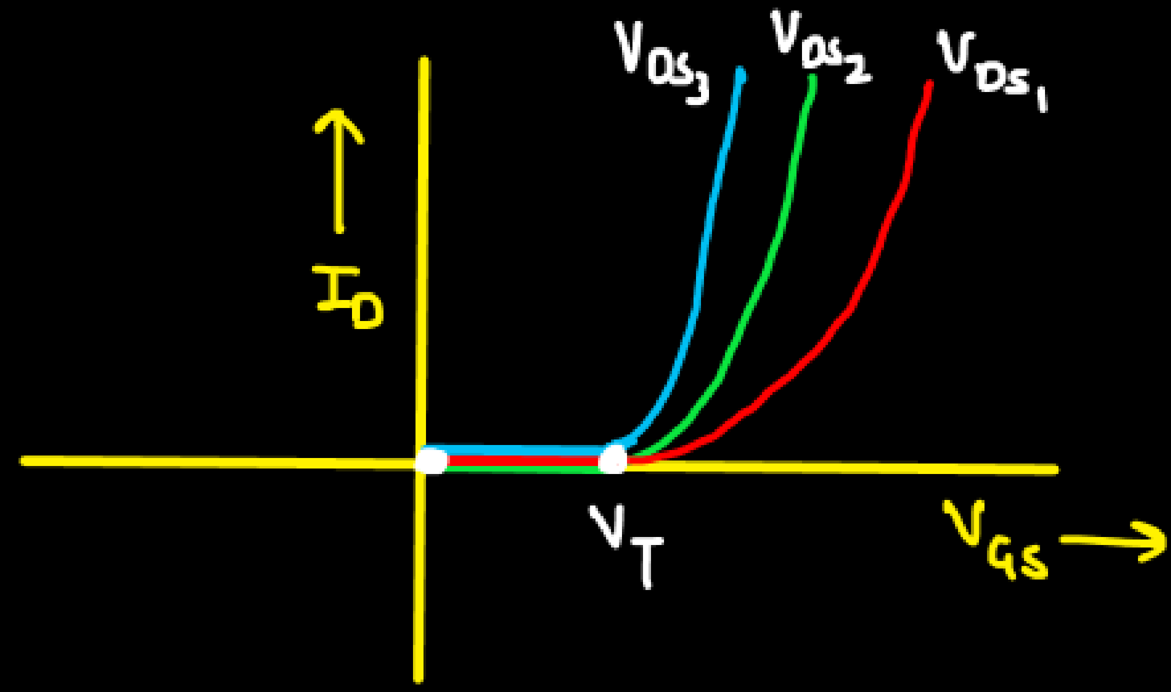


$V_{DS} < 0 \Rightarrow$ cut off

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

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

I_D v/s V_{GS}



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

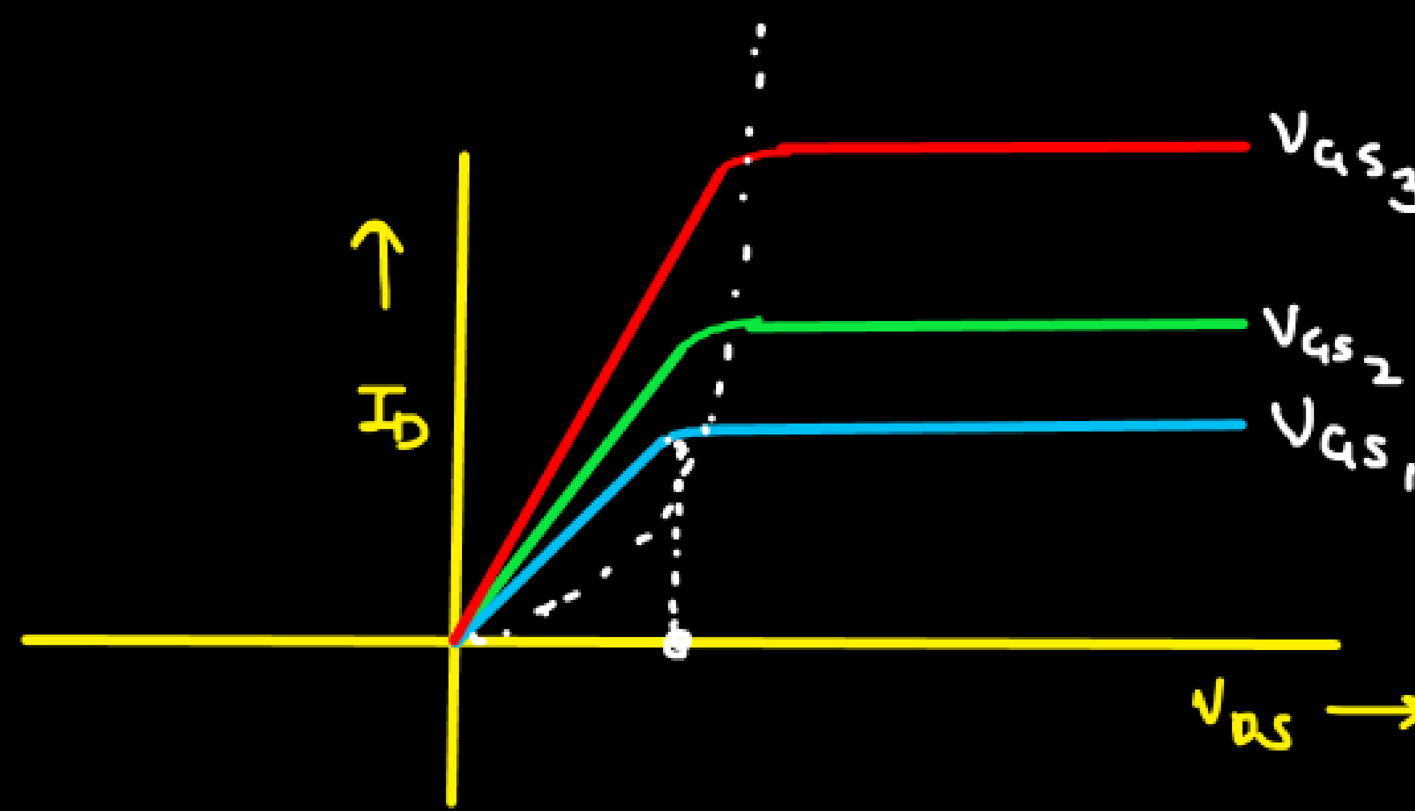
I_D v/s V_{DS}

Sat. voltage

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

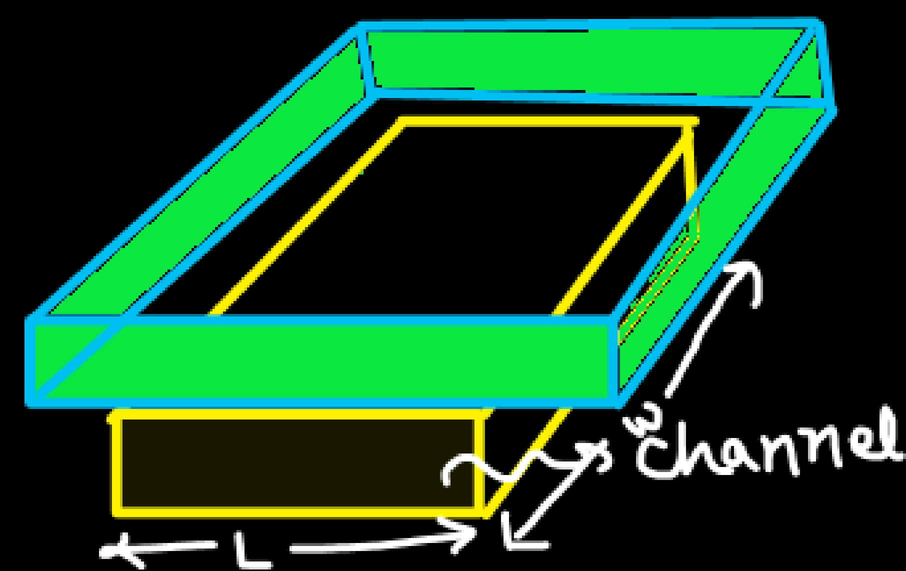
$V_{DS_2} = V_{GS_2} - V_T$

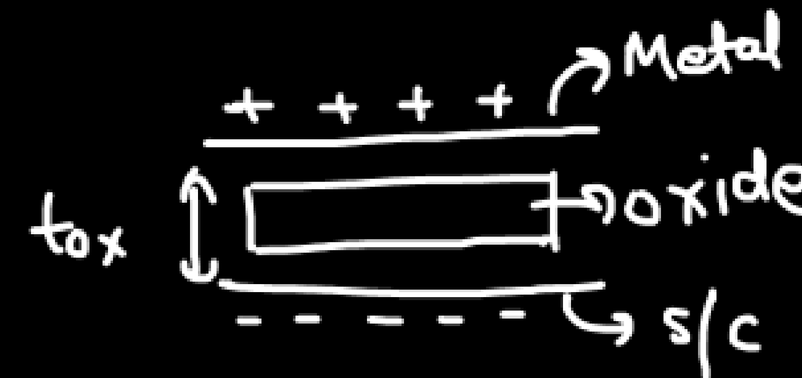
$V_{DS_3} = V_{GS_3} - V_T$



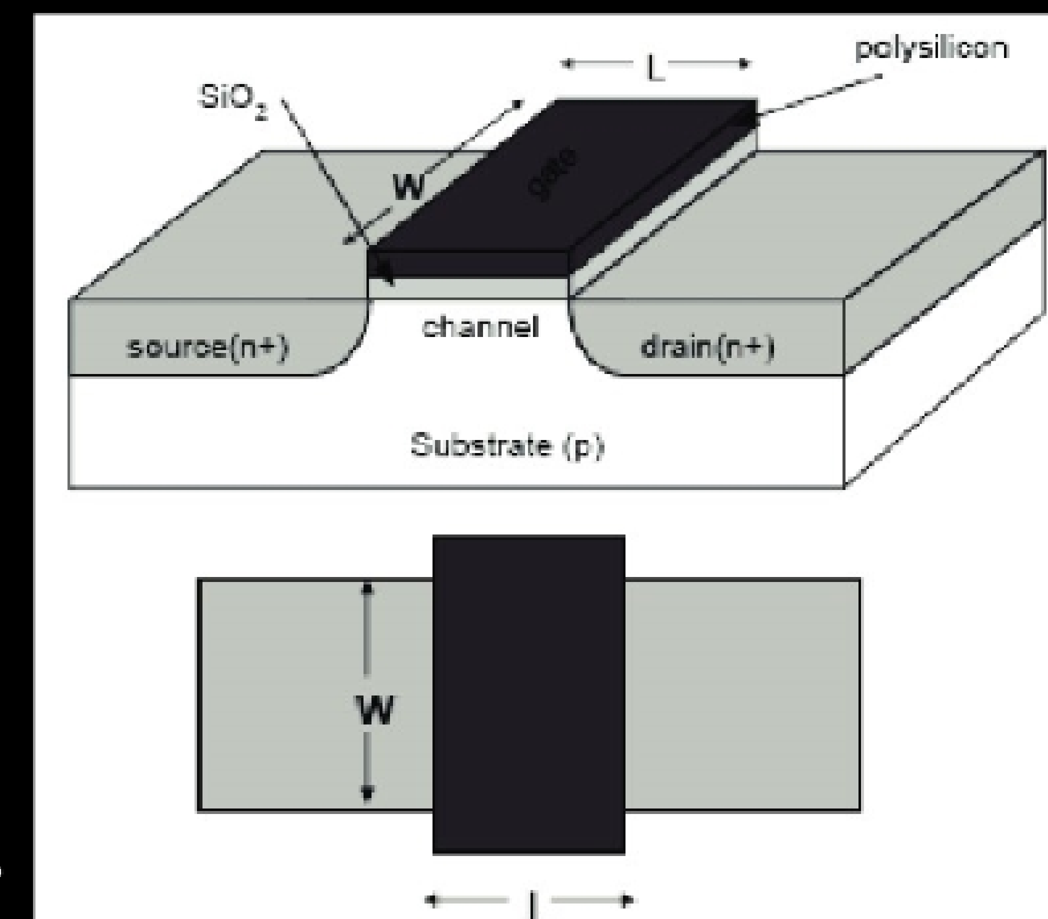
$$V_{GS_3} > V_{GS_2} > V_{GS_1}$$

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 $e^{\ominus}$

L → channel length

W → channel width

V_{T_n} → Threshold voltage

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

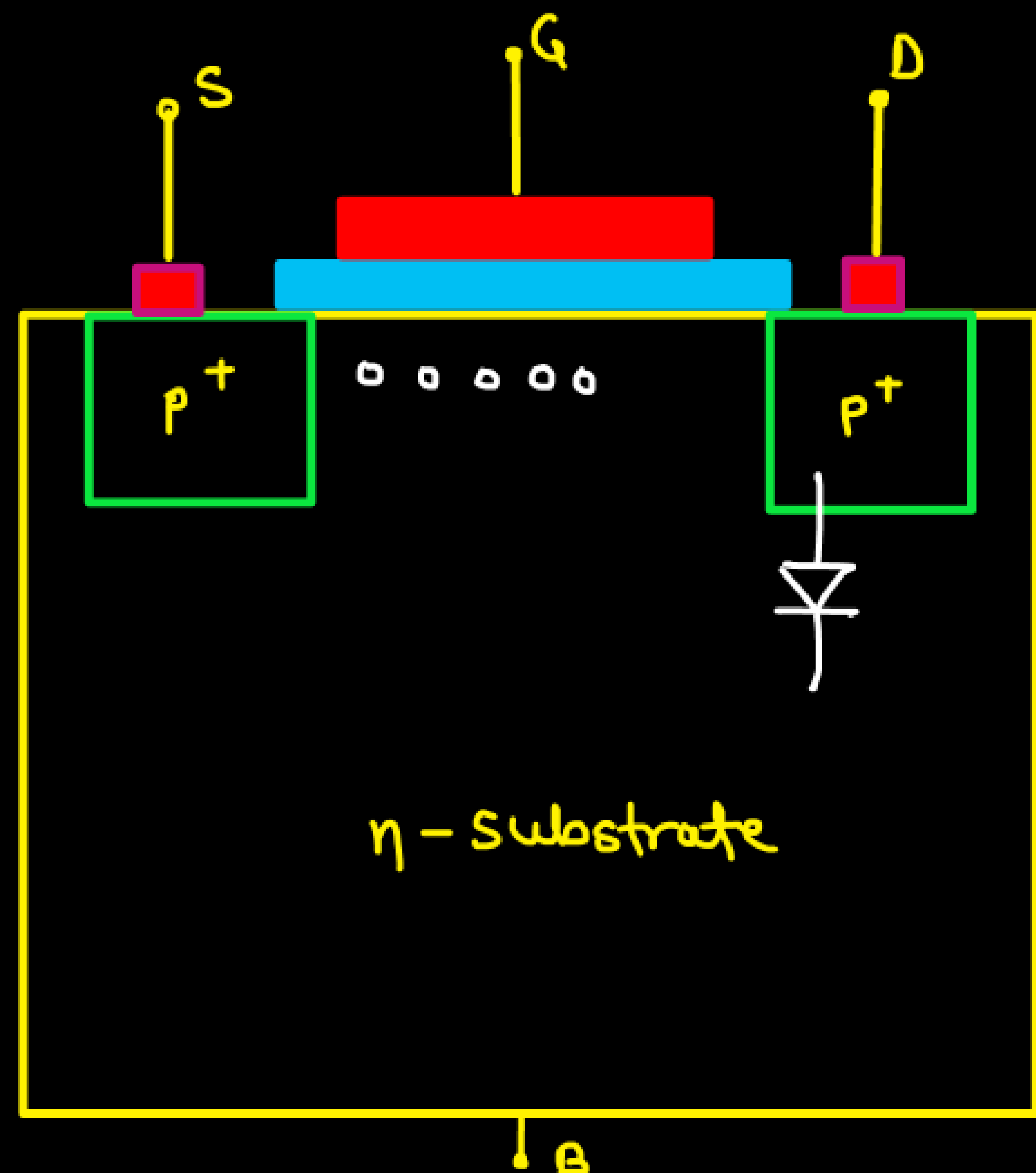
$$\boxed{(I_D)_{sat.} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_{T_n})^2}$$

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:-

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

Cod^n 3:-

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

Cond^n 4 :-

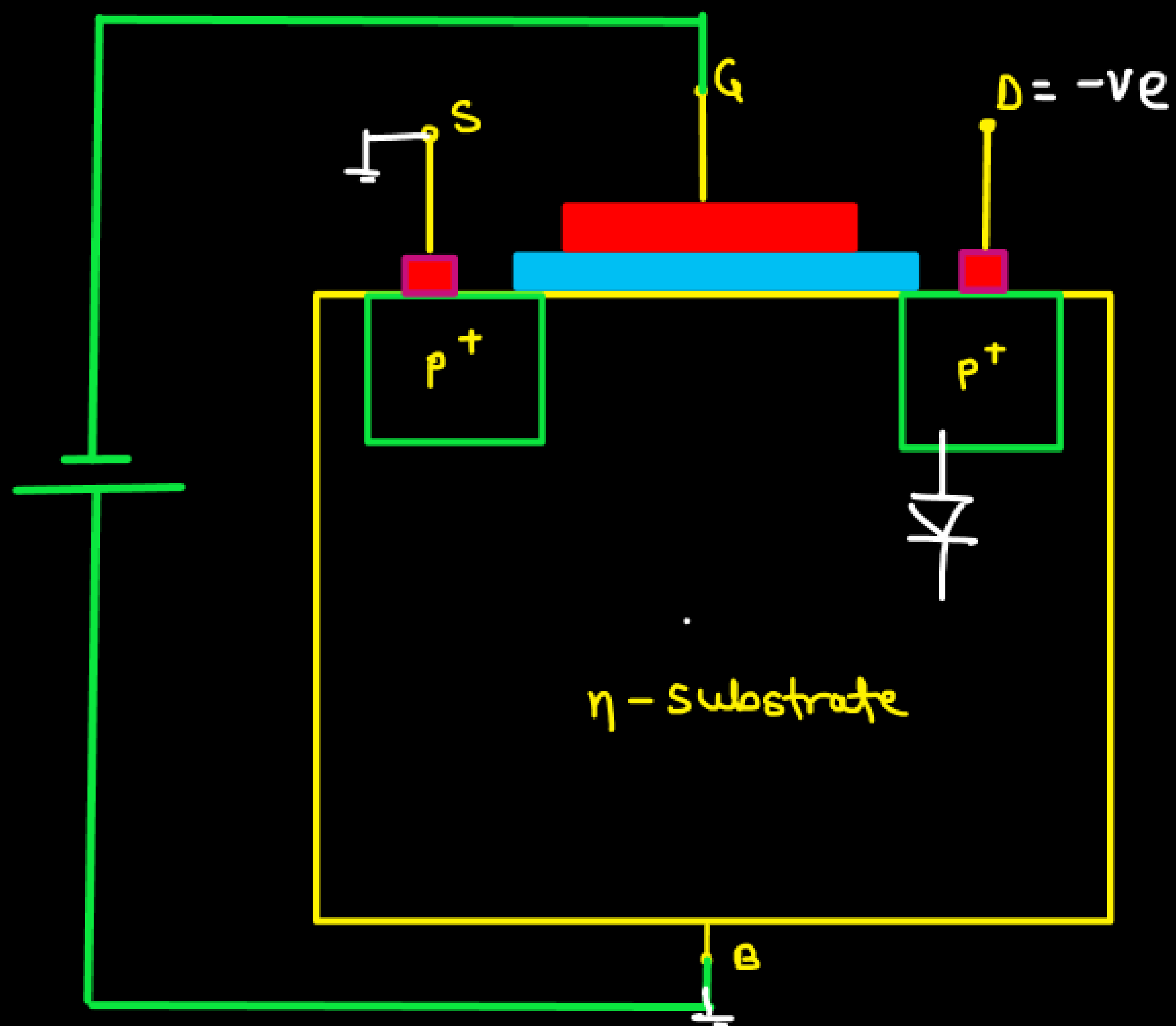
$V_{GS} = -ve$ (very less)

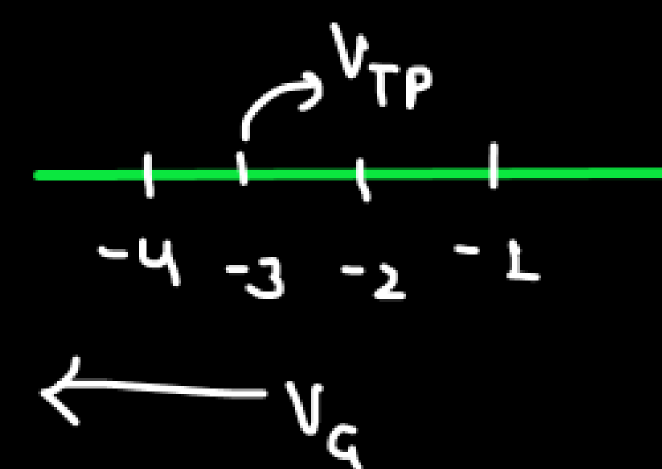
$V_{DS} = -ve$

$\Rightarrow$ channel is not framed

$\Downarrow$

You have to apply more negative potential.



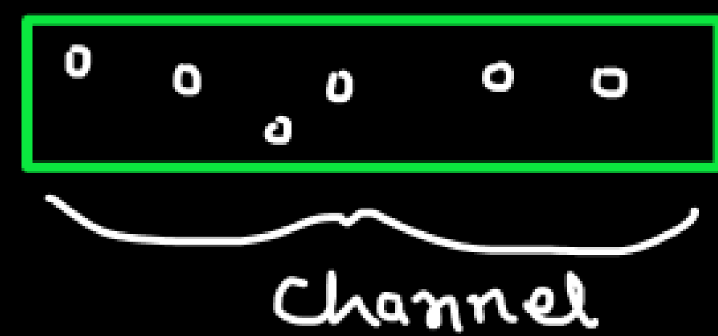


$\Rightarrow V_{GS} < V_{TP}$

$\Downarrow$

current flows

when $V_{GS} < V_{Tp}$



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 ⇒	$V_{DS} \geq V_{GS} - V_{Tn}$	$V_{SD} \geq V_{SG} - \lvert V_{Tp} \rvert$

Cod^n 5: -

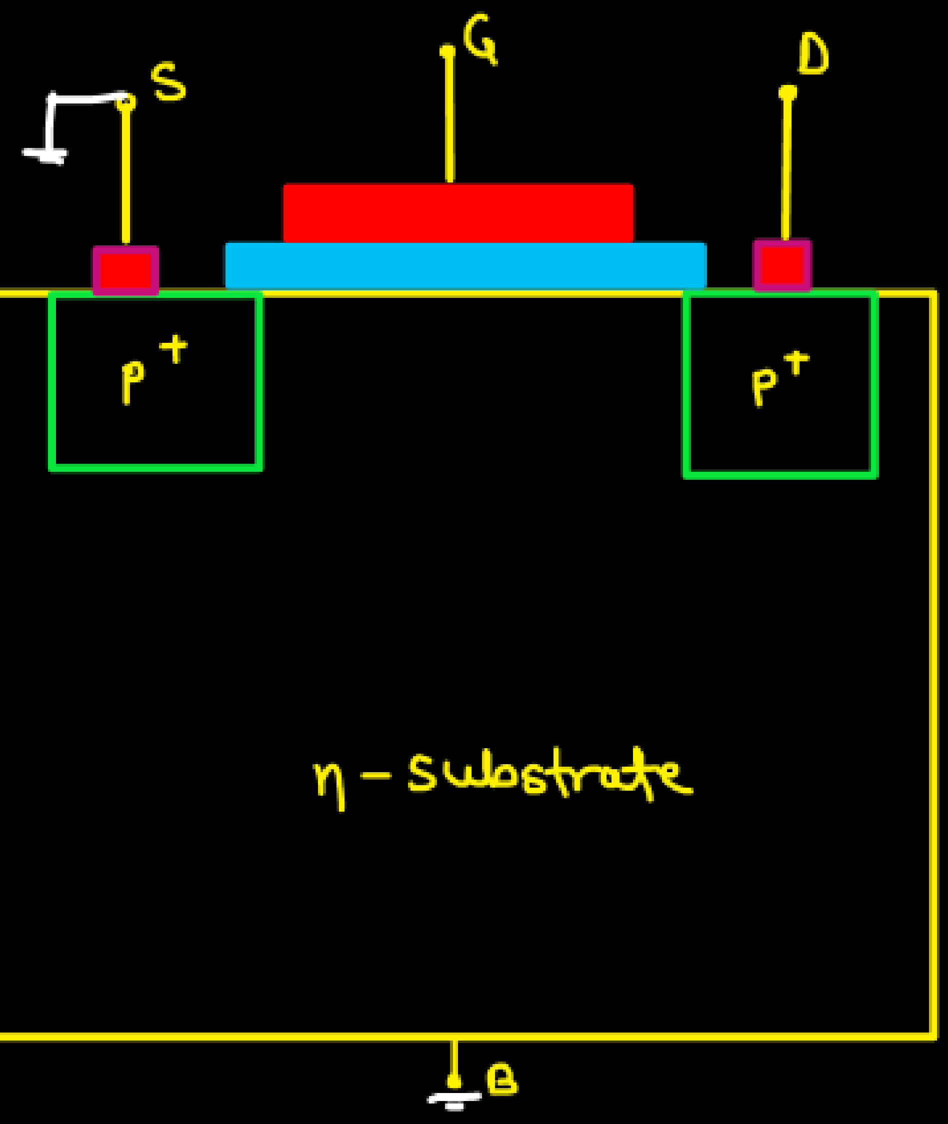
(i) $V_{GS} < V_{Tp}$ OR $V_{SG} > |V_{Tp}|$

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

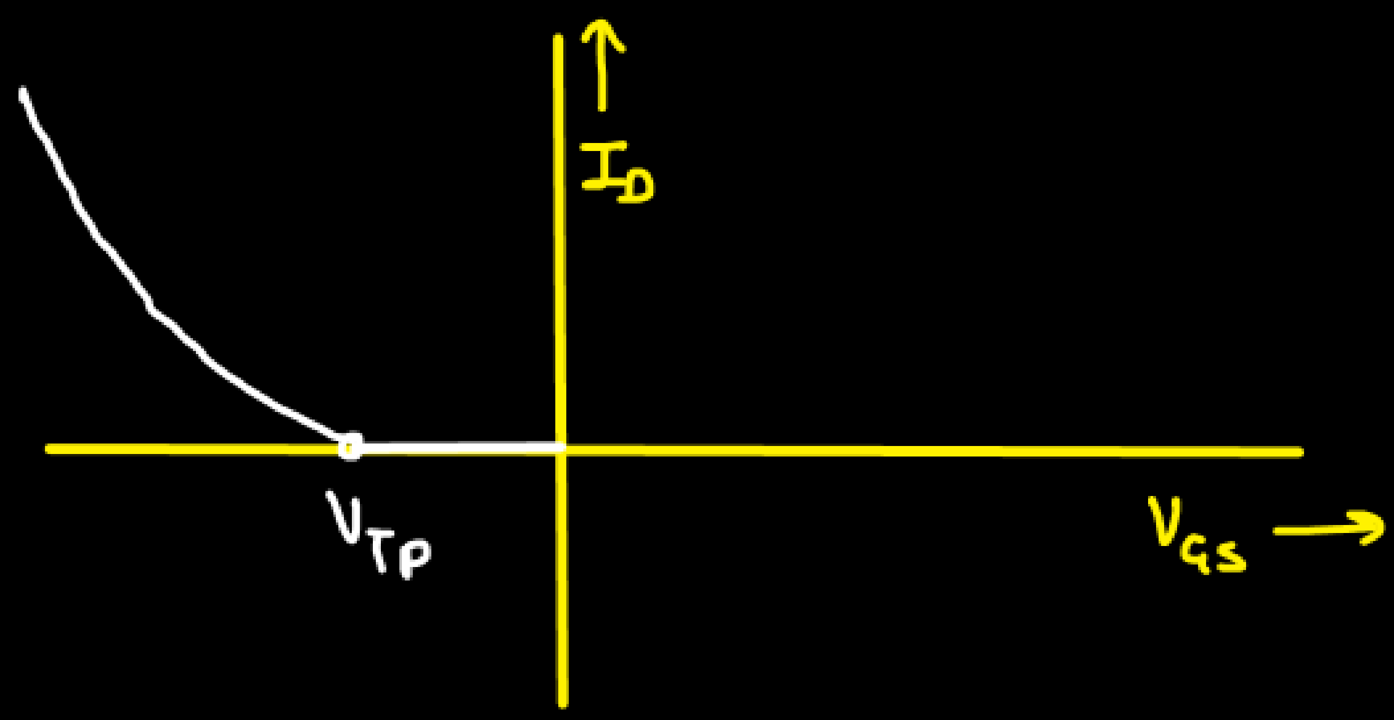
$\Rightarrow$ I_D flows

$\Downarrow$

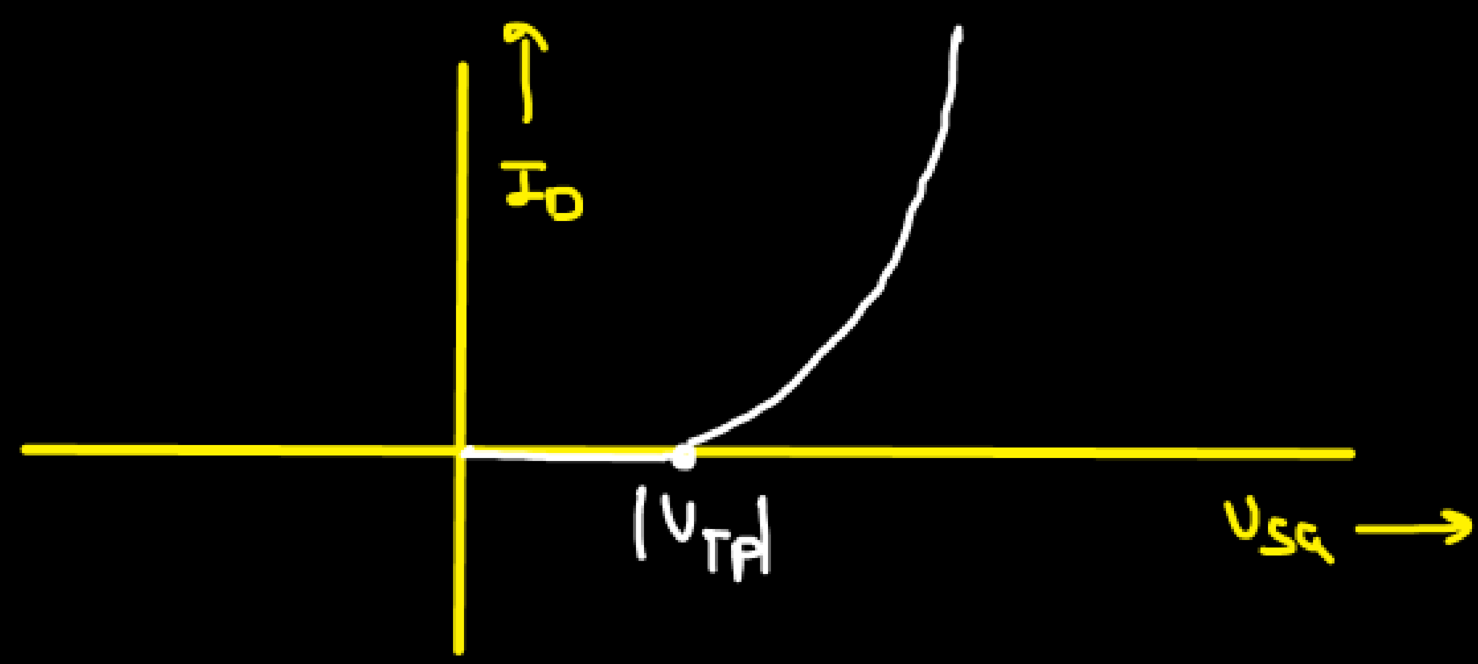
source to drain



I_D v/s V_{GS} curve:-



I_D v/s V_{SG} curve:-



current dir^n:-

source to drain

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

Cond^n 6:-

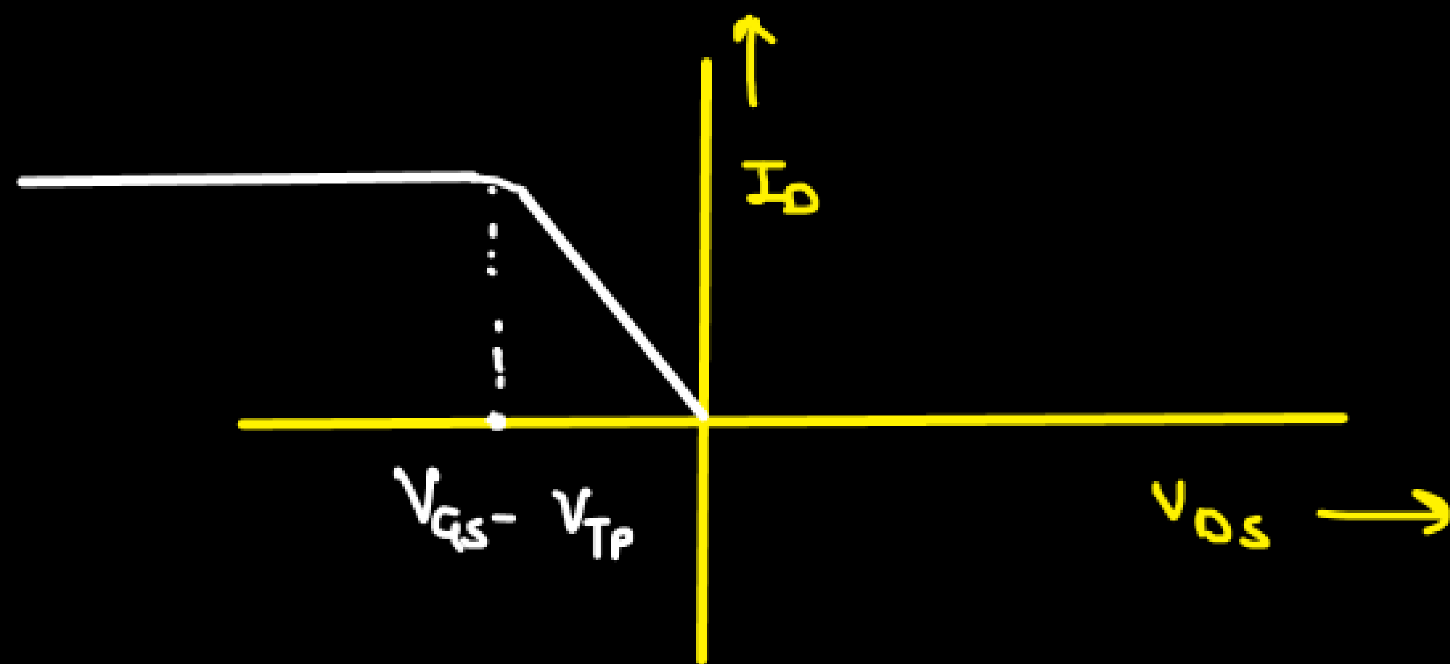
$V_{GS} < V_T$ {Fixed}

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

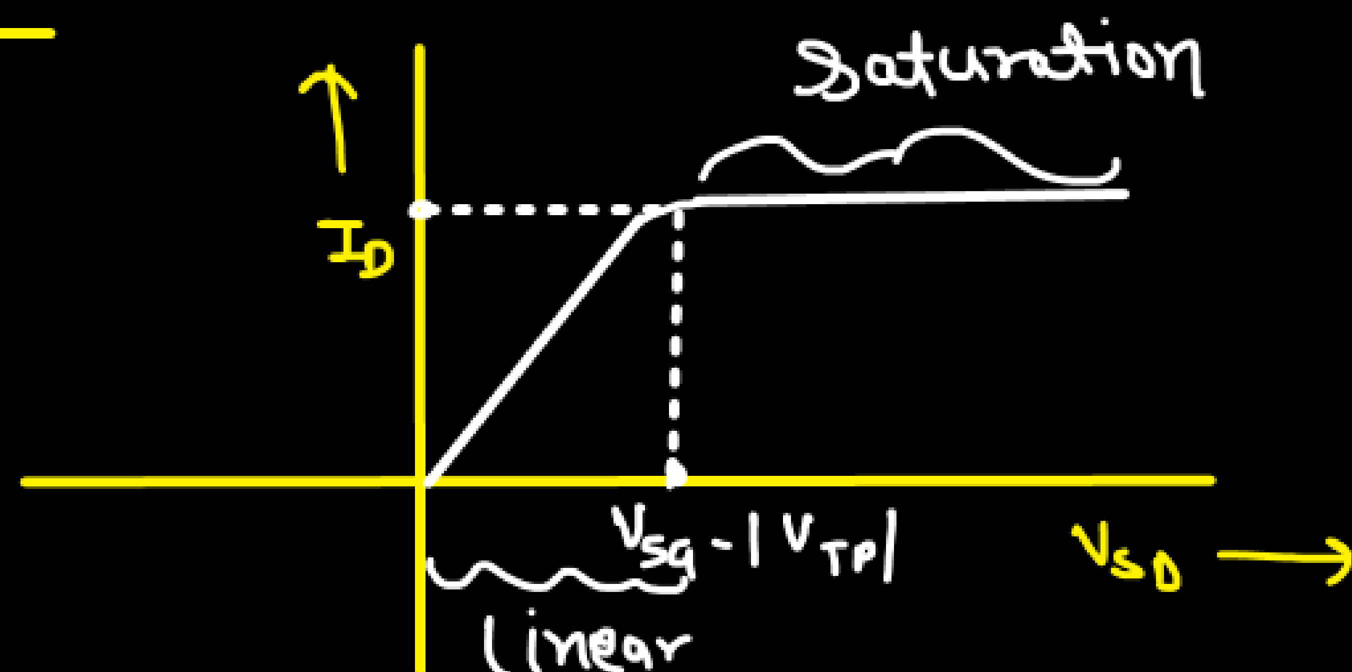
$\Downarrow$

current initially increases linearly and then saturates.

I_D v/s V_{DS} curve

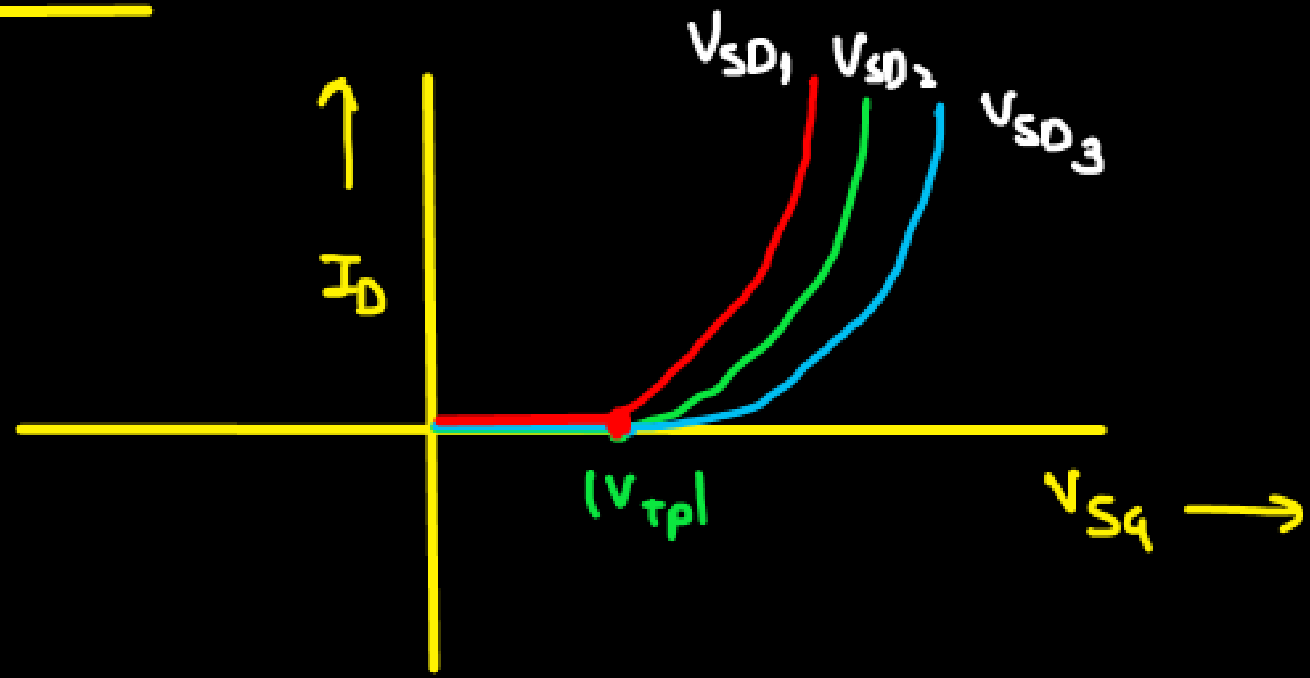


I_D v/s V_{SD} curve :-



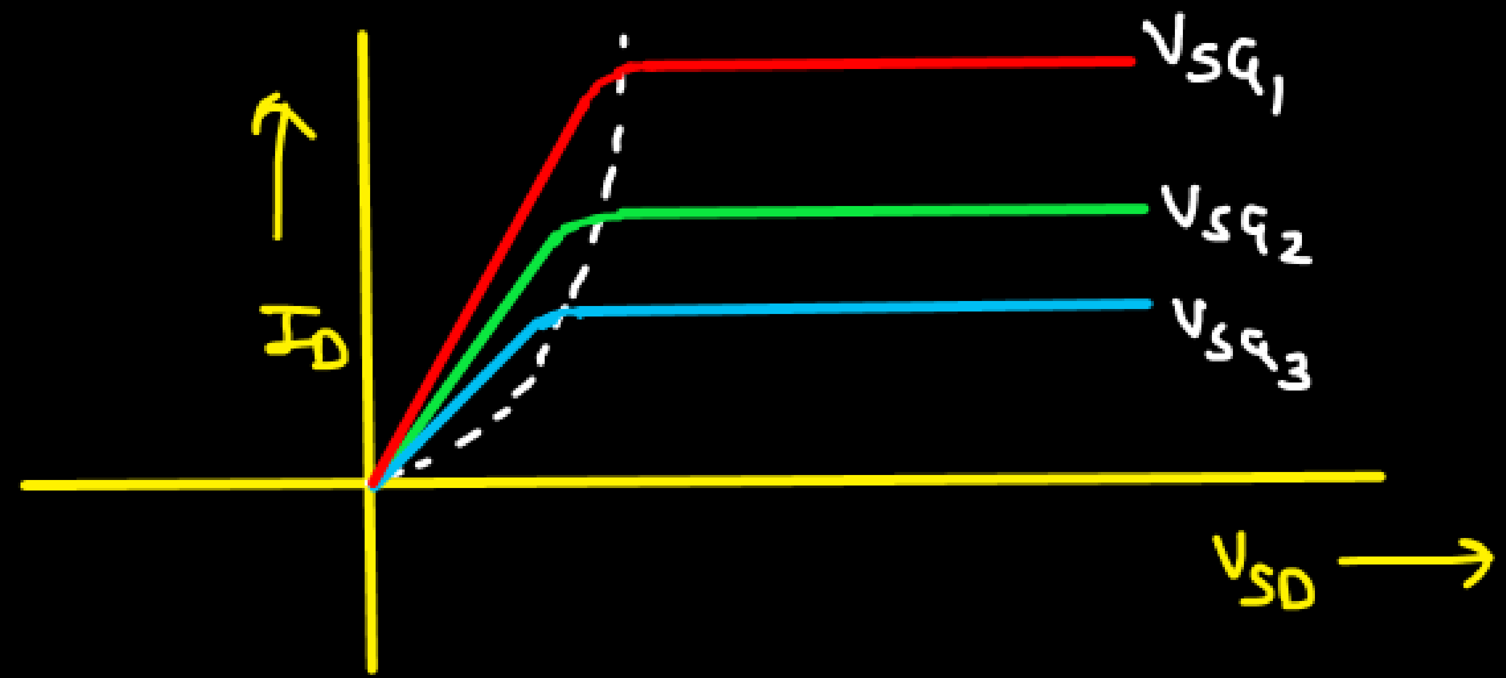
$$(V_{SD})_{sat} = V_{SG} - |V_{Tp}|$$

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:- $[V_{SD} \geq V_{SG} - |V_{Tp}|]$

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

N.B.-

IN PMOS,

Higher potential = Source

lower potential = Drain

dir^n of current = Source to Drain

IN NMOS,

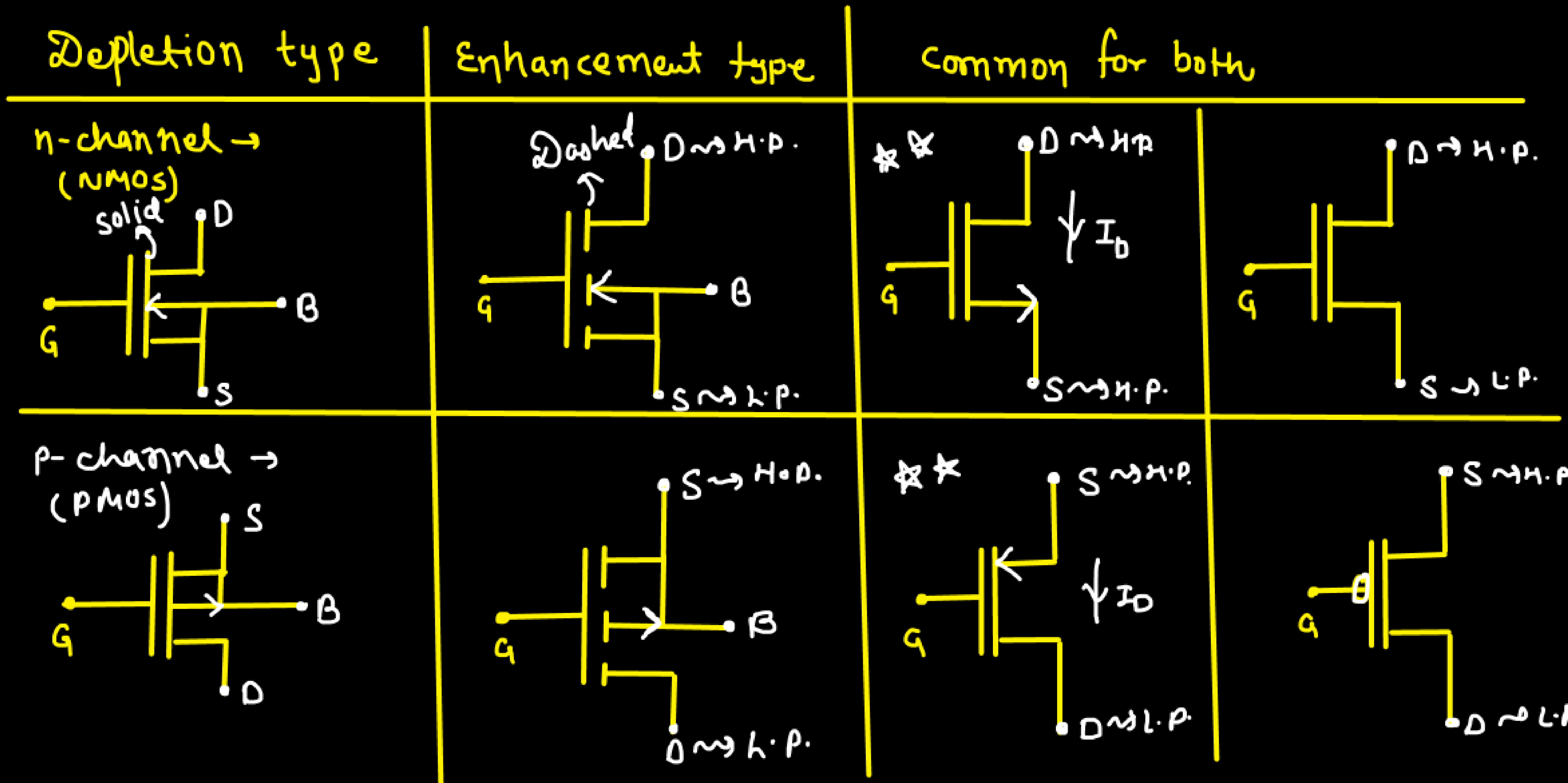
Higher potential = Drain

lower potential = source

dir^n of current = Drain to Source

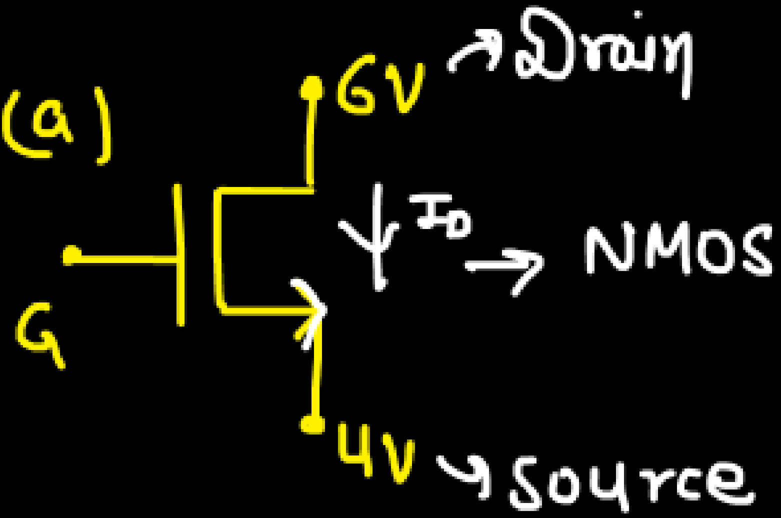
* MOSFET Circuit Symbol:-

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

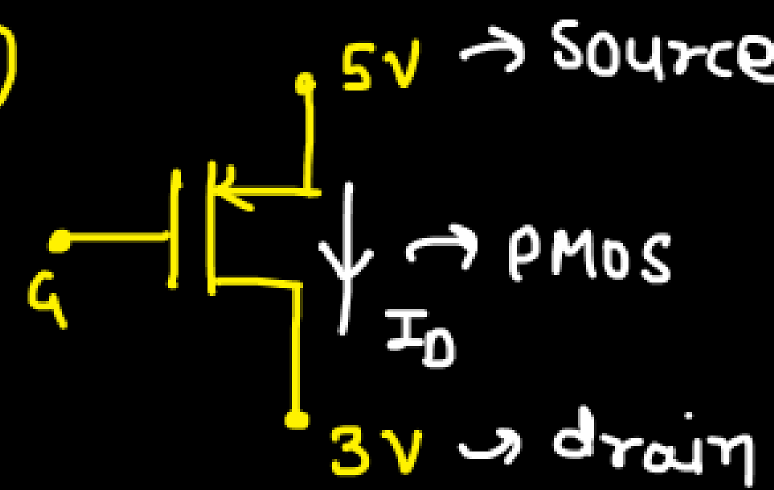


Q. Mark source and drain and the current dir^n.

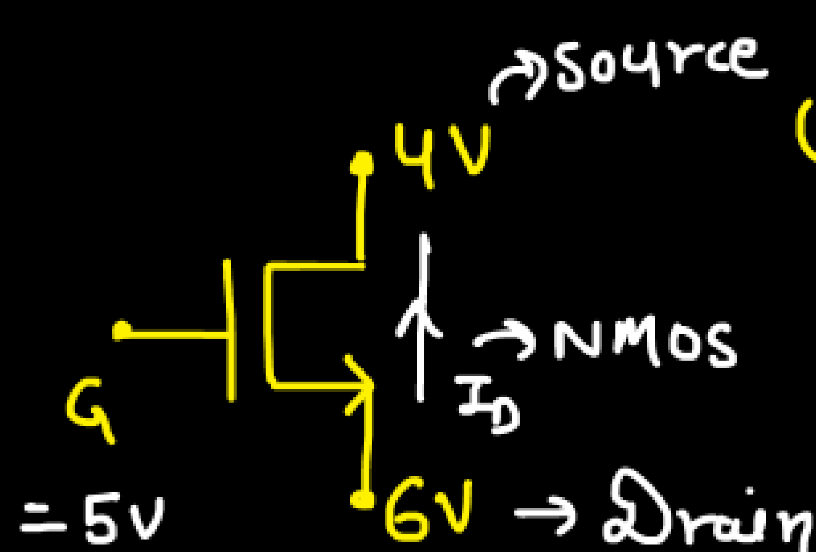
(a)



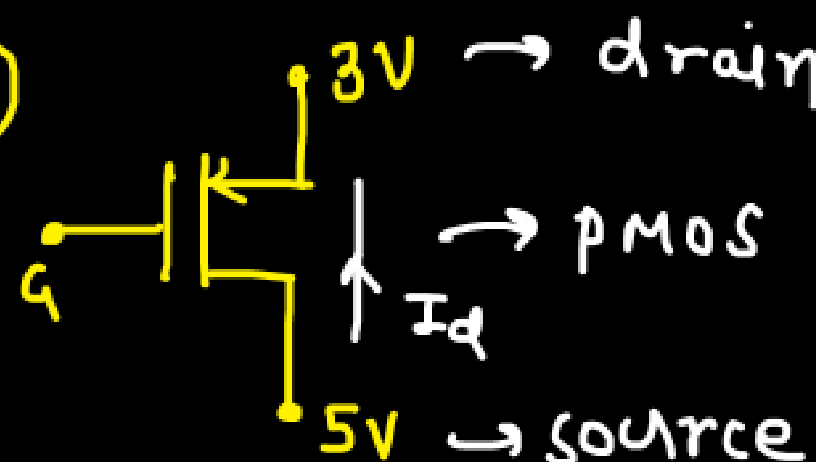
(b)



(c)



(c)



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 <u>saturation</u> mode with <u>overdrive</u> voltage of the same magnitude.

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

$\downarrow$ NMOS $\qquad \downarrow$ PMOS

$$(I_D)_P = (I_D)_N$$

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

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

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

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

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.?

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

$V_{DS} = 0.4V$

$$\underbrace{V_{DS} < V_{OV} \text{ OR } V_{DS} < V_{GS} - V_T}_{\Downarrow}$$

Linear region

MOS is working in Linear region

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

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

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

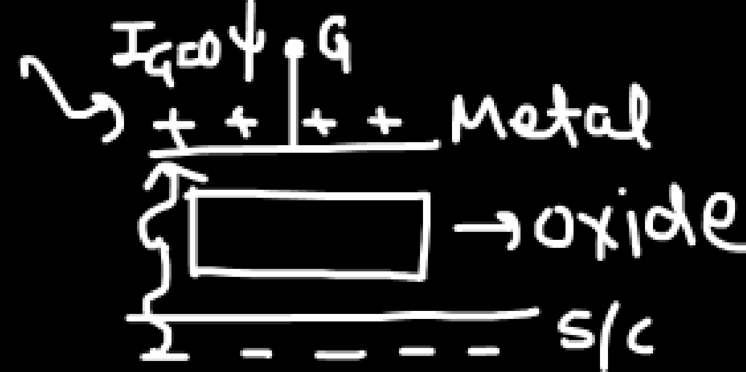
Q. How many charge carriers are there in a MOS?

→ One one. PMOS → Holes

NMOS → Electrons

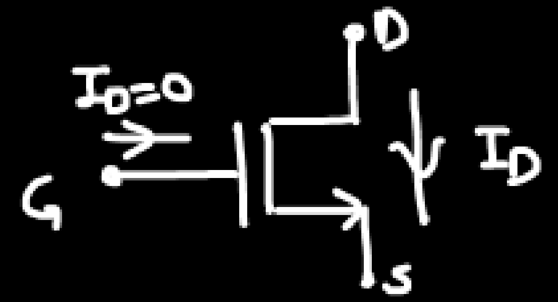
Q. What is the need of oxide Layer in MOS.

→



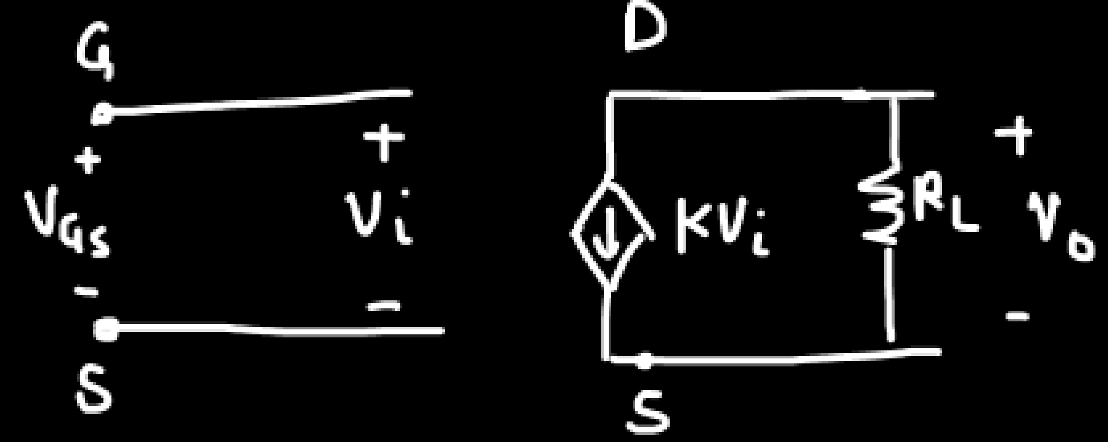
⇒ NMOS

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.

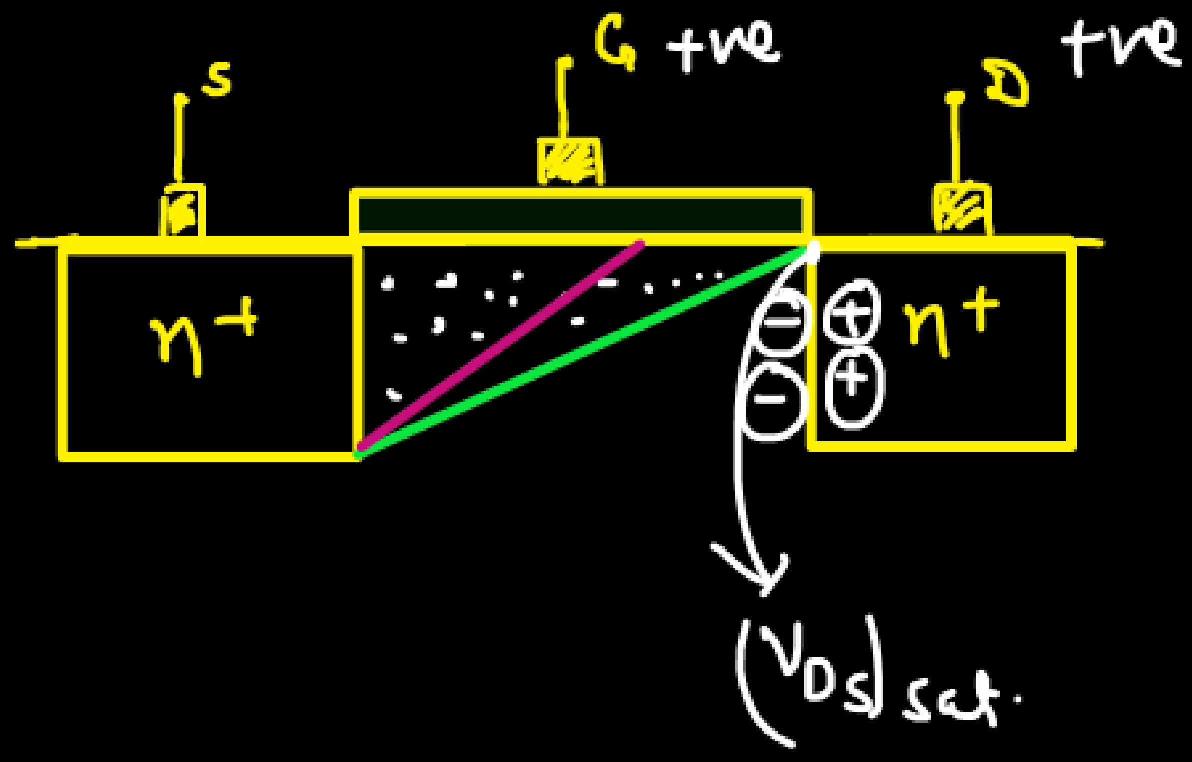
For conduction, $\boxed{V_{GS} > V_T}$

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

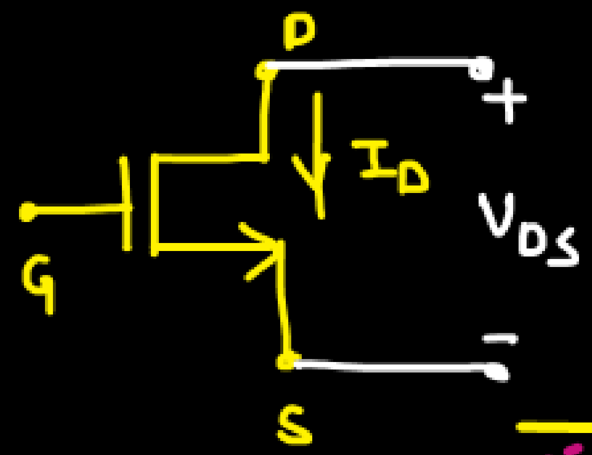
Channel length Modulation (CLM):-

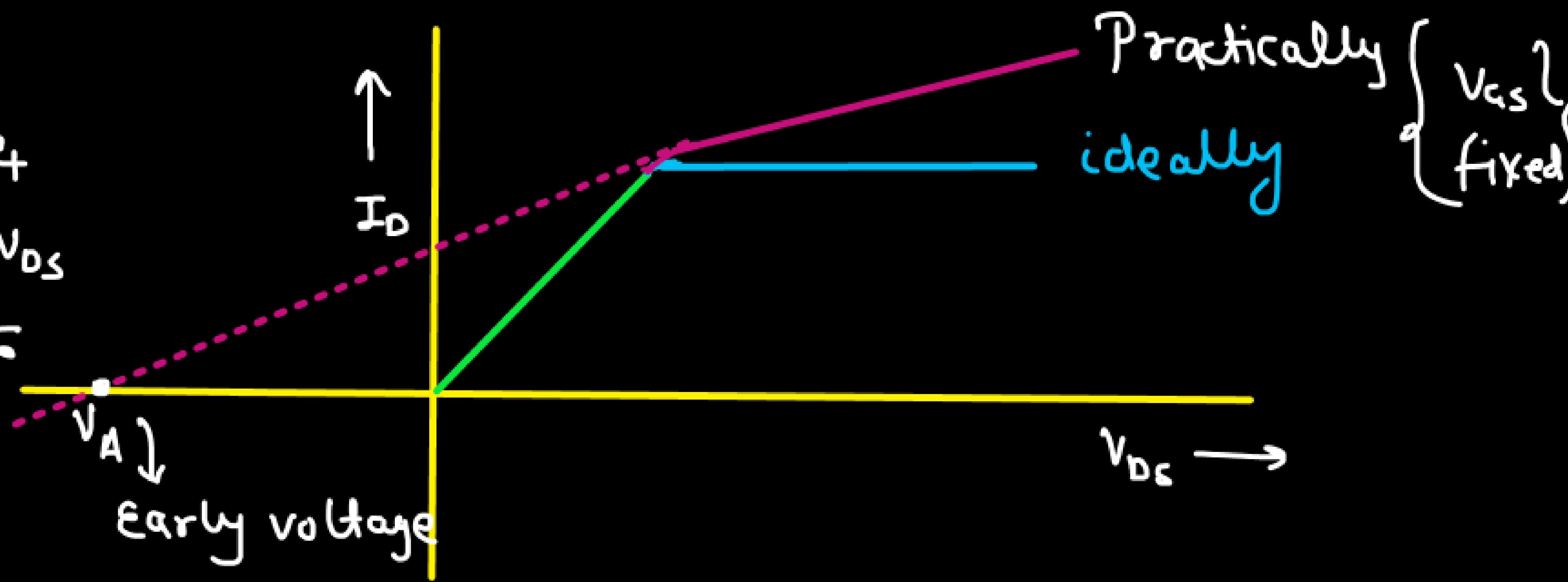
Ideally, for $V_{DS} > (V_{DS})_{sat.} \Rightarrow$ current saturates

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



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



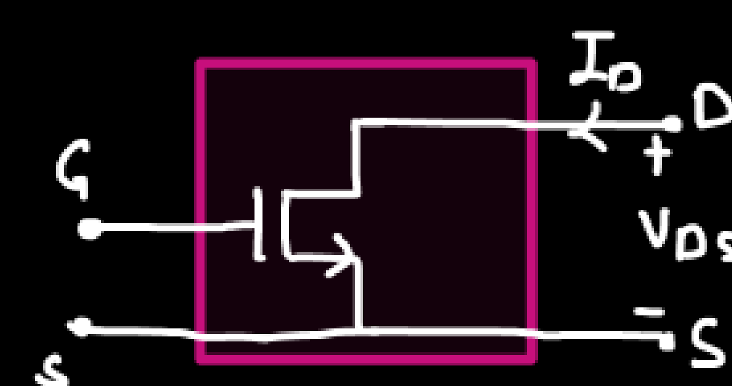


Ideal case:- (Saturation)

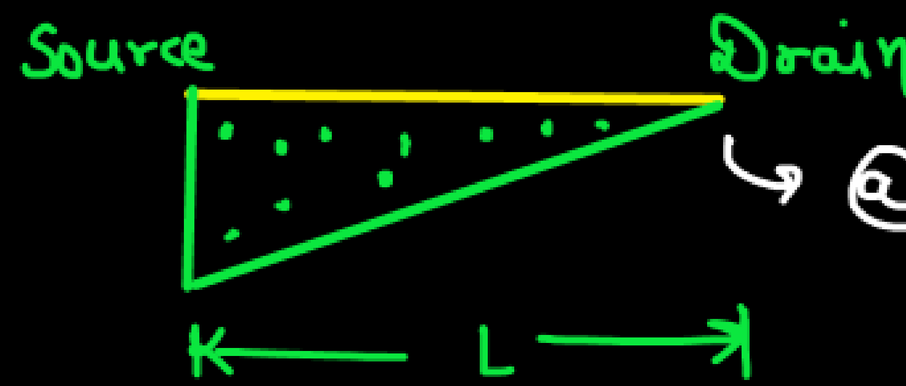
$$(I_D)_{sat.} = \frac{\mu_n C_{ox} W}{2L}(V_{GS}-V_T)^2 \Rightarrow$$ constant for fixed V_{GS} (Independent of V_{DS})

Drain-Source ON Resistance:- (Saturation)

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

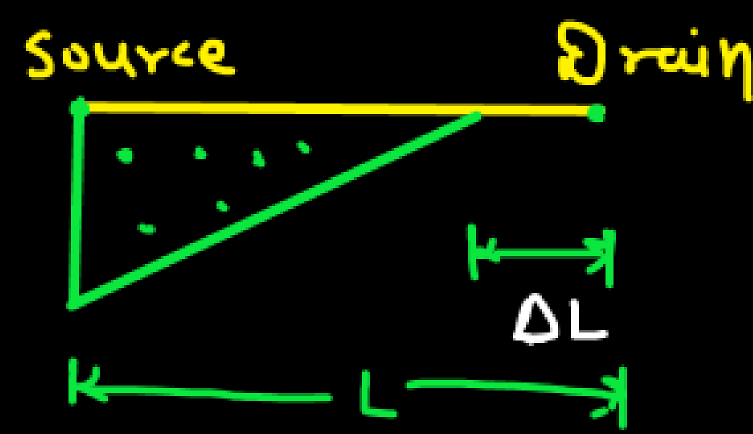


Practically:-



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

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]:-

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

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

Early voltage-

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

$$= 0$$

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

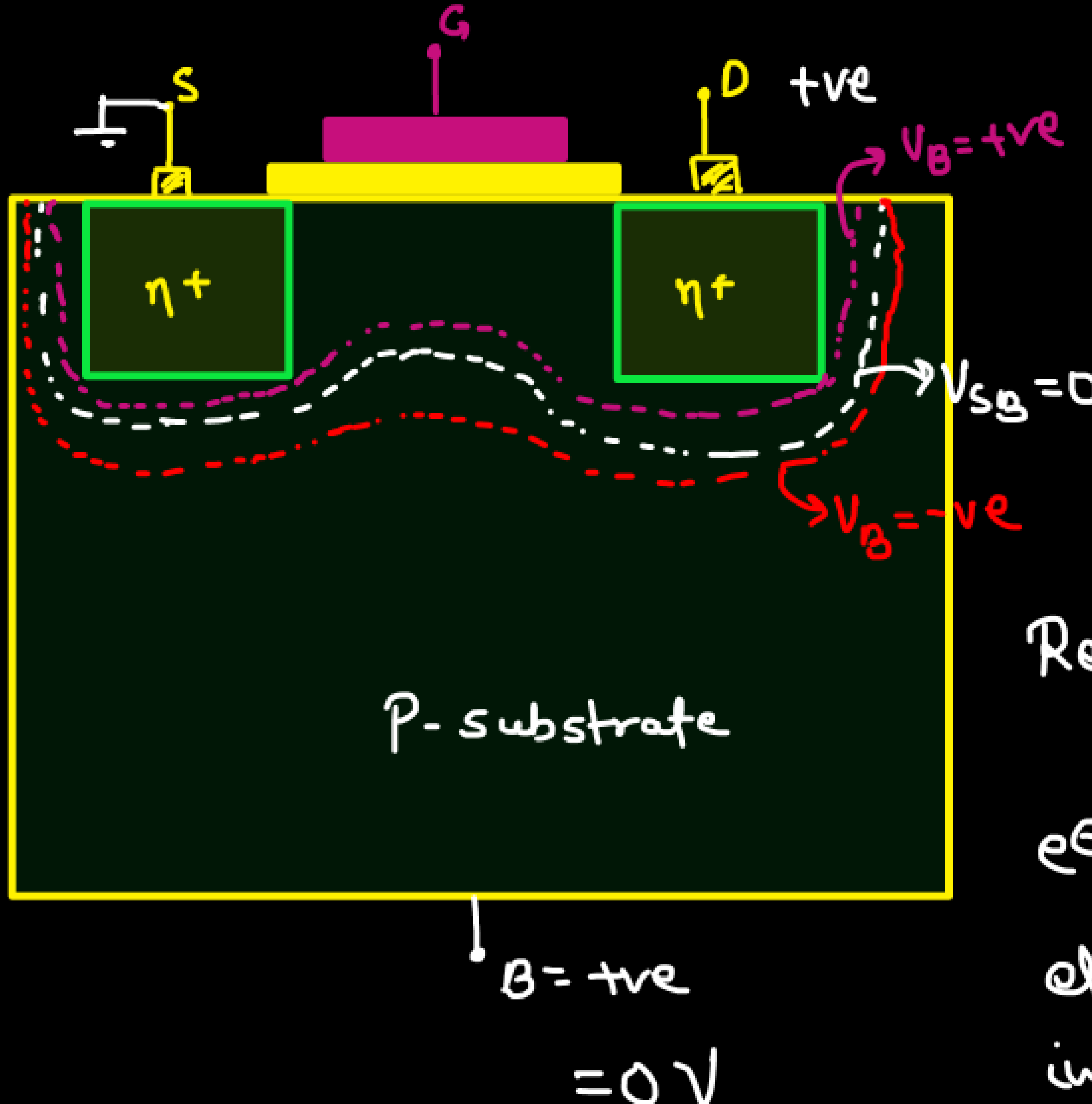
$$\boxed{V_{DS} = \frac{-1}{\lambda}}$$

$\Rightarrow$ 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 $\rightarrow$ $\boxed{V_T = V_{T_0} + \gamma\left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right]}$



① $V_{SB} = 0$

$\Rightarrow$ No change in Threshold voltage.

② $V_{SB} = +ve$; $V_B = -ve$

Reverse bias @ source side ↑

$\Downarrow$

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

$\Downarrow$

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

③ $V_{SB} = -ve$, $V_B = +ve$

$\Downarrow$

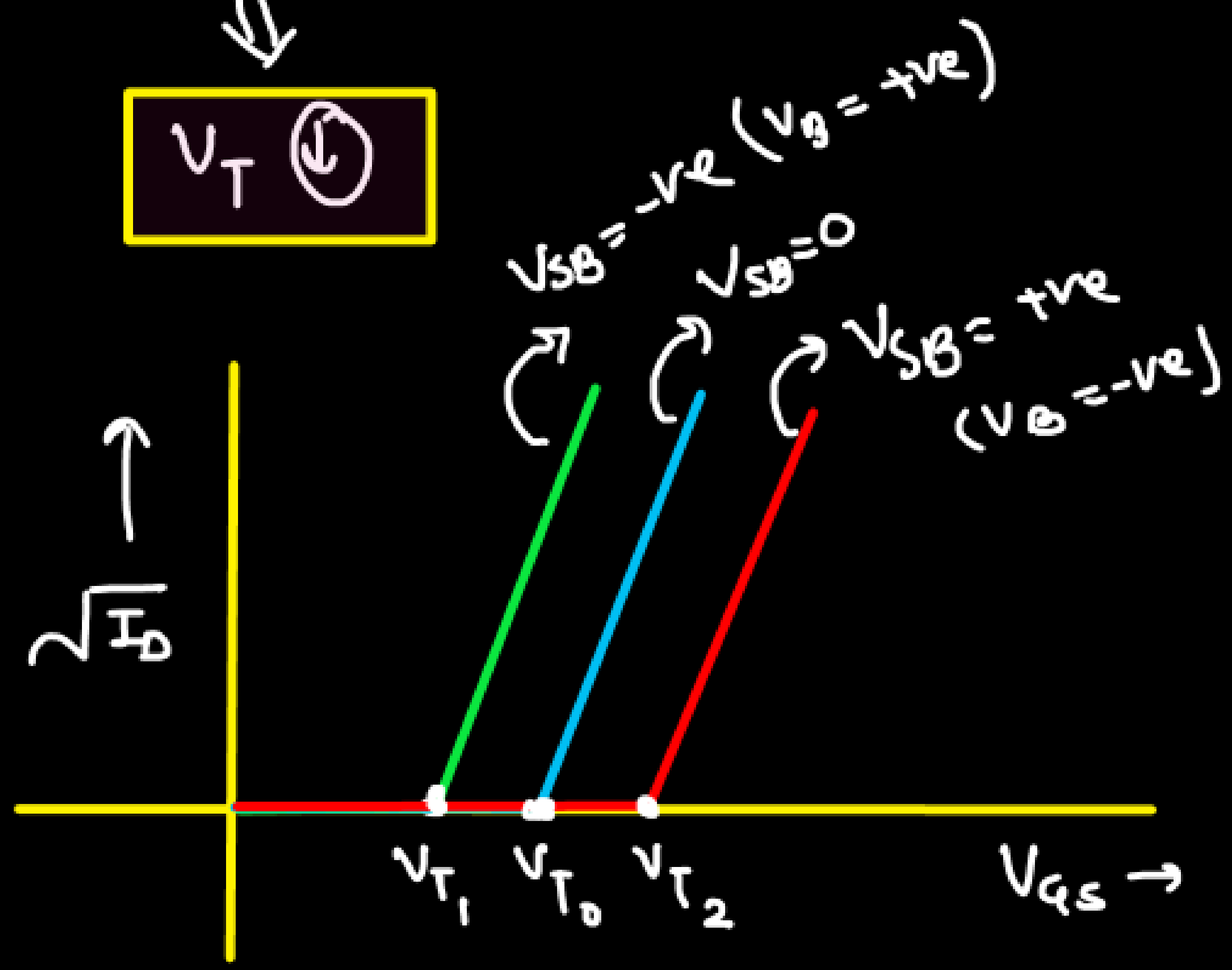
Forward bias Towards source side ↑

$\Downarrow$

Source can supply more electrons @ lower V_G

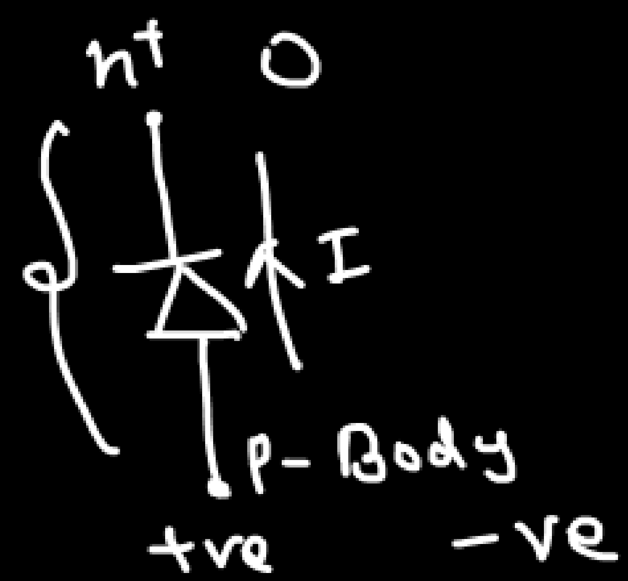
$\Downarrow$

$\boxed{V_T \downarrow}$



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

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

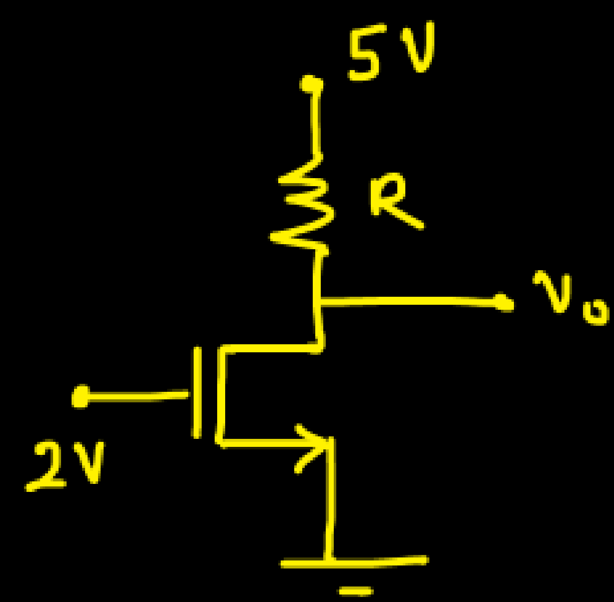


$\Rrightarrow$ $\boxed{\text{We always try to keep } V_{SB} = 0V \text{ ; Source- Body shorted}}$

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

Assignment - 4

Q.



$W/L = 10$

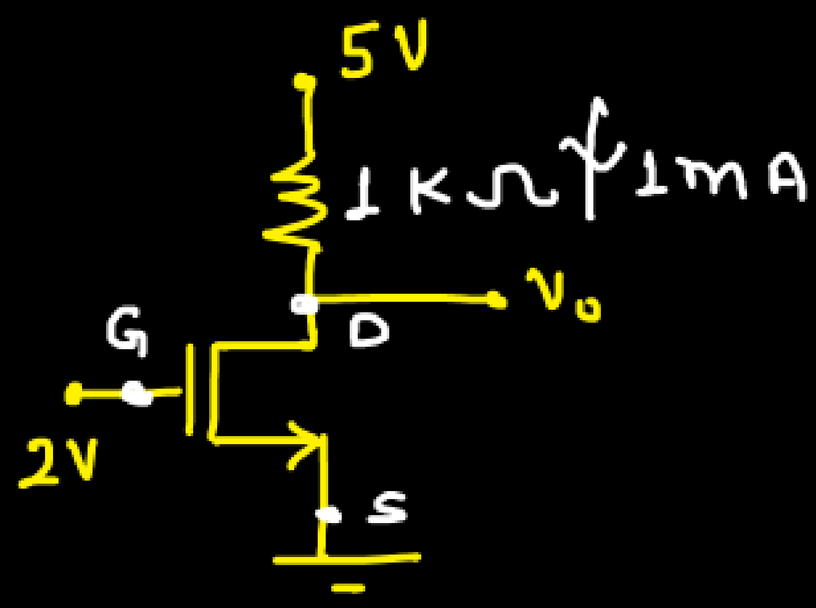
$\mu_n C_{ox} = 200\,\mu A/V^2$

$V_T = 1V$

Find $v_o = ?$

(i) $R = 1K\Omega$

(ii) $R = 4.5K\Omega$



(a)

$V_{GS} = 2\,V$

$V_{DS} = V_o$

$V_T = 1V$

Let, MOS is working in sat. region

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

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

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

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

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

$= 2 - 1 = 1V$

$V_{DS} = 4V$

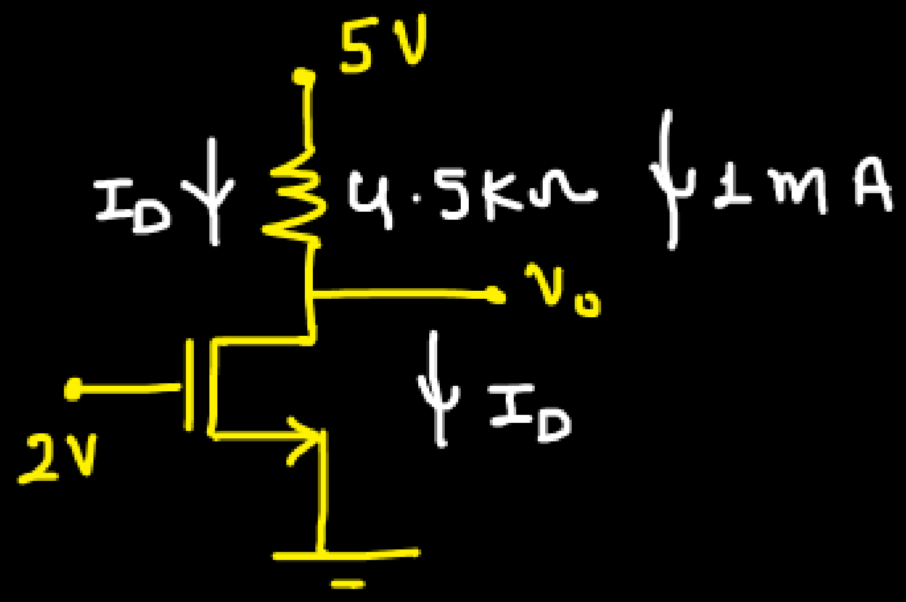
Here, $V_{DS} > V_{GS} - V_T$

OR

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

Assumption correct ✓

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



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

Assumption wrong

Assuming, linear region;

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

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

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

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

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

$$\swarrow \qquad \searrow$$

1.46V 0.76V

$$V_0 \begin{cases} \to 1.46\,V \\ \to 0.76\,V \end{cases}$$

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

$V_{GS} - V_T = 1V$

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

$\Rightarrow$ sat.

$V_0 = 0.76V = V_{DS}$

$V_{GS} - V_T = 1V$

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

$\Rightarrow$ Linear ✓

$\Downarrow$

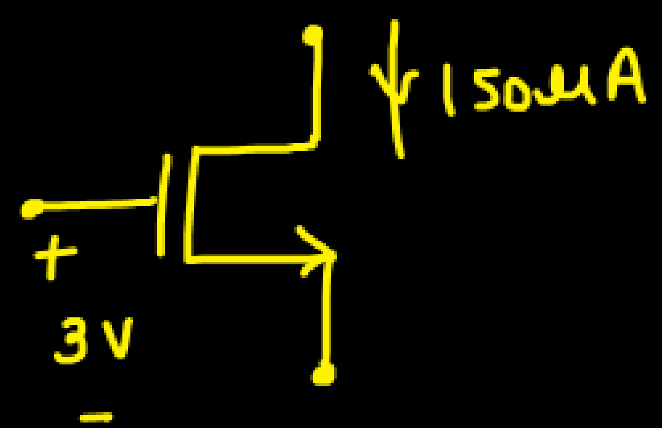
Assumption correct

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

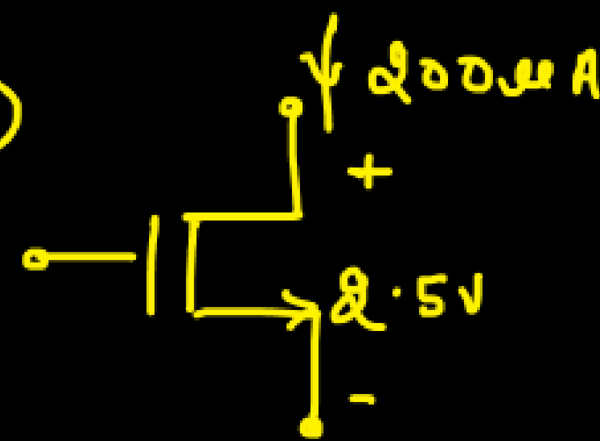
Q. Given, $\mu_n C_{ox} = 100\,\mu A/V^2$, $W/L = 1$, $V_T = 1V$

Find region of operation.

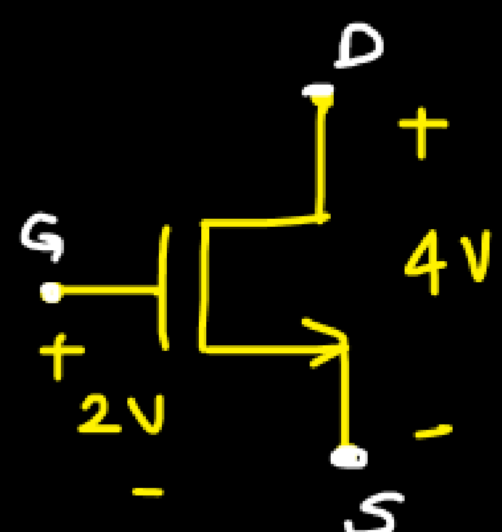
(1)



(2)



(3)



$V_{DS} = 4V$

$V_{GS} = 2V$

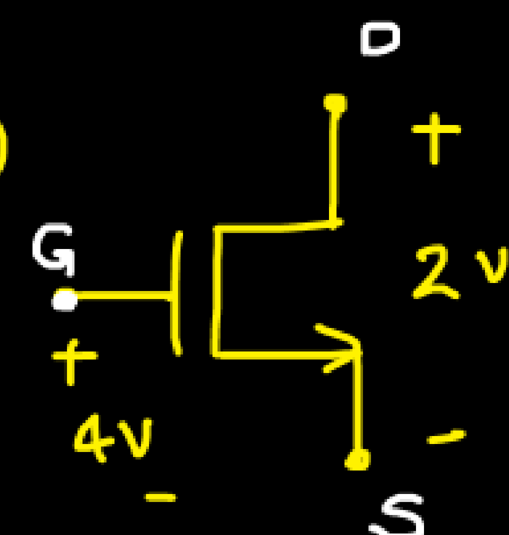
$V_{OV} = 1V$

$V_{DS} > V_{OV}$

$\Downarrow$

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

(4)



$V_{DS} = 2V$

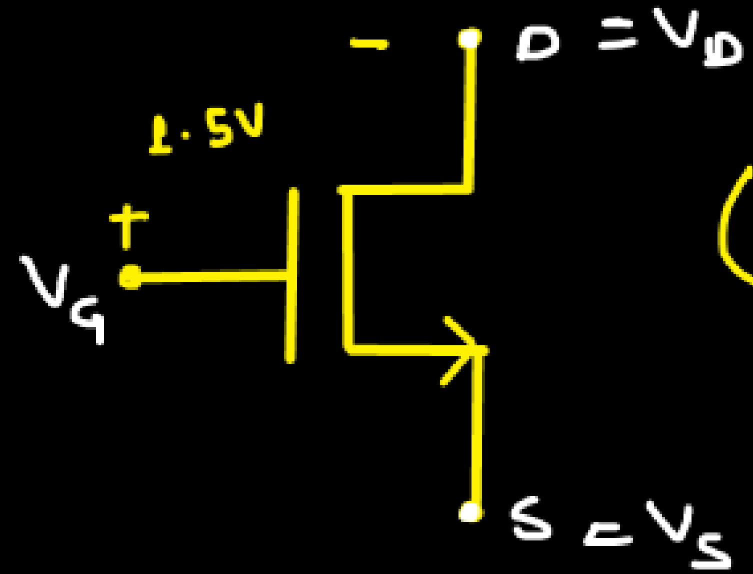
$V_{OV} = 3V$

$V_{DS} < V_{OV}$

$\Downarrow$

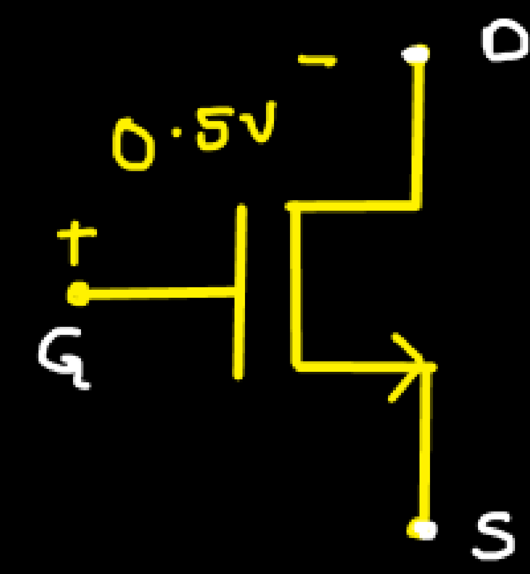
$\boxed{\text{Linear region}}$

⑤



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

⑥



$V_{DS} = V_D - V_S$

$V_{GS} = V_G - V_S$

$= V_D + 1.5 - V_S$

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

$V_T = 1V$

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

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

$V_{DS} = V_D - V_S$

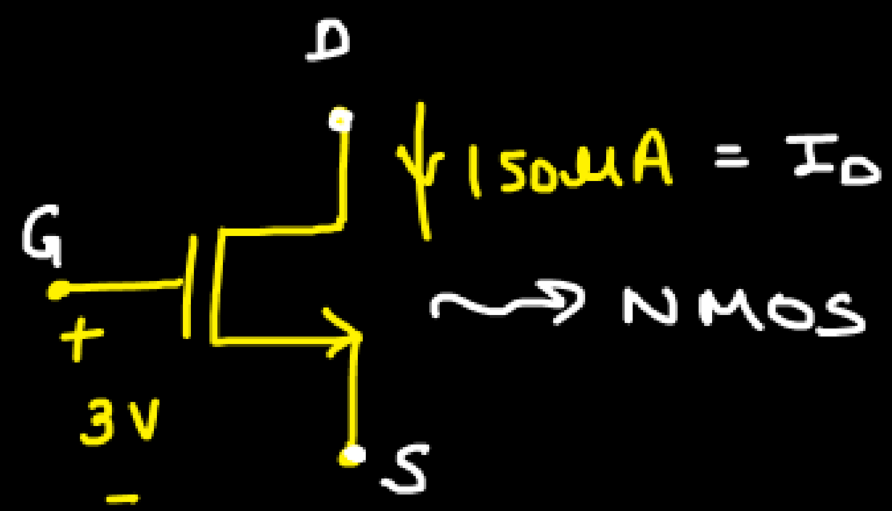
$V_{GS} = V_D + 0.5 - V_S$

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

$V_T = 1V$

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

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



(a)

$V_{GS} = 3V$

$V_T = 1V$

$I_D = 150\mu$ Amp.

Let MOS is in sat. region

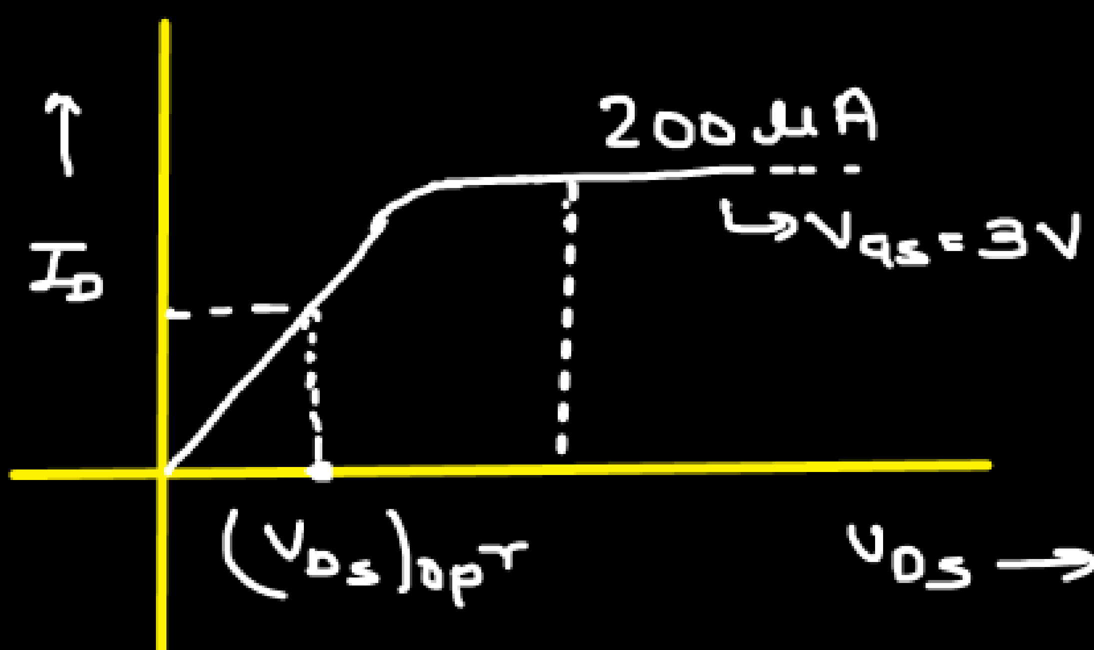
$$I_D = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2$$

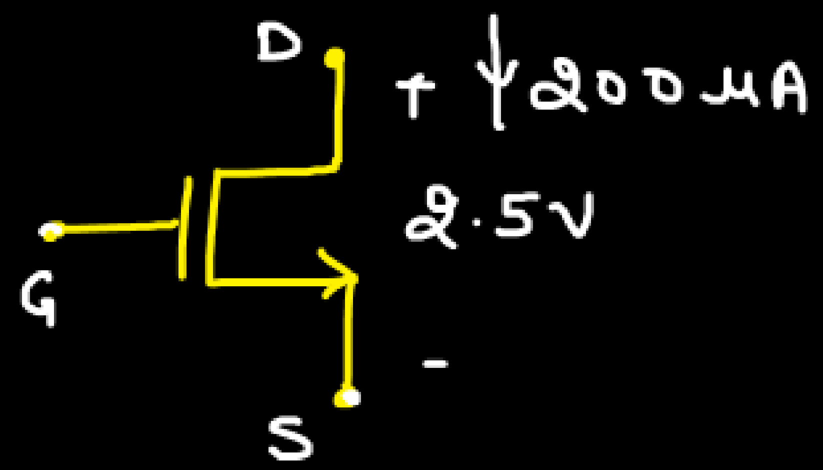
$$= \frac{100\mu \times 10}{2} (3-1)^2$$

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

$\Downarrow$

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





$I_D = 200\ \mu A$

Let, sat. region

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

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

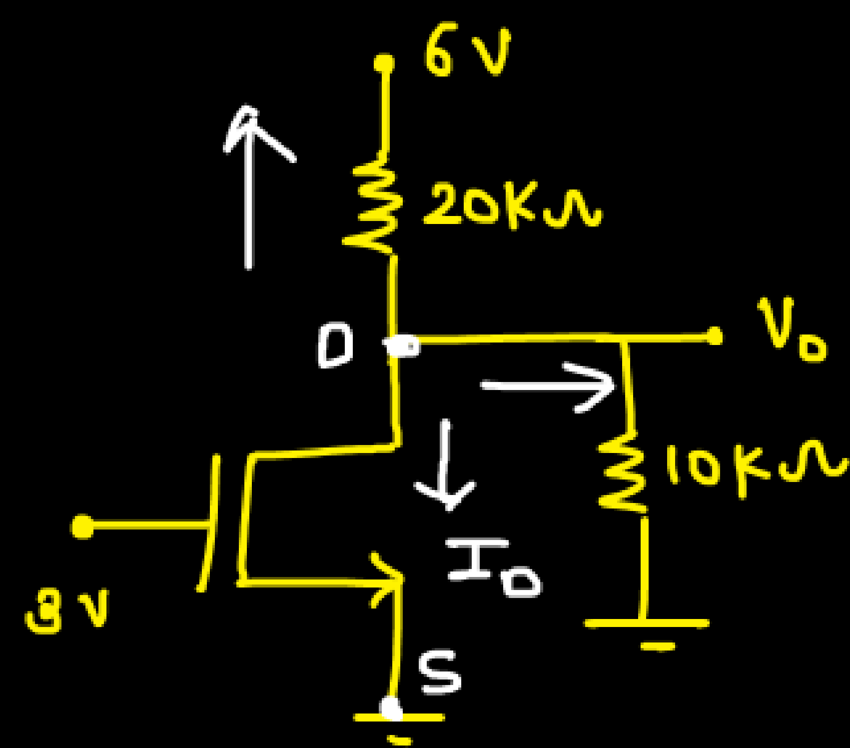
$$\boxed{V_{GS} = 3V}$$

$V_{DS} = 2.5V$

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

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

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

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

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

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 ✗

Assuming , MOS in linear region

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

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

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

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

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

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

if $V_0 = 1V$

$V_{OV} = 2V$

$V_{DS} < V_{OV}$

$\Rightarrow$ linear region ✓

$\boxed{V_0 = 1V}$

if $V_0 = 6V$

$V_{OV} = 2V$

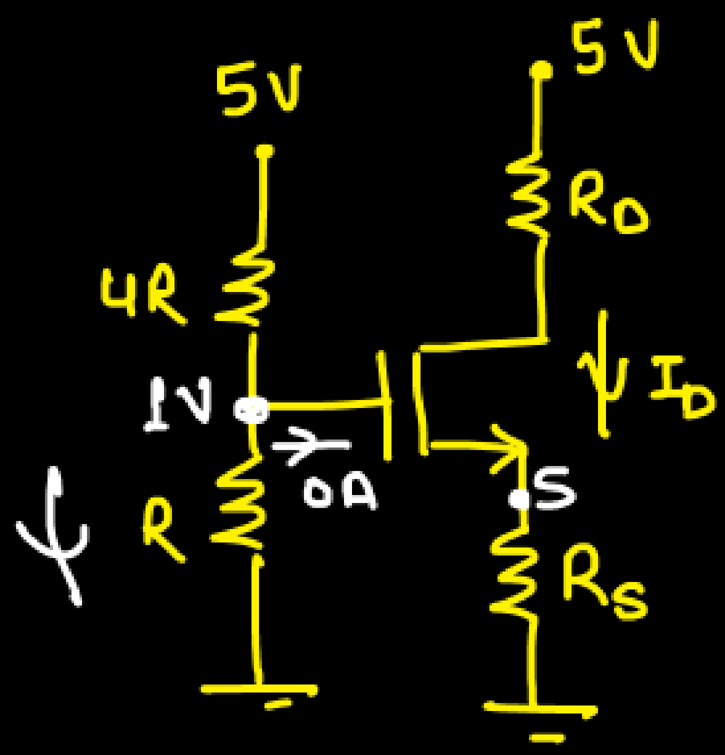
$V_{DS} > V_{OV}$

$\Downarrow$

sat.

✗

Q.



Find R_s such that MOS works in saturation region.

Given

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

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

$V_G = 1V$

$V_S = I_D R_S$

$V_{GS} = 1 - I_D R_S$

$V_T = 0.5V$

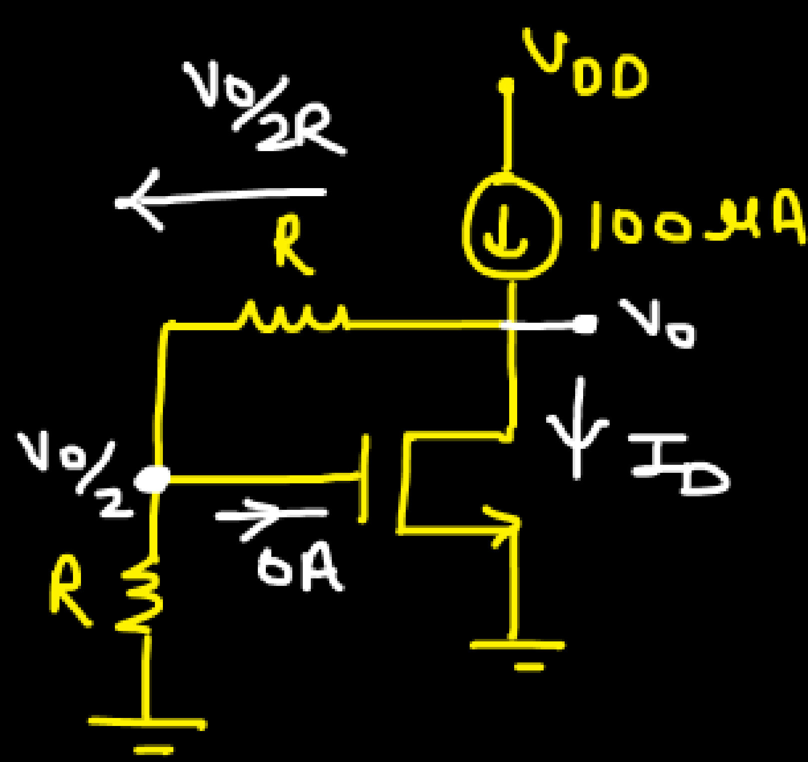
$I_D = K_n(\underbrace{V_{GS} - V_T}{})^2$

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

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

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

Q.



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

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

Find bias current in Transistor.

$V_{DS} = V_0$

$V_{GS} = V_0/2$

$V_T = 1V$

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

$$I_D = 100\mu - \frac{V_0}{80K}$$

$$I_D = 100\mu - \frac{1000}{80} V_0 \times \mu$$

$$\boxed{I_D = 100\mu - 12.5V_o\,\mu} \quad \text{①}$$

Let, MOS in sat,

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

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

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

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

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

$$V_o^2 - 3V_o - 4 = 0 \quad \begin{cases} V_o = 4V \\ V_o = -1V \end{cases}$$

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

<u>Check:-</u>

MOS cut-off

$I_D = 0$ Amp.

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

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

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

$V_D > V_{OV}$
also $V_{GS} > V_T$
also $V_{DS} > 0V$

$\Rightarrow$ MOS goes into sat.
$\Downarrow$
(Can't be cut-off)

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 ✓

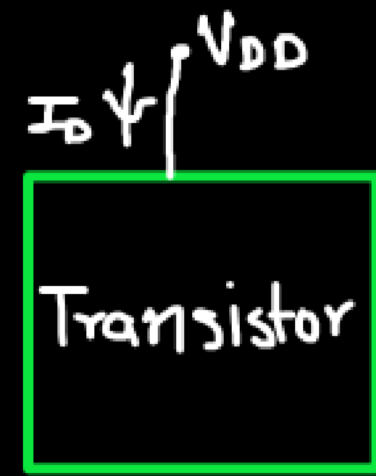
$$\boxed{V_o = 4V}$$

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

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

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.

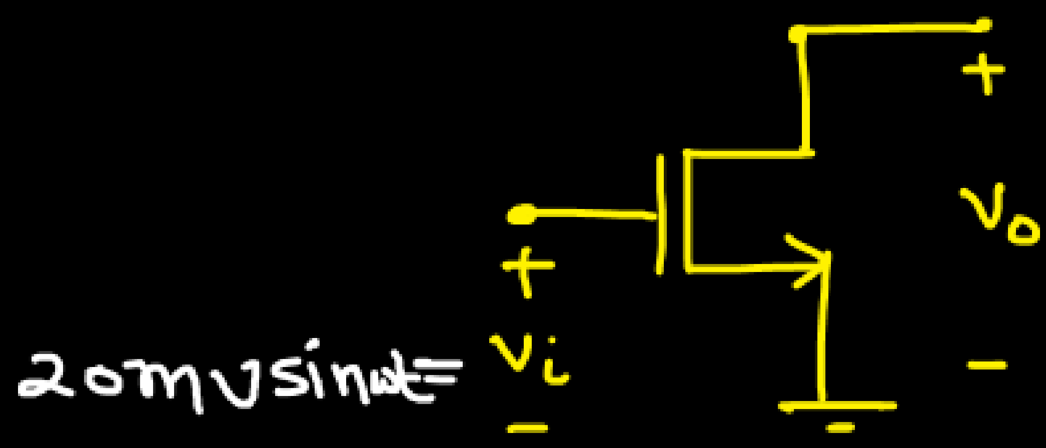


Why biasing is required ?

↳ Why we needed MOSFET:-

$$20mV \sin\omega t = v_i \qquad v_o = 100mV \sin\omega t$$

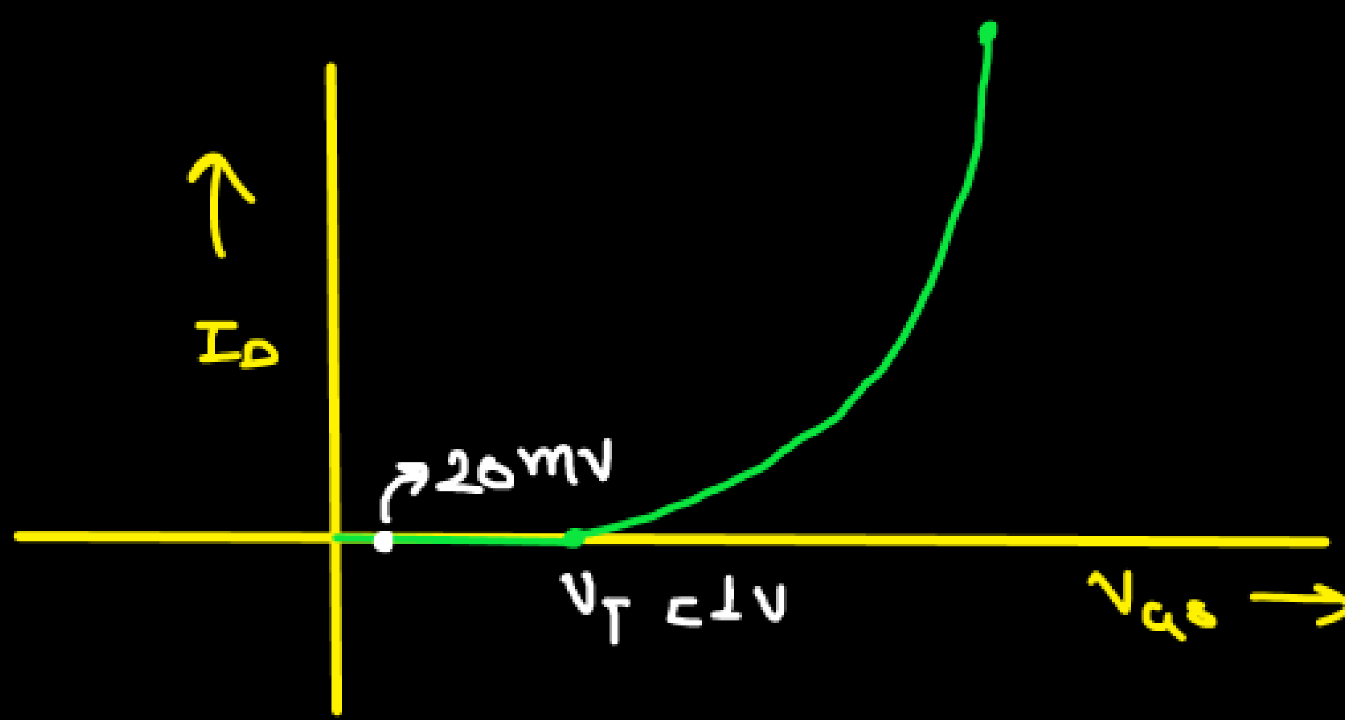
* Let I don't apply an dc bias to my Amplifier and directly give small signal Ac voltage.



$\Rightarrow V_{GS} = 20mV\sin\omega t$

max = 20mV

min = −20mV

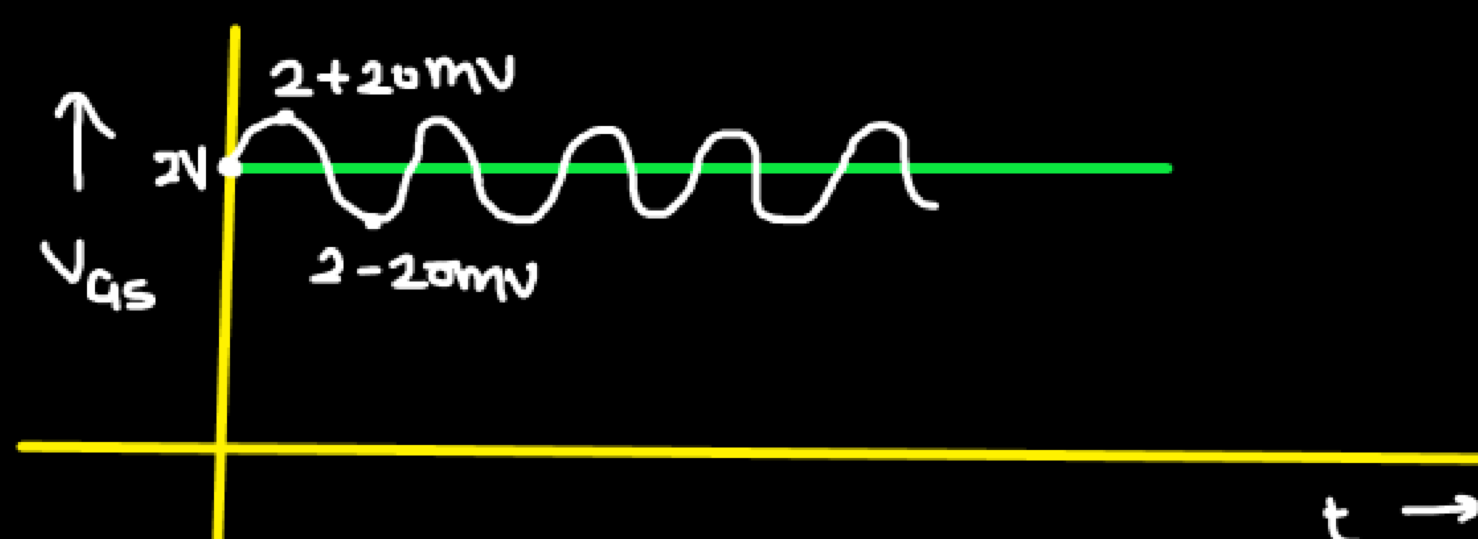


$\Rightarrow$ Transistor doesn't even turn ON.

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.

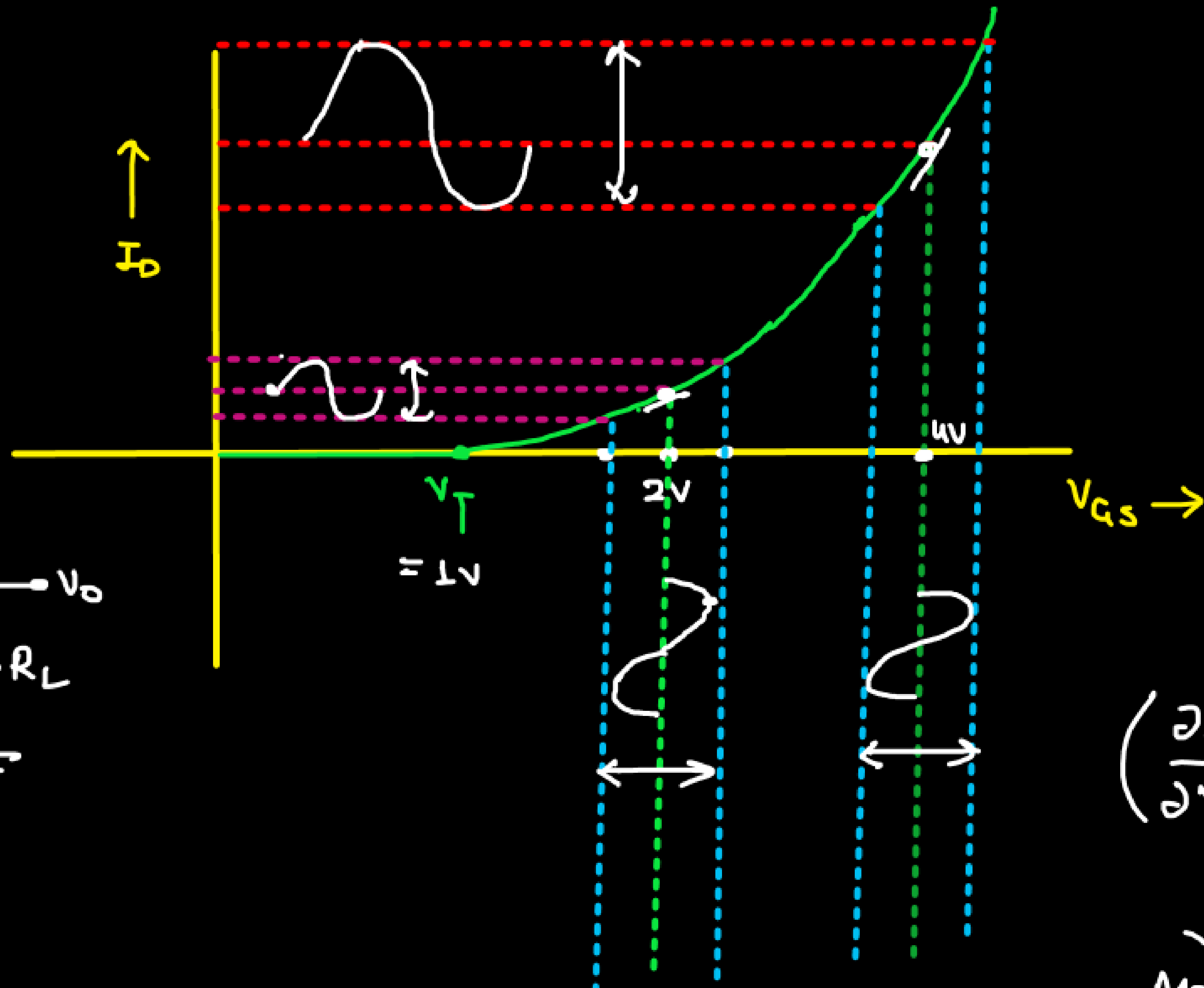
$$\Rightarrow V_{GS} = V_{GG} + v_i$$

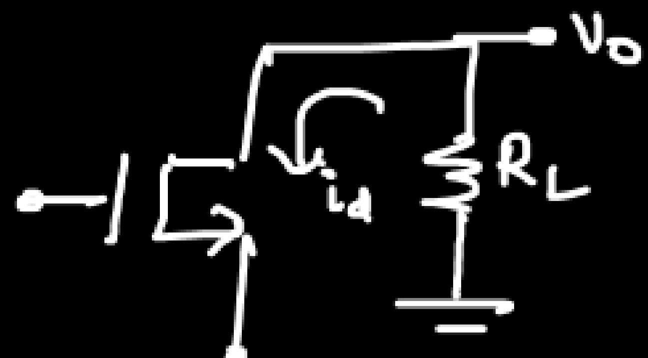
$$V_{GS} = 2V + 20mV \sin\omega t$$



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

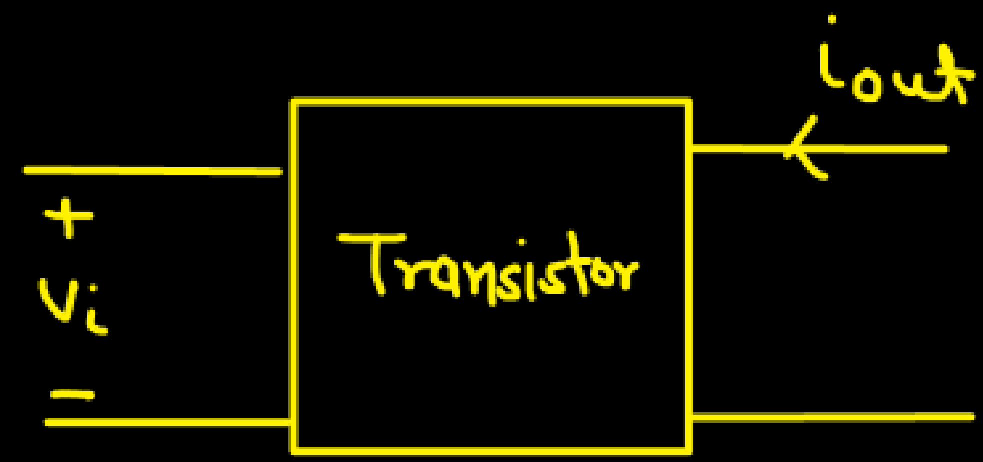
and that eventually gives more gain.

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

(i) More power consumption

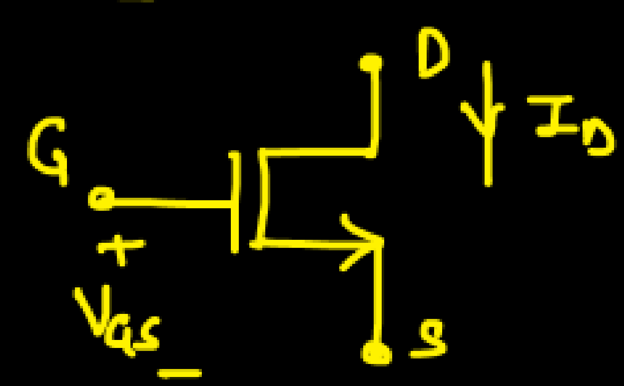
(ii) MOS will fall out of saturation.

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:-

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

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

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

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

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)

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

*

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

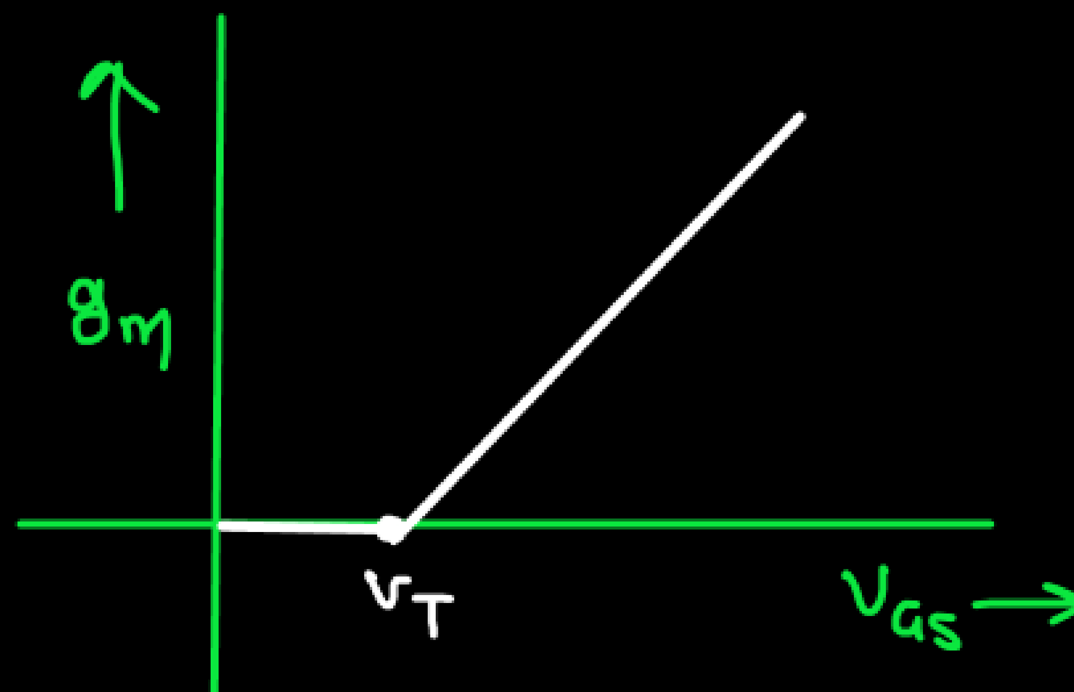
$$I_D = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_t)^2$$

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

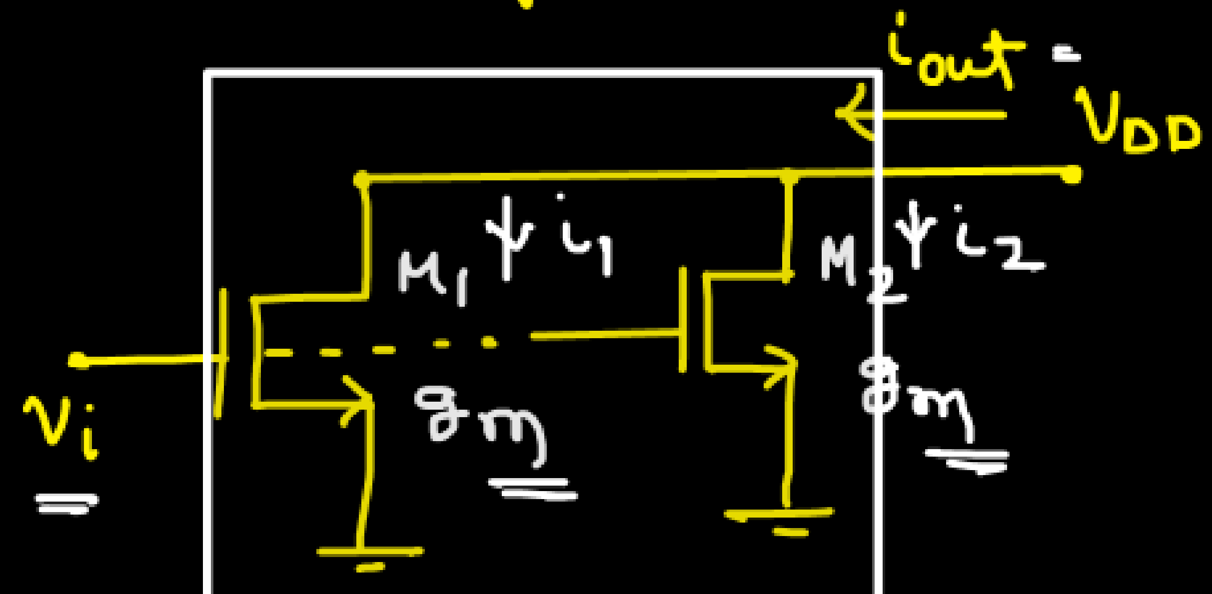
$$\sqrt{2\frac{\mu_n C_{ox} W}{L} I_D} = \frac{\mu_n C_{ox} W}{L}(V_{GS} - V_T) = g_m$$

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

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

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

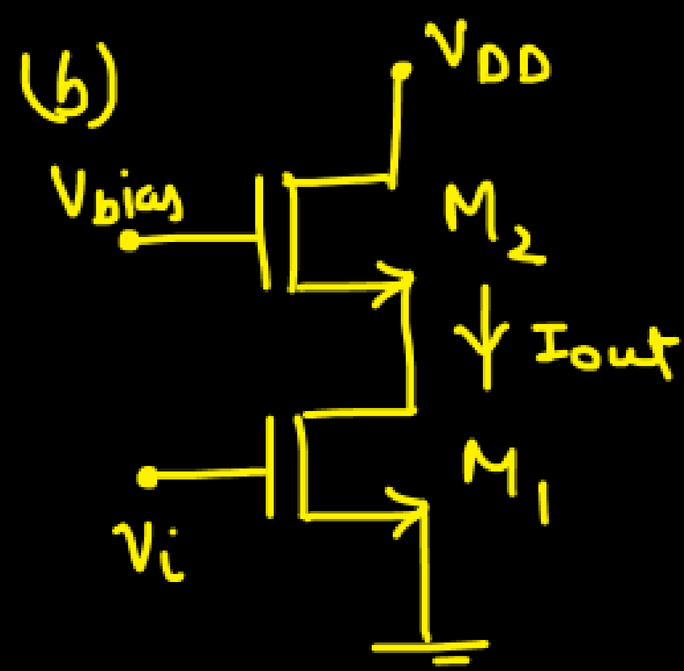
$$G_m = \frac{\partial i_{out}}{\partial v_{in}} \quad ; \quad i_{out} = i_1 + i_2$$

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

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

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

(b)



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

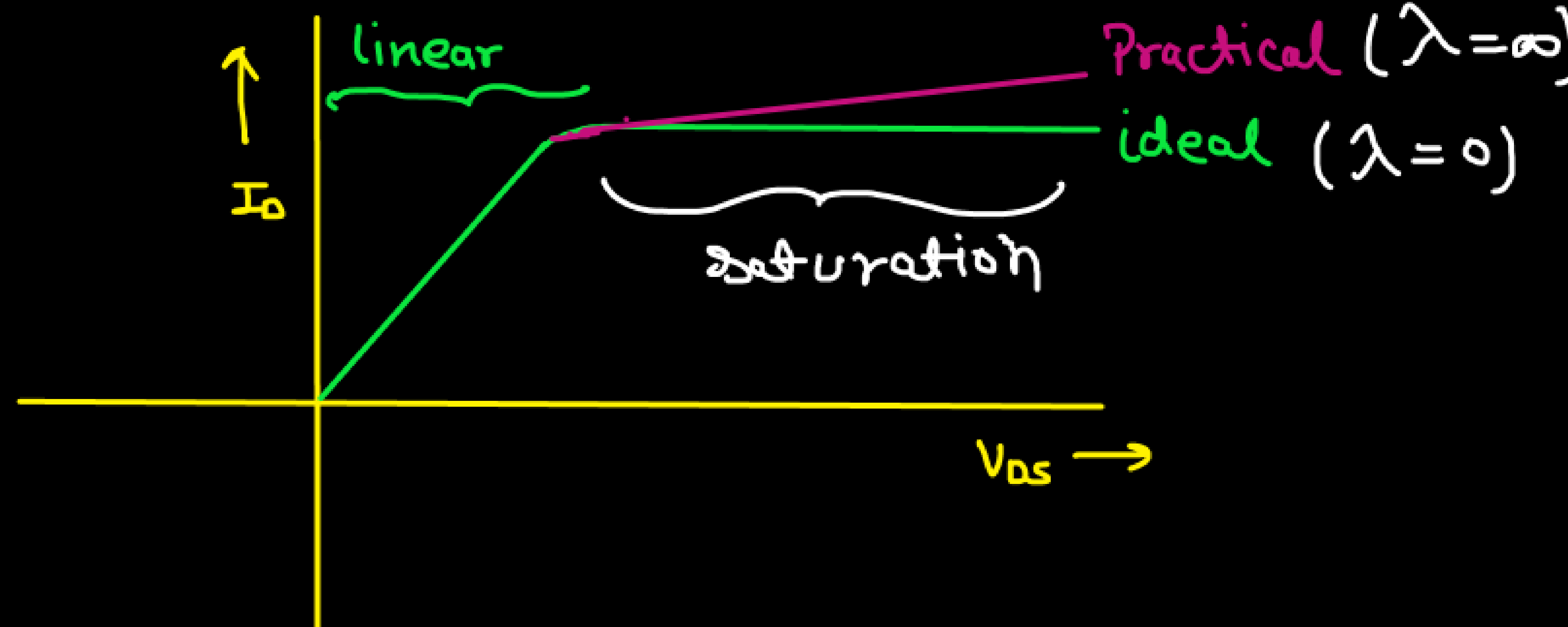
Find overall Transonductance of given ckt.

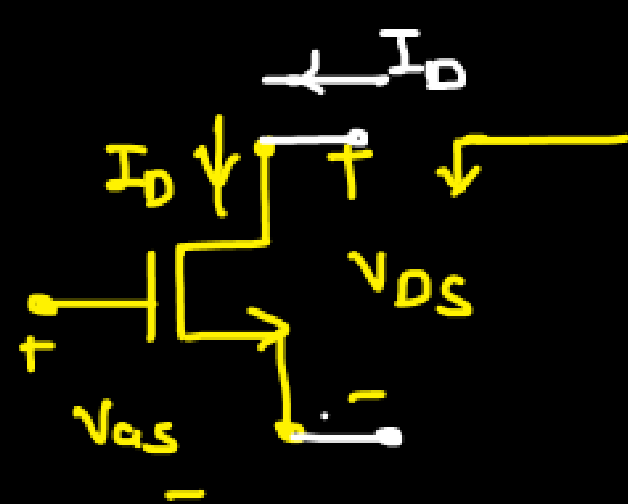
$\rightarrow$ overall Transconductance $= \boxed{\dfrac{\partial i_{out}}{\partial V_{in}} = G_m}$

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

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

☆ O/P characteristics of MOS:-





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

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

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

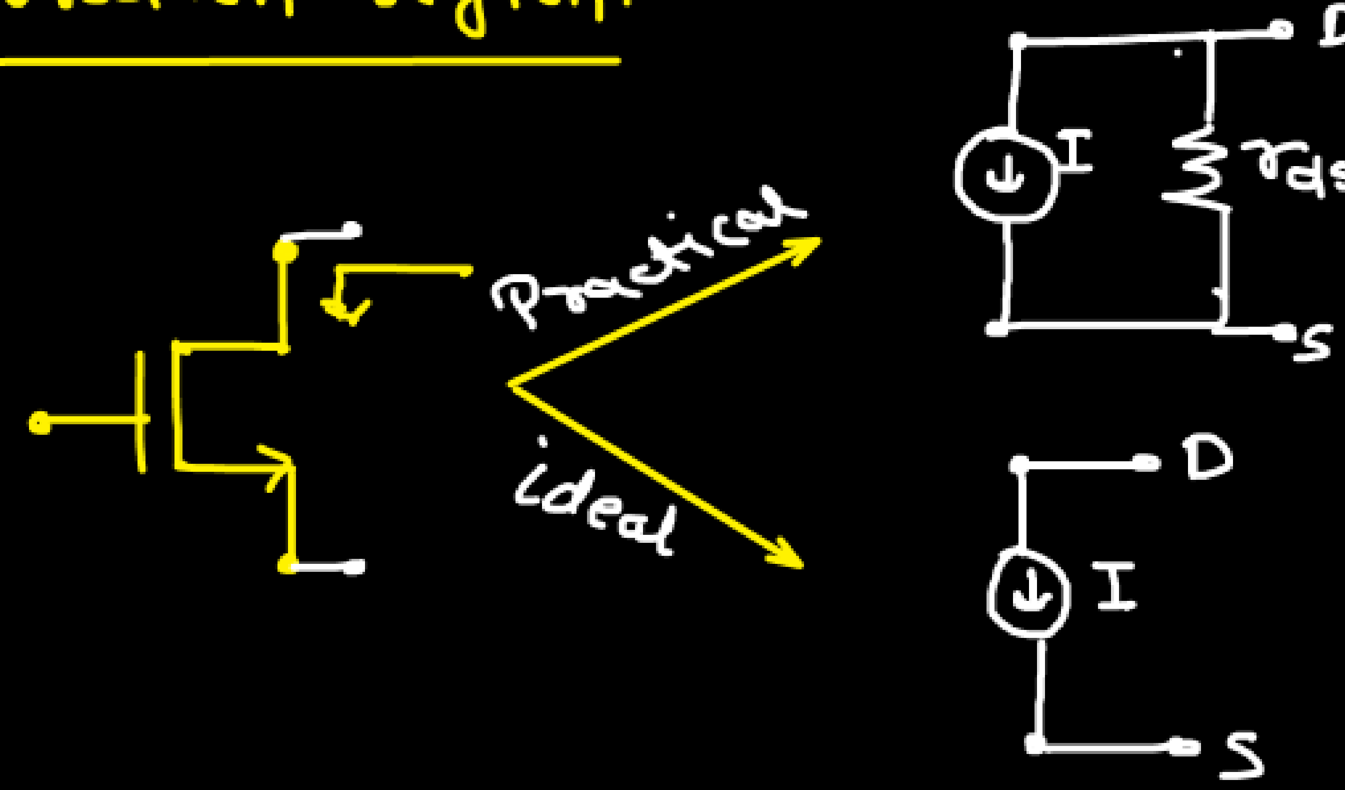
<u>For saturation region:-</u>

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

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

ideal → $\boxed{r_{ds} = \infty}$

MOS in saturation region:-



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

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

$\Rightarrow$

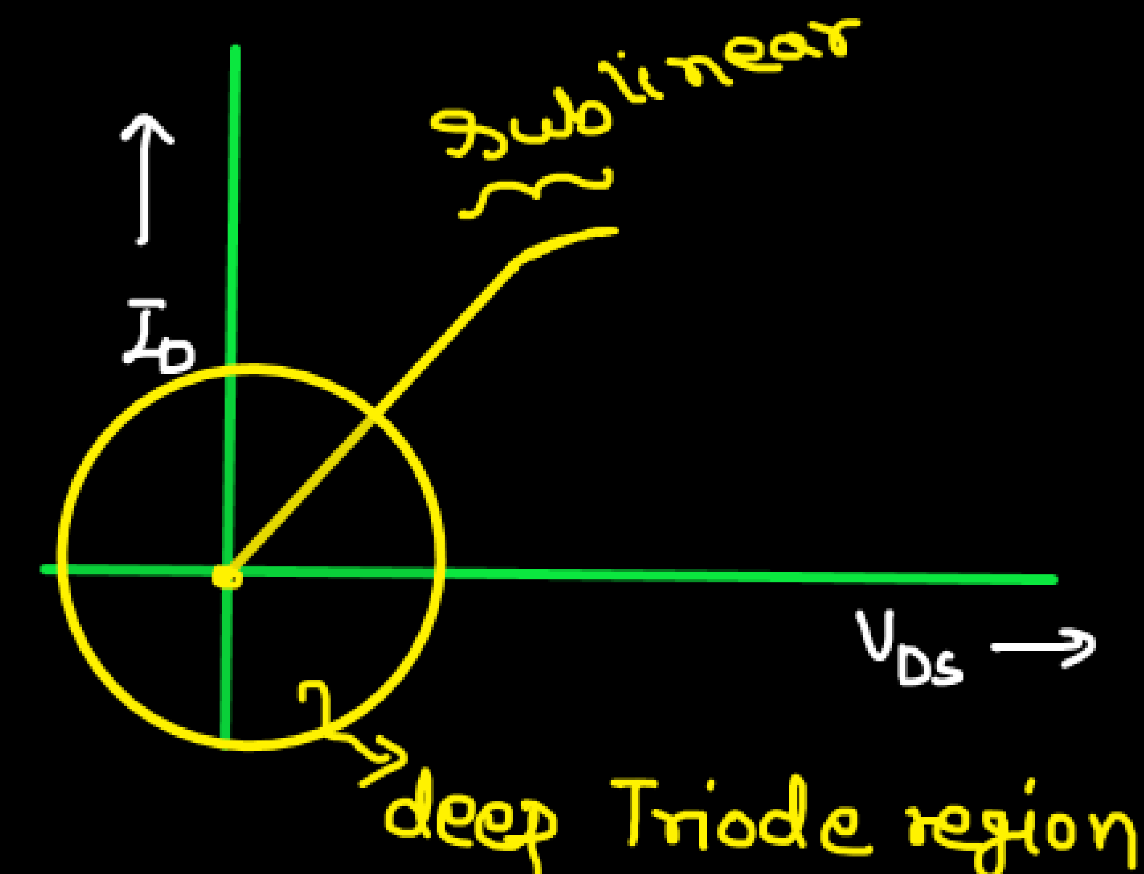
For Triode region:-

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

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

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

$$V_{DS} \simeq 0$$

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

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

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

MOS in deep Triode region

Assignment - 5 (Fusion_Special)

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

Take $V_{Tn} = 0.7V = |V_{Tp}|$

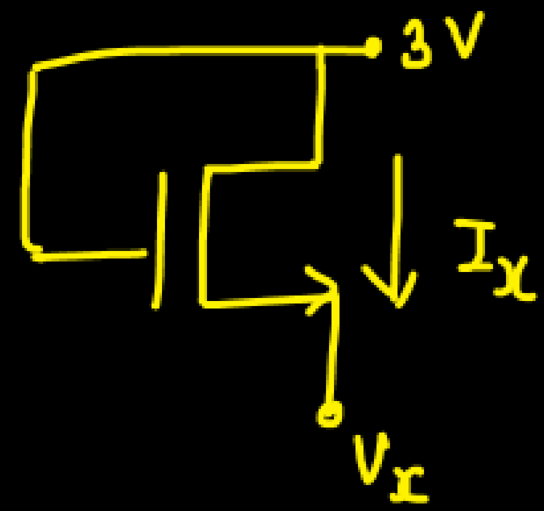
Plot I_x v/s V_x and g_m v/s V_x.

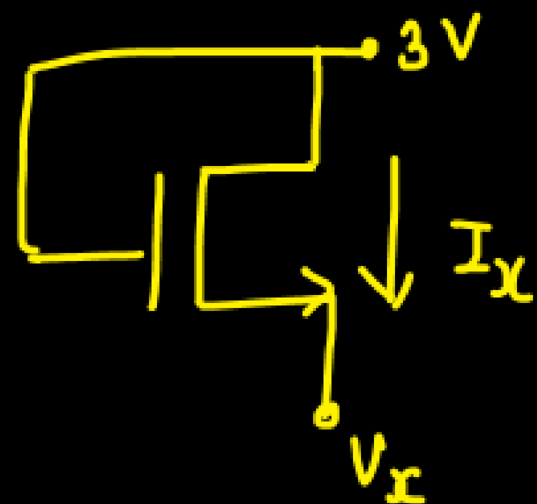
where $g_m = \frac{\partial I_D}{\partial V_{GS}}$, $g_m = \frac{\partial I_D}{\partial V_{SG}}$

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

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

(a)





(a)

$V_{DS} = 3 - V_x$ ✓

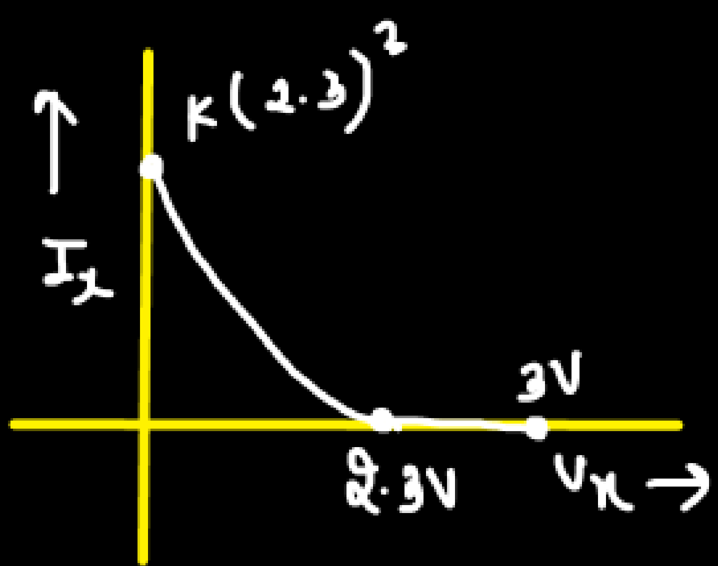
$V_{GS} = 3 - V_x$

$V_T = 0.7$

$V_{OV} = V_{GS} - V_T = 2.3 - V_x$ ✓

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

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



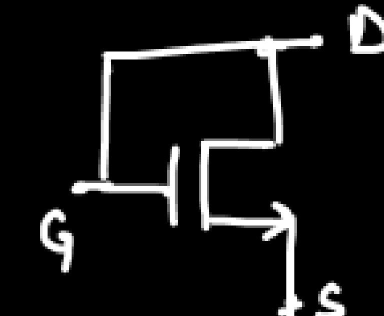
For cut off :-

$V_{GS} < V_T$

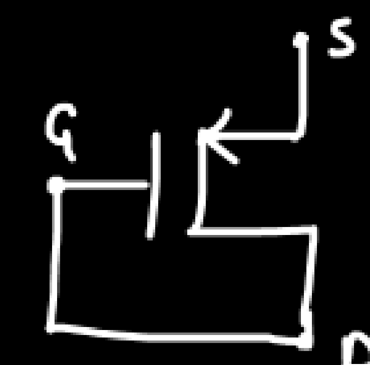
$3 - V_x < 0.7$

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

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



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



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

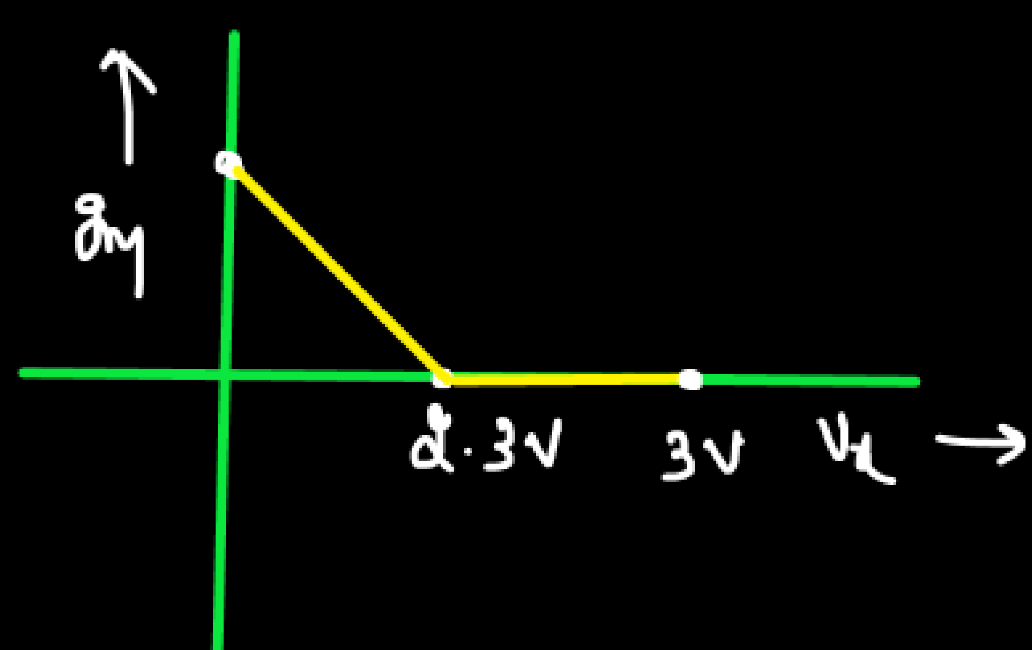
Talking about g_m :-

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

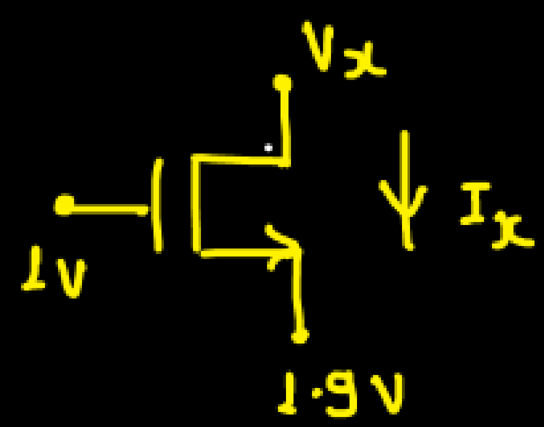
$$(g_m)_{sat} = K'(V_{GS} - V_T)$$

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

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



(b)

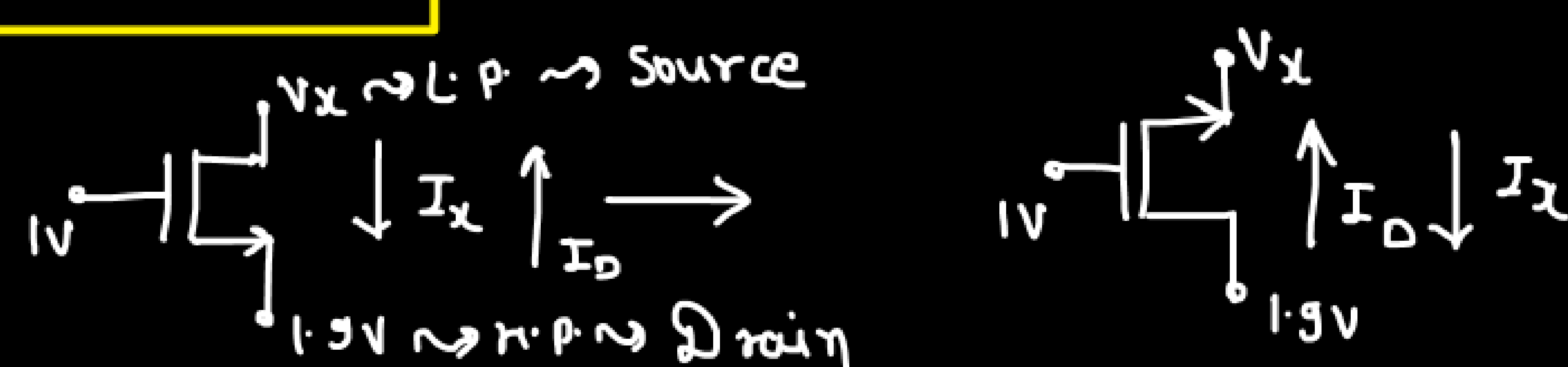


$V_x \equiv 0 \to 3V$

$V_T = 0.7V$

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

$V_x > 0.3V$

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

$0 < V_x < 0.3 \Rightarrow$ sat.

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

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

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

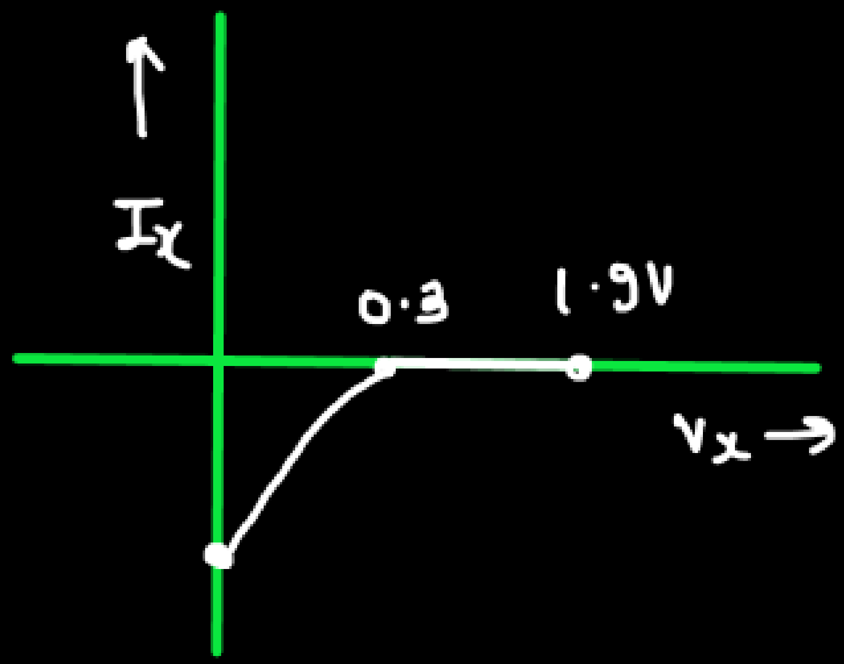
$$g_m = K'(V_{GS} - V_T)$$

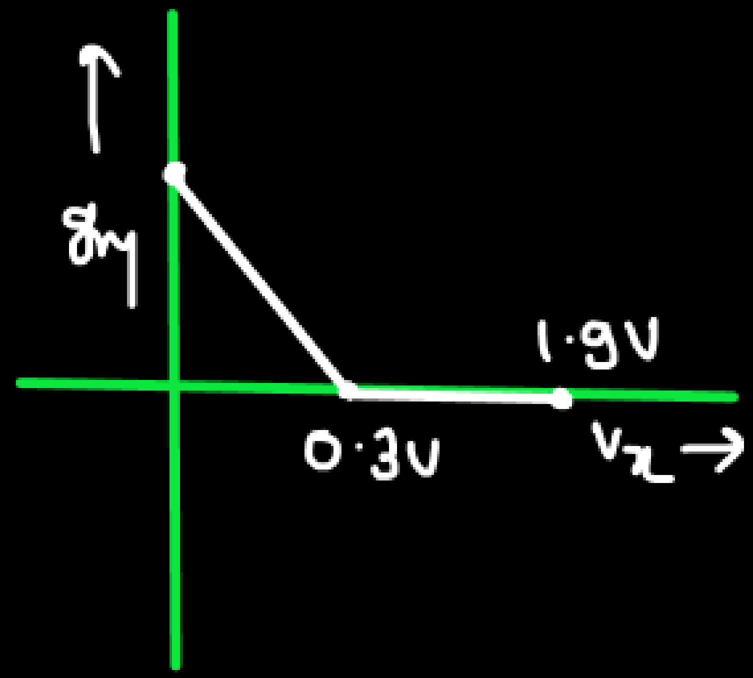
$$\boxed{g_m = k'(0.3 - V_x)}$$

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

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

$$\boxed{g_m = 0}$$

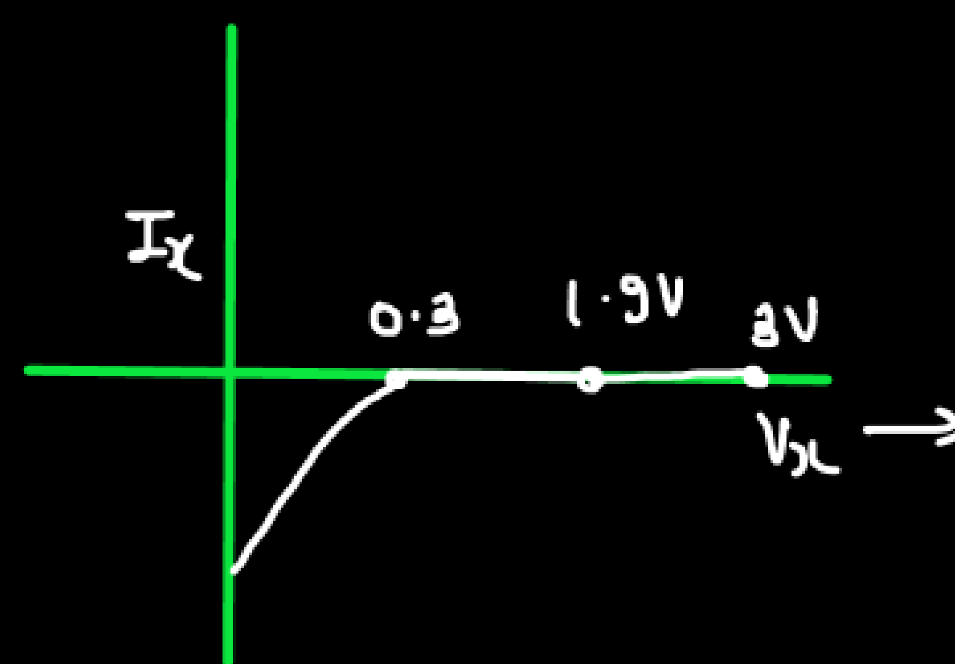


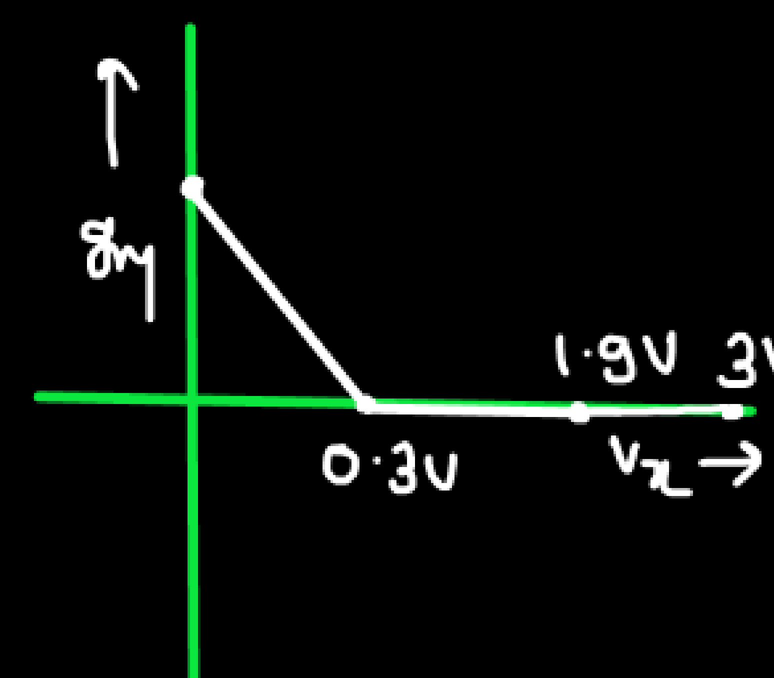


For $V_x > 1.9V$

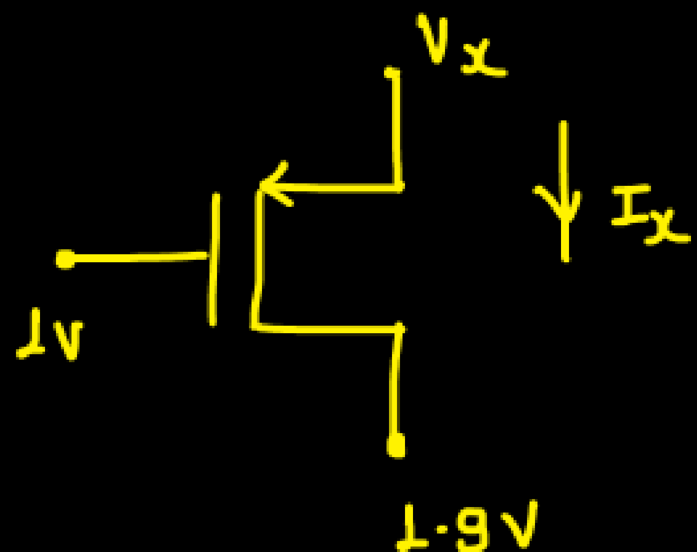
$V_{GS} = 1 - 1.9 = -0.9 < V_T \Rightarrow$ MOS is off

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





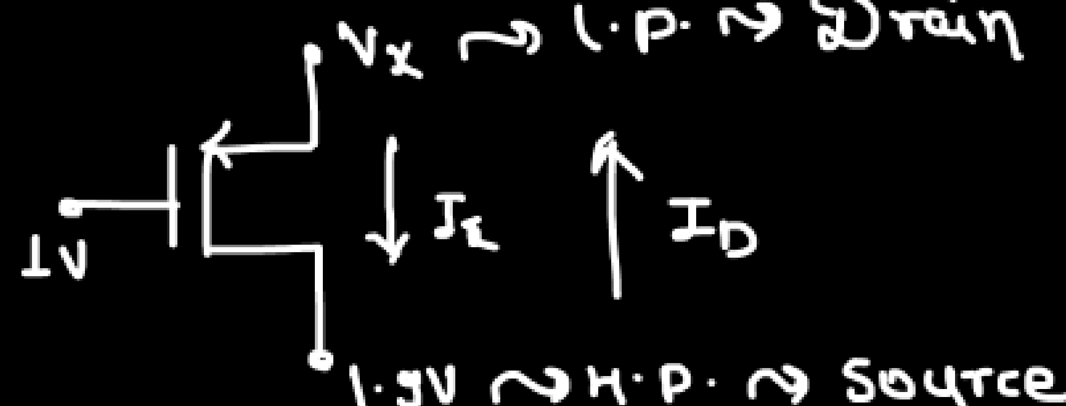
(c)



$V_x \equiv 0 \rightarrow 3V$

$|V_{T_p}| = 0.7V$

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



$V_{SG} = 0.9V$

$V_{SD} = 1.9 - V_x$

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

$\boxed{\text{For sat.}}$

$V_{SD} > V_{ov}$

$1.9 - V_x > 0.2V$

$\boxed{V_x < 1.7V}$

$\Rightarrow V_x < 1.7 \Rightarrow$ Sat.

$1.9 > V_x > 1.7 \Rightarrow$ linear

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

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

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

$$I_x = -I_D$$

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

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

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

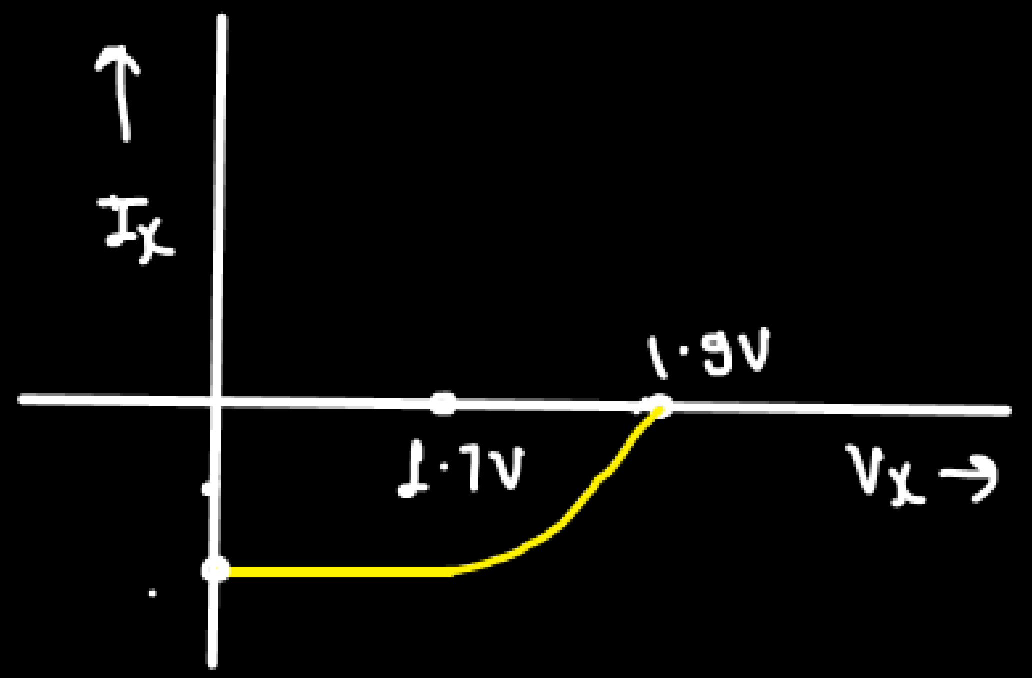
$\boxed{1.9\,V < V_x < 1.7\,V}$:-

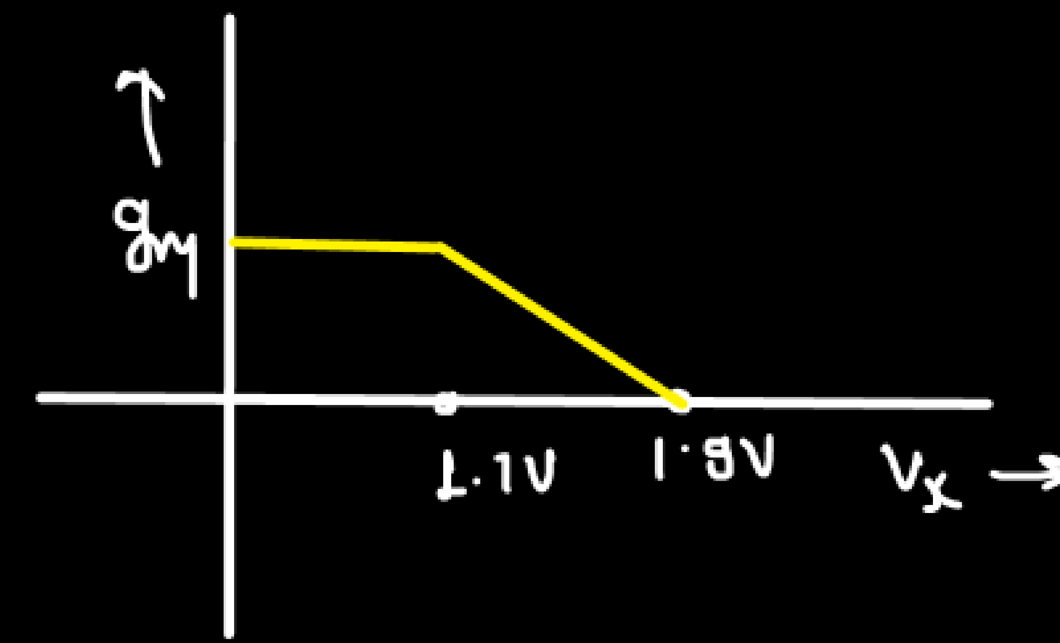
$$I_D = k''\left[(V_{SG} - V_T)V_{SD} - V_{SD}^2/2\right]$$

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

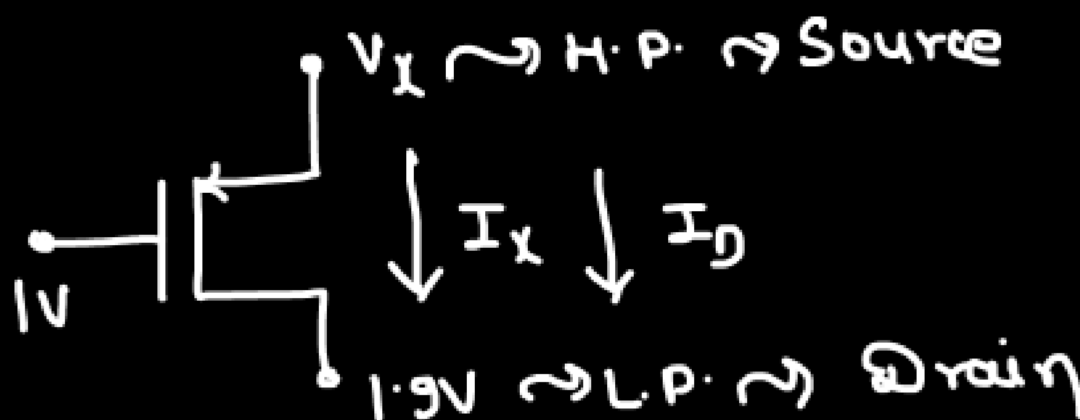
$$(g_m)_{linear} = k''' \times V_{SD}$$

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





For $\boxed{V_x > 1.9V}$



$V_{SD} = V_x - 1.9V$

$V_{SG} = V_x - 1$

$V_T = 0.7V$

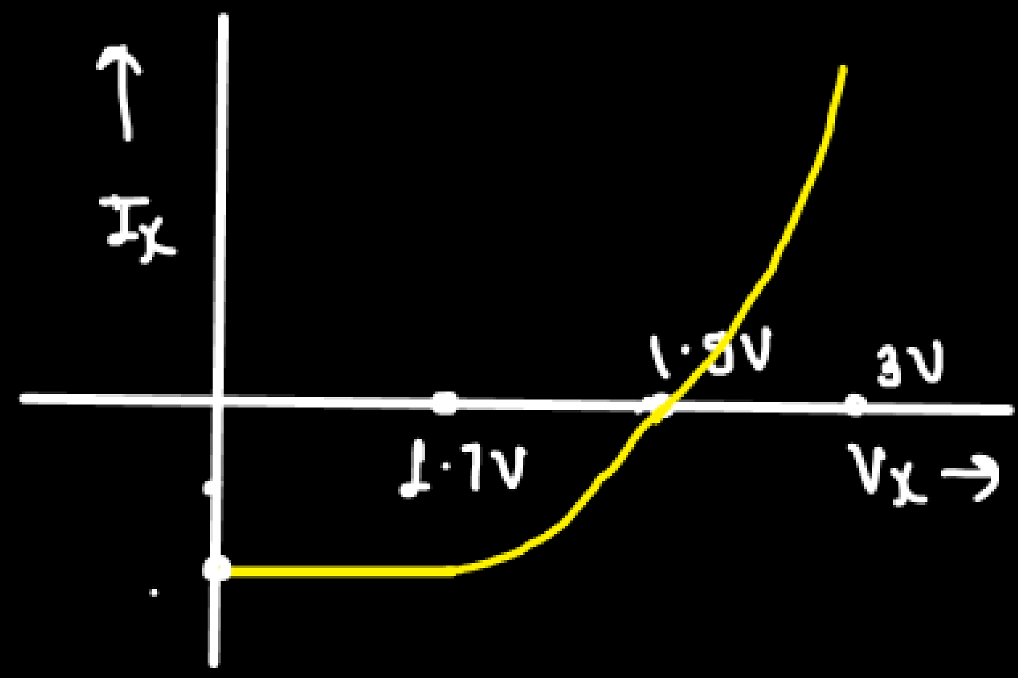
$V_{ov} = V_x - 1.7V$

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

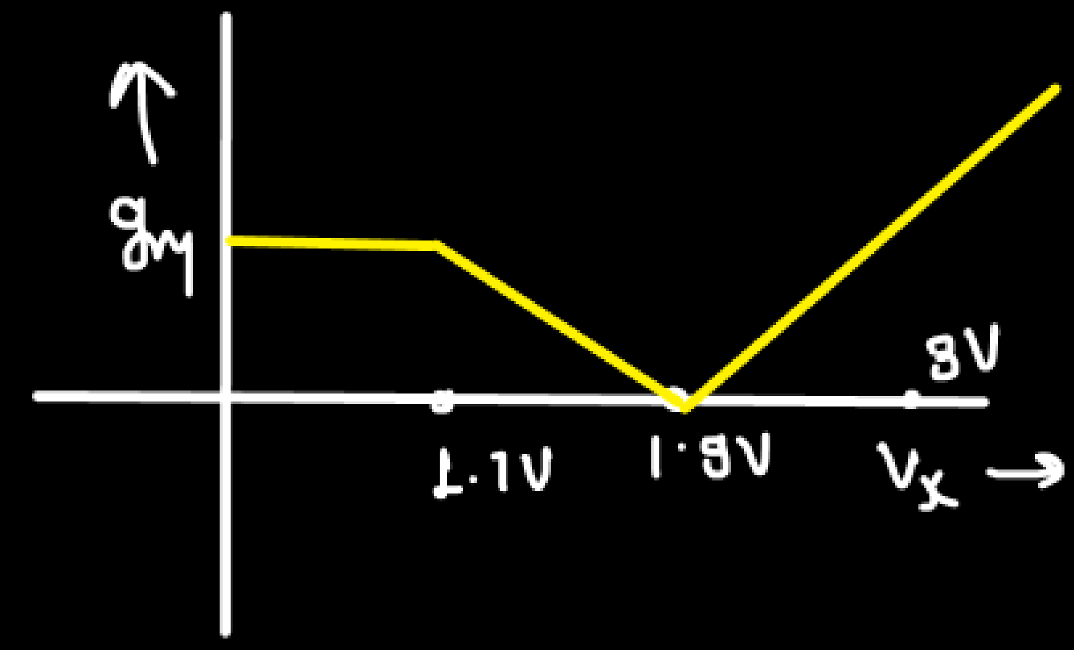
$$I_D = K\left[(V_{SG} - V_T)V_{SD} - V_{SD}^2/2\right]$$

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

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

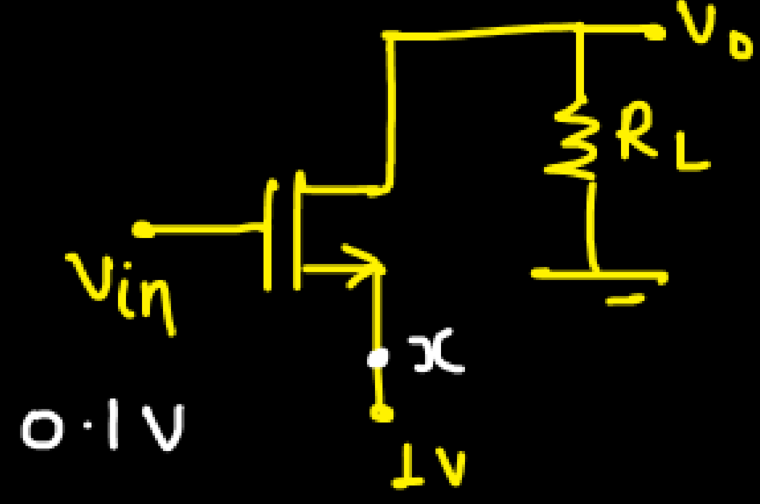


I_X
1.7V
1.8V
3V
V_X



g_m
1.7V
1.8V
3V
V_X

Q.



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

$V_T = 0.7V$

Plot V_o v/s V_{in}.

Given $R_L \to$ very low

Find max value of V_o.

→

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

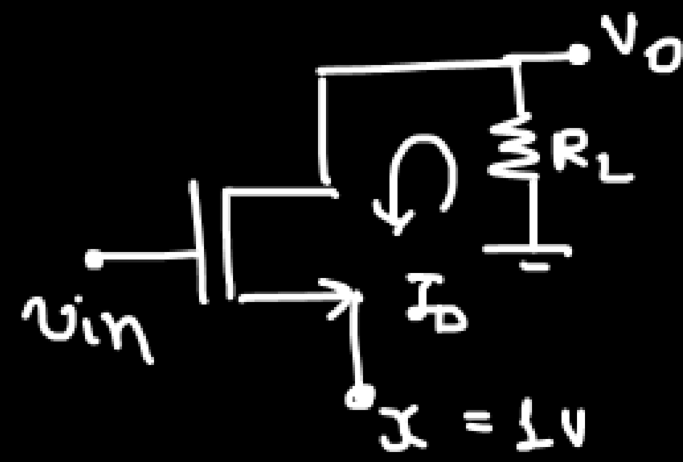
initially, MOS current = 0 Ap $\Rightarrow V_o = 0V$

$\Rightarrow V_o \to$ Source

$V_x \to$ Drain

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

$\Downarrow$



But $V_S = V_x = 1V$

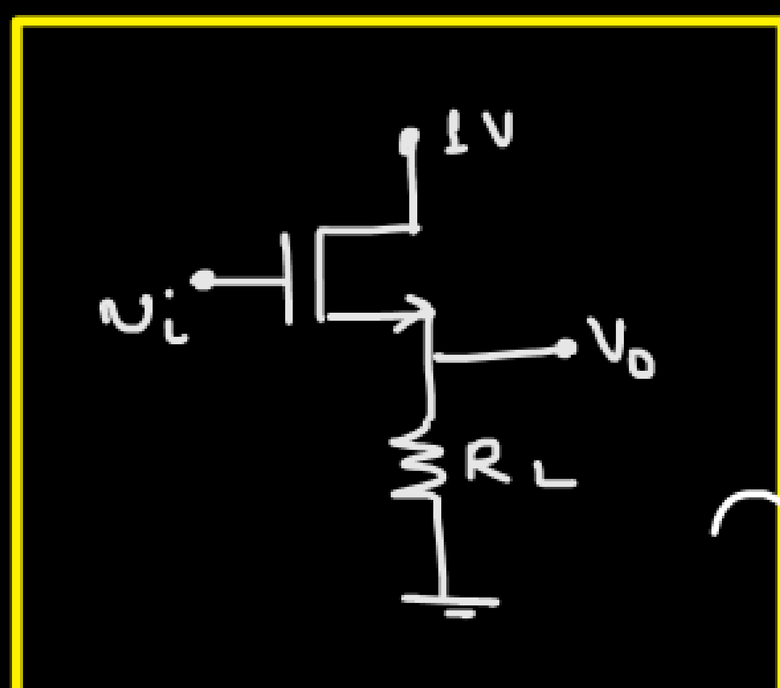
and $V_o = V_D = -ve$

$\Downarrow$

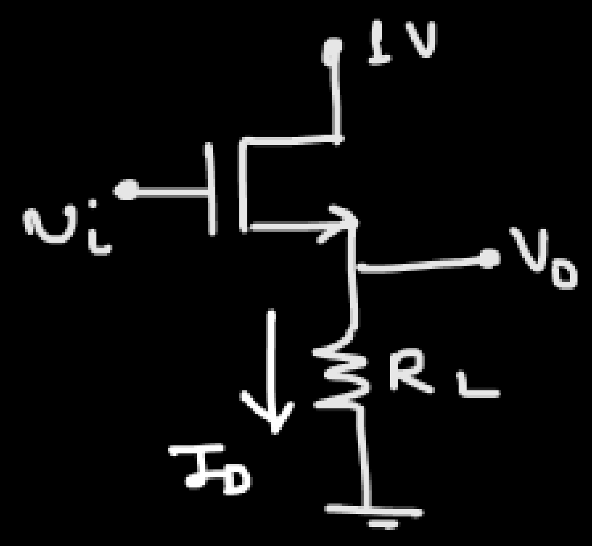
NOT POSSIBLE

$\Rightarrow$ x will always be drain

V_o will always be source



Final ckt



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

initially, $v_o = 0V$

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

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

$\Rightarrow$ MOS is ON

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

$V_o = I_D R_L =$ very small

$V_{DS} = 1 - V_o$

$V_{GS} = v_i - v_o$

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

$\Rightarrow$ for sat.

$1 - V_o > v_i - 0.7 - v_o$

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

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

for $0 < V_i < 1.7V$

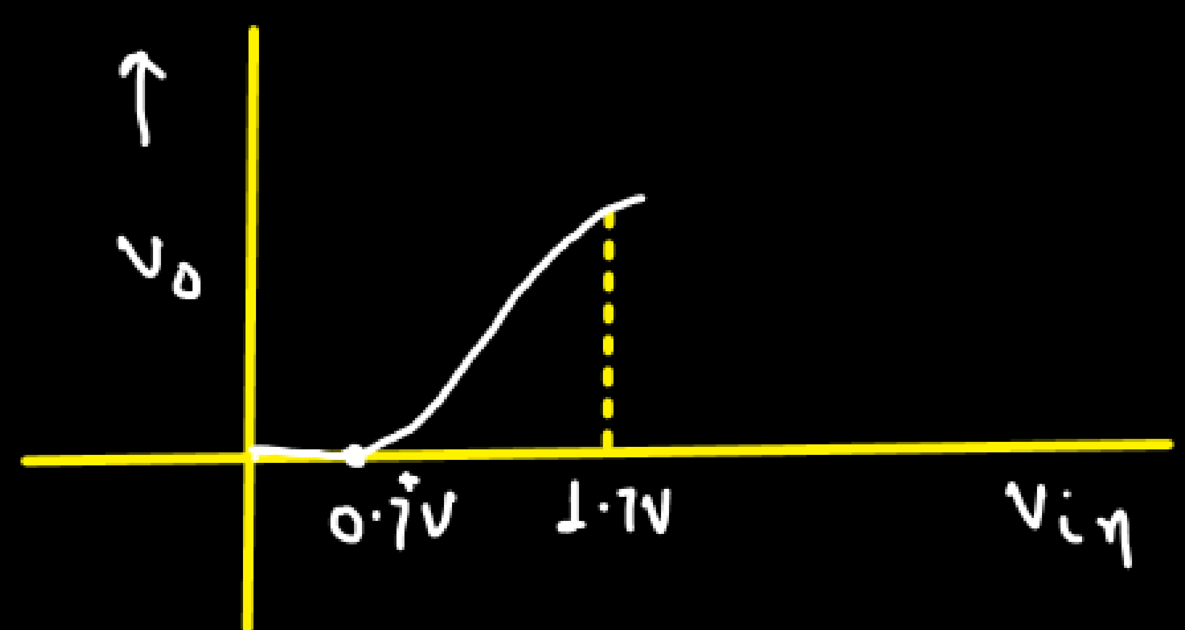
$$I_D = K[V_i - 0.7 - V_0]^2$$

$$V_0 = I_D R_L$$

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

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

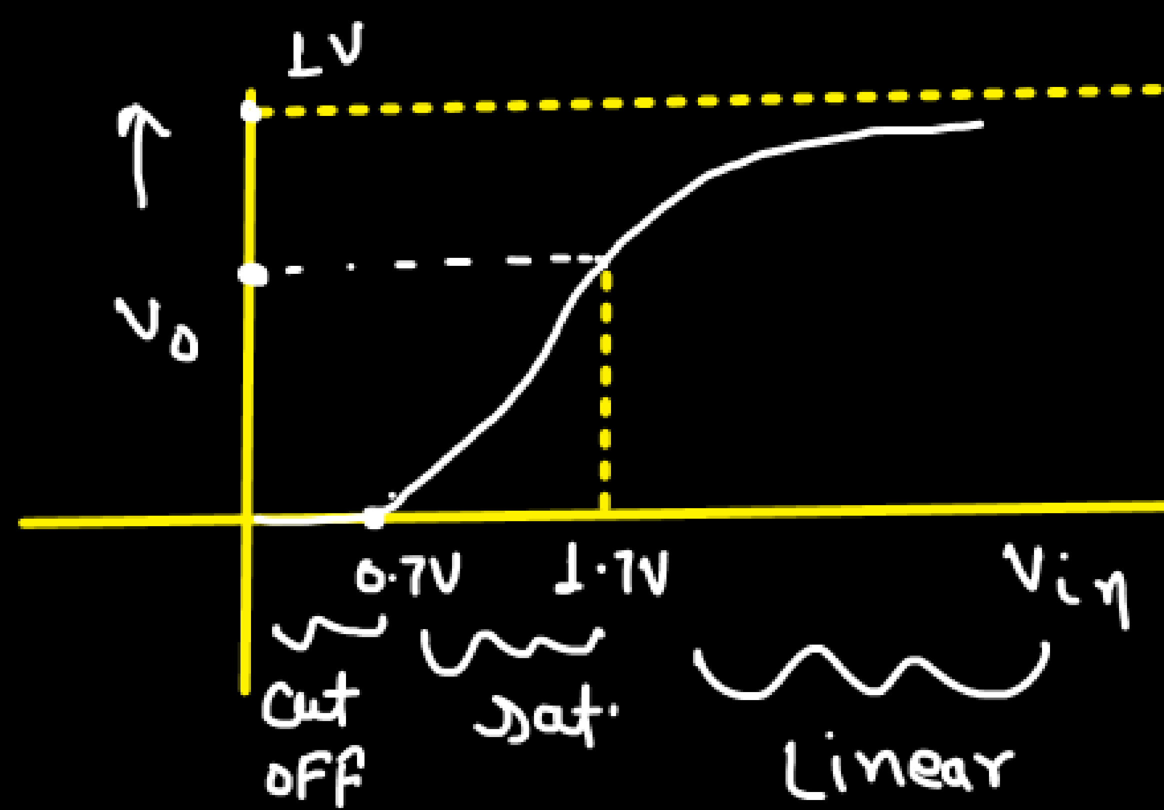
But V_0 will not increase as much as V_i.

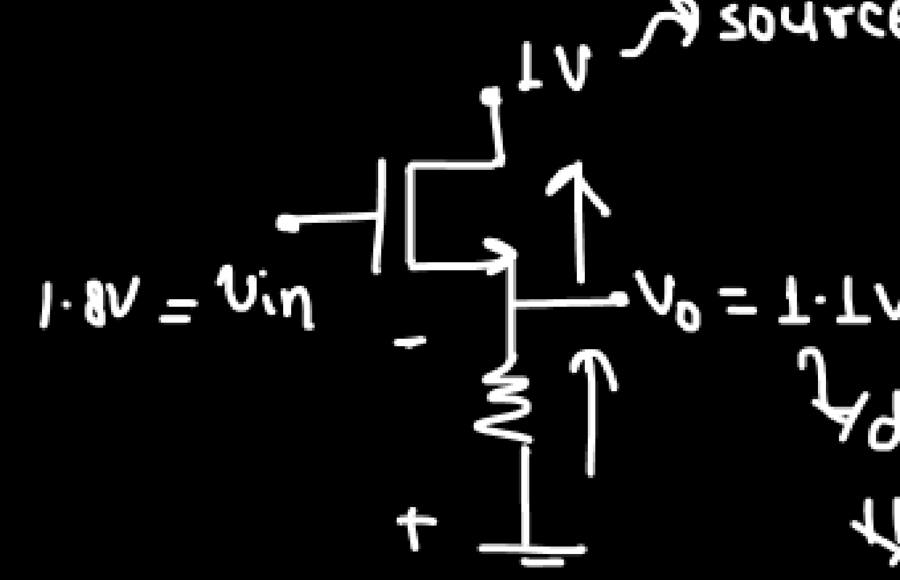


For $V_i > 1.7V \Rightarrow$ diode Triode

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

$$V_0 = I_D R_L$$





drain

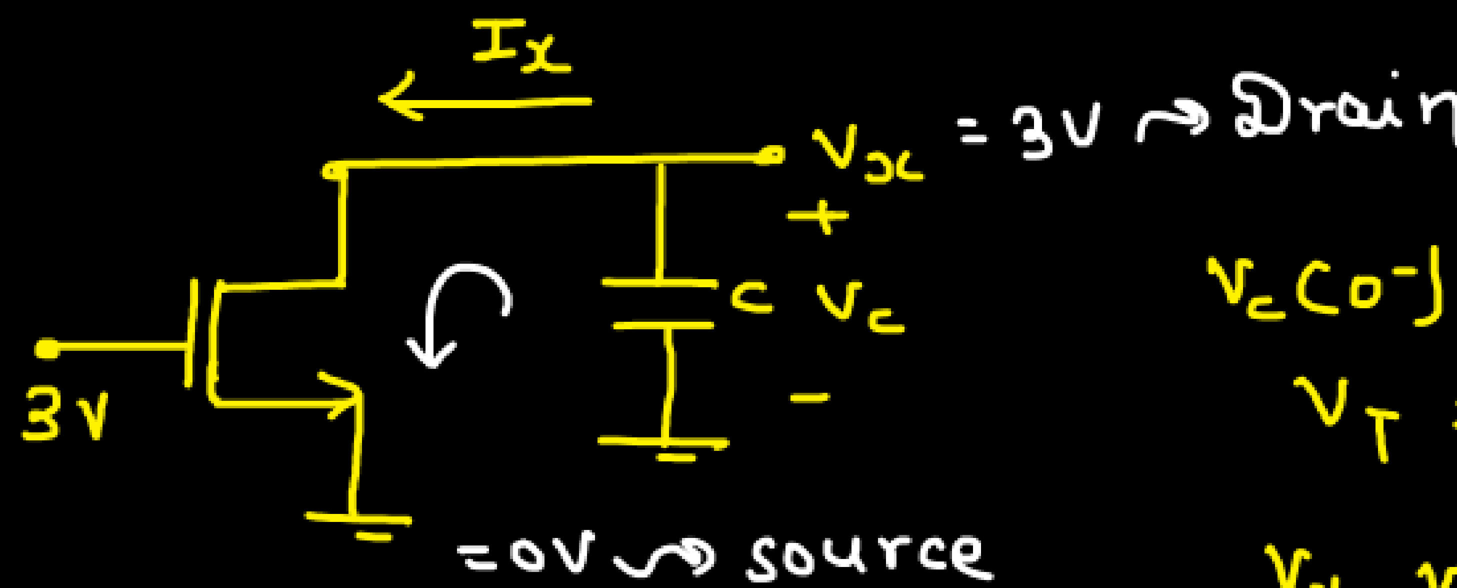
⇓

negative potential

⇓

NOT possible

Q.



$V_c(0^-) = 3V$

$V_T = 1V$

V_x v/s $t = ?$

I_x v/s $t = ?$

→ $V_{GS} = 3V$, $V_{DS} = V_x = V_c$

$V_T = 1V$

$V_{ov} = 2V$

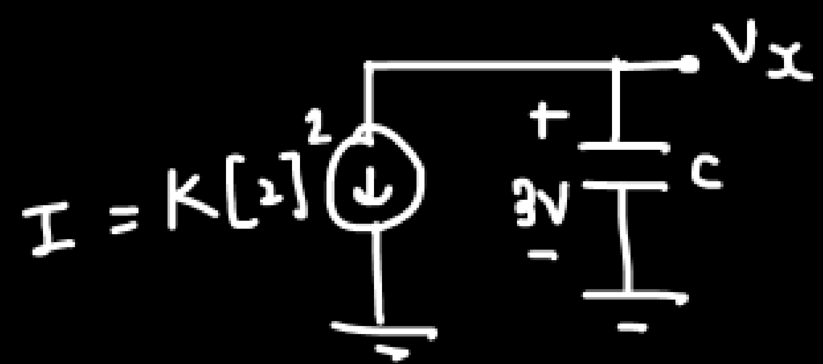
@ $t = 0^+$

$V_{DS} = 3$

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

$I_x = K[2]^2$

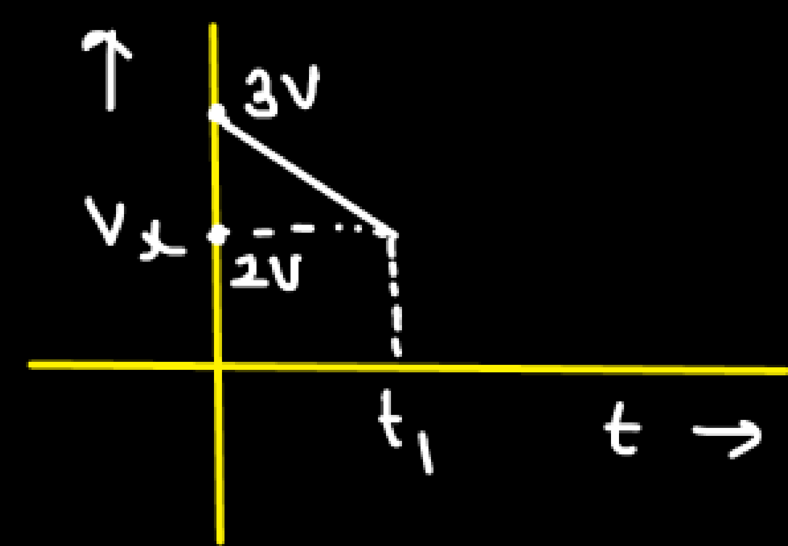
@ $t = 0^+$

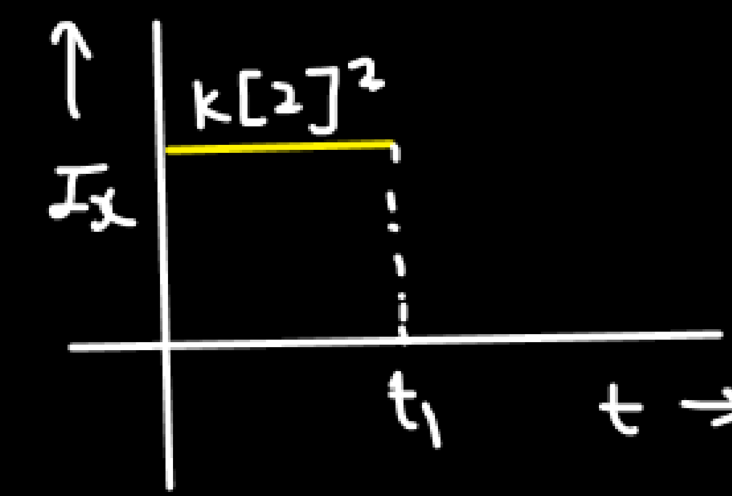


$\Rightarrow$ cap. will start discharging linearly.

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

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

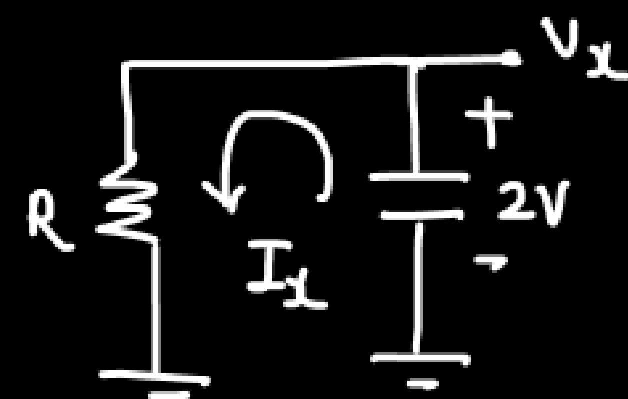


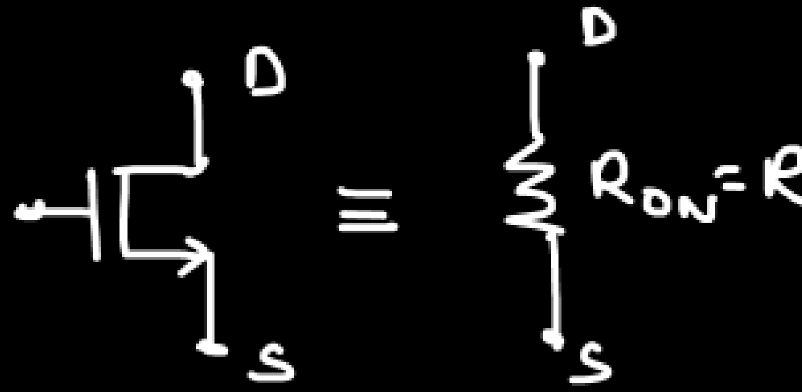


when V_{DS} or $V_x < 2$

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

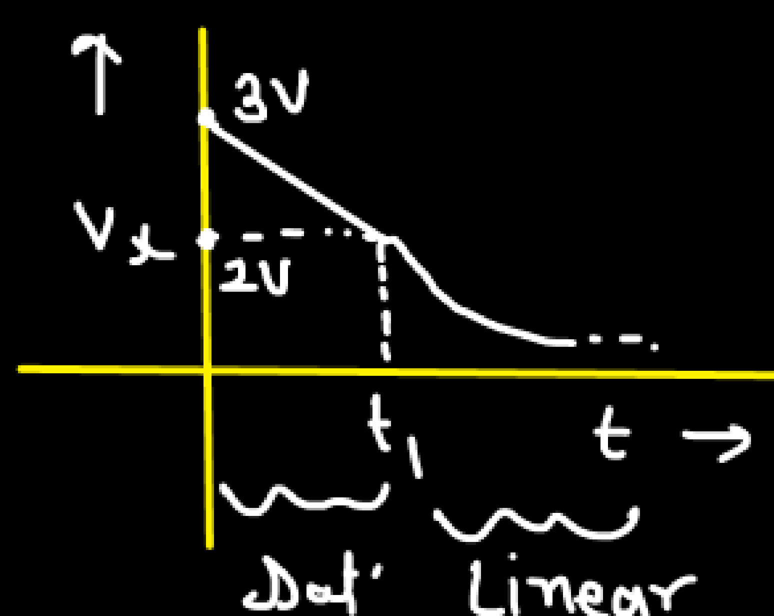
For $t > t_1 \Rightarrow$ MOS goes into linear region.

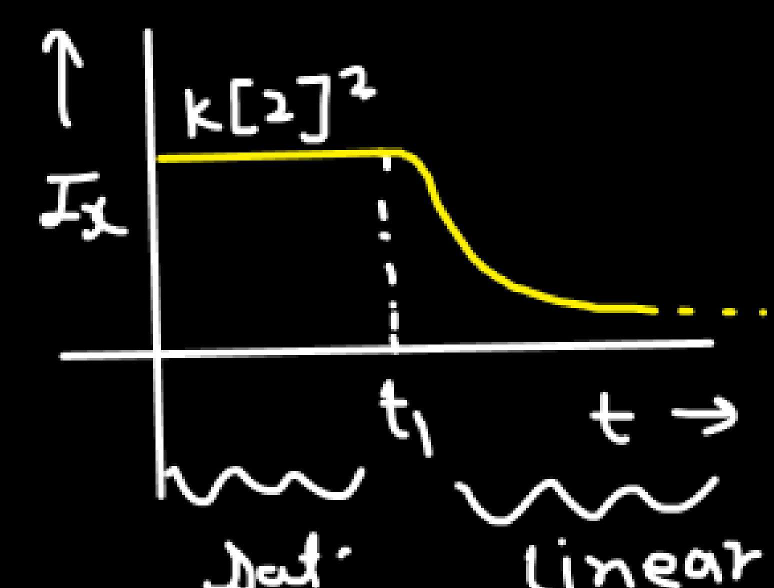




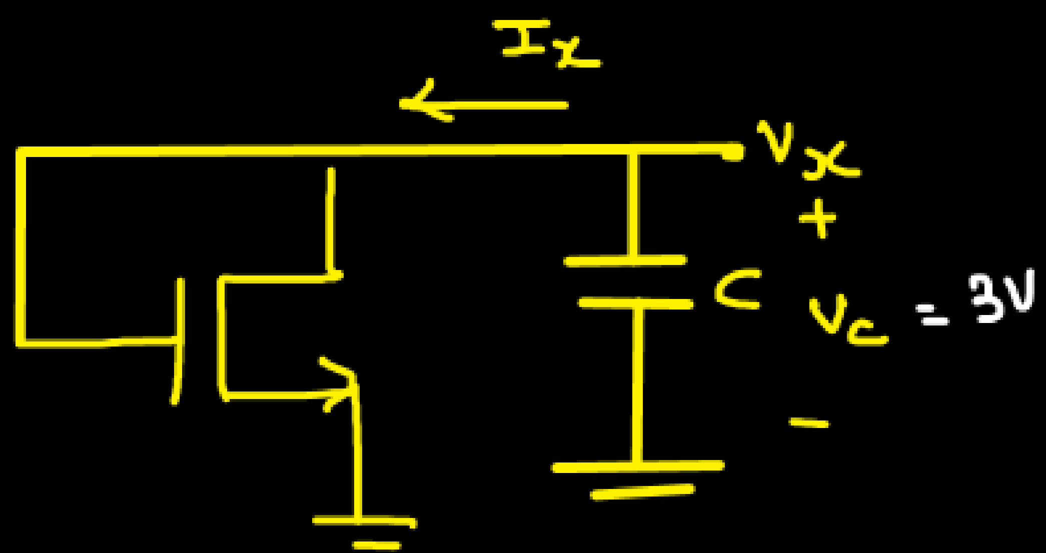
$$I_x = k\left[2 \cdot V_x - \frac{V_x^2}{2}\right]$$

$\Rightarrow$ 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

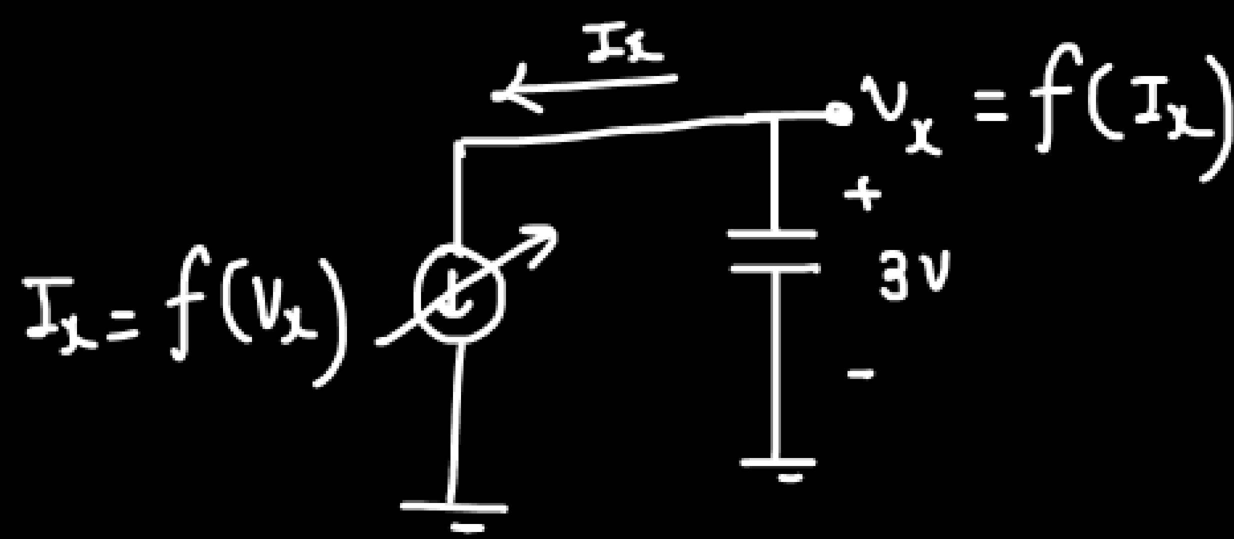
→ D and G are shorted ⇒ MOS always be in sat.

$V_{GS} = V_x$

$V_{DS} = V_x$ ⇒ sat.

$V_{OV} = V_x - 1$

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



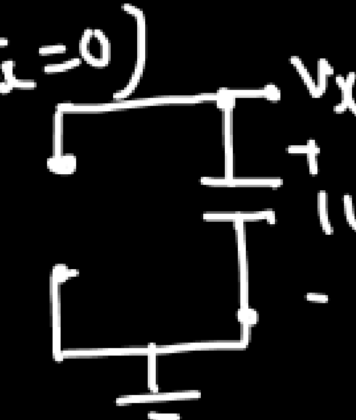
$$\boxed{V_x = 3 - \frac{1}{C}\int I_x(t)\cdot dt}$$

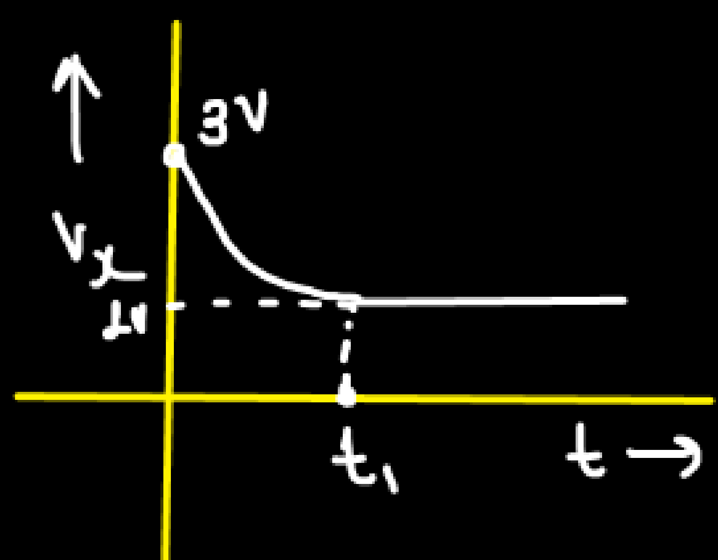
Here, V_x is going down. when $V_{GS} < V_T \Rightarrow$ MOS will be off

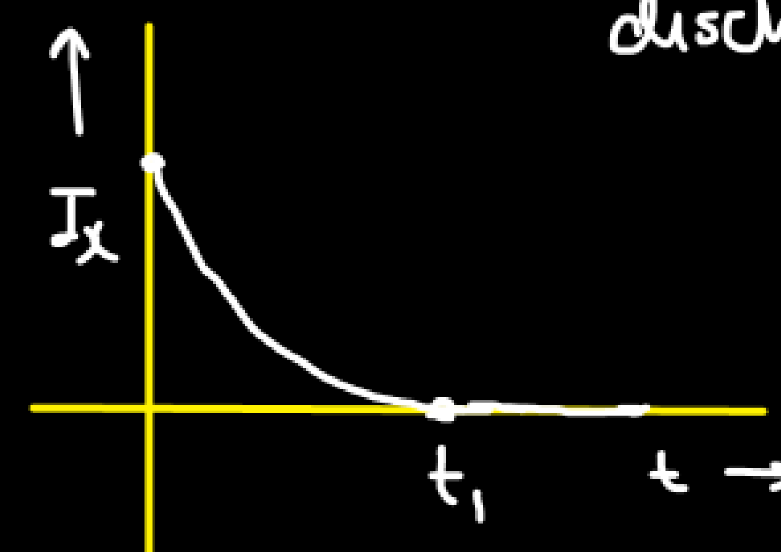
$\boxed{V_x < 1} \Rightarrow$ No current $(I_x = 0)$

$\Downarrow$

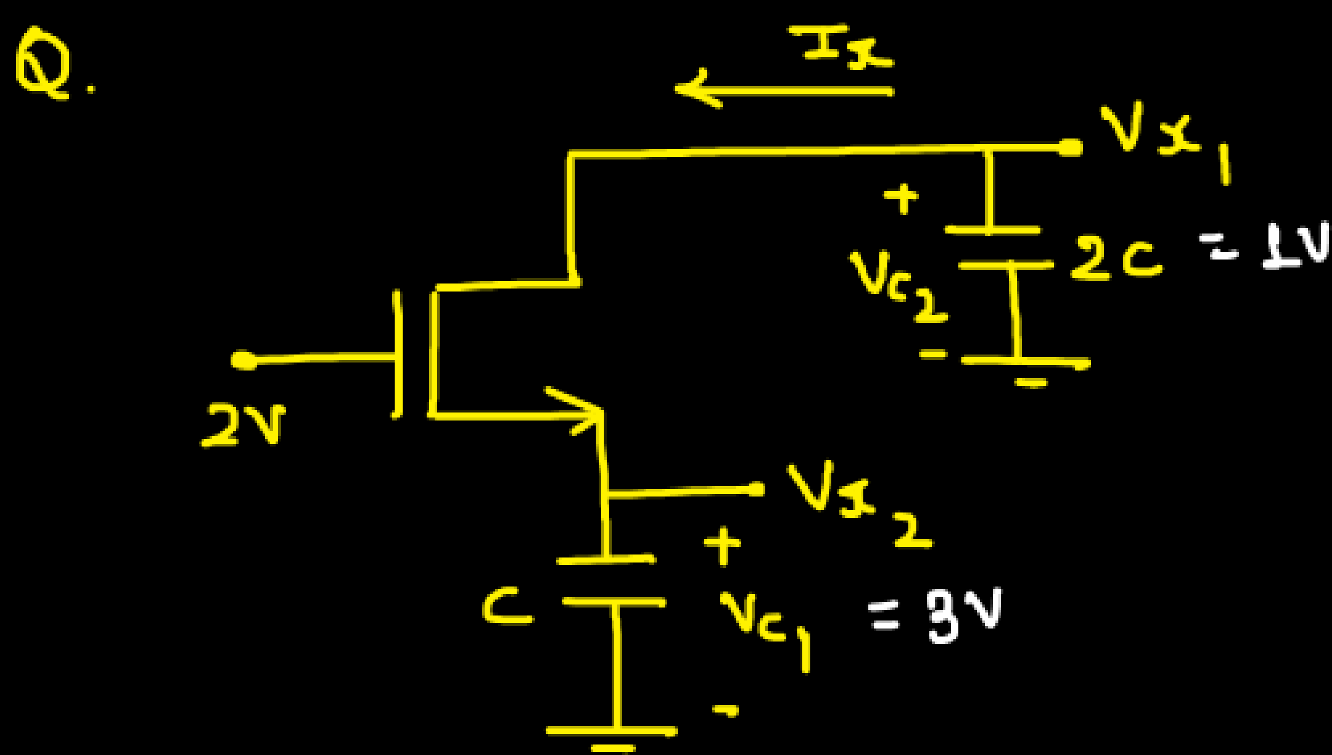
No further discharging







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 $t = ?$

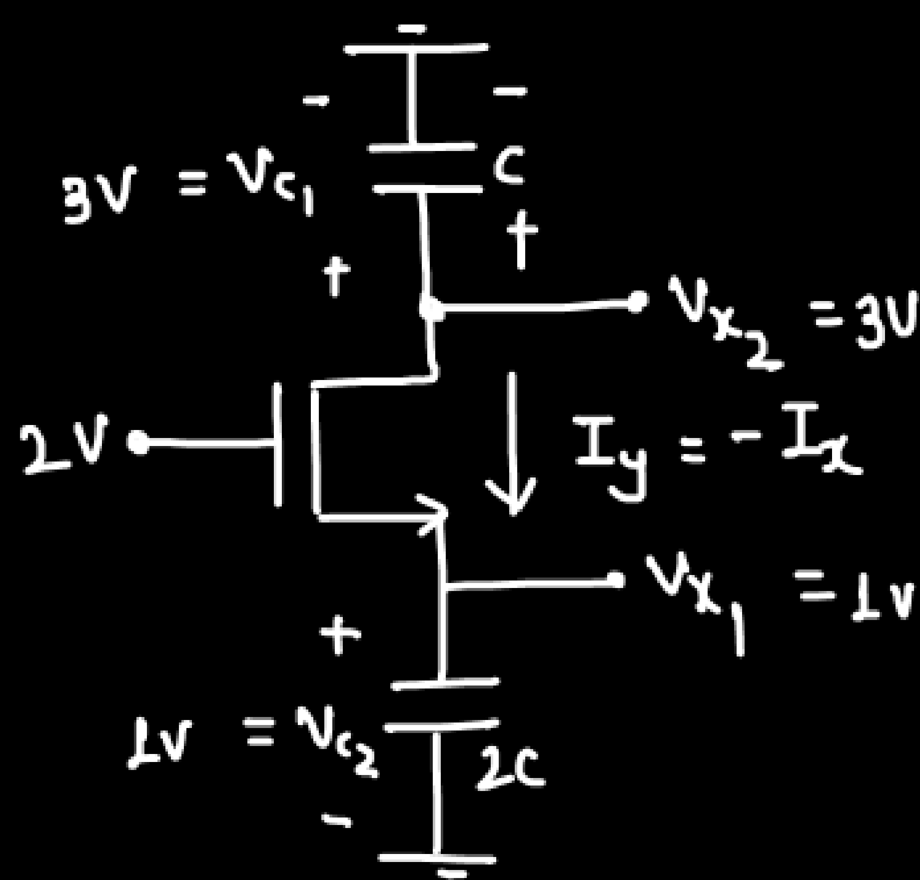
I_x v/s $t = ?$

@ $t = 0^+$

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

$\downarrow$ H.P. $\downarrow$ Drain

$\downarrow$ L.P. $\downarrow$ source



$C \rightarrow$ discharged

$2C \rightarrow$ charged

$V_{GS} = 1V$

$V_T = 0.7V$ $\Rightarrow V_{ov} = 0.3$

$V_{DS} = 2V$

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

$I_y = f(V_{x_1})$

$\Rightarrow$ Cap. 2C can charge upto 1.3V only.

Because, if 2C charges above 1.3V $\Rightarrow$ 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

$$I_C = I_{2C}$$

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

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

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

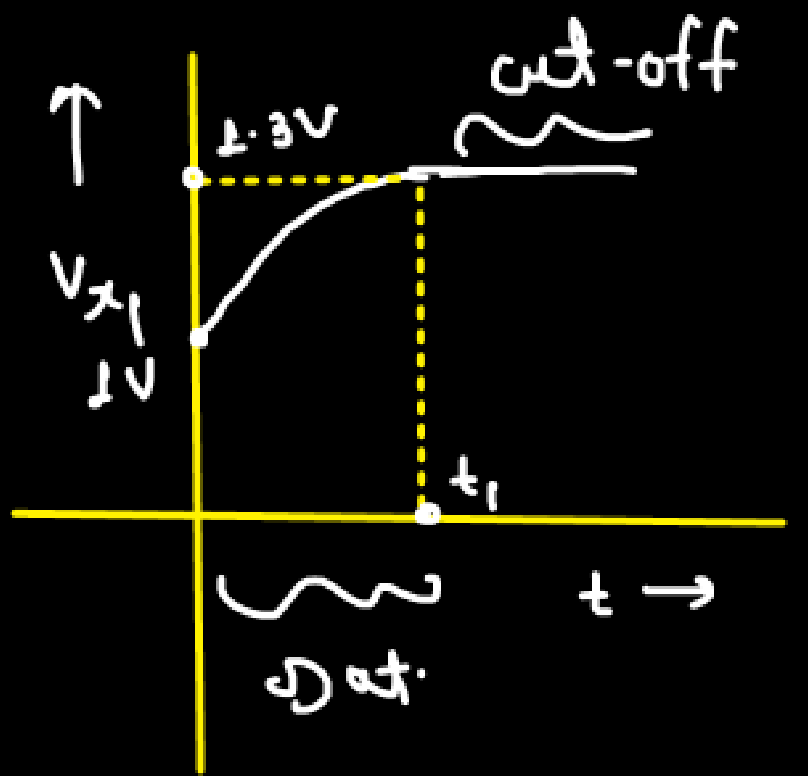
$$\boxed{\Delta V_C = 0.6V}$$

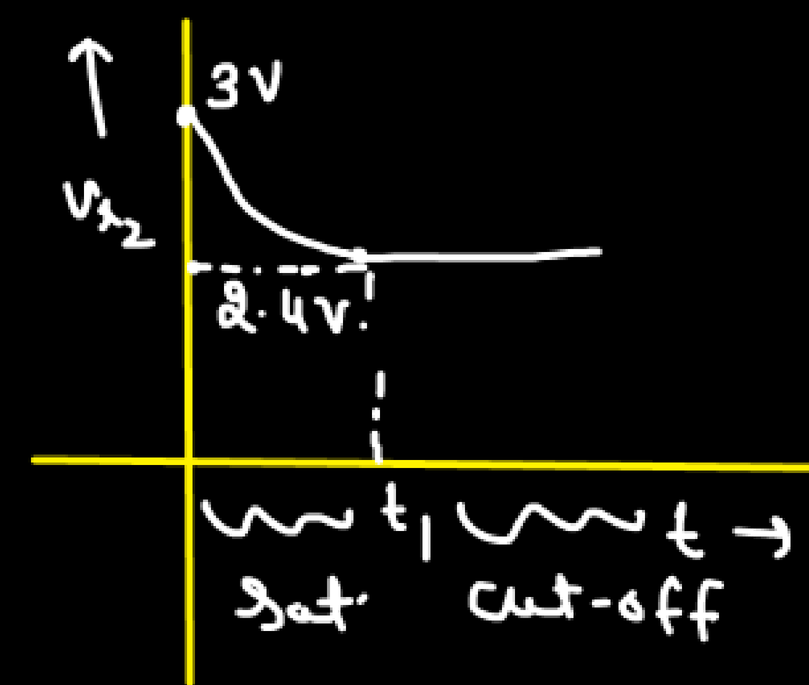
$\Rightarrow$ change in capacitor C voltage would be 0.6 V

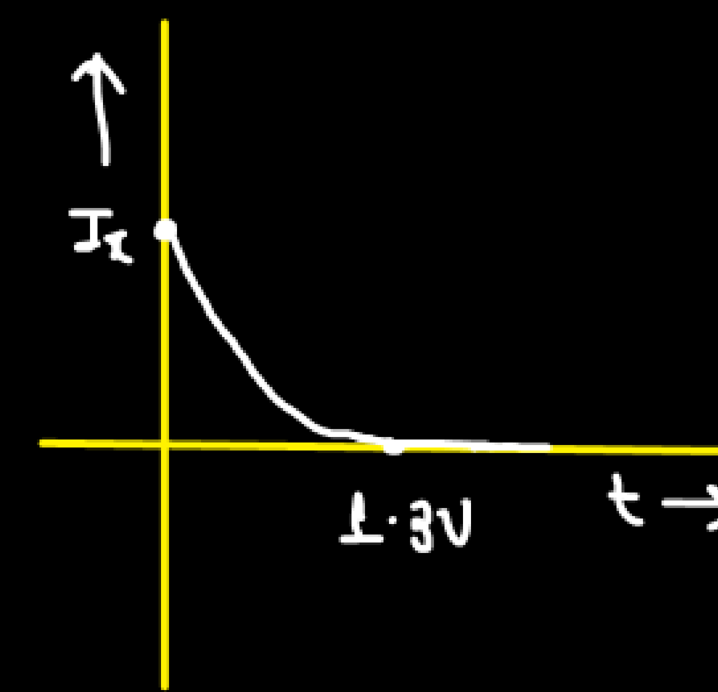
Cap. C will discharge from 3V to 2.4V

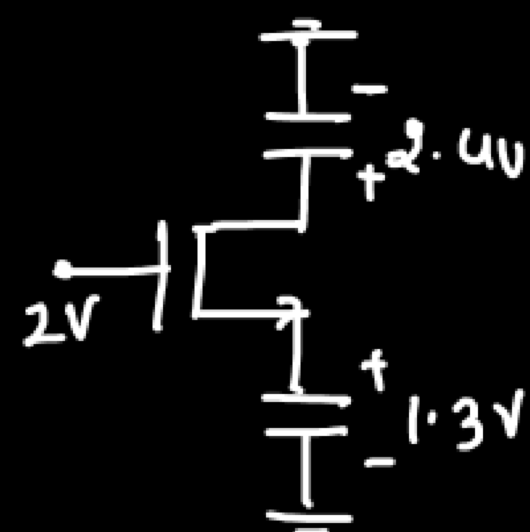
V_{x_2} will decay down from 3V to 2.4V

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





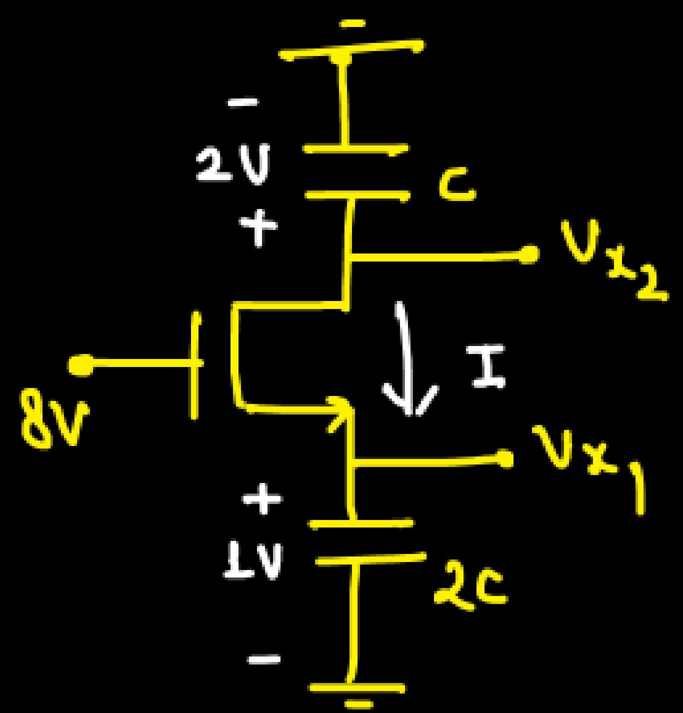




$$\left.\begin{aligned} V_{DS} &= 1.1V \\ V_{GS} &= 0.7V \\ V_{OV} &= 0 \end{aligned}\right\} \Rightarrow \text{sat.}$$

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

Q.



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

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

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

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

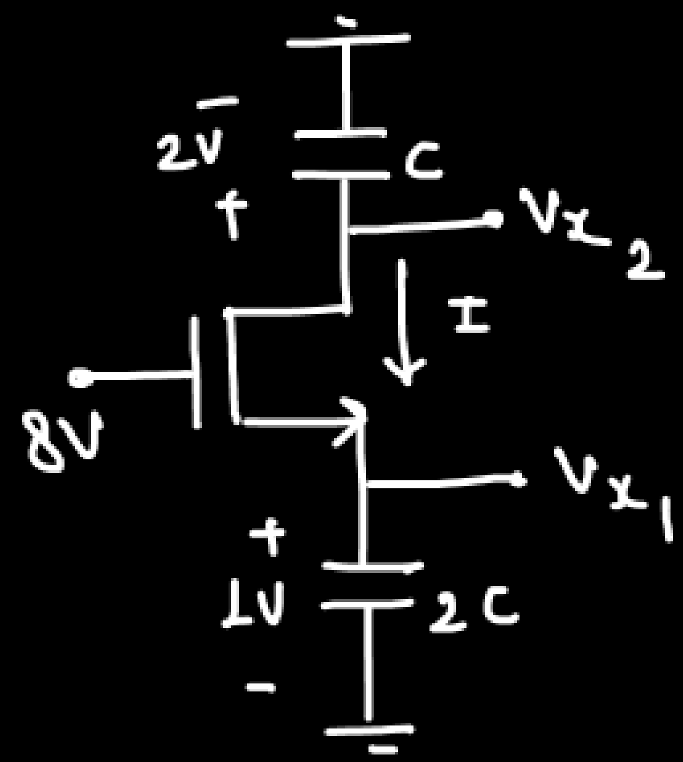
$2C(6V) = C(\Delta V_c)$

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

c is discharging

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

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



$C \rightarrow$ discharging

$2C \rightarrow$ charging

$$I_{2C} = I_C$$

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

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

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

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

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

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

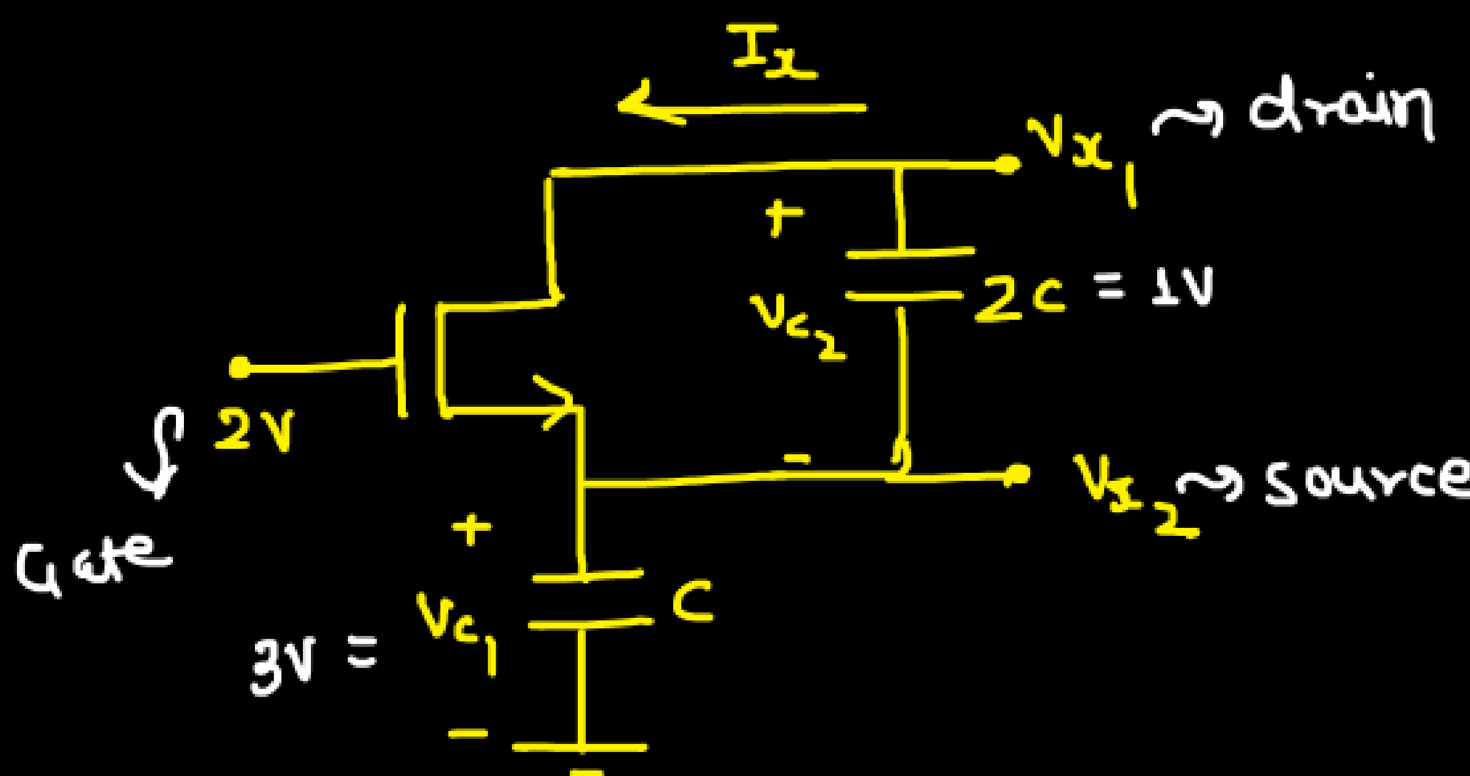
$$2 - 2x = 1 + x$$

$$\boxed{x = 1/3 \, V}$$

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

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

Q.



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

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

V_{x_1} v/s t = ?

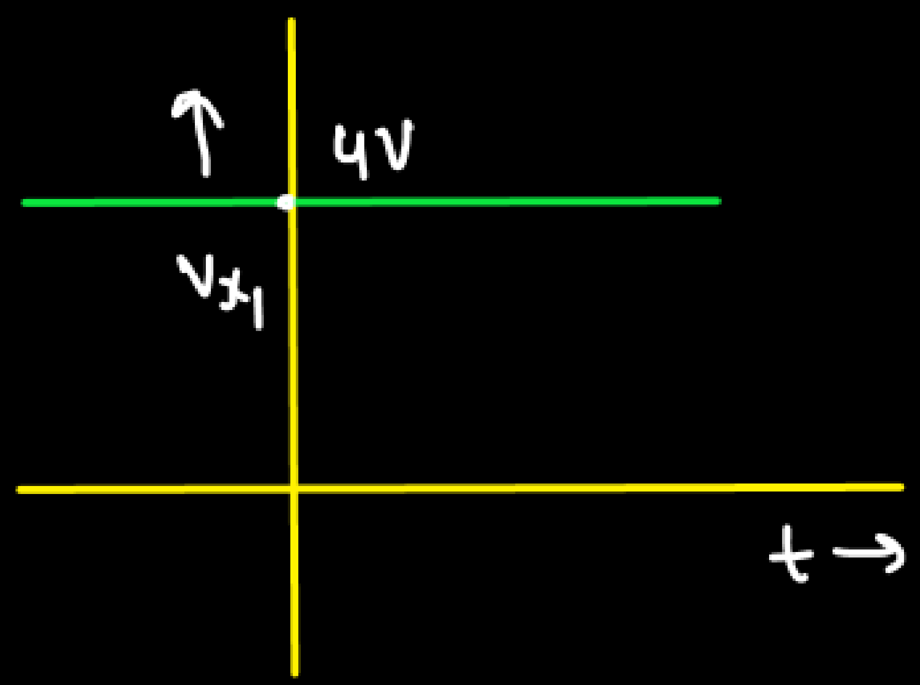
V_{x_2} v/s t = ?

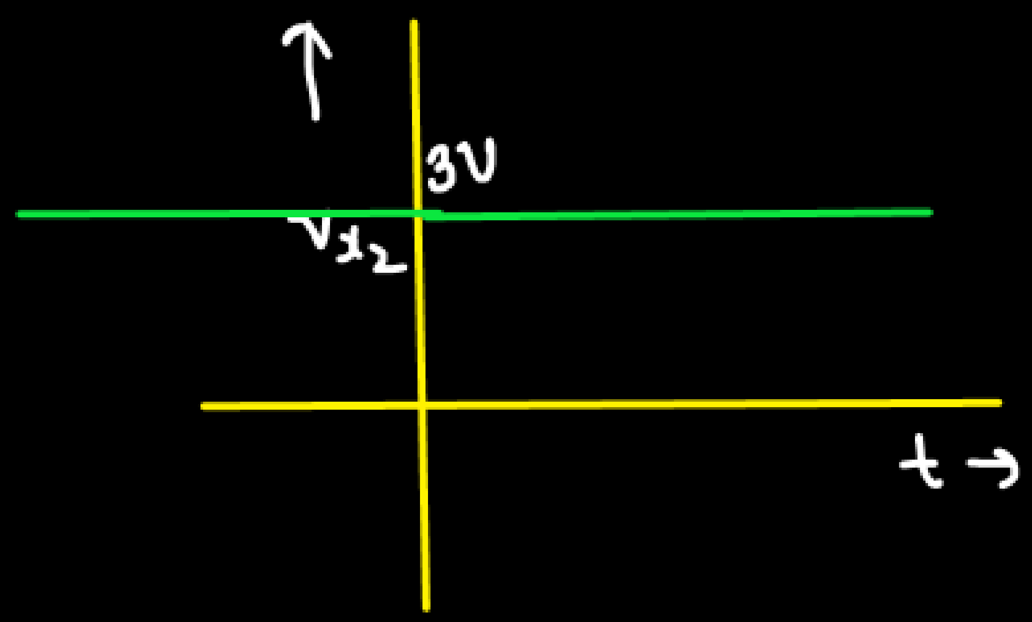
I_x v/s t = ?

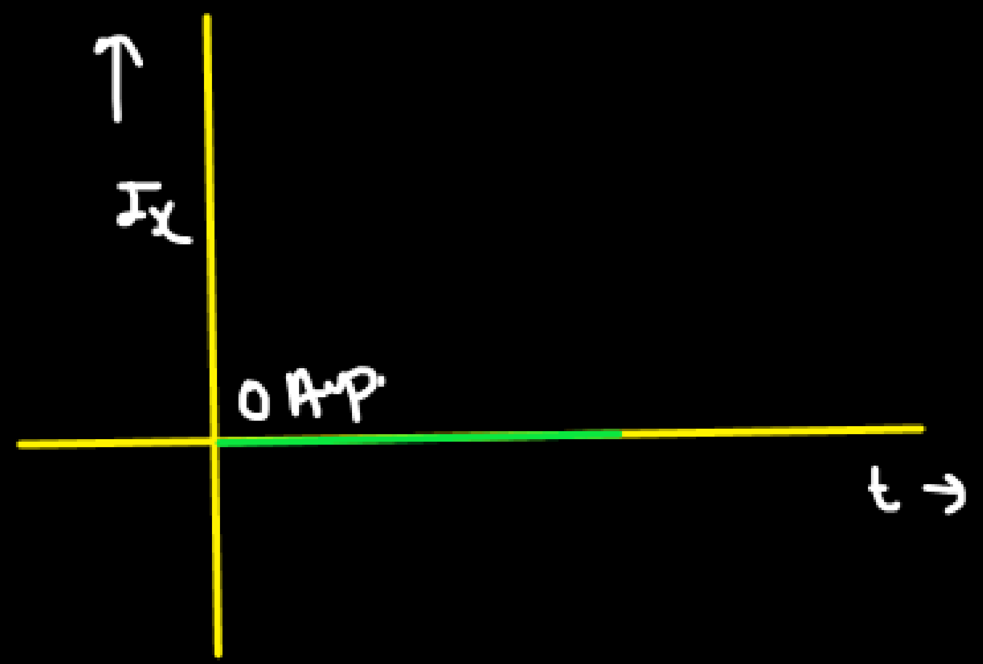
$V_{x_1}(t=0^+) = 4V$ ~> Drain

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

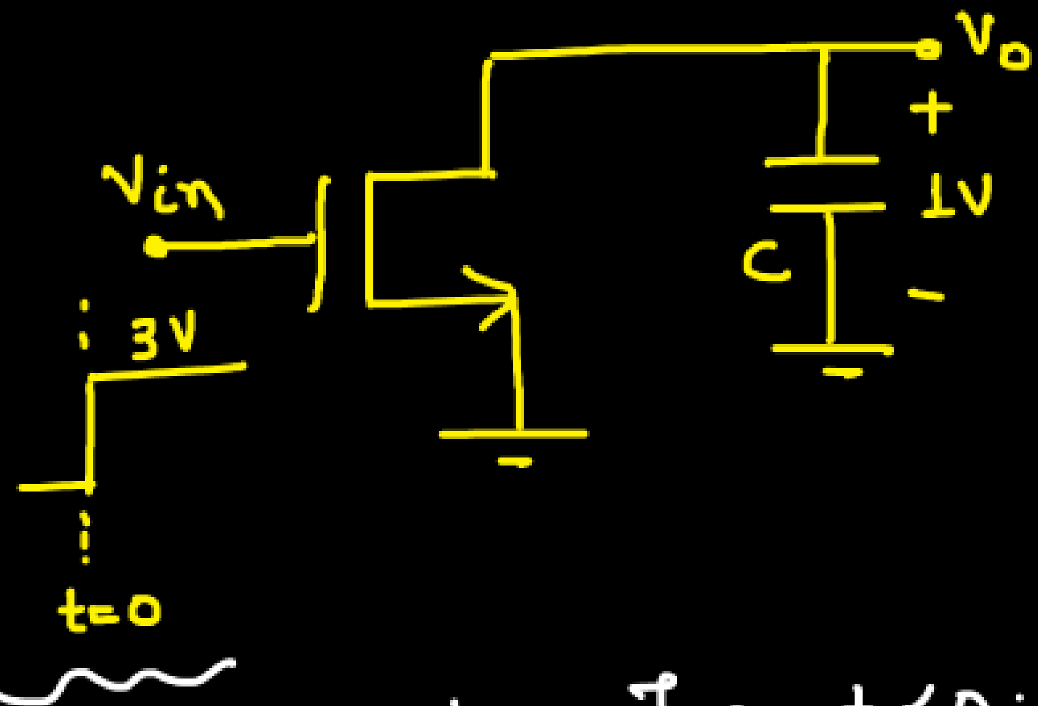
$V_{GS} = 2-3 = -1V < V_T \Rightarrow$ MOS doesn't even turn ON $\Rightarrow I_x = 0 \Rightarrow$ S.S.


4V
V_{x_1}
t →


3V
V_{x_2}
t →


I_x
0 A.P.
t →

Q.



step

V_o v/s t = ?

$V_T = 1V$

↳ for $t<0$:-

$V_{in} = 0V$

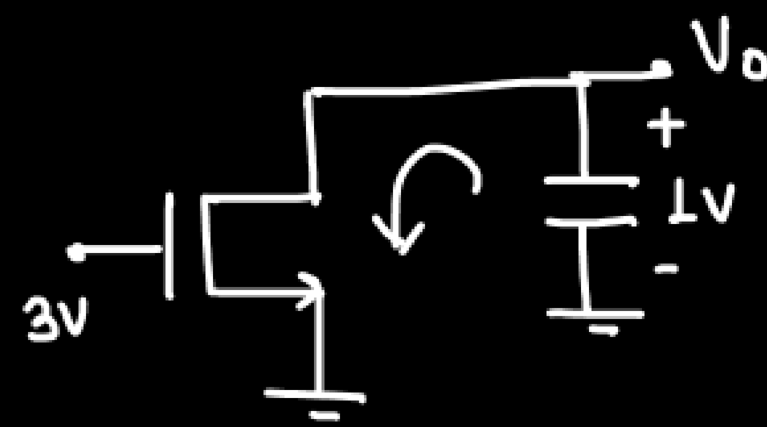
$V_{GS} = 0V$ ⇒ NO current

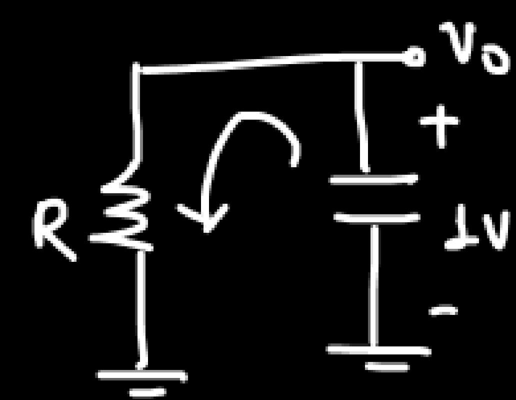
$V_o(t=0^-) = V_c(t=0^-) = 1V$

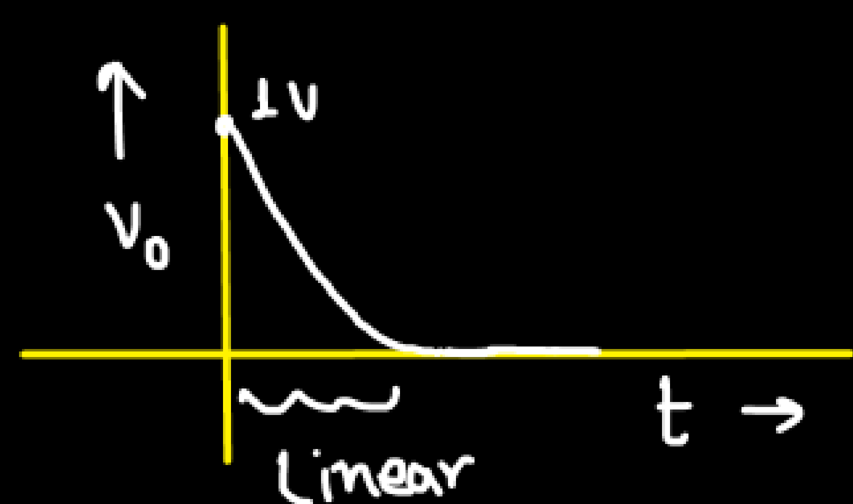
for $t>0$:-

@ $t=0^+$

$V_{in} = 3V$







@ $t = 0^+$

$V_{DS} = V_o = 1V$

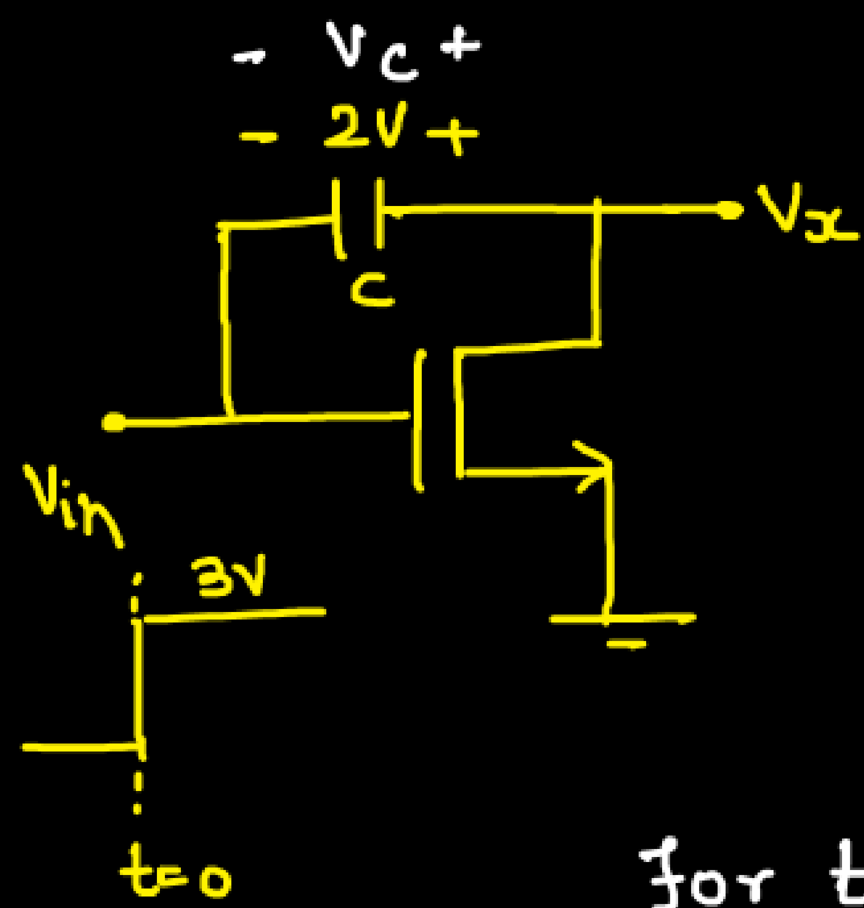
$V_{GS} = 3V$

$V_T = 1V$

$V_{ov} = 2V$

$\Rightarrow$ linear region

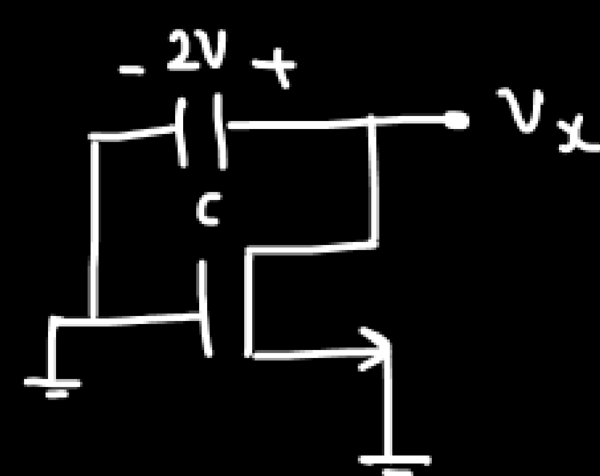
Q.



$V_T = 1V$

V_x v/s t = ?

for t<0:-



$V_{GS} = 0V$

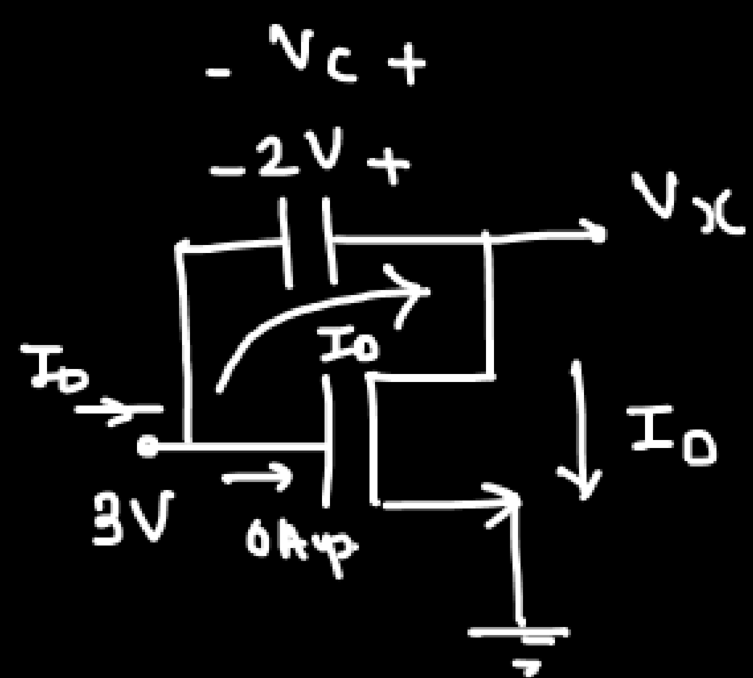
$\Rightarrow I_D = 0$

S.S.

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

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

For $t>0$



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

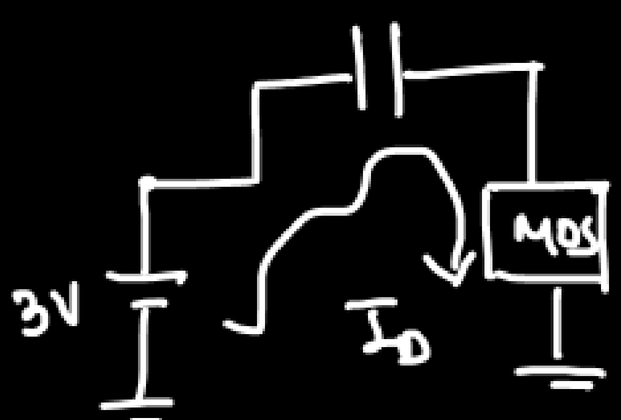
$V_{GS} = 3V$, $V_T = 1V \Rightarrow$ ON

$V_{DS} = 5V$

$V_{OV} = 2V$

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

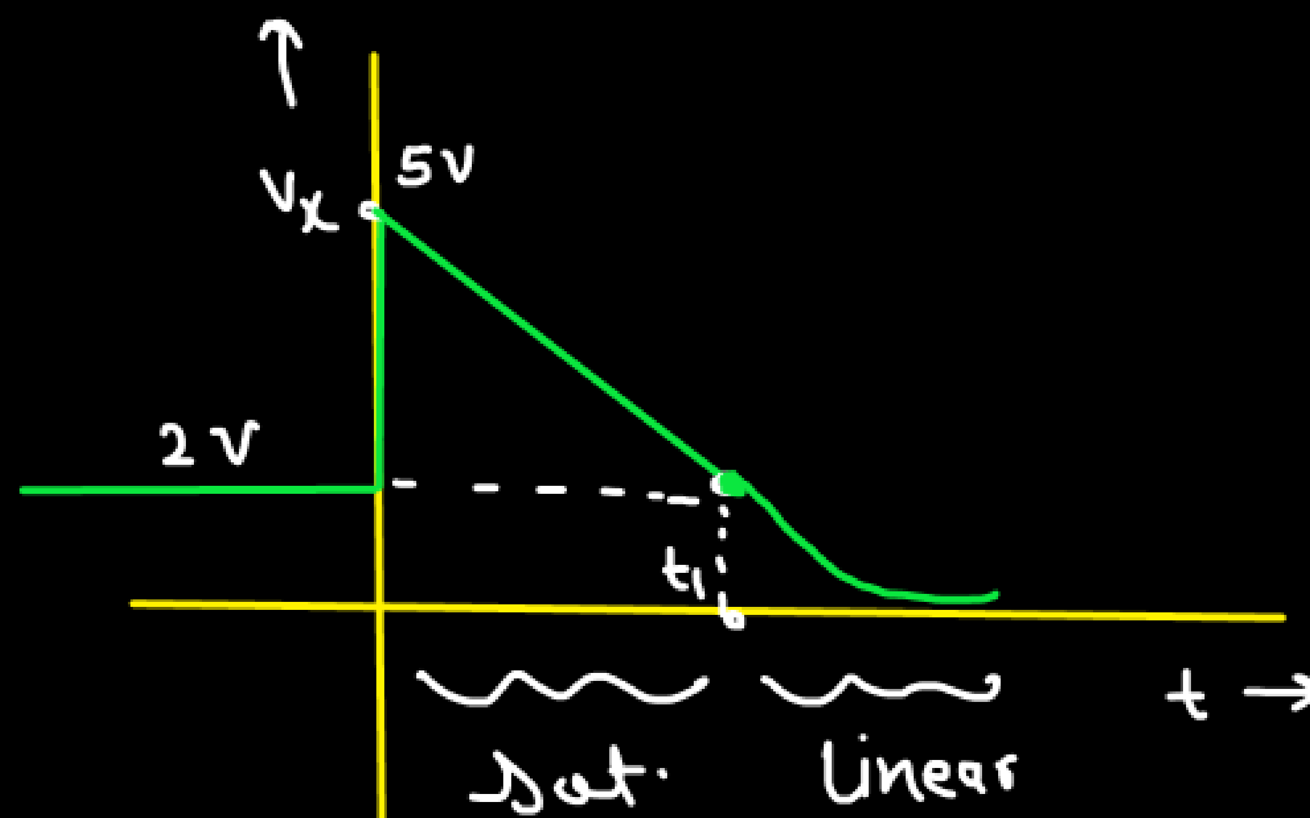
$$V_c = 2 - \frac{1}{C}\int I \cdot dt$$

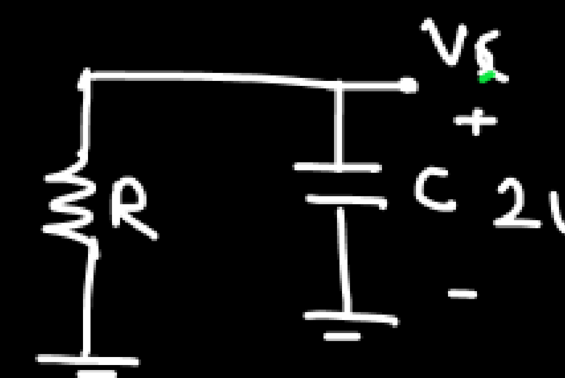
$$\boxed{V_c = 2 - \frac{I}{C}t}$$

$$V_{DS} = V_x$$

$$V_{ov} = 2$$

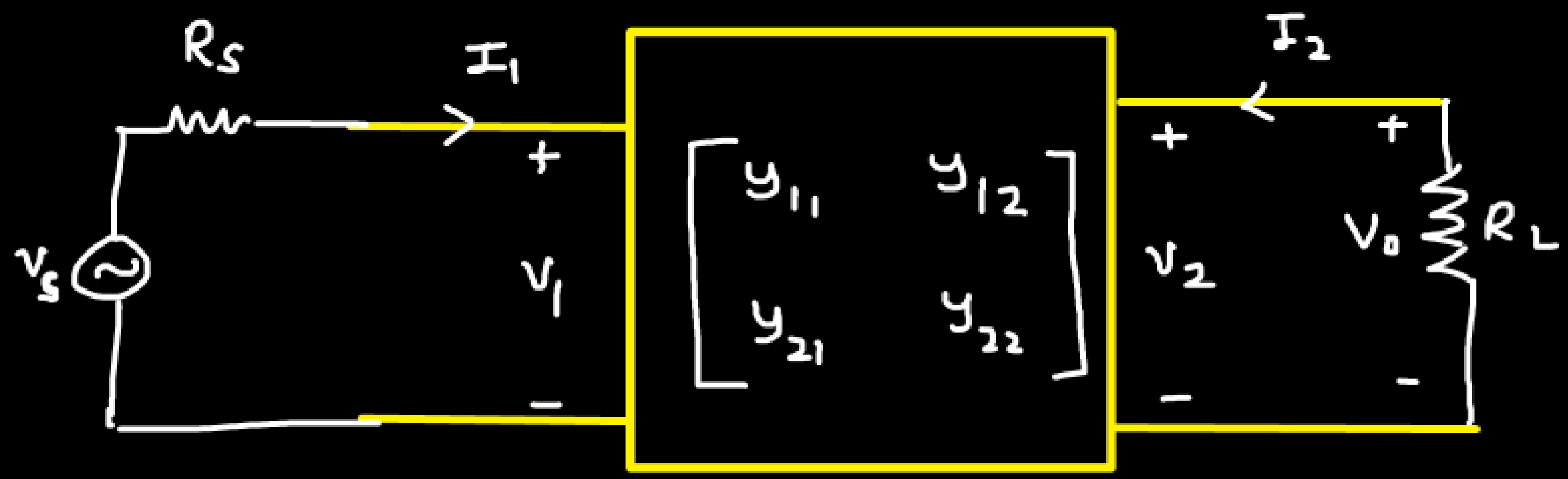
$V_x < 2V \Rightarrow$ linear region





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

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

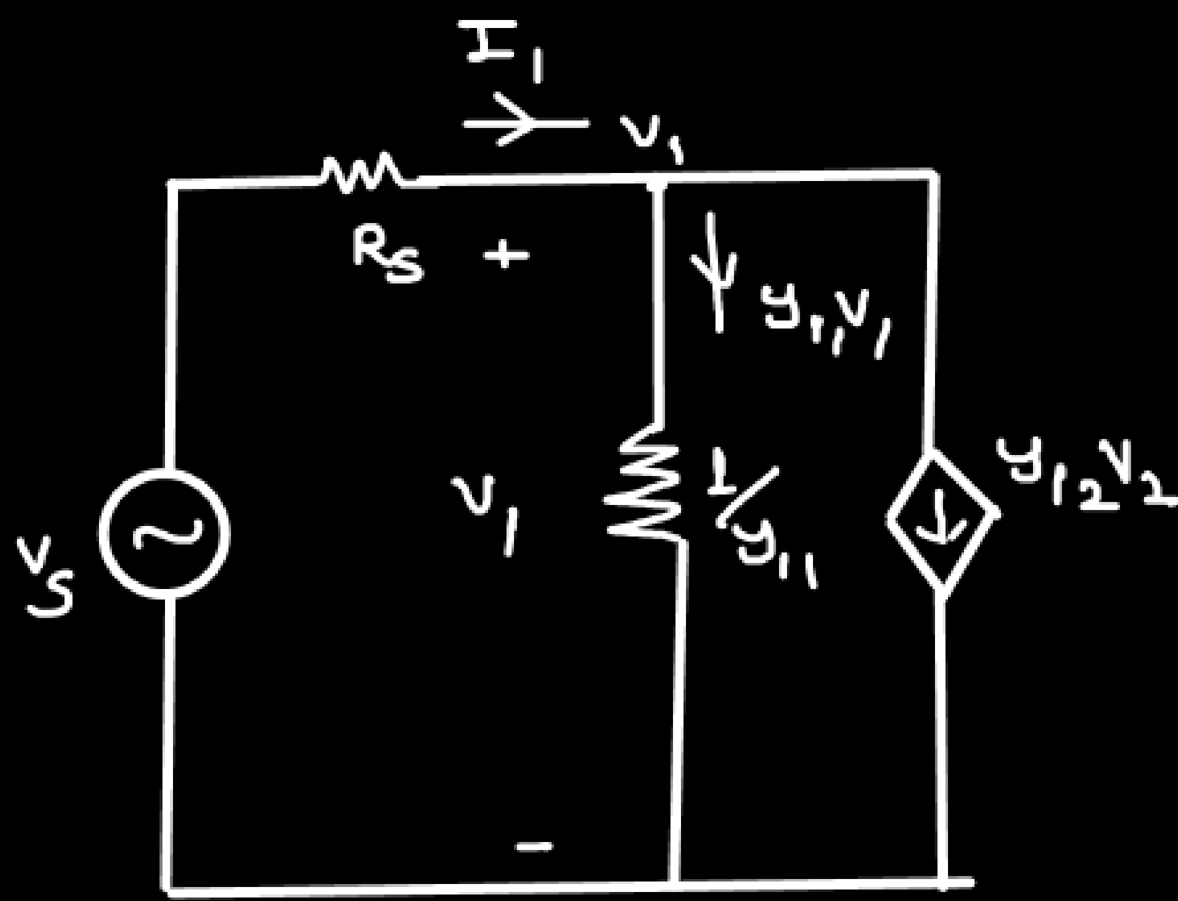


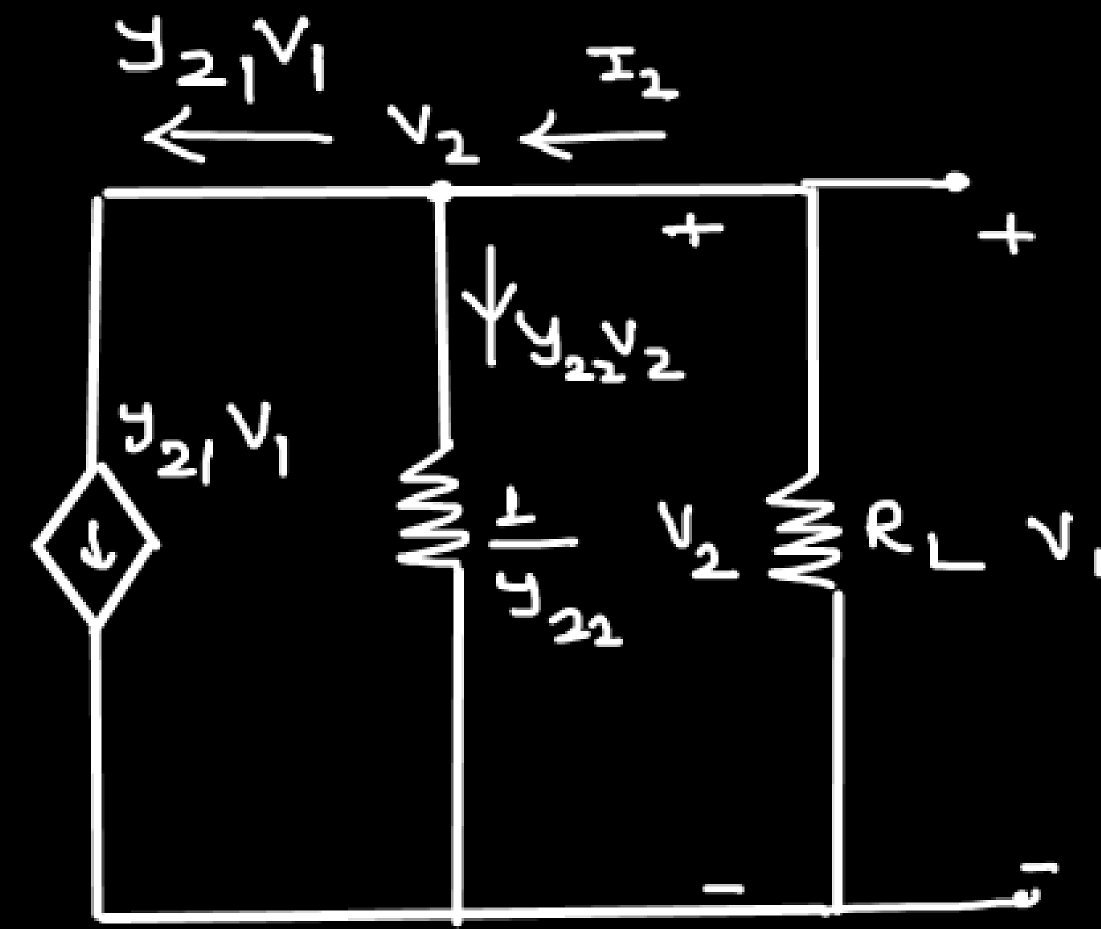
$\dfrac{V_0}{V_S} \rightarrow$ maximize

→

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

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



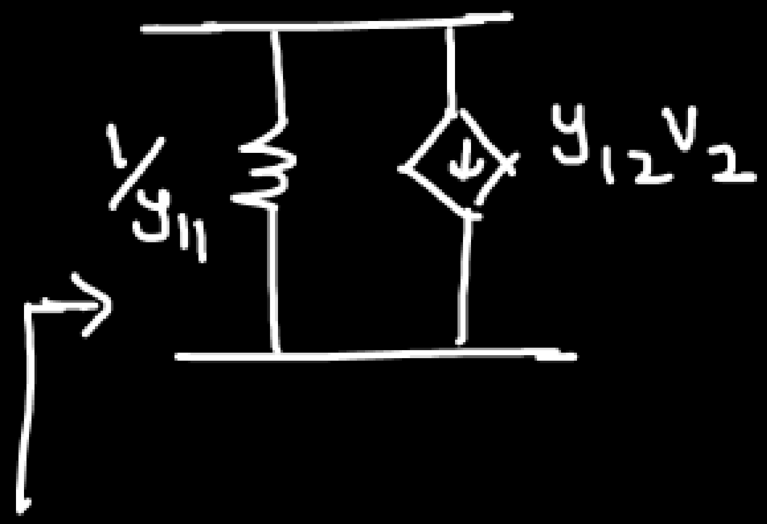


$$\frac{V_0}{V_s} \rightarrow \text{maximize}$$

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

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

1. maximize V_1



$R = \infty$

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 $y_{22}V_2$

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

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

$$V_1 = V_S$$

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

**

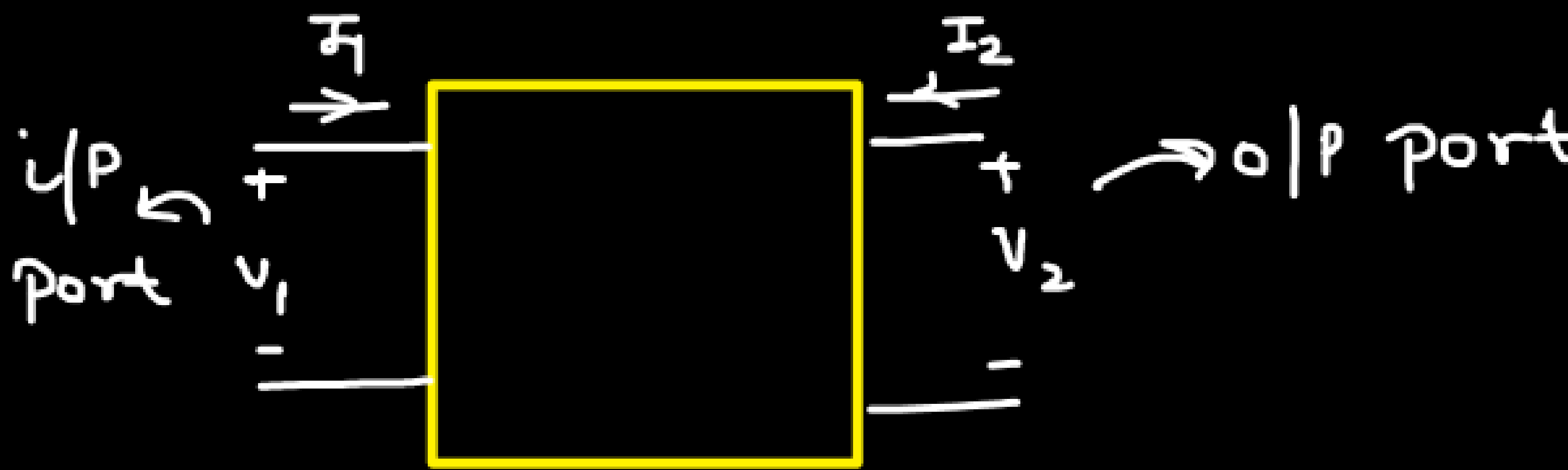
To have max^m gain $\boxed{y_{21} = \text{max}^m}$

*

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

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

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



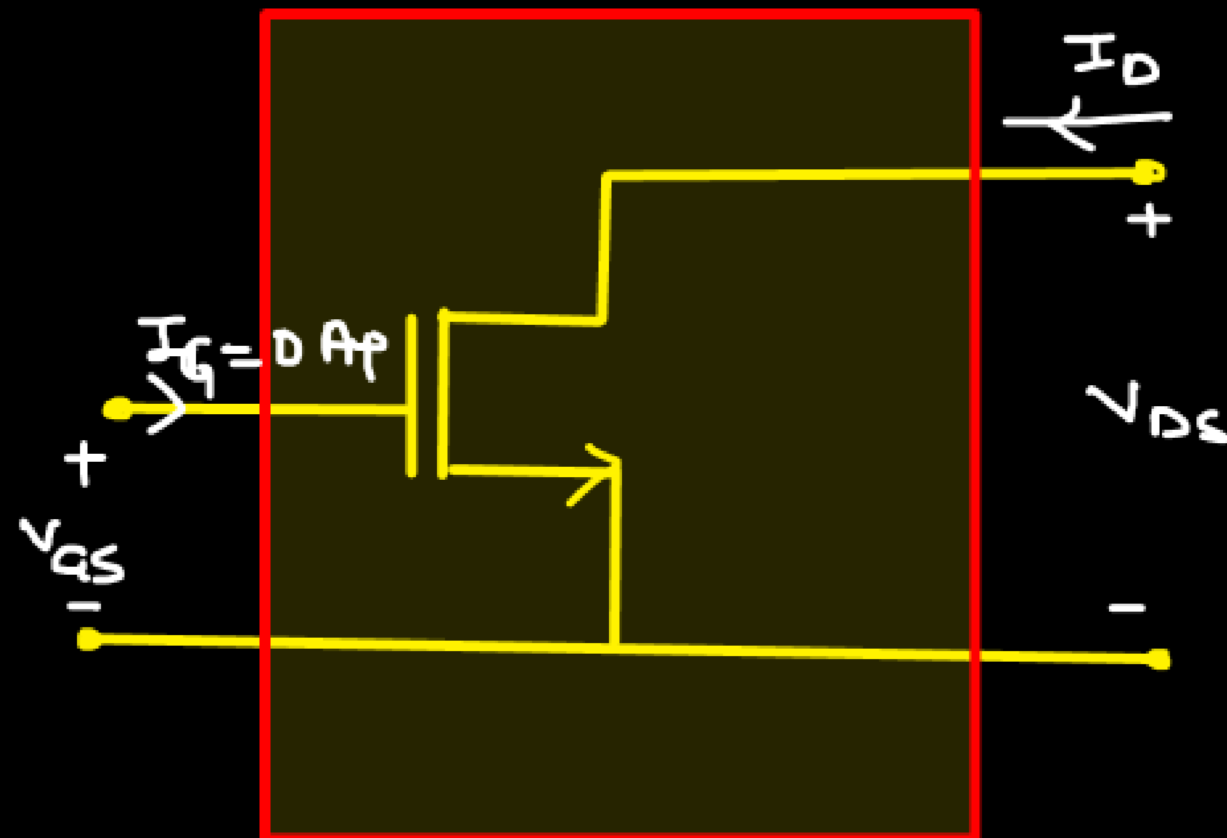
$$y_{11} = \frac{\partial I_1}{\partial V_1}\bigg|_{V_2 = \text{const.}}$$

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

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

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

Consider a MOS :-



For both Triode and Sat. region

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

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

$\Downarrow$

$\boxed{g_m \text{ will be very low in Triode region}}$

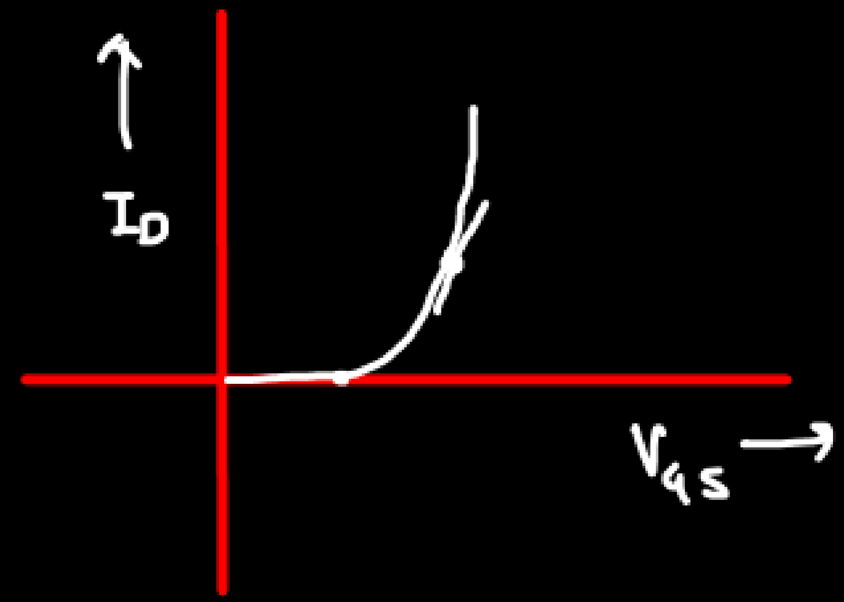
$$\boxed{(g_m)_{sat.} = \frac{\mu_n C_{ox} W}{L}(V_{GS} - V_T)}$$

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

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

**

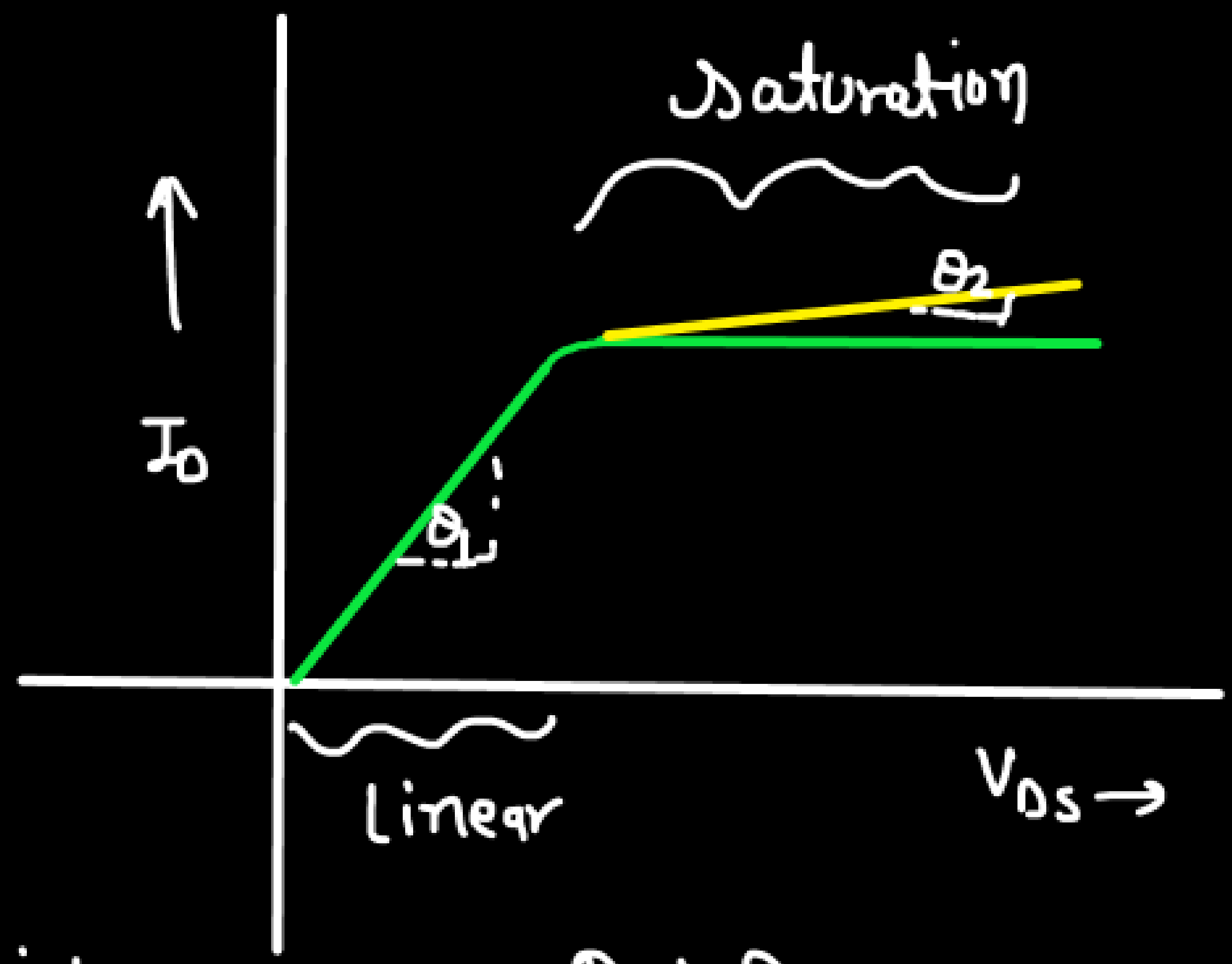
$$\boxed{(g_m)_{sat.} > (g_m)_{Triode}}$$



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

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

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



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,

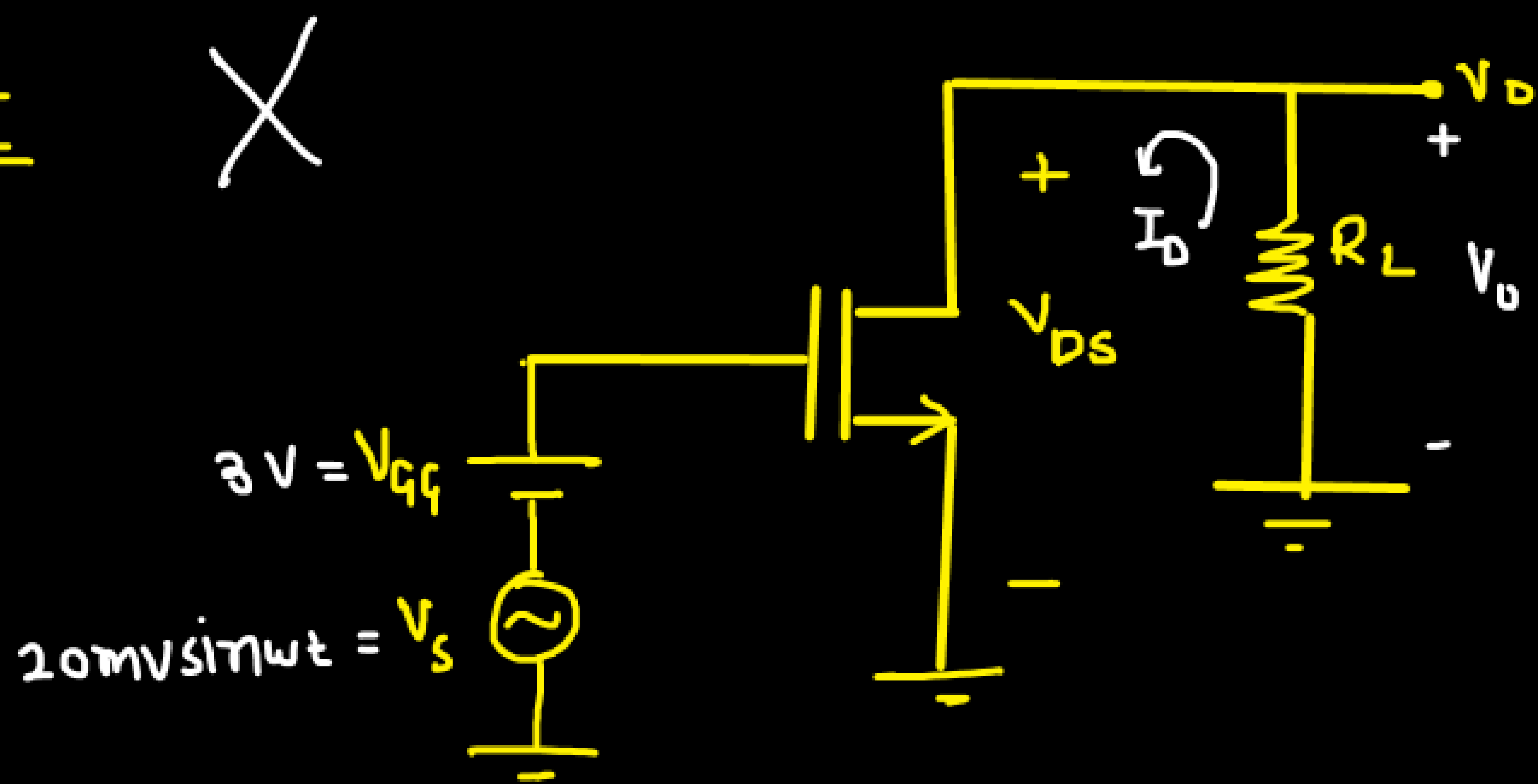
o/p resistance is High

⇒ 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. →

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

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

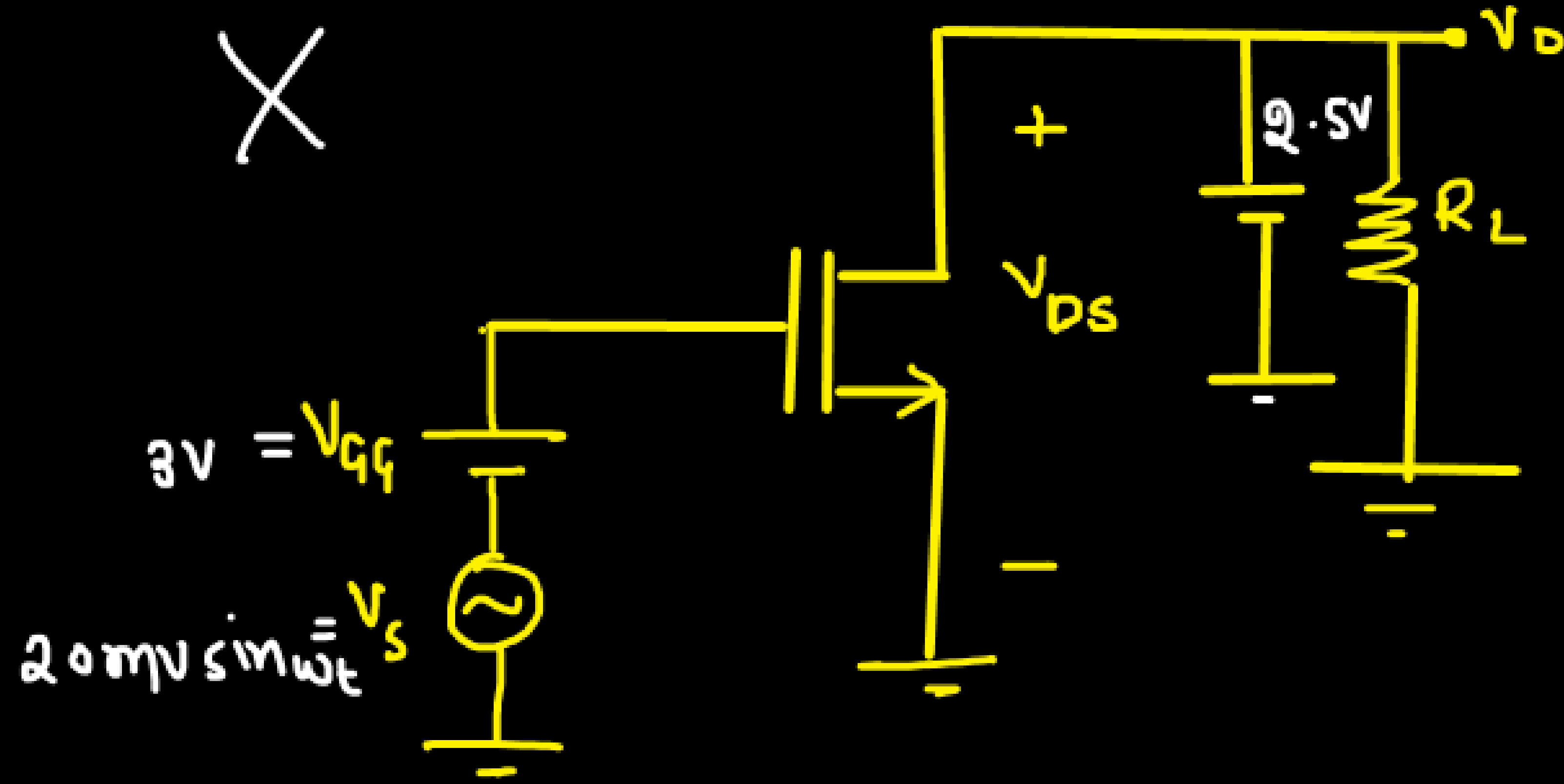
$\boxed{V_{DS} > 2V}$

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

NOT DESIRED

[MOS will be in CUT-OFF]

Try-2   Fixing V_{DS}



$\boxed{V_{DS} > 2V}$ → for sat.

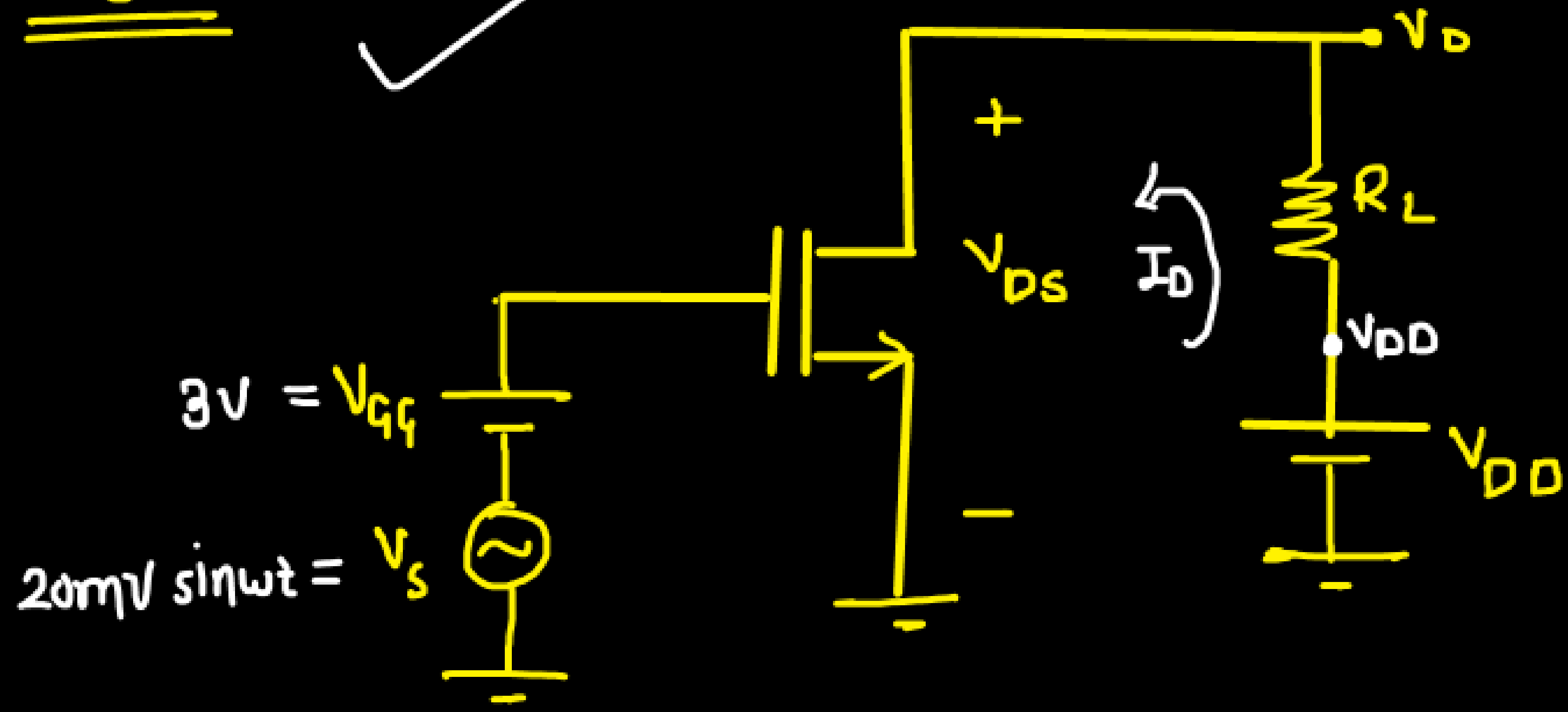
Here, $\boxed{V_{DS} > V_{GS} - V_T \Rightarrow \text{sat.} \times}$

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

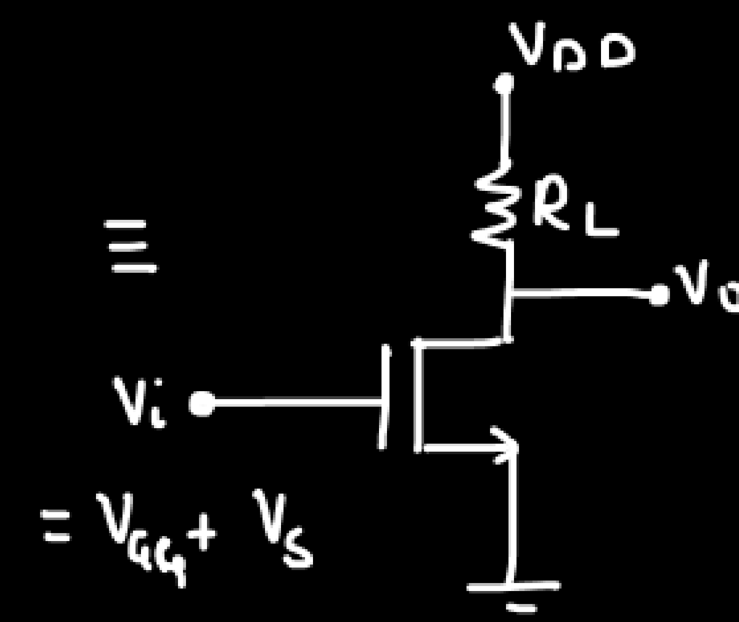
$\Downarrow$

NOT working as an amplifier

Try-3



$V_T = 1V$



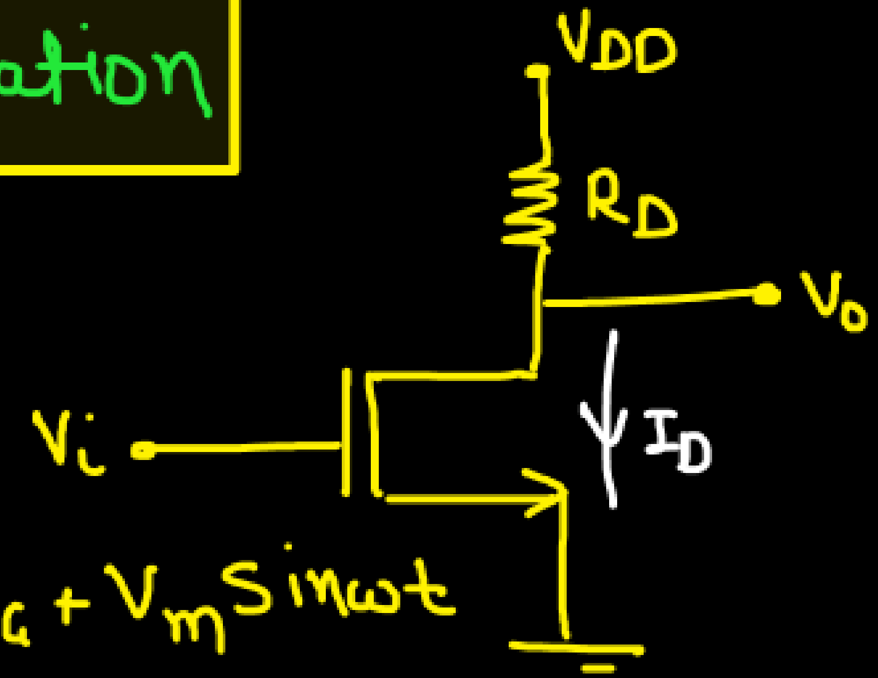
$$\boxed{V_{DS} = V_{DD} - I_D R_L}$$

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

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

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

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

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

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

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

$$I_D = \underset{\substack{\Downarrow \\ \text{current if only } V_{GG}\text{(dc) was applied}}}{I_{DC}}\left[1 + \frac{2V_m \sin\omega t}{V_{GG} - V_T}\right]$$

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

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

$\{ v_{gs} = v_m \sin \omega t$
$= \text{small signal ac i/p} \}$

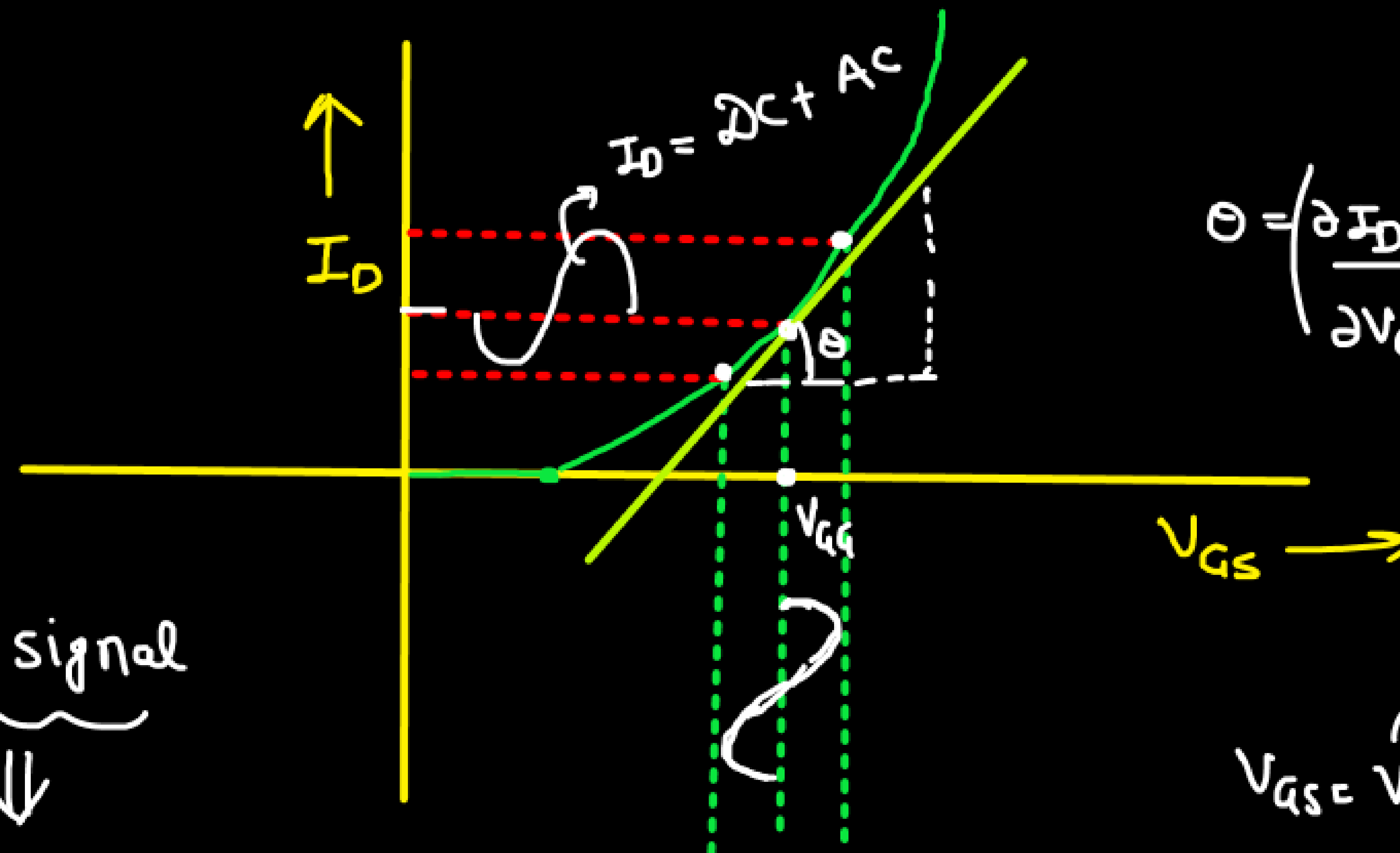
$$V_o = V_{DD} - I_D R_D$$

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

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

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

Method 2 (Understanding by Graph):-



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

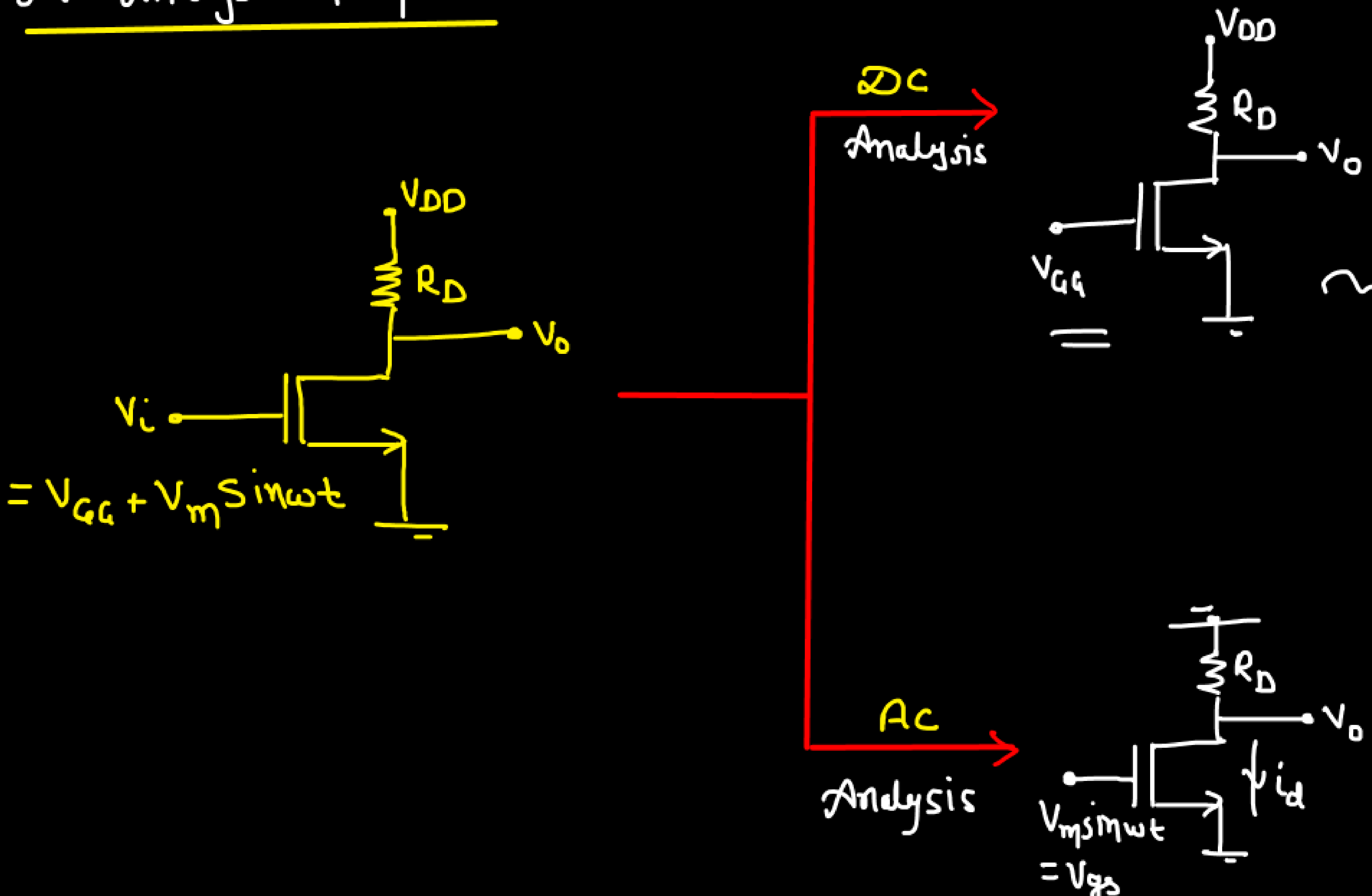
$$I_D = \underbrace{I_{DC}}_{DC} + \underbrace{Ac \text{ signal}}_{\Downarrow}$$

$$g_m v_{gs} = i_d$$

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

$$= 2 + 20\text{mV} \sin\omega t$$

For Analysis Purpose:-



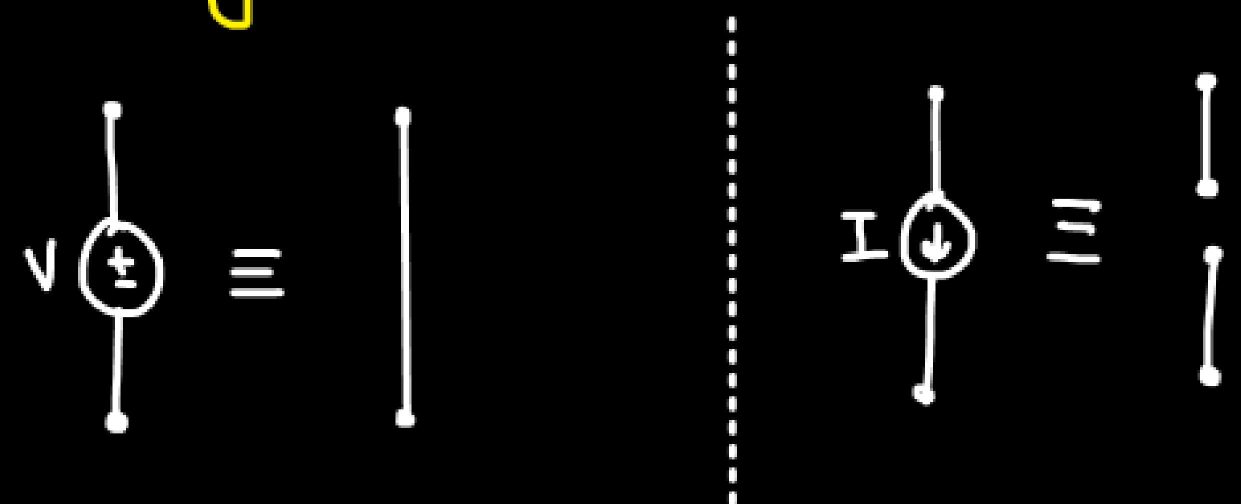
$$\rightsquigarrow \quad g_m = \frac{2I_{DC}}{V_{GG} - V_T}$$

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

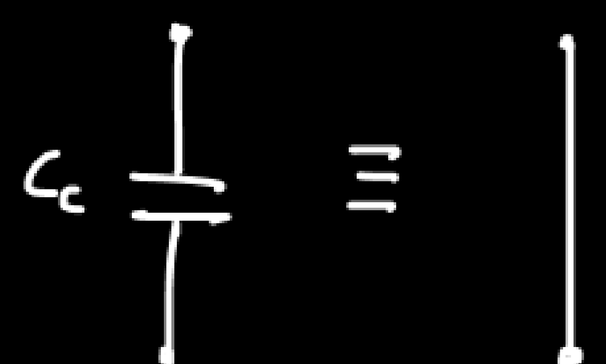
Small Signal Model of MOSFET:-

★ **AC Analysis:-**

① Nullify all the dc sources.



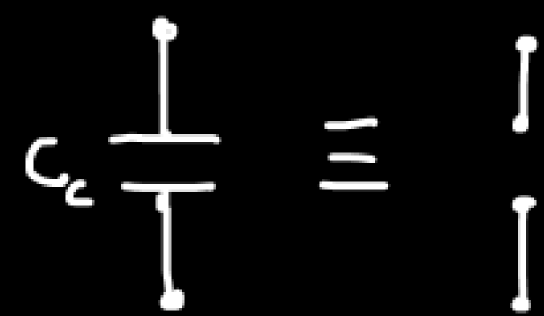
② Coupling Cap. will be shorted. (Generally)



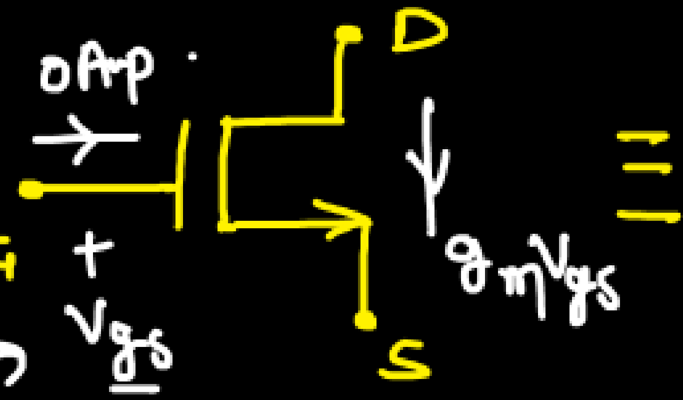
DC Analysis:-

① Nullify all the ac sources.

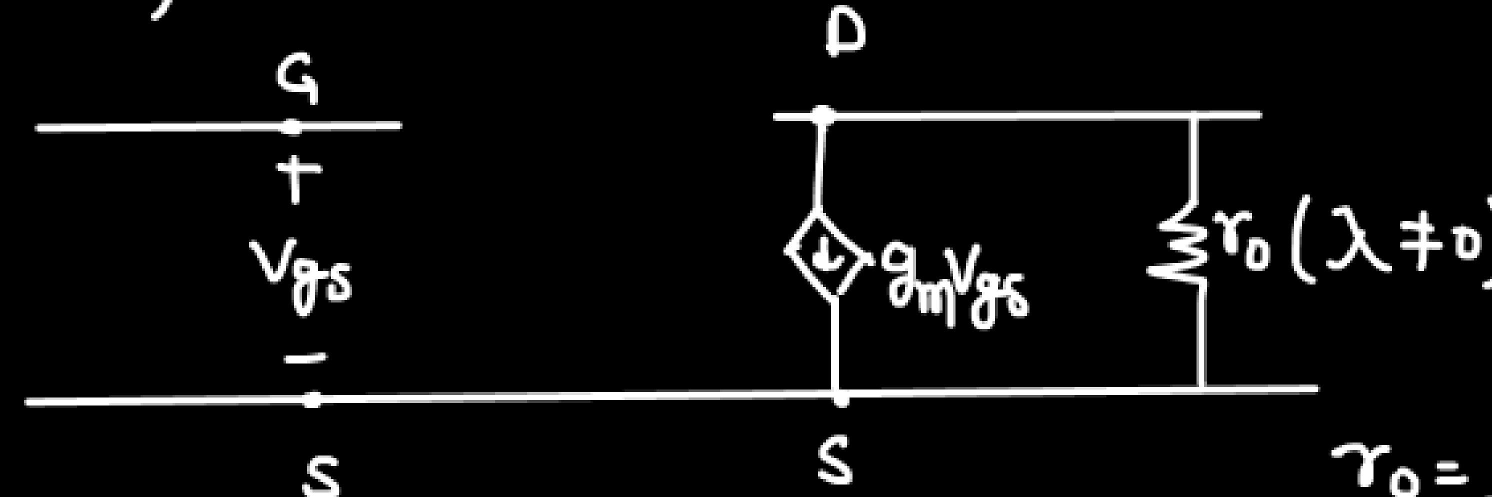
② Coupling cap. will be open circuited.



NMOS :- (Small Signal Model)



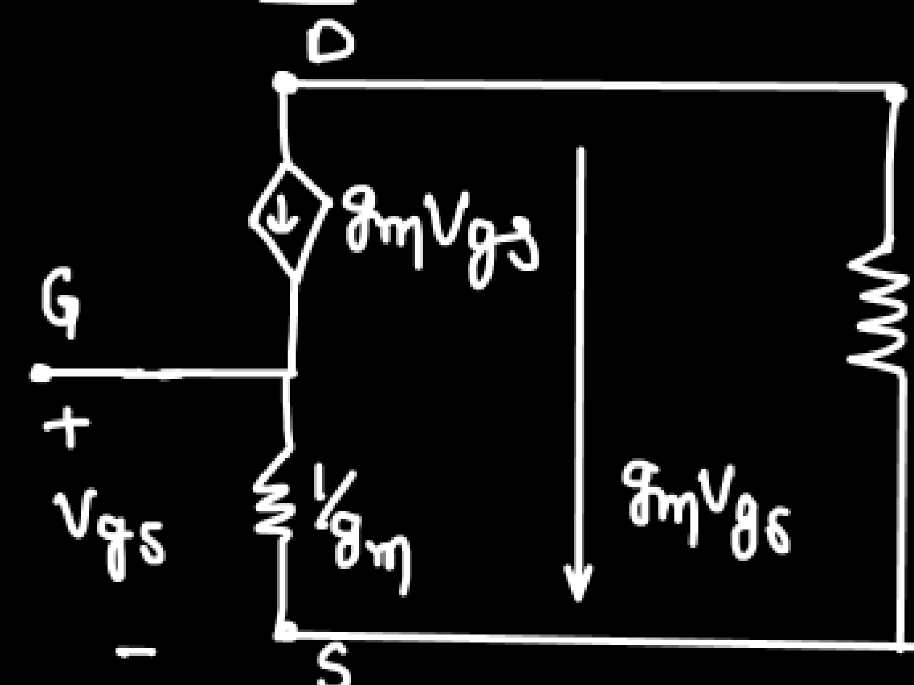
Small signal voltage



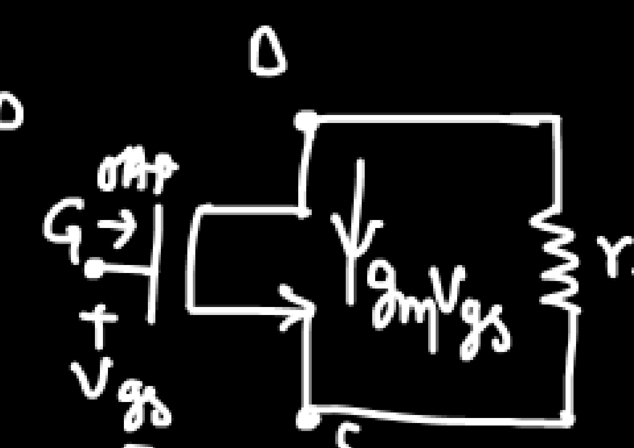
$$r_0 = \frac{1}{\lambda (I_D)_{sat.-ideal}}$$

π- model

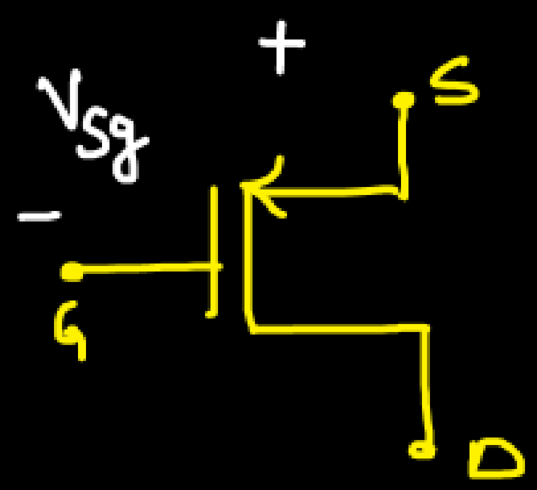
OR



OR

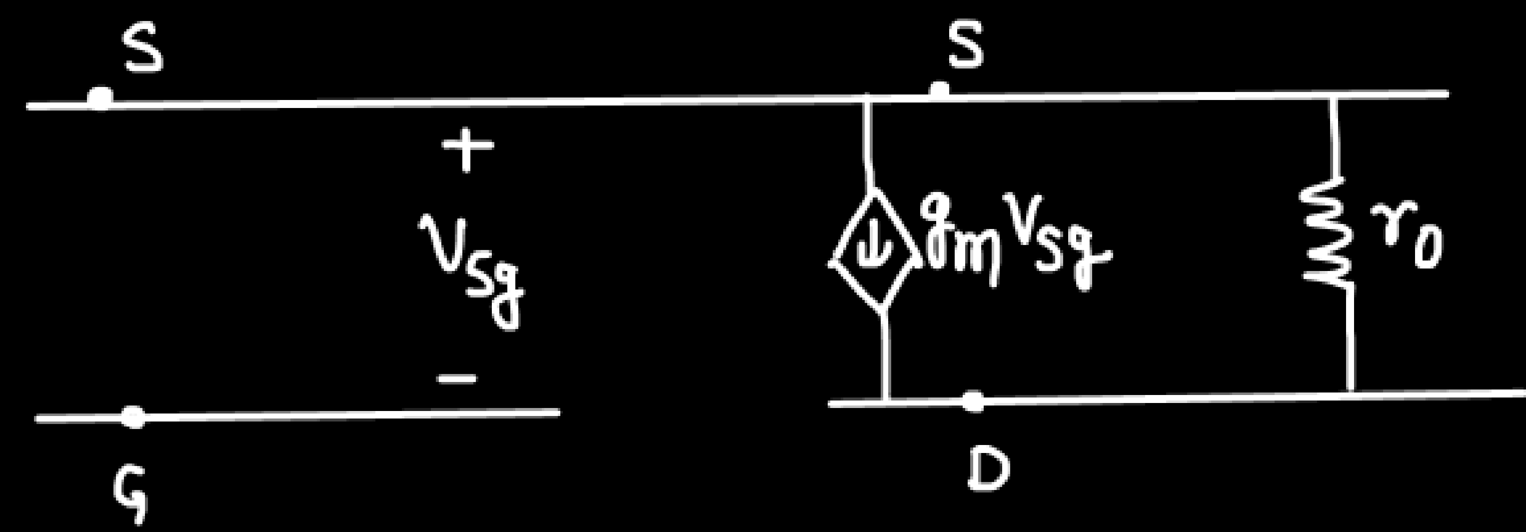


PMOS:-



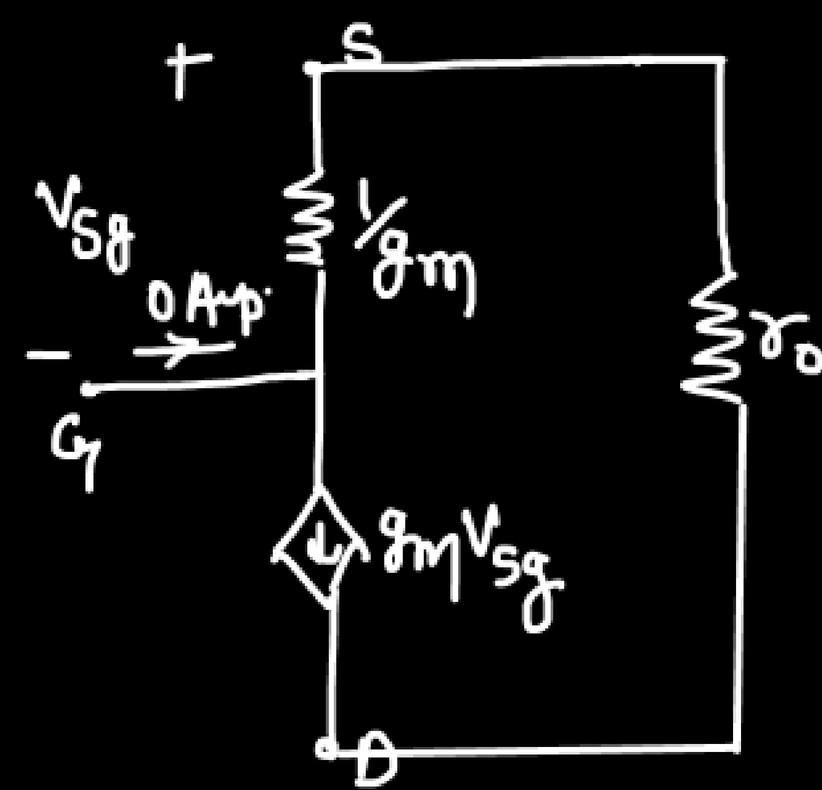
+
V_{sg}
−
S
G
D

≡



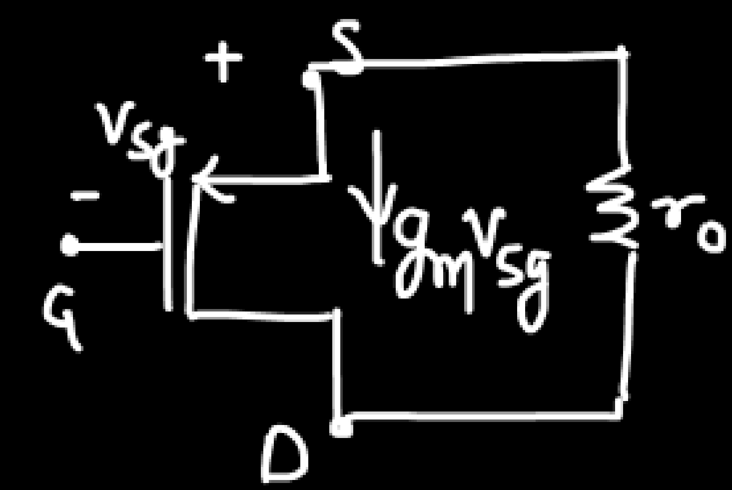
S
+
V_{sg}
−
G
S
$g_m V_{sg}$
r_o
D

OR



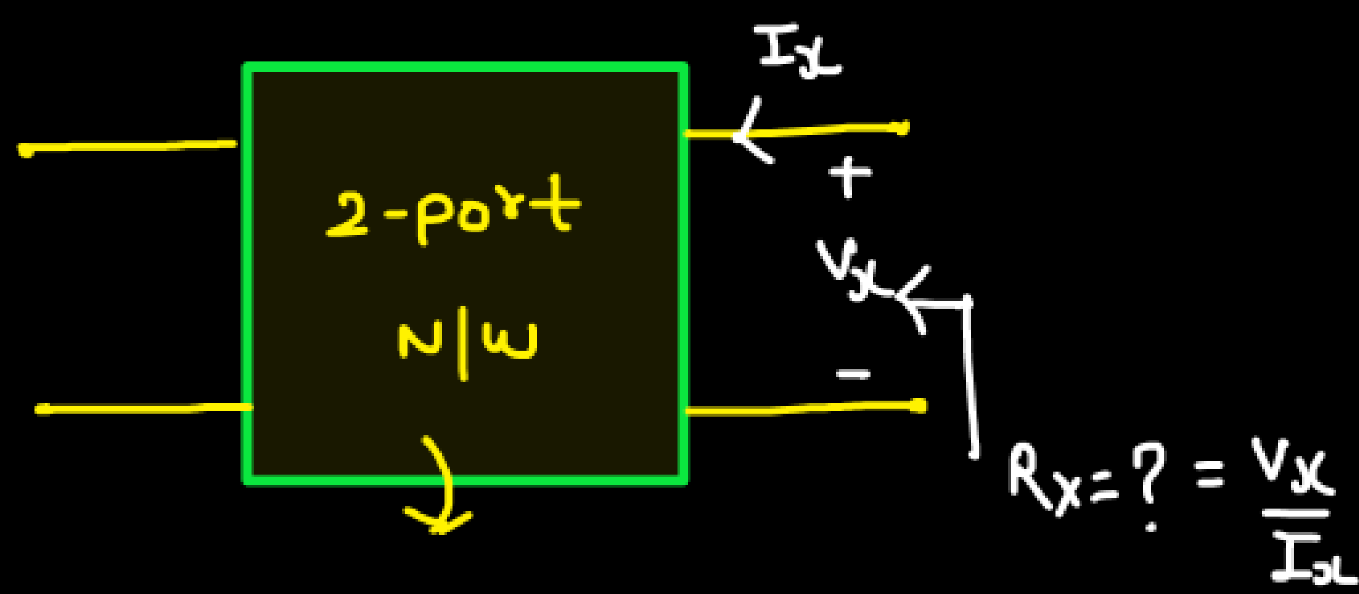
+
S
V_{sg}
$1/g_m$
0 Amp.
−
G
$g_m V_{sg}$
r_o
D

OR



+
S
V_{sg}
−
G
$g_m V_{sg}$
r_o
D

Concept of port impedance:-



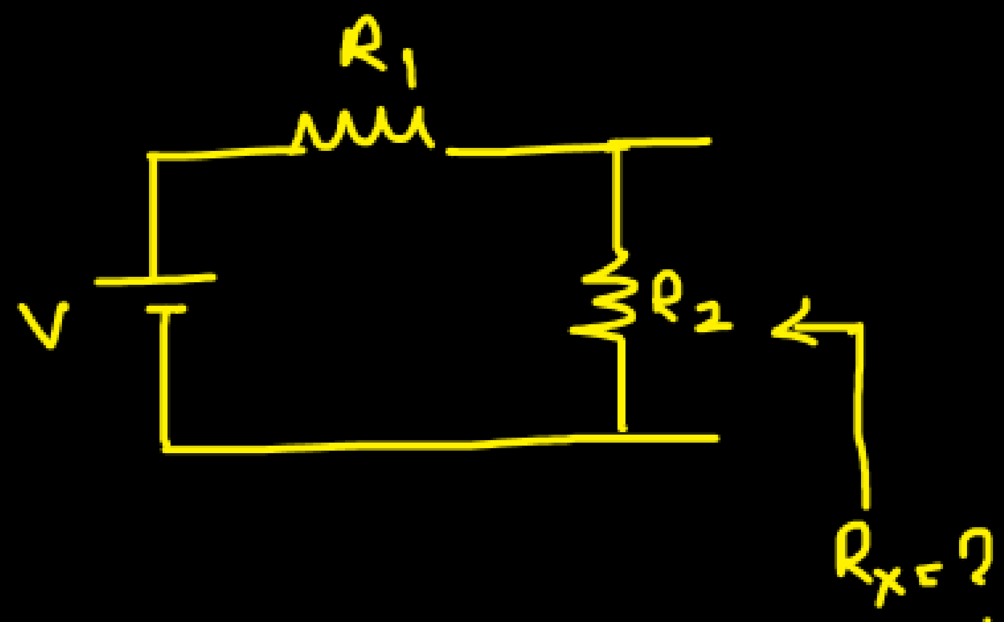
(i) All independent source = 0

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

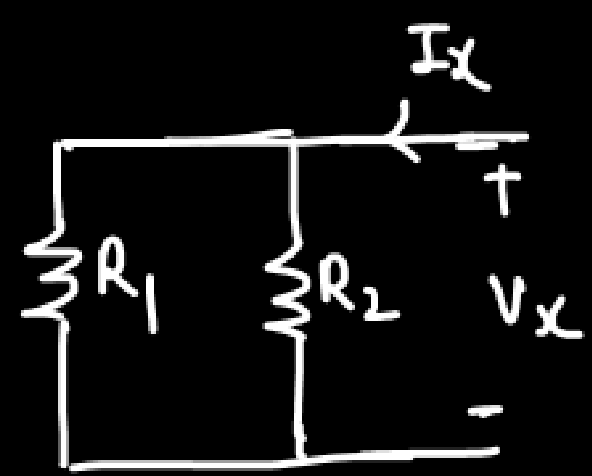
(iii) $R_x = \frac{V_x}{I_x}$

Eg. →

1



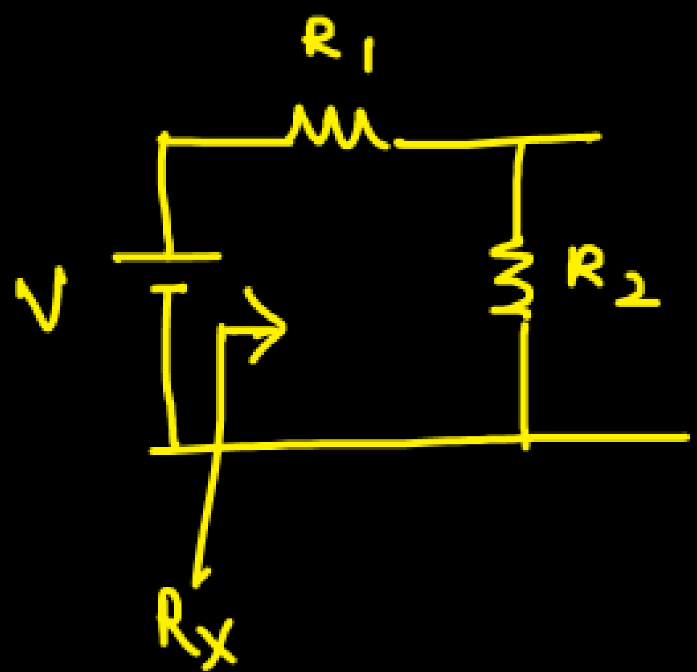
⇛



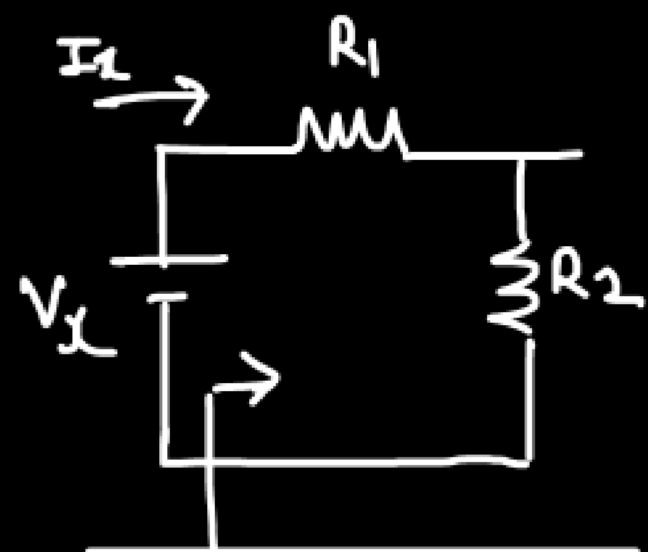
$$\frac{V_x}{R_2} + \frac{V_x}{R_1} = I_x$$

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

2

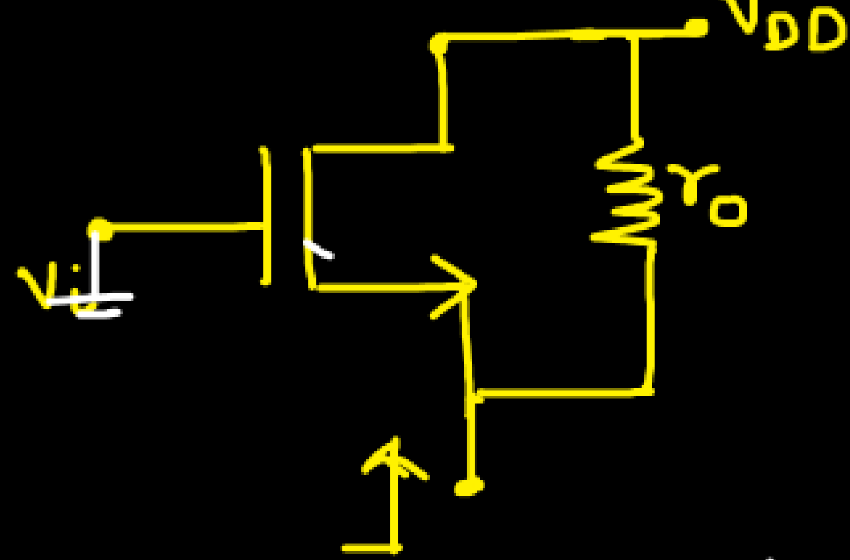


⇒

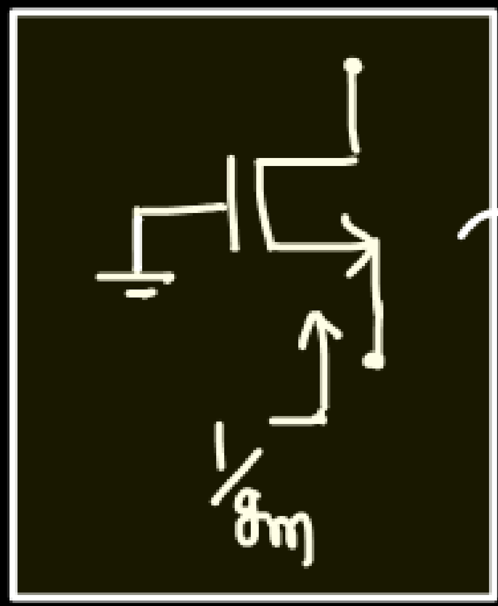


$$\boxed{R_x = R_1 + R_2}$$

3

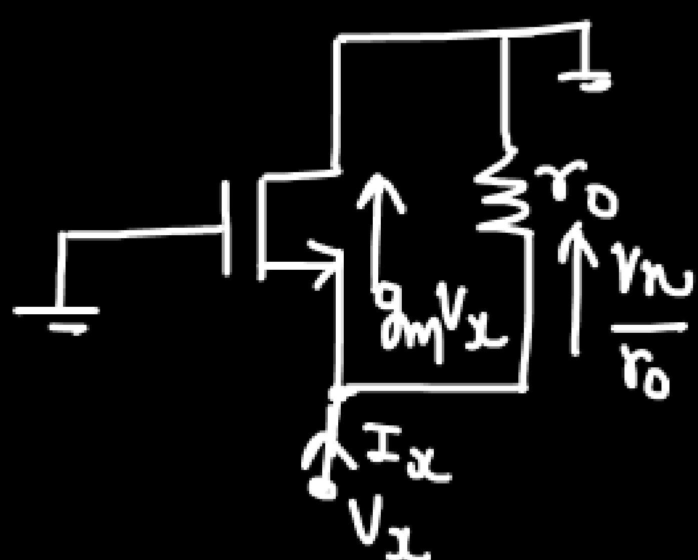


R_x (Small signal resistance)



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

→



$V_{gs} = -V_x$

Nodal @ V_x

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

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

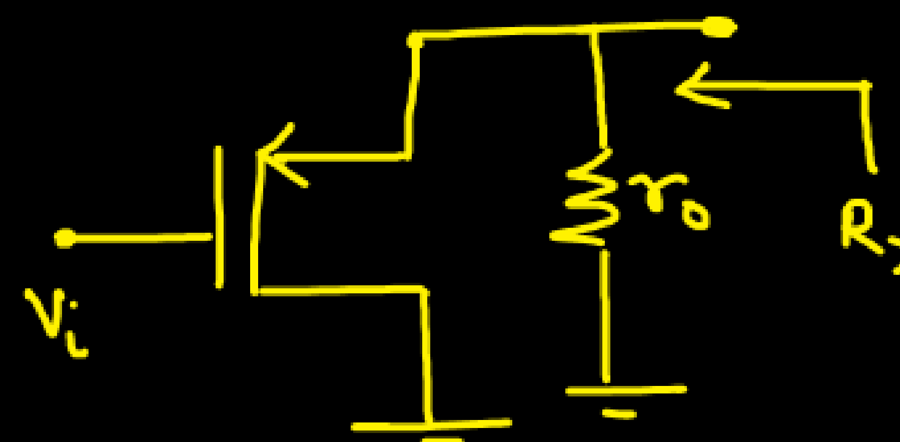
$$\boxed{R_x = \frac{r_o}{1+g_m r_o}}$$

↑

★★

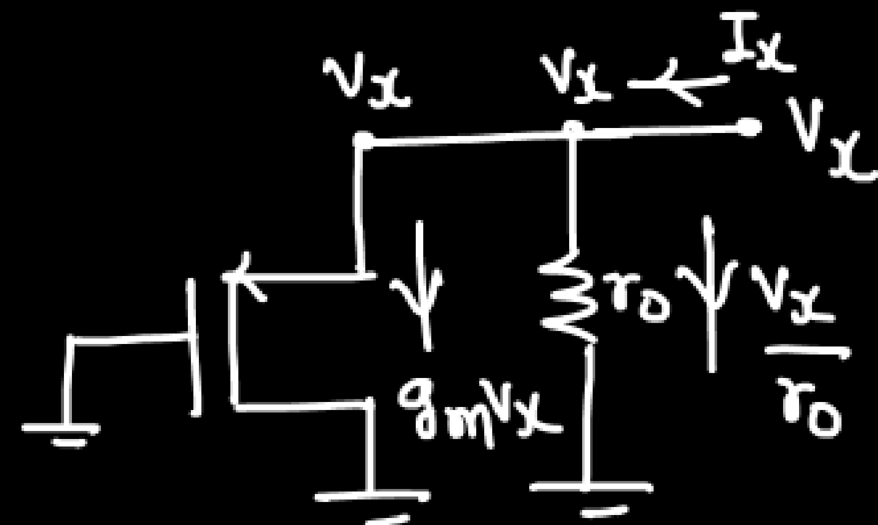
$$\boxed{R_x = \frac{1}{g_m} \parallel r_o}$$

(4)



R_x (small signal resistance)

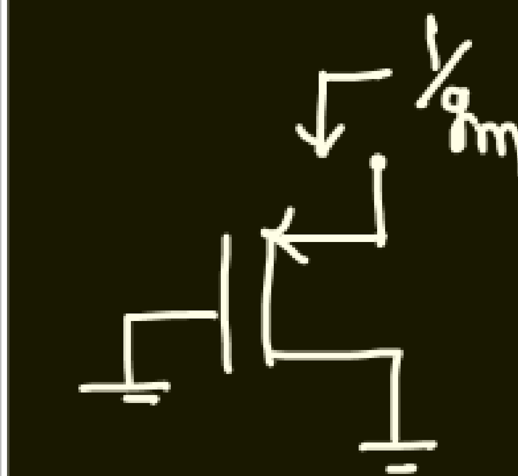
→



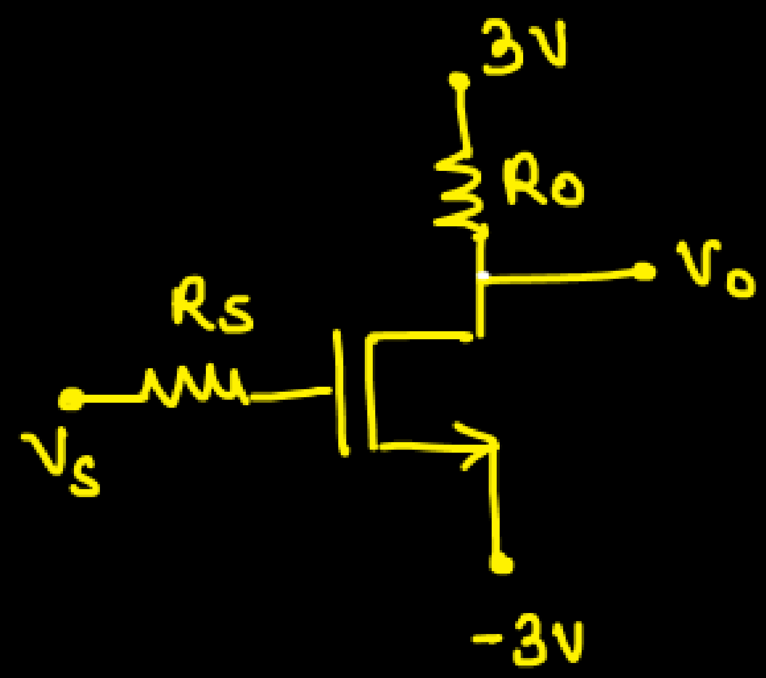
$$g_m V_x + \frac{V_x}{r_o} = I_x$$

**

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



Q.



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

$W/L = 1$

$V_T = 1V$

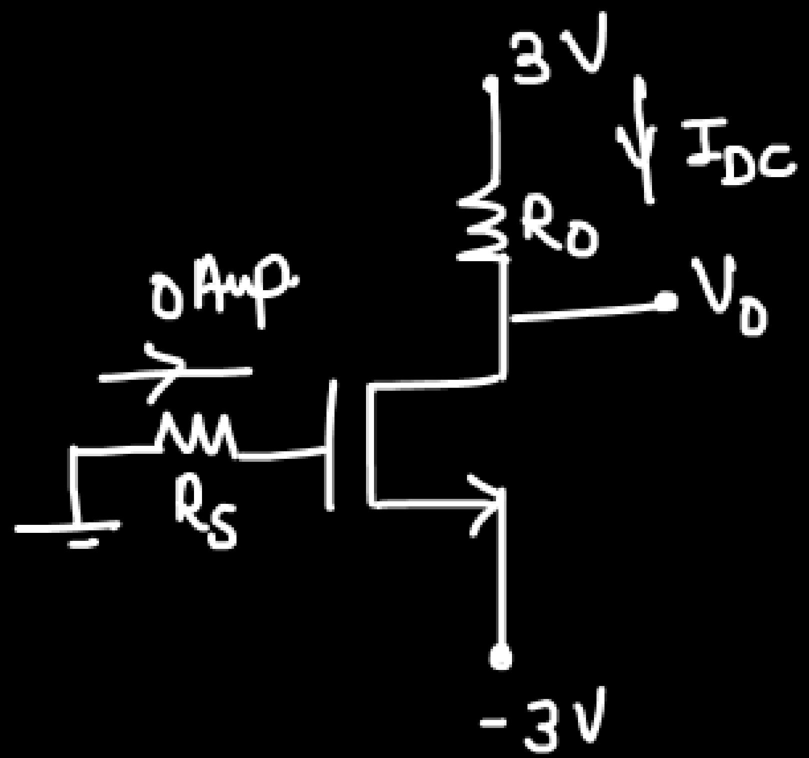
$V_S \rightarrow$ small signal source (ac)

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

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

DC Analysis

Target $V_o = 0V$



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

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

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

$V_{DS} = 3V$

$V_{GS} = 3V$

$V_T = 1V$

$V_{OV} = 2V$

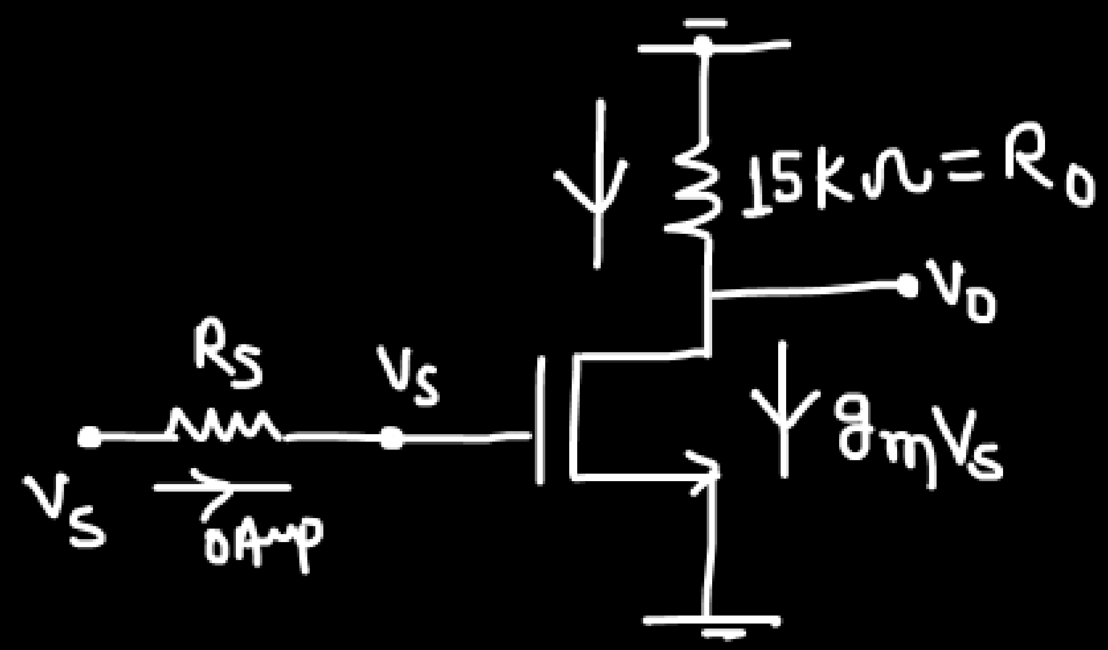
$V_{DS} > V_{OV} \Rightarrow \underline{\text{sat.}}$

$$V_o = 3 - I_{DC}R_O = 0$$

$$I_{DC}R_O = 3$$

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

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 ✓ = 15 kΩ

g_m ?

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

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

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

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

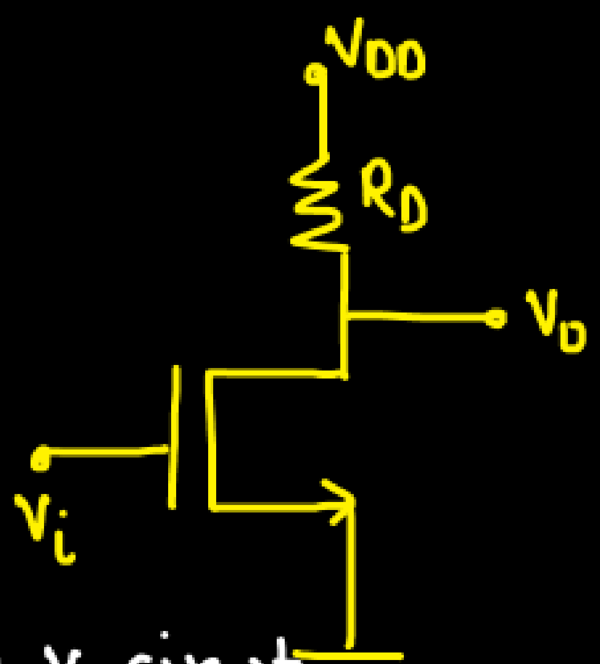
$$\boxed{g_m = 200\,\mu\mho}$$

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

$$= 200\mu \mho$$

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

Common Source Amplifiers:-



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

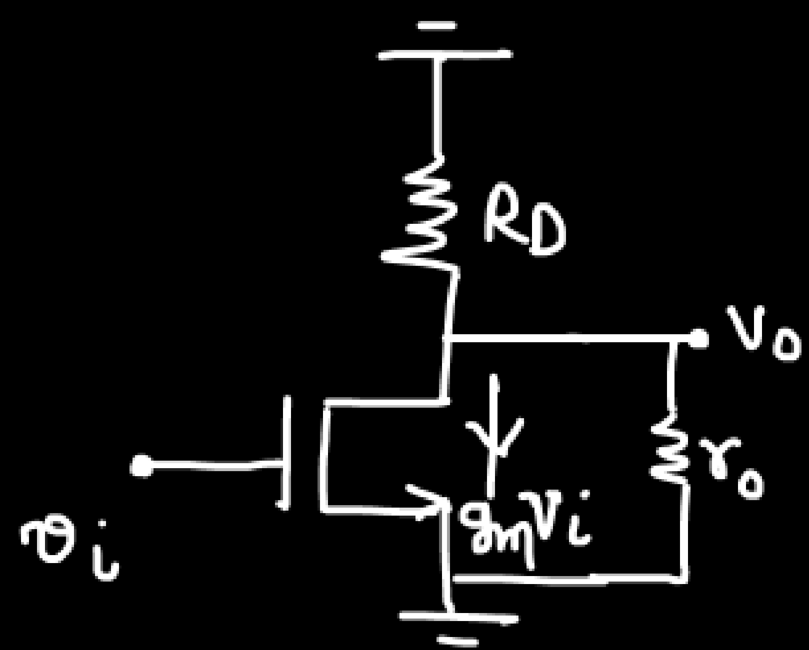
$= V_{DC} + v_i$

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

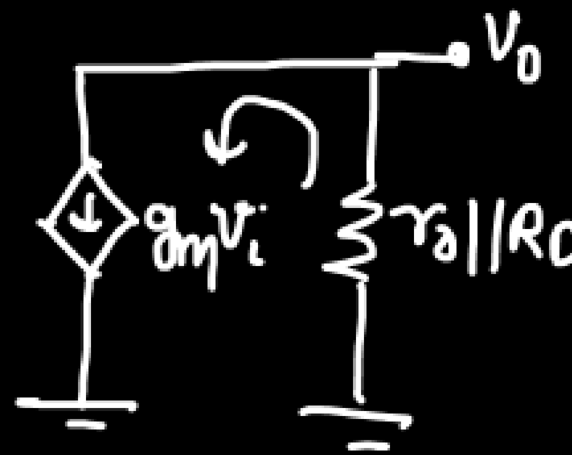
Common source amplifier →

input → Gate , o/p → Drain

Small signal analysis (ac):-



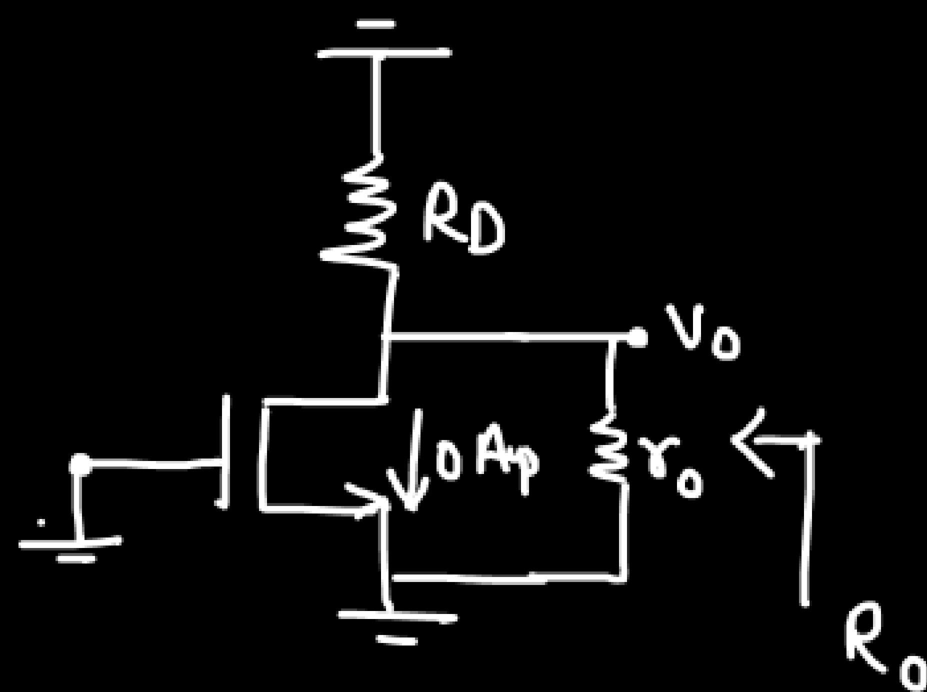
$\equiv$

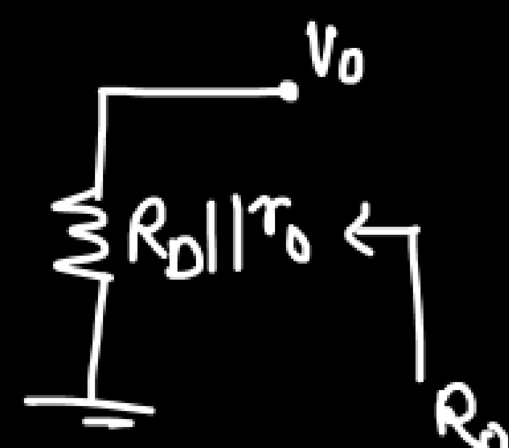


$$v_o = -g_m v_i [R_D \| r_o]$$

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

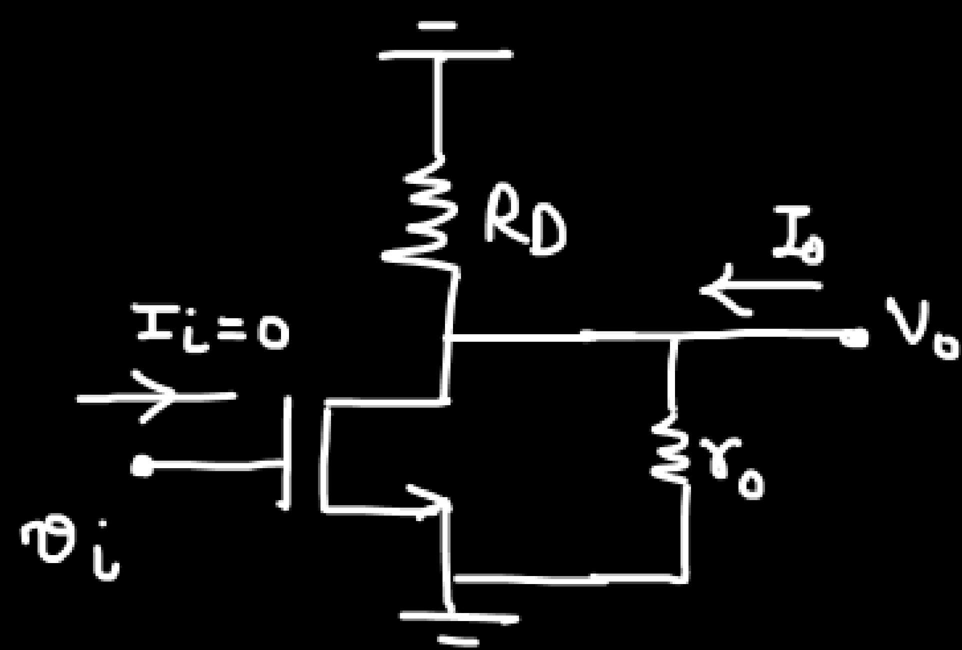
② Small signal o/p resistance (R_o) :-





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

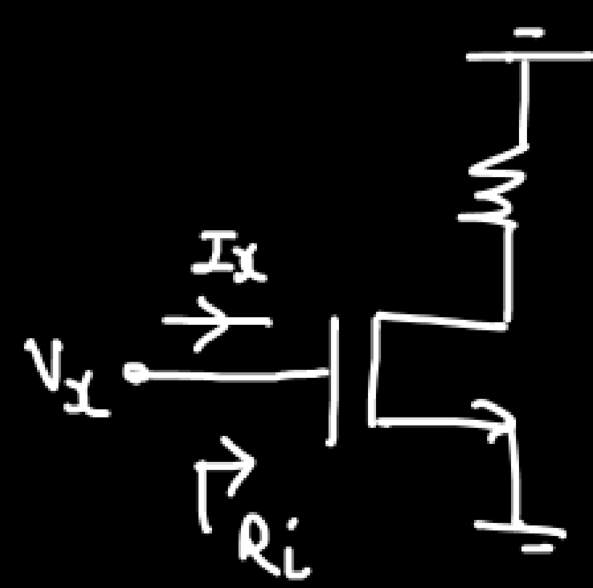
③ Small signal Current gain:-



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

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

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:-

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

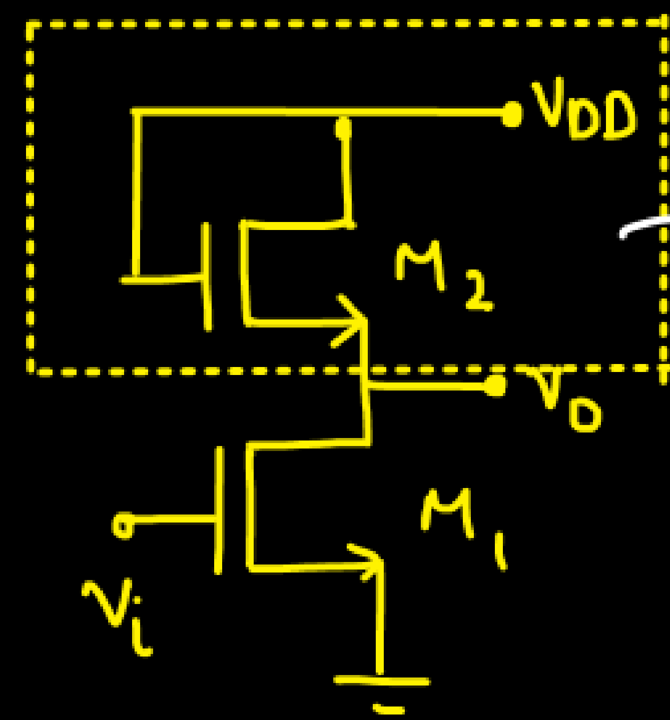
$$\boxed{A_V = -\sqrt{\frac{2\mu_n C_{ox} W}{L} I_D} \times R_D}$$

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

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

Because of Temp. change, the gain can change $\Rightarrow$ NOT Desirable

Using diode connected load in common Source Amplifier:



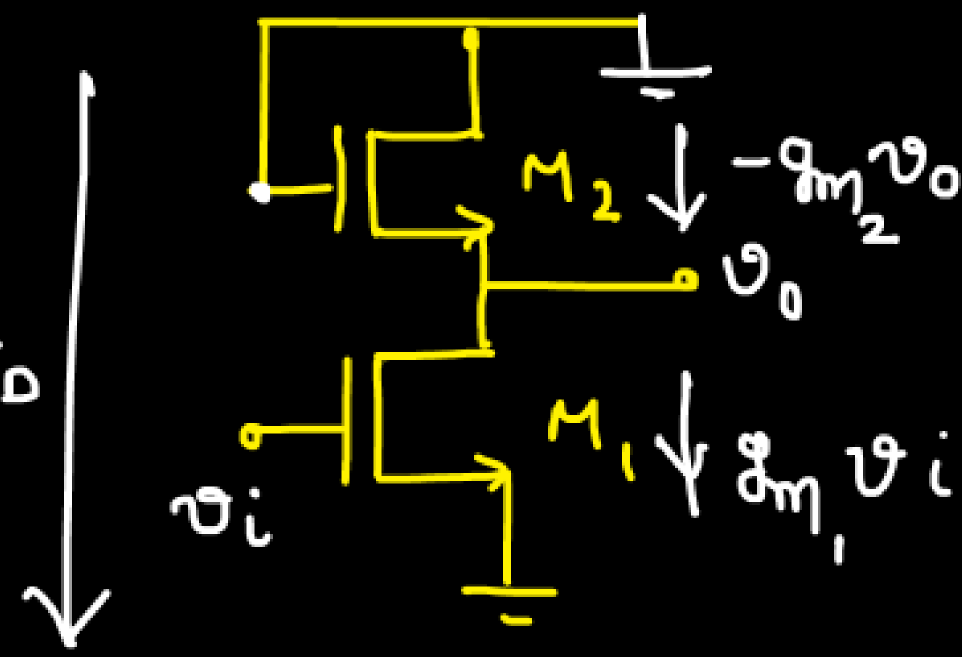
→ diode connected load.

→

Small signal Analysis:-

Assuming $[\lambda = 0]$

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



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

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

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

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

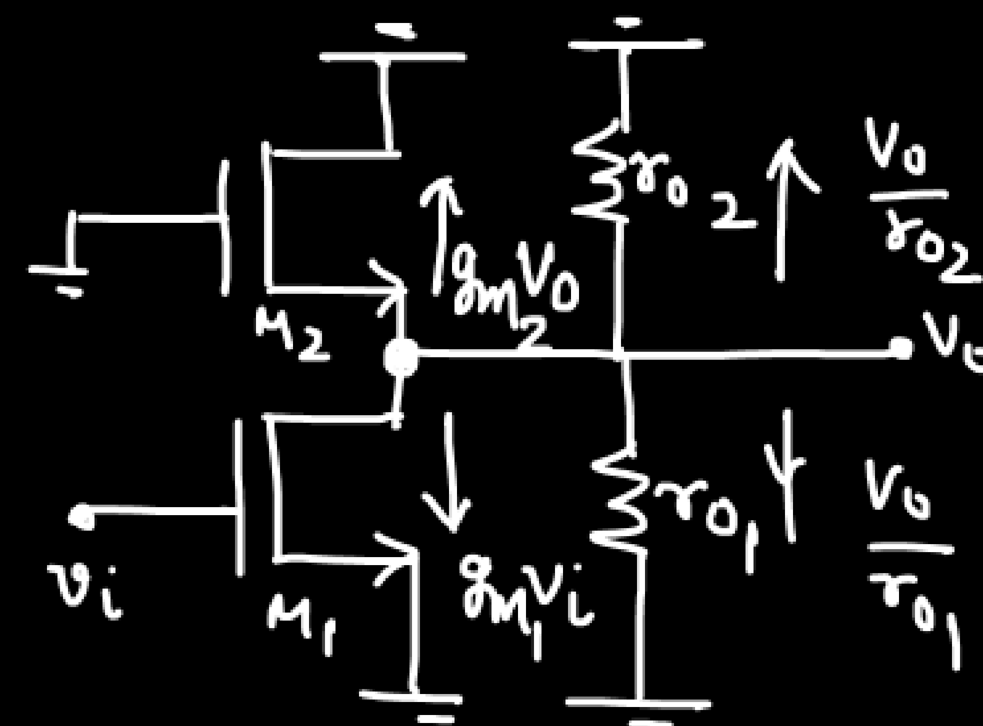
$$A_v = \frac{\sqrt{2\left(\frac{\mu_n C_{ox} W}{L}\right)_{M_1} I_{D_1}}}{\sqrt{2\left(\frac{\mu_n C_{ox} W}{L}\right)_{M_2} I_{D_2}}}$$

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

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

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

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



KCL @ V_o :-

$$g_{m2}V_o + g_{m1}V_i + \frac{V_o}{r_{o2}} + \frac{V_o}{r_{o1}} = 0$$

$$V_o\underbrace{\left[g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{o1}}\right]}= -g_{m1}V_i$$

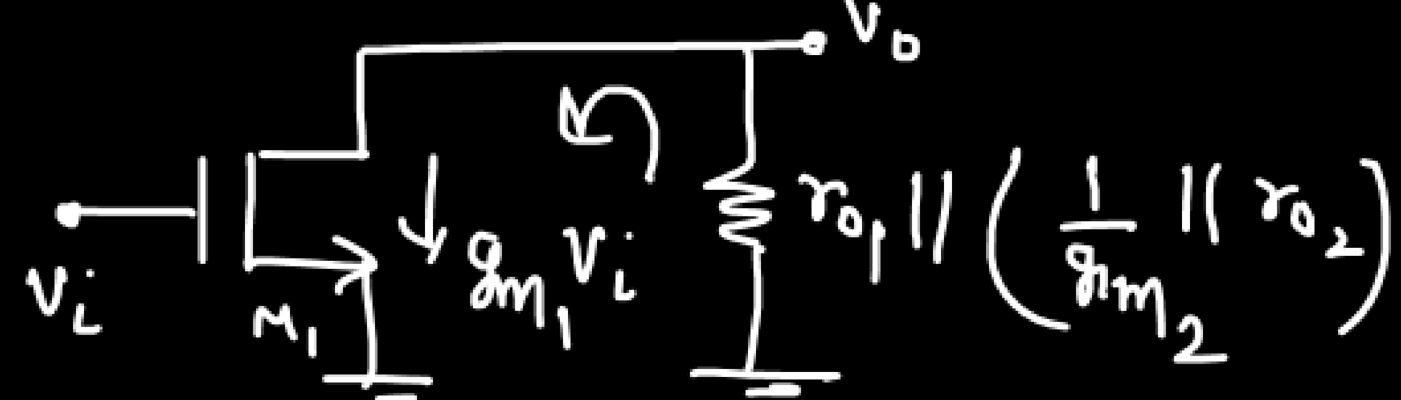
$$\frac{V_o}{\left[\frac{1}{g_{m2}} \| r_{o1} \| r_{o2}\right]} = -g_{m1}v_i$$

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

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

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

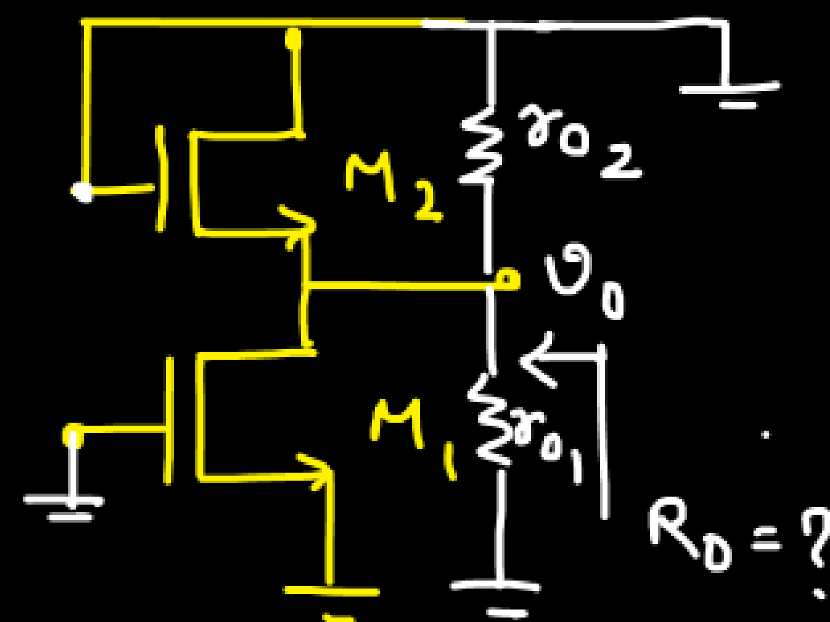
M-II



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

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

o/p resistance:-

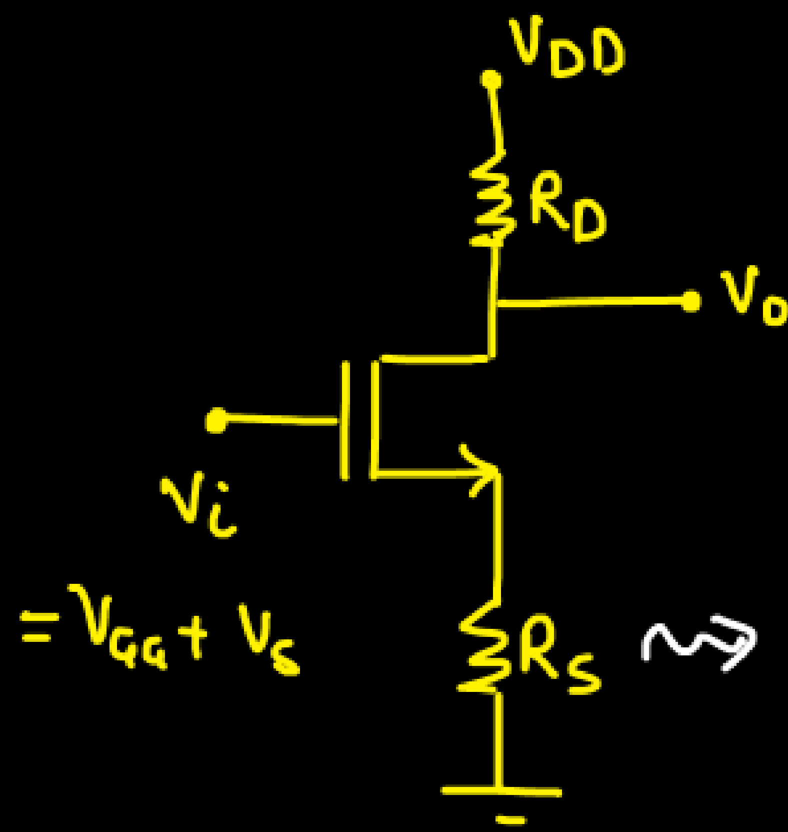


$$\boxed{R_o = r_{o1} \| r_{o2} \| \frac{1}{g_{m2}}}$$

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

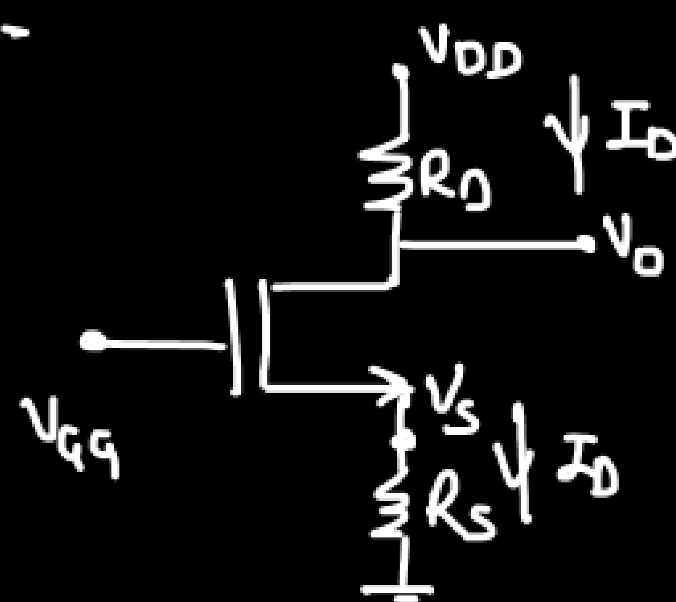
$$\boxed{R_o = \frac{1}{g_{m2}}}$$

Common source Amplifier with degeneration:-



R_S ⇝ degeneration resistance

DC Analysis:-

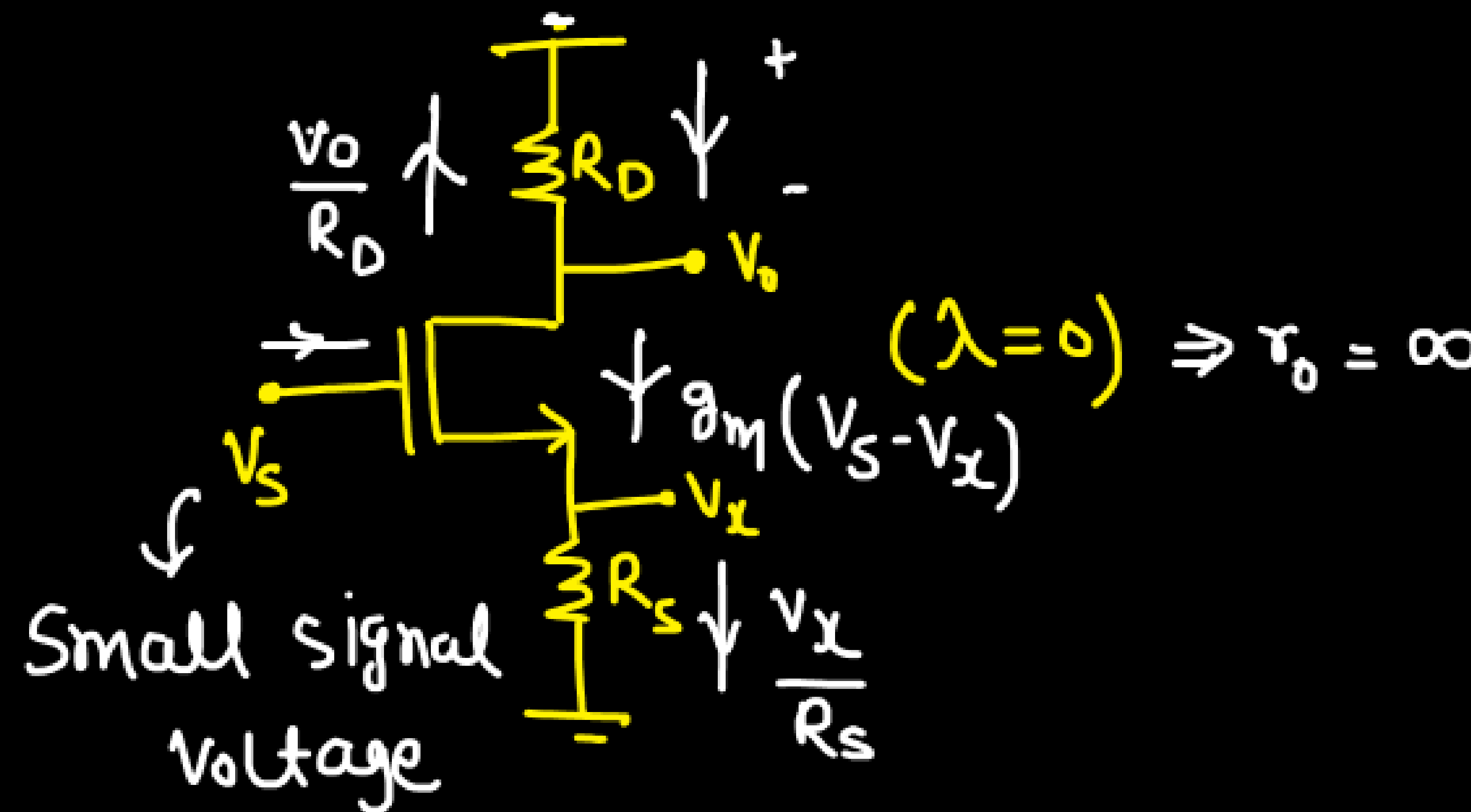


Let's assume, Because of Temp. $I_D \uparrow$

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

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

Small signal Analysis:-



$$v_o = -g_m(v_s - v_x) \times R_D$$

$$v_o = -g_m R_D (v_s - v_x) \quad \text{--- (1)}$$

$$\frac{v_o}{R_D} = -\frac{v_x}{R_S} \quad \Rightarrow \quad v_x = -\frac{R_S}{R_D} v_o \quad \text{--- (2)}$$

By eq^n 1 and 2

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

$$v_o = -g_m R_D V_s - g_m R_s v_o$$

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

$$\boxed{\frac{v_o}{V_s} = \frac{-g_m R_D}{1 + g_m R_s}} \rightarrow \text{small signal voltage gain}$$

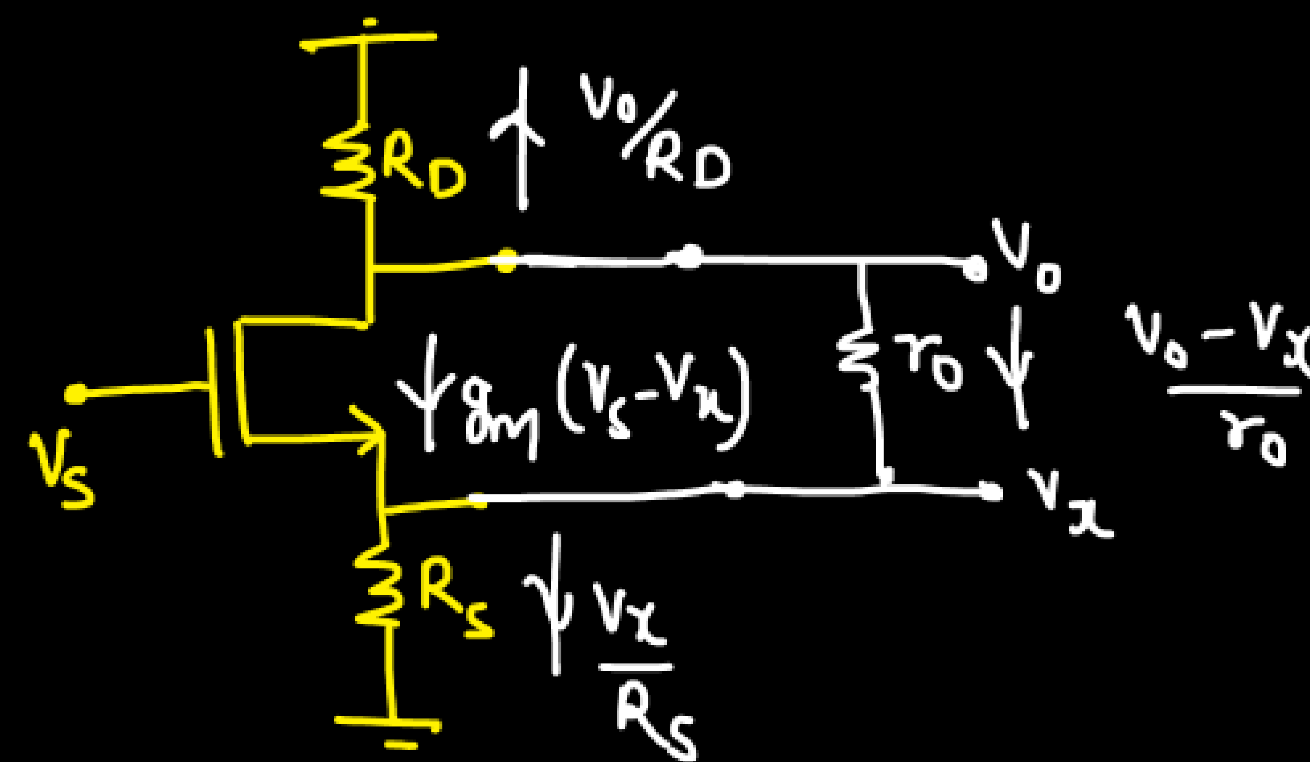
<u>current gain:-</u>

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

<u>input Resistance:-</u>

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

Voltage gain considering r_o :-



KCL @ V_o

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

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

By eq^n ① and ②

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

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

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

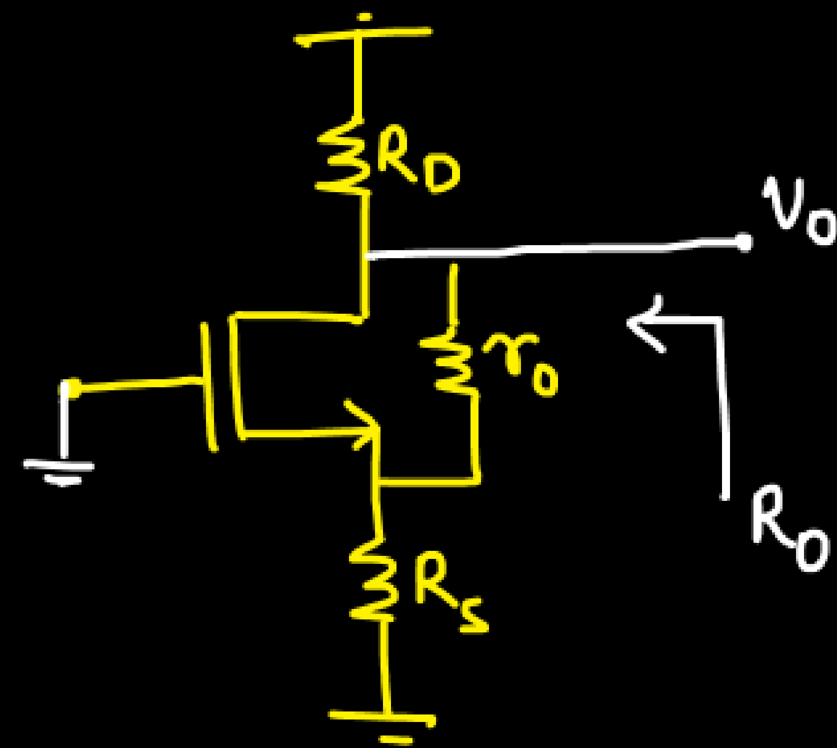
$$\boxed{\frac{v_o}{v_s} = -g_m R_D\left[\frac{r_o}{g_m r_o R_S + r_o + R_D + R_S}\right]}$$

if $r_o = \infty$ [very large]

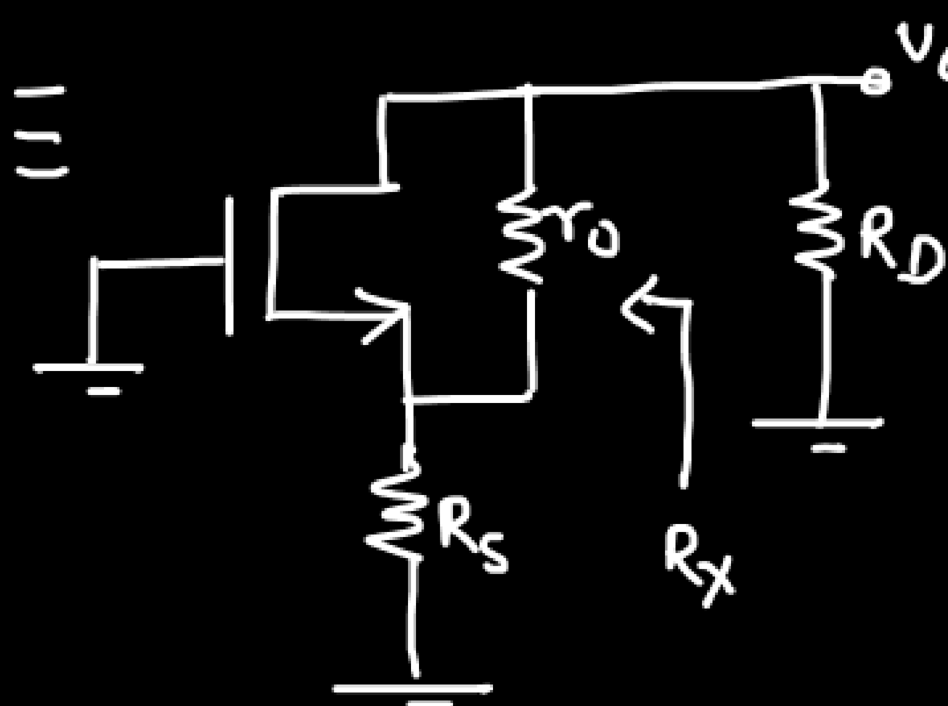
$$\frac{v_o}{v_s} = -g_m R_D \left[\frac{r_o}{g_m r_o R_S + r_o} \right]$$

$$\boxed{\frac{v_o}{v_s} = \frac{-g_m R_D}{1 + g_m R_S}}$$

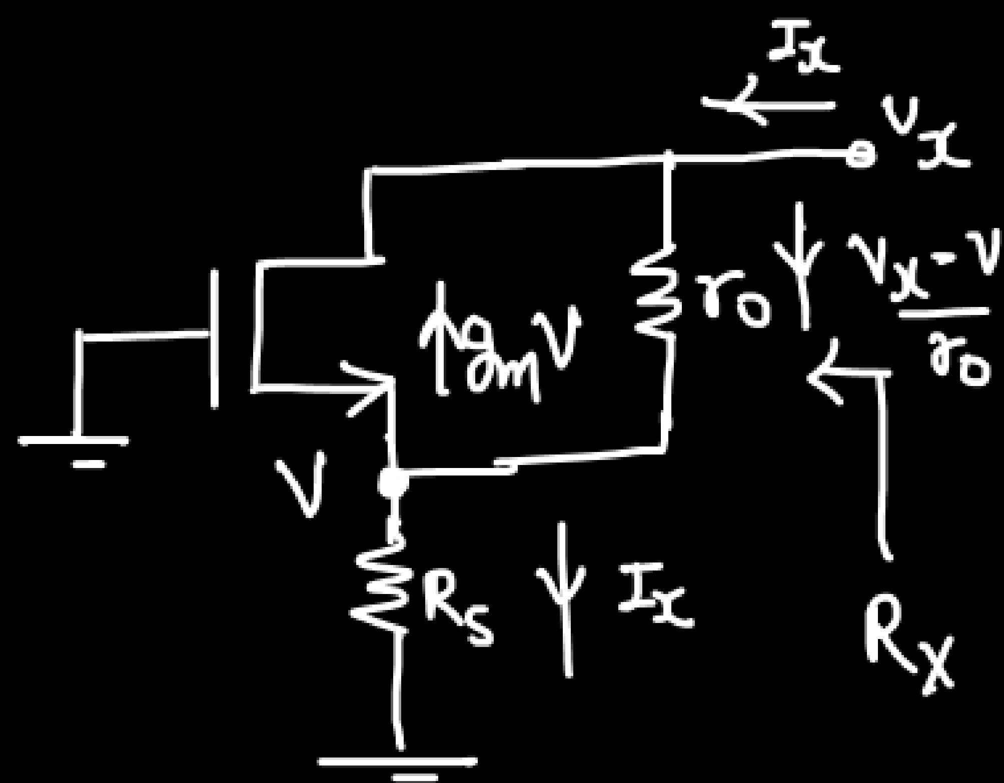
O/P resistance :-



$\equiv$



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



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

Nodal @ V_x :-

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

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

$$V = I_x R_S \quad \text{—— (2)}$$

By eq^n ① and ②

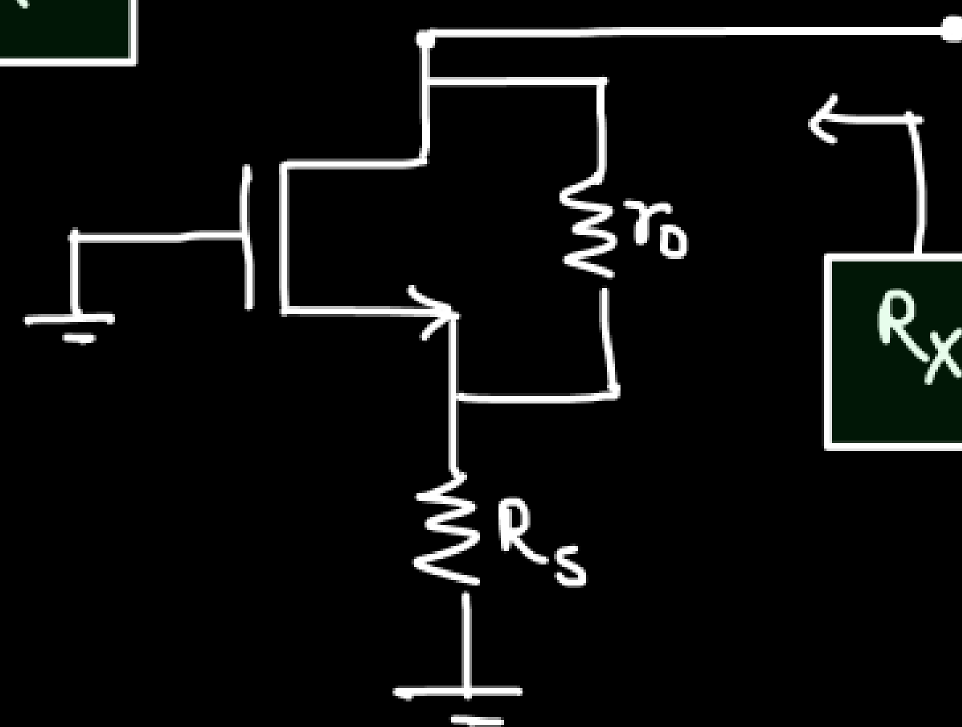
$$I_x r_o + g_m r_o [I_x R_s] = V_x - I_x R_s$$

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

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

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

To REMEMBER:-



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

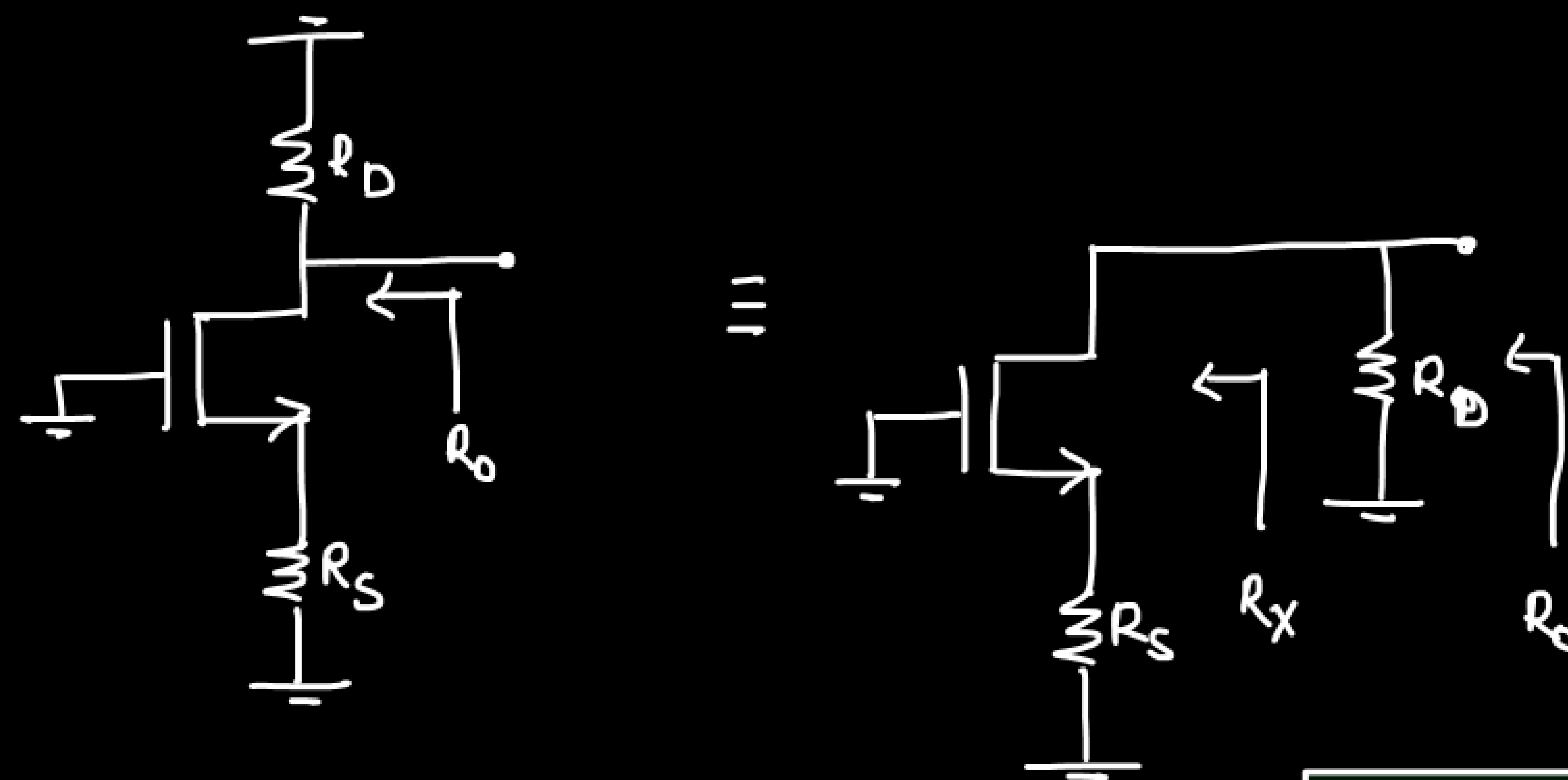
$$\approx g_m r_o R_S$$

O/P resistance:-

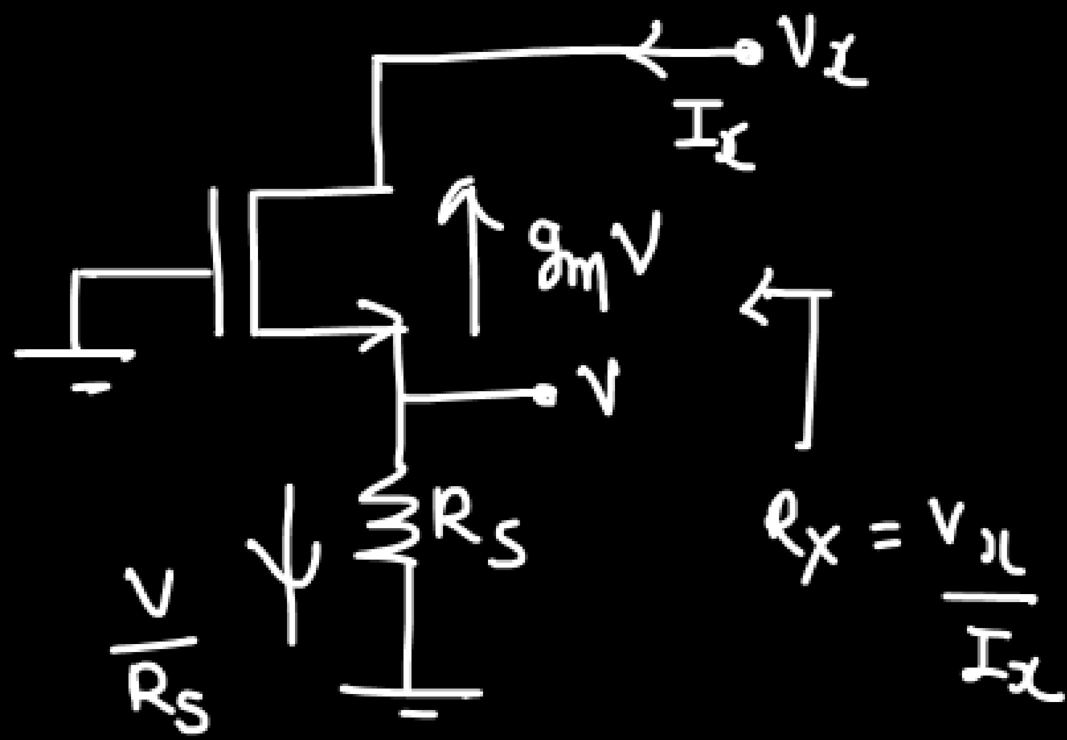
$$R_o = R_D \,||\, R_X$$

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

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



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



$$g_m V = -I_x \quad \text{—— (1)}$$

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

By eq^n (1) and (2)

$$g_m I_x R_s = -I_x$$

$$I_x [g_m R_S + 1] = 0$$

$$\boxed{I_x = 0}$$

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

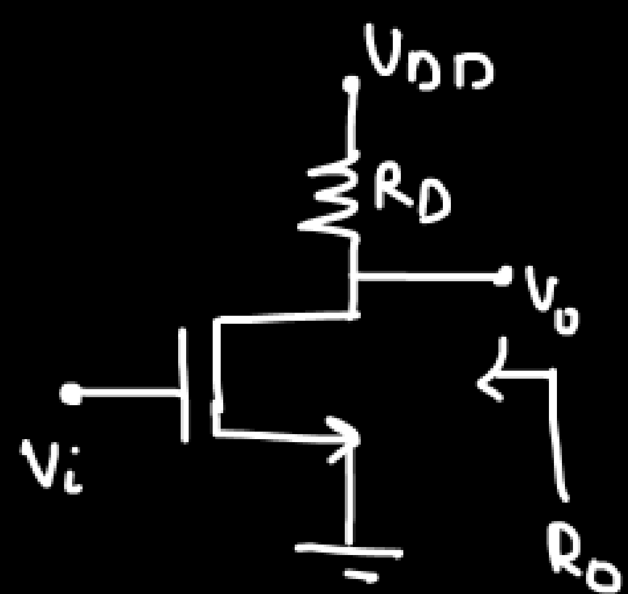
$$R_o = R_D \| R_x$$

$$R_o = R_D \| \infty$$

$$\boxed{R_o = R_D}$$

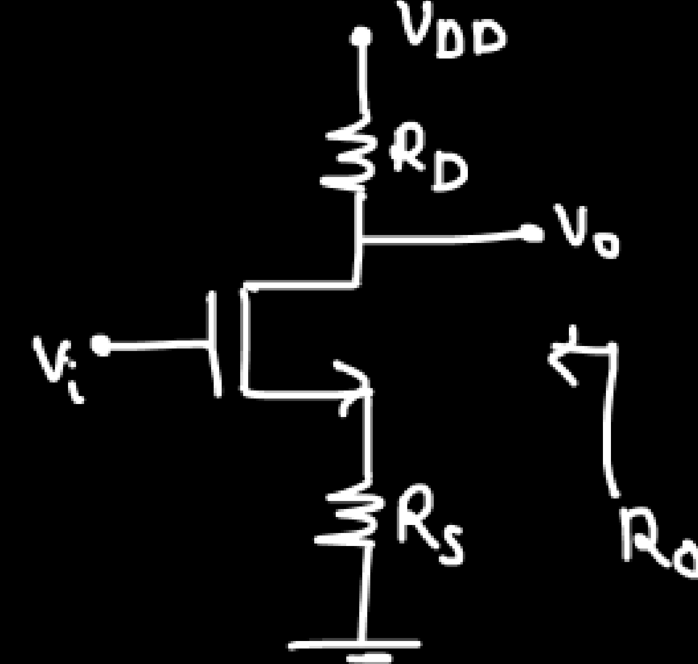
Common Source Amplifier:-

without degeneration



1. Less stability
2. $\frac{V_o}{V_i} = -g_m R_D \rightarrow$ more gain
3. $R_o = R_D \| r_o$

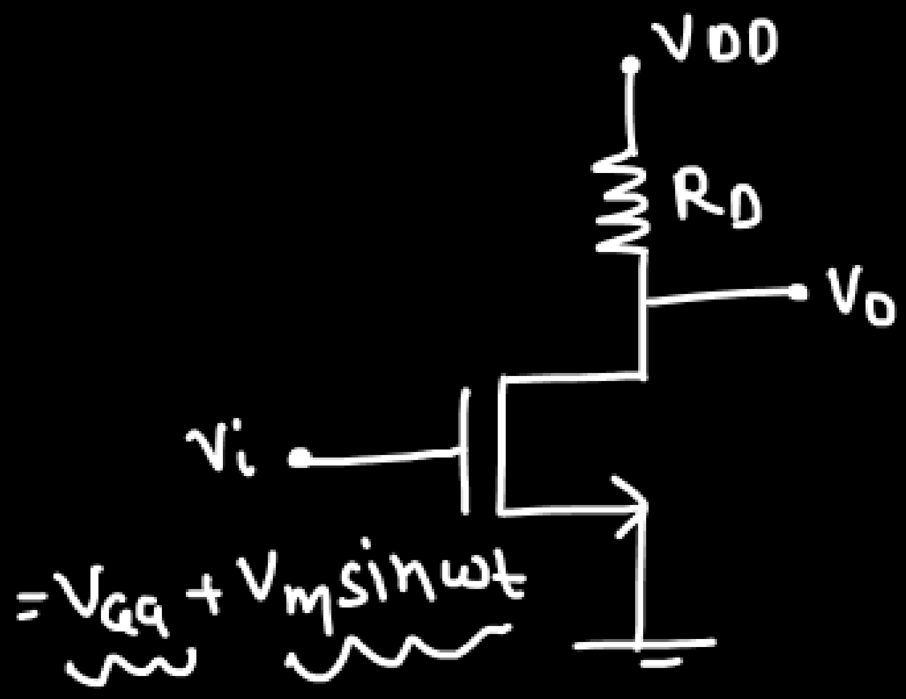
with degeneration



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:-



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

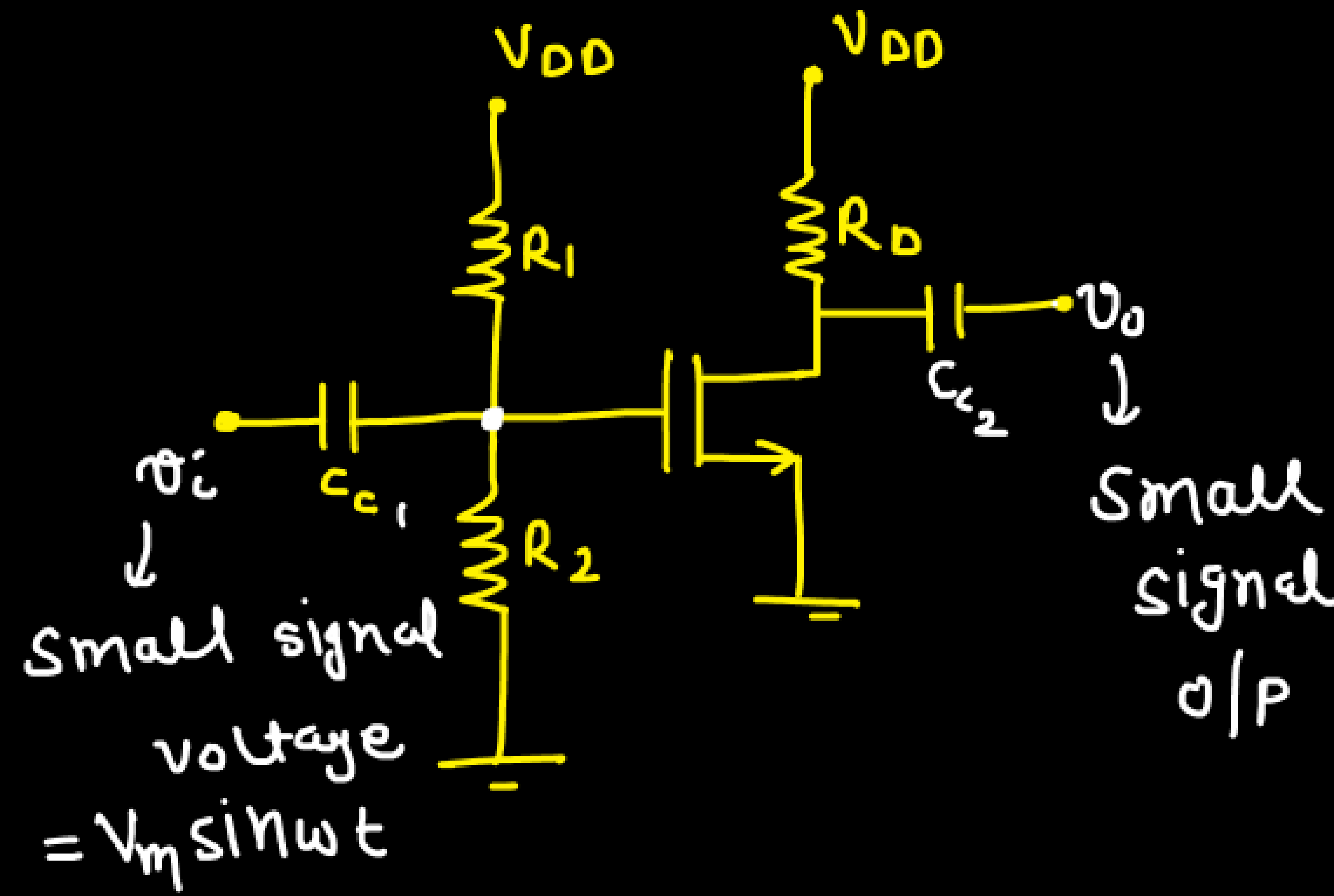
$\Downarrow$

NOT DESIRABLE

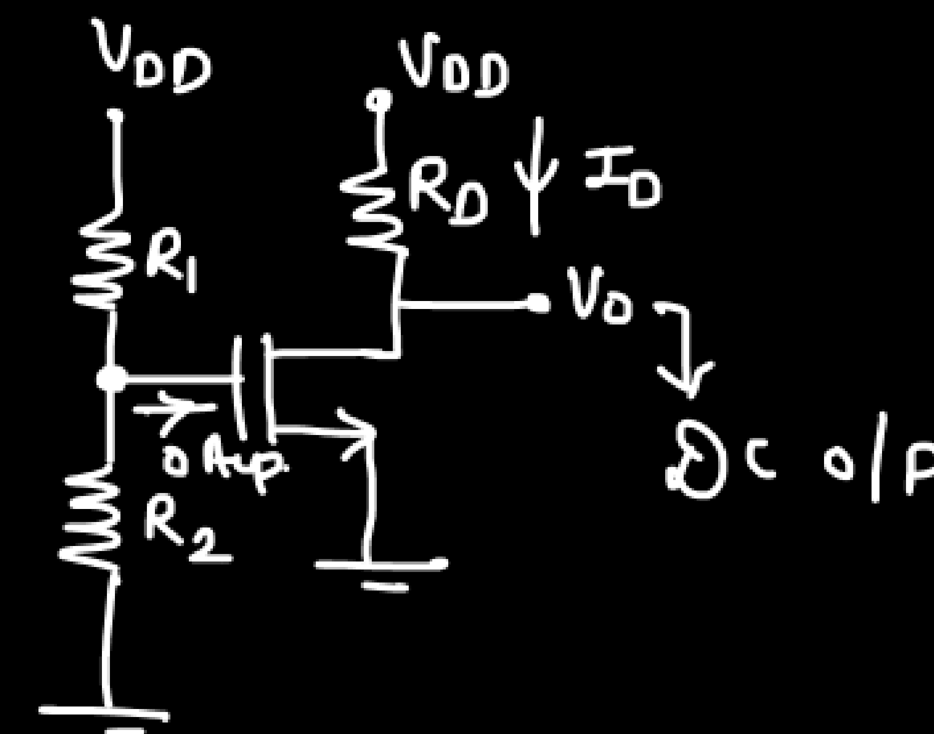
$\Rightarrow$ I will use only one supply.

New way of biasing:-

①



DC Analysis:-



① set R_1 and R_2 ; such that $V_{GS} > V_T$

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

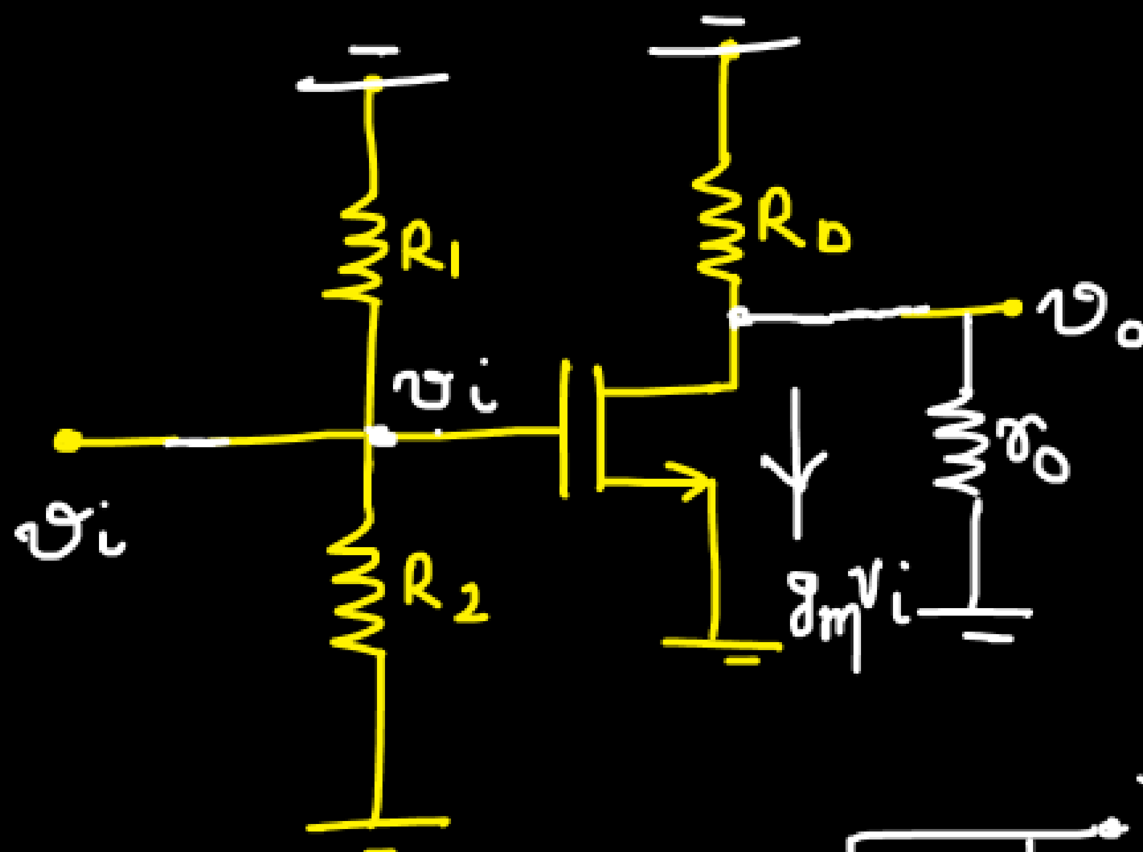
$$\boxed{V_{GS} = \frac{V_{DD} R_2}{R_2 + R_1}}$$

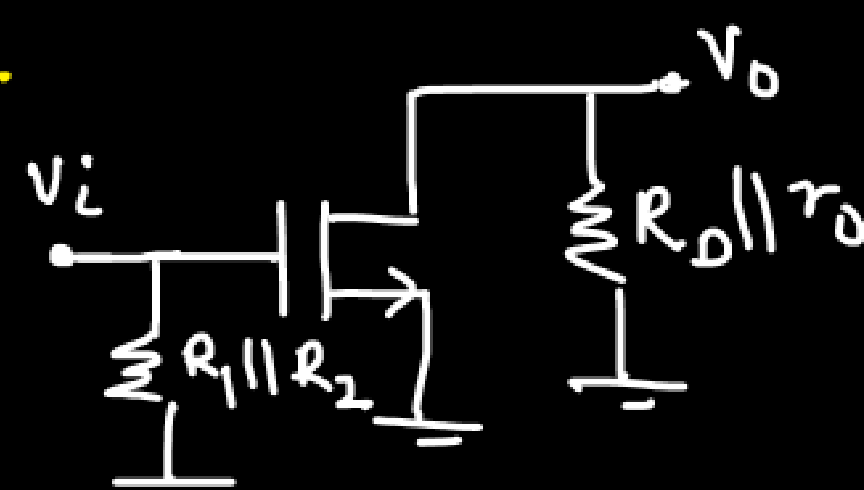
$$\boxed{I_D = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2}$$

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

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

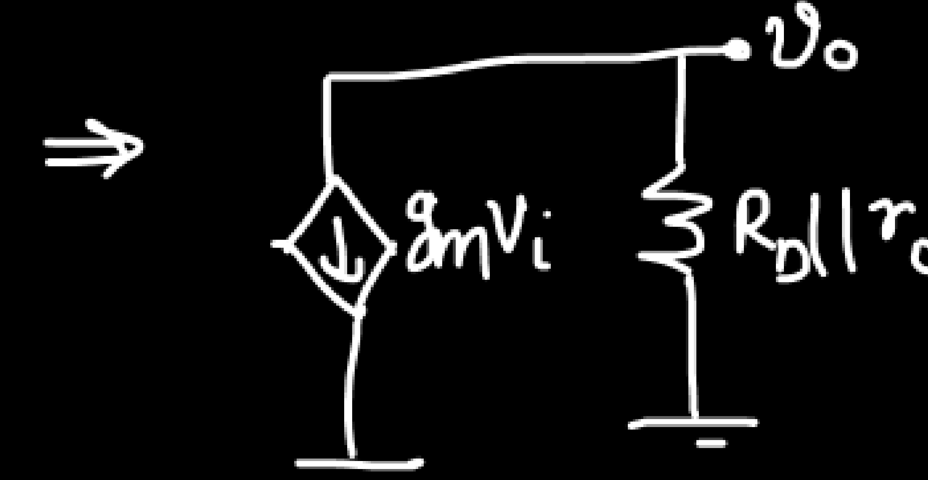
⇒ <u>AC Analysis</u>:-





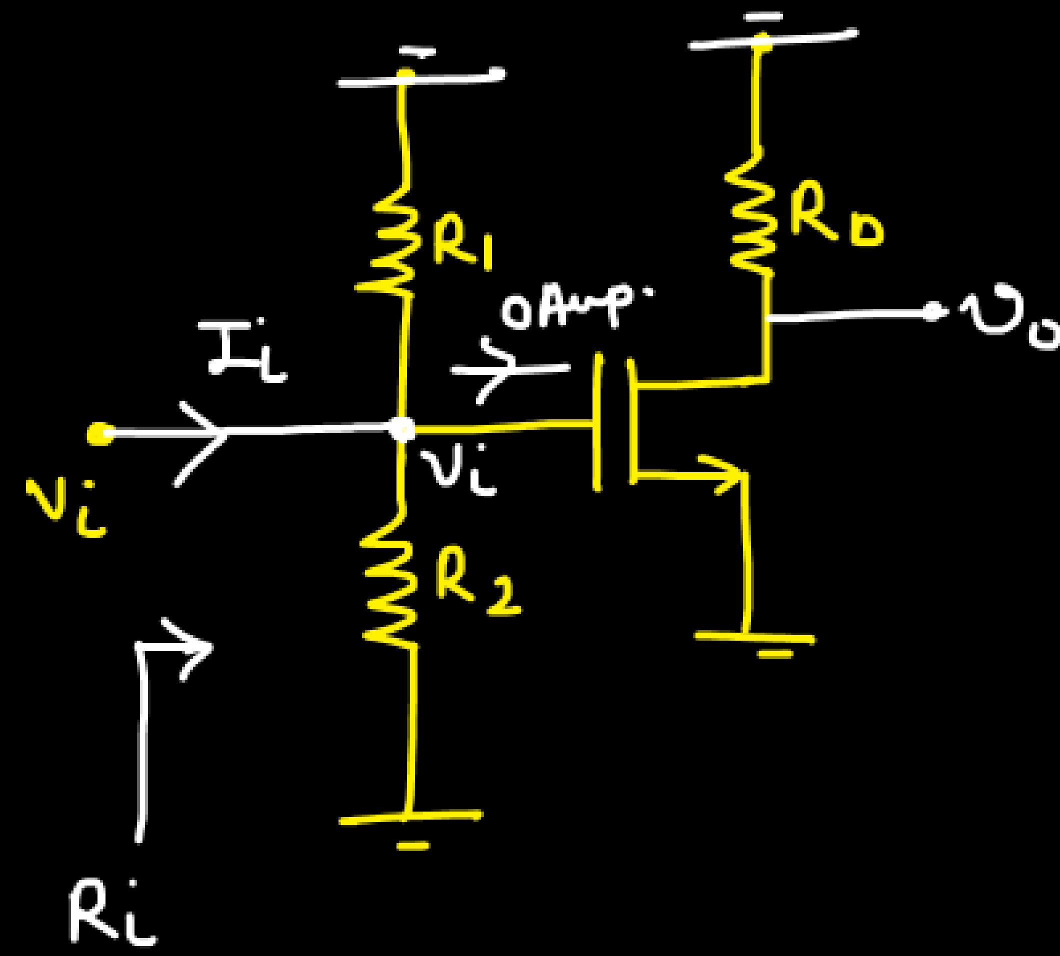
$$v_{gs} = v_i$$

⇒



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

Small signal i/p resistance:-



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

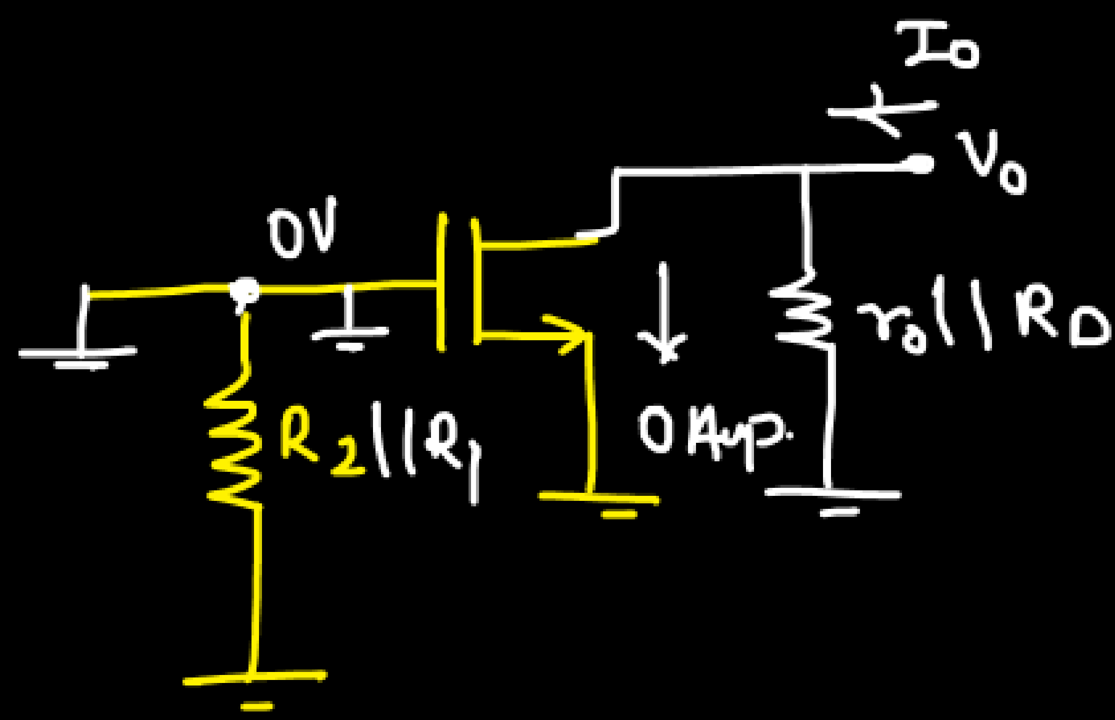
Nodal @ v_i

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

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

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

o/p resistance:-



$v_{gs} = 0V$

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

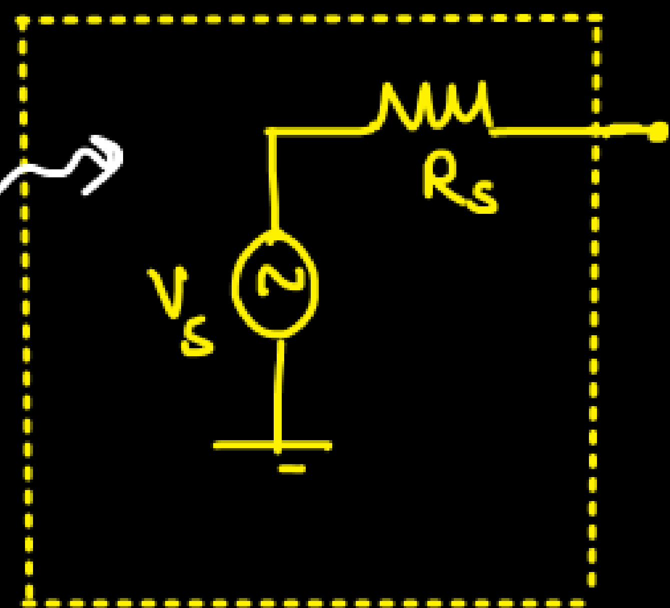
Why we use coupling capacitor (C_c) ?

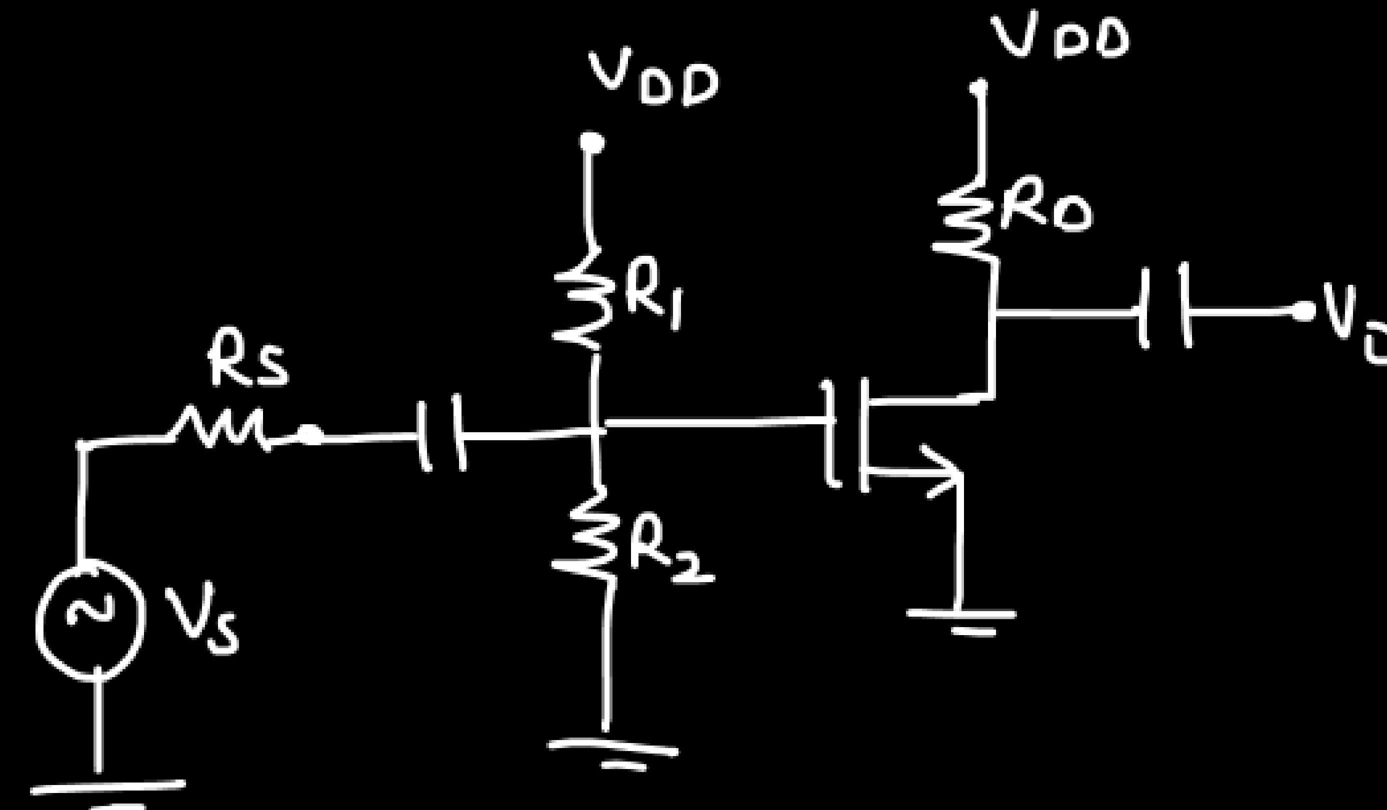
① Helps in isolating the dc bias setting.

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.

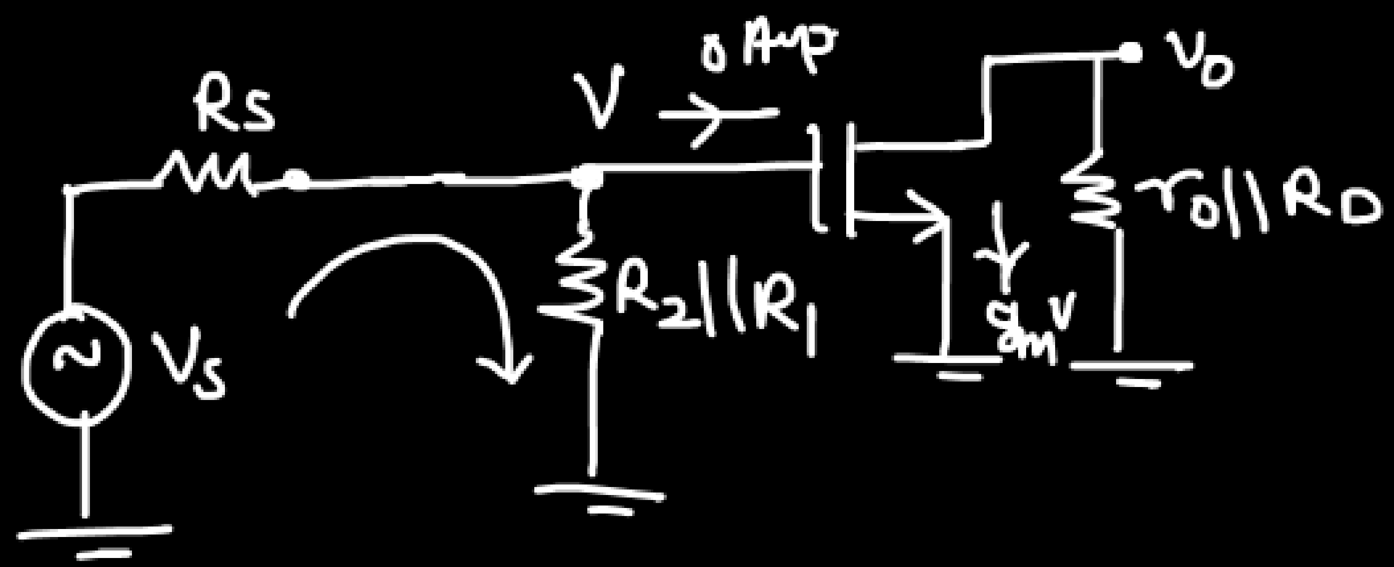
If small signal input source has some Resistance R_S.

v_i
↓
small signal i/P voltage





Small Signal Analysis:-



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

$$\boxed{V_0 = -g_m\,[R_D || r_0]\,v} \quad \text{—} \; (1)$$

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

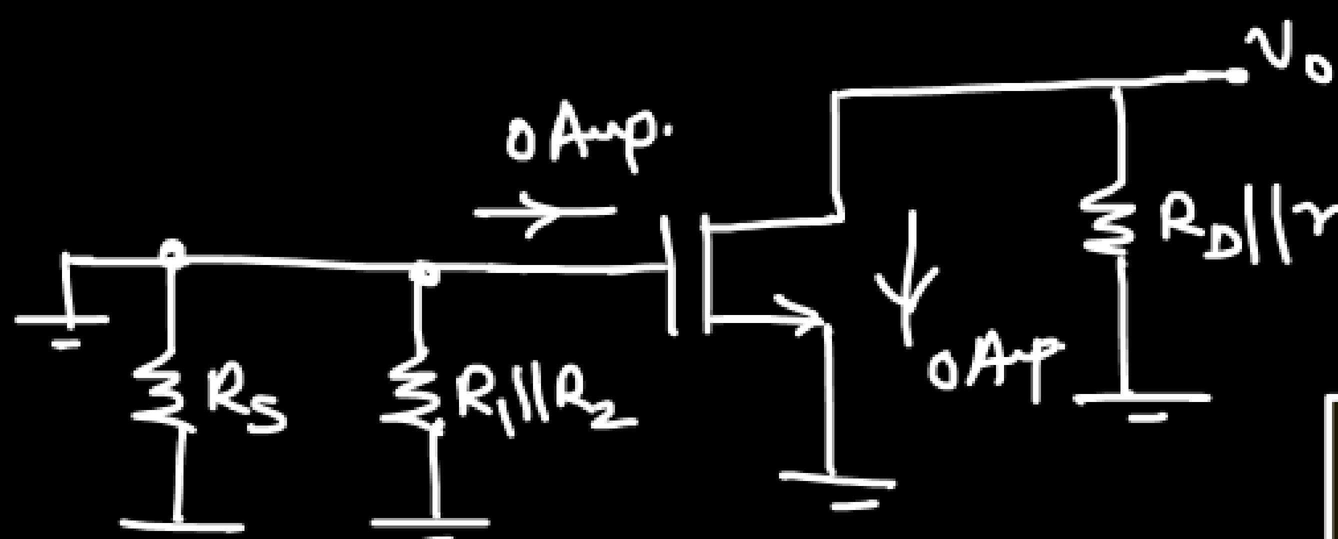
$$\boxed{A_V = \frac{V_0}{V_S} = -g_m\,[R_D || r_0] \times \frac{[R_2||R_1]}{[R_2||R_1]+R_s}} \rightarrow \text{Voltage gain}$$

input resistance:-

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

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

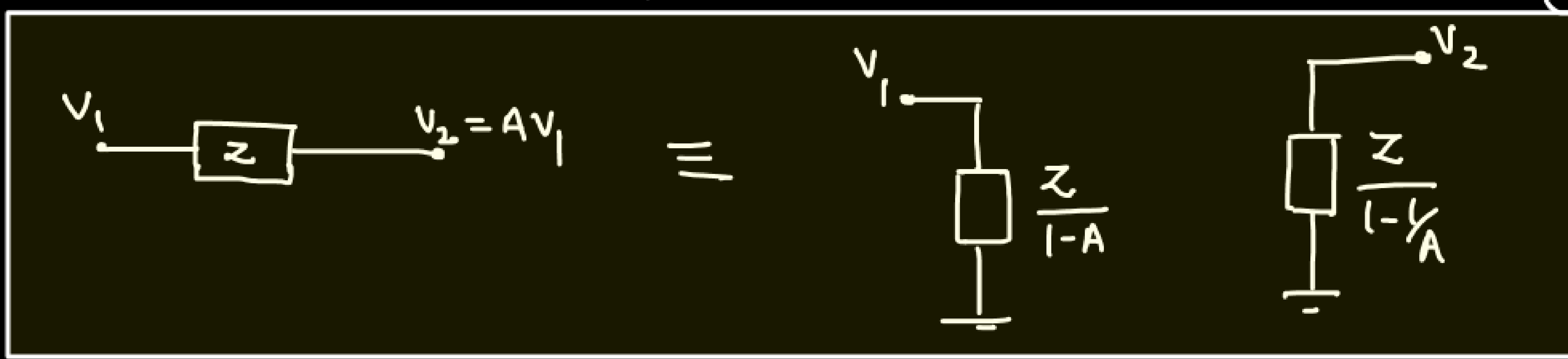
output resistance:-



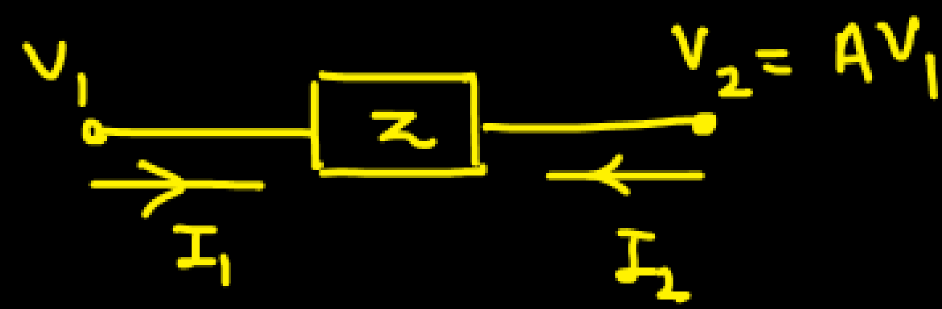
$$\boxed{R_o = R_D || r_o}$$

Miller's Theorem :-

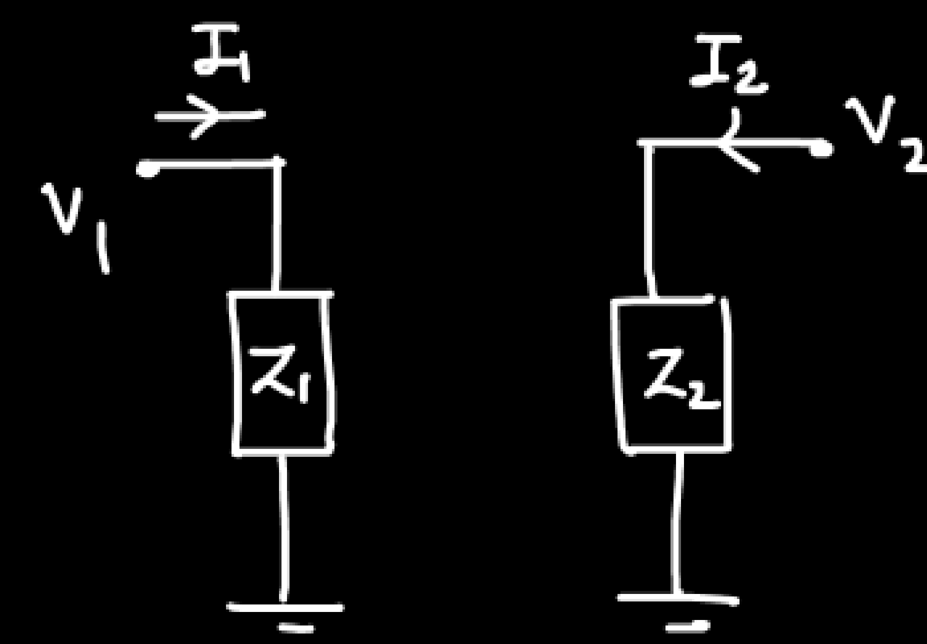
In a linear ckt, if there exist a branch with impedance Z, connecting two nodes with nodal voltage V_1 and V_2. We can replace this branch by two branches connecting the corresponding to ground by impedance respectively $\frac{Z}{1-A}$ and $\frac{Z}{1-\frac{1}{A}}$; where $A = \frac{V_2}{V_1}$



Derivation:-



$\equiv$



$$I_1 = -I_2$$

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

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

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

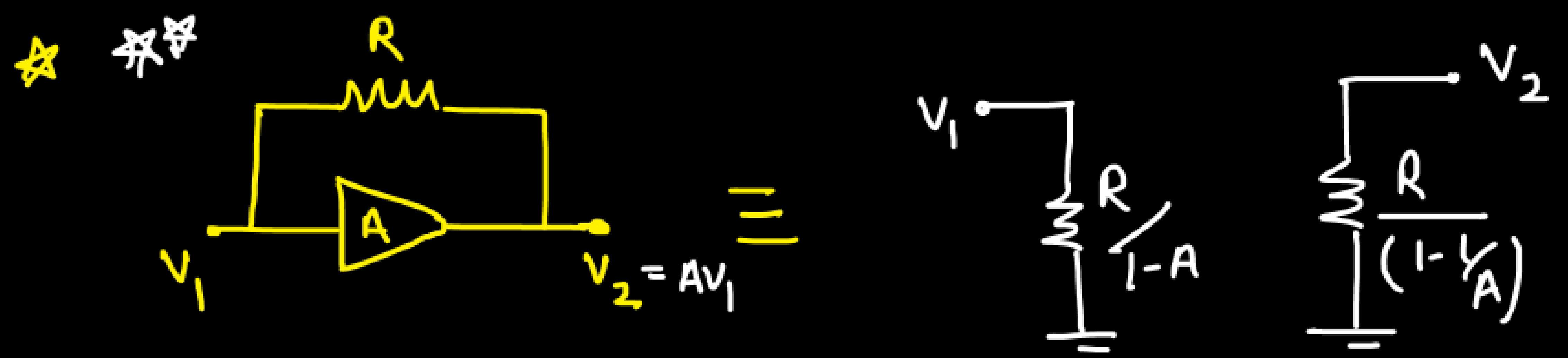
$$\boxed{\frac{V_1}{I_1} = \frac{Z}{1-A} = Z_1}$$

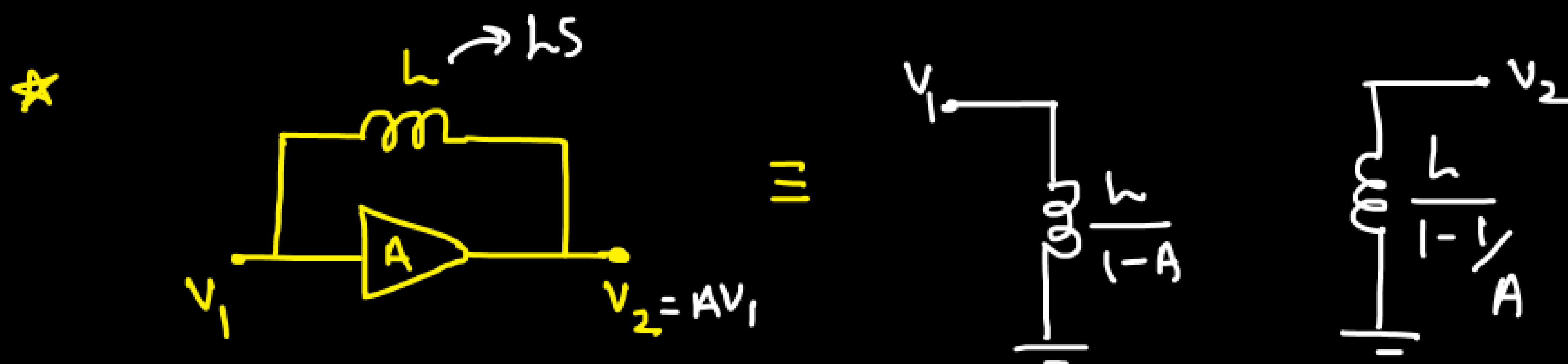
$$\boxed{Z_2 = \frac{V_2}{I_2}}$$

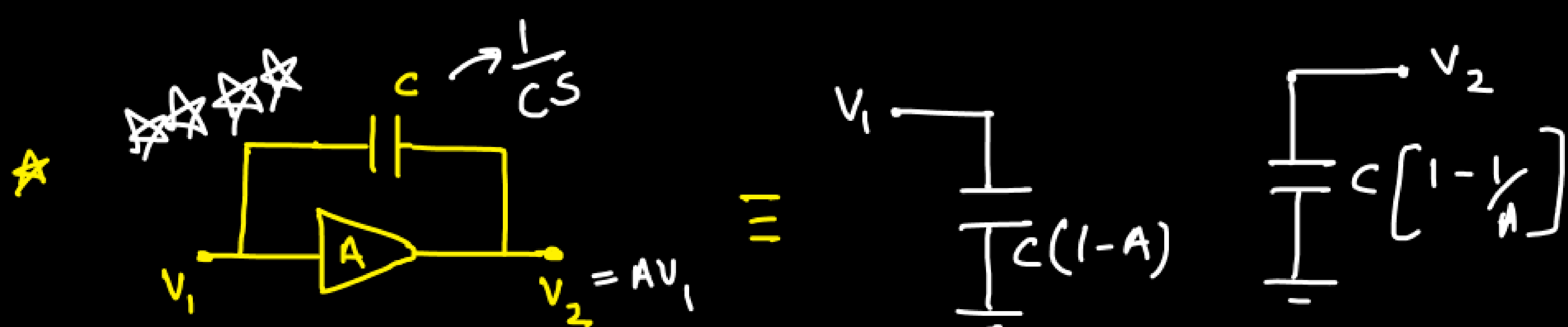
$$\frac{V_2 - V_1}{Z} = I_2$$

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

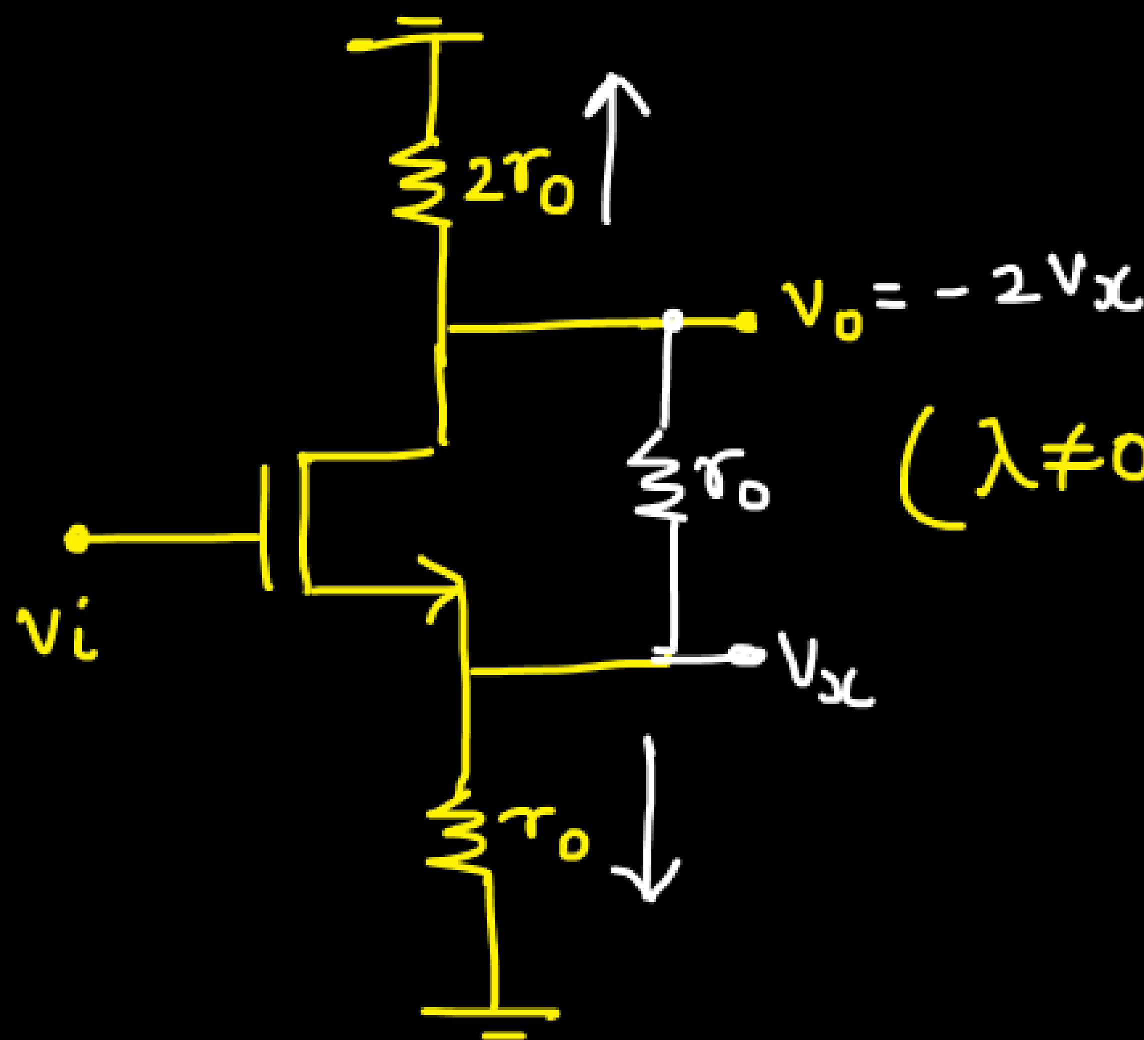
$$\boxed{\frac{V_2}{I_2} = \frac{Z}{1-1/A} = Z_2}$$


R
A
V1
V2 = AV1
≡
V1
R/(1-A)
V2
R/(1-1/A)

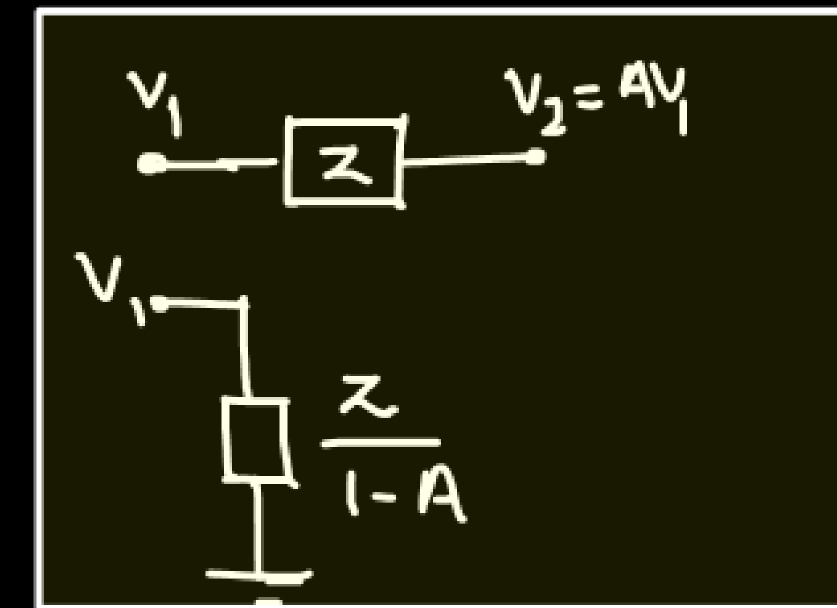

L → LS
A
V1
V2 = AV1
≡
V1
L/(1-A)
V2
L/(1-1/A)


C → 1/CS
A
V1
V2 = AV1
≡
V1
C(1-A)
V2
C[1-1/A]

Eg.



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

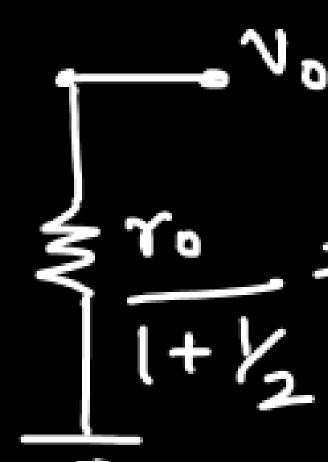


$$\frac{V_x}{r_o} = -\frac{V_o}{2r_o}$$

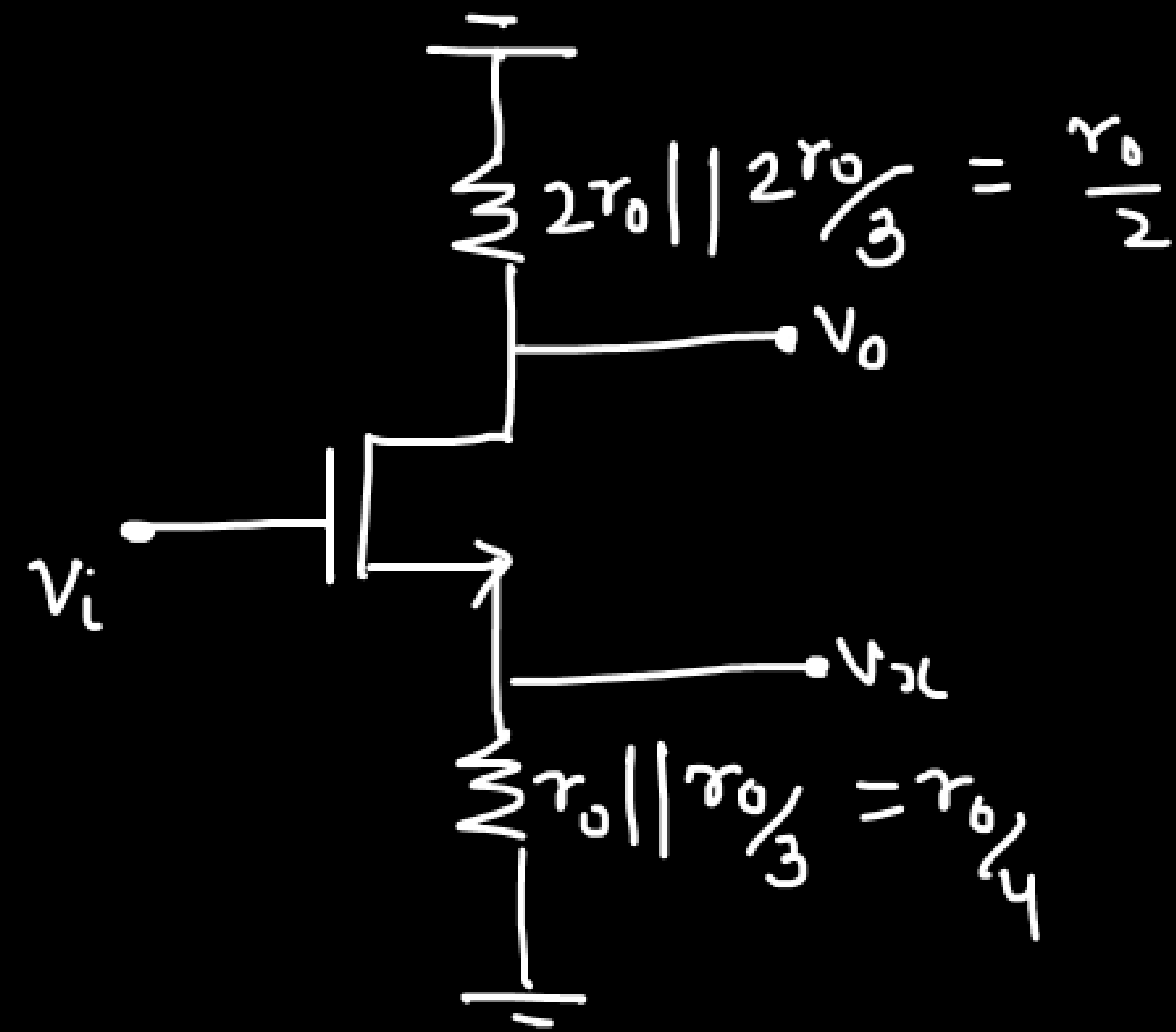
$$\frac{V_o}{V_x} = -2 \Rightarrow \boxed{V_o = -2V_x}$$

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

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



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

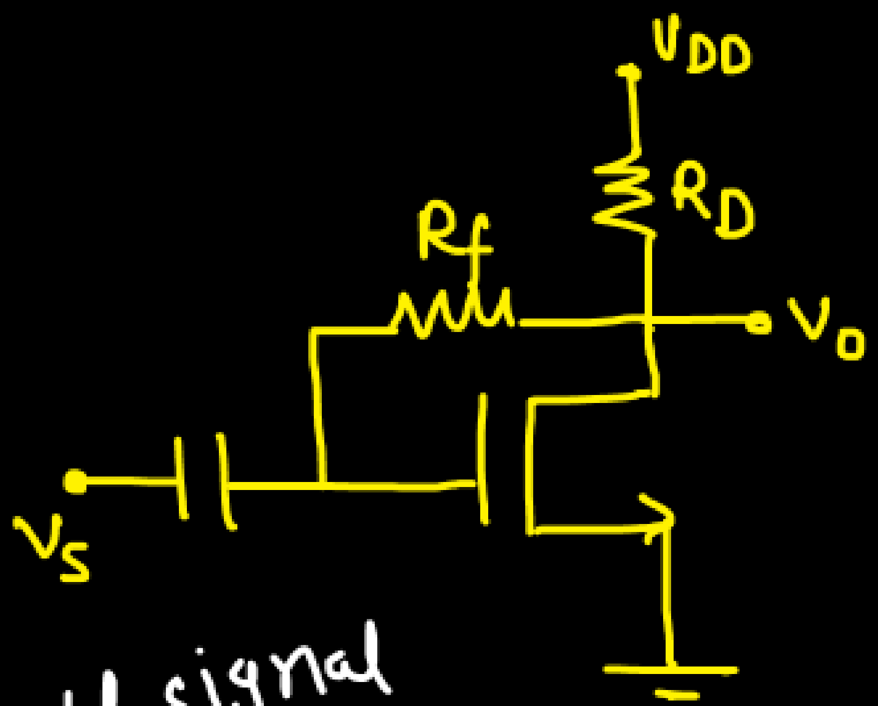


$$\frac{v_o}{v_i} = \frac{-g_m\left[r_0/2\right]}{1+g_m\left[r_0/4\right]}$$

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

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

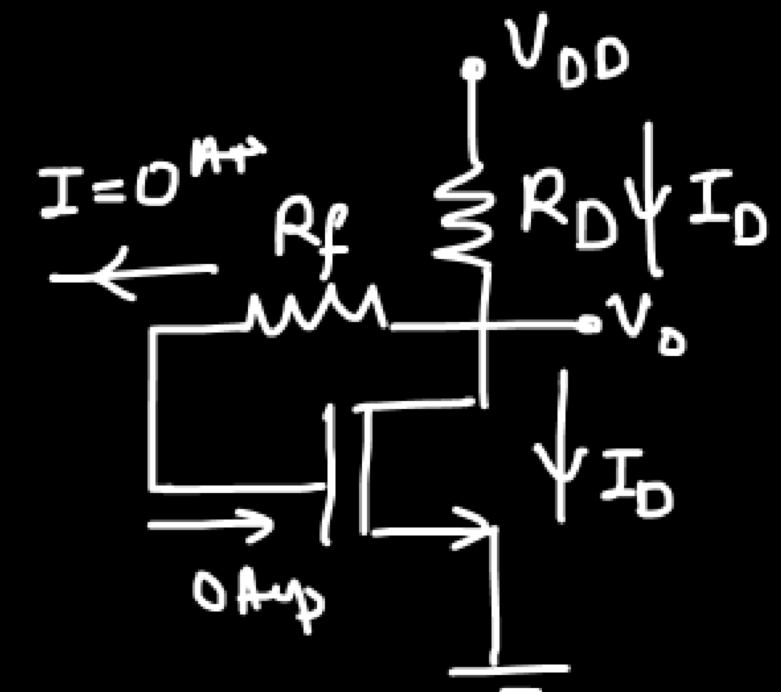
② Self bias stage:-



Small signal i/p voltage

$\Rightarrow$

DC Analysis:-



$V_{GS} = V_o$

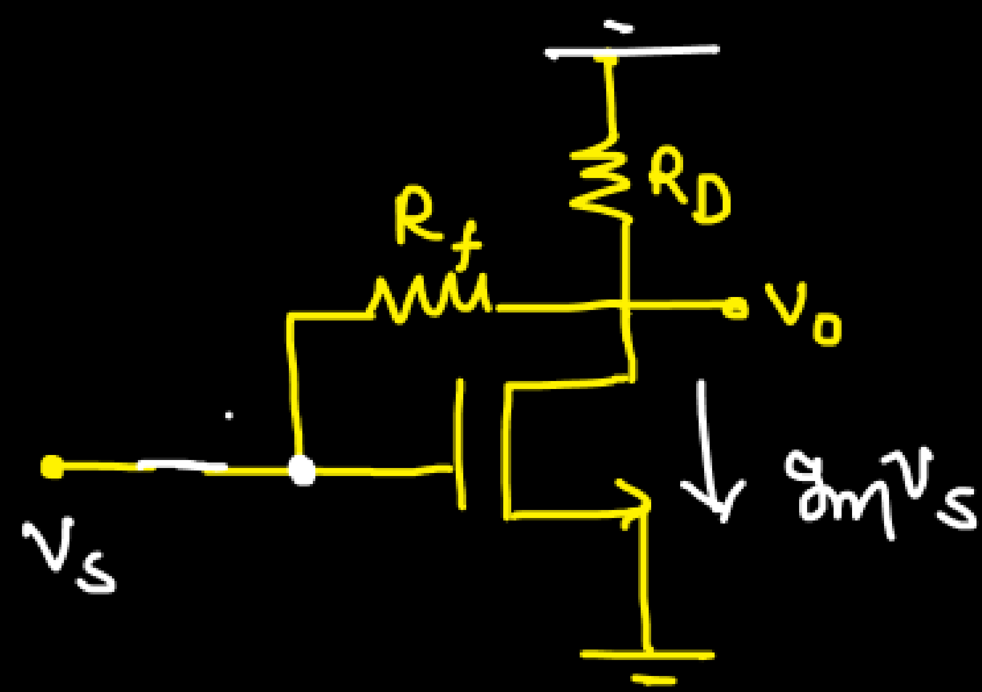
$V_{DS} = V_o$

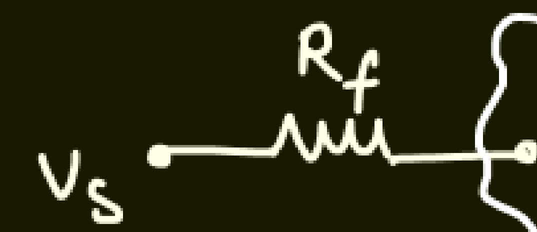
$V_{ov} = V_o - V_T$

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

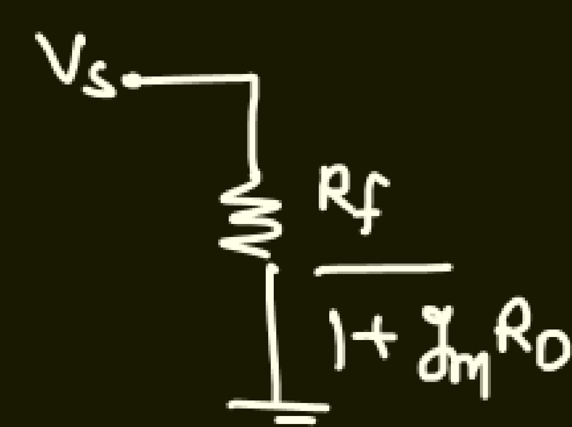
① Make sure that $\boxed{V_{DD} - I_D R_D > V_T}$ → Ensuring MOS is ON

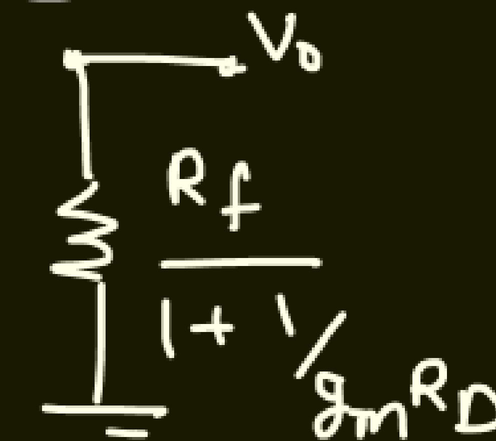
AC Analysis:-





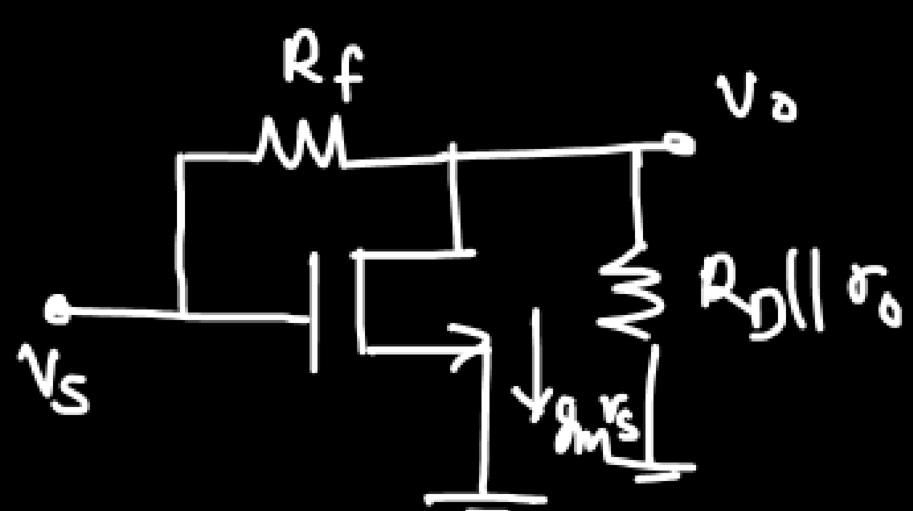
$V_o = -g_m R_D V_s$





Correct only $R_f \rightarrow$ very High

$\Rightarrow$



nodal @ V_o

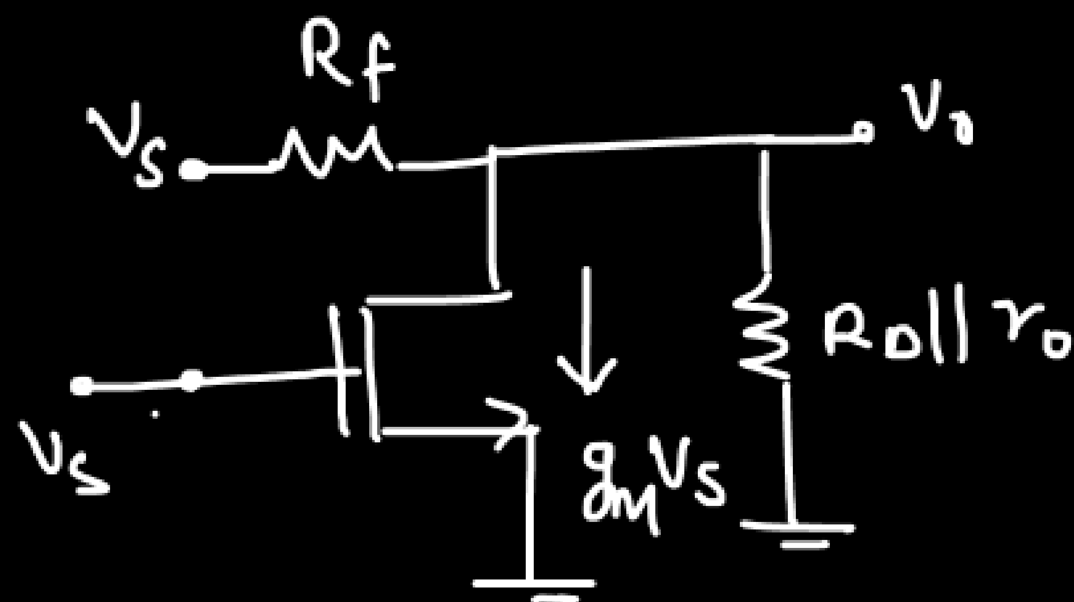
$$\frac{V_o}{R_D \| r_o} + g_m V_s + \frac{V_o - V_s}{R_f} = 0$$

$$\frac{v_o}{R_D \| r_o} + \frac{v_o}{R_f} = \frac{v_s}{R_f} - g_m v_s$$

$$\frac{v_o}{R_f \| R_D \| r_o} = \frac{v_s}{\left(-\frac{1}{g_m} \| R_f\right)}$$

$$\boxed{\frac{v_o}{v_s} = \frac{R_f \| R_D \| r_o}{-\frac{1}{g_m} \| R_f}} = A$$

M - II :-

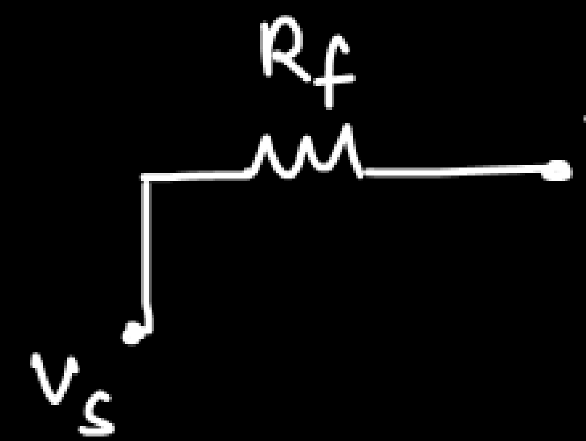


$\Rightarrow$

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

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

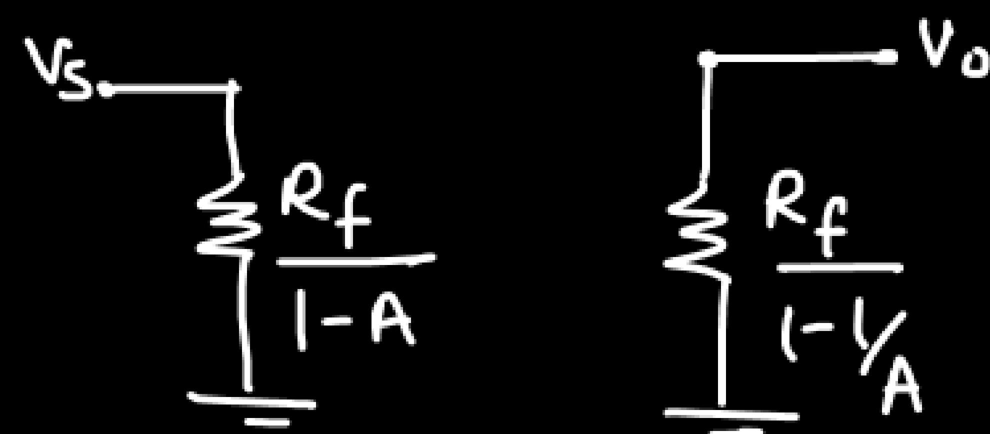
☆



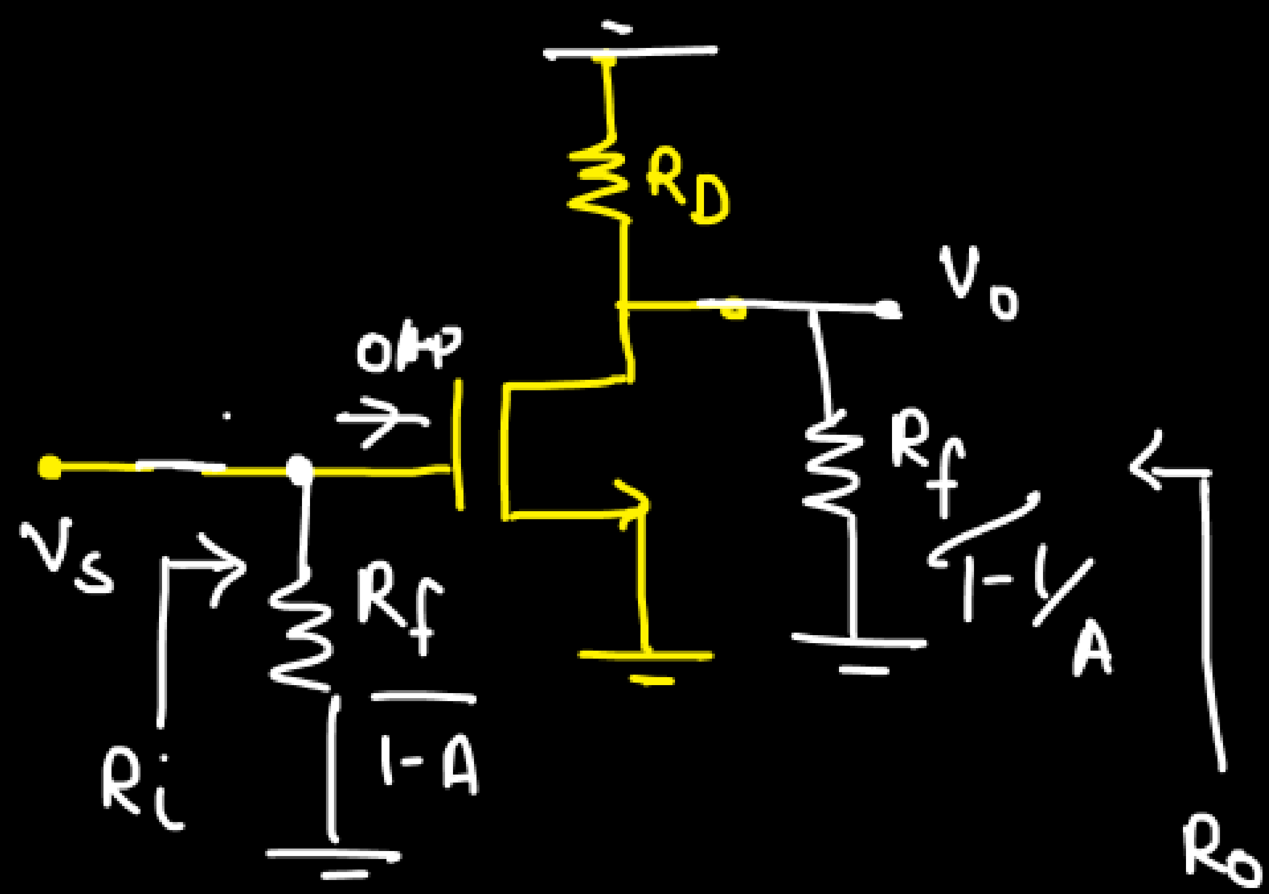
$V_o = A V_s$

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

$\Rightarrow$



input resistance :- / Output resistance :-



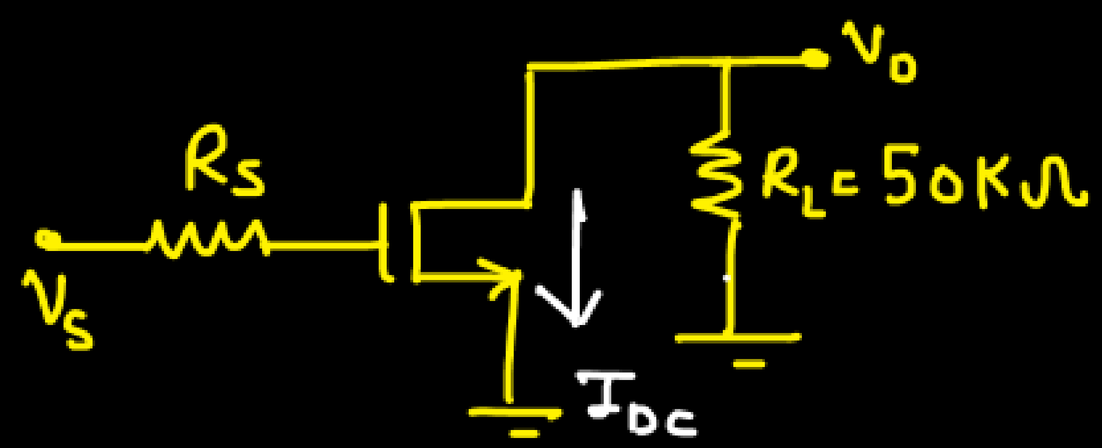
$$\boxed{R_i = \frac{R_f}{1-A}}$$

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

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

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.

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

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

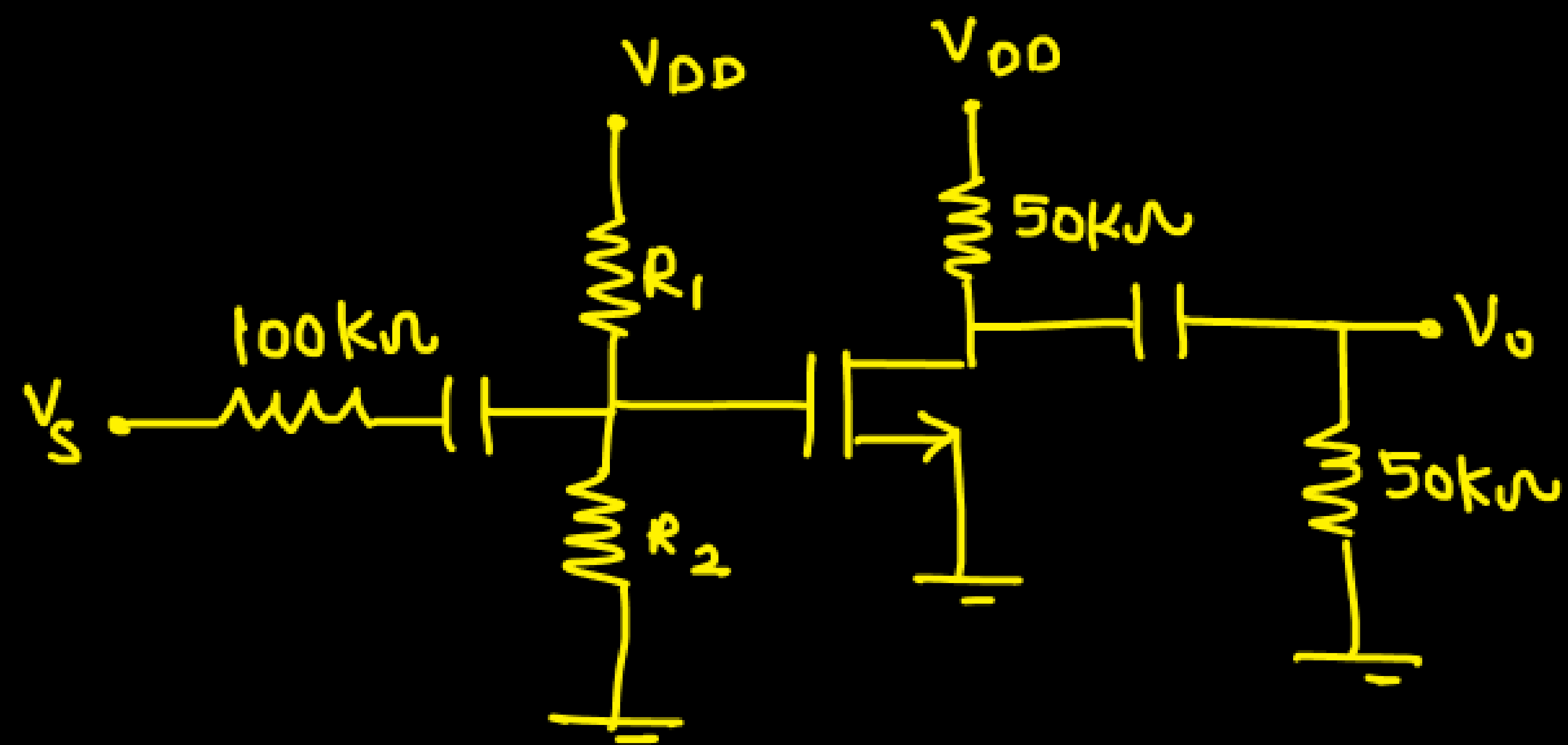
$$g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_{DC}} = 0.16m$$

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

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

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

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; $V_{DS} = V_{GS} + 1$

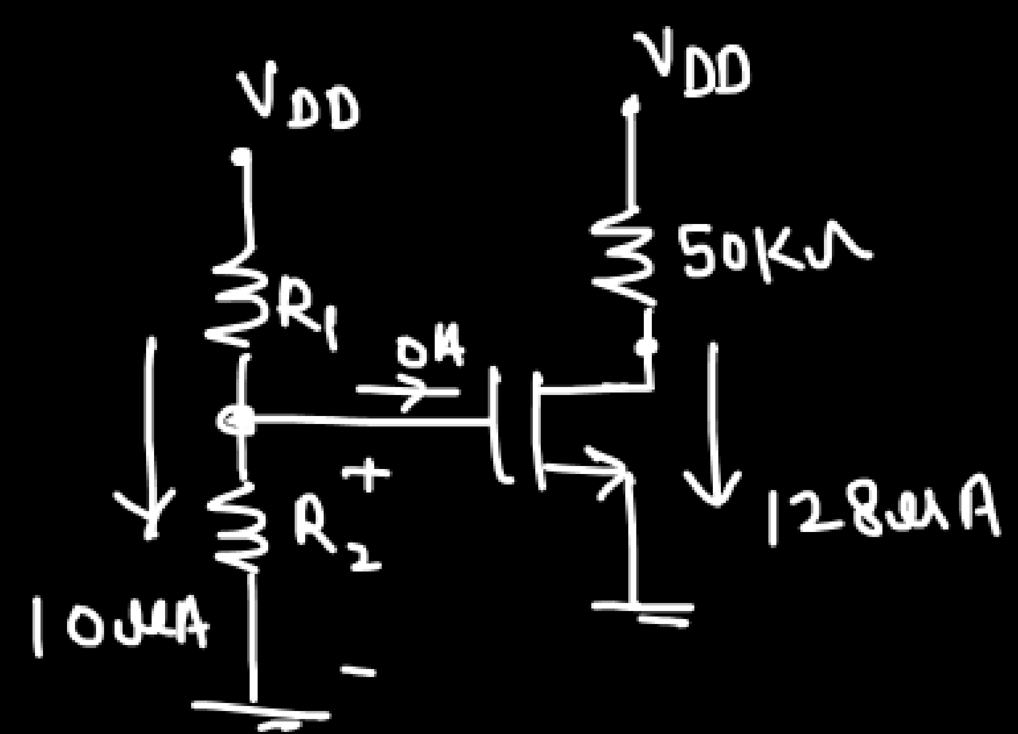
The bias current flowing through $R_{1,2}$ is $10\,\mu A$.

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

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

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

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

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

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

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

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

$$\boxed{V_{DD} = 10V}$$

ANS.

② $R_1 = ?$, $R_2 = ?$

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

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

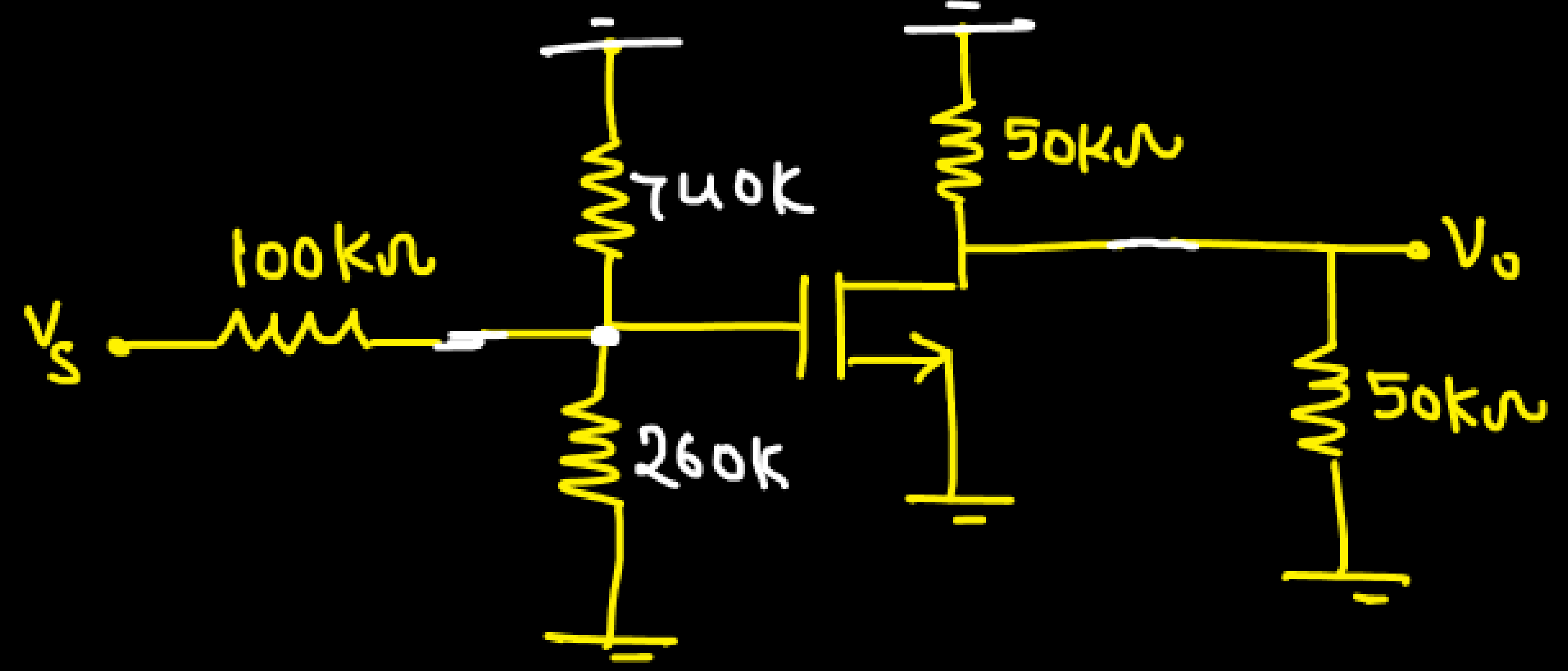
$$\boxed{R_1 + R_2 = 1\,M\Omega} = 1000\,K\Omega$$

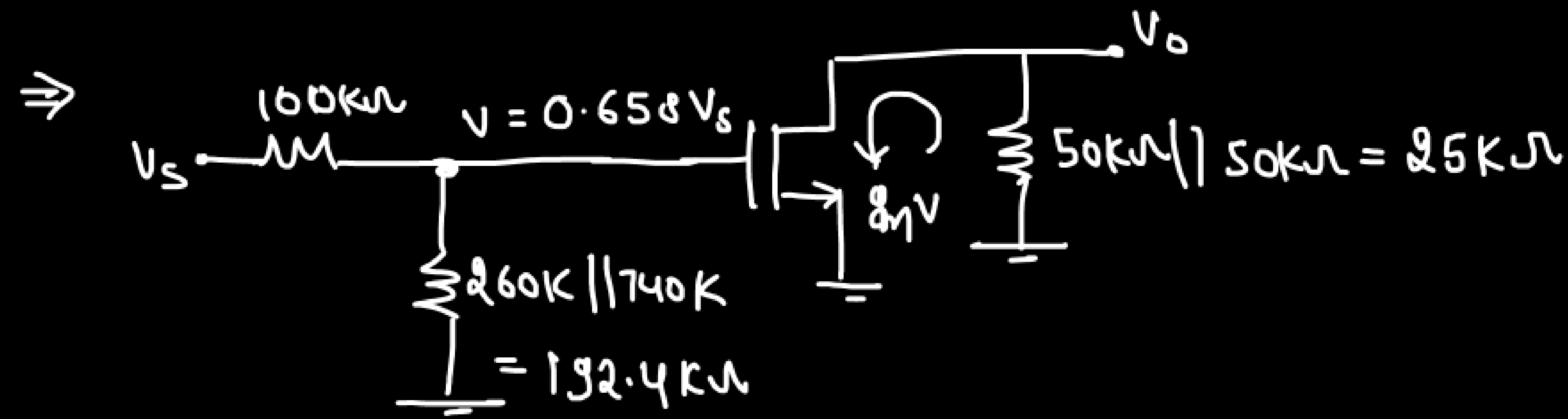
Here , $V_{GS} = 10\,\mu \times R_2 = 2.6$

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

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

③ Small signal voltage gain:-





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

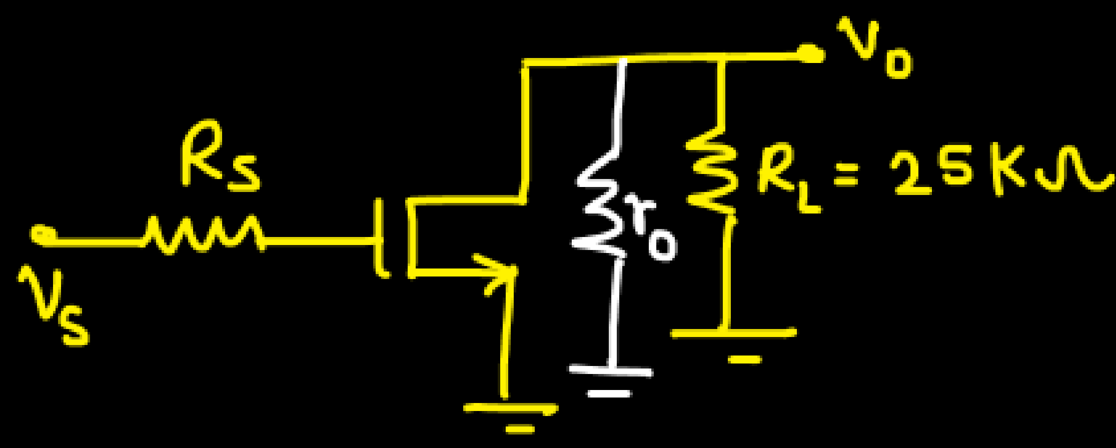
$g_m = ?$

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

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

$$\boxed{\frac{v_o}{v_s} = -2.63\ V/V}$$

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.

→ $-g_m \times 25K\Omega = -4$

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

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

$$r_o = ?$$

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

$$g_m = 0.16\,mS$$

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

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

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

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

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

Actual gain $= -0.16 \times 10^{-3} [125 \| 25] \times 10^{3}$

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

N.B. -

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

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

$$[g_m]_{\lambda \neq 0} = \frac{\mu_n C_{ox} W}{2} (V_{GS} - V_T)^2 [1 + \lambda V_{DS}]$$

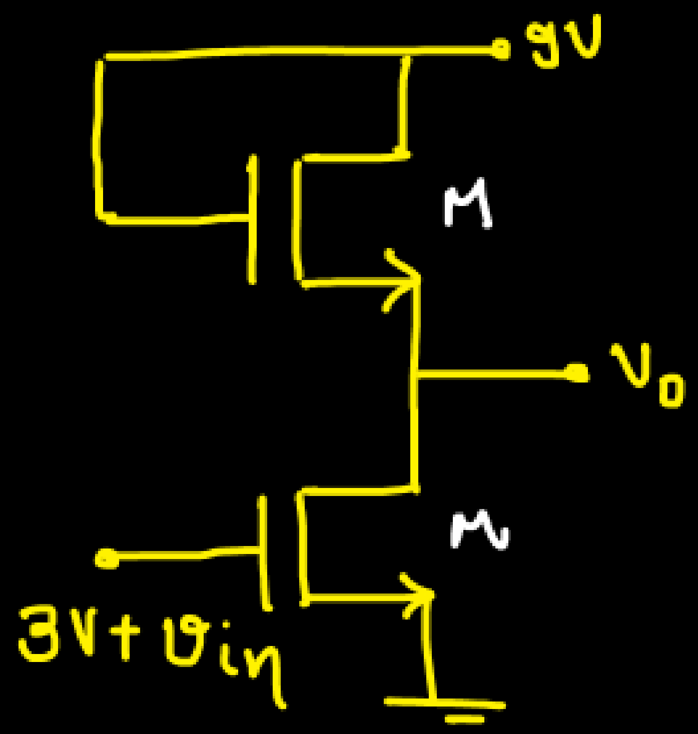
since λ = very small $\Rightarrow$ $\boxed{[g_m]_{\lambda=0} = [g_m]_{\lambda \neq 0}}$

Q. All the transistor are identical with

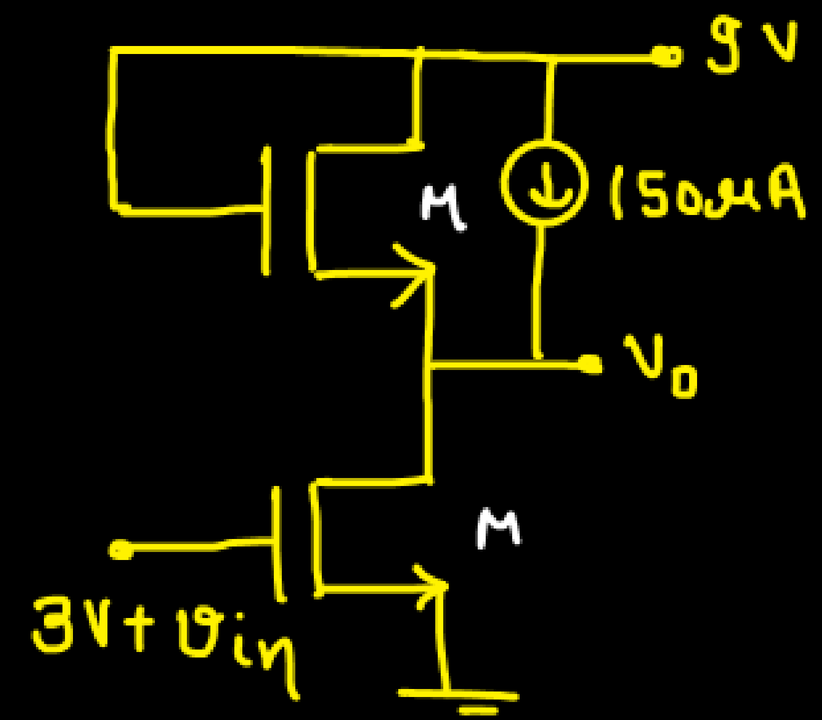
$$\frac{\mu_n C_{ox} W}{L} = 100\,\mu A/V^2 \,, \quad V_T = 1V \,, \quad \lambda = 0$$

(biased in sat. region)

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

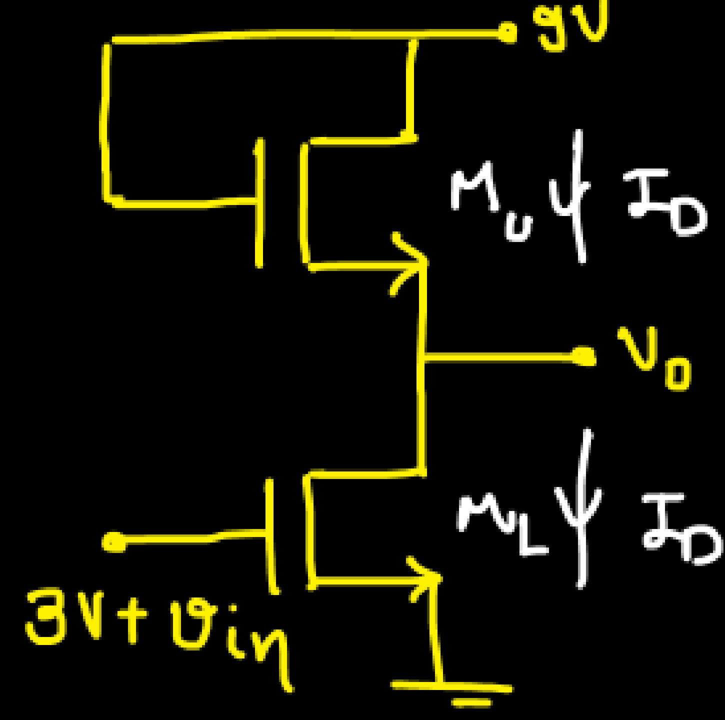


(a)



(b)

(i)

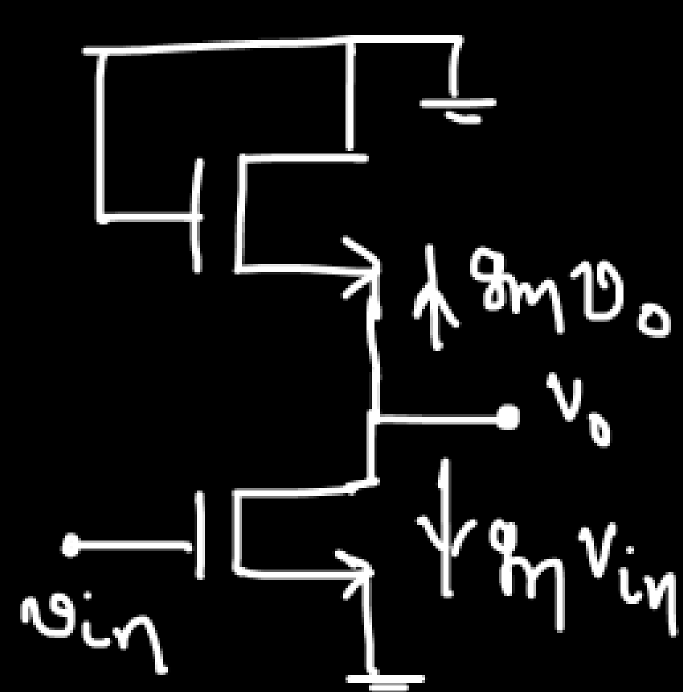


(a)

Both M_U and M_L will have same g_m value.

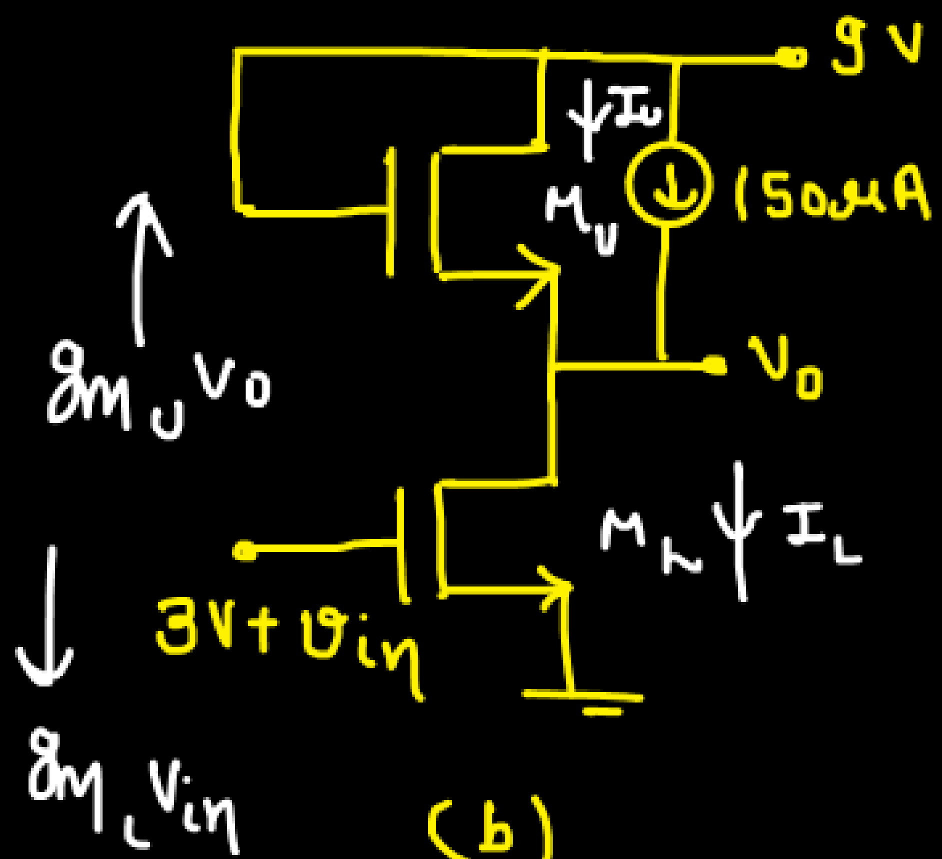
$$\left[g_m = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_D} \right]$$

$\Rightarrow$



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

$$\boxed{\frac{V_0}{v_{in}} = -1}$$



(b)

$I_U = 150\mu - I_L$

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

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

$$\boxed{\begin{array}{l} I_L = 200\,\mu A \rightarrow g_{m_L} \\ I_U = 50\,\mu A \rightarrow g_{m_U} \end{array}} \longrightarrow (1)$$

Small signal gain

$$\boxed{A_V = \frac{-g_{m_L}}{g_{m_U}}} \longrightarrow (2)$$

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

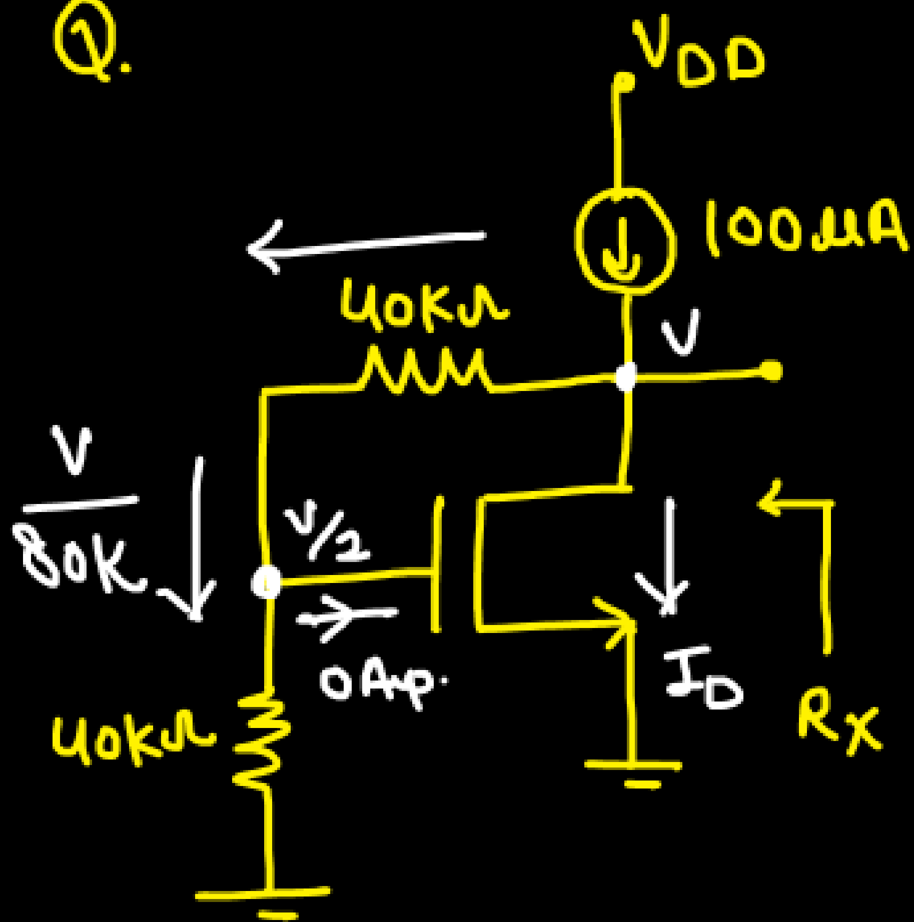
$$\frac{g_{m_L}}{g_{m_U}} = \frac{\sqrt{I_{D_L}}}{\sqrt{I_{D_U}}}$$

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

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

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

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.

① $V_{DS} = V$

$V_{GS} = V/2$

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

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

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

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

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

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

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

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

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

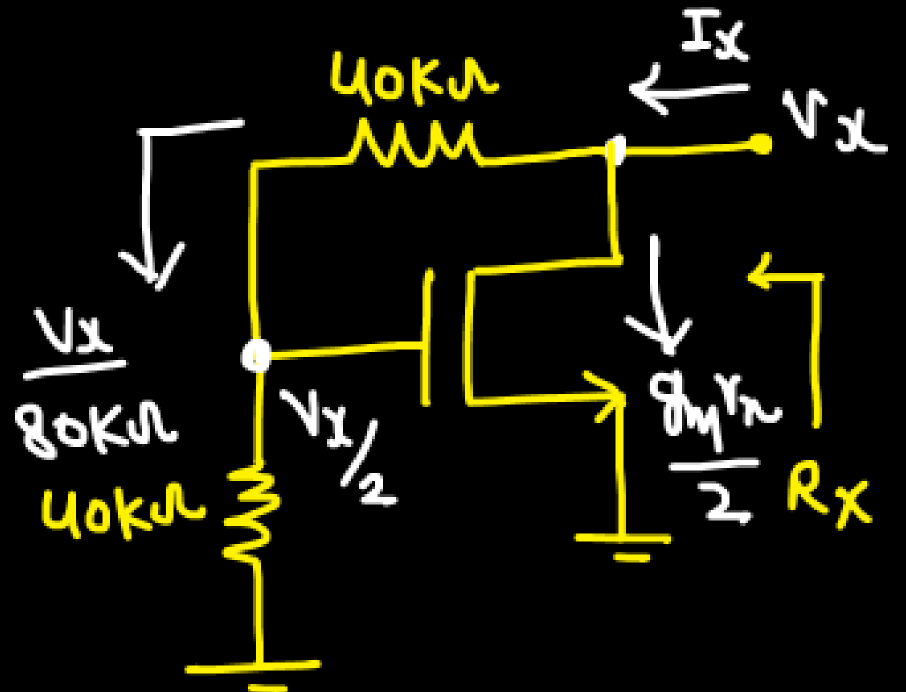
$$V^2 - 4V + V - 4 = 0$$

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

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

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

Small Signal Analysis:-



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

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

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

$g_m = ?$

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

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

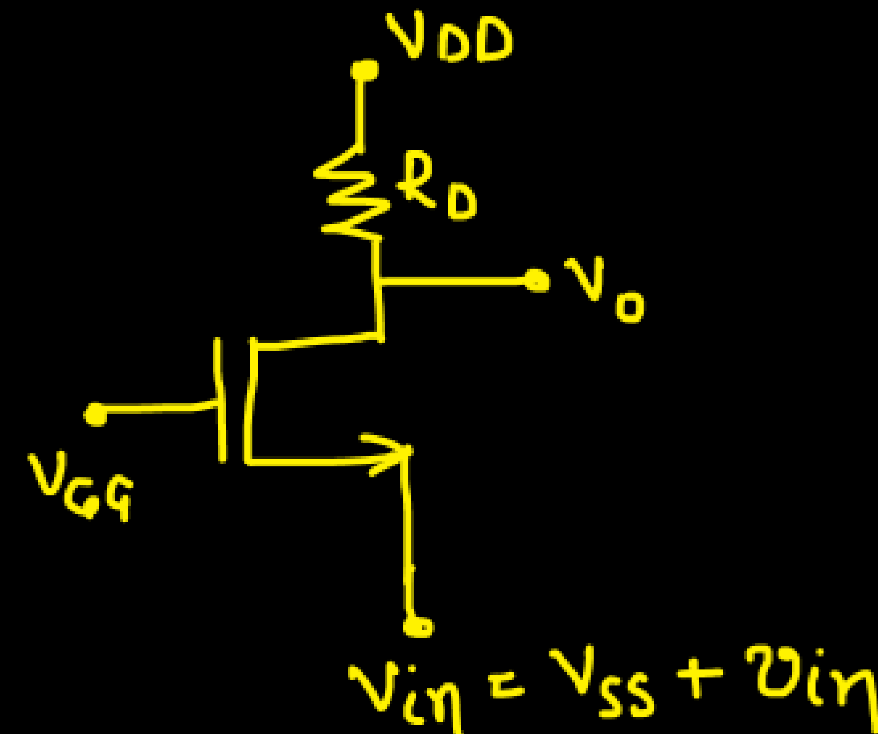
$$\boxed{g_m = 100\,\mu S}$$

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

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

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

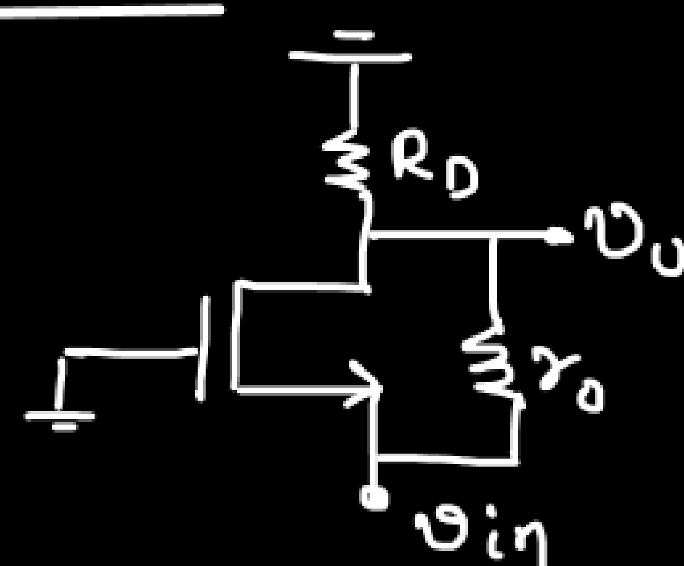
Common Gate Amplifier:-



Small signal i/p → source

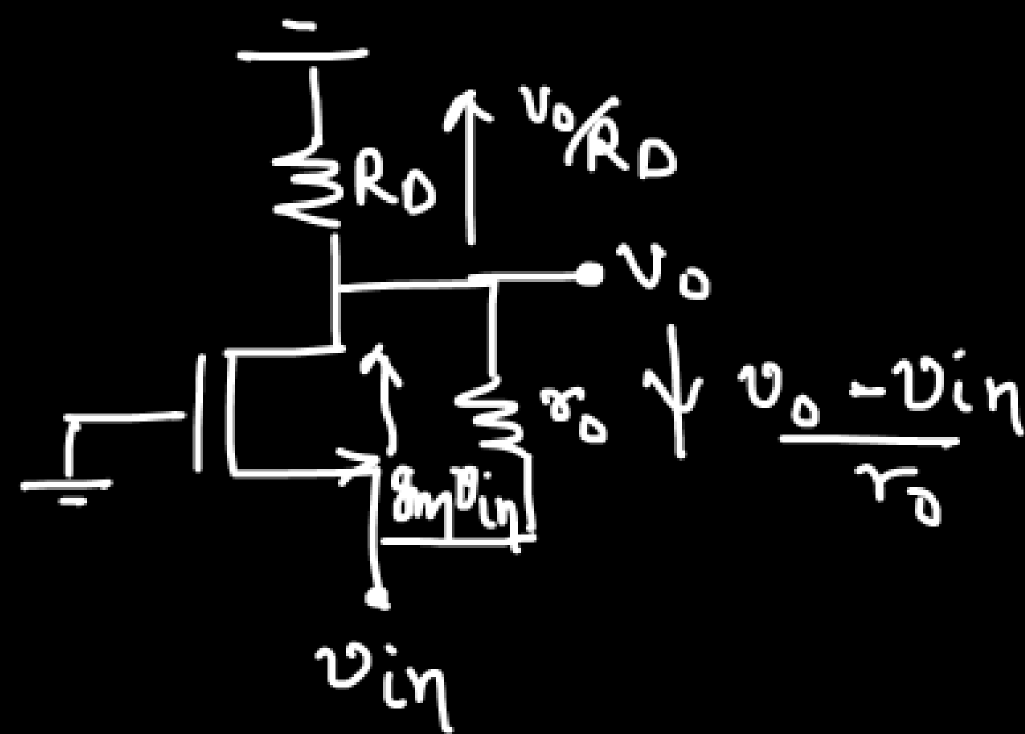
" " o/p → Drain

Small signal model:-



⇒ Voltage gain :-

$(\lambda \neq 0)$ r_o = finite



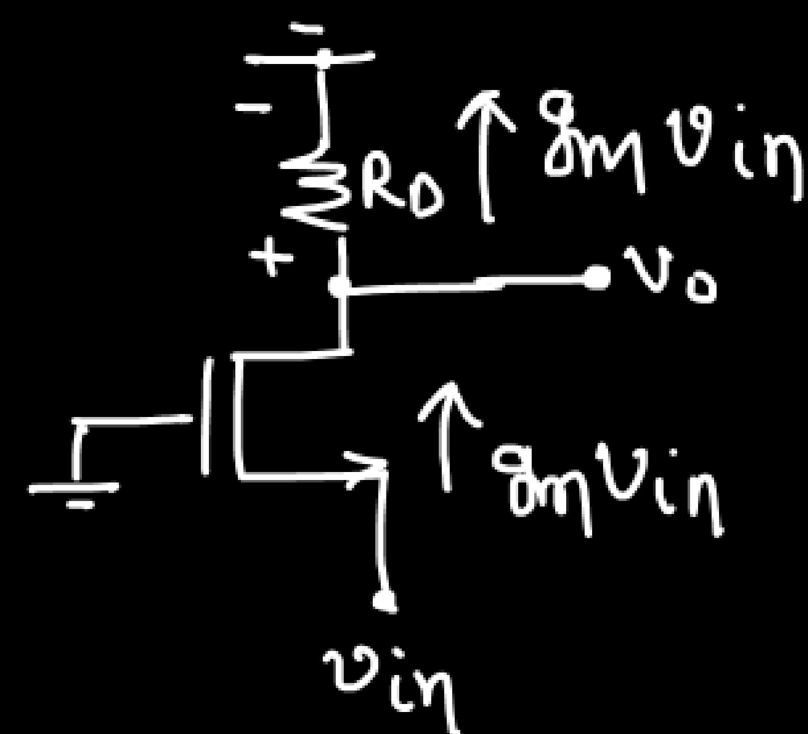
$$g_m v_{in} = \frac{v_o}{R_D} + \frac{v_o - v_{in}}{r_o}$$

$$v_{in}\left[g_m + \frac{1}{r_o}\right] = v_o\left[\frac{1}{R_D} + \frac{1}{r_o}\right]$$

$$v_{in}\left[\frac{g_m r_o + 1}{r_o}\right] = v_o\left[\frac{r_o + R_D}{R_D r_o}\right]$$

$$\boxed{\frac{v_o}{v_{in}} = \frac{R_D\left[g_m r_o + 1\right]}{r_o + R_D}}$$

Voltage gain ($\lambda = 0$) :-



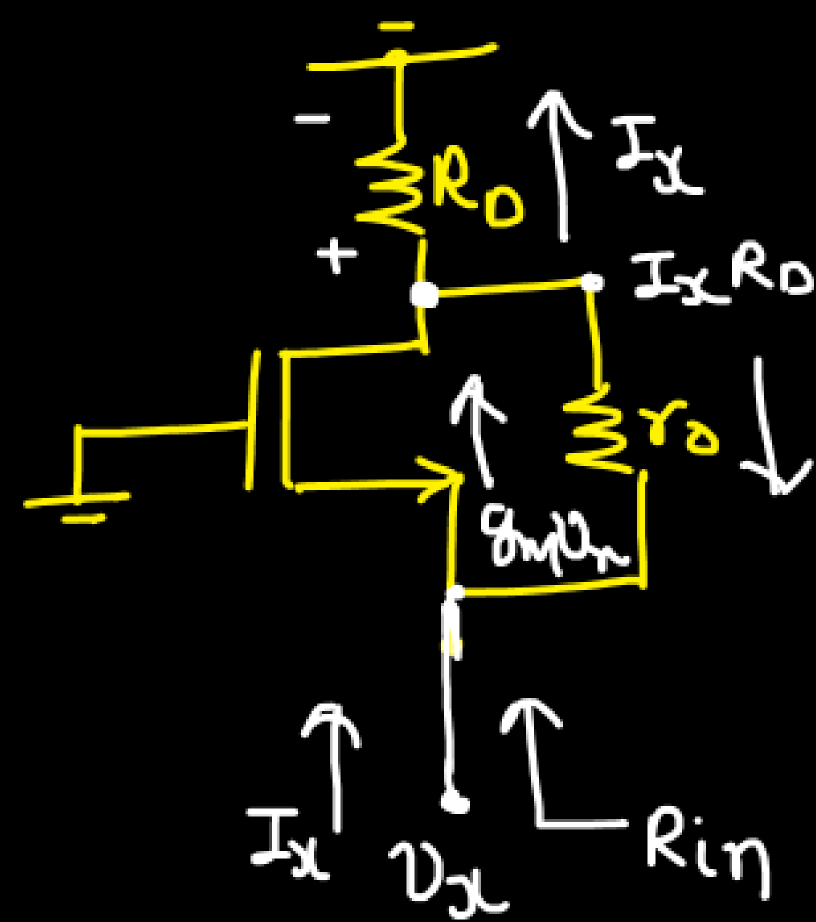
$$v_o = (g_m v_{in}) R_D$$

$$\boxed{\frac{v_o}{v_{in}} = g_m R_D}$$

B/w o/p and i/p there is 0° phase shift.

③ Input Impedance:-

$(\lambda \neq 0)$



Nodal @ $I_x R_D$:-

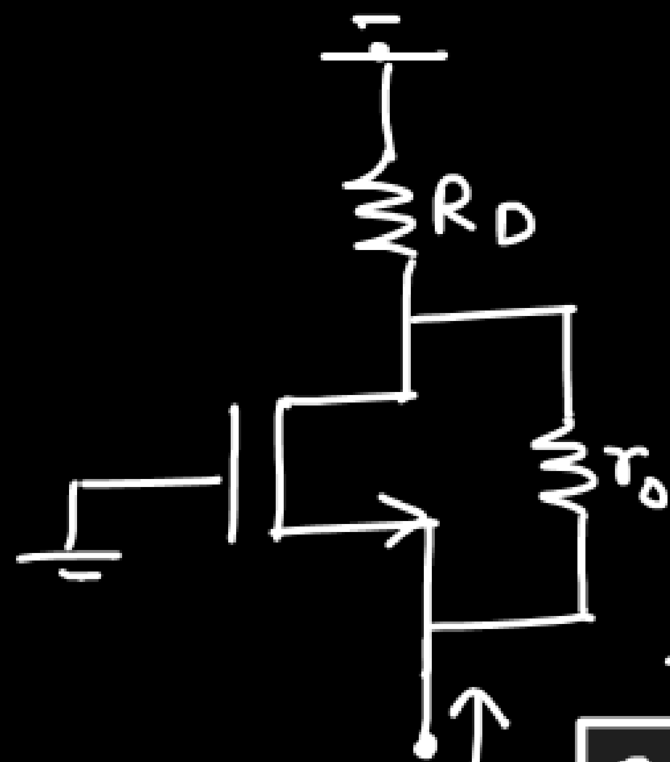
$$I_x + \frac{I_x R_D - V_x}{r_o} = g_m v_x$$

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

$$I_x\left[r_o + R_D\right] = v_x\left[g_m r_o + 1\right]$$

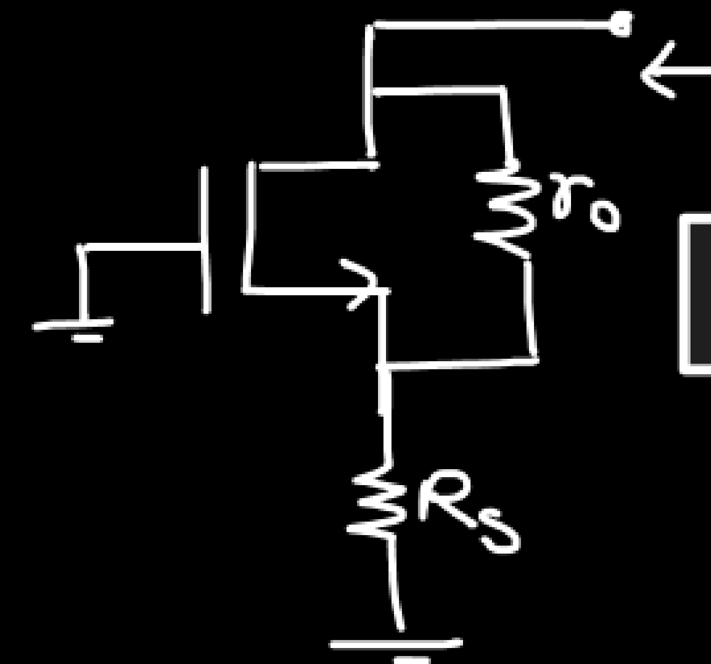
$$\boxed{R_x = \frac{v_x}{I_x} = \frac{r_o + R_D}{1 + g_m r_o}}$$

TO REREMBER :-



**

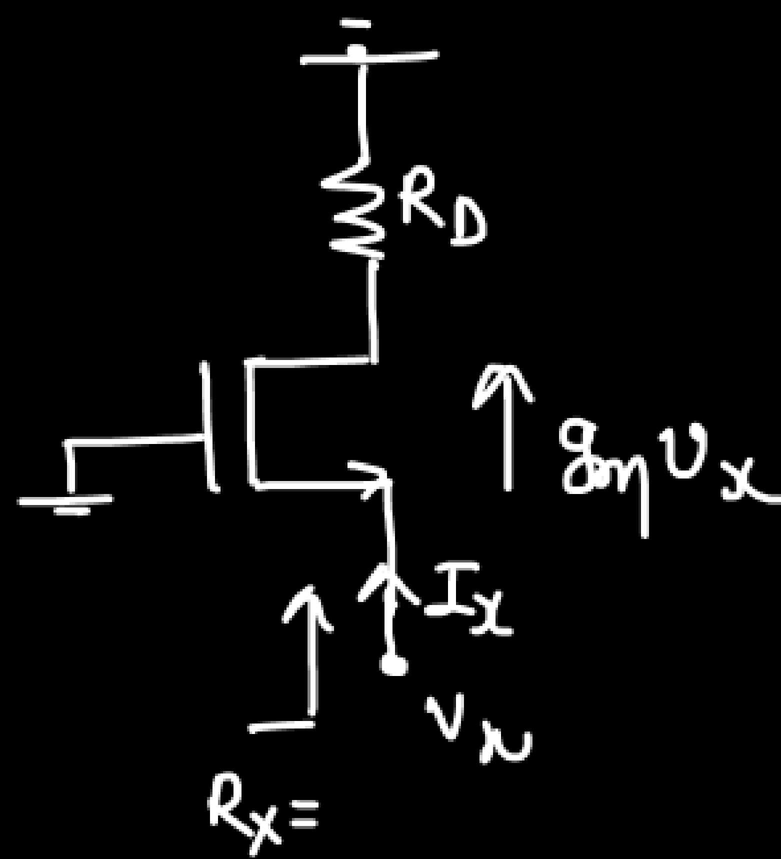
$$\boxed{R_X = \frac{r_o + R_D}{1 + g_m r_o}}$$



**

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

input impedance ($\lambda = 0$):-



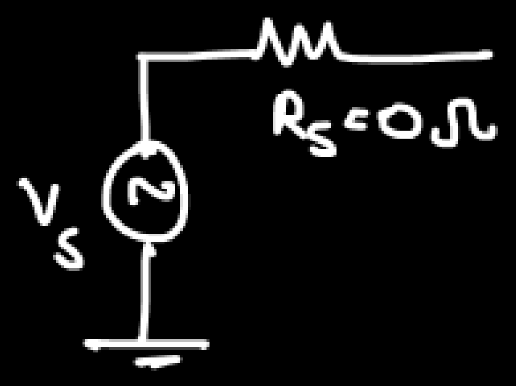
$$g_m v_x = I_x$$

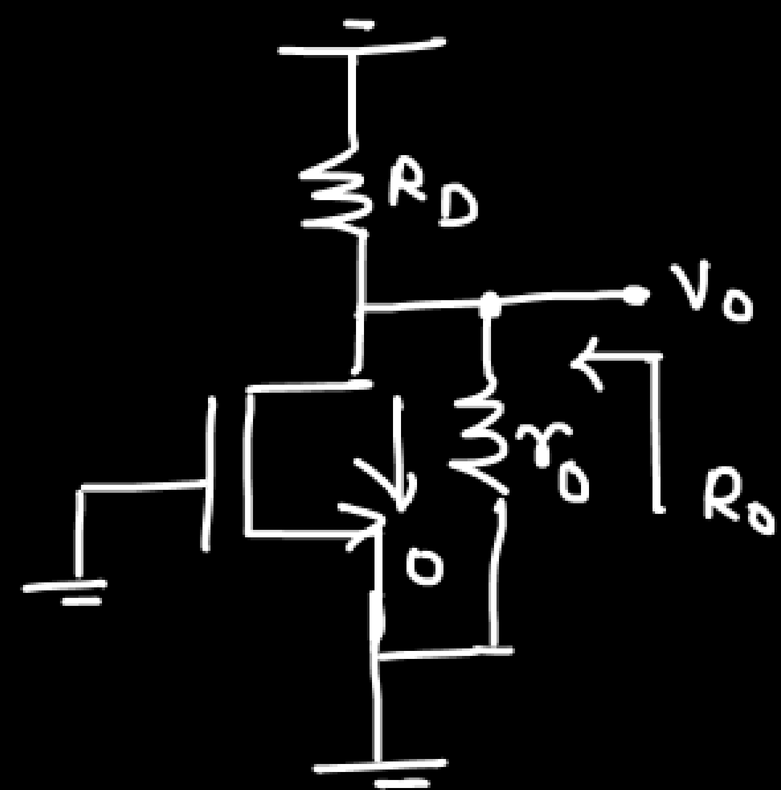
$$\boxed{R_x = \frac{v_x}{I_x} = \frac{1}{g_m}}$$

Output impedance:-

(input source doesn't have any internal resistance)

$v_i \Rightarrow$

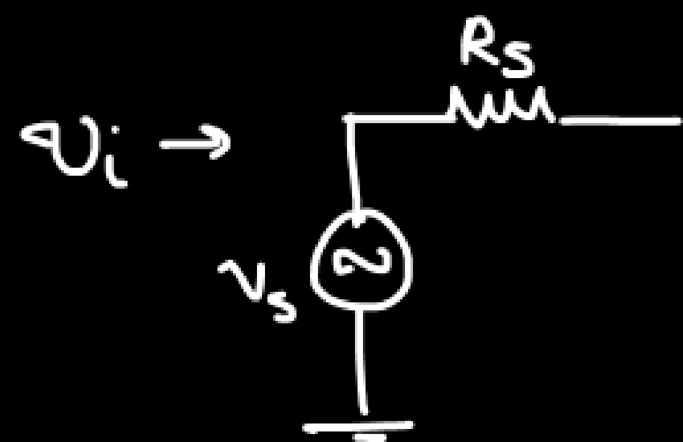


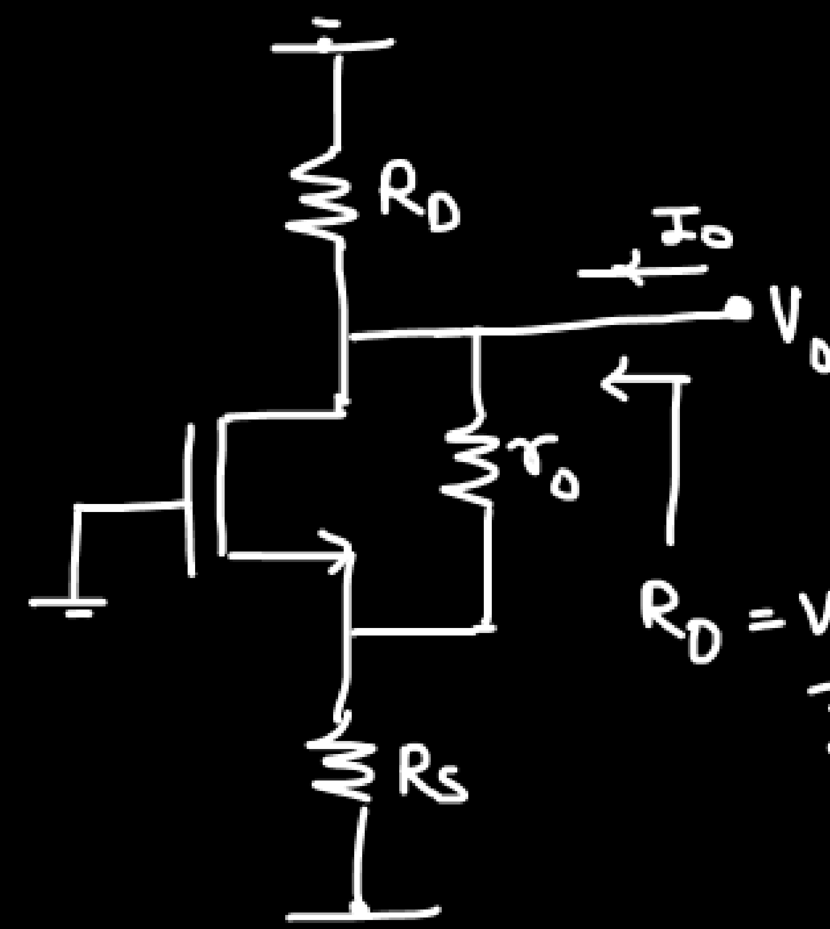


$$\boxed{R_o = R_D \parallel r_o}$$

Output resistance :

(input source has some internal resistance)

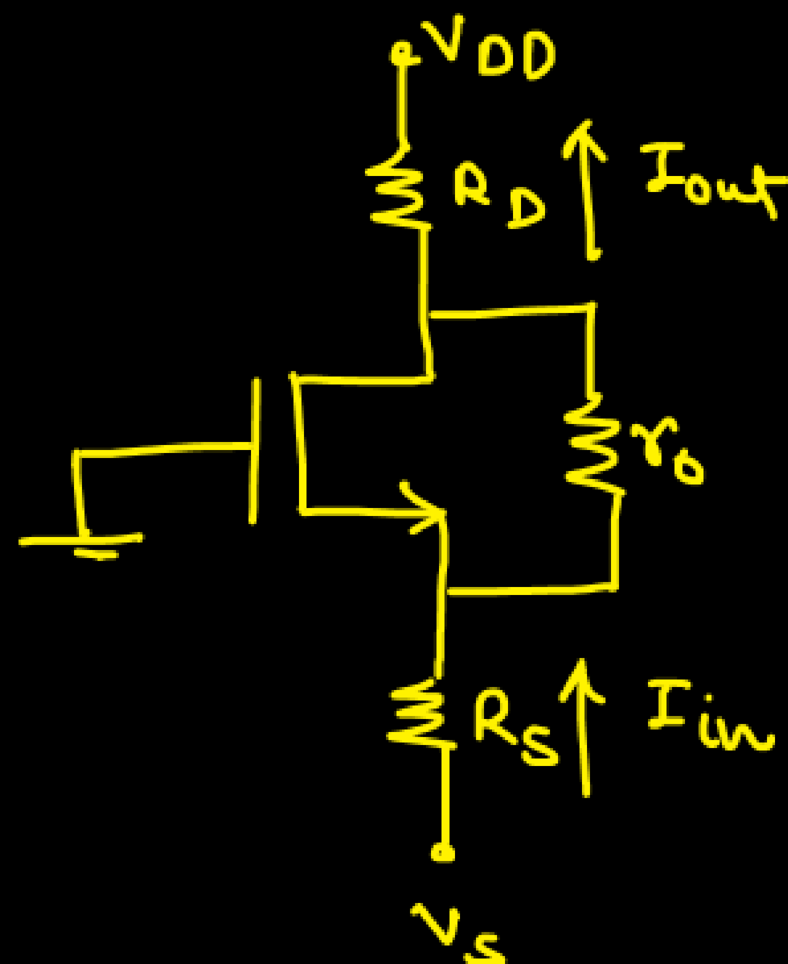




$$R_D = \frac{V_o}{I_o}$$

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

Current-gain:-

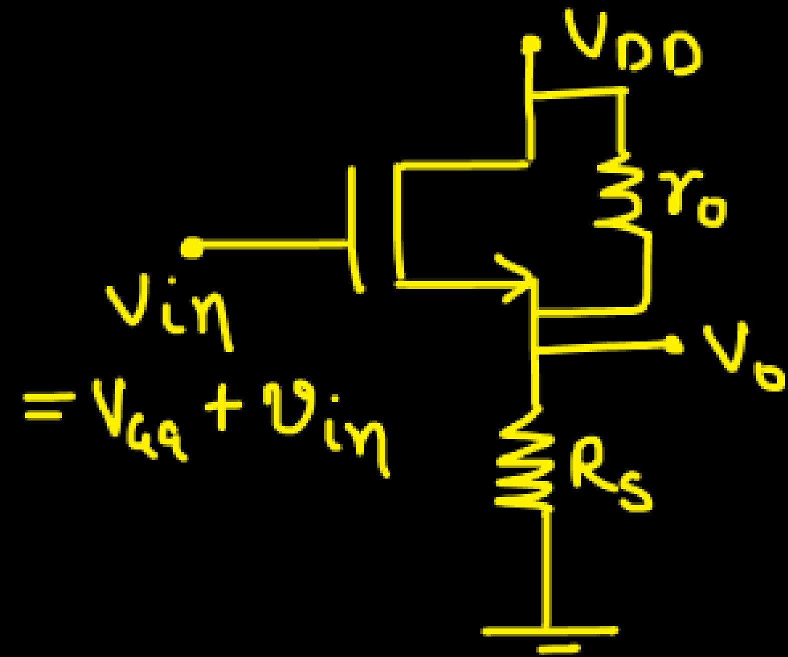


$$I_{in} = I_{out}$$

$$\boxed{\frac{I_{out}}{I_{in}} = 1} \Rightarrow \text{CURRENT-BUFFER}$$

$$\boxed{\text{COMMON GATE AMPLIFIER} = \text{C-BUFFER}}$$

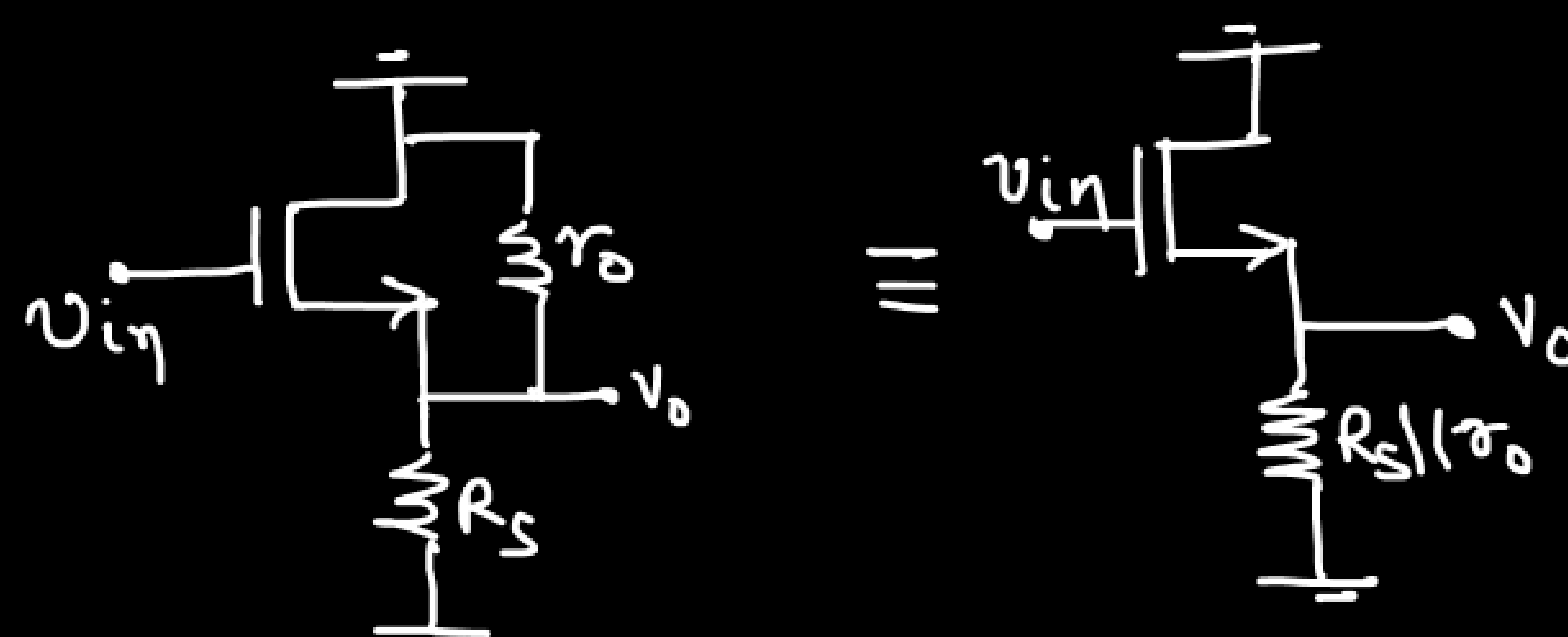
* Common-drain Amplifier :-



Small signal i/p → Gate

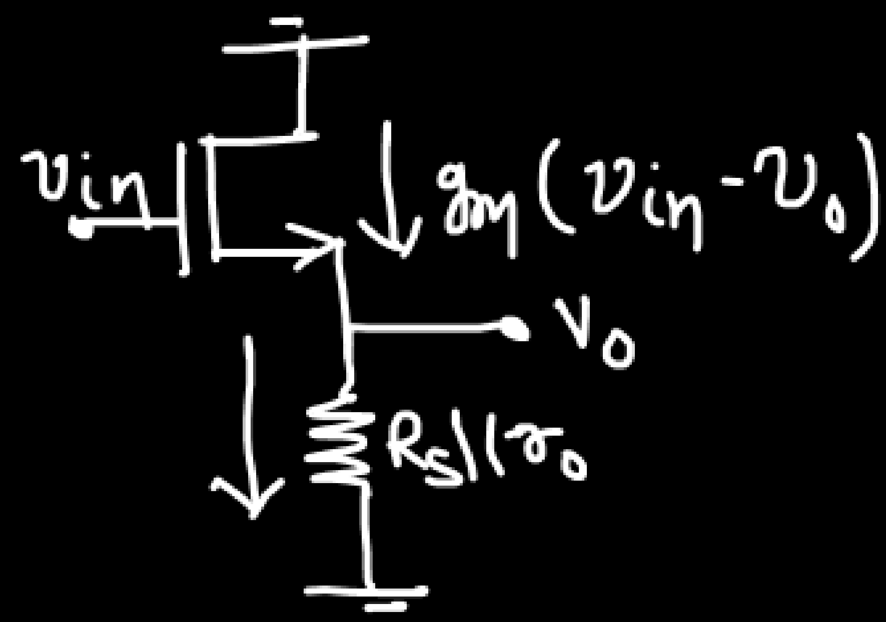
" " o/p → Source

Small signal Model :-



Voltage gain:-

M-I



$$g_m(v_{in}-v_0)\times(R_S\|r_0)=v_0$$

$$g_m(R_S\|r_0)\,v_{in}=\left[1+g_m(R_S\|r_0)\right]v_0$$

$$\boxed{\frac{v_0}{v_{in}}=\frac{g_m(R_S\|r_0)}{1+g_m(R_S\|r_0)}}$$

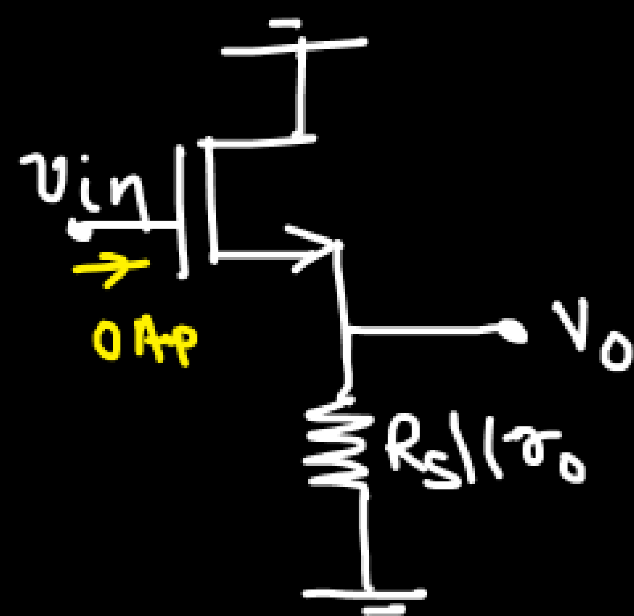
**

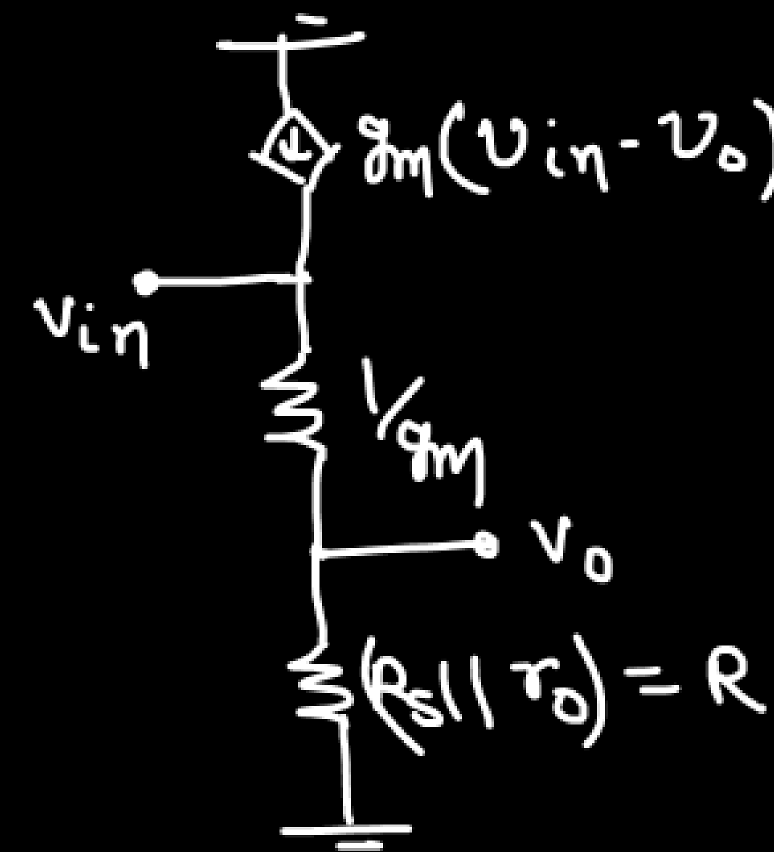
$$\boxed{\text{common-drain} \equiv \text{source-follower}}$$

$$g_m(R_S\|r_0) >>> 1$$

$$\boxed{\frac{v_0}{v_{in}}=1} \rightarrow \text{source-follower}$$

M-II :-





$$v_o = \frac{R}{R + 1/g_m} v_i$$

$$\boxed{\frac{v_o}{v_i} = \frac{g_m R}{1 + g_m R}}$$

$$\boxed{R = R_s \| r_o}$$

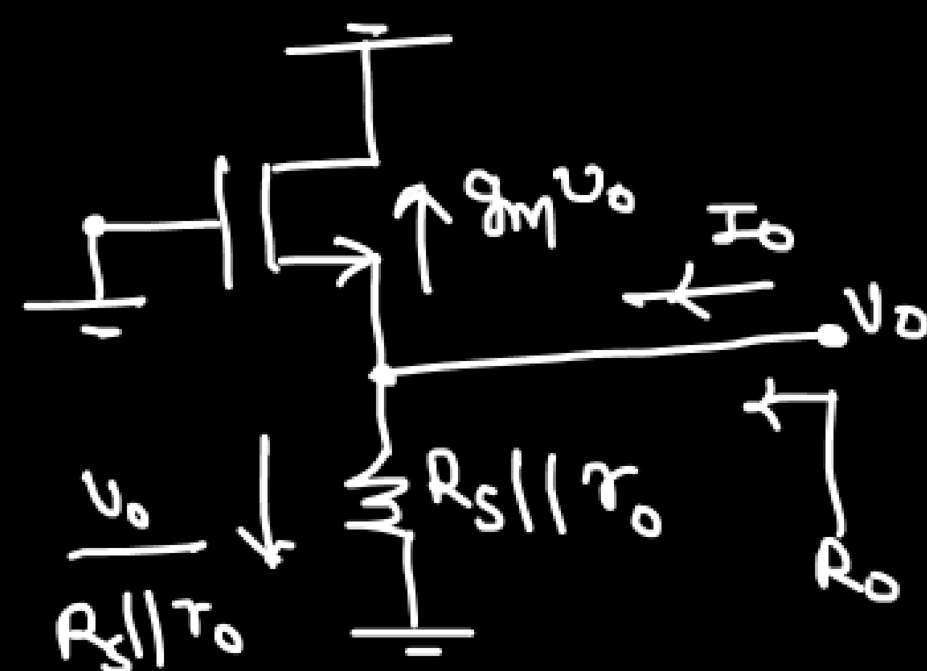
Current gain :-

$$\boxed{A_I = \frac{I_o}{I_{in}} = \frac{I_o}{0} = \infty}$$

Input Impedance :-

$$\boxed{R_i = \frac{V_i}{I_i} = \frac{V_i}{0} = \infty}$$

Output Impedance :-

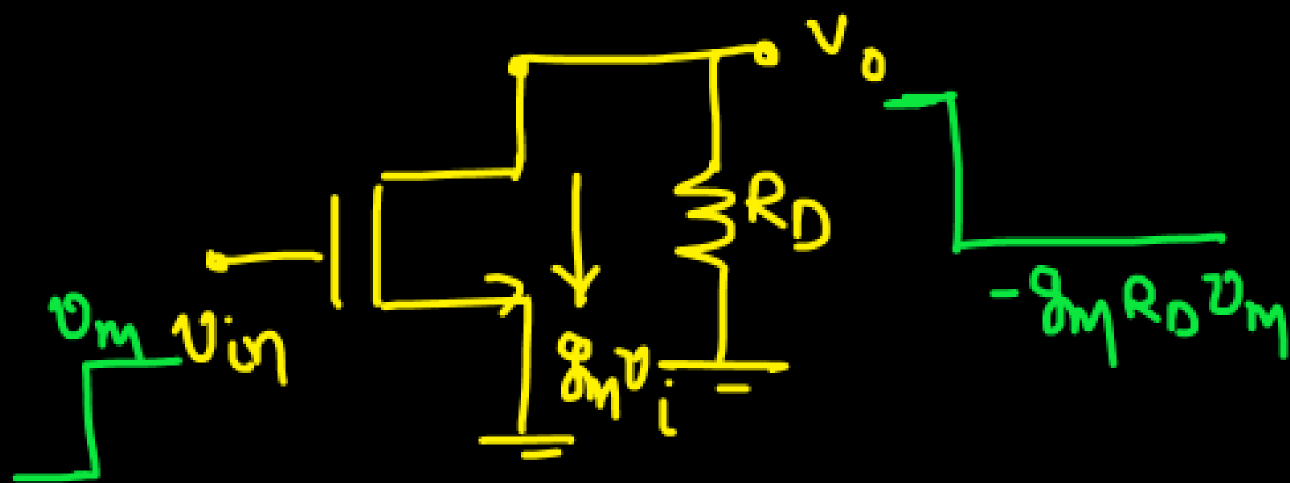


$$\boxed{R_o = R_s || r_o || \frac{1}{g_m}}$$

$$\boxed{g_m v_o + \frac{v_o}{R_s || r_o} = I_o}$$

★ Summary:-

① Common Source Amplifier:-

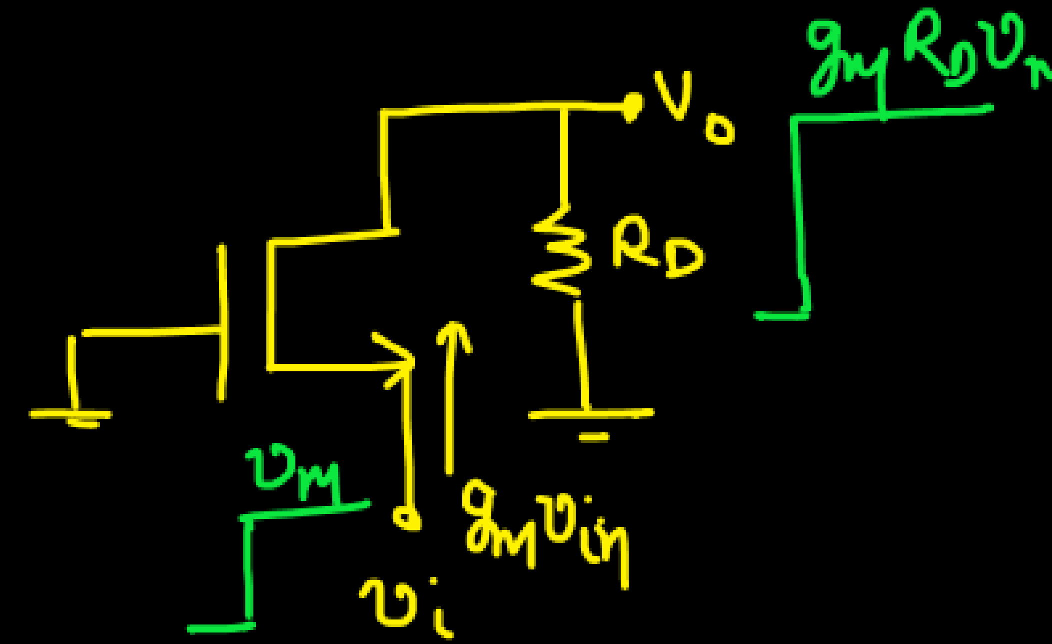


$$\boxed{A_V = -g_m R_D}$$

★ ⇒ There is 180° phase shift b/w i/p and o/p

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

② Common GATE Amplifier:-



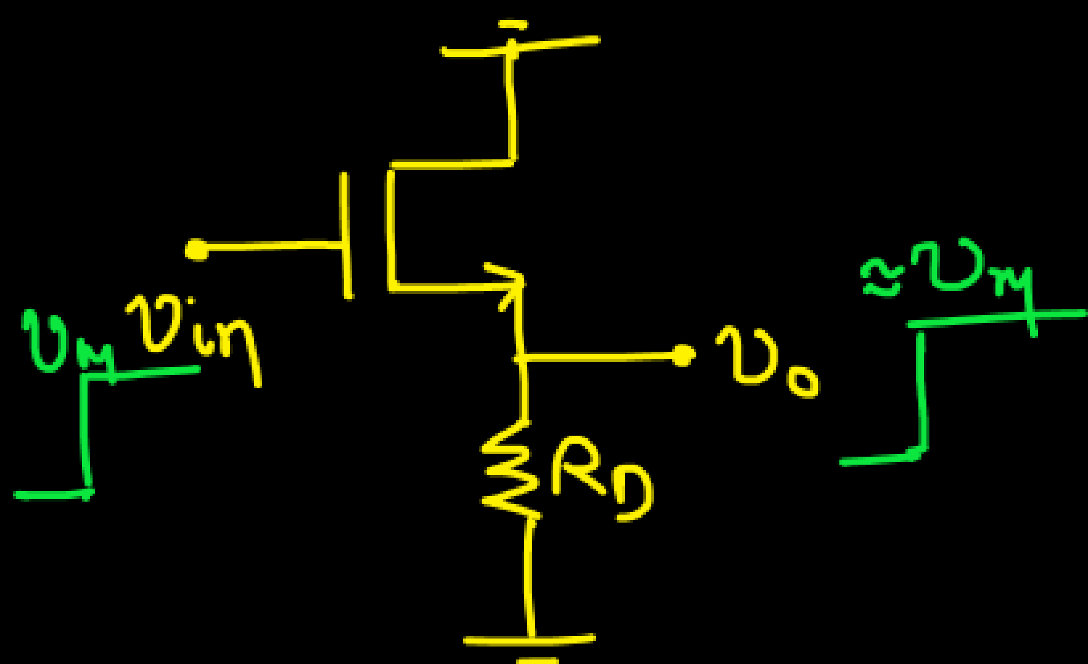
$$\boxed{A_V = g_m R_D}$$

⇒ 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 :-

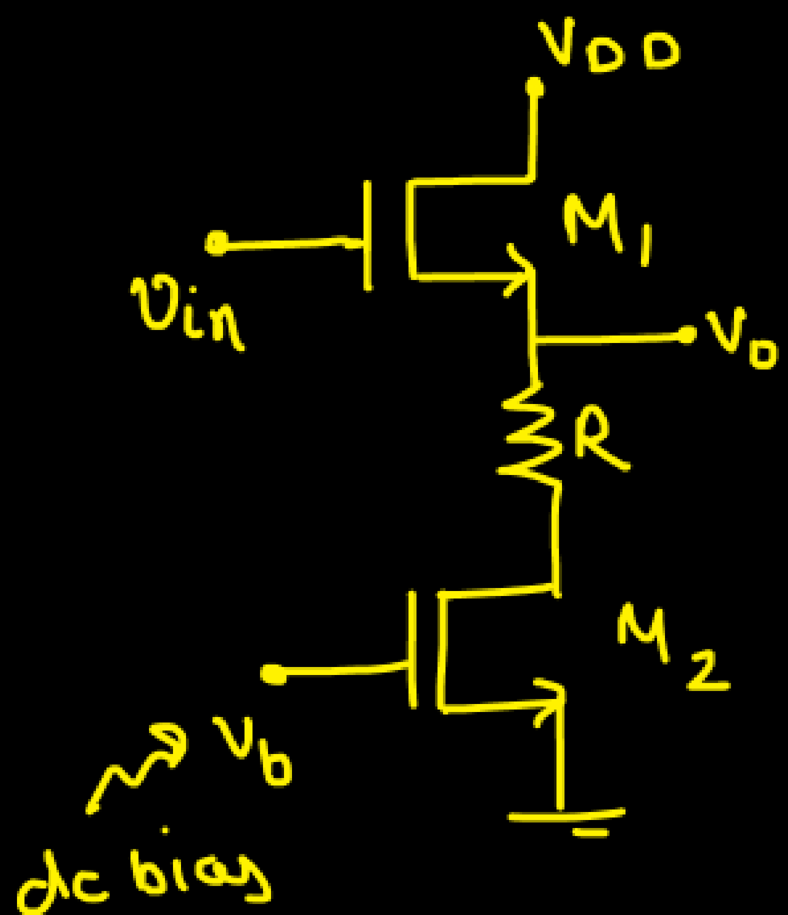


$$\boxed{A_V = \frac{g_m R_D}{1 + g_m R_D} \approx 1}$$ ⇒ source - follower

⇒ There is zero degree phase shift b/w i/p and o/p

⇒ $\boxed{R_o = R_D \| r_o \| 1/g_m}$

Q.



$g_{m_1} = 1.92\,mS$

$g_{m_2} = 1.8\,mS$

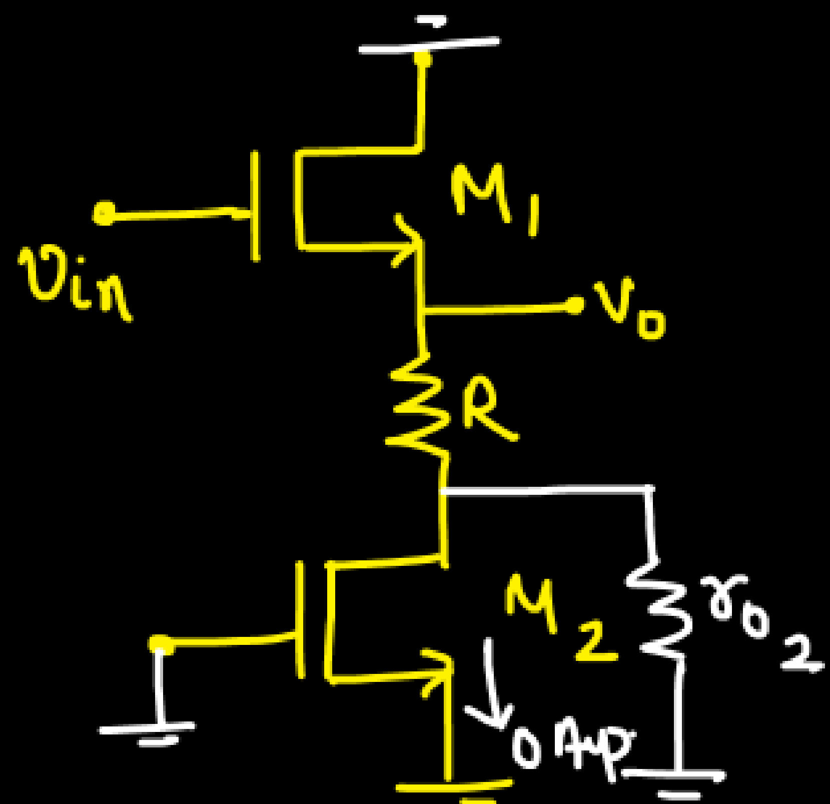
$r_{ds_1} = 20.69\,k\Omega = r_{o_1}$

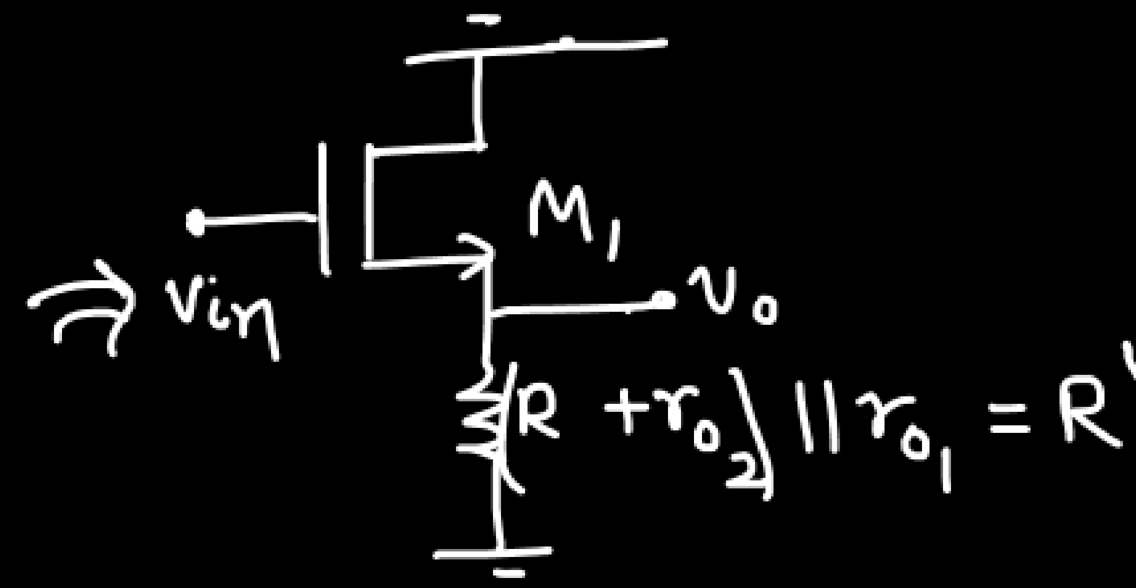
$r_{ds_2} = 23.89\,k\Omega = r_{o_2}$

$R = 4.6\,k\Omega$

Find small signal voltage gain $\frac{v_o}{v_{in}}$.

$\rightarrow$





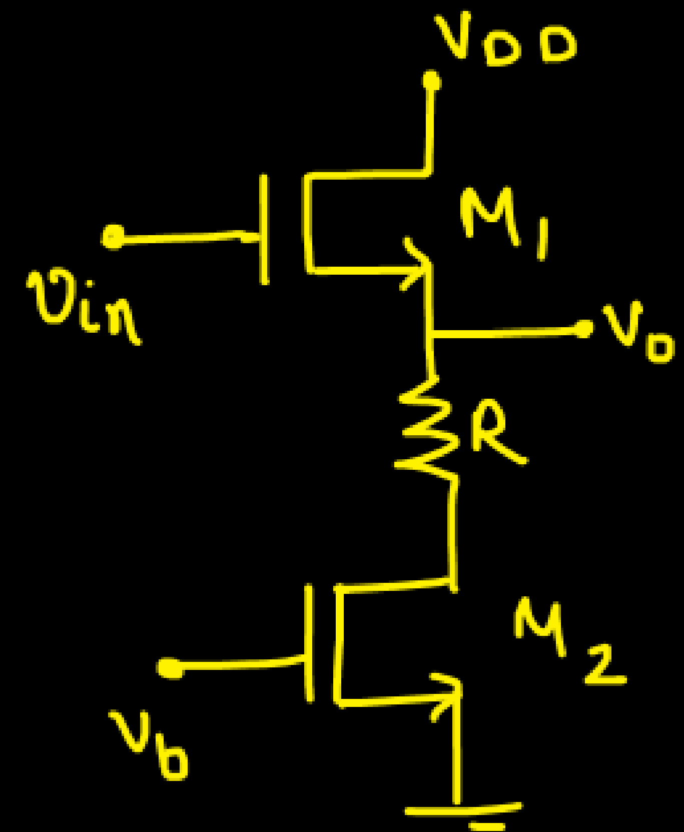
$$\boxed{\frac{v_o}{v_{in}} = \frac{R'}{R' + 1/g_{m1}} = \frac{g_{m1}R'}{1 + g_{m1}R'}}$$

$$R' = 28.49\,k\Omega \,||\, 20.63\,k\Omega = 11.96\,k\Omega$$

$$g_{m1}R' = 1.92m \times 11.96K = 22.97$$

$$\boxed{\frac{v_o}{v_i} = \frac{22.97}{23.97} \approx 0.96}$$

Q.



$$g_{m_1} = 1.92\,mS$$

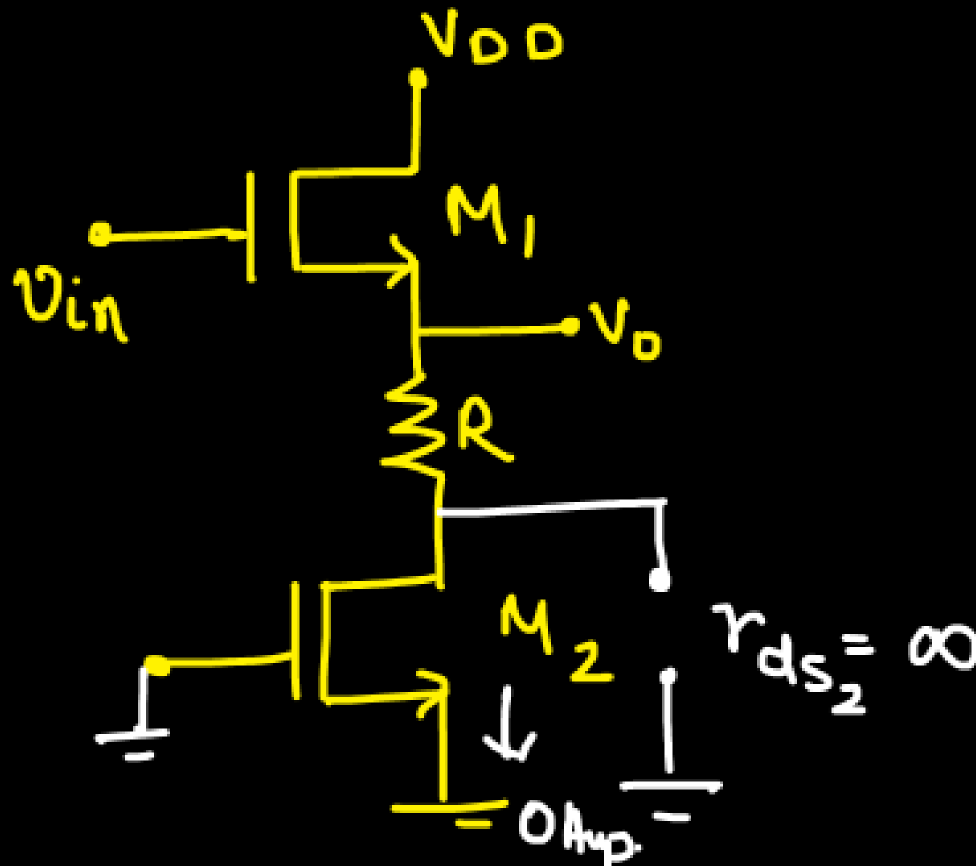
$$g_{m_2} = 1.8\,mS$$

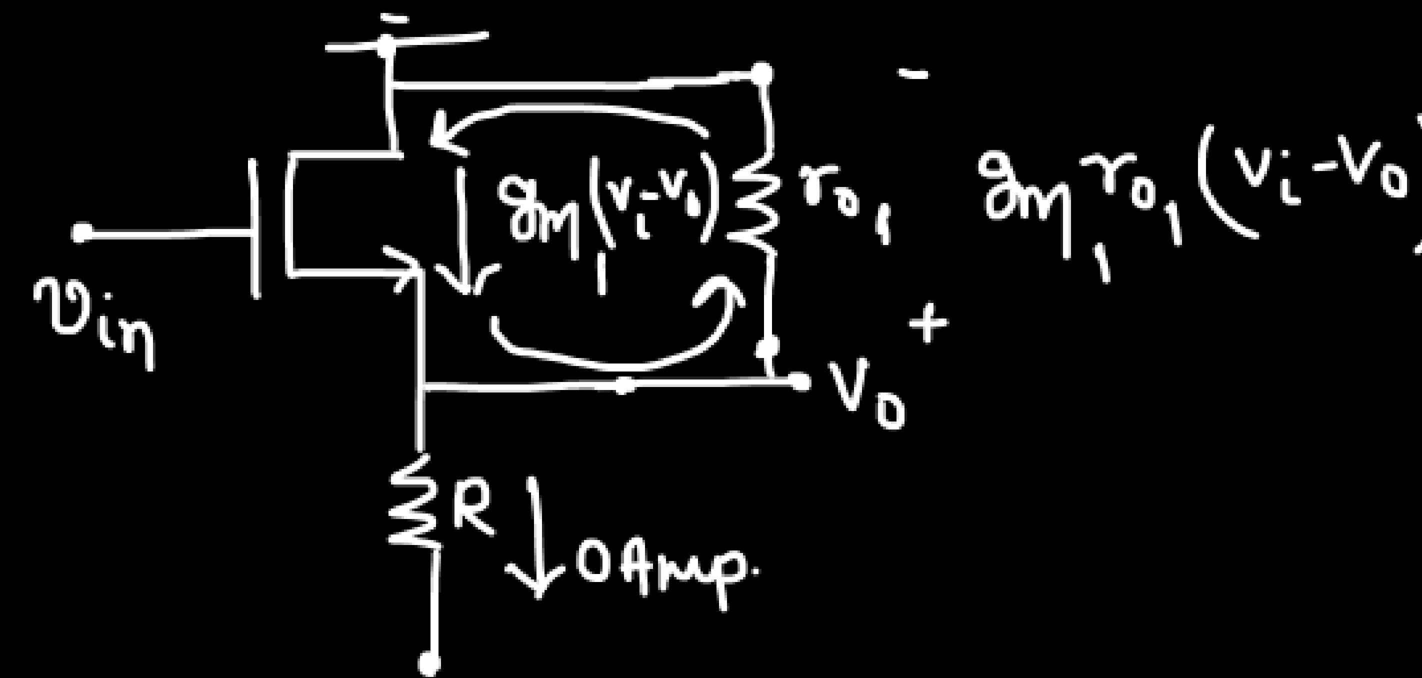
$$r_{ds_1} = 20.69\,k\Omega$$

$$r_{ds_2} = \infty$$

$$R = 4.6\,k\Omega$$

small signal voltage gain $\frac{v_o}{v_{in}} = ?$





$$g_{m_1} r_{o_1} (v_i - v_o) = v_o$$

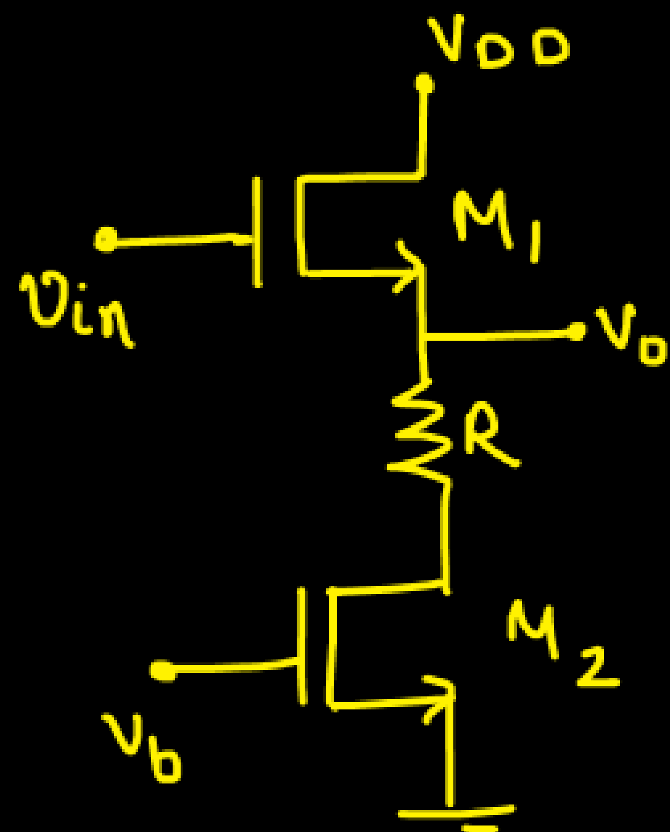
$$g_{m_1} r_{o_1} v_i = (1 + g_{m_1} r_{o_1}) v_o$$

$$\boxed{\frac{v_o}{v_i} = \frac{g_{m_1} r_{o_1}}{1 + g_{m_1} r_{o_1}}}$$

$$\Leftarrow$$

$$\boxed{\frac{v_o}{v_i} = \frac{39.6096}{40.6096} = 0.975}$$

Q.



$g_{m_1} = 1.92\ mS$

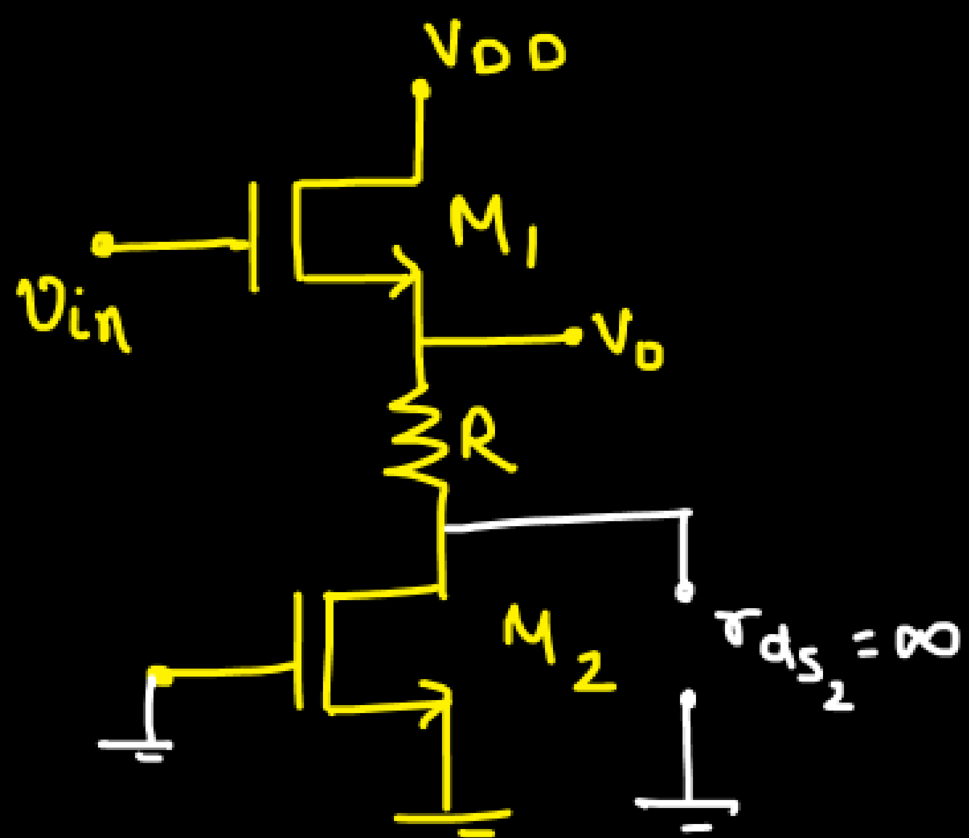
$g_{m_2} = 1.8\ mS$

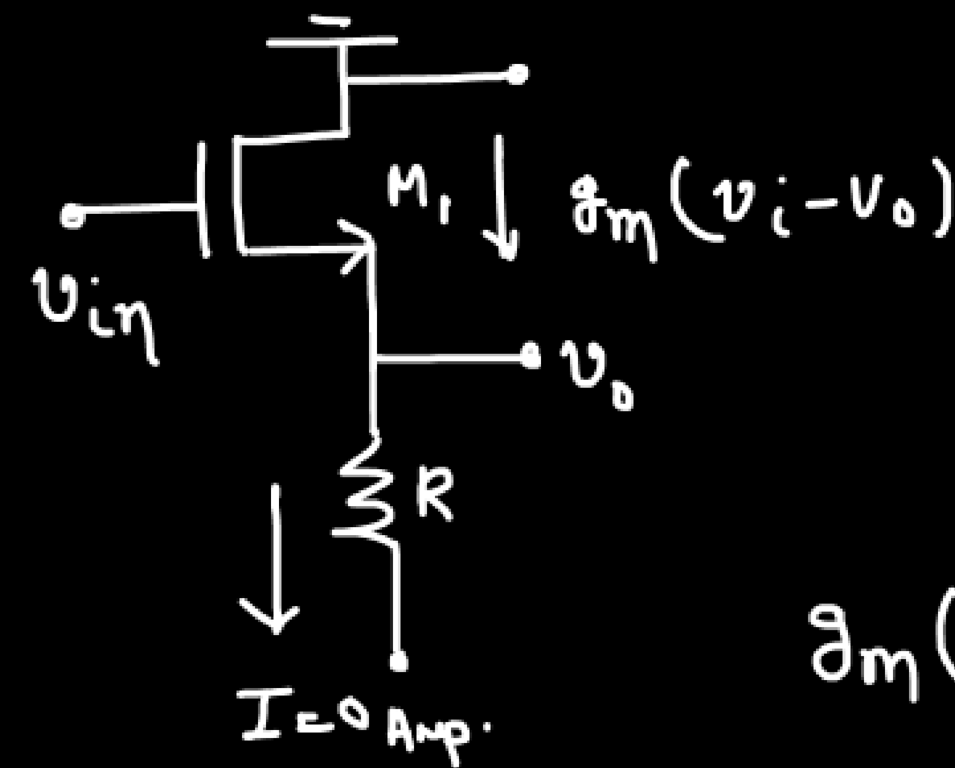
$r_{ds_1} = \infty$

$r_{ds_2} = \infty$

$R = 4.6\ K\Omega$

small signal voltage gain $\frac{v_o}{v_{in}} = ?$





$$g_m(v_i - v_o) = 0$$

$$v_i = v_o$$

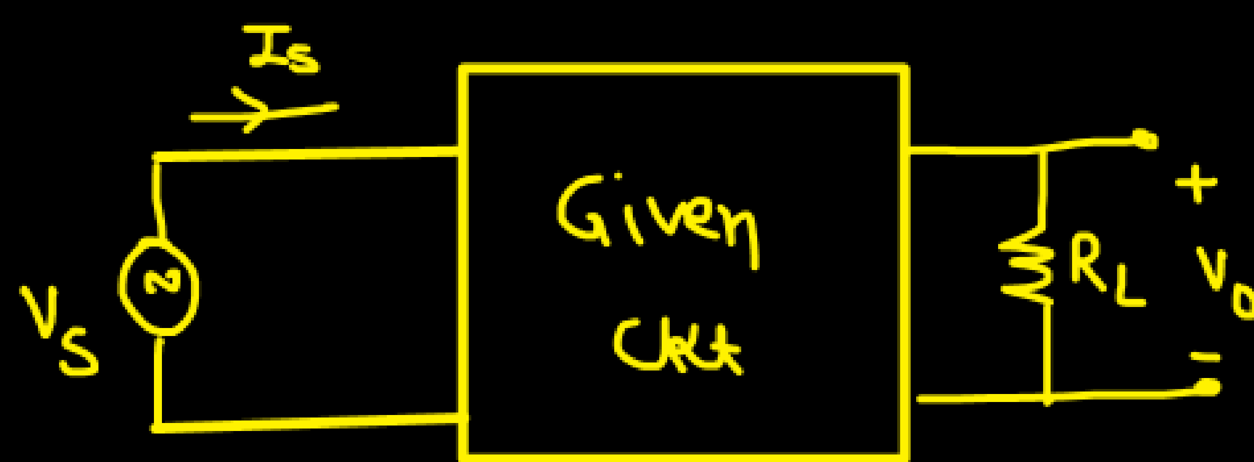
** $$\boxed{\frac{v_o}{v_i} = 1}$$

* Interesting Method of finding voltage gain :.
($G_m R_{out}$ Method)

* Small signal voltage gain of any configuration

$$A_v = G_m R_{out}$$

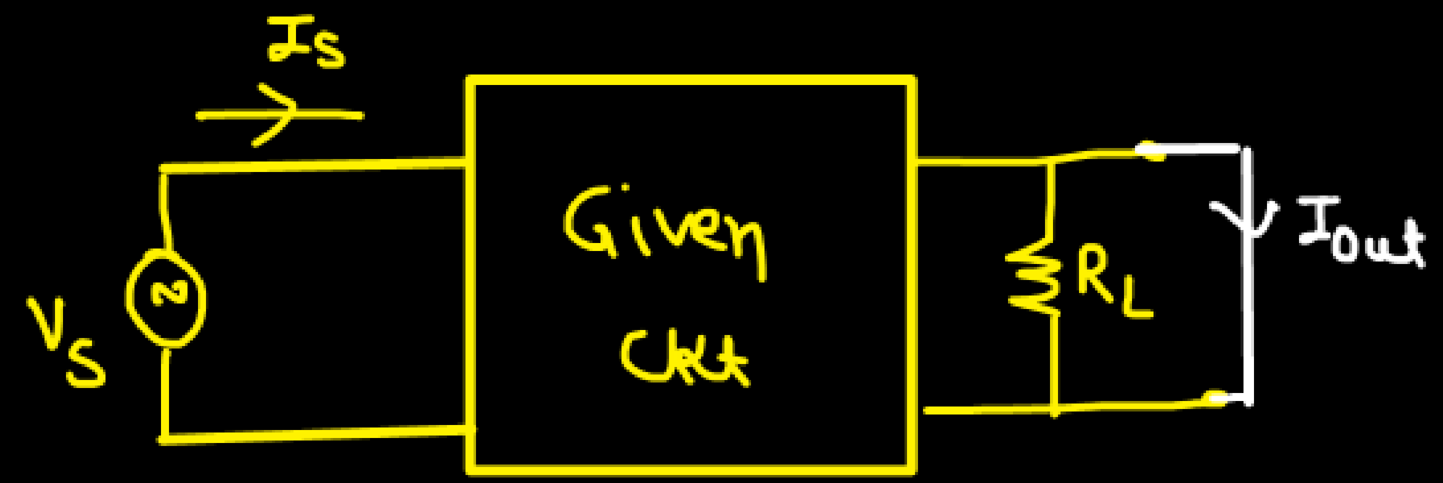
$\boxed{G_m \neq g_m}$



$$\boxed{A_v = \frac{V_o}{V_s} = G_m R_{out}}$$

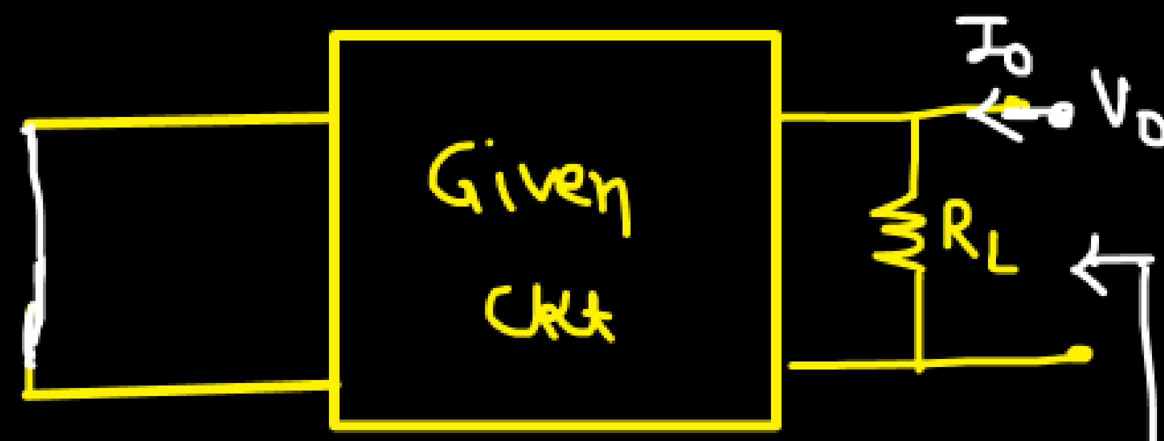
(1) $G_m \rightarrow$

Short ckt the o/p and find out the relation b/w i_{out} and V_s.



$$\boxed{G_m = \frac{I_{out}}{V_s}}$$

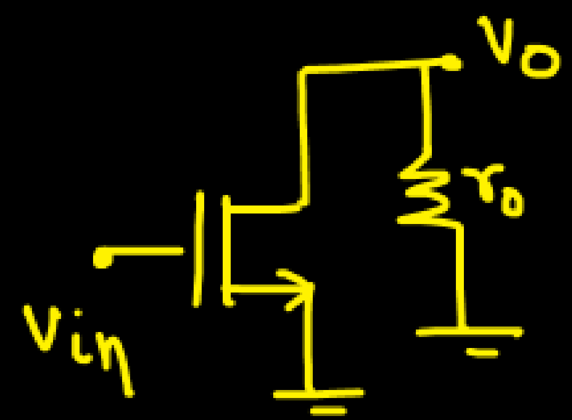
② Find small signal out resistance:-



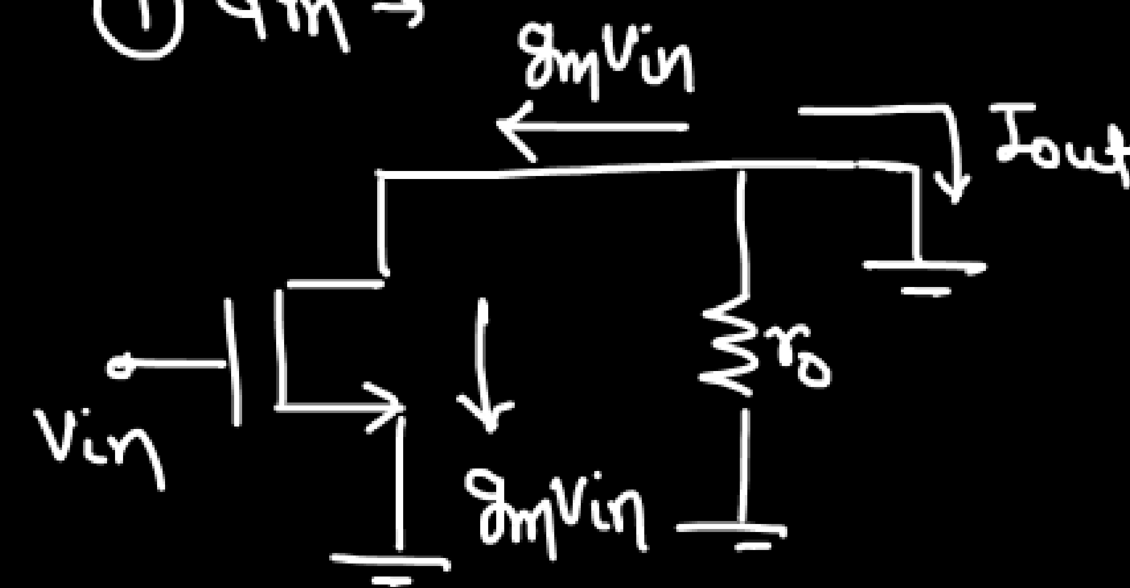
$$R_{out} = \frac{V_o}{I_o}$$

Eg → Find small signal gain.

①



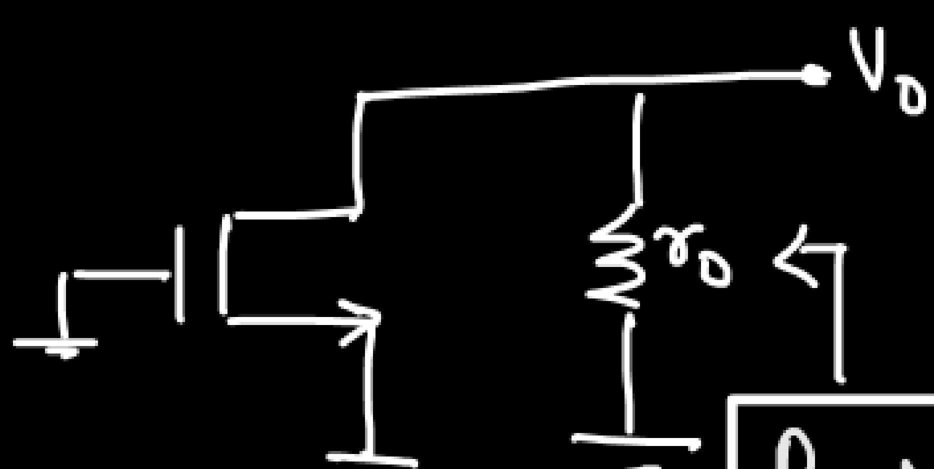
① G_m →



$$I_{out} = -g_m V_{in}$$

$$\boxed{G_m = \frac{I_{out}}{v_{in}} = -g_m}$$

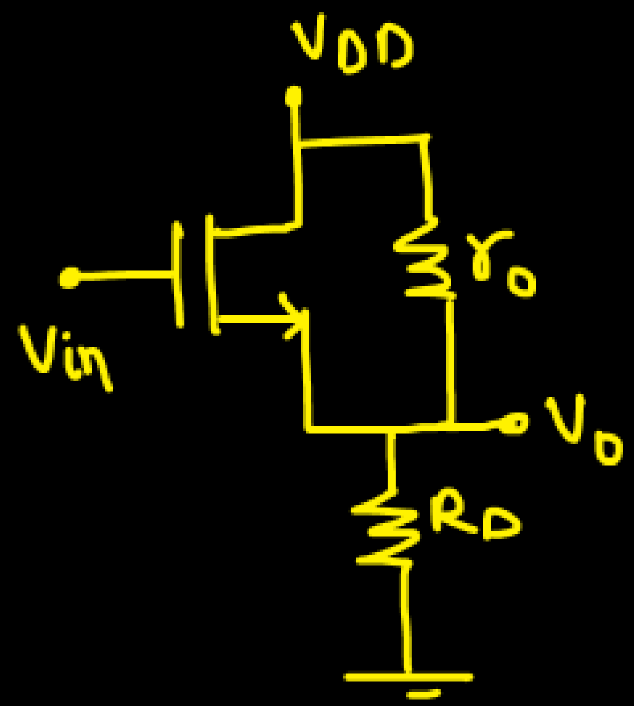
② R_{out} →



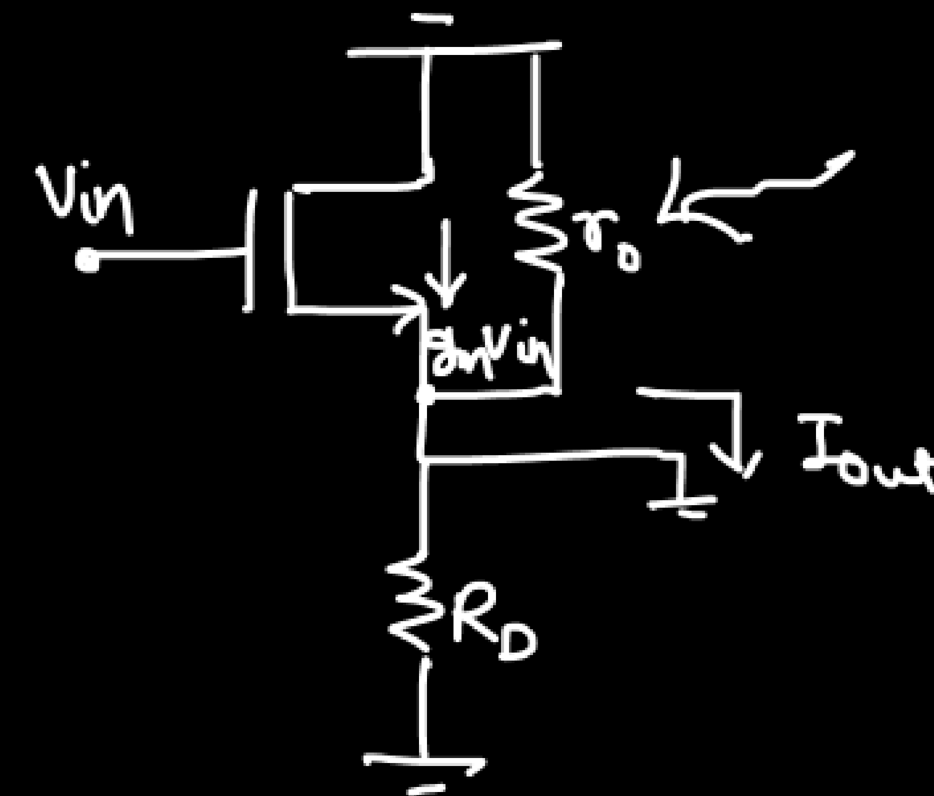
$$\boxed{R_{out} = r_o}$$

$$\boxed{\text{Gain} = -g_m r_o}$$

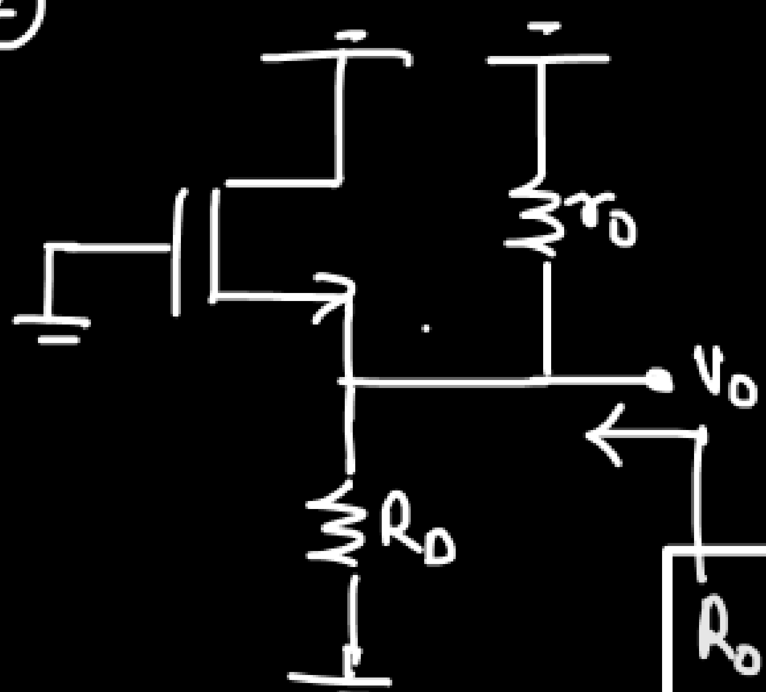
②



→ ① G_m →



②



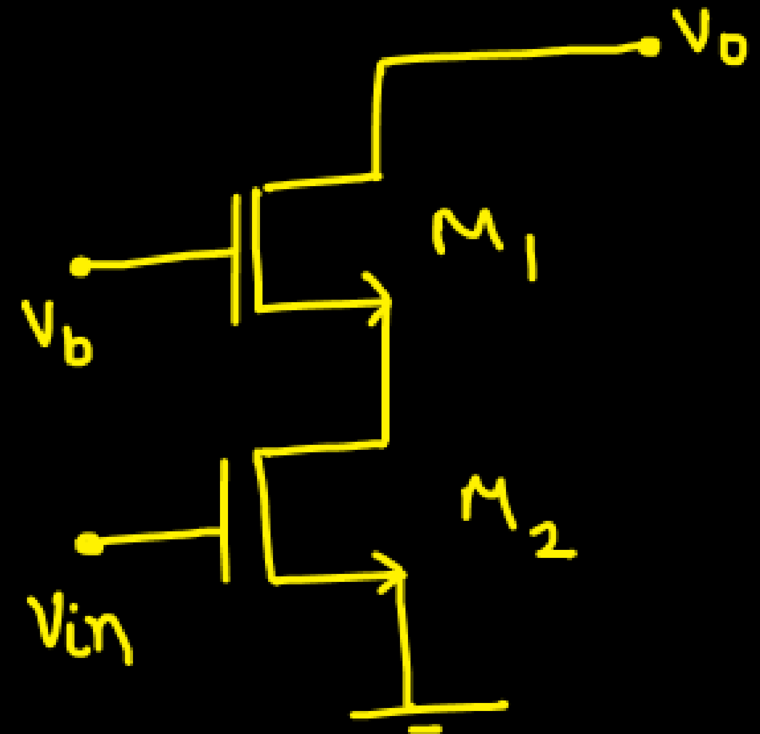
$$\boxed{R_o = R_D \,\|\, r_o \,\|\, 1/g_m}$$

$\Rightarrow I_{out} = g_m v_{in}$

$$\boxed{G_m = g_m}$$

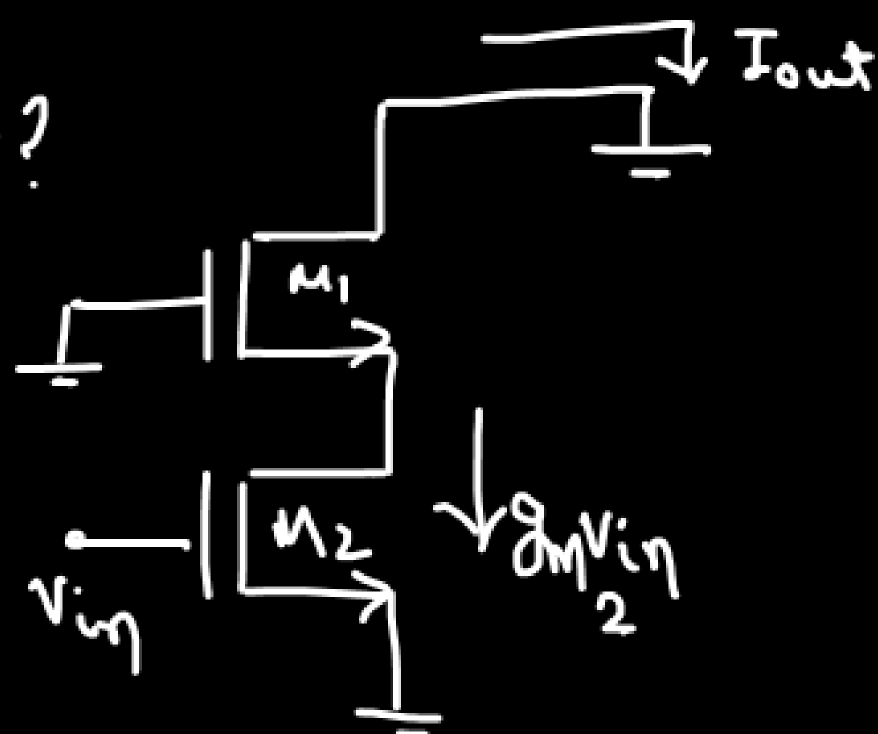
$$\Rightarrow \boxed{A_v = g_m \left[R_D \,\|\, r_o \,\|\, 1/g_m \right]}$$

3



r_{o_1} and r_{o_2} are very high.

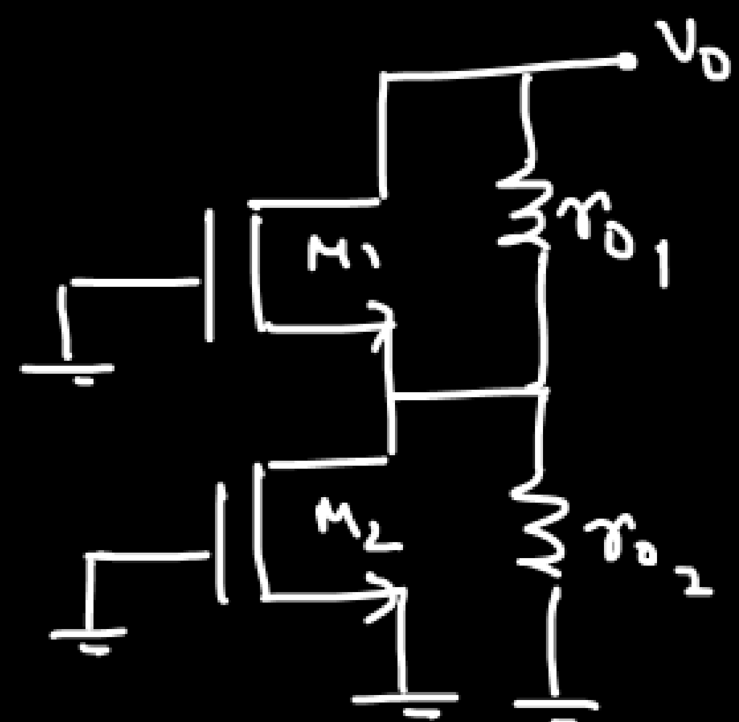
$\Rightarrow$ $G_m = ?$



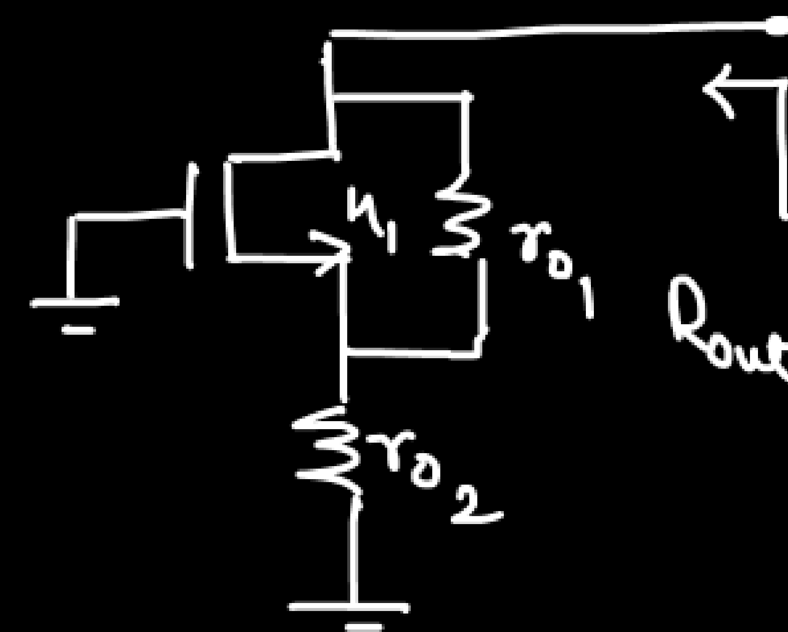
$I_{out} = -g_{m_2} v_{in}$

$$\boxed{G_m = -g_{m_2}}$$

R_{out}



$\Rightarrow$

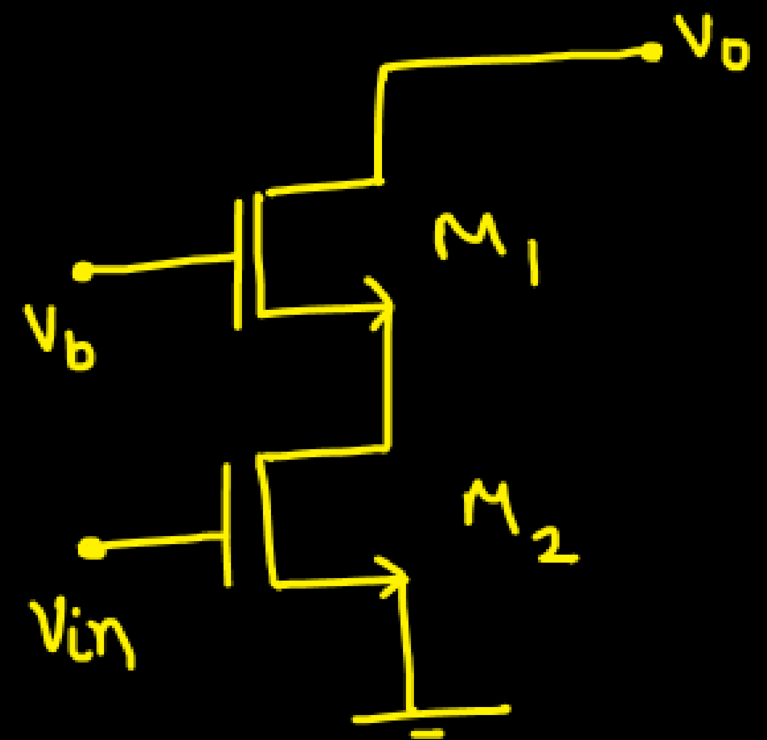


$$R_{out} = r_{o1} + r_{o2} + g_{m1} r_{o1} r_{o2}$$
$$\approx g_{m1} r_{o1} r_{o2}$$

$$\Rightarrow \text{Gain} \approx -g_{m2}\left[r_{o1} + r_{o2} + g_{m1} r_{o1} r_{o2}\right]$$

$$\boxed{\text{Gain} \approx -g_{m2}\, g_{m1}\, r_{o1}\, r_{o2}}$$

Q.



Let's assume,

$$\frac{1}{g_{m_1}} = r_{o_1} = r_{o_2} = 2k\Omega$$

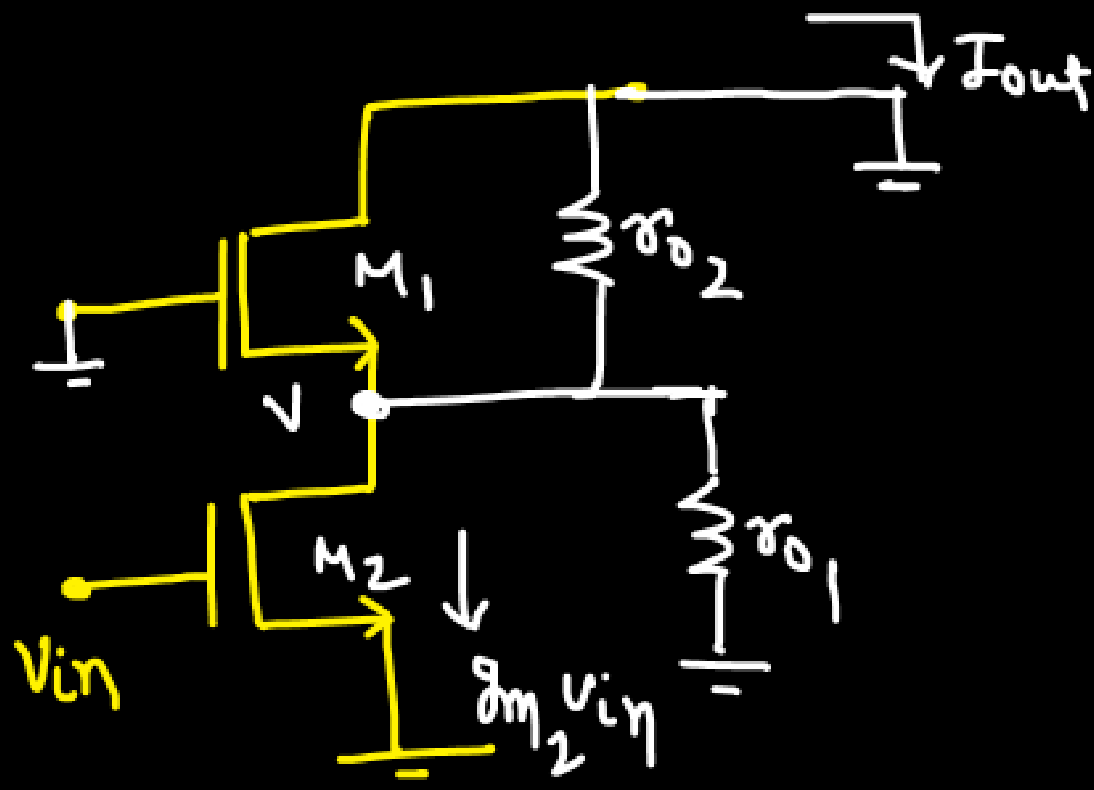
$$g_{m_2} = 3mS$$

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.

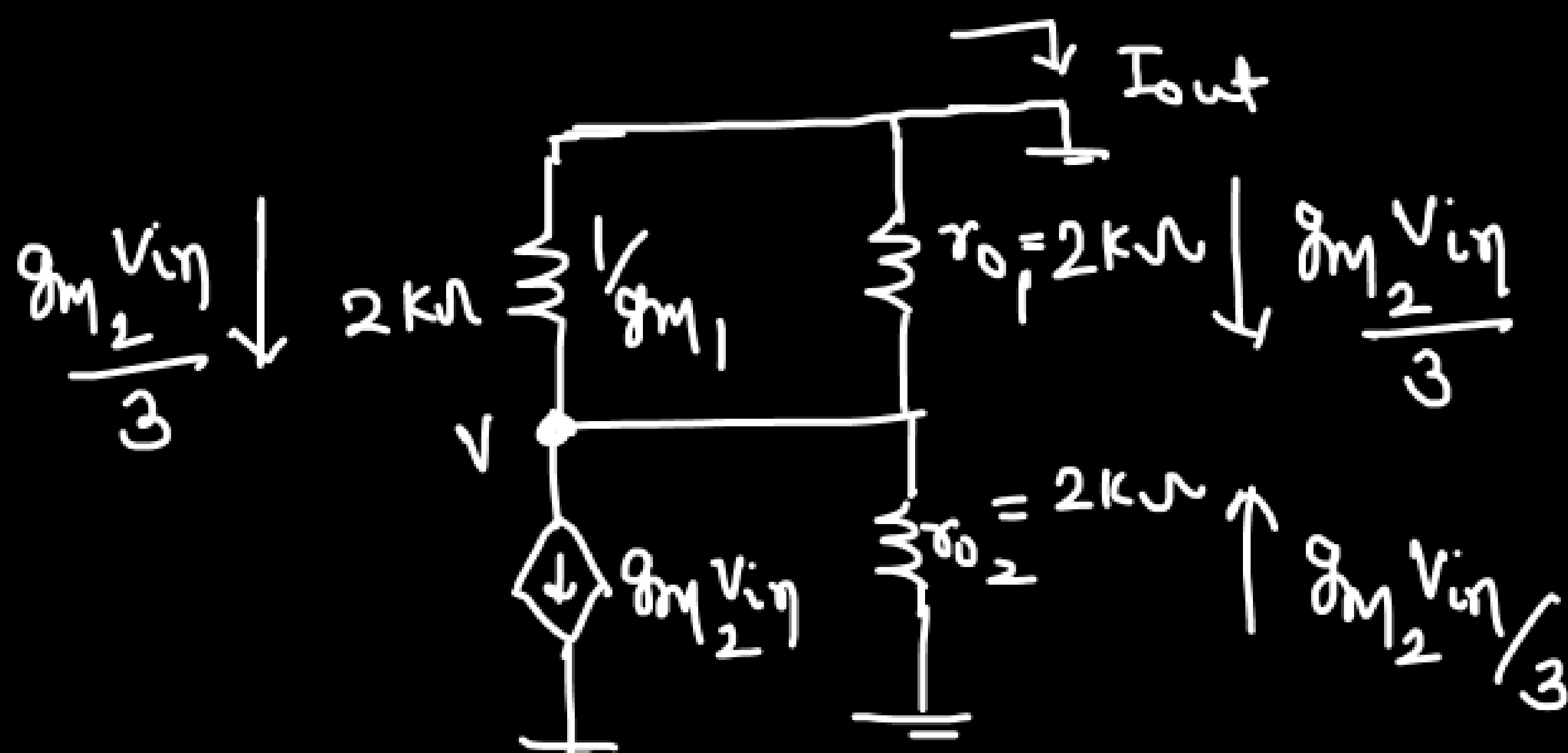
① $G_m \rightarrow$



$$I_{out} = -\left[\frac{g_{m_2} V_{in}}{3} + \frac{g_{m_2} V_{in}}{3}\right]$$

$$I_{out} = \frac{-2 g_{m_2} V_{in}}{3}$$

$$\boxed{G_m = \frac{-2 g_{m_2}}{3}}$$



$$R_{out} = r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2}$$

$$= 2K + 2K + \frac{1}{2K} \times 2K \times 2K$$

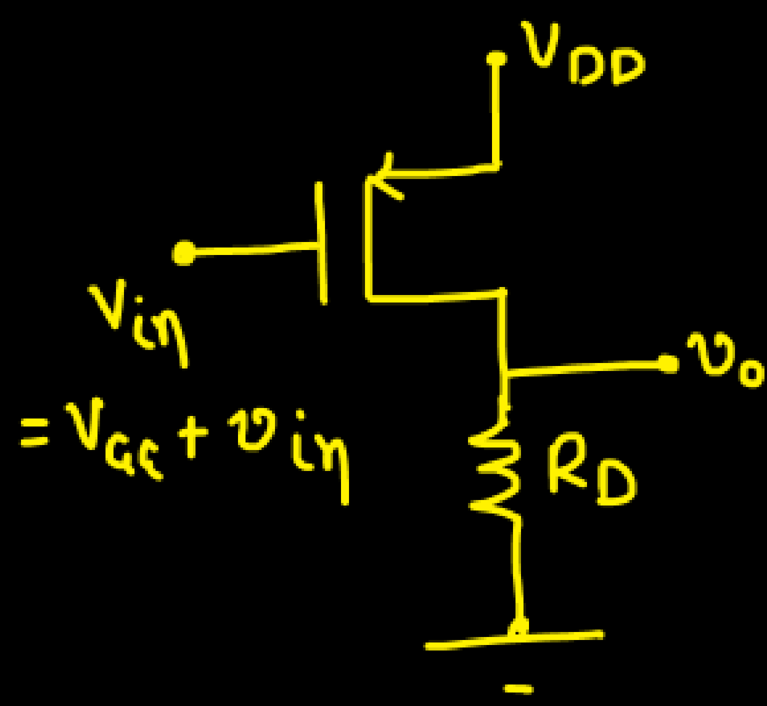
$$\boxed{R_{out} = 6\,k\Omega}$$

$$A_v = -\frac{2}{3} \times 3\,mS \times 6\,k\Omega$$

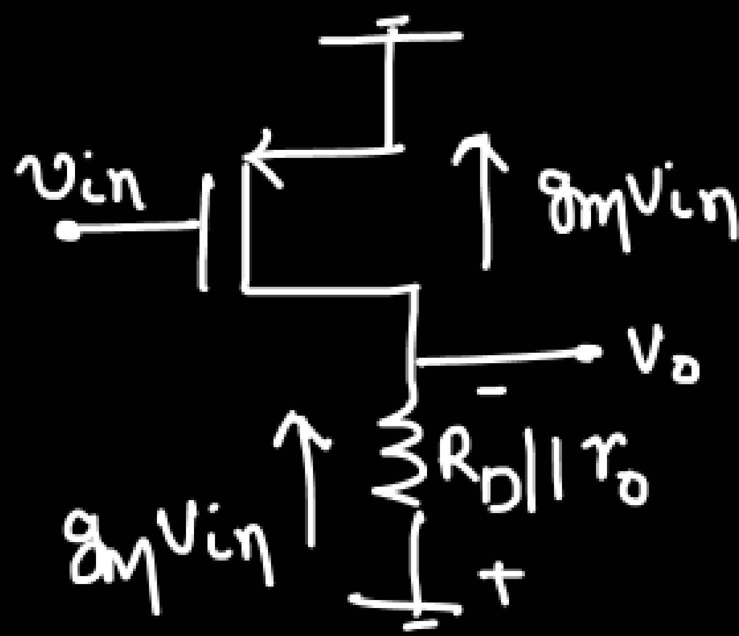
$$\boxed{A_v = -12\,V/V}$$

MOS Amplifiers using PMOS:-

① Common Source Amplifier:-



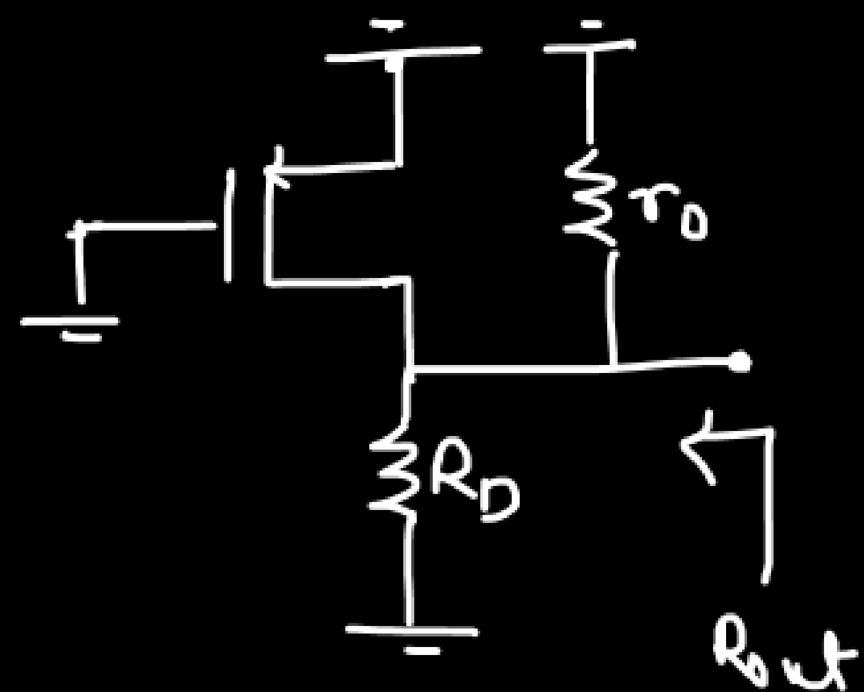
$\Rightarrow$



$$\boxed{\frac{v_o}{v_{in}} = -g_m (R_D \| r_o)}$$

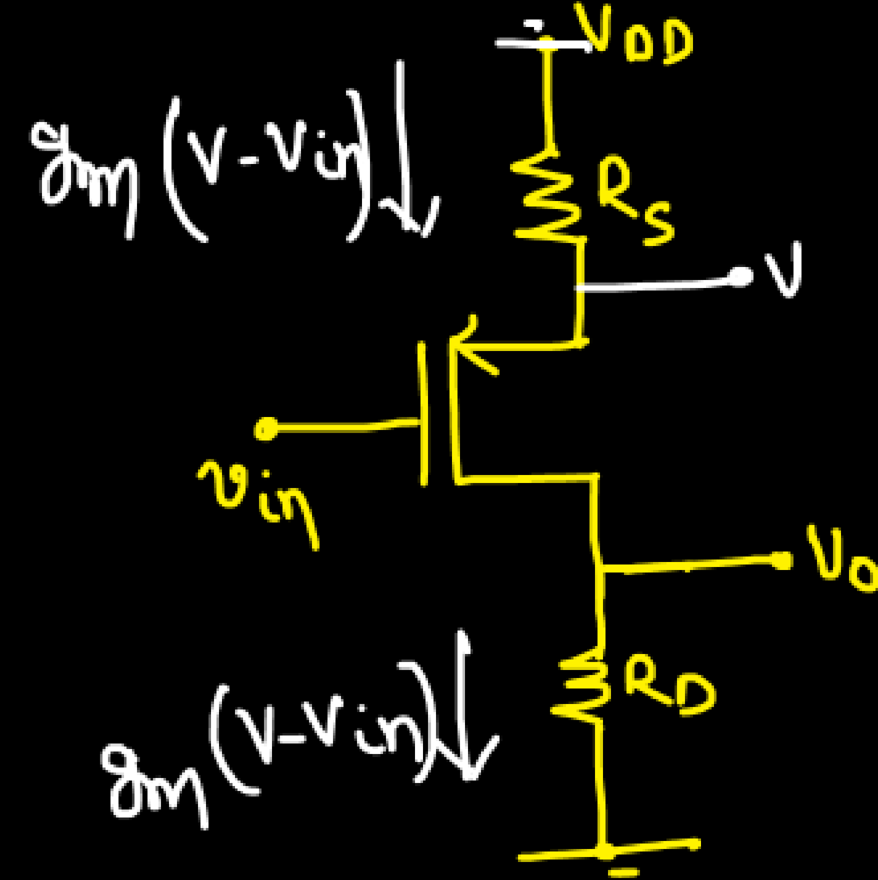
⇒ $\boxed{\text{Current gain} = \text{I/P resistance} = \infty}$ (I/P current = 0)

⇒ <u>o/p impedance:-</u>



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

Common source Amplifier with degeneration:-



$$\boxed{\lambda = 0}$$

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

$$\Rightarrow \frac{V}{R_S} = \frac{-V_o}{R_D}$$

$$V = -\frac{R_S}{R_D} V_o$$

$$V_o = g_m R_D\left[-\frac{R_S}{R_D} V_o - V_{in}\right]$$

$$V_o\left[1 + g_m R_S\right] = -g_m R_D V_{in}$$

$$\Rightarrow \boxed{\frac{V_o}{V_{in}} = \frac{-g_m R_D}{1+g_m R_S}}$$

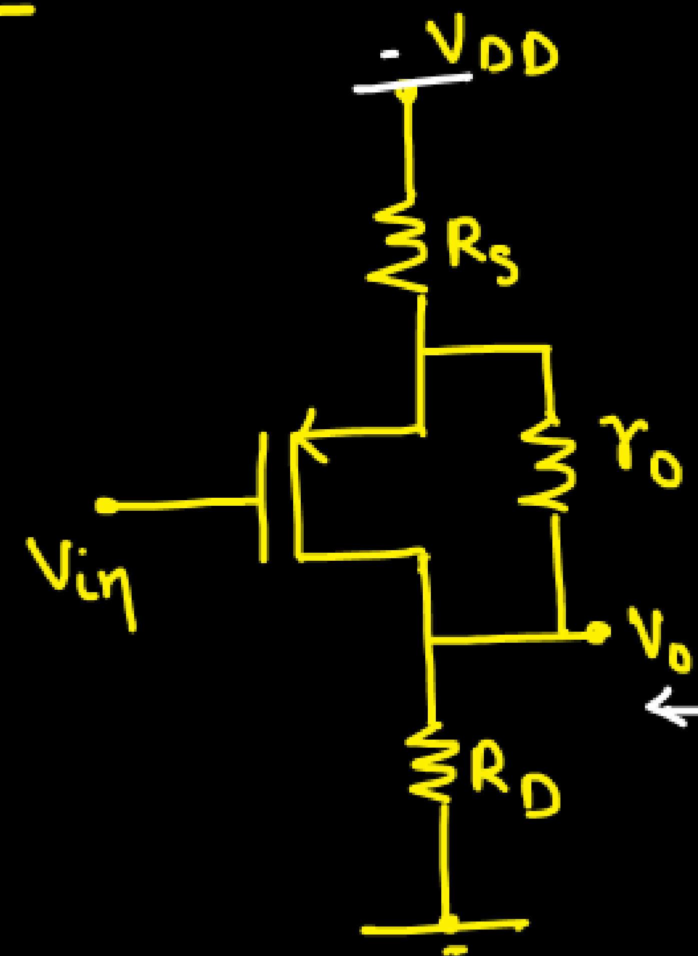
$$A_v = \frac{-g_m R_D}{1 + g_m R_S}$$

$$g_m R_S >> 1$$

$$A_v = \frac{-g_m R_D}{g_m R_S}$$

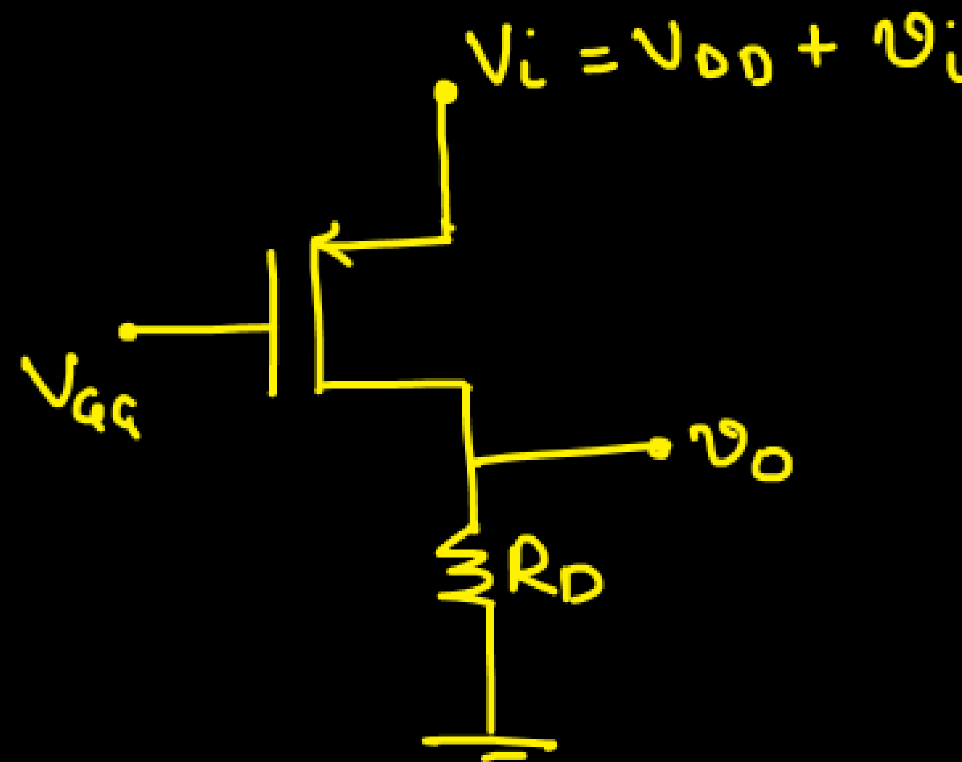
$$\boxed{A_v = \frac{-R_D}{R_S}} \rightarrow \text{constant gain (very stable)}$$

O/P impedance :-

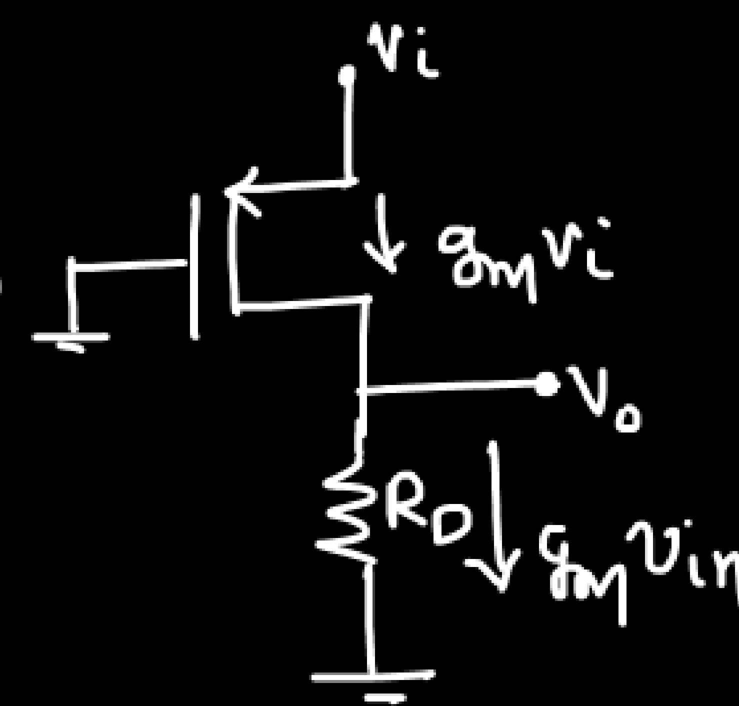


$$\boxed{R_{out} = R_D \| (r_o + R_S + g_m r_o R_S)}$$

② Common Gate Amplifier:-



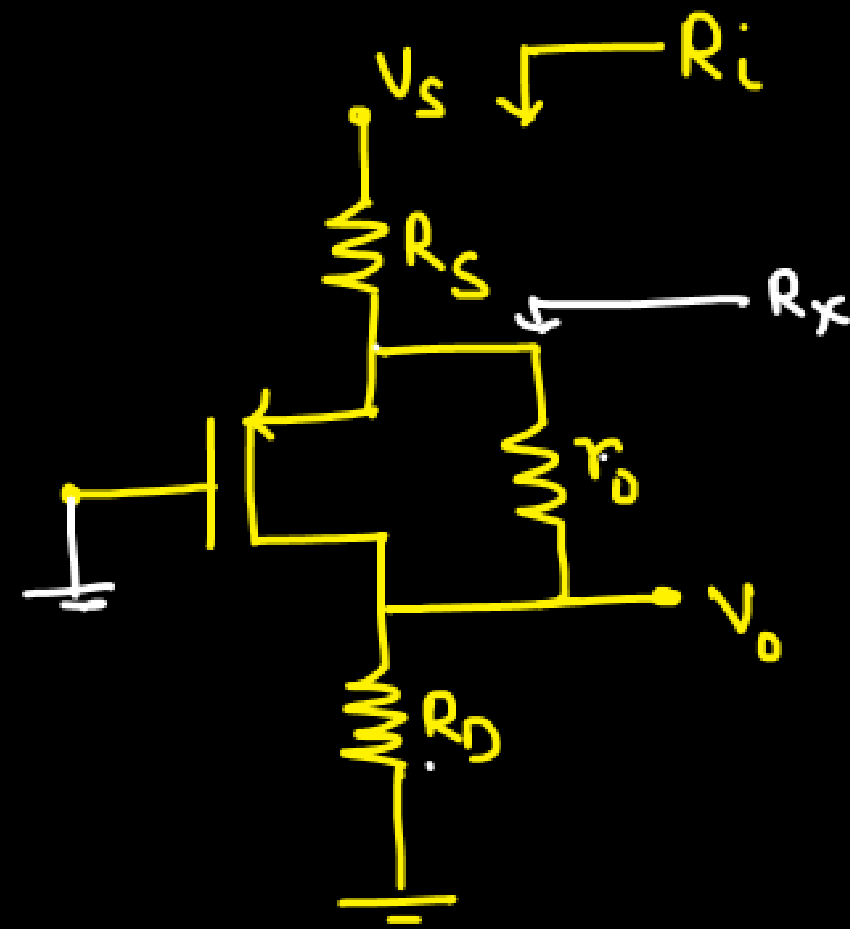
$\Rightarrow$



$\lambda = 0$

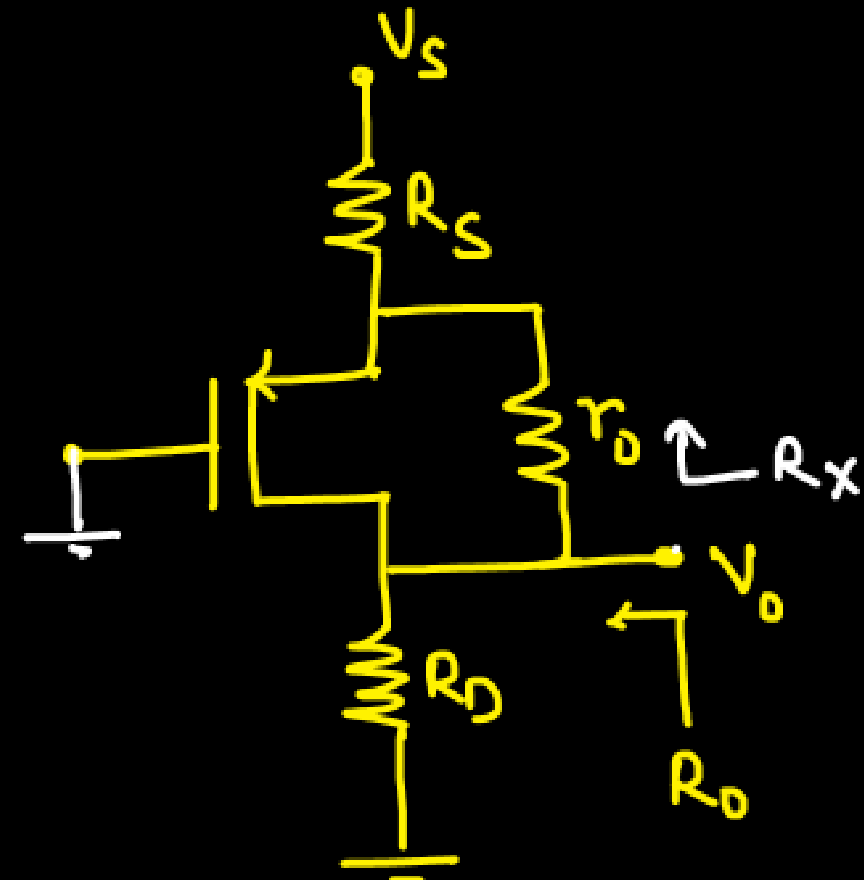
$$\boxed{\frac{v_o}{v_i} = g_m R_D}$$

Input Impedance:-



$$\boxed{R_i = R_S + \frac{R_D + r_o}{1 + g_m r_o}}$$

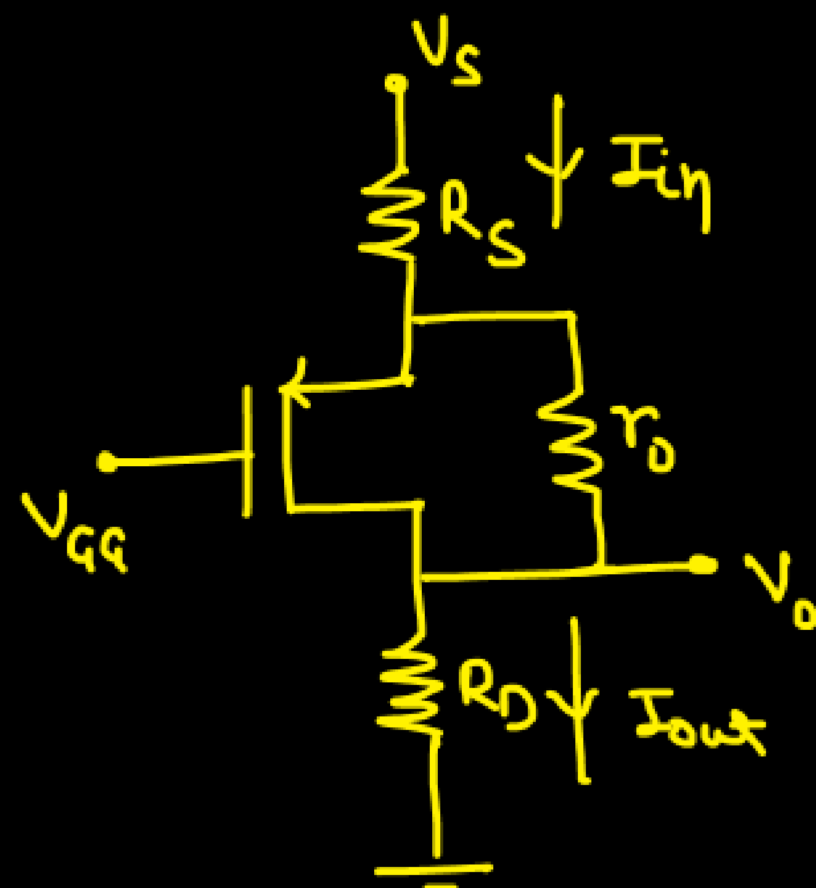
Output Impedance:-



$R_0 = R_D \| R_X$

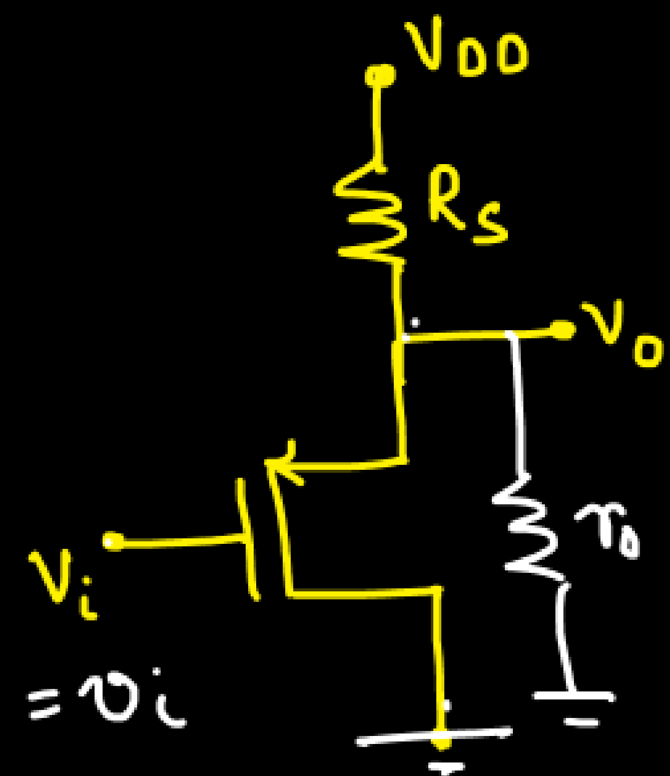
$$\boxed{R_0 = R_D \| \; r_0 + R_S + g_m r_0 R_S}$$

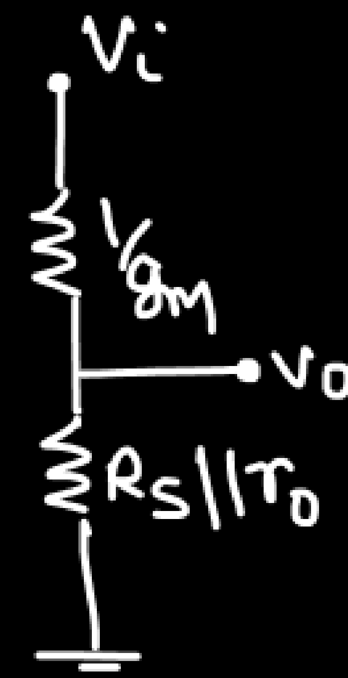
Current gain:-



$$\boxed{\frac{I_o}{I_{in}} = 1}$$

③ Common-Drain Amplifiers:-



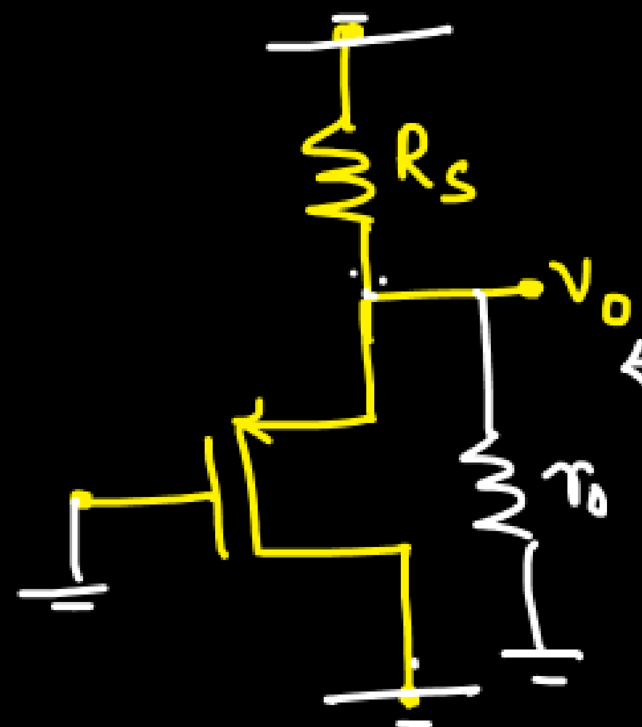


$$\frac{v_o}{v_i} = \frac{R_S}{R_S + 1/g_m}$$

$\lambda = 0$
$$\boxed{\frac{v_o}{v_i} = \frac{g_m R_S}{1 + g_m R_S}}$$

$\lambda \neq 0$
$$\boxed{\frac{v_o}{v_i} = \frac{g_m (R_S \| r_o)}{1 + g_m (R_S \| r_o)}}$$

Output Impedance:

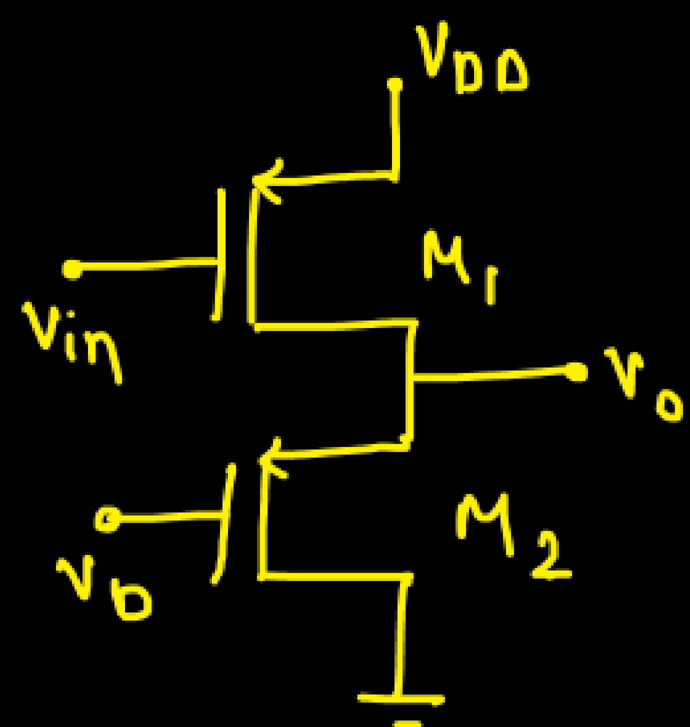


$$\boxed{R_{out} = r_o \,||\, R_S \,||\, 1/g_m}$$

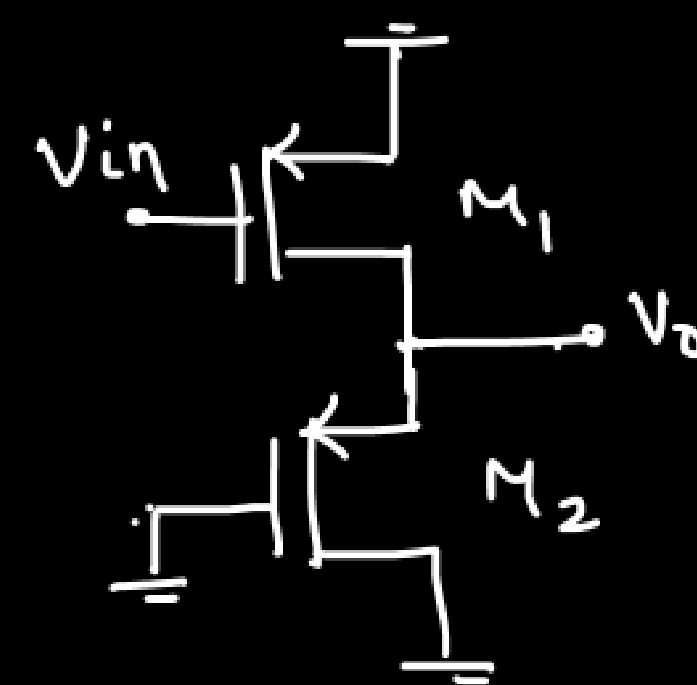
Assignment - 7

Q. Find small signal voltage gain.

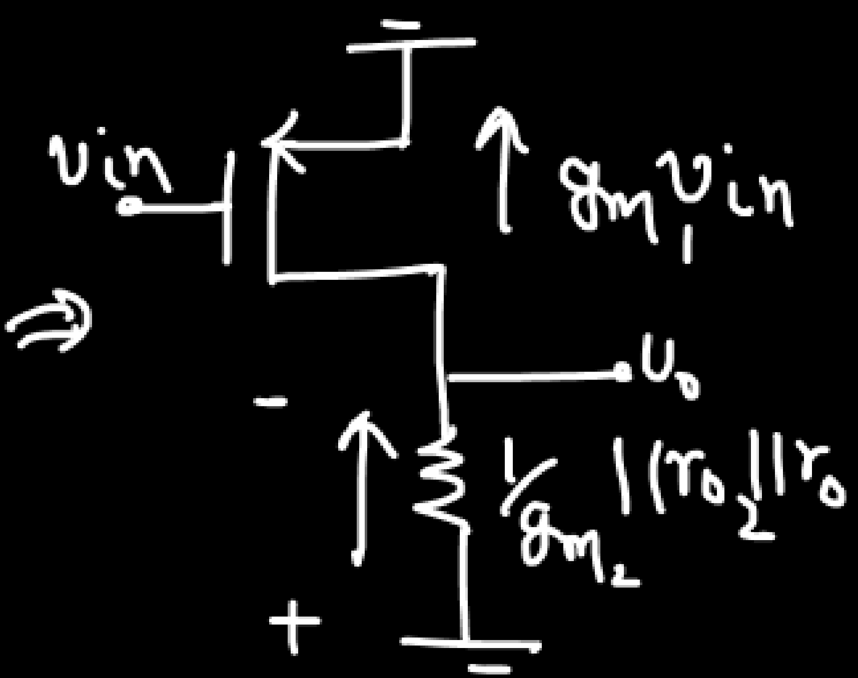
$(\lambda \neq 0)$



⇒

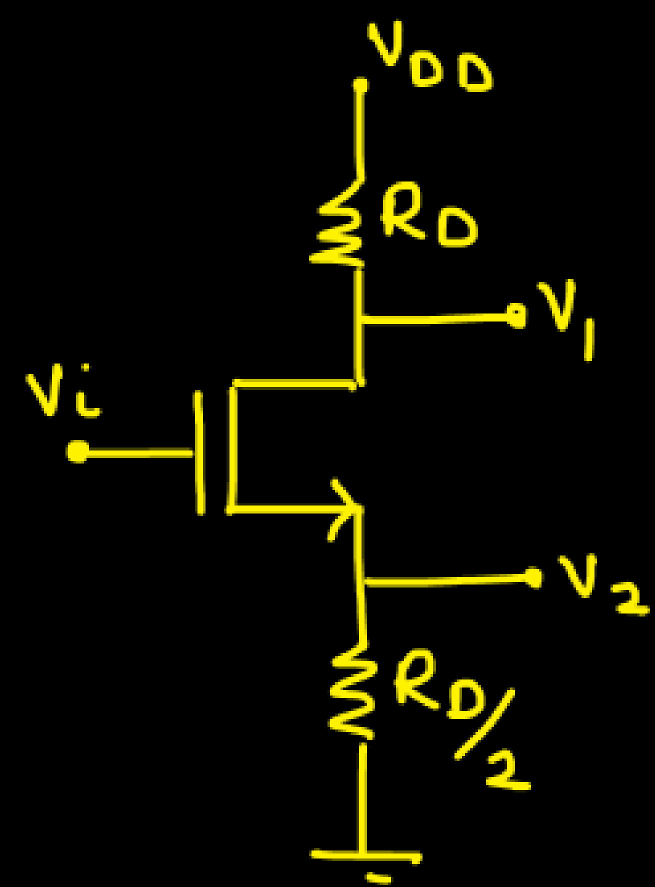


⇒



$$\boxed{\frac{v_o}{v_i} = -g_{m1}\left[\frac{1}{g_{m2}} \,\|\, r_{o2} \,\|\, r_{o1}\right]}$$

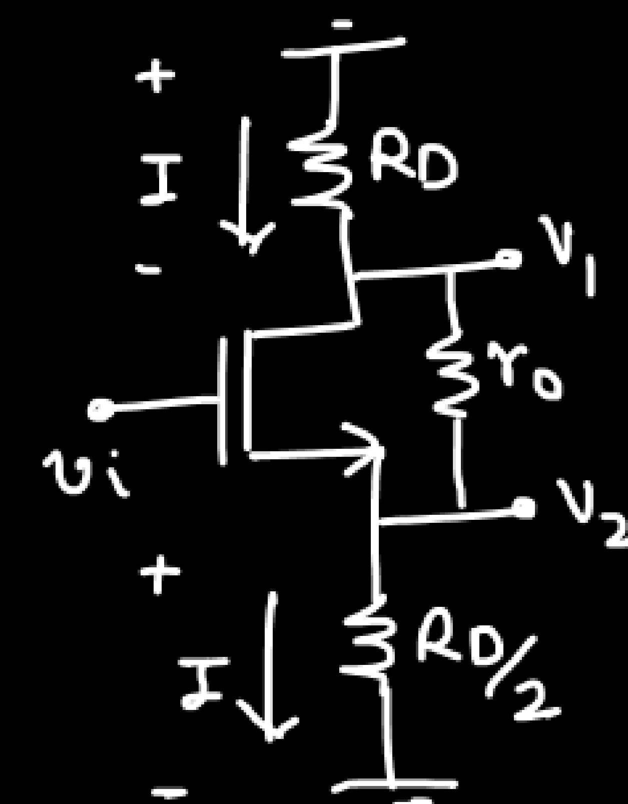
Q.



Find $\frac{V_1}{V_2} = ?$ [small signal]

$(\lambda \neq 0)$

$\Rightarrow$

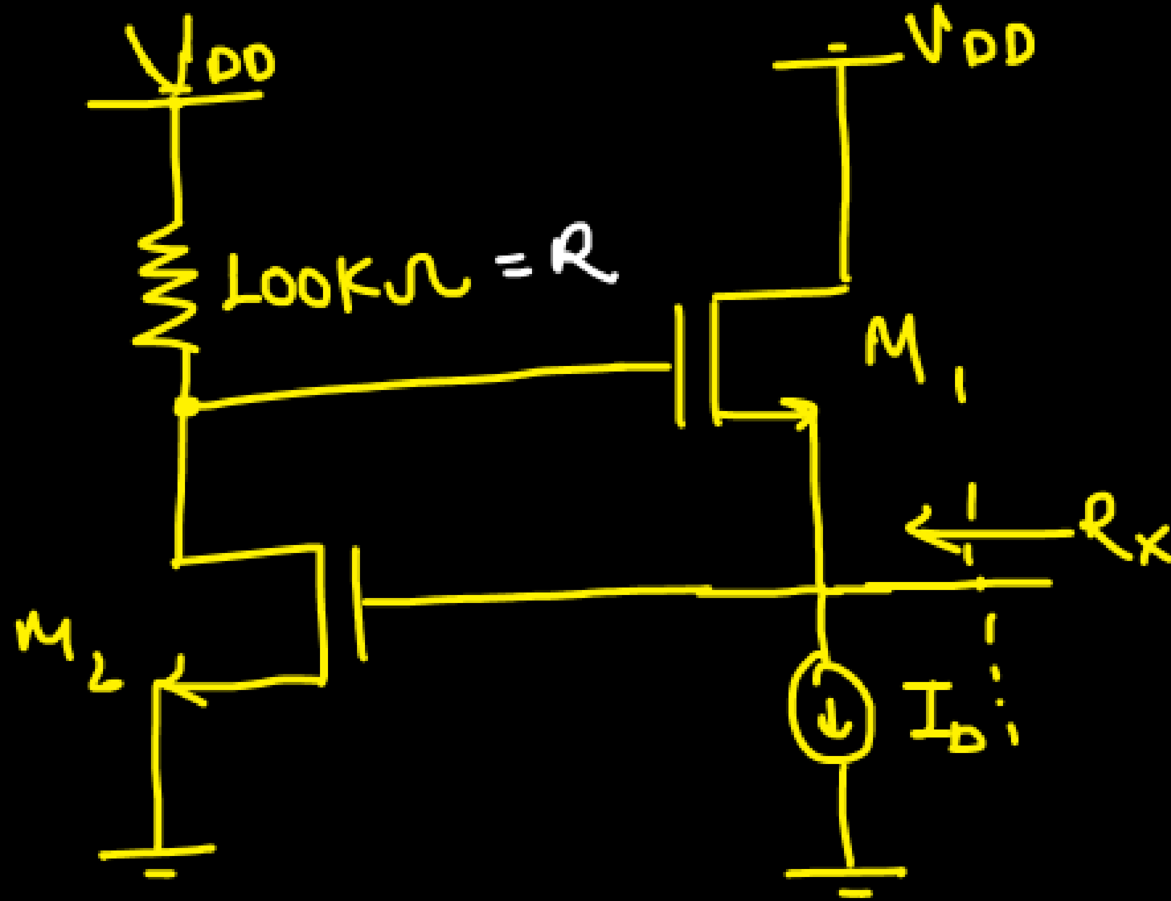


$V_1 = -IR_D$

$V_2 = -IR_D/2$

$$\boxed{\frac{V_1}{V_2} = 2}$$

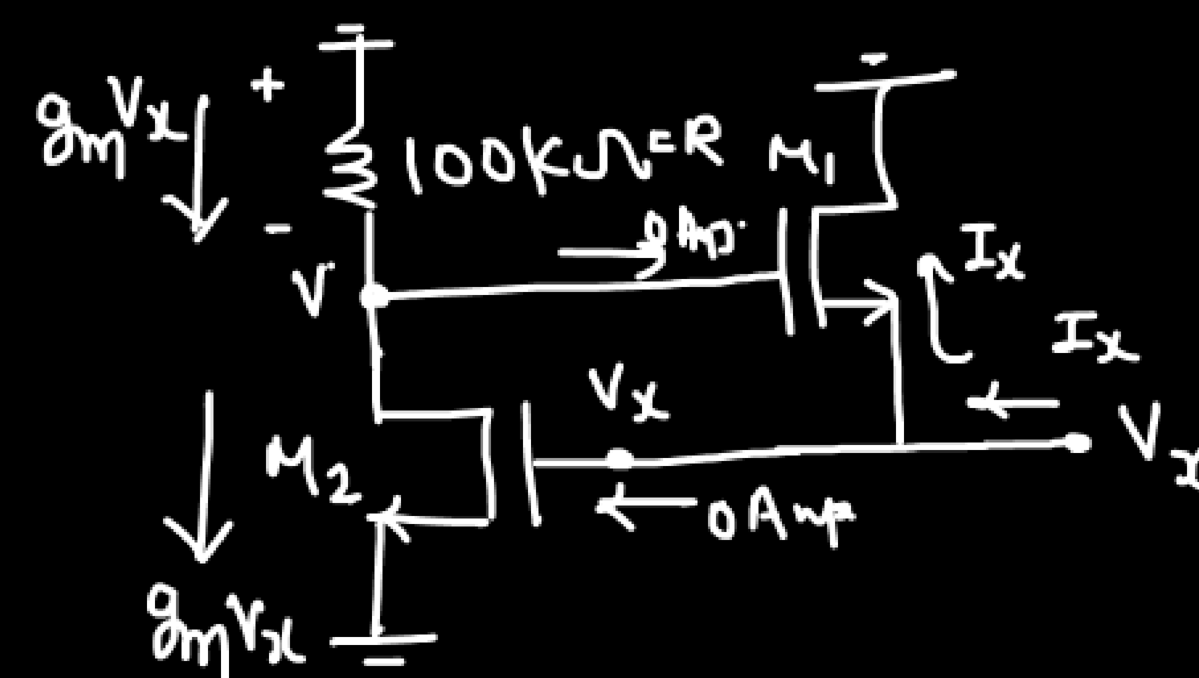
Q.



$g_m = g_{m_1} = g_{m_2} = 100\mu S$

Determine small signal R_x = ?

$R = 100k\Omega$



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

$I_x = g_m(V_x - V) \rightarrow (1)$

$V = -g_m V_x R \rightarrow (2)$

$I_x = g_m(V_x + g_m V_x R)$

$$I_x = g_m\left[1 + g_m R\right] V_x$$

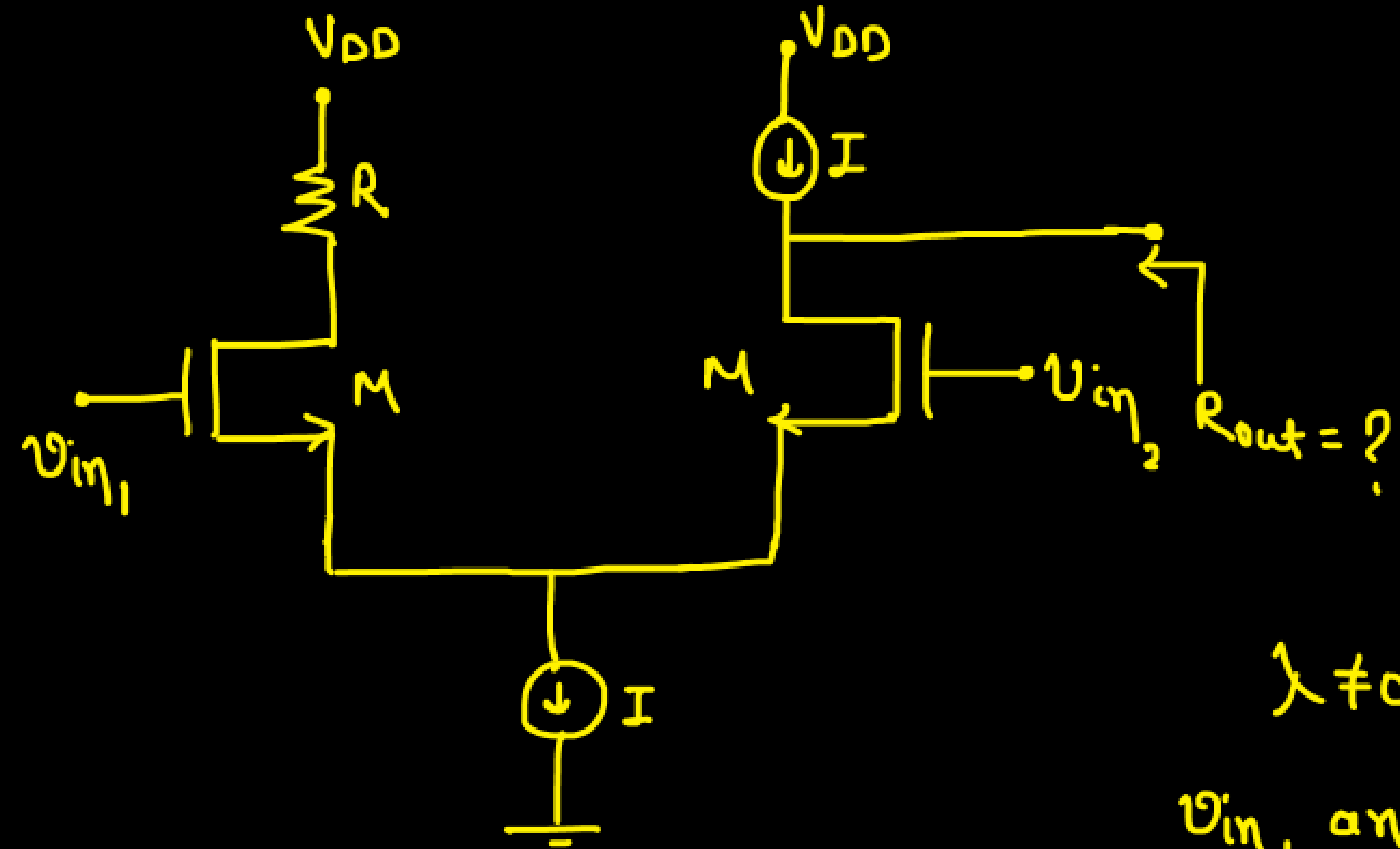
$$R_x = \frac{V_x}{I_x} = \frac{1}{g_m\left[1 + g_m R\right]}$$

$$= \frac{1}{10^{-4}\left[1 + 10^{-4} \times 10^{5}\right]}$$

$$R_x = \frac{1}{11} \times 10^{4}$$

$$\boxed{R_x = 909.09\ \Omega}$$

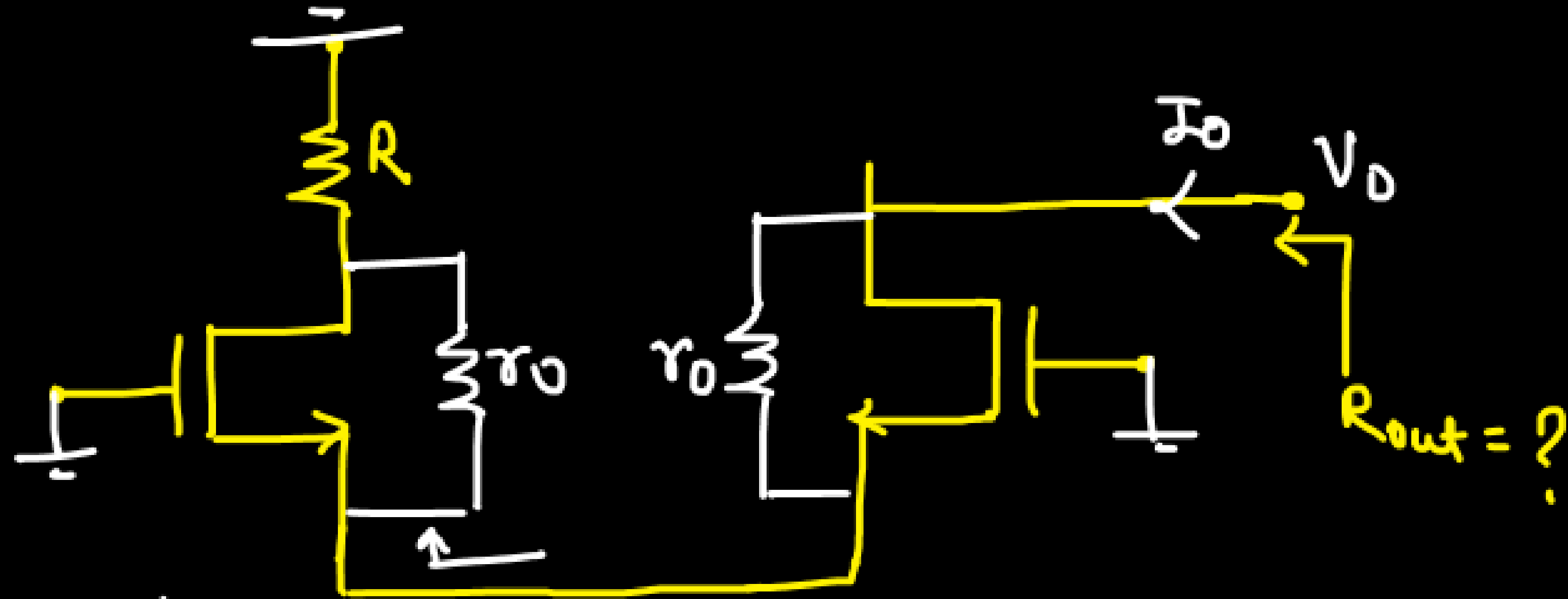
Q.



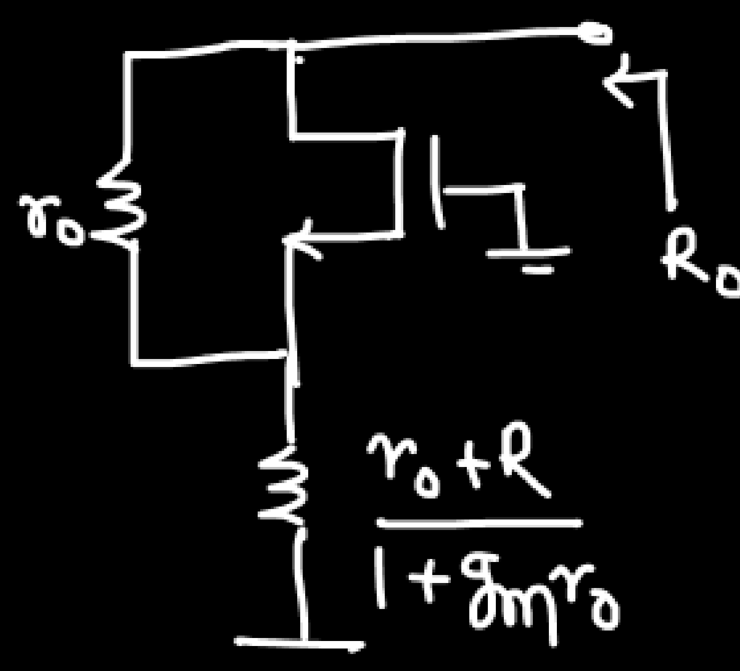
$\lambda \neq 0$

v_{in_1} and v_{in_2} are small signal i/p.

Find small signal R_{out} = ?



$$R_{out} = \frac{V_0}{I_0}$$

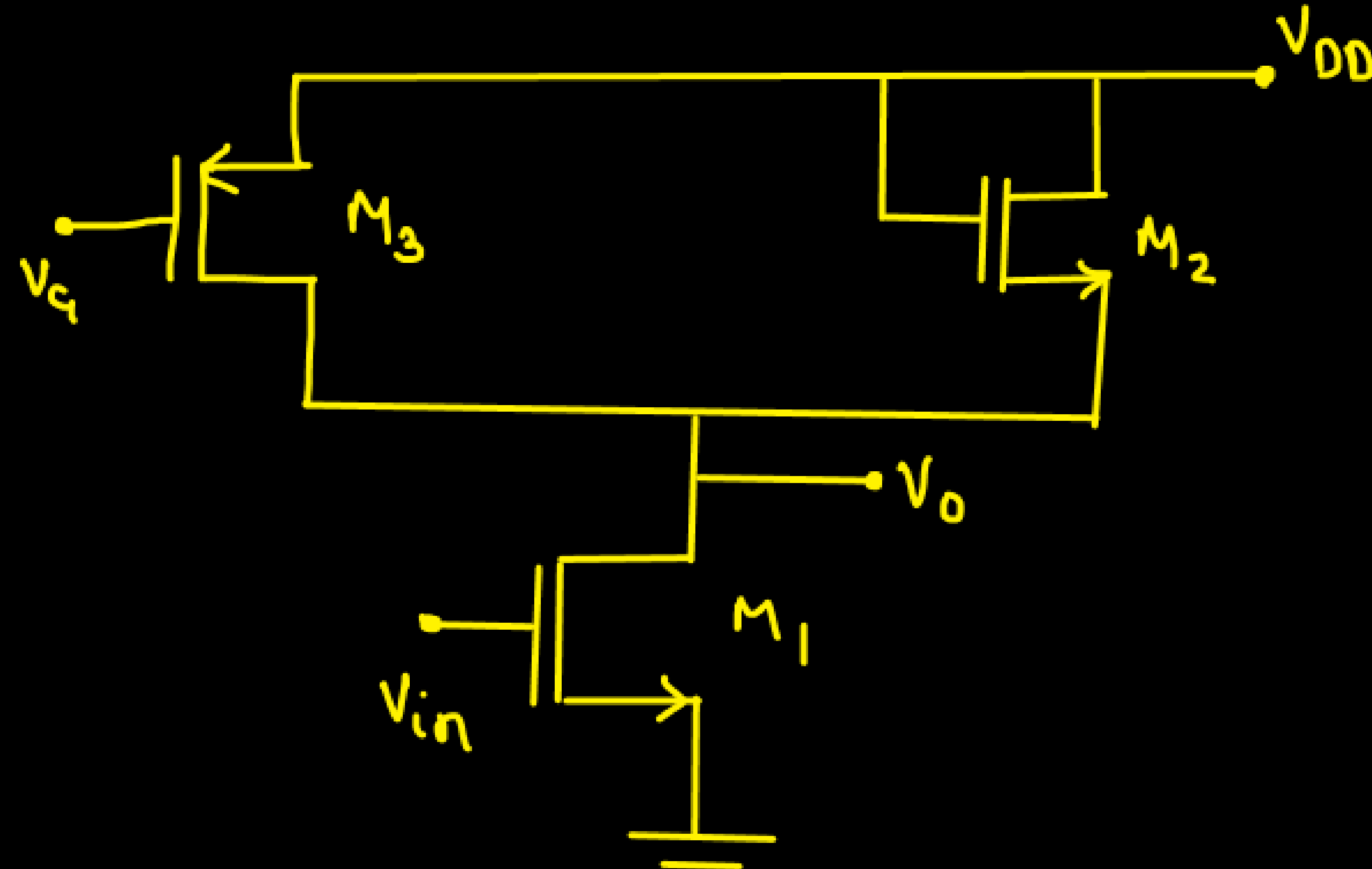


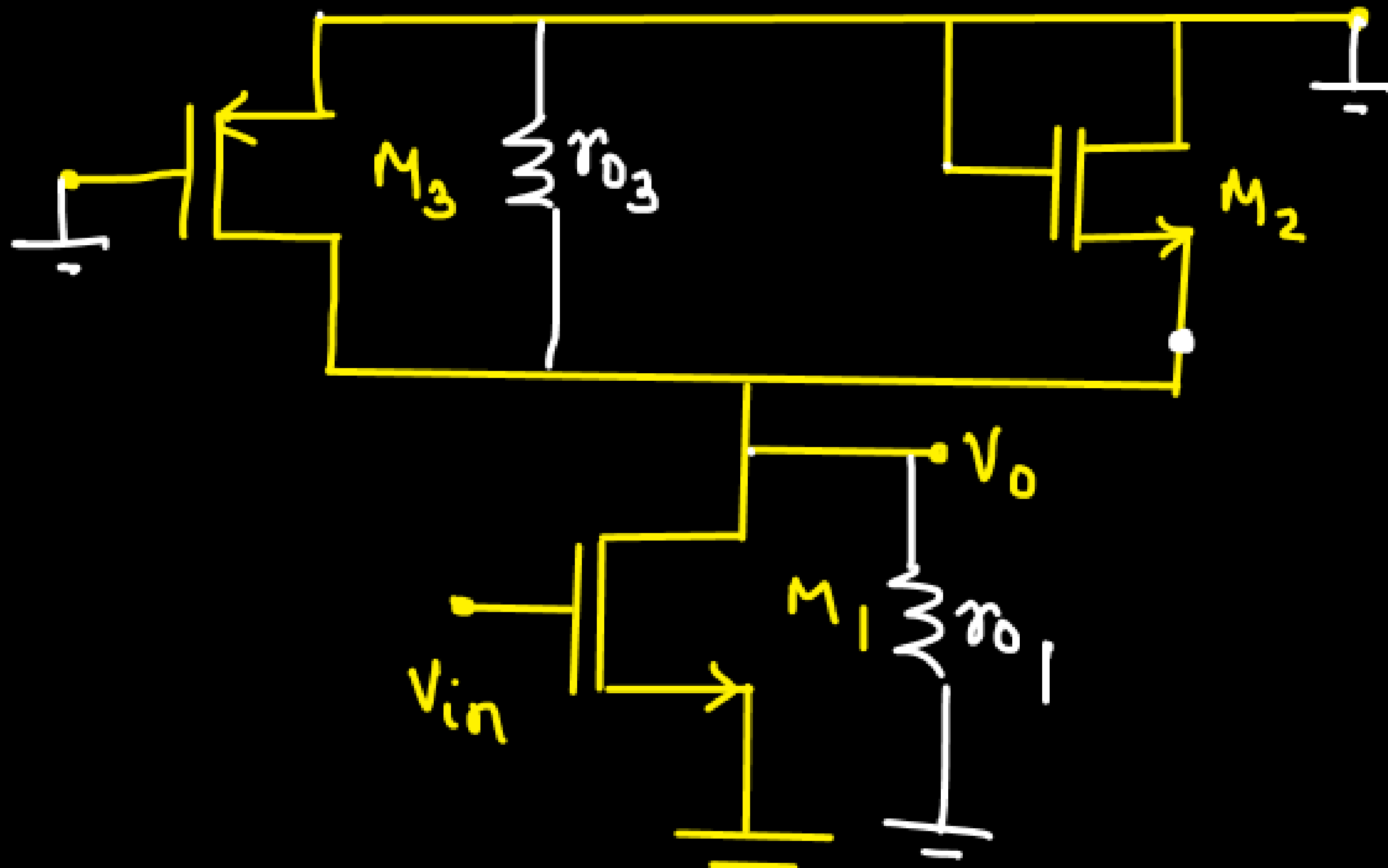
$$R_0 = r_0 + \frac{r_0+R}{1+g_m r_0} + g_m r_0\left[\frac{r_0+R}{1+g_m r_0}\right]$$

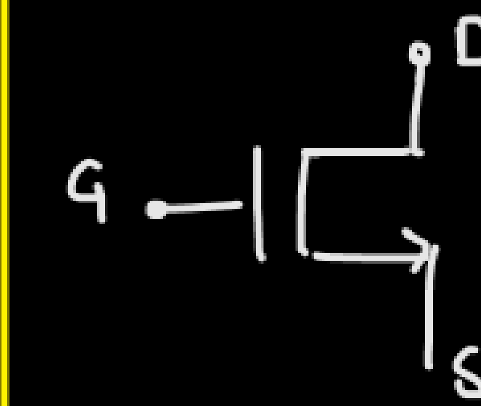
$$= r_0 + \left(\frac{r_0+R}{1+g_m r_0}\right)\left[1+g_m r_0\right]$$

$$\boxed{R_{out} = 2r_0 + R}$$

Q. Find small signal voltage gain. ($\lambda \neq 0$)

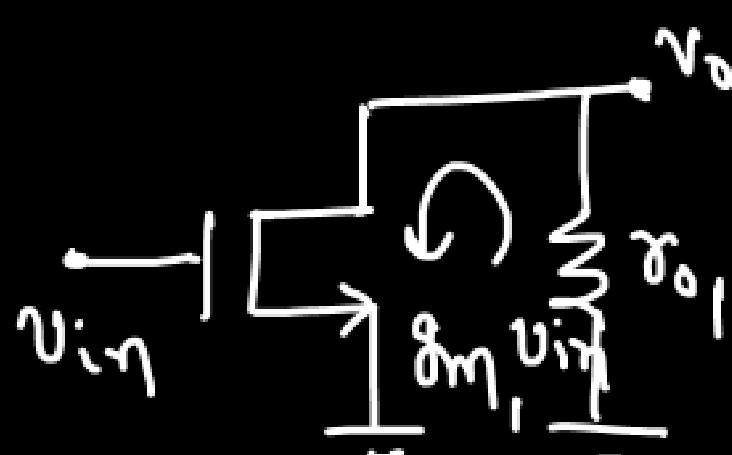






$S \rightarrow G \Rightarrow 1/g_m$

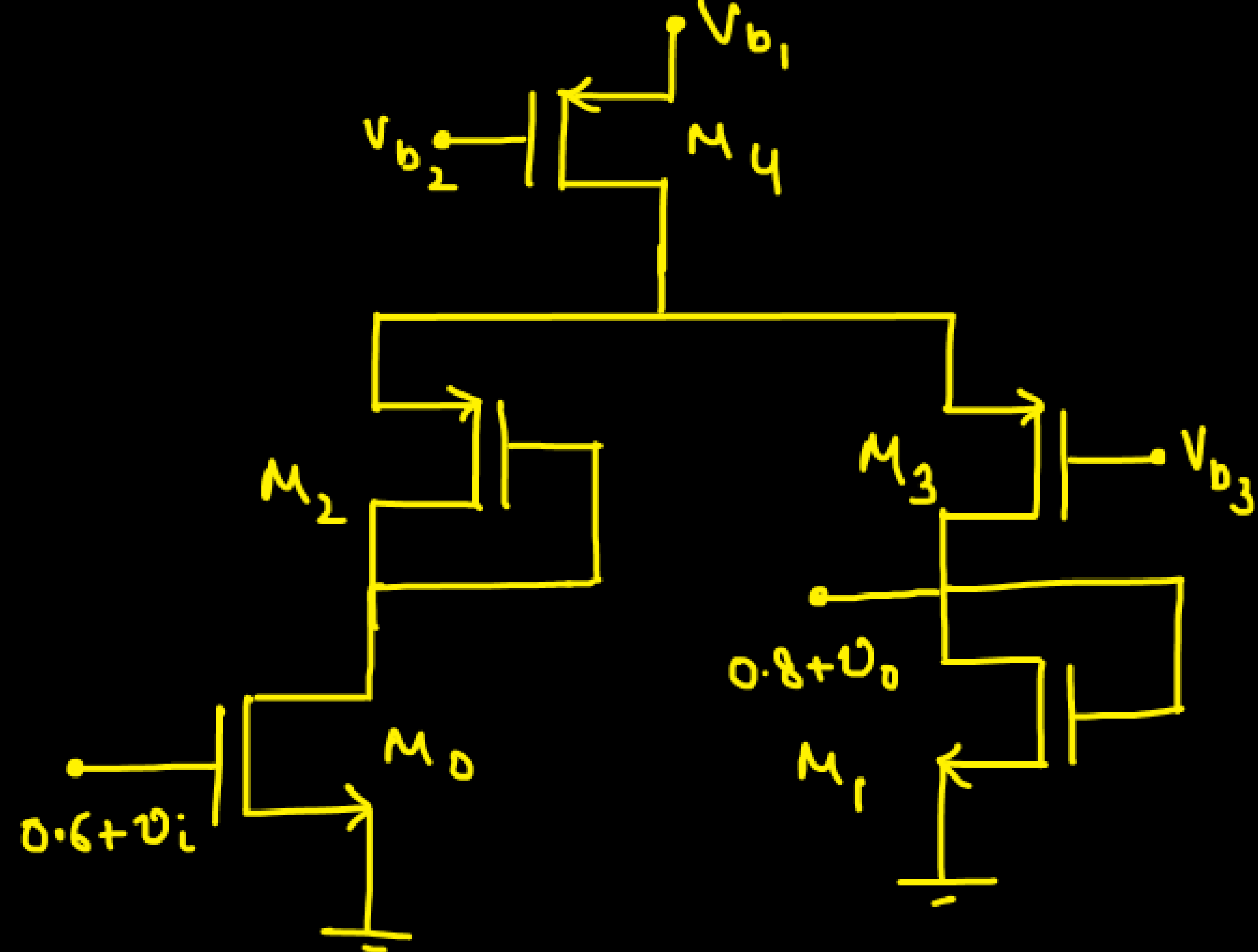
$S \rightarrow D \rightarrow r_o$



$r_{o_1} \,||\, r_{o_3} \,||\, \dfrac{1}{g_{m_2}} \,||\, r_{o_2}$

$$\boxed{\frac{v_o}{v_i} = -g_{m_1}\left[\frac{1}{g_{m_2}} \,||\, r_{o_2} \,||\, r_{o_1} \,||\, r_{o_3}\right]}$$

Q.

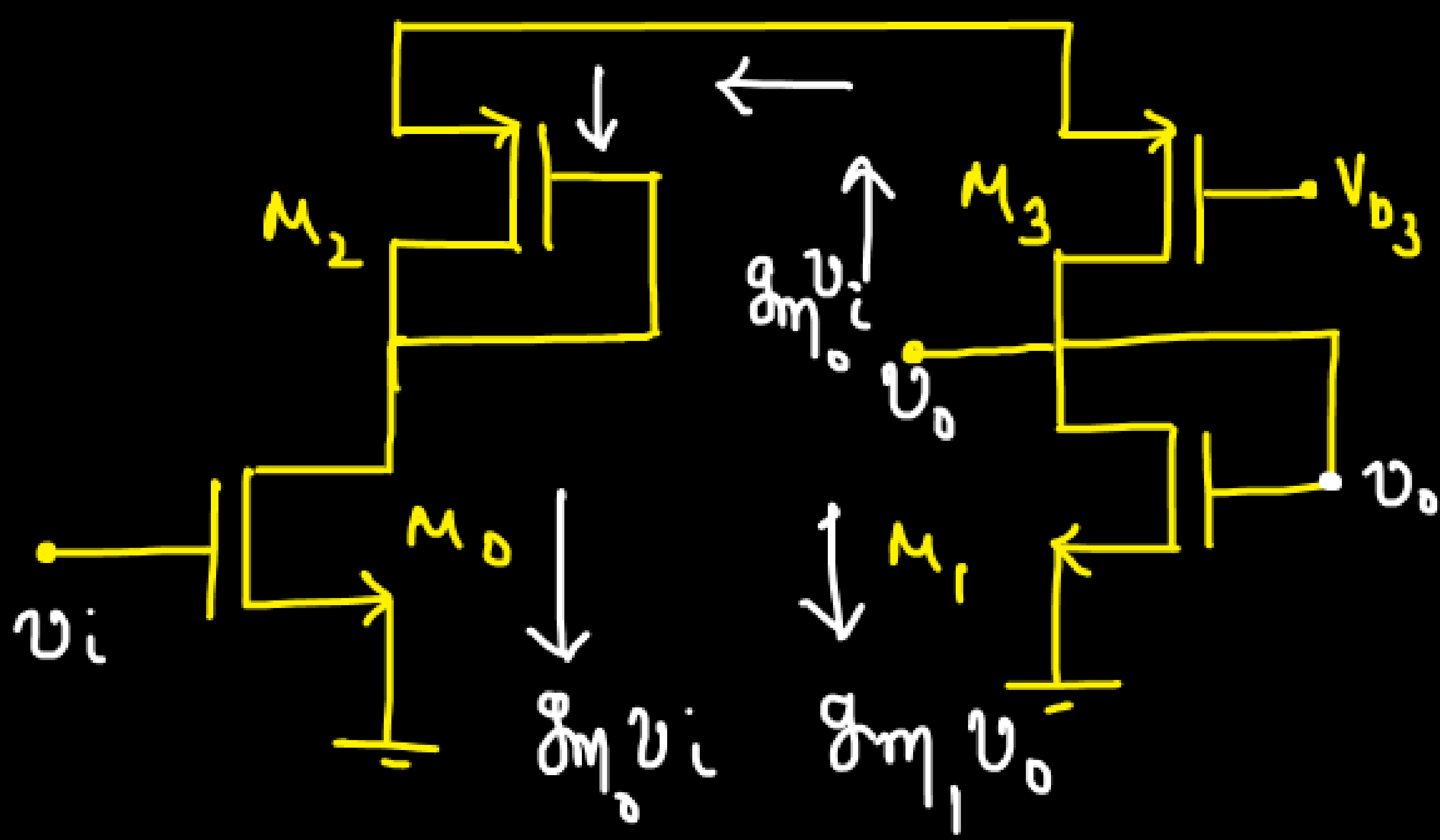


$\lambda = 0$

$$g_m = \frac{2I_{DC}}{V_{GS}-V_T}$$

Transistors are biased such that all Transistors are working in sat. region. $M_0 - M_3$ are biased with <u>5mA</u> current. V_T value for all the transistors is 0.4 V.

Find small signal voltage gain v_o/v_i ?



$$g_{m_0} v_i = -g_{m_1} v_0$$

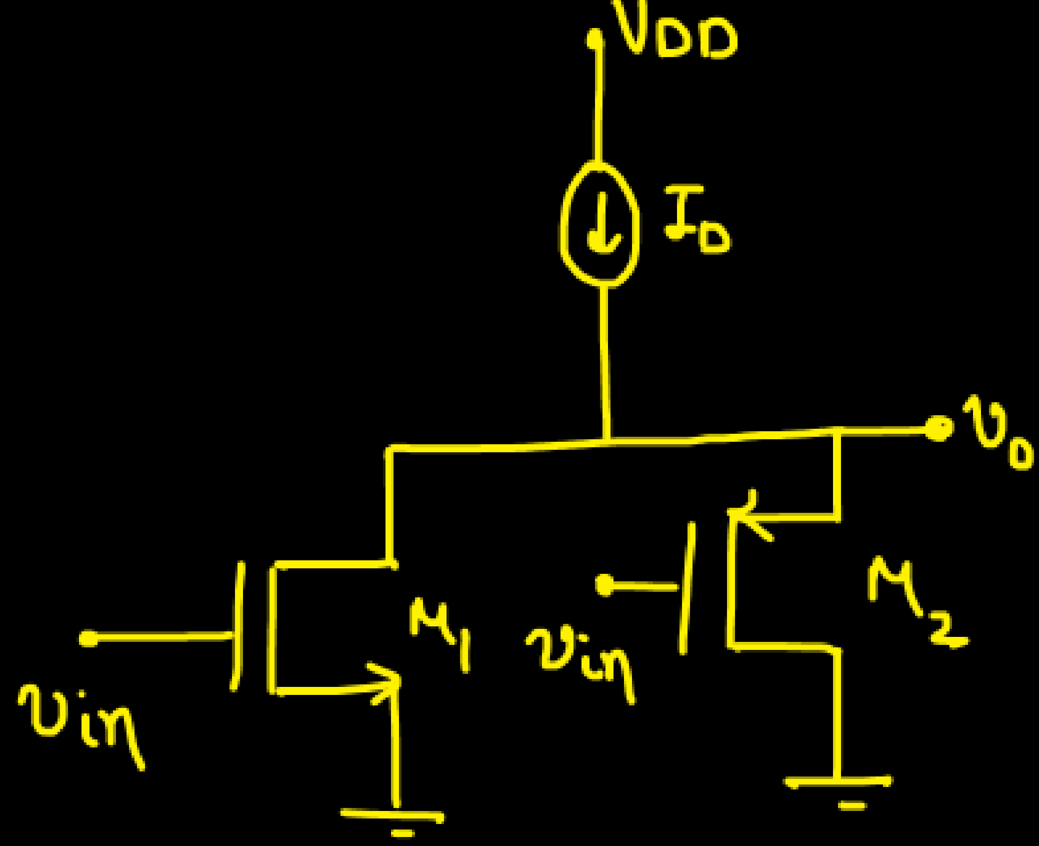
$$\boxed{\frac{v_0}{v_i} = \frac{-g_{m_0}}{g_{m_1}}}$$

$$g_{m_0} = \frac{(2 I_{DC})_{M_0}}{(V_{GS})_{M_0} - V_T} = \frac{2 \times 5\,mA}{0.6 - 0.4} = 50\,mS$$

$$g_{m_1} = \frac{2 \times 5\,mA}{0.8 - 0.4} = 25\,mS$$

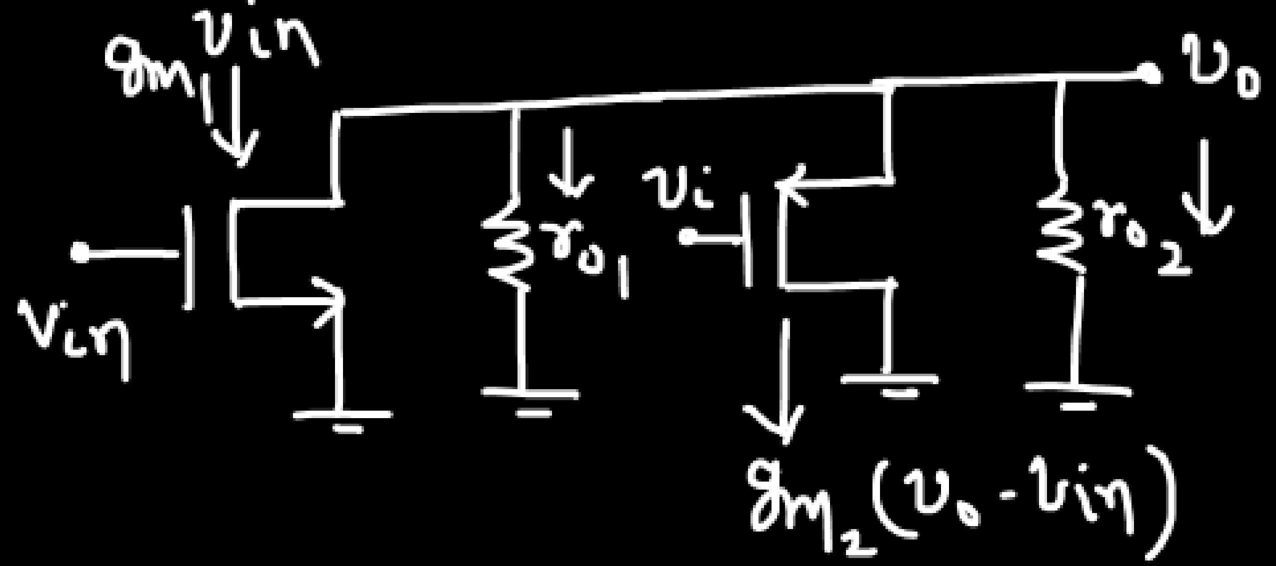
$$\boxed{\frac{v_0}{v_i} = -\frac{50m}{25m} = -2\,V/V}$$

Q. Find small signal voltage gain.



$\lambda \neq 0$

$\Rightarrow$



$$g_{m_1} v_{in} + \frac{v_0}{r_{o_1}} + g_{m_2}(v_0 - v_{in}) + \frac{v_0}{r_{o_2}} = 0$$

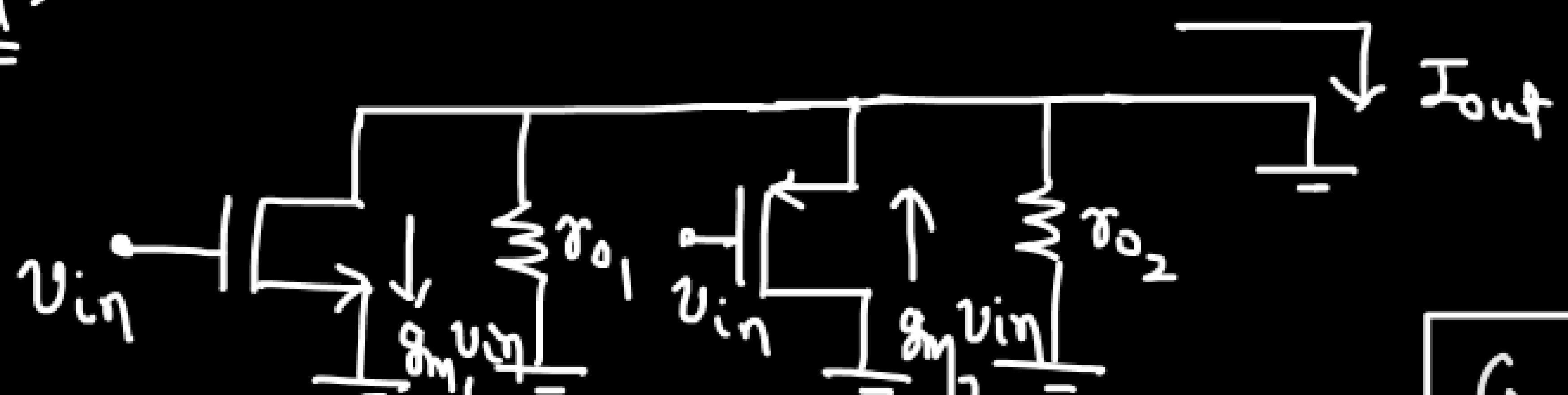
$$\frac{v_0}{r_{o_1}} + g_{m_2} v_0 + \frac{v_0}{r_{o_2}} = (g_{m_2} - g_{m_1}) v_{in}$$

$$\frac{v_0}{r_{o1} \| r_{o2} \| \frac{1}{g_{m2}}} = (g_{m2} - g_{m1}) v_{in}$$

$$\boxed{\frac{v_0}{v_{in}} = (g_{m2} - g_{m1}) \left(r_{o1} \| r_{o2} \| \frac{1}{g_{m2}} \right)}$$

M-II Gm Rout Mtd:-

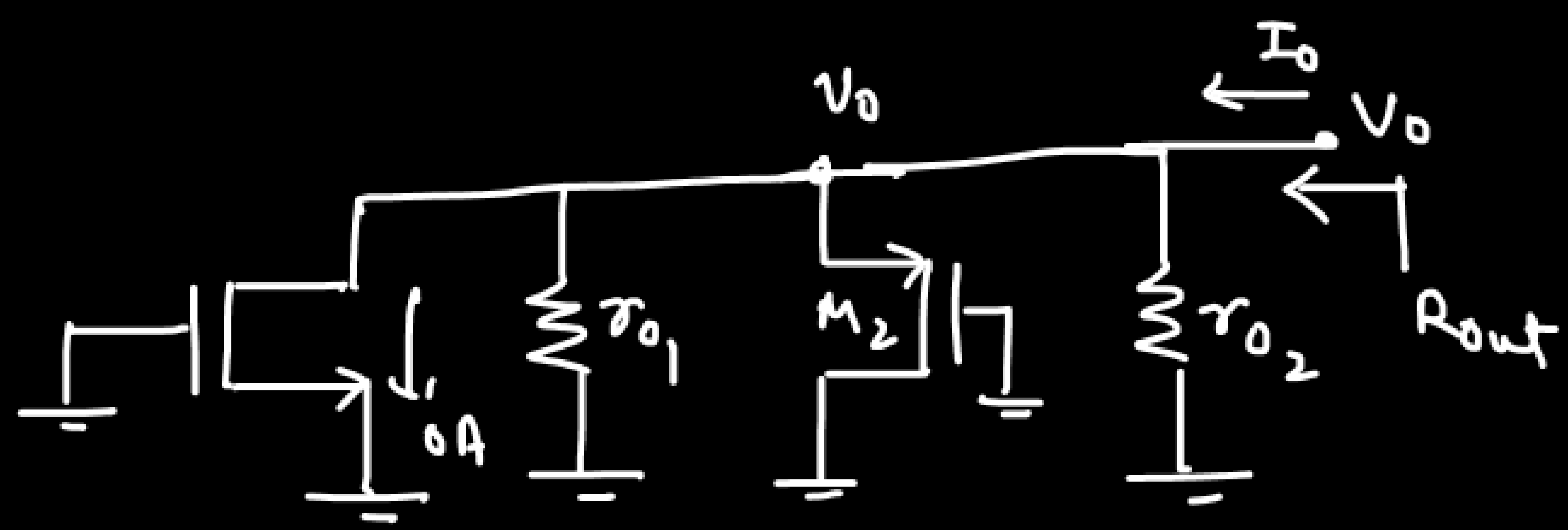
Gm →



$$g_{m1} v_{in} + I_{out} = g_{m2} v_{in}$$

$$\boxed{G_m = \frac{I_{out}}{v_{in}} = g_{m2} - g_{m1}}$$

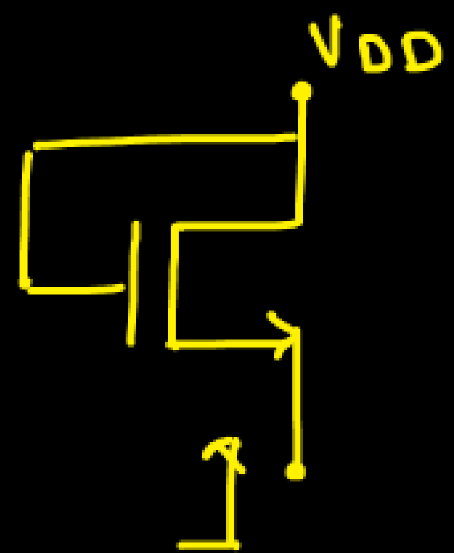
$\underline{\underline{R_{out}}} \rightarrow$



$$\boxed{R_{out} = r_{o_1} \parallel r_{o_2} \parallel \frac{1}{g_{m_2}}}$$

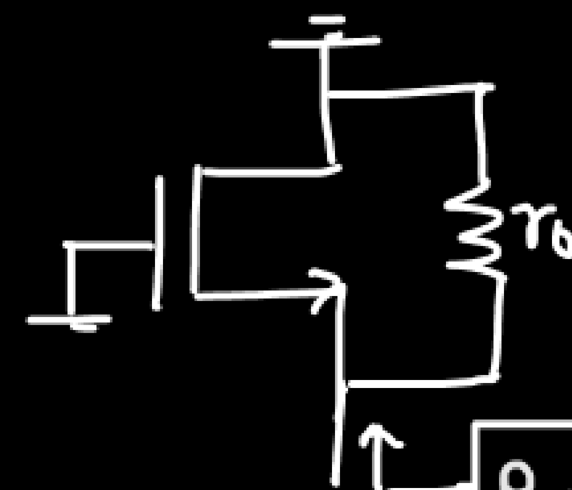
$$\boxed{A_V = \left(g_{m_2} - g_{m_1}\right)\left(r_{o_1} \parallel r_{o_2} \parallel \frac{1}{g_{m_2}}\right)}$$

Q.



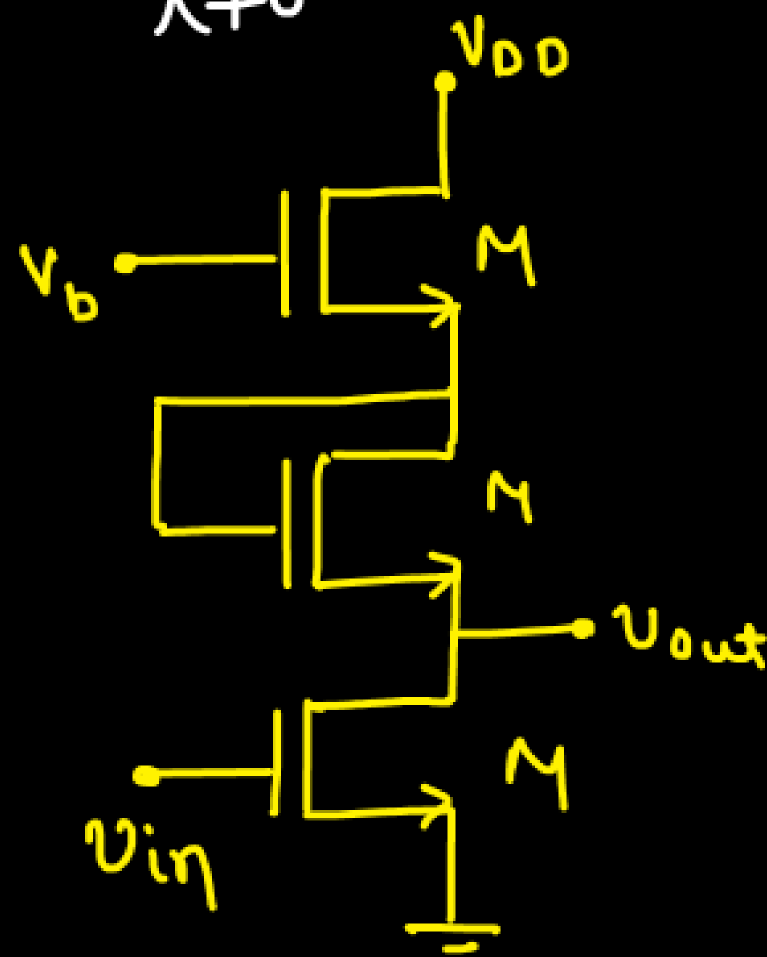
$R_x = ?$

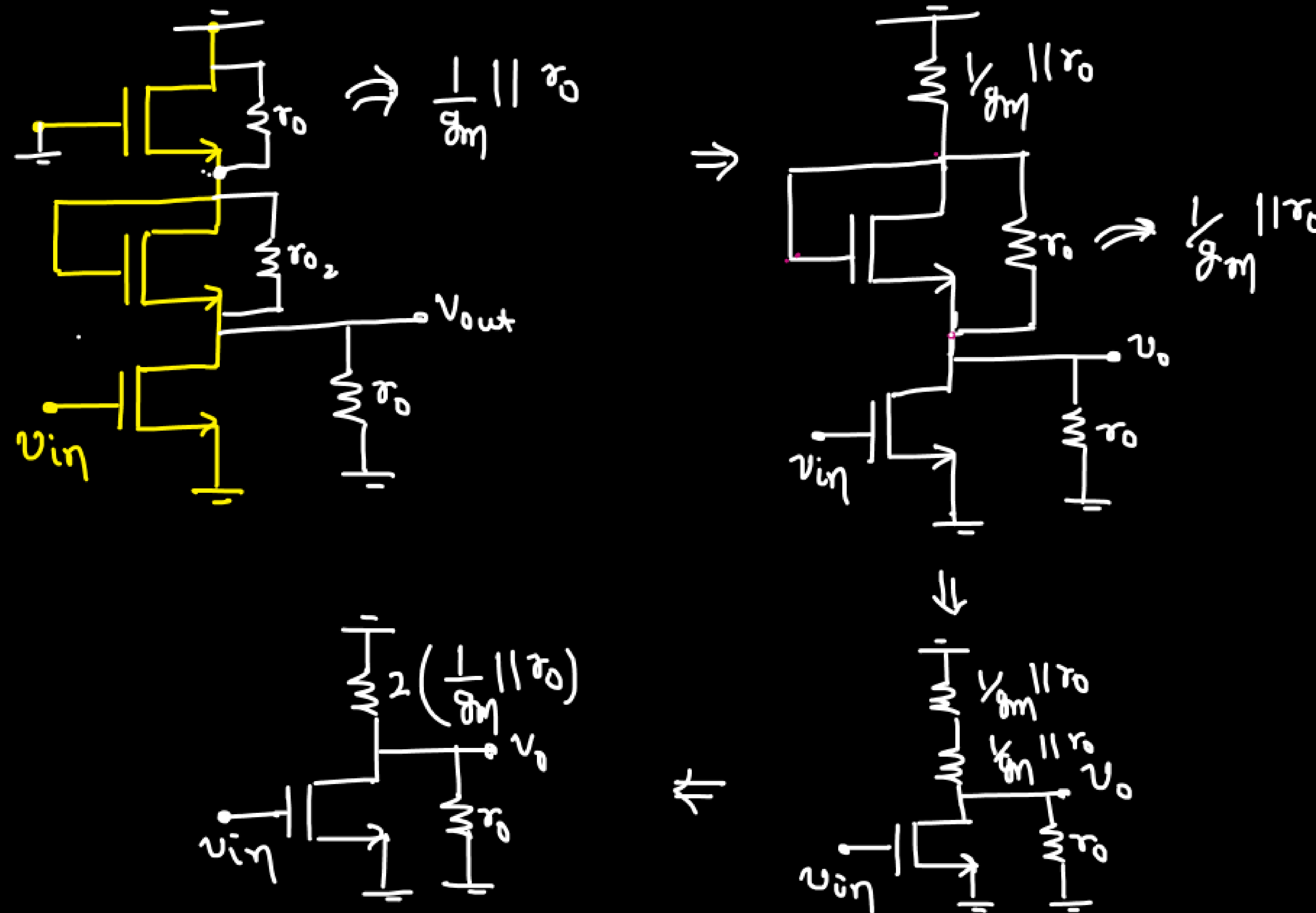
$\Rightarrow$



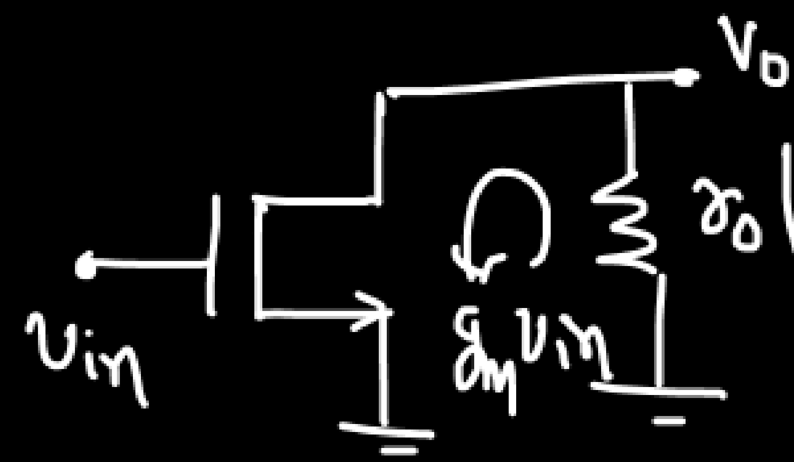
$$\boxed{R_x = \frac{1}{g_m} \parallel r_o}$$

Q. $\lambda \neq 0$





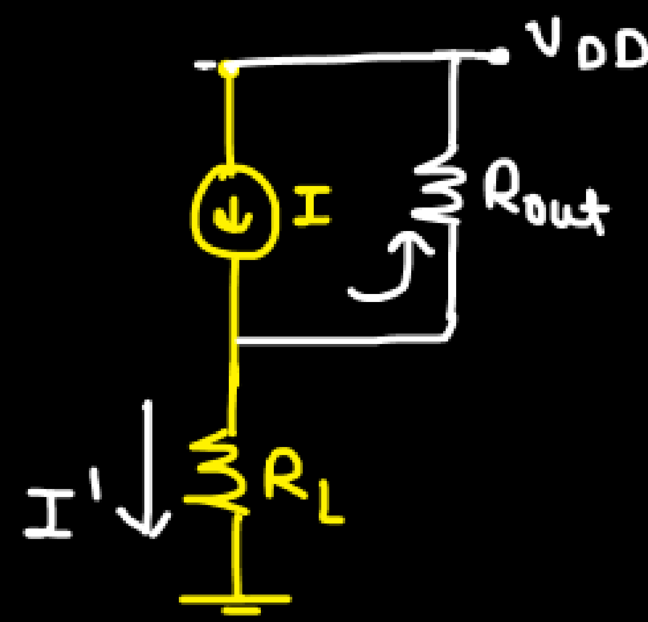
r0
1/gm || r0
r02
Vout
r0
vin
1/gm || r0
r0
1/gm || r0
v0
r0
vin
1/gm || r0
1/gm || r0
v0
r0
vin
2(1/gm || r0)
v0
r0
vin



$$r_o \| 2\left(r_o \| 1/g_m\right) = r_o \| 2r_o \| 2/g_m$$

$$\boxed{\frac{v_o}{v_{in}} = -g_m \left[\frac{2}{g_m} \| \frac{2r_o}{3}\right]}$$

⇒ Current Source:-



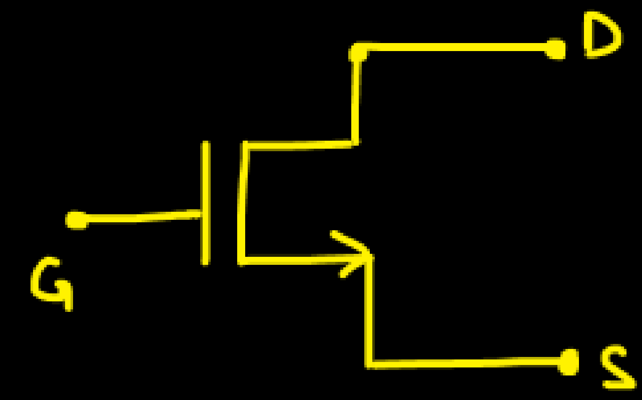
$$\boxed{I' < I}$$

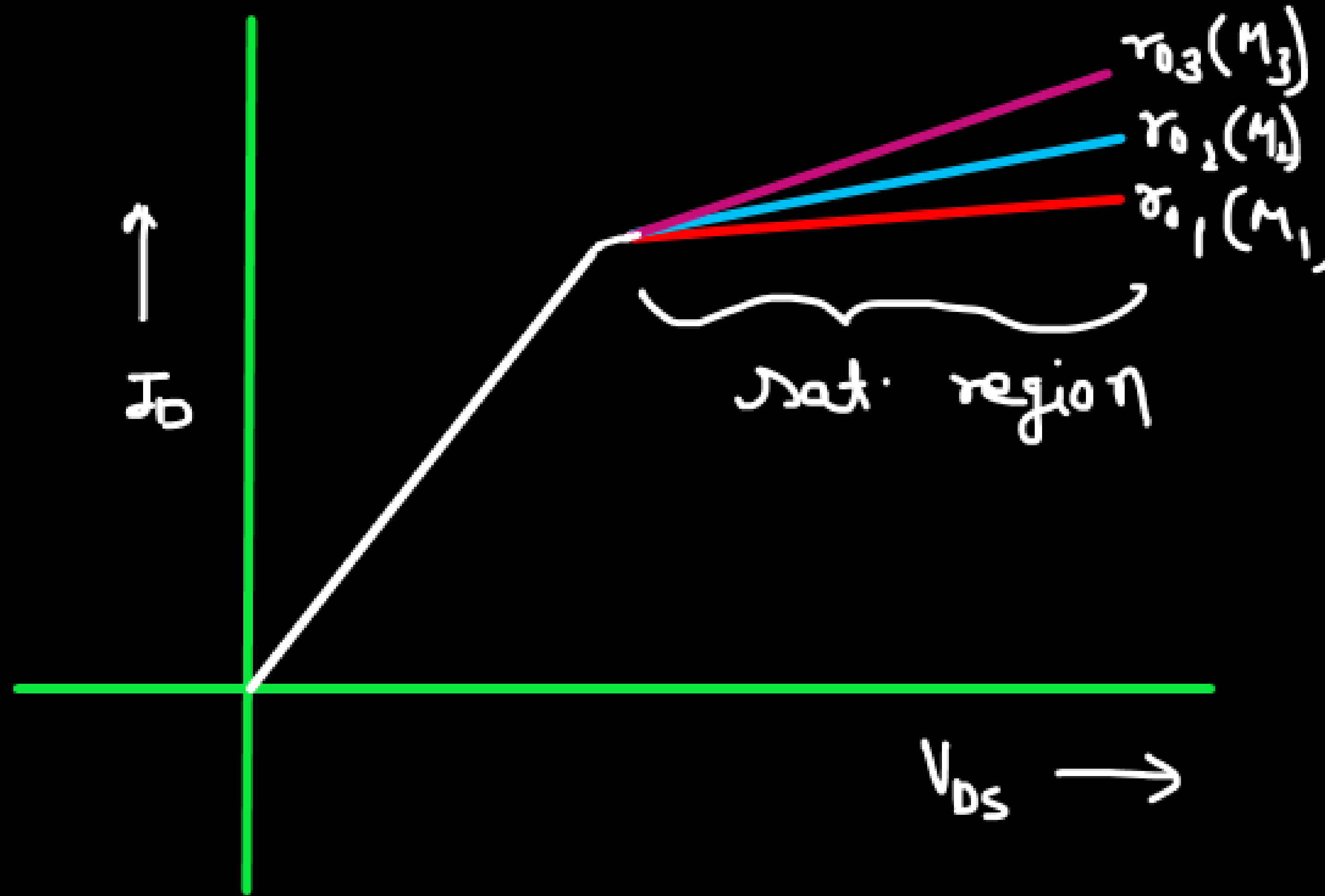
if $R_{out} \to \infty$

$$\boxed{I' \to I}$$

$$\boxed{\text{more } R_{out} \Rightarrow \text{better current source}}$$

Making current source from MOS:-





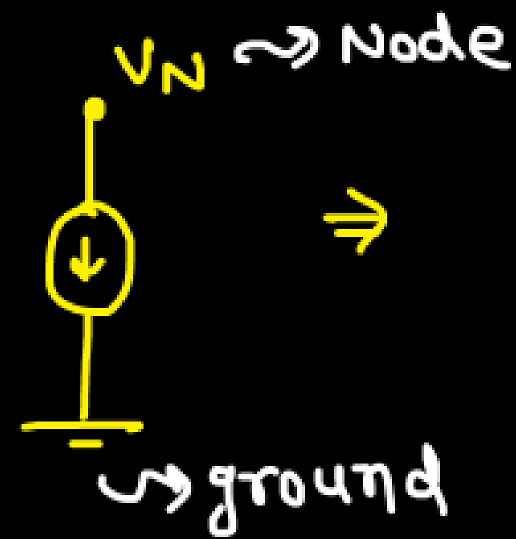
$r_{o1} > r_{o2} > r_{o3}$

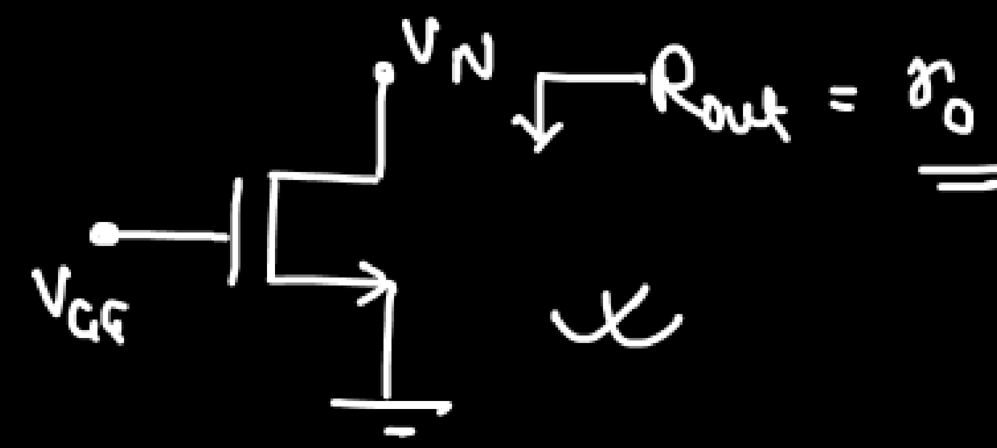
$\Downarrow$

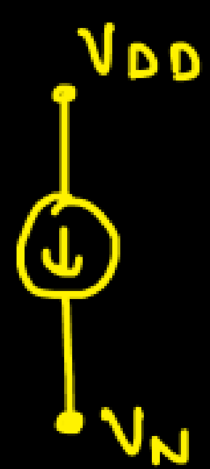
Best current source

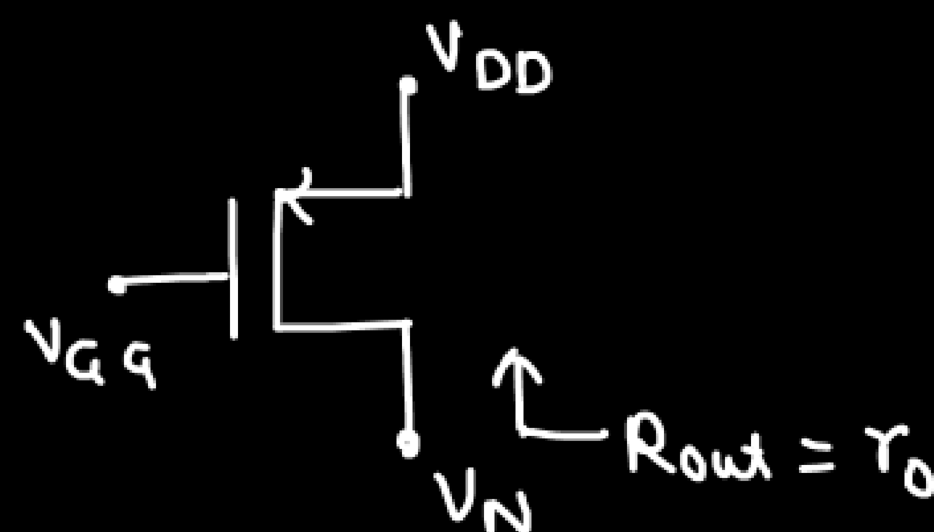
$M_1 \rightarrow$ Best current source

For using MOS as a current source, it should be biased in sat. region.

★ 

⇒ 

★ 

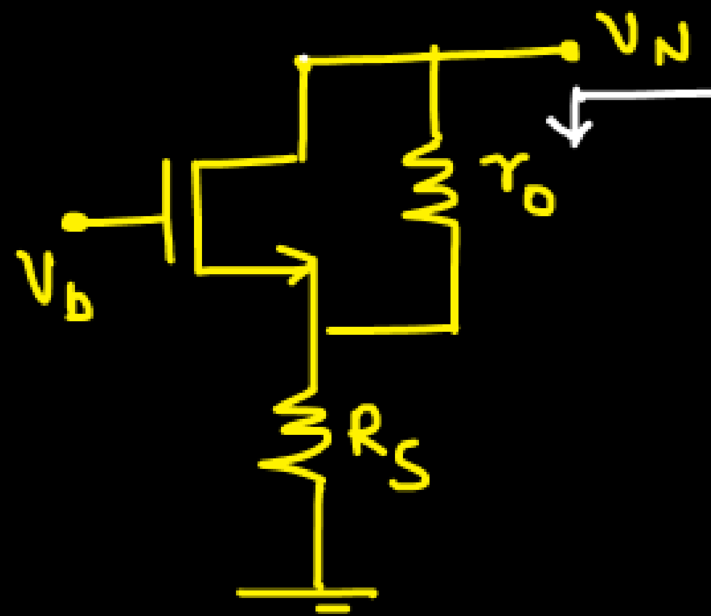
⇒ 

Node to ground → NMOS

Supply to Node → PMOS

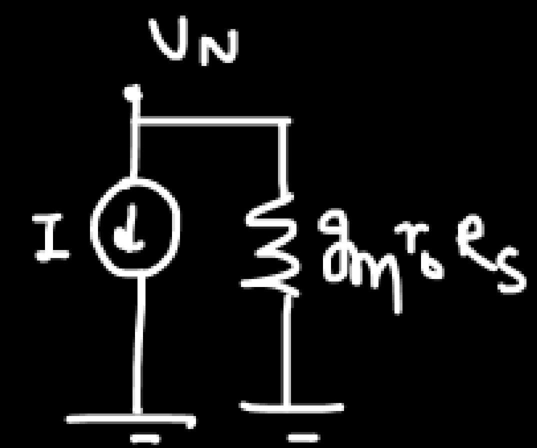
⇒ what if I need a Higher o/p impedance?

★

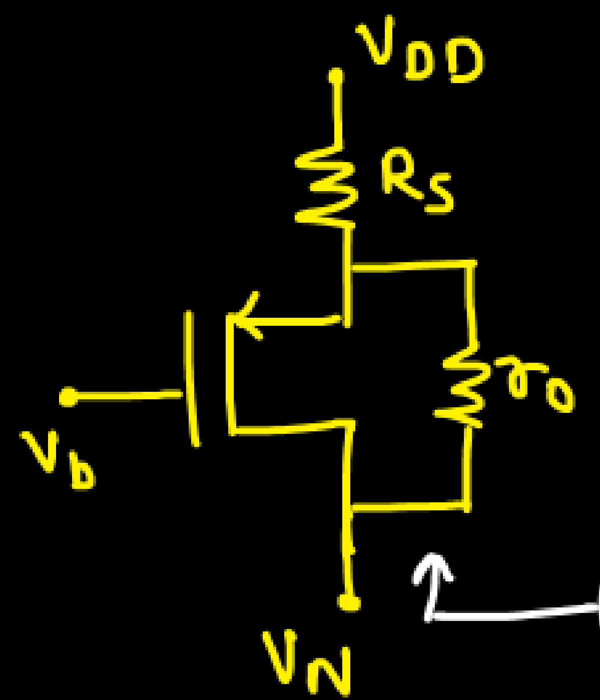


$$R_{out} = r_o + R_S + g_m r_o R_S$$
$$\approx g_m r_o R_S$$

$\Rightarrow$

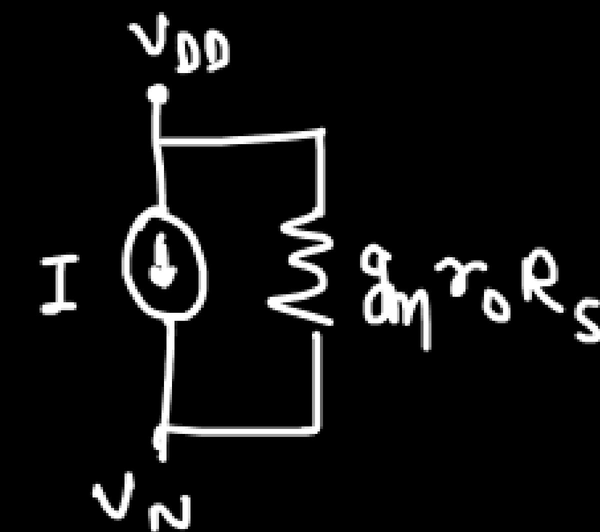


★



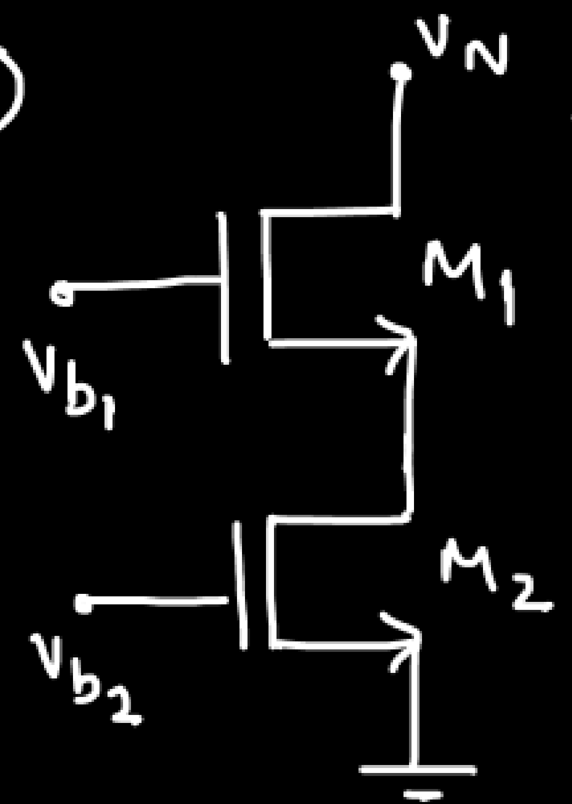
$$R_{out} = r_o + R_S + g_m r_o R_S$$
$$\approx g_m r_o R_S$$

$\Rightarrow$



Cascode Current Source:-

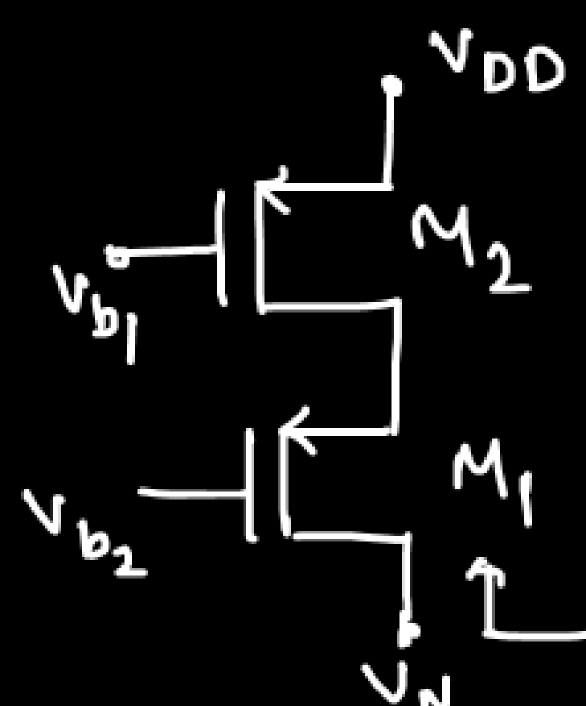
①



$$R_{out} = r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2}$$
$$\approx g_{m_1} r_{o_1} r_{o_2}$$

(using NMOS)

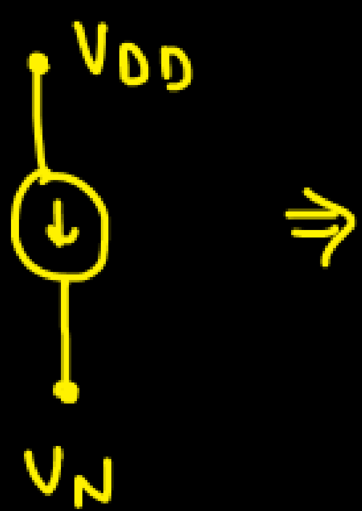
②



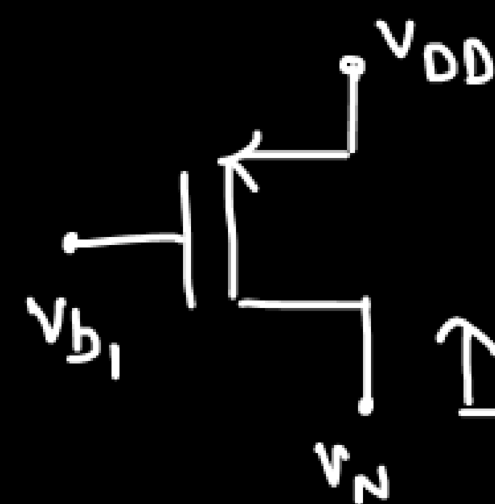
$$R_{out} = r_{o_1} + r_{o_2} + g_{m_1} r_{o_1} r_{o_2} \approx g_{m_1} r_{o_1} r_{o_2}$$

Summary:-

①

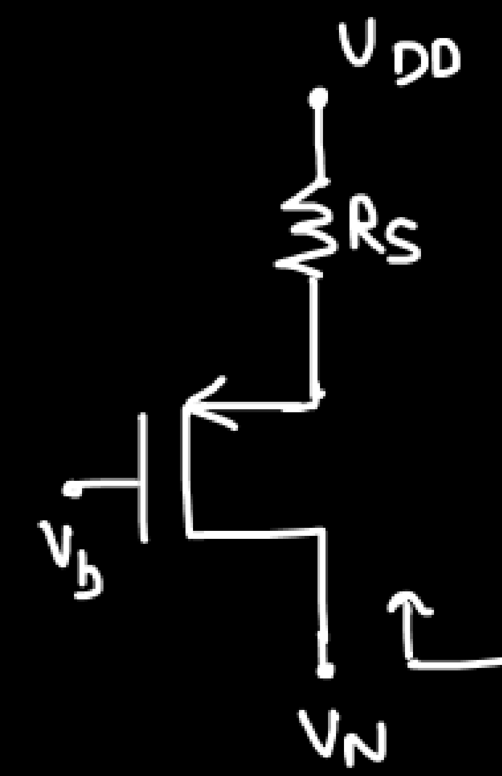


$\Rightarrow$



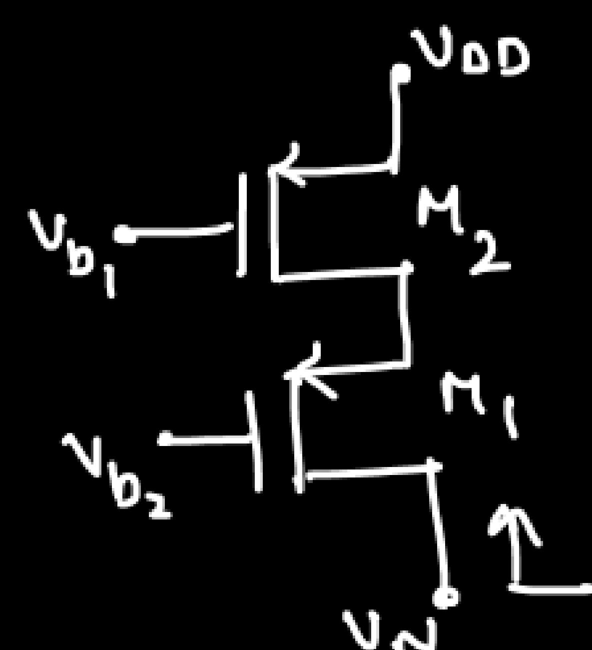
$R_{out} = r_o$

①



$\boxed{R_{out} \approx g_m r_o R_S}$

②

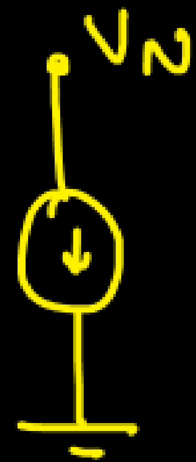


⇝ cascode current source

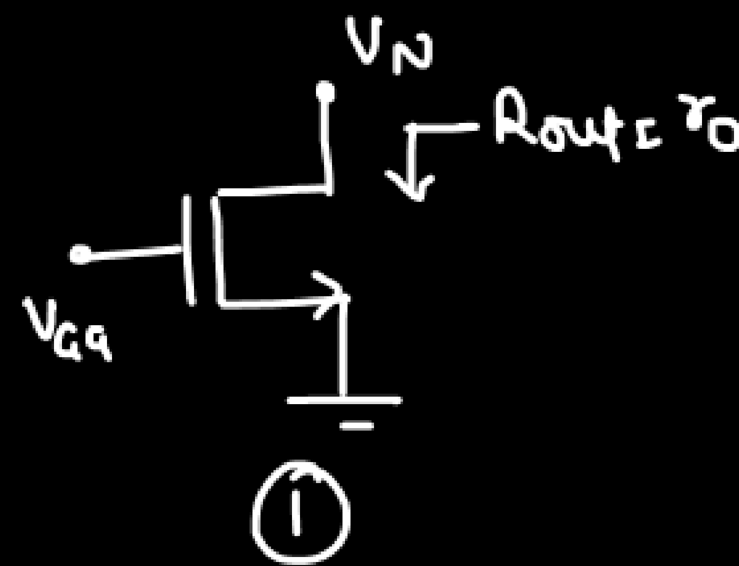
$\boxed{R_{out} \approx g_{m1} r_{o1} r_{o2}}$

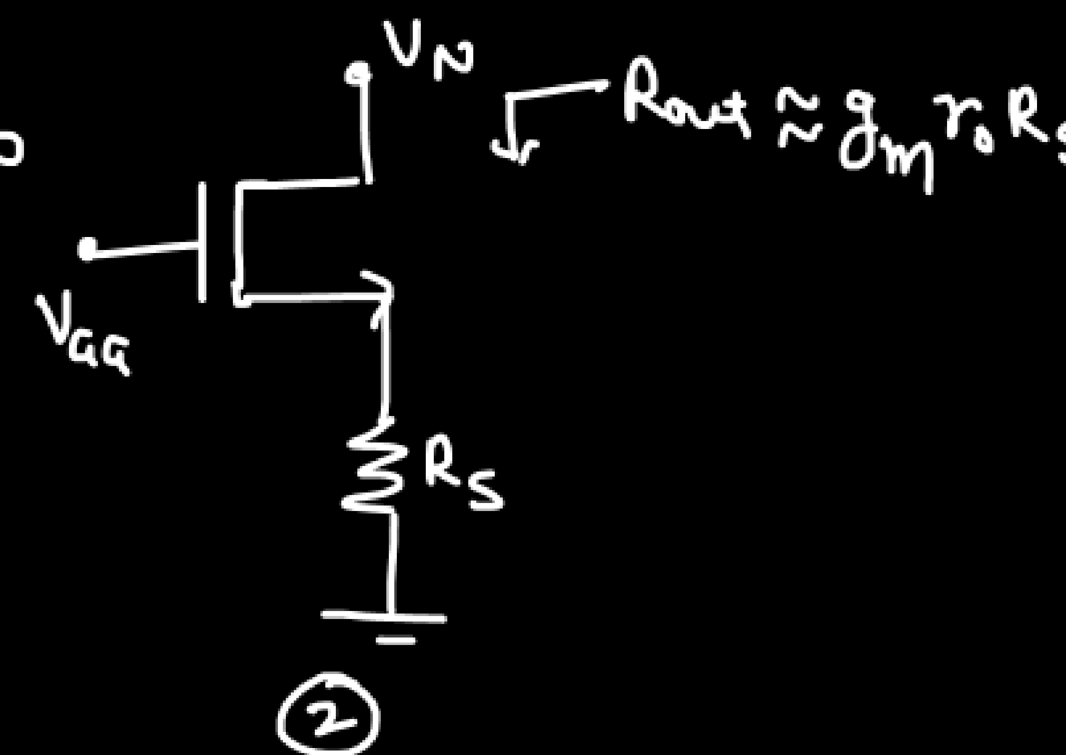
③

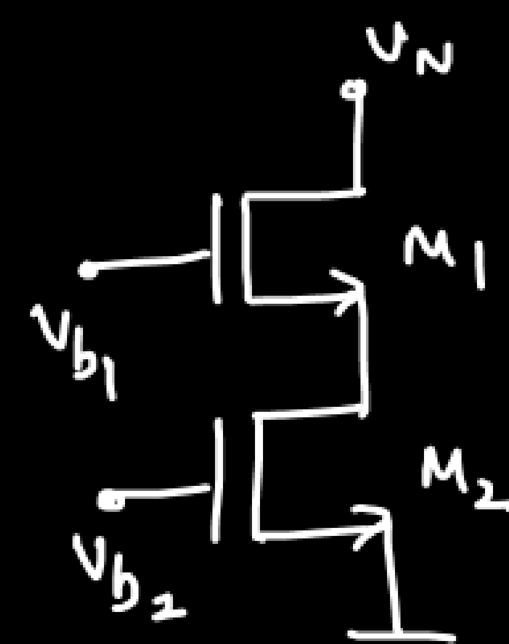
②



$\Rightarrow$



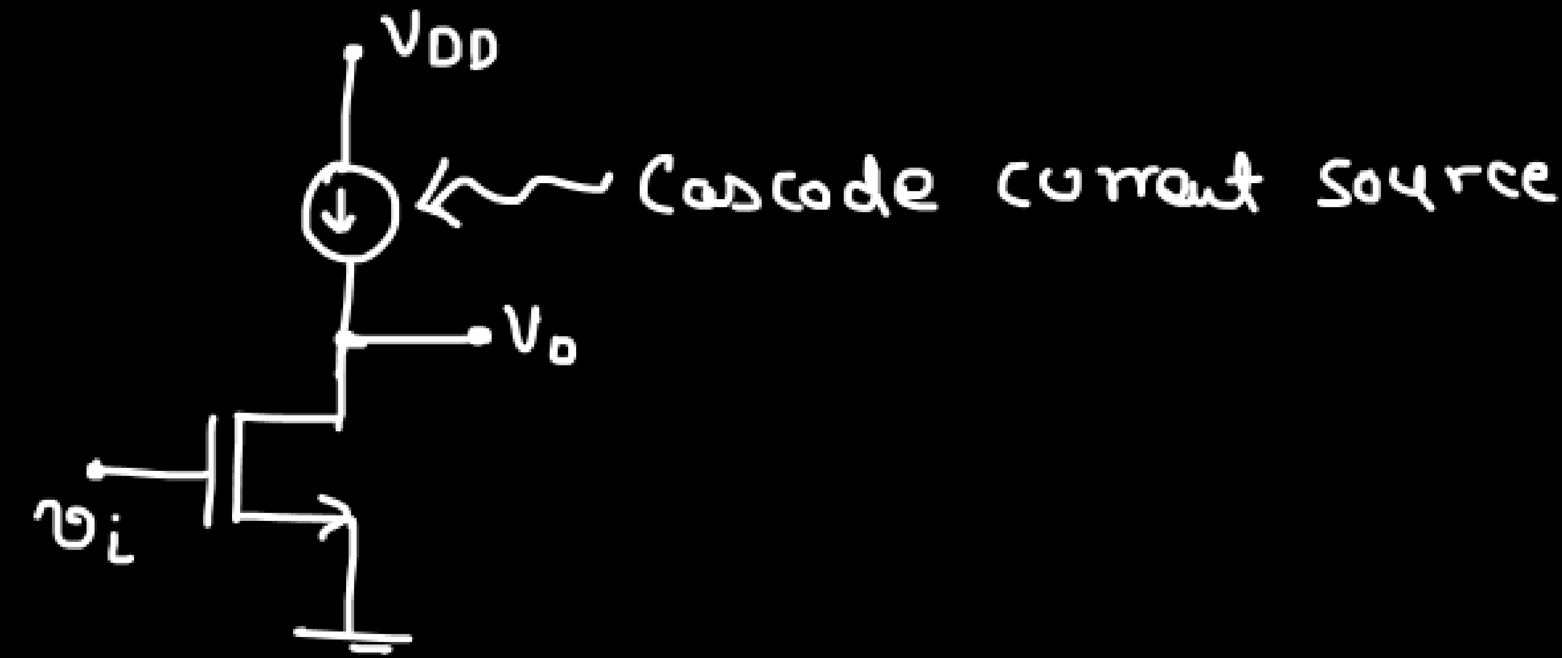


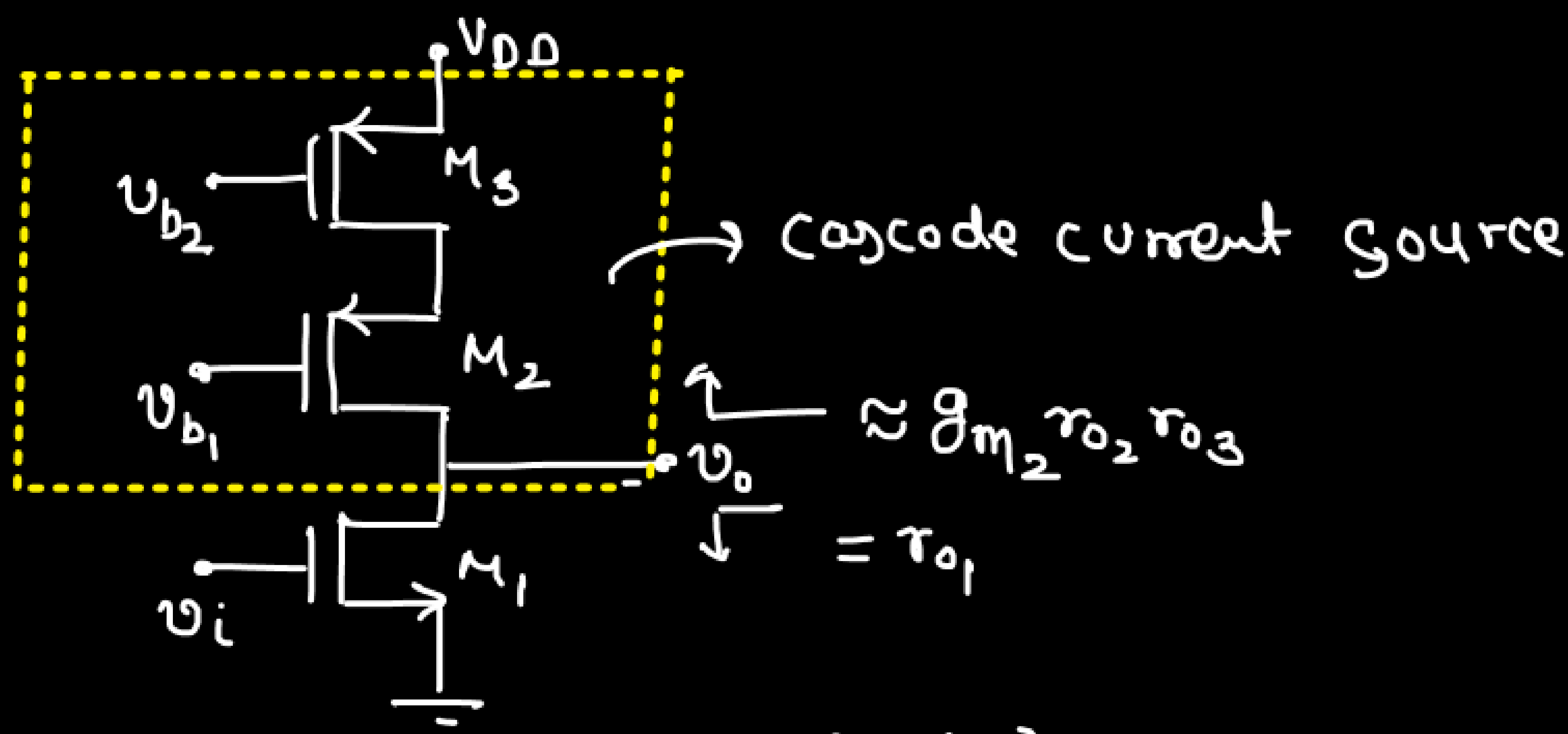


$$\boxed{R_{out} \approx g_{m_1} r_{o_1} r_{o_2}}$$

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:-





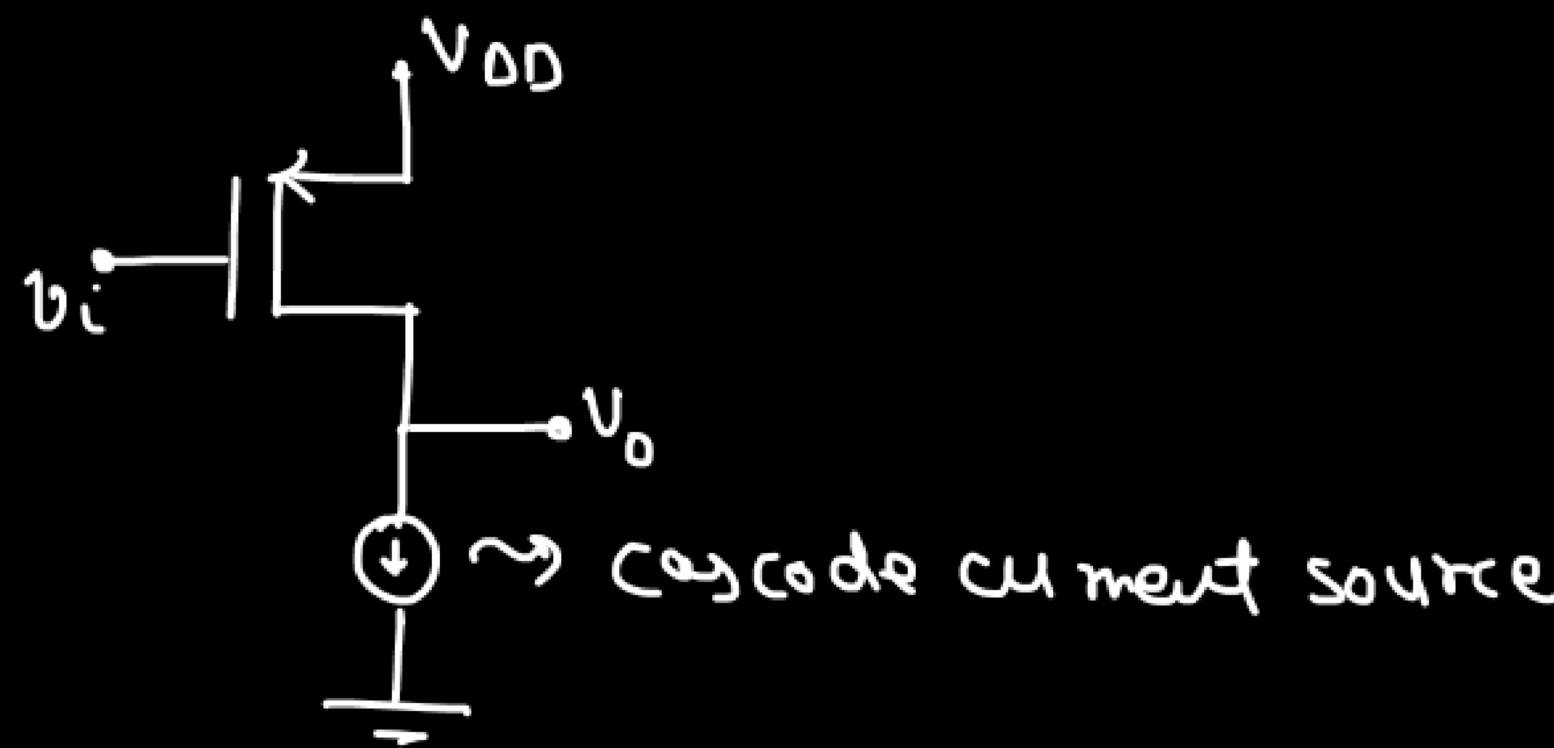
(NMOS)

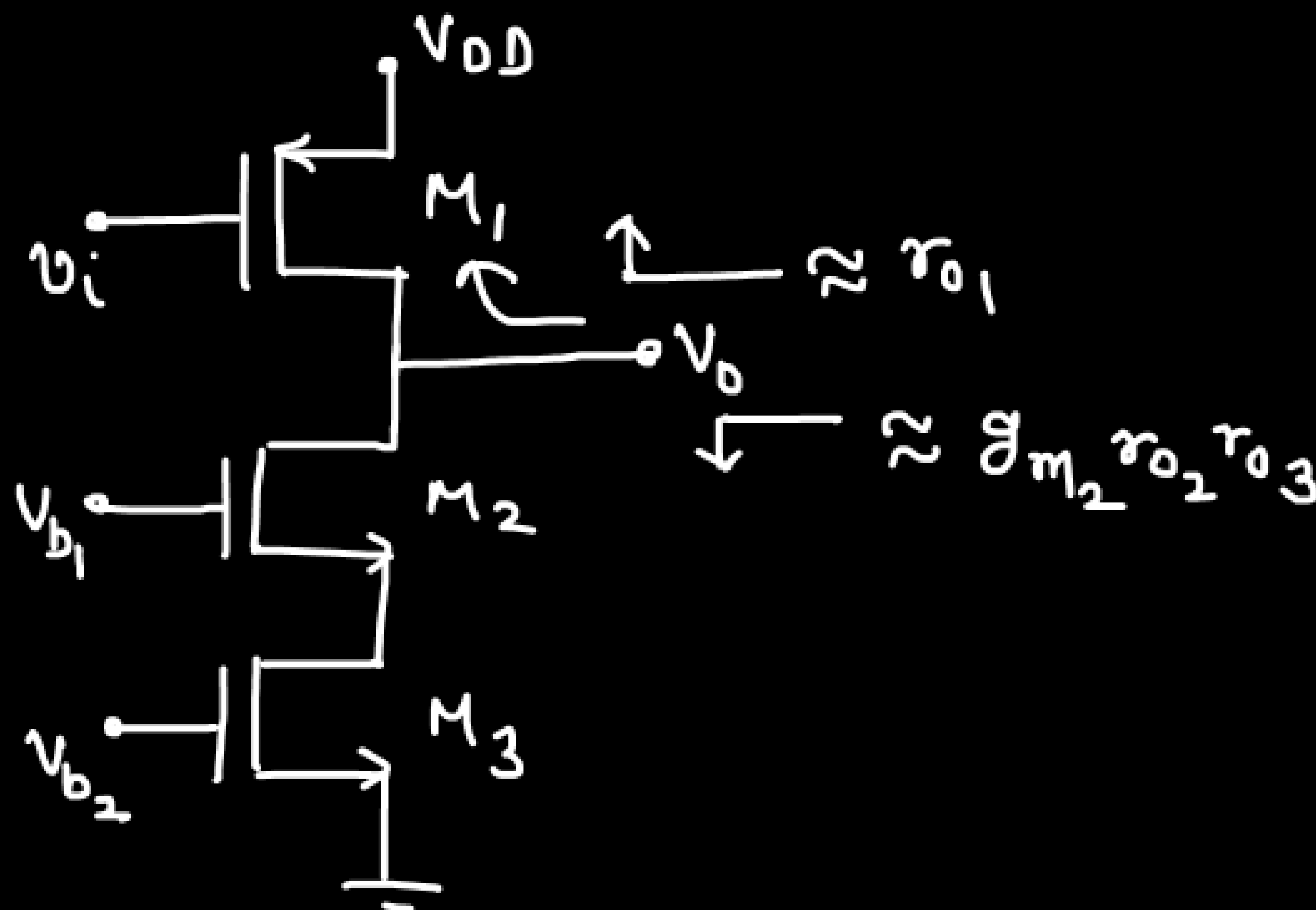
fig→ common source amplifier with cascode current source in load. (PMOS)

$$\boxed{A_v \approx -g_{m_1}\left[r_{o_1} \parallel g_{m_2} r_{o_2} r_{o_3} \right]}$$

$$\approx -g_{m_1} r_{o_1}$$

⇒ CS amplifier using PMOS with current source in load.





$$\boxed{A_v = -g_{m_1}\left[r_{o_1} \,||\, g_{m_2} r_{o_2} r_{o_3}\right]} \approx -g_{m_1} r_{o_1}$$

fig → common source amplifier (PMOS) with cascode current source (NMOS) in load.

Target:-

Buiding a High gain Amplifier.

$$\boxed{A_V = G_m R_{out}}$$

Keeping G_m constant, increase R_{out}

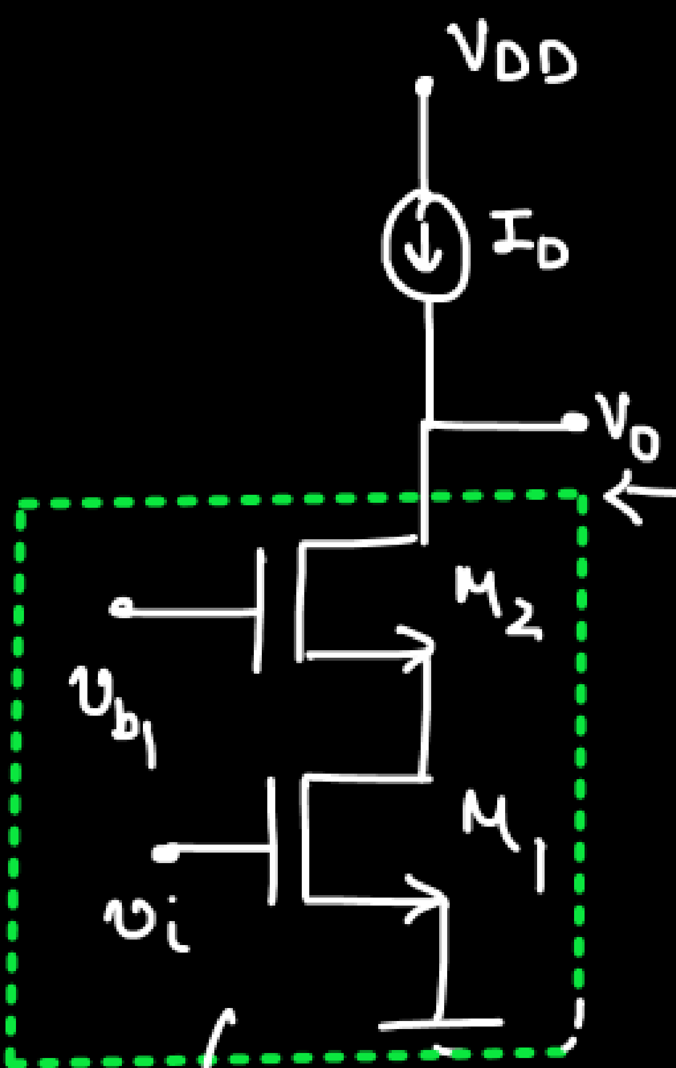
⇒ The design we made in the previous problem.

$$\boxed{R_{out} = r_{o_1} \parallel g_{m_2} r_{o_2} r_{o_3}}$$

⇓

increase R_{out}

Cascode Amplifier :-

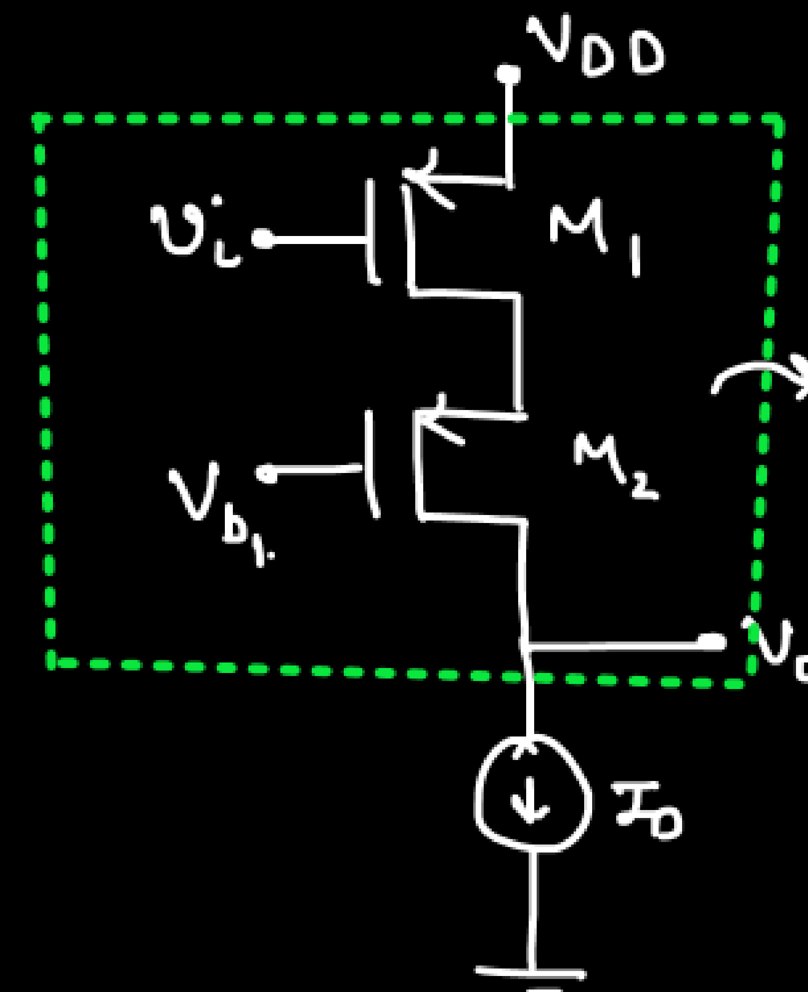


Cascode Amplifier (NMOS)

$R_{out} \approx g_{m_2} r_{o_2} r_{o_1}$

$G_m \approx -g_{m_1}$

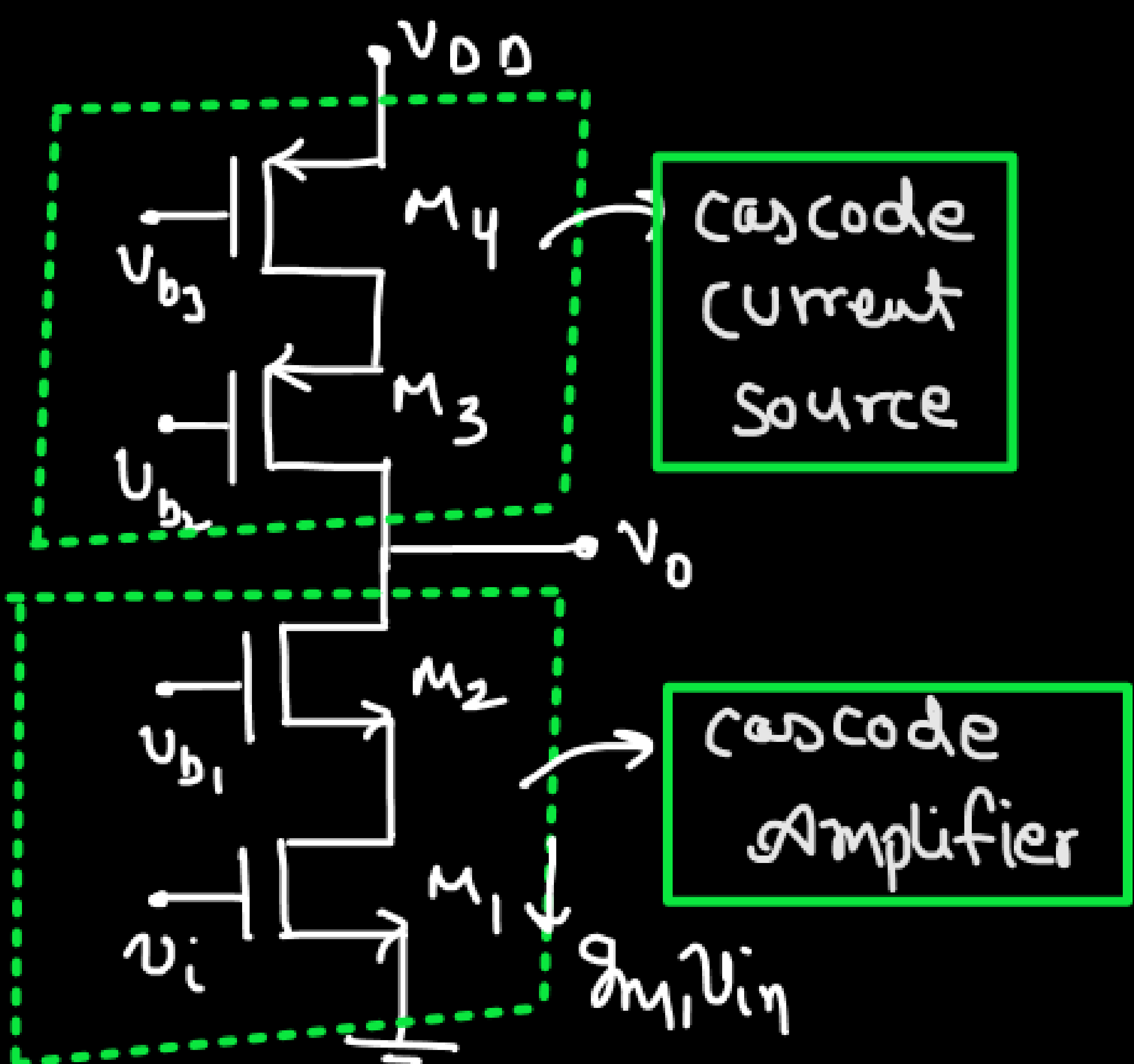
$$\boxed{A_V \approx -g_{m_1} g_{m_2} r_{o_2} r_{o_1}}$$

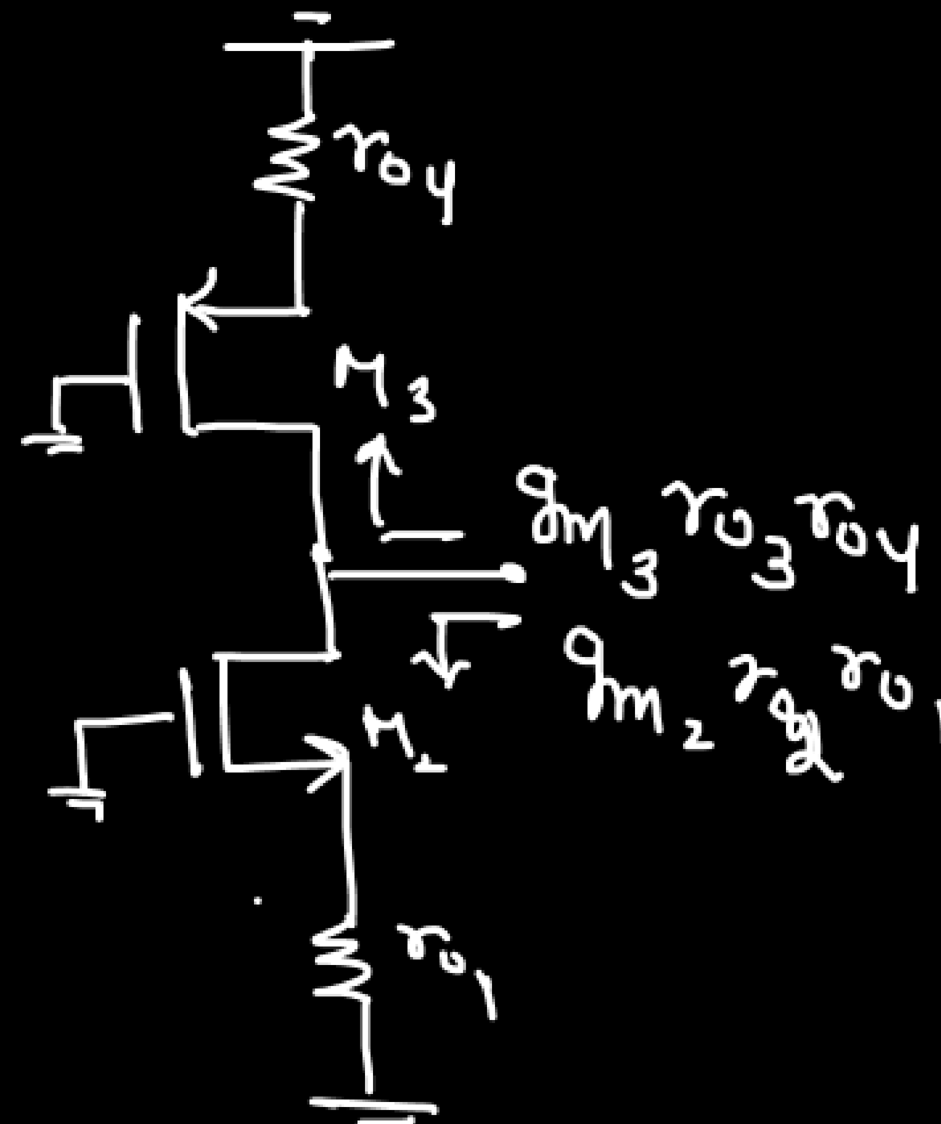


Cascode Amplifier (PMOS)

$$\boxed{A_V \approx -g_{m_1} g_{m_2} r_{o_2} r_{o_1}}$$

Cascode Amplifier with cascode current source:-



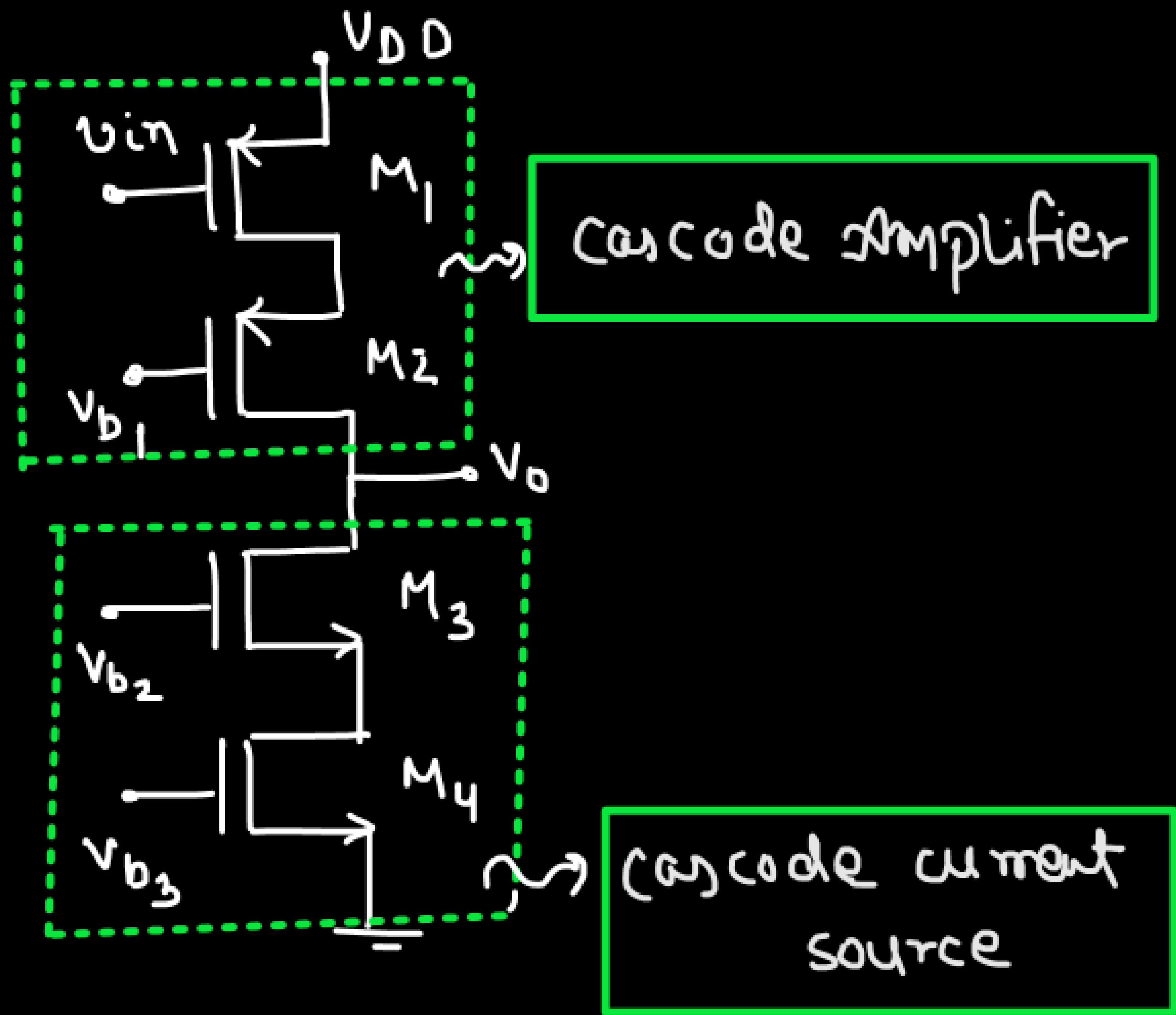


$$G_m \approx -g_{m_1}$$

$$R_{out} \approx g_{m_3}r_{o_3}r_{o_4} \,||\, g_{m_2}r_{o_2}r_{o_1}$$

**

$$\boxed{A_V \approx -g_{m_1}\left[g_{m_3}r_{o_3}r_{o_4} \,||\, g_{m_2}r_{o_2}r_{o_1}\right]}$$

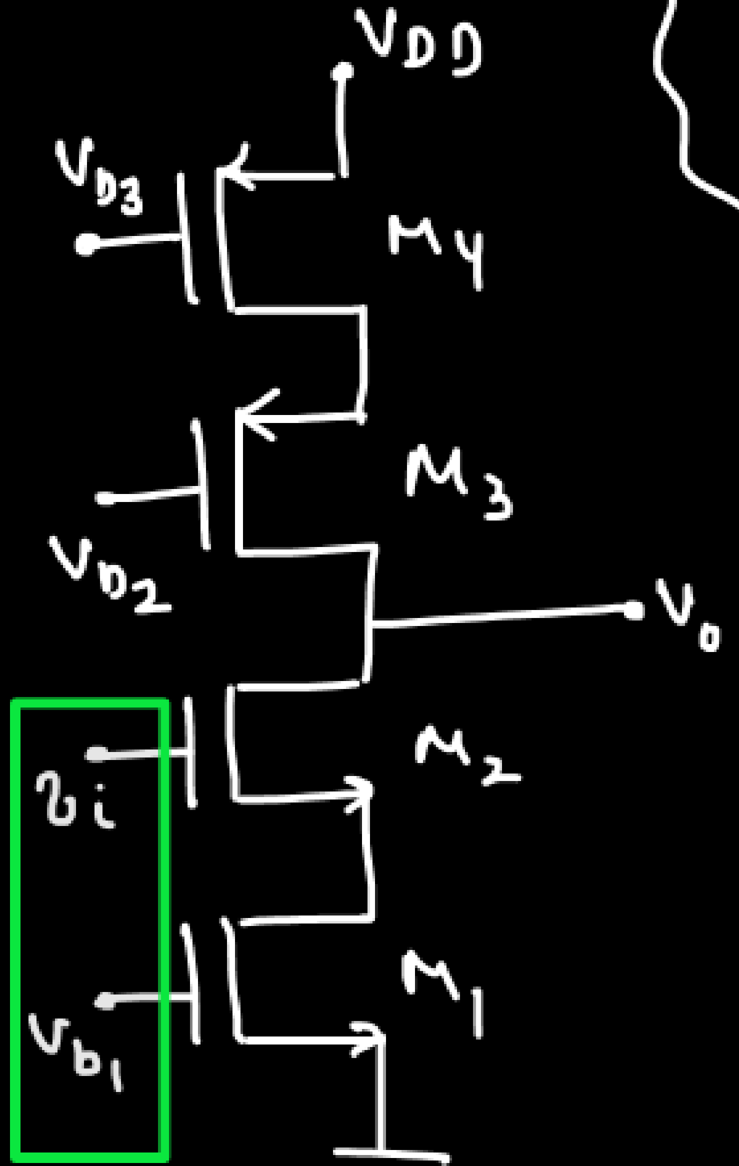


$$G_m \approx -g_{m_1}$$

$$R_{out} \approx g_{m_2} r_{o_2} r_{o_1} \,||\, g_{m_3} r_{o_3} r_{o_4}$$

$$\boxed{A_V = -g_{m_1}\left[g_{m_2} r_{o_2} r_{o_1} \,||\, g_{m_3} r_{o_3} r_{o_4}\right]}$$

What if :-



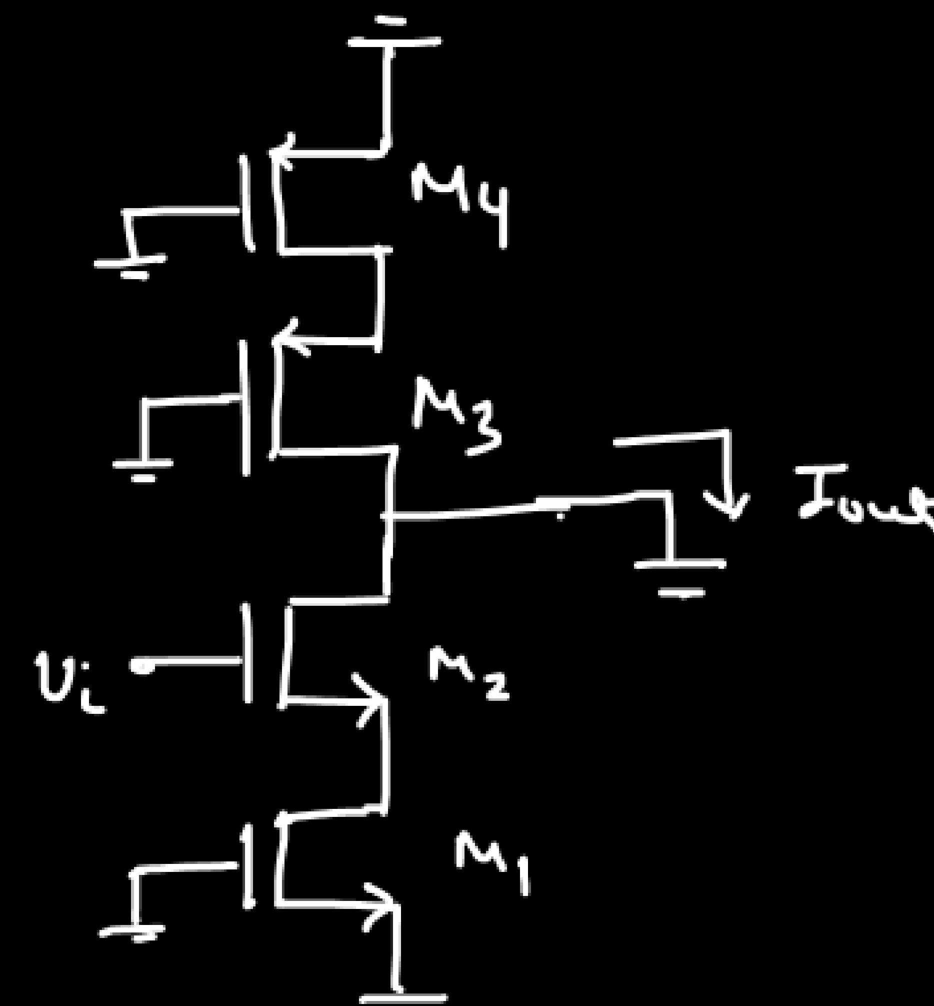
$$\frac{-g_m R_D}{1+g_m R_S}$$

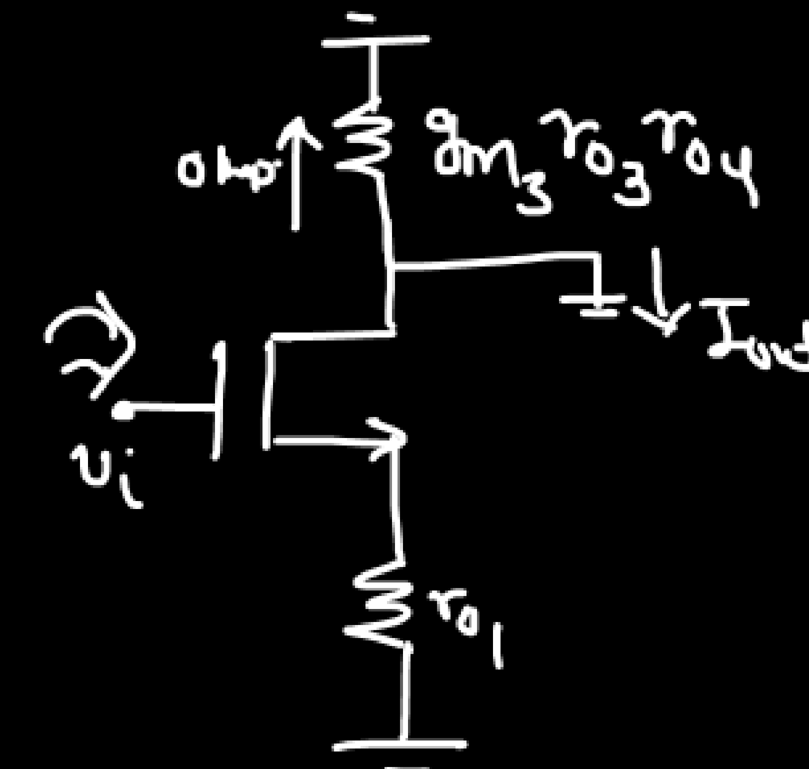
$$\boxed{R_{out} \approx g_{m_3} r_{o_3} r_{o_4} \,||\, g_{m_2} r_{o_2} r_{o_1}}$$

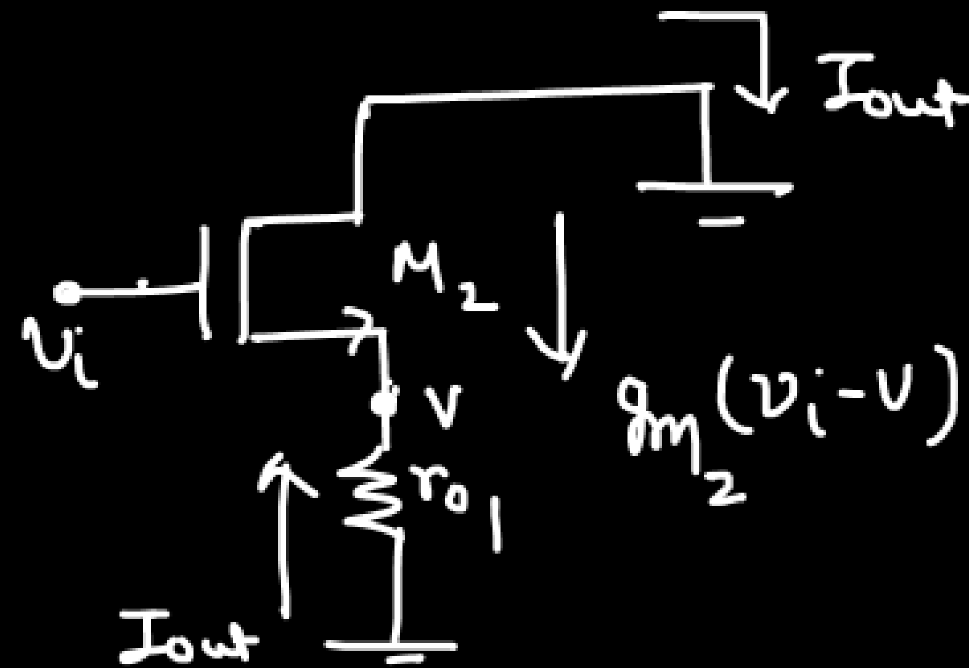
$\Downarrow$

Same as before

$G_m = ?$







$$I_{out} = -g_{m2}(v_i - V)$$

$$\frac{V}{r_{o1}} = -I_{out}$$

$$V = -I_{out} r_{o1}$$

$$I_{out} = -g_{m2}(v_i + I_{out} r_{o1})$$

$$I_{out} = -g_{m2} v_i - g_{m2} r_{o1} I_{out}$$

$$\boxed{\frac{I_{out}}{v_i} = G_m = \frac{-g_{m2}}{1 + g_{m2} r_{o1}}}$$

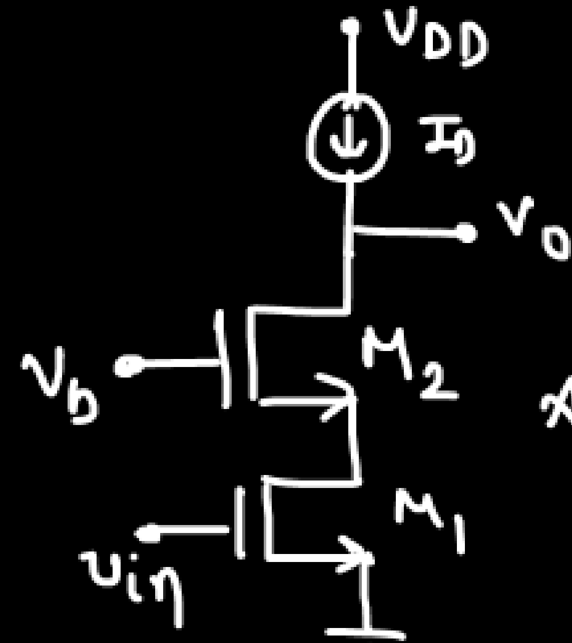
$\rightsquigarrow$ G_m is reduce

$$\boxed{\text{gain} \approx -\frac{g_{m2}}{1 + g_{m2} r_{o1}} \left[g_{m3} r_{o3} r_{o4} \,||\, g_{m2} r_{o2} r_{o1} \right]}$$

Gain is reduced [than cascode amplifier]

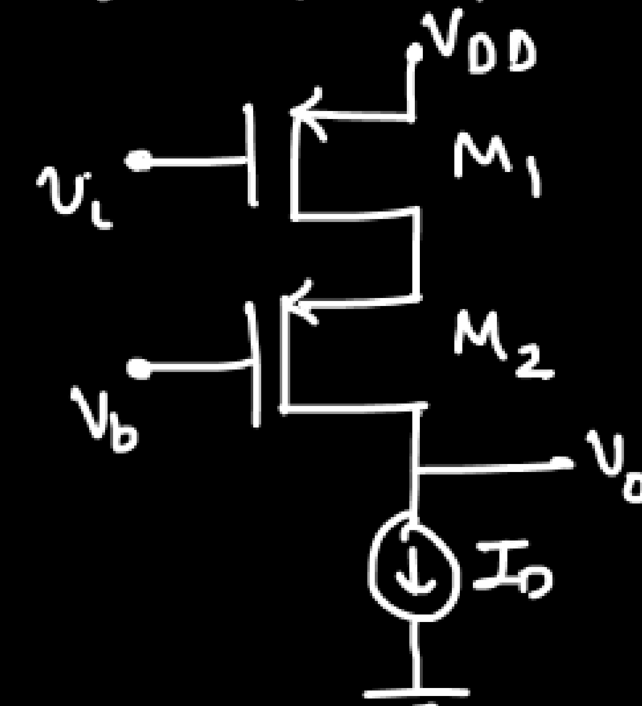
Cascode Amp. v/s Common Source Amp. with degeneration:-

1. Cascode Amp. (NMOS)

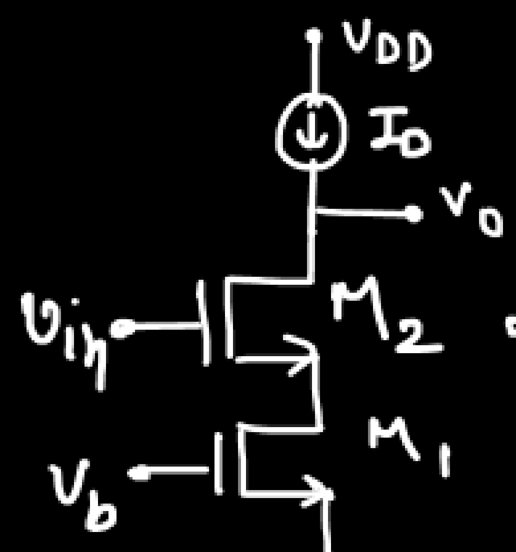


$$A_V = -g_{m_1}\left[g_{m_2} r_{o_2} r_{o_1}\right]$$

3. Cascode Amp. (PMOS)

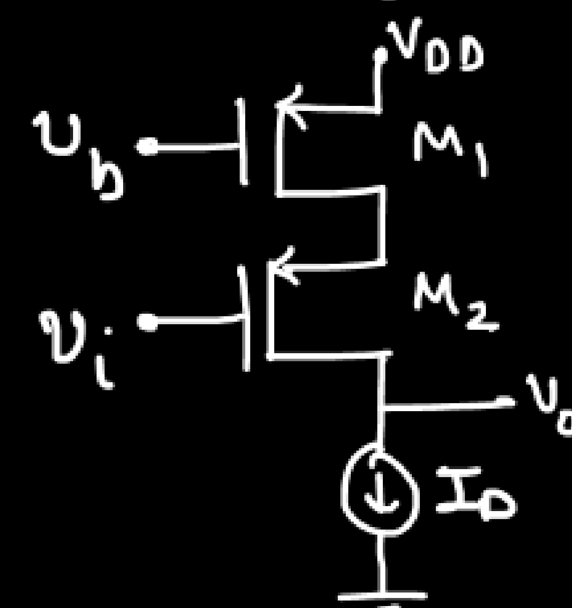


2. CS with degen. Amp. (NMOS)



$$A_V = \frac{-g_{m_2}\left[g_{m_2} r_{o_2} r_{o_1}\right]}{1 + g_{m_2} r_{o_1}}$$

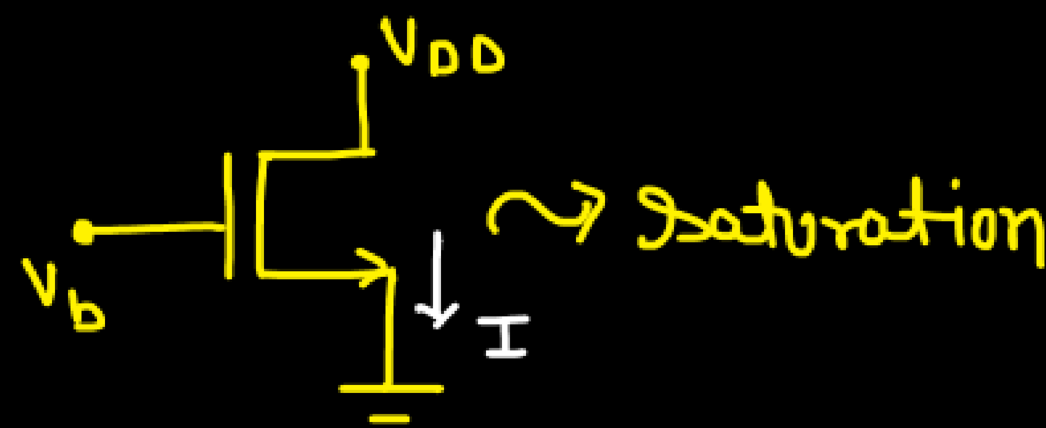
4. CS with degen. Amp. (PMOS)



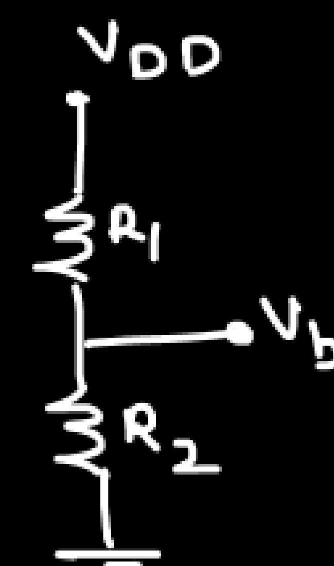
N.B. -

Cascode Amplifier :- Common Source Amp. in series with Common Gate Amp.

⇒ Using MOS as a current Source:-



$$I = \frac{\mu_n C_{ox} W}{2L}(V_b - V_T)^2$$



$$V_b = \frac{R_2}{R_2+R_1} V_{DD}$$

$$I = \frac{\mu_n C_{ox} W}{2L}\Bigg[\underbrace{\frac{R_2}{R_2+R_1}}_{\text{Supply dependent}} V_{DD} - V_T\Bigg]^2$$

μ_n: Temp. dependent

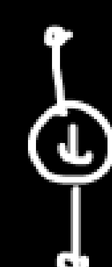
V_T: Temp. dependent

$$\Rightarrow \boxed{I \neq \text{constant}}$$

⇒ For making a current source which is independent of supply and Temp. , we need to use "Bandgap" circuit.
variation

[OUT OF The scope of this course]

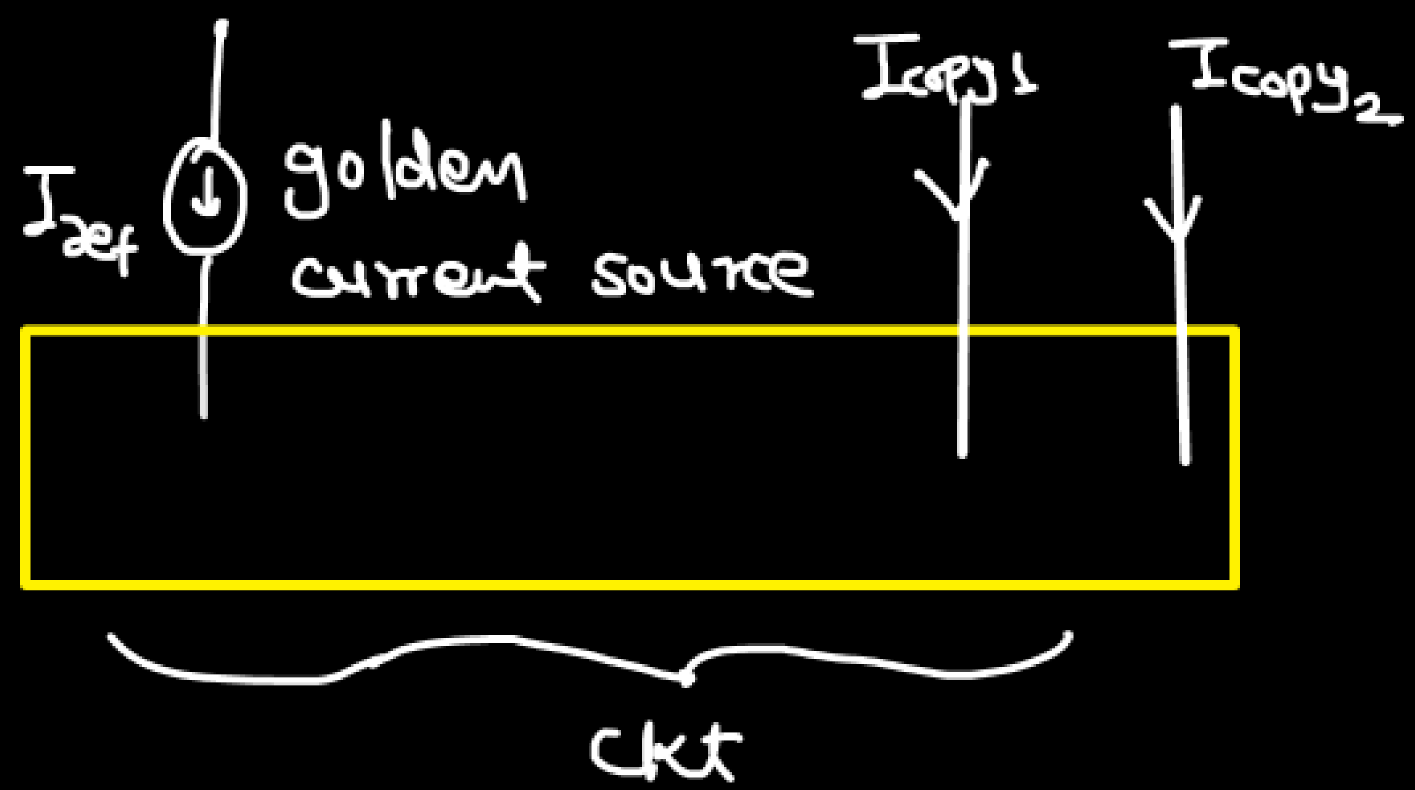
$$\boxed{\text{Golden current source} \Rightarrow \text{Constant current source}}$$



$I_{golden} = I_{ref}$

Current Mirror ckt:-

With the help of golden current source, we will generate other current sources which are identical to golden current source.

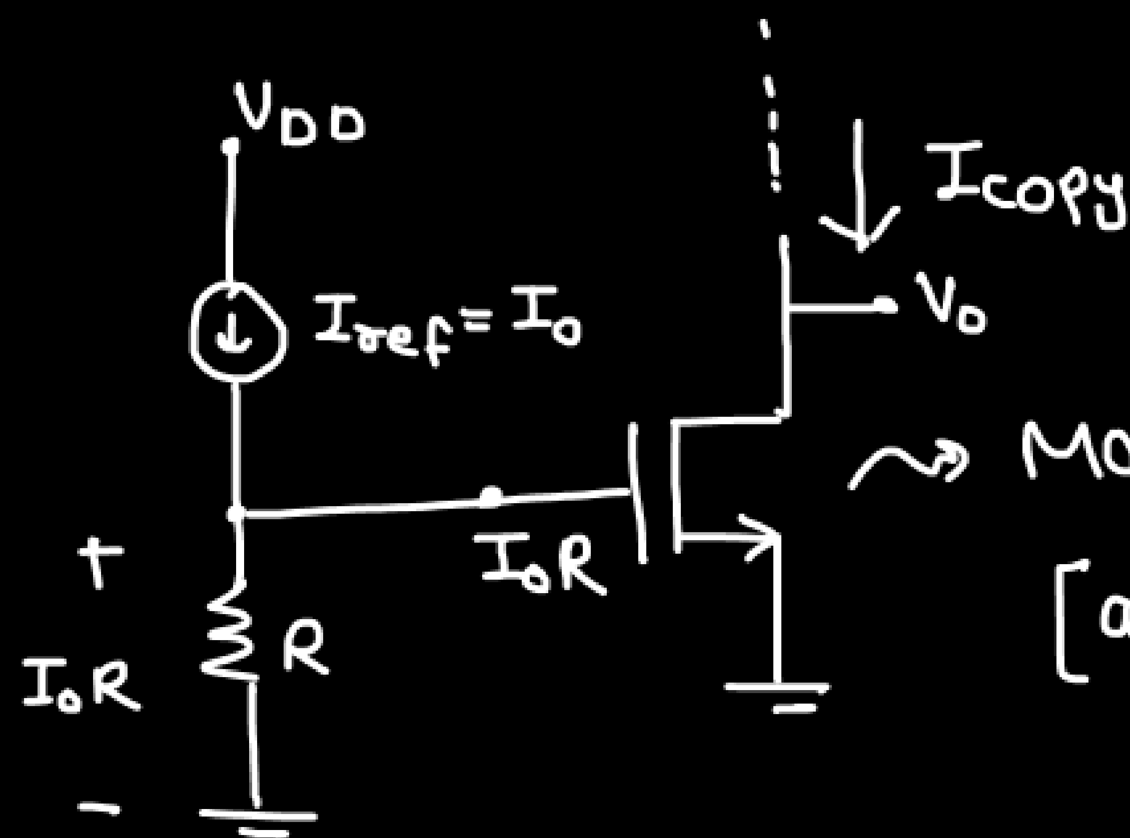


$I_{copy_1} \propto I_{ref}$

$I_{copy_2} \propto I_{ref}$

Try-1 :-

Using a resistor :-



MOS is sat region

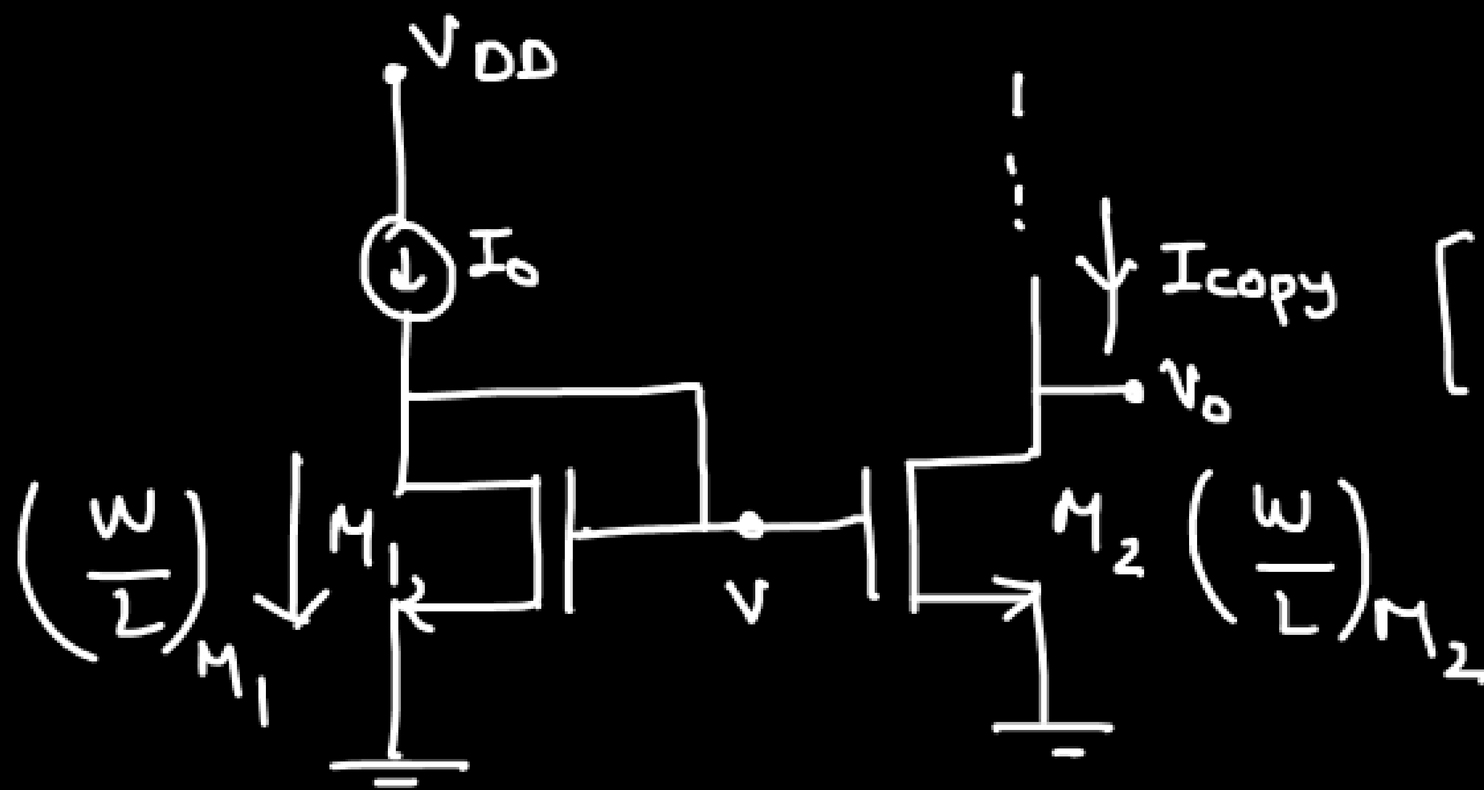
[adjust V_0 such that MOS is working in sat.]

$$I_{copy} = \frac{\mu_n C_{ox} W}{2L}\left[I_0 R - V_T\right]^2$$

Temp. dependent

Try-2:-

Using diode connected Transistor:-



[adjust V_0 such that M_2 is in sat. region]

$$I_0 = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{M_1}(V-V_T)^2$$

$$V = \sqrt{\frac{2I_0}{\mu_n C_{ox}(W/L)_{M_1}}} + V_T \quad \text{——} \; (1)$$

$$I_{copy} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{M_2}\left[V - V_T\right]^2$$

$$= \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{M_2}\left[\sqrt{\frac{2I_0}{\mu_n C_{ox}\left(\frac{W}{L}\right)_{M_1}}} + V_T - V_T\right]^2$$

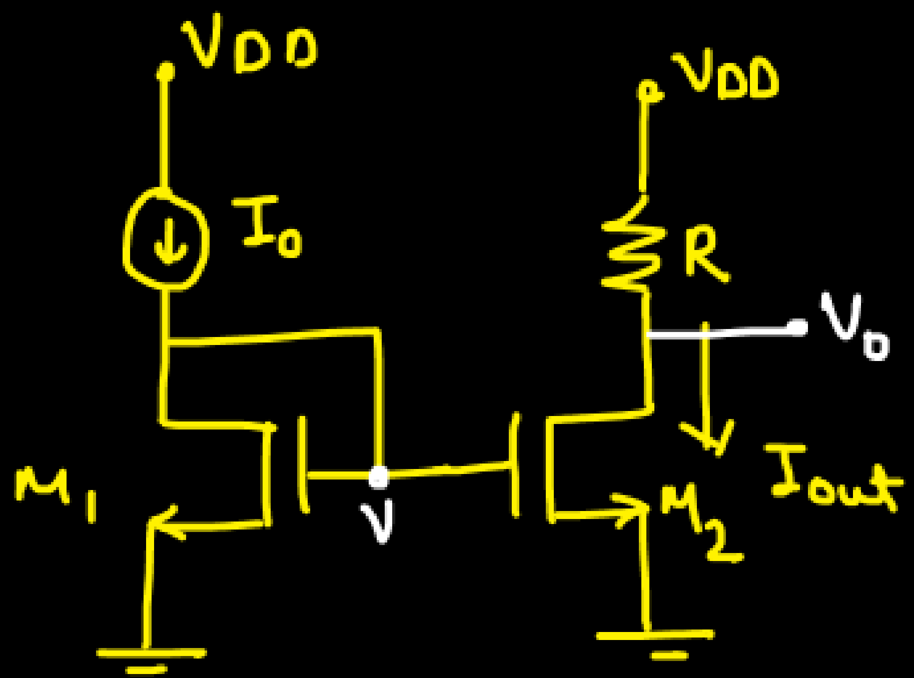
$$\boxed{I_{copy} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0}$$

$$\boxed{I_{copy} \propto I_0}$$

$\Downarrow$

independent of supply and Temp. variation.

Alternative Analysis of current Mirror Ckts:-



$\Rightarrow$ Both M_1 and M_2 are in sat. region.

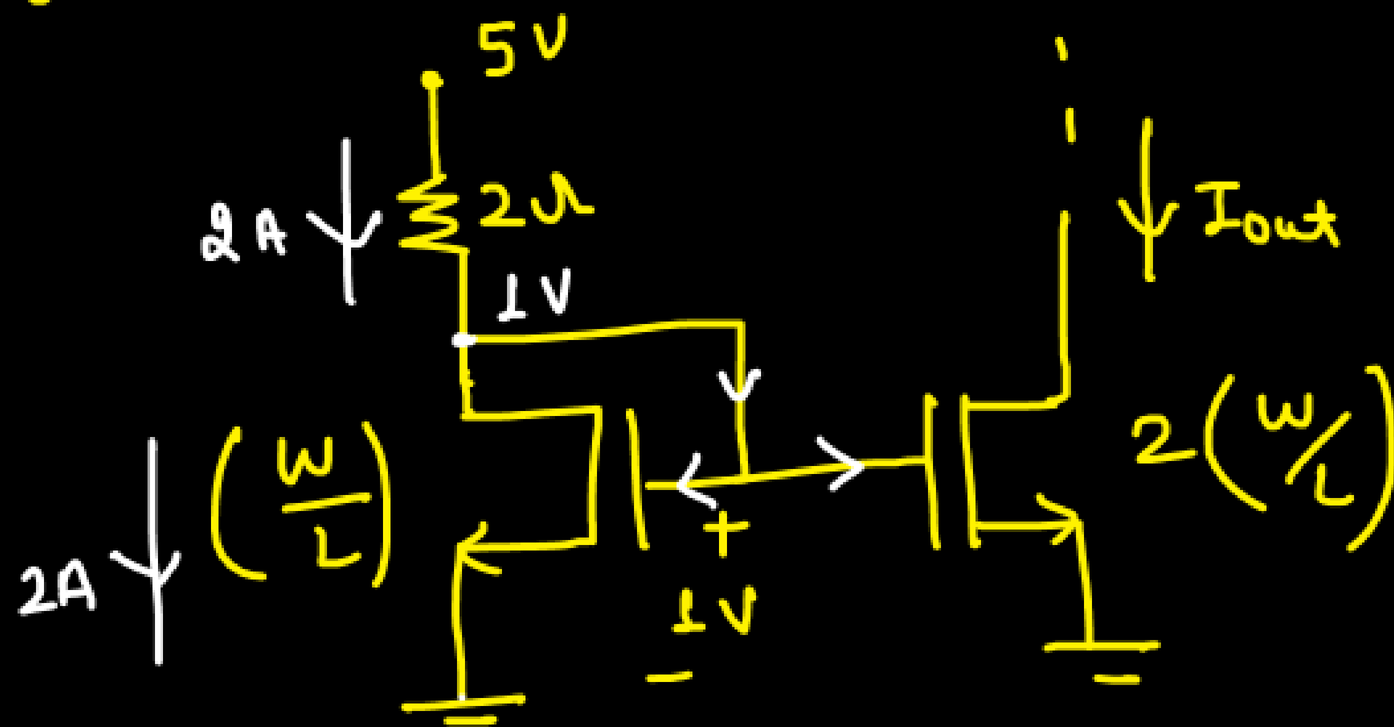
$$(V_{GS})_{M_1} = (V_{GS})_{M_2} = V$$

$$I_0 = \mu_n C_{ox} \left(\frac{W}{L}\right)_{M_1} (V - V_T)^2 \quad \text{—— (1)}$$

$$I_{out} = \mu_n C_{ox} \left(\frac{W}{L}\right)_{M_2} (V - V_T)^2 \quad \text{—— (2)}$$

$$(2) \div (1) \Rightarrow \frac{I_{out}}{I_0} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} \Rightarrow \boxed{I_{out} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0}$$

Eg.

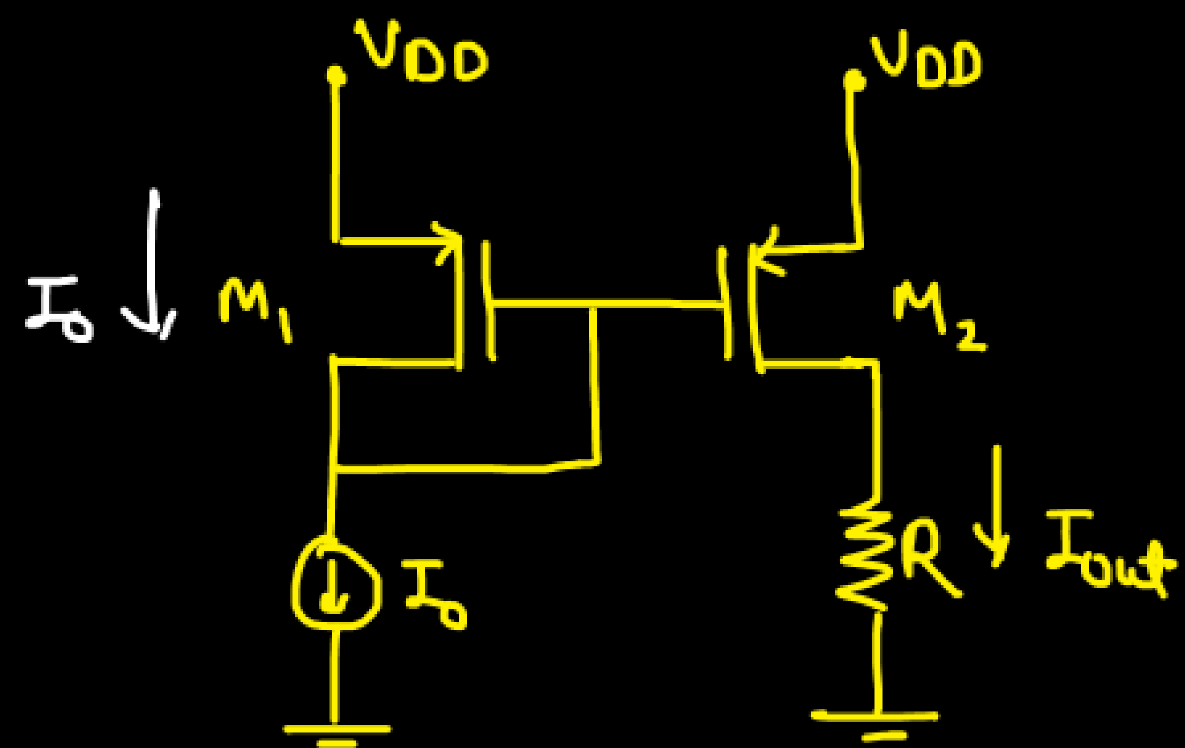


Both Transistors are working in sat. region.
Find $I_{out} = ?$

$$I_{out} = \frac{2\left(W/L\right)}{\left(W/L\right)} \times 2\ \text{Amp.}$$

$$\boxed{I_{out} = 4\ \text{Amp.}}$$

Current mirror using PMOS :-



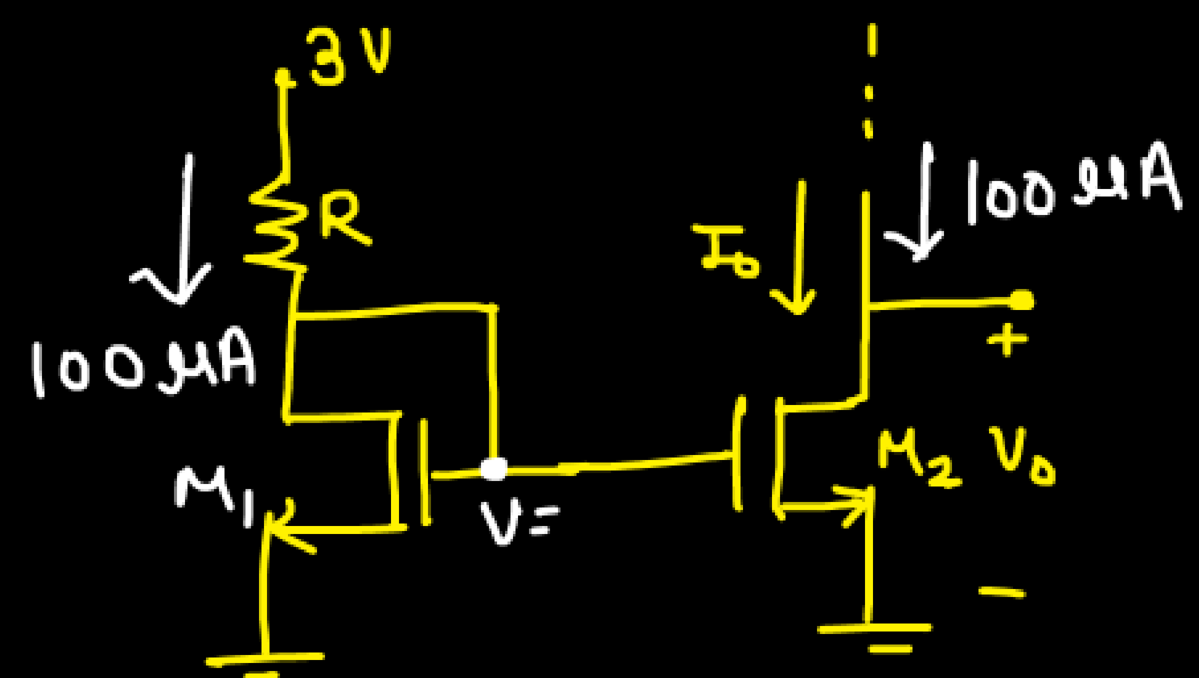
$$\boxed{I_{out} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0}$$

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.

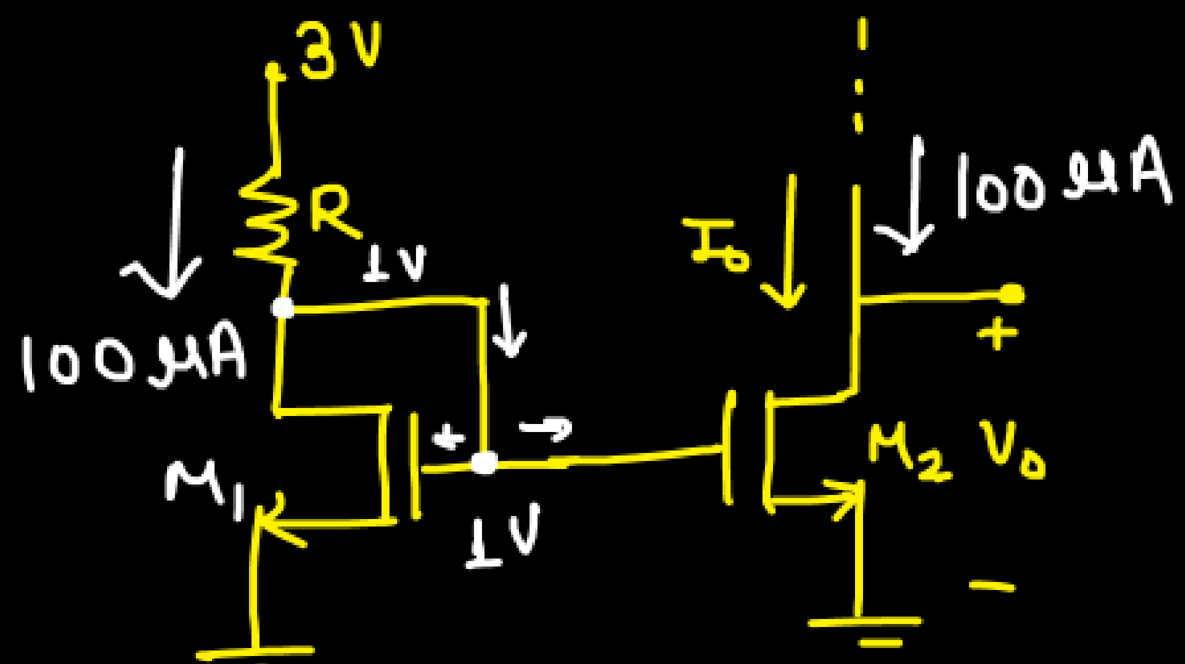
What is the lowest possible value of V_o such that M_2 is working in sat. region.



$$100\mu A = \frac{200\mu \times 10}{2}\left[V-0.7\right]^2$$

$$V - 0.7 = \sqrt{10}$$

$$\boxed{V = 1V}$$



$$\frac{3-1}{R} = 100\mu A$$

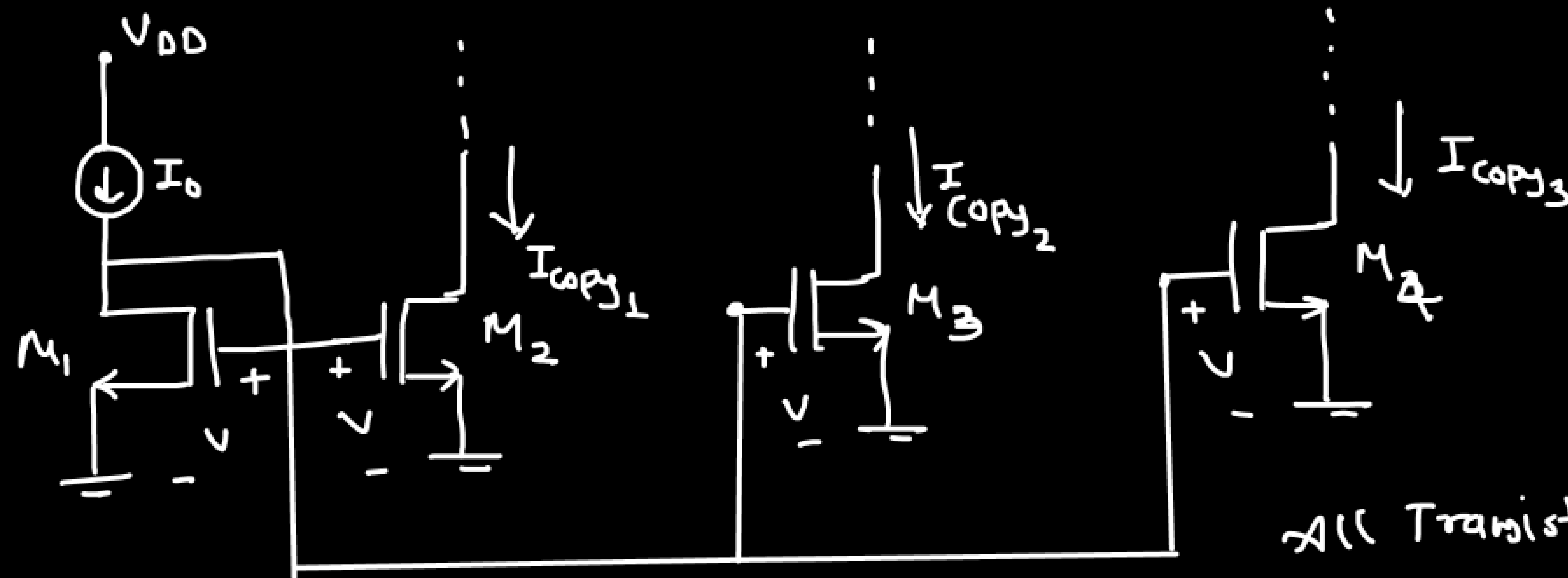
$$\boxed{R = 20k\Omega}$$ ANS.

⇒ For sat. region

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

$$V_0 = 1 - 0.7 = 0.3 \Rightarrow \boxed{V_0 = 0.3V}$$

⇒ Buiding Multiple current sources:-

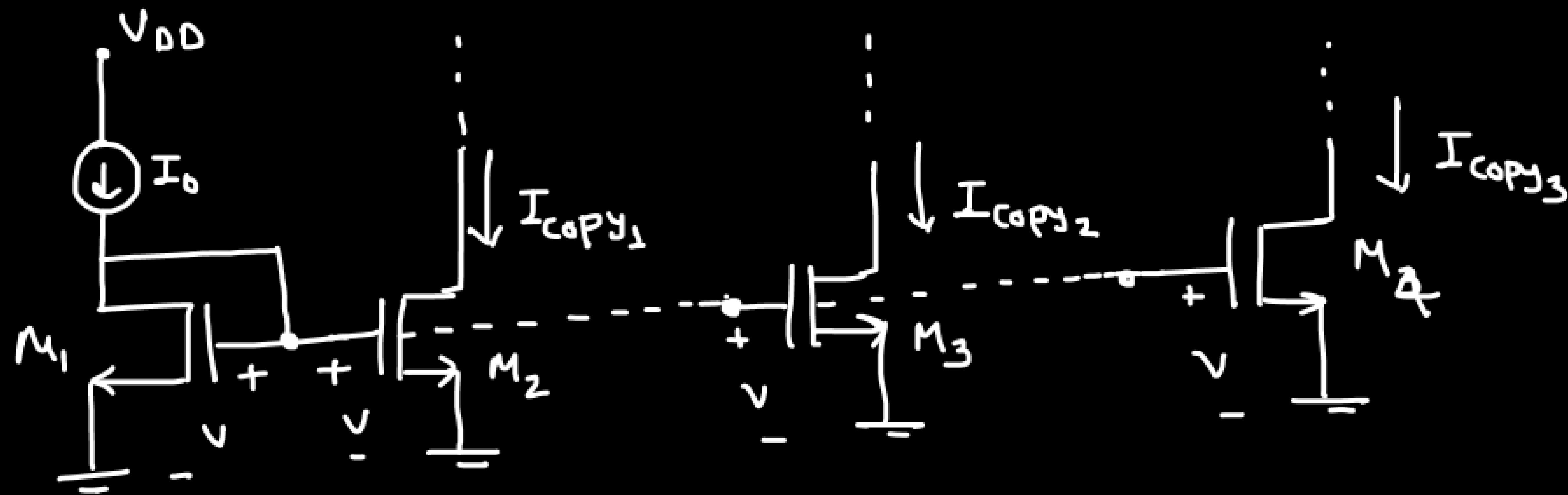


All Transistors are in sat.

$$I_{copy_1} = \frac{(W/L)_{M_2}}{(W/L)_{M_1}} I_0$$

$$I_{copy_2} = \frac{(W/L)_{M_3}}{(W/L)_{M_1}} I_0$$

Other way of showing the same ckt:-



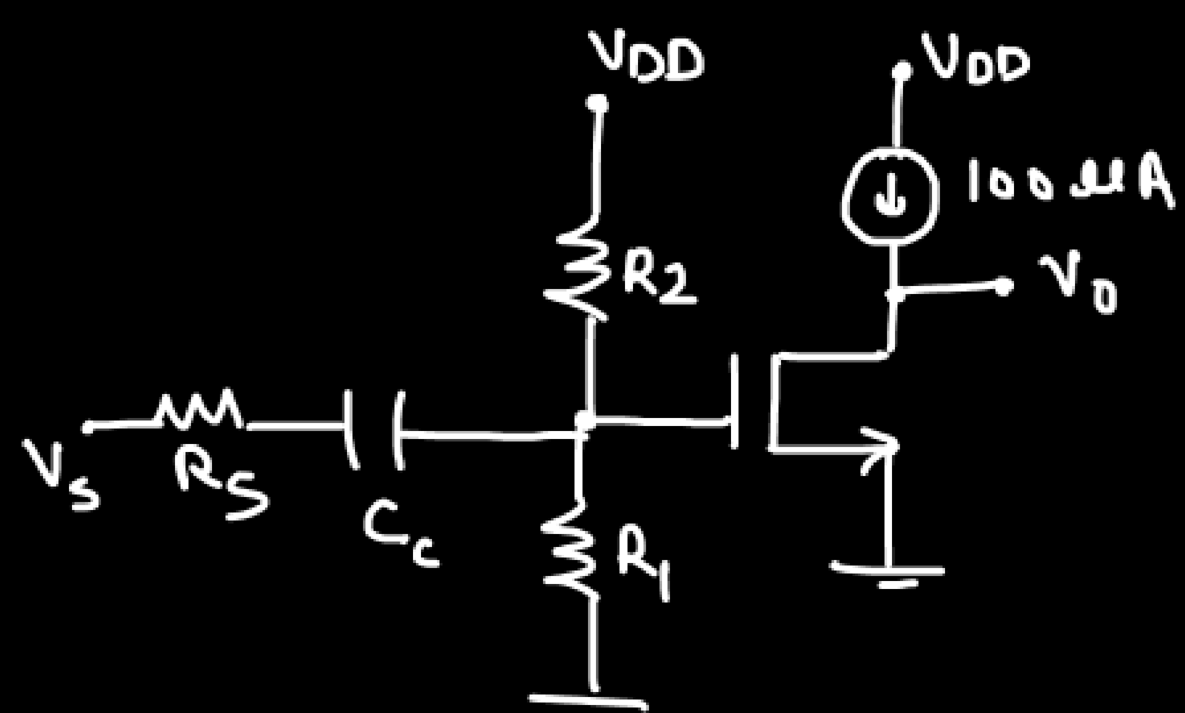
Q. Make a common source Amplifier (using NMOS) with 100 μA current source in load. You have a reference current source of 200 μA.

You only have one supply V_{DD}.

Your small signal i/p V_s has internal resistance R_S.

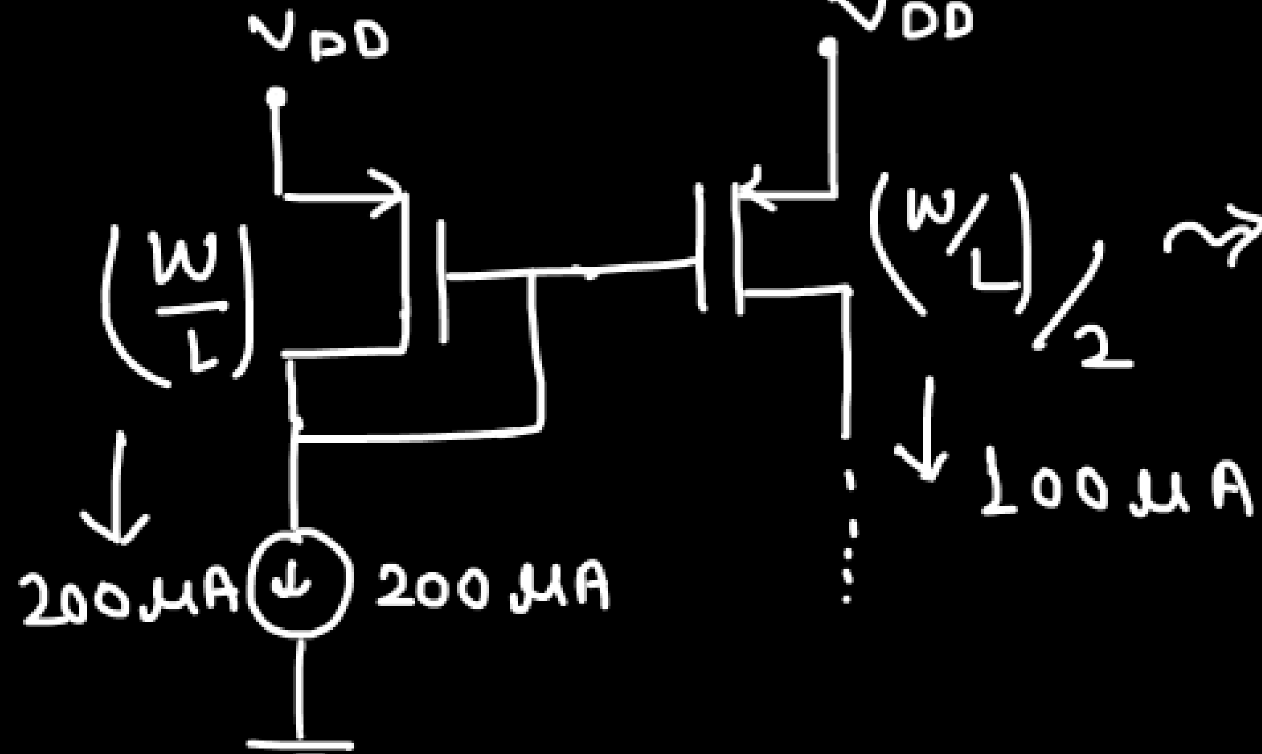
After desiging the ckt, find the small signal voltage gain.

→



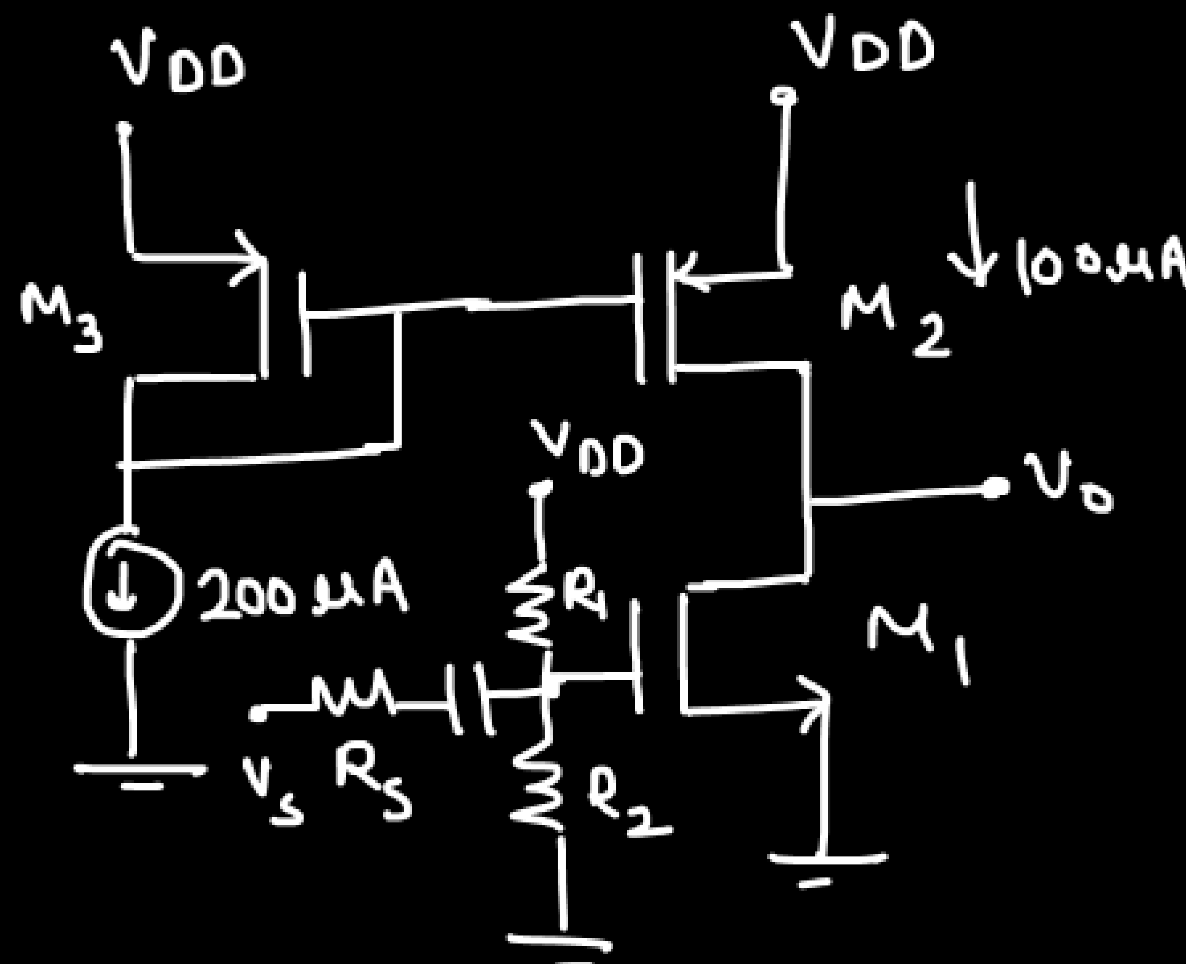
Next task:-

designing 100 μA current source from 200 μA ref. current.



→ Making sure that this T^r is working in sat.

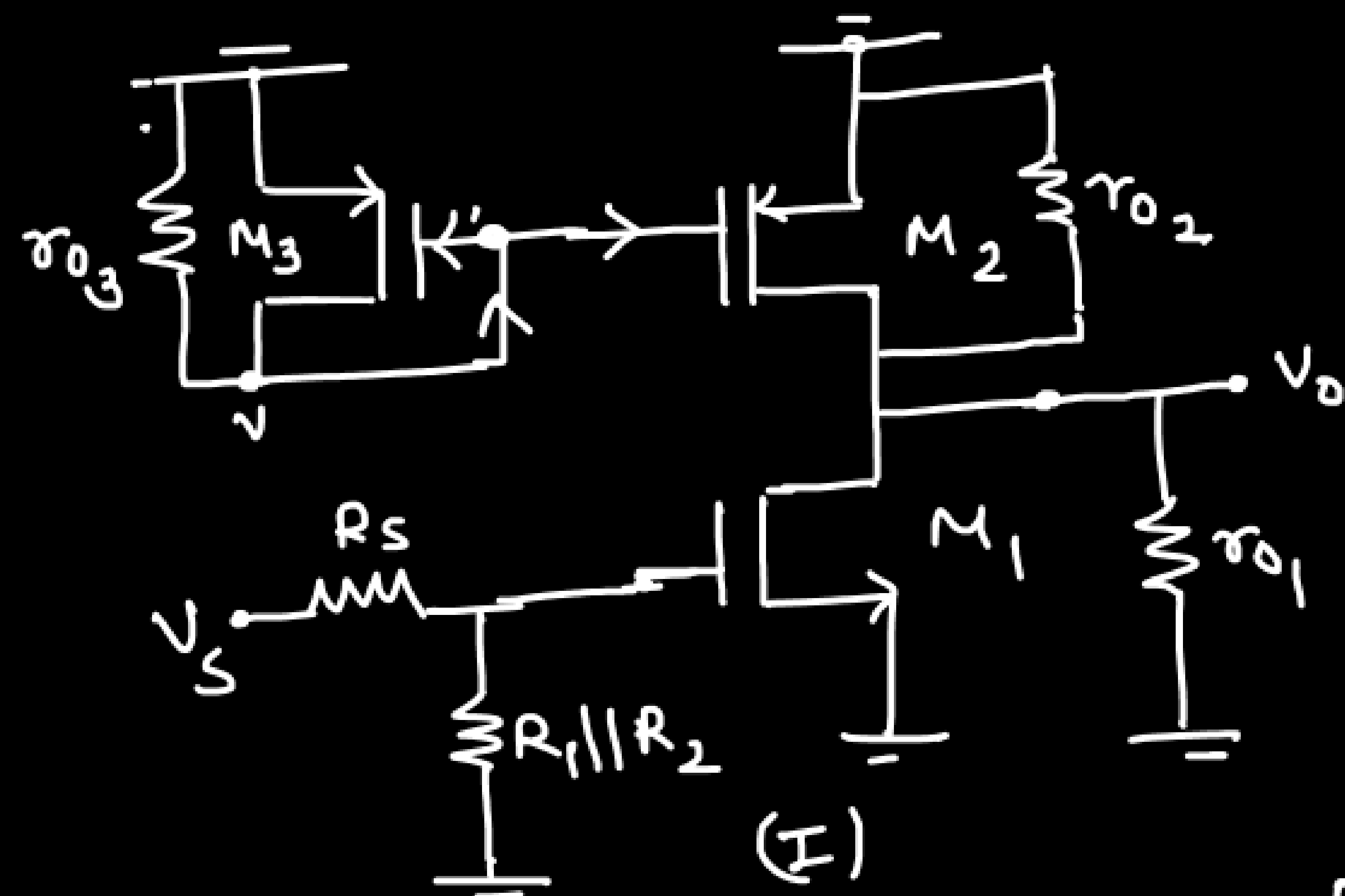
Final design:-



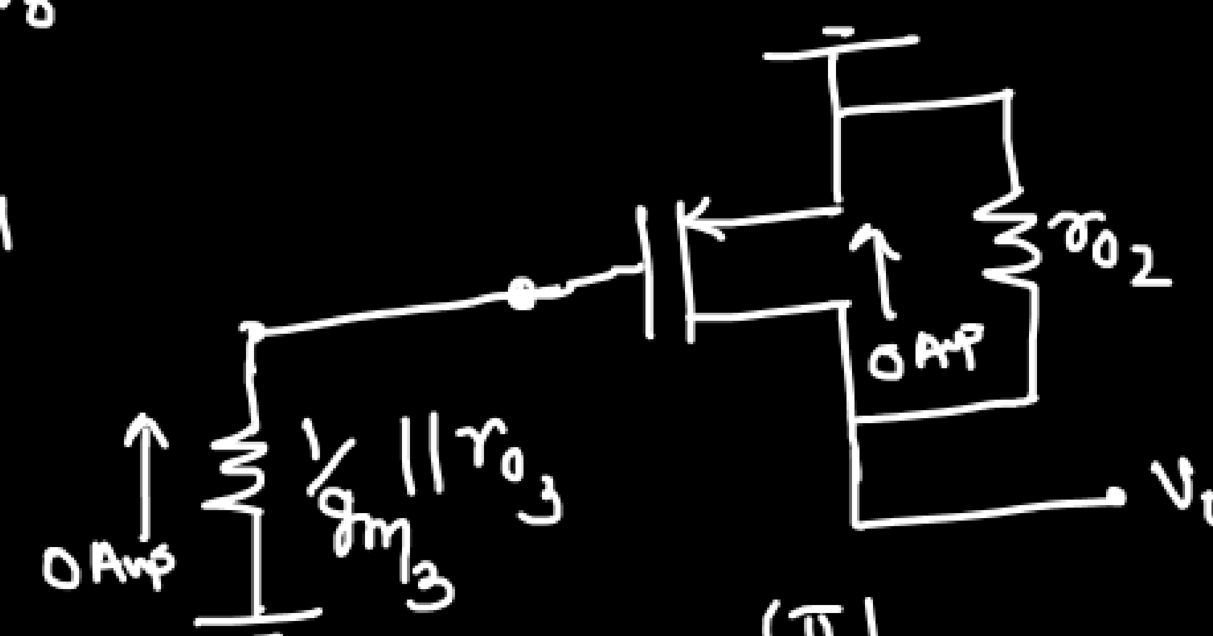
Adjust V_{DD}, R_1, R_2 such that all T^r are working in sat.

$$\left(\frac{W}{L}\right)_3 = 2\left(\frac{W}{L}\right)_2$$

Small signal Voltage gain :-

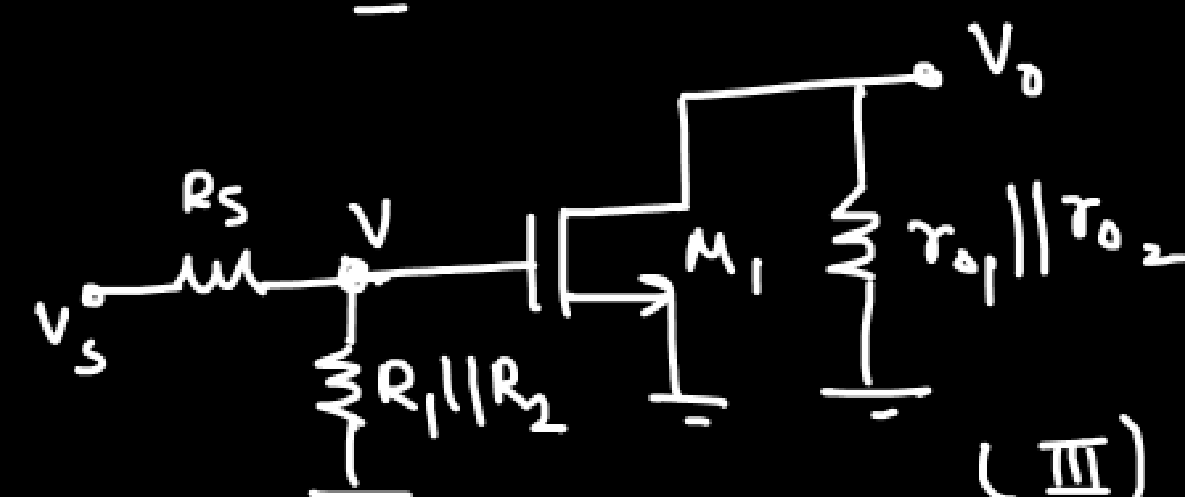


(I)



(II)

$\Rightarrow$

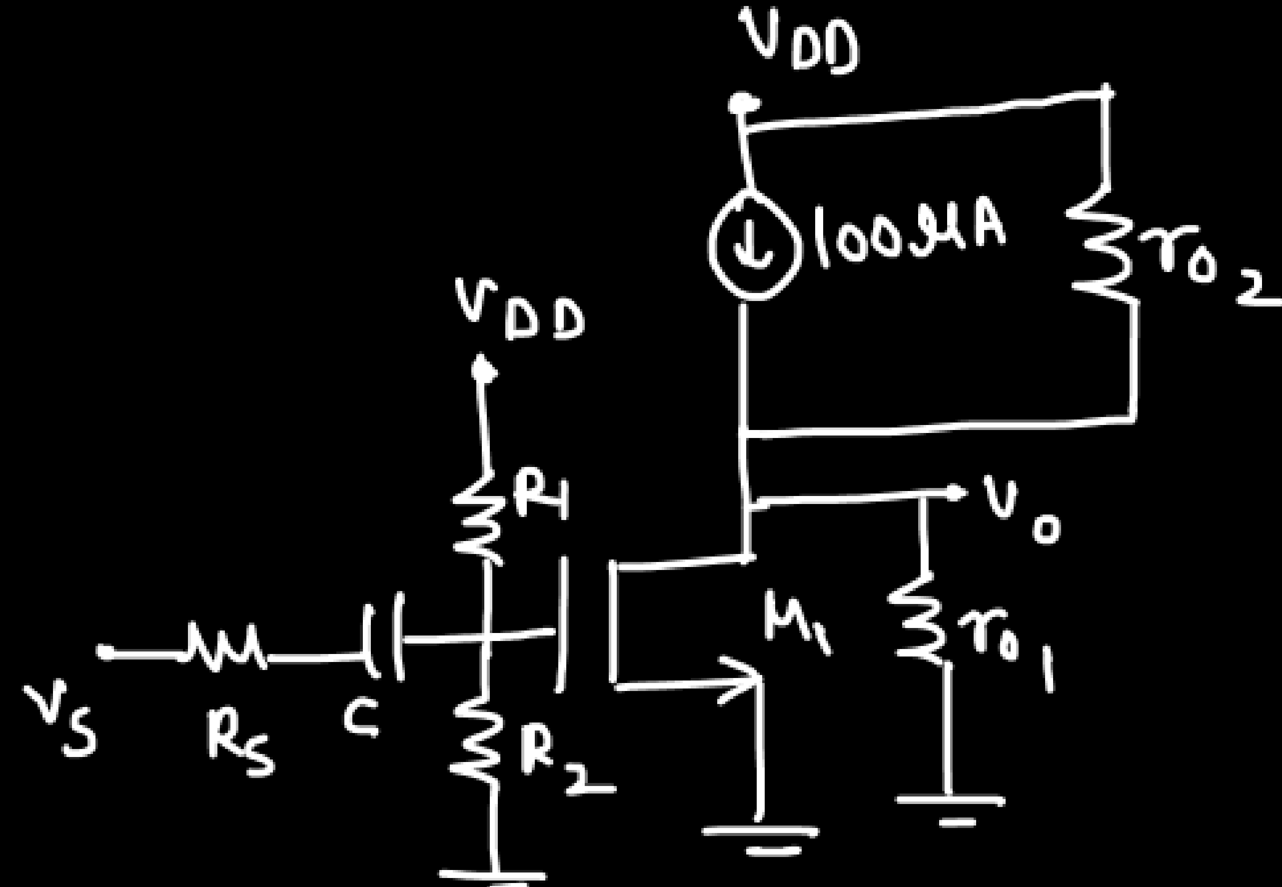


(III)

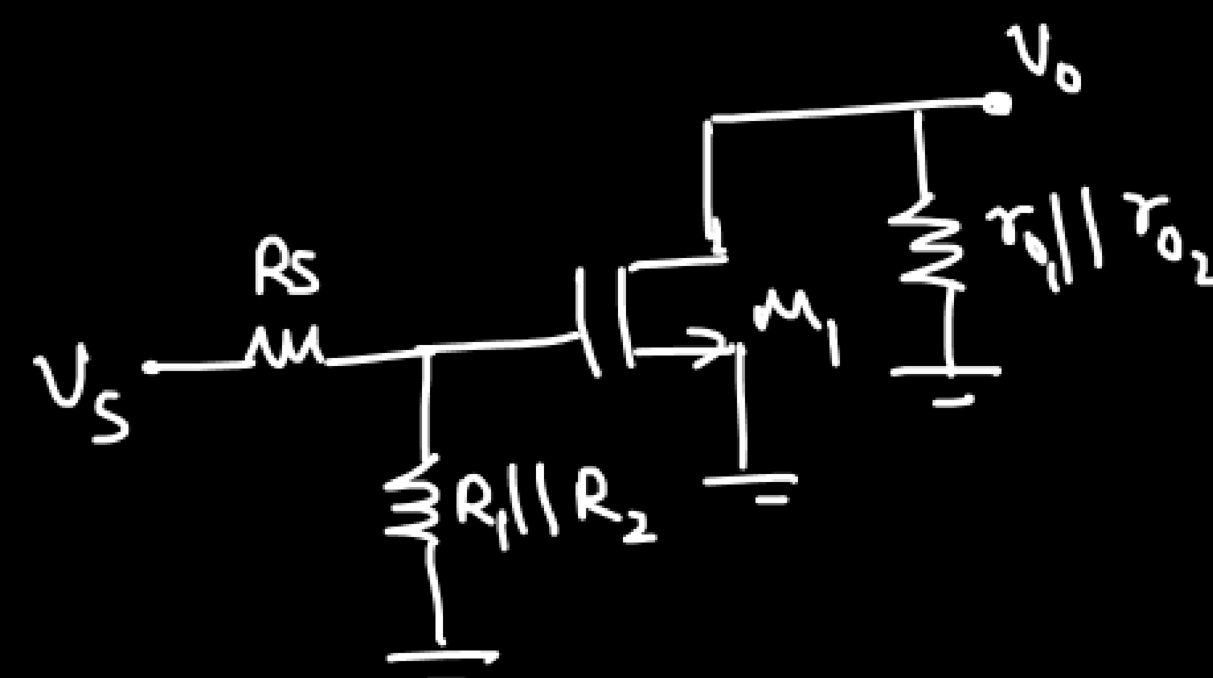
**

$$\boxed{\frac{v_O}{v_S} = -g_{m_1}\left[r_{o_1} \| r_{o_2}\right] \times \frac{(R_1 \| R_2)}{R_S + (R_1 \| R_2)}}$$

M − II



⇒

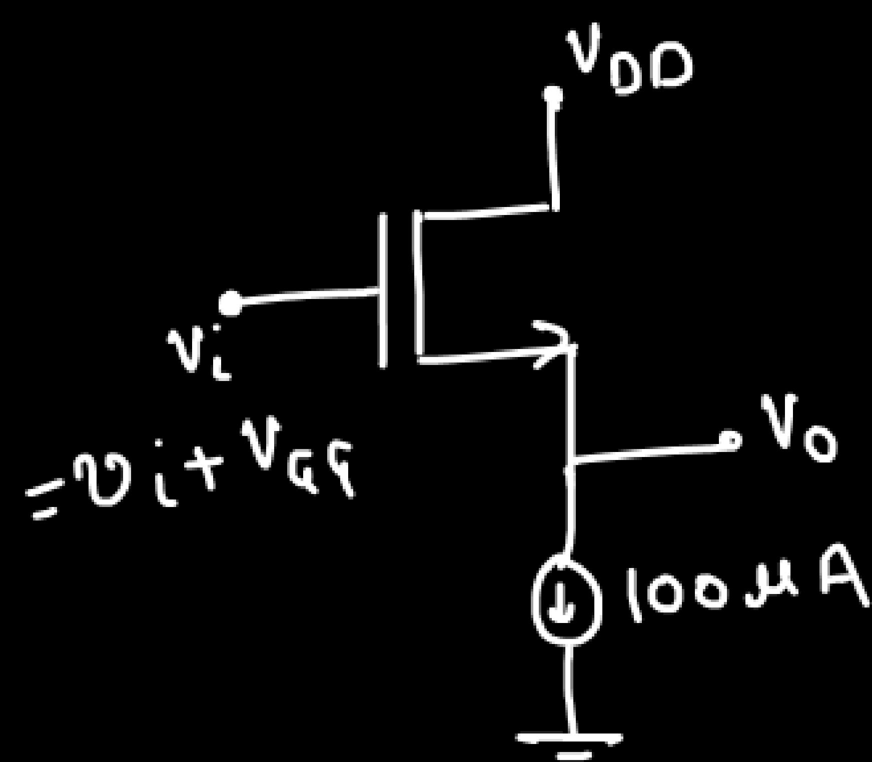


Q. Design a common drain Amplifier (using NMOS) with 100 μA current source in load.

You have a reference current source of 200 μA.

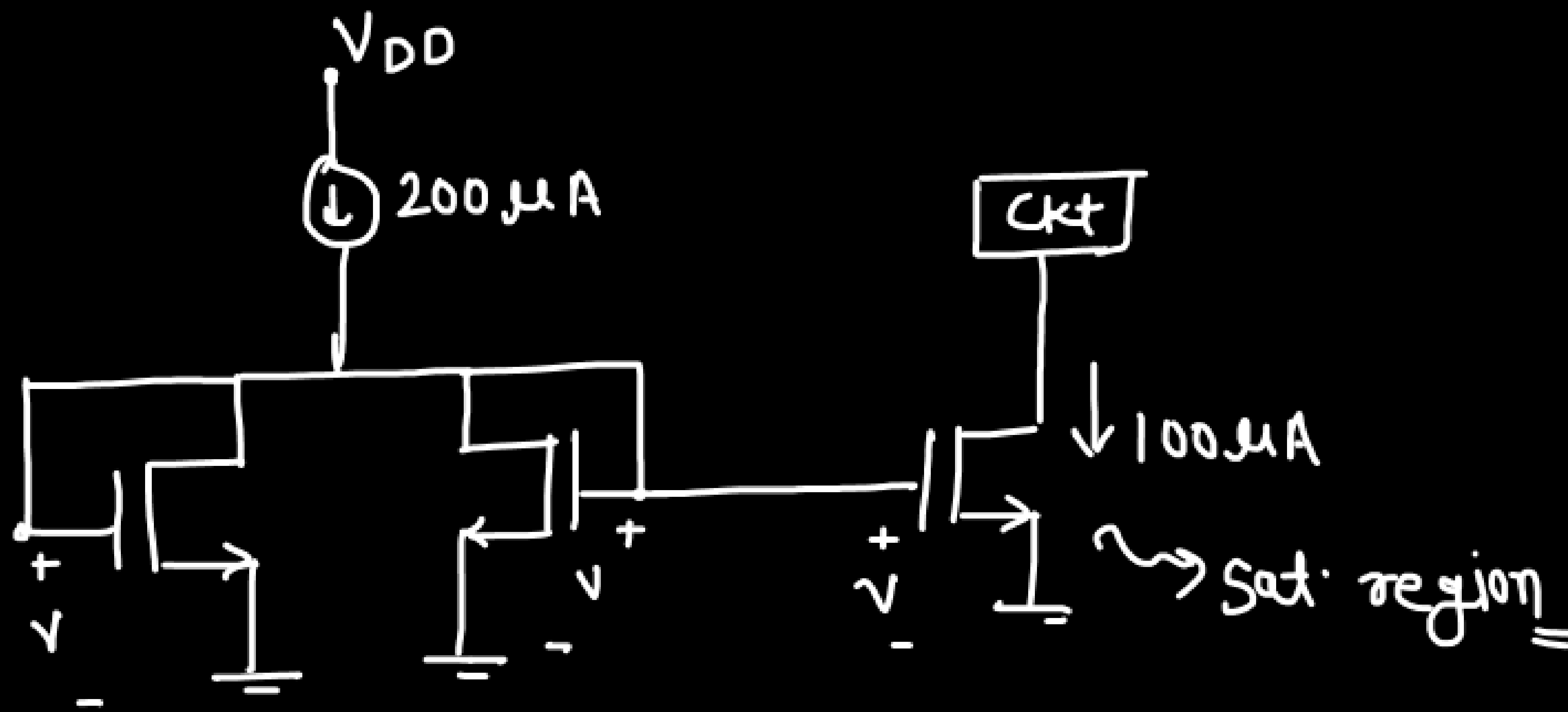
[Note:- All the avaible transistor have same W/L ratios.]

→

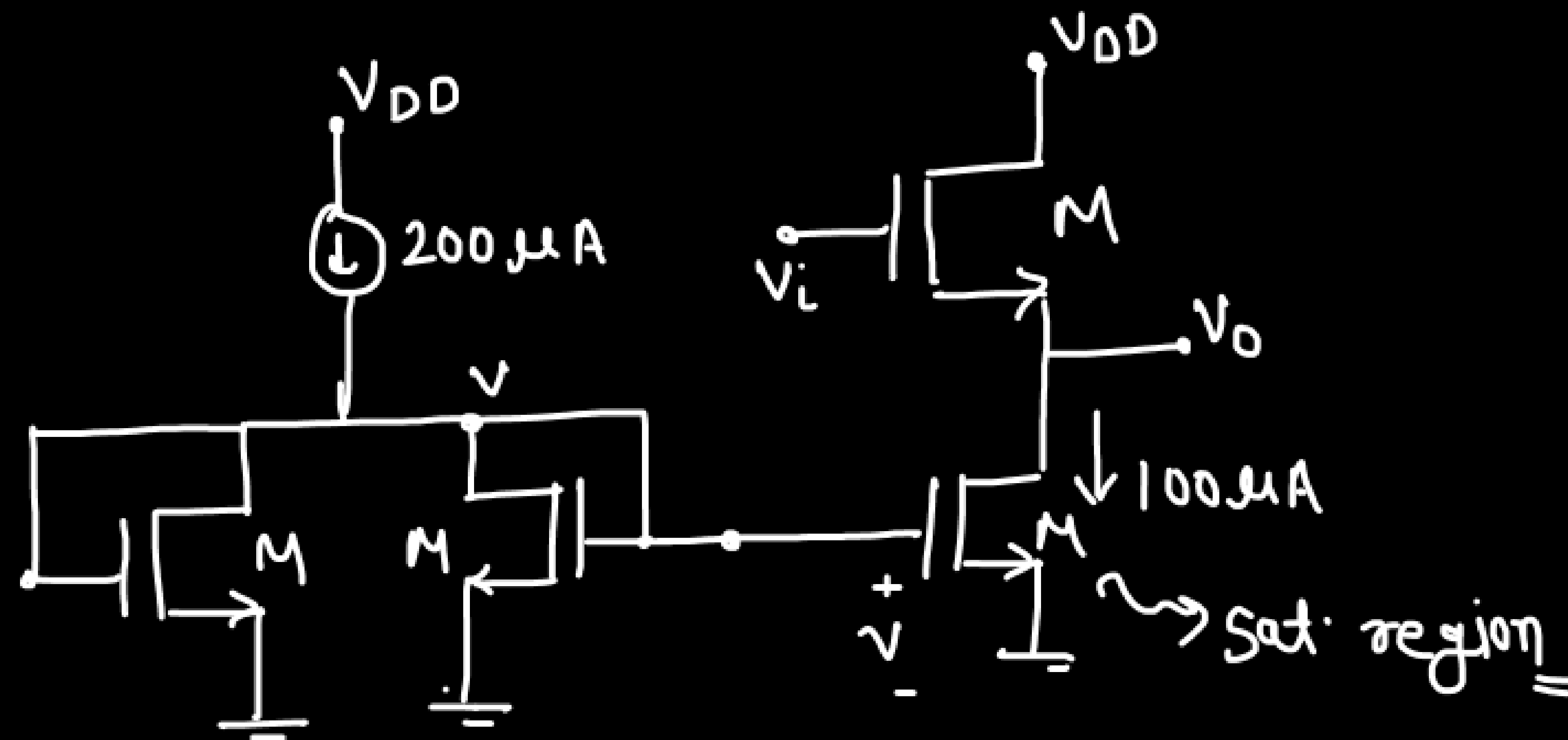


Task:-

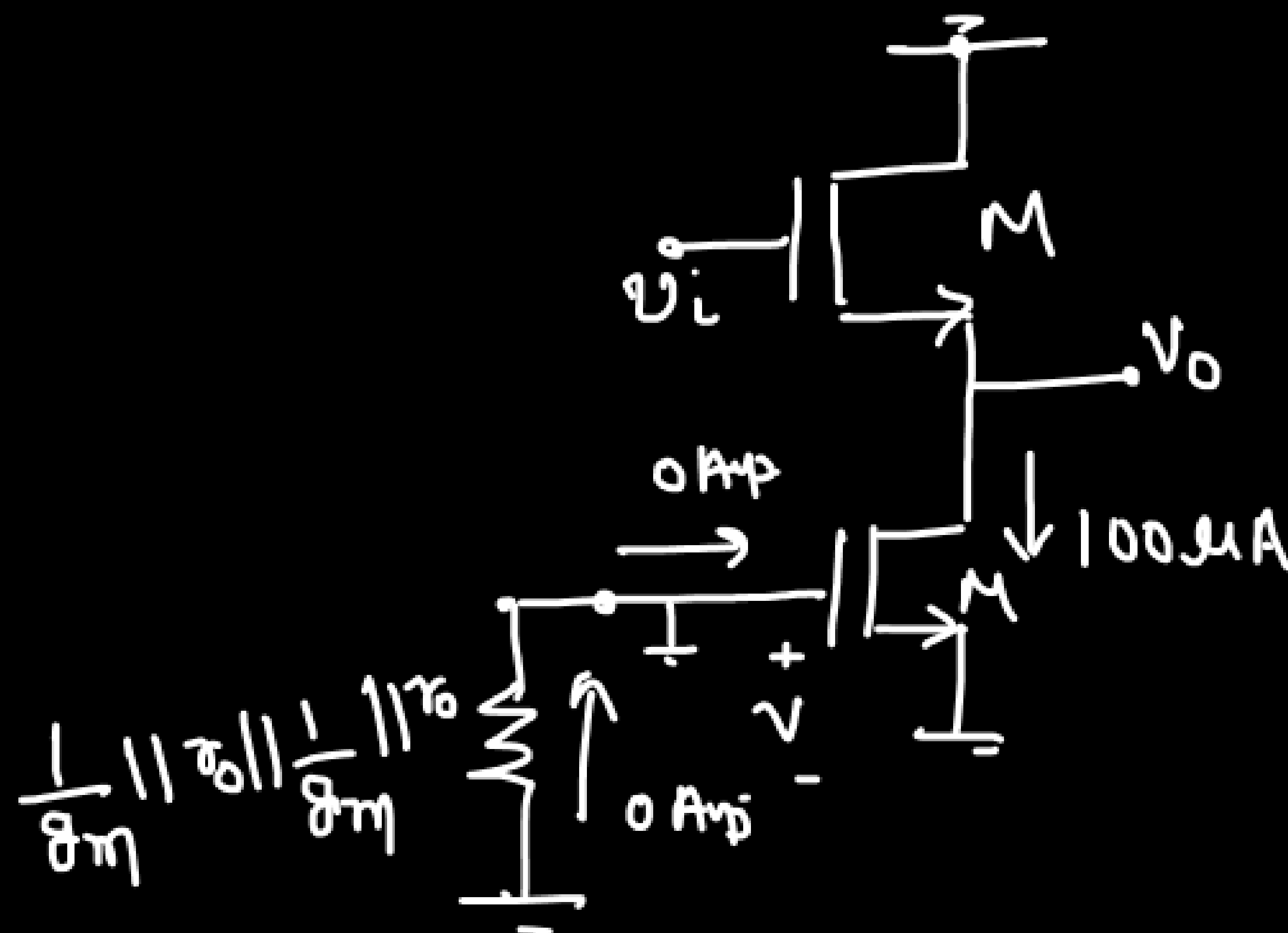
designing 100 μA current source:-



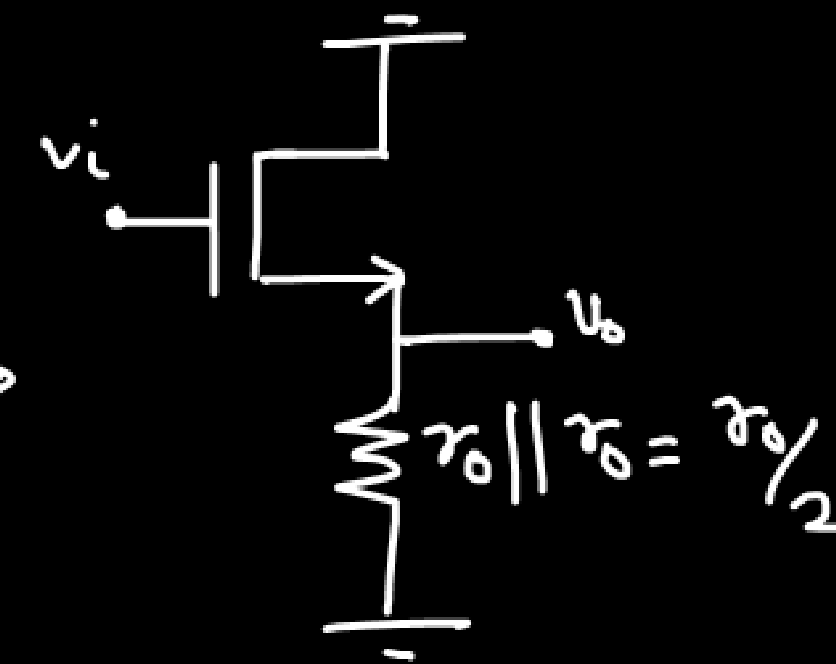
Final design:-



small signal Analysis:-



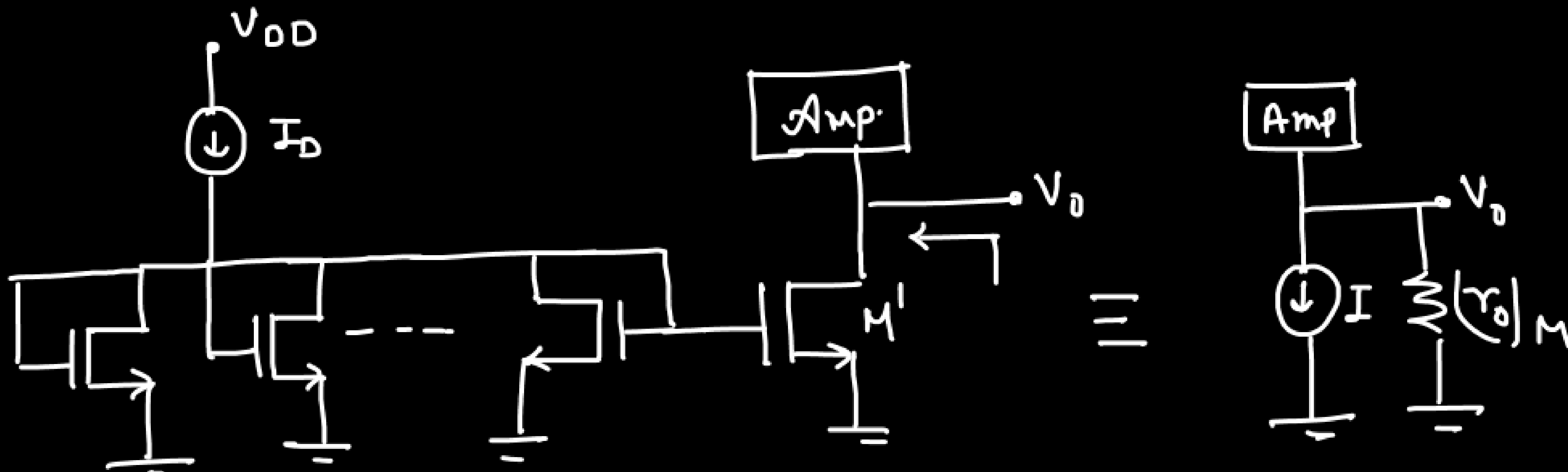
$\Rightarrow$



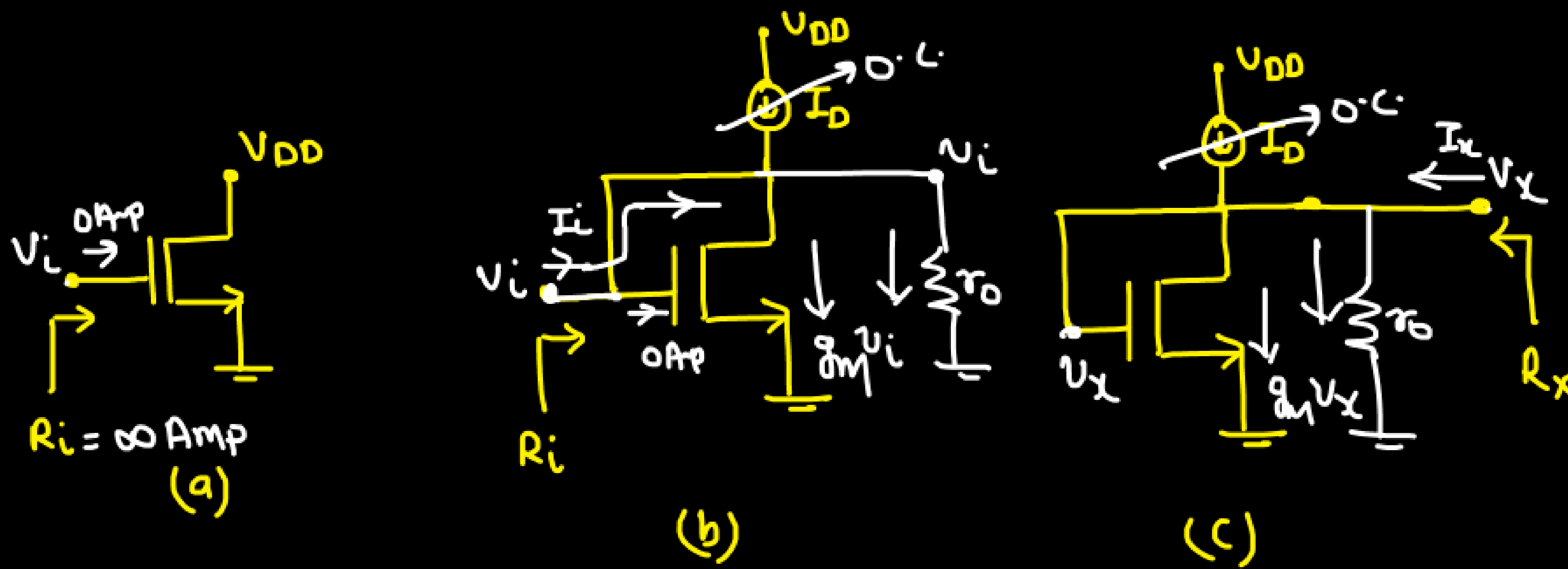
$$\frac{v_o}{v_i} = \frac{r_o/2}{1/g_m + r_o/2}$$

$$\boxed{\frac{v_o}{v_i} = \frac{g_m r_o}{2 + g_m r_o}}$$

Conclusion :-



N·B· →

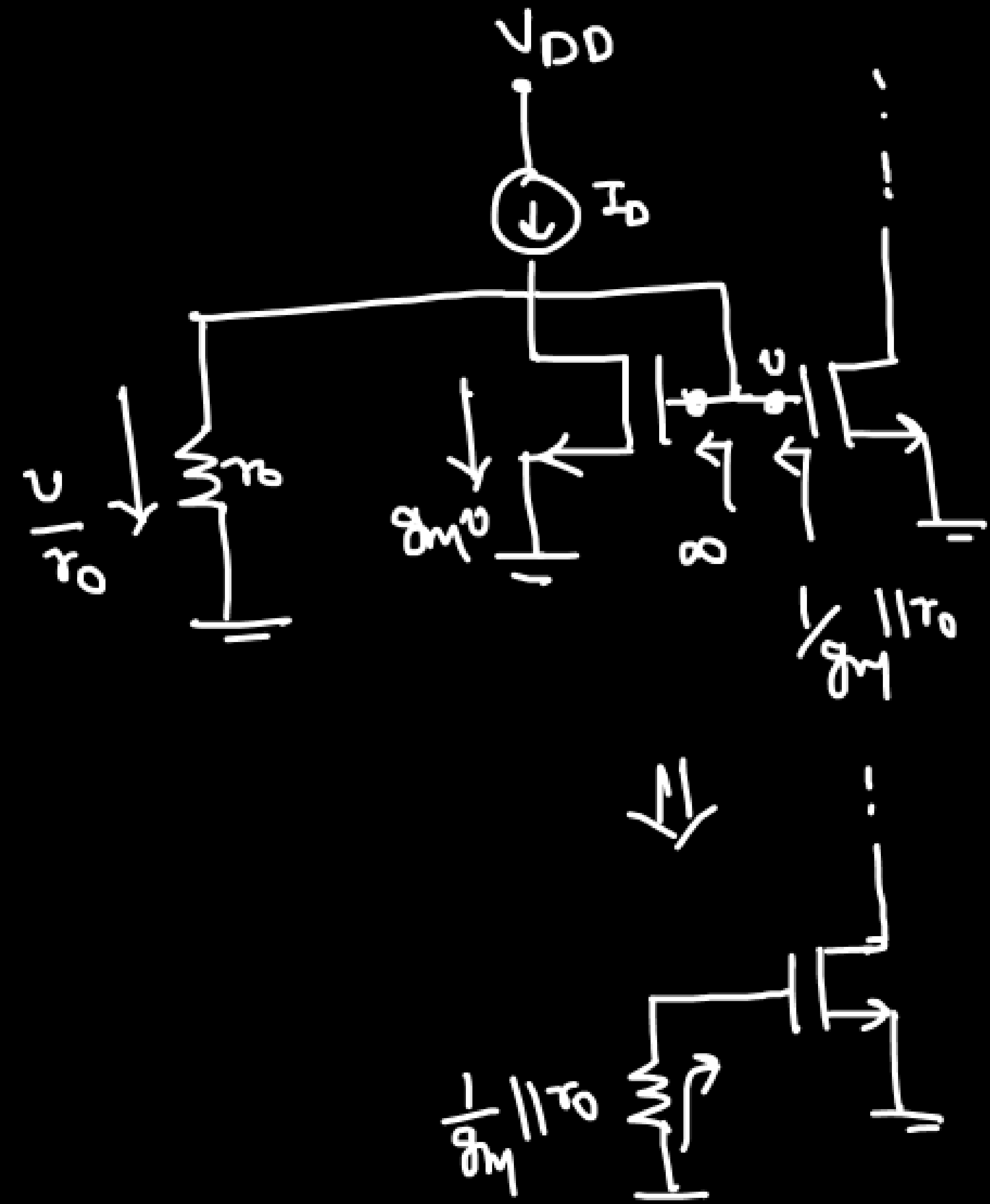


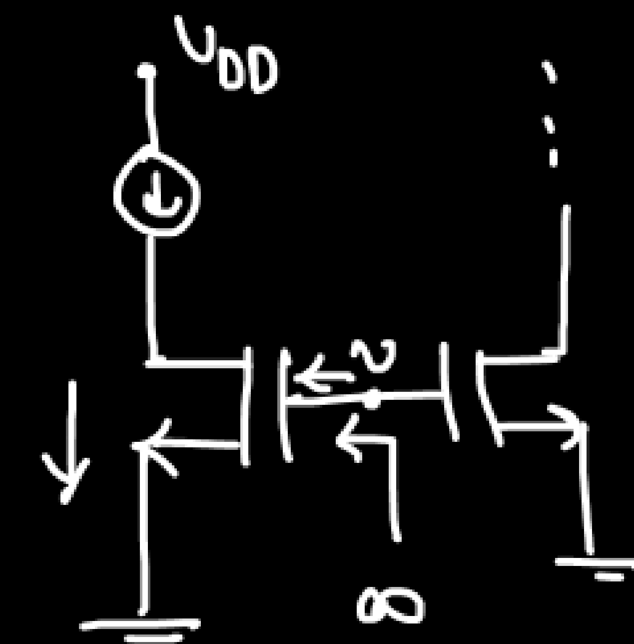
$$I_i = g_m v_i + \frac{v_i}{r_o}$$

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

$$\boxed{\frac{v_i}{I_i} = R_i = \frac{1}{g_m} \| r_o}$$

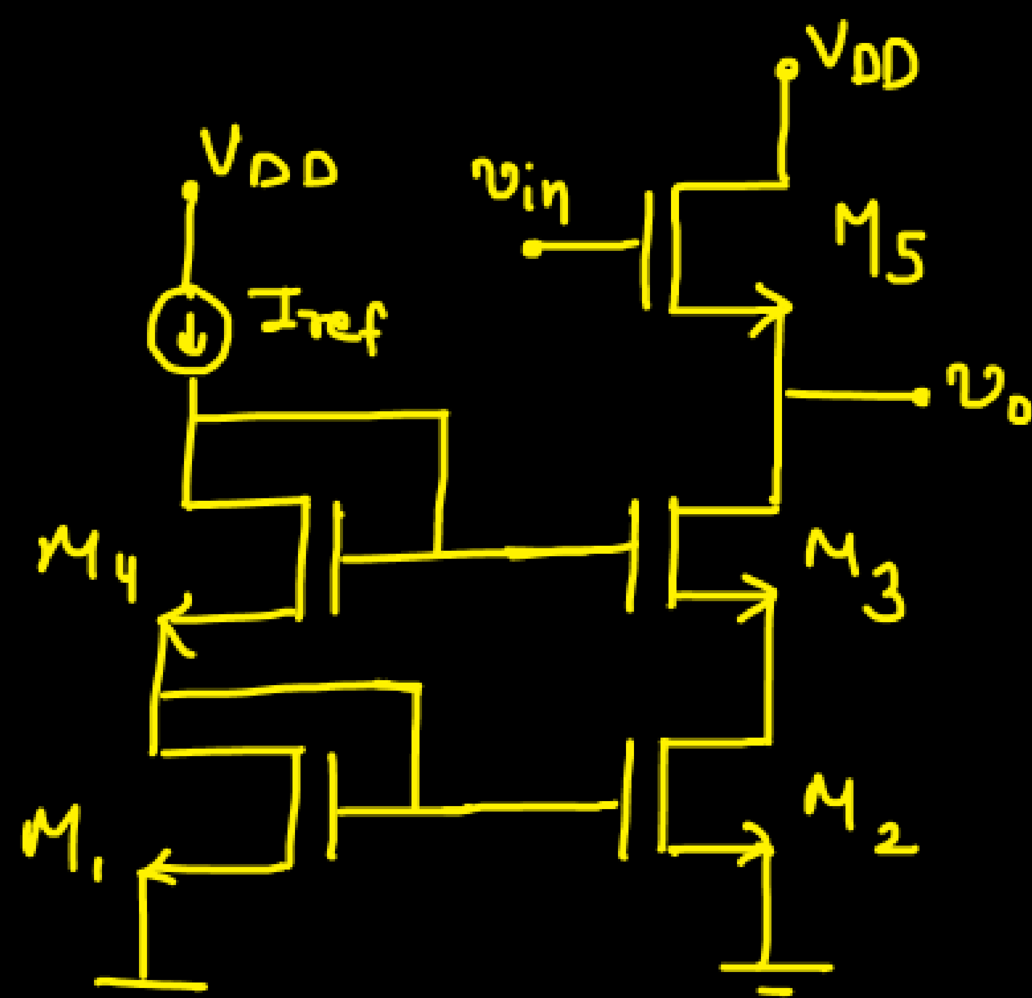
$$\boxed{\frac{v_x}{I_x} = R_x = \frac{1}{g_m} \| r_o}$$


VDD
ID
v/r0
r0
gmv
v
∞
1/gm || r0
1/gm || r0

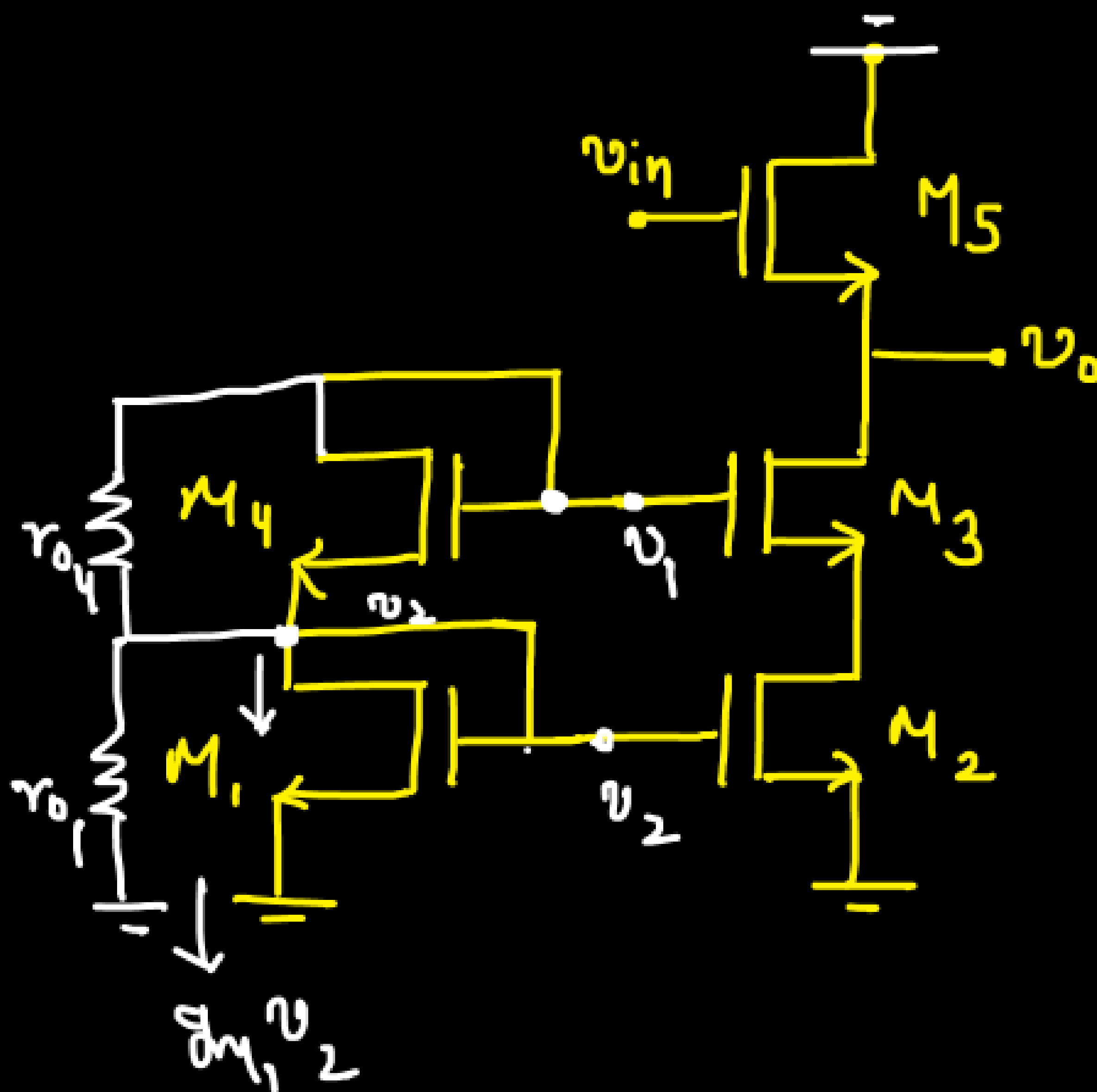

VDD
v
∞

Assignment-8

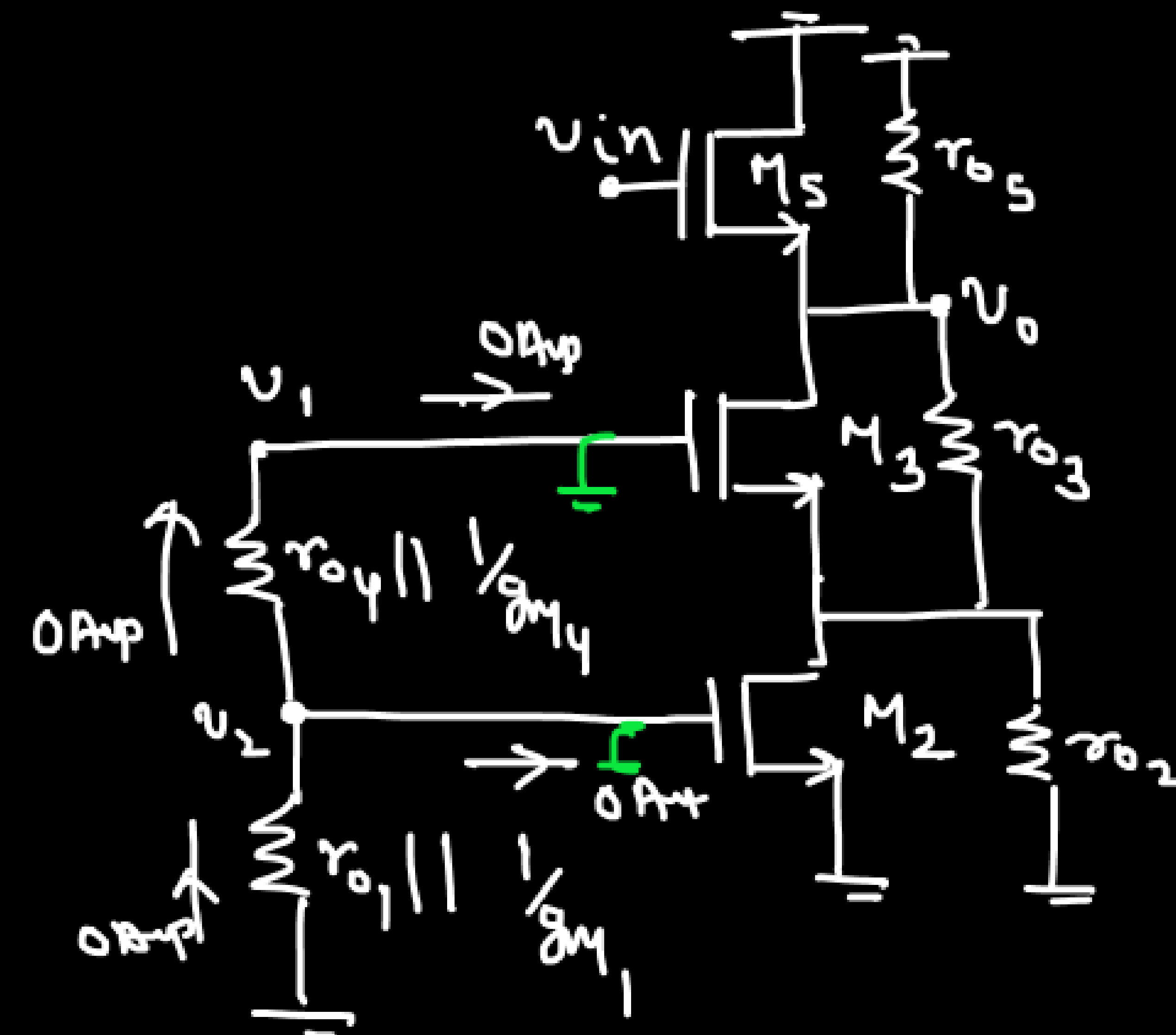
Q.



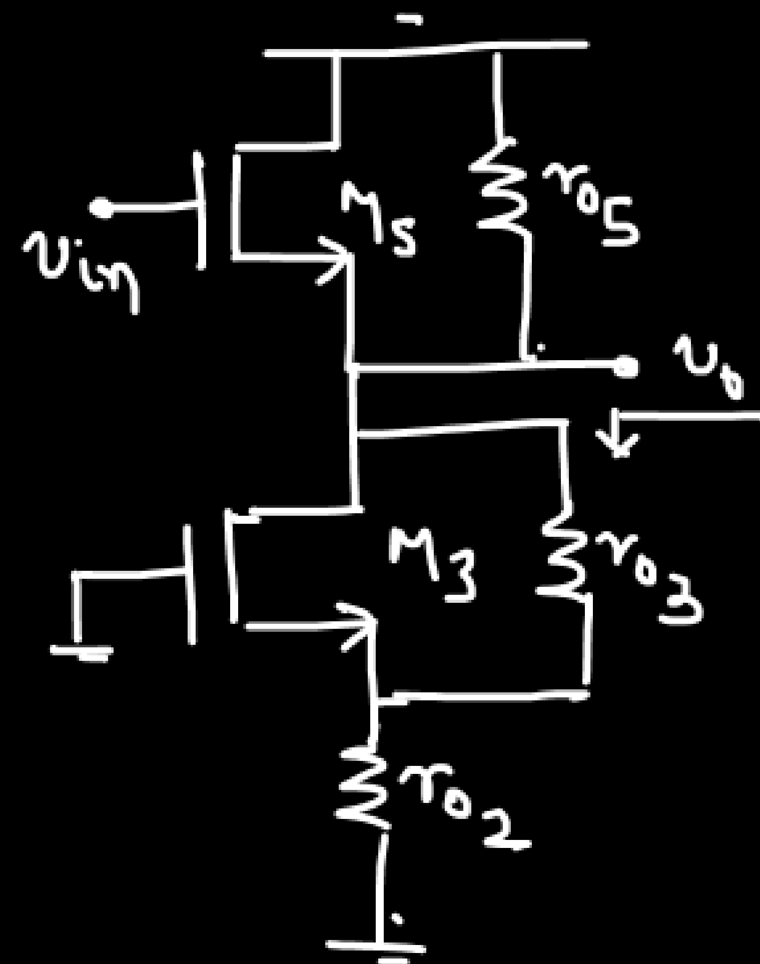
Find small signal voltage gain $\frac{v_o}{v_i}$?



vin
M5
vo
M4
ro4
v1
M3
v2
M1
ro1
v2
M2
gm1 v2

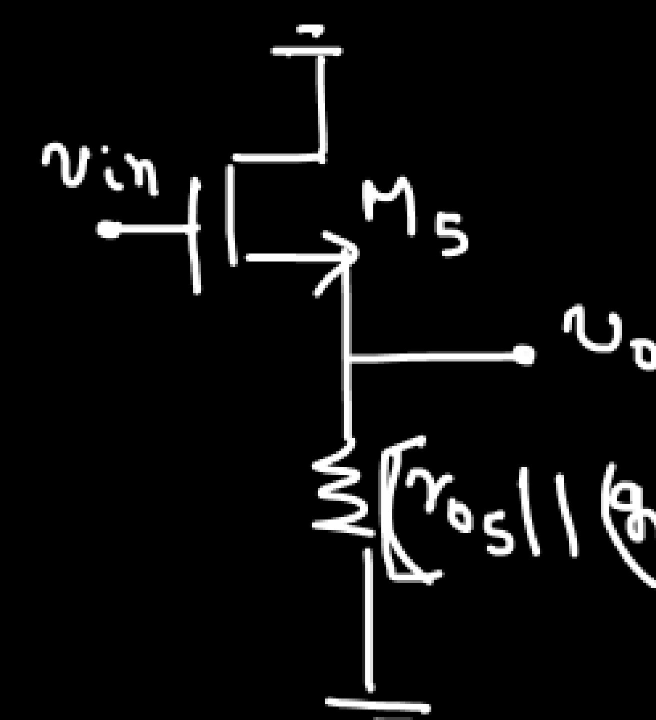


vin
M5
ro5
vo
OAmp
v1
M3
ro3
ro4 || 1/gm4
OAmp
v2
M2
ro2
OAmp
ro1 || 1/gm1
OAmp



$$\left[g_{m3} r_{o3} r_{o2} + r_{o3} + r_{o2}\right]$$

$\Rightarrow$

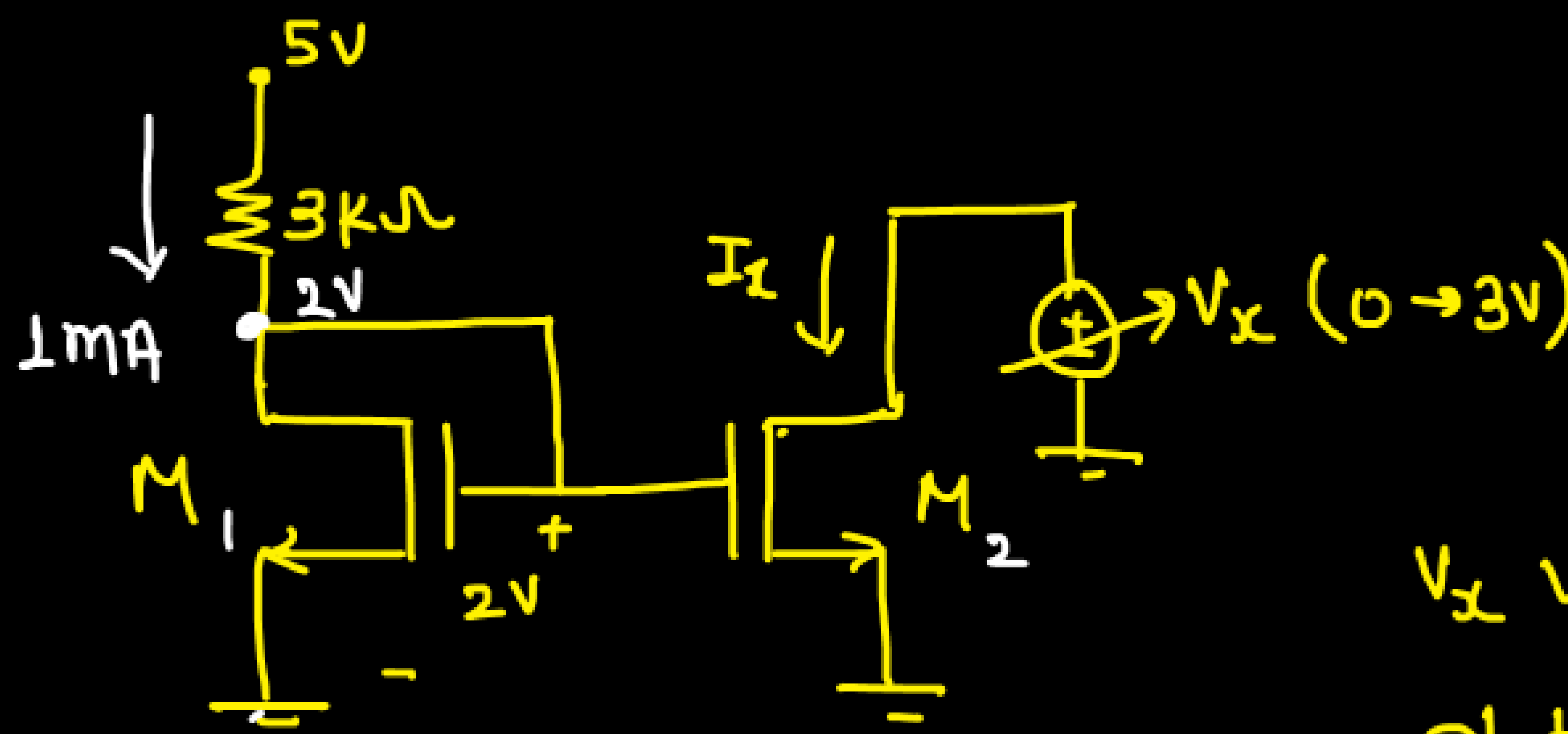


$$\left[r_{o5} \,||\, \left(g_{m3} r_{o3} r_{o2} + r_{o3} + r_{o2}\right)\right] = R$$

$$\boxed{\frac{v_o}{v_i} = \frac{g_{m5} R}{1 + g_{m5} R}}$$

$$R = r_{o5} \,||\, \left(g_{m3} r_{o3} r_{o2} + r_{o2} + r_{o3}\right)$$

Q.



$V_T = 1V$

V_x value is swept from 0→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

$\Downarrow$

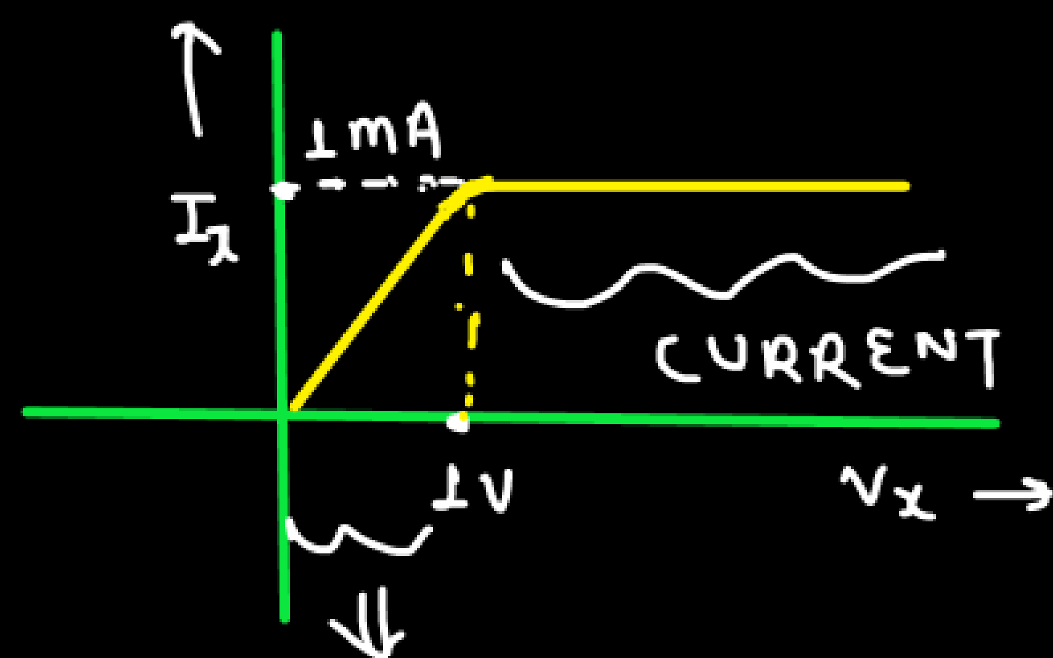
$\boxed{I_x = 1mA} \Leftarrow$ M_1 & M_2 are in current mirror

$$\boxed{\text{For } V_x > 1V \Rightarrow I_x = 1mA}$$

For $V_x < 1V \Rightarrow M_2$ is in linear region

current in linear region < current in sat. region

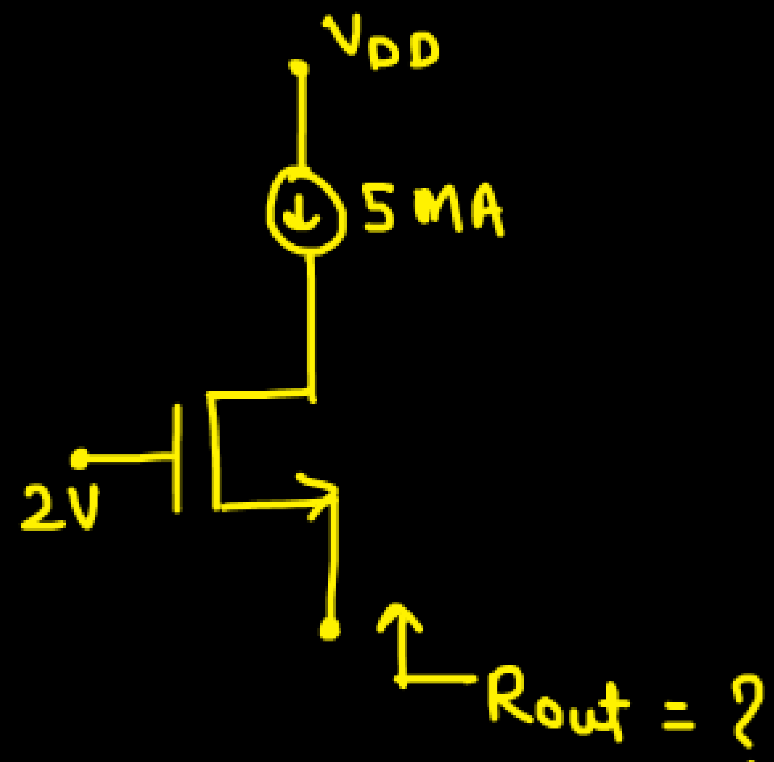
(for fixed V_{GS})



$$\Downarrow$$

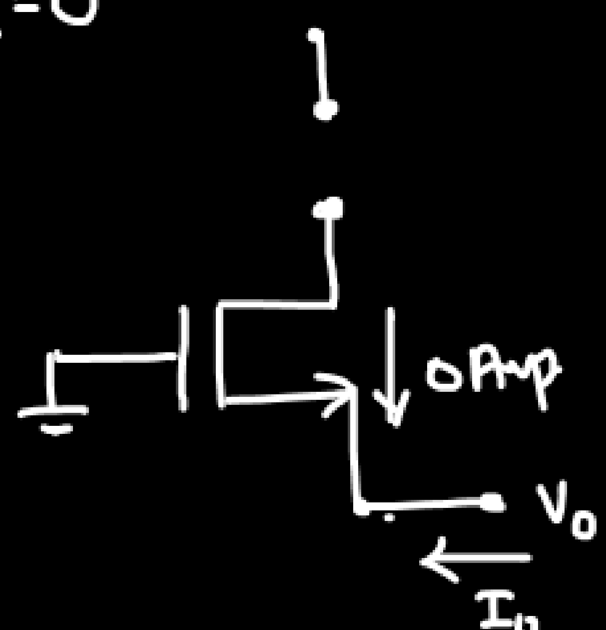
$$I_x = K\left[1 \times V_x - \frac{V_x^2}{2}\right]$$

Q.



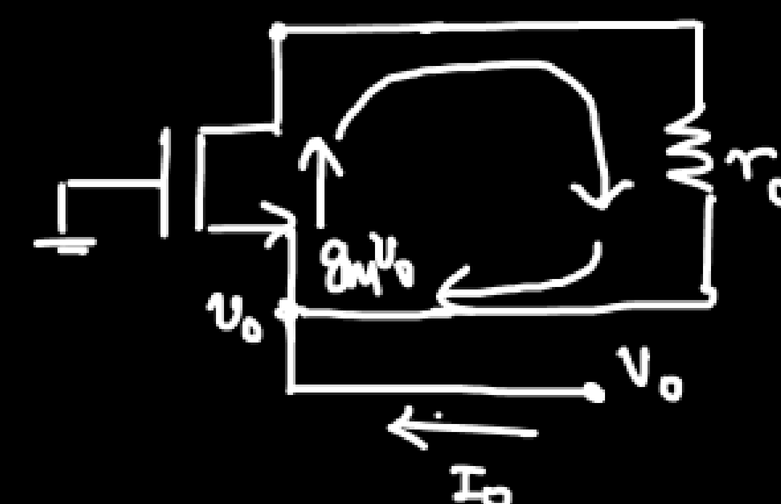
Find R_{out} for $\lambda = 0$, $\lambda \neq 0$

$\Rightarrow$ $\lambda = 0$



$$\boxed{R_{out} = \frac{V_o}{I_o} = \frac{V_o}{0} = \infty}$$

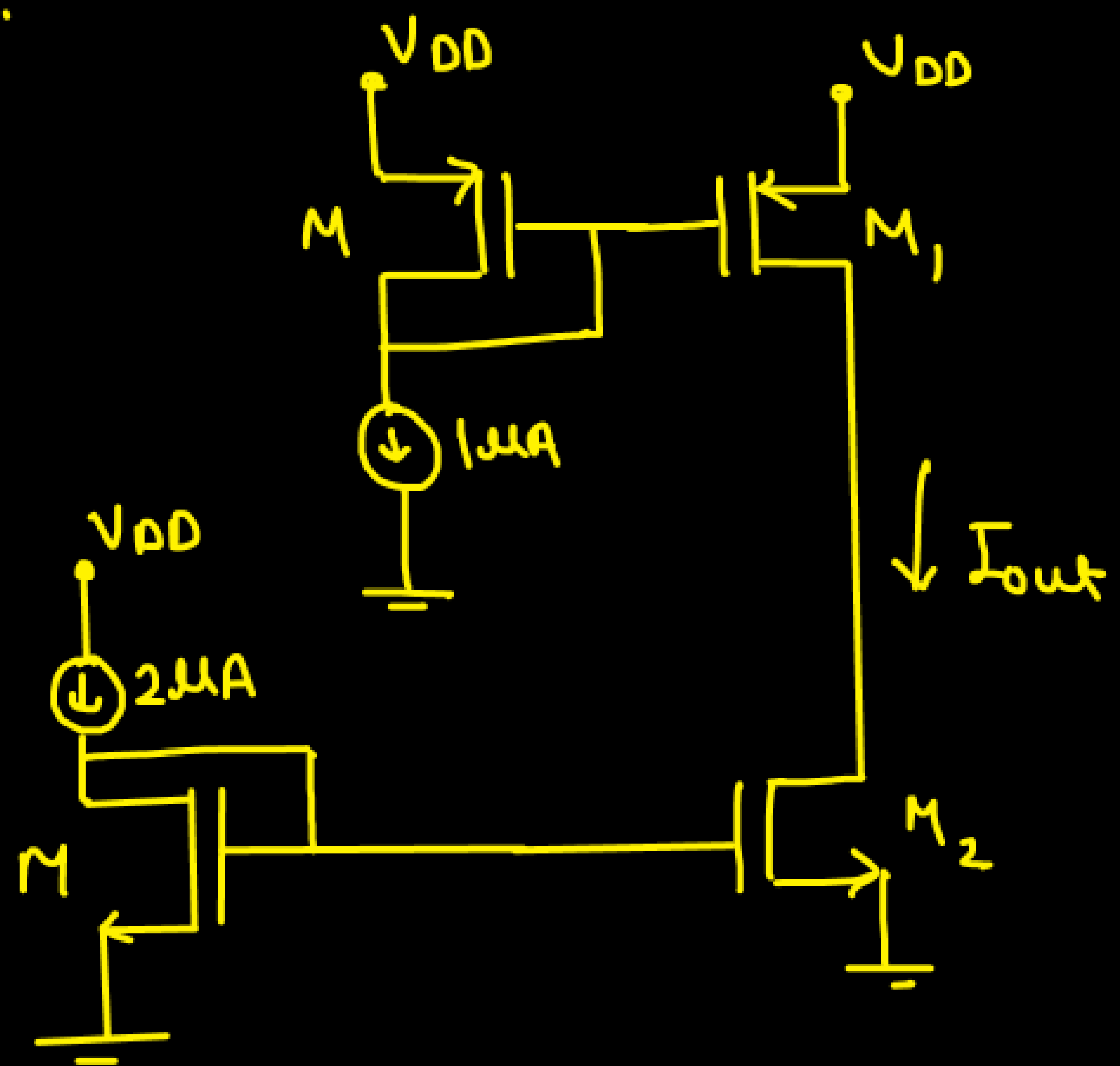
$\lambda \neq 0$



$I_o = 0$ Amp.

$$\boxed{R_o = \infty}$$

Q.



All Tr are identical.

Find I_{out} ?

⇒ if M and M_2 are in C.M. ⇒ $I_{out} = 2\mu A$

if M and M_1 are in C.M. ⇒ $I_{out} = 1\mu A$

$\boxed{I_{out} = 2\mu A = 1\mu A}$ ⇒ NOT POSSIBLE

⇒ There will be only one current mirror working.

⇒ 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

$\Rightarrow$ $\boxed{\text{Assumption is wrong}}$

$\boxed{\text{Let } M_1 \text{ is in sat., } M_2 \text{ is in Triode}}$

$I_{out} = 1\,\mu A$

$\Downarrow$

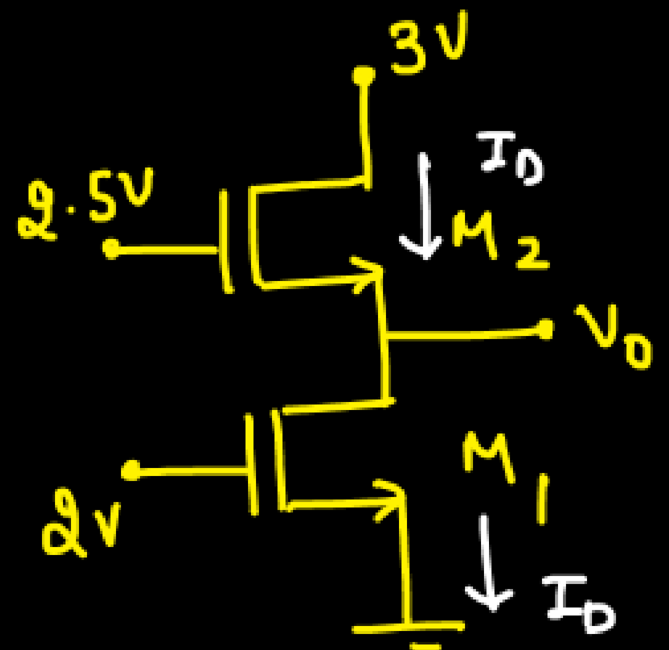
Same current is taken by M_2

[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.

$$V_T = 1V$$

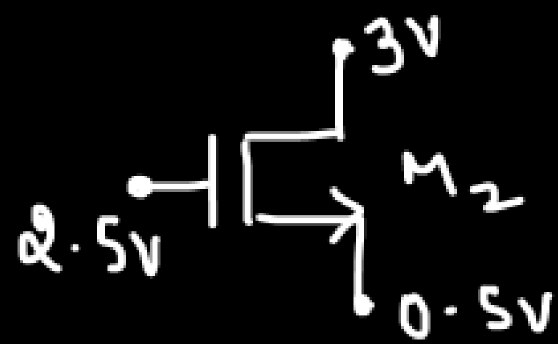
Find operating $cond^n$ of M_1 & M_2.

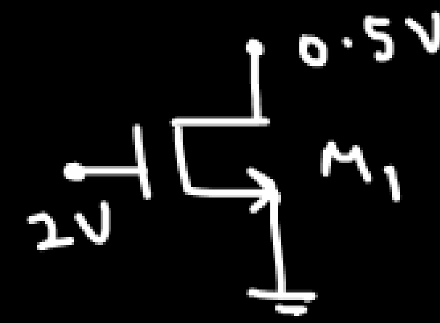
→ Let both M_1 and M_2 are in sat.

$$(I_D)_{M_2} = (I_D)_{M_1}$$

$$\cancel{\frac{\mu_n C_{ox} W}{2L}}(2.5 - V_0 - 1)^2 = \cancel{\frac{\mu_n C_{ox} W}{2L}}(2-1)^2$$

$$\boxed{V_0 = 0.5V} \quad \times$$





$\Downarrow$

$V_{DS} = 2.5\,V$

$V_{ov} = 2 - 1 = 1\,V$

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

$\Downarrow$

$V_{DS} = 0.5\,V$

$V_{ov} = 1.5\,V$

$\boxed{V_{DS} < V_{ov}} \Rightarrow$ linear / Not in sat.

Let M_1 is in linear, M_2 is in sat.

$$(I_D)_{M_1} = (I_D)_{M_2}$$

$$\frac{\mu_n C_{ox} W}{L}\left[(1)(v_o) - \frac{v_o^2}{2}\right] = \frac{\mu_n C_{ox} W}{2L}\left[2.5 - v_o - 1\right]^2$$

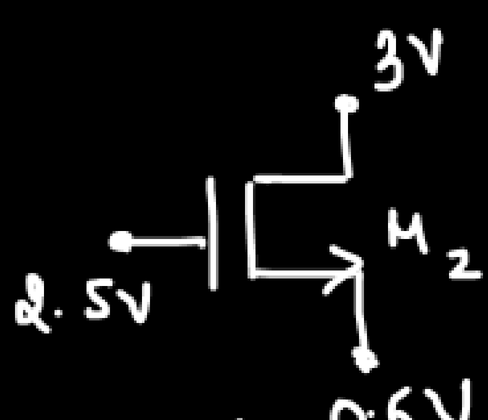
$$2V_0 - V_0^2 = [1.5 - V_0]^2$$

$$2V_0 - V_0^2 = 2.25 + V_0^2 - 3V_0$$

$$2V_0^2 - 5V_0 + 2.25 = 0$$

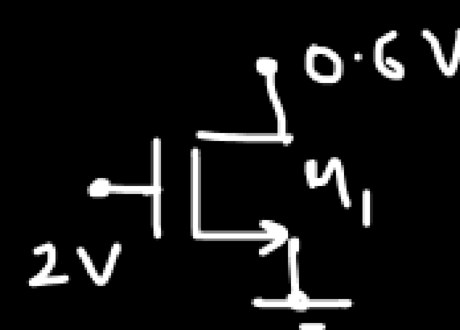
$$V_0 = \frac{5 \pm 2.64}{4}$$

$$V_0 = 1.9\,V \quad \text{OR} \quad \boxed{0.6V}$$



$\Downarrow$

sat.



$\Downarrow$

linear

$\Rightarrow$ $\boxed{\begin{array}{l} M_2 \text{ is sat} \\ M_1 \text{ is in linear} \\ V_0 = 0.6V \end{array}}$

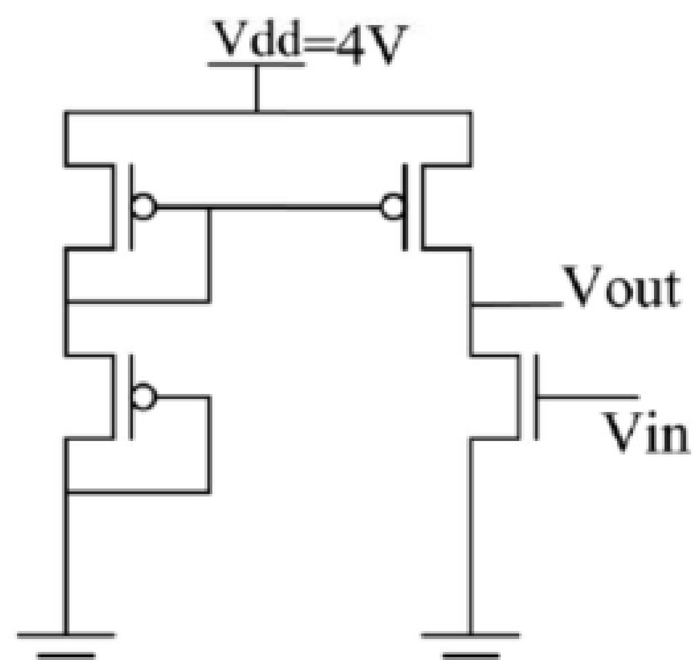
Q.

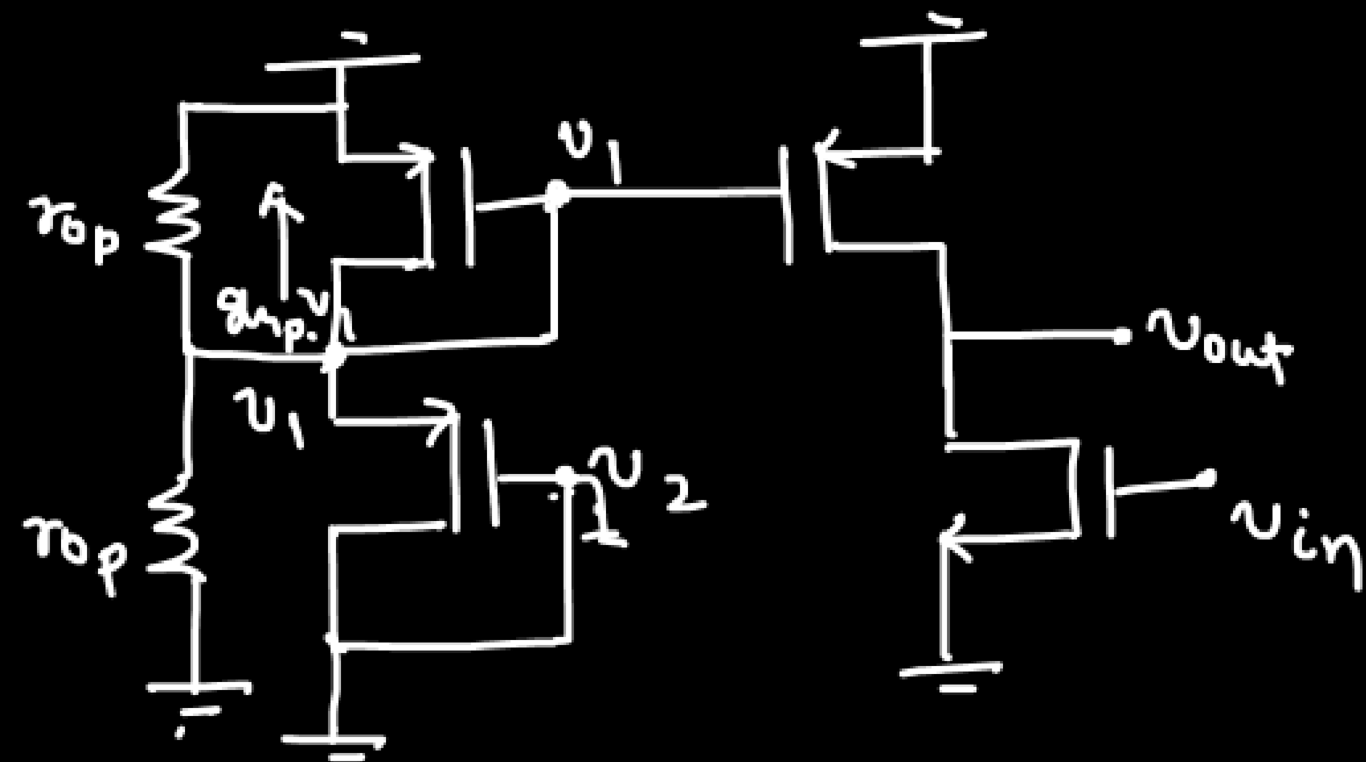
In the circuit shown, the threshold voltages of the pMOS ($|V_{tp}|$) and nMOS (V_{tn}) transistors are both equal to 1 V. All the transistors have the same output resistance r_{ds} of 6 MΩ. The other parameters are listed below:

$\mu_n C_{ox} = 60\ \mu A/V^2$; $\left(\frac{W}{L}\right)_{nMOS} = 5$

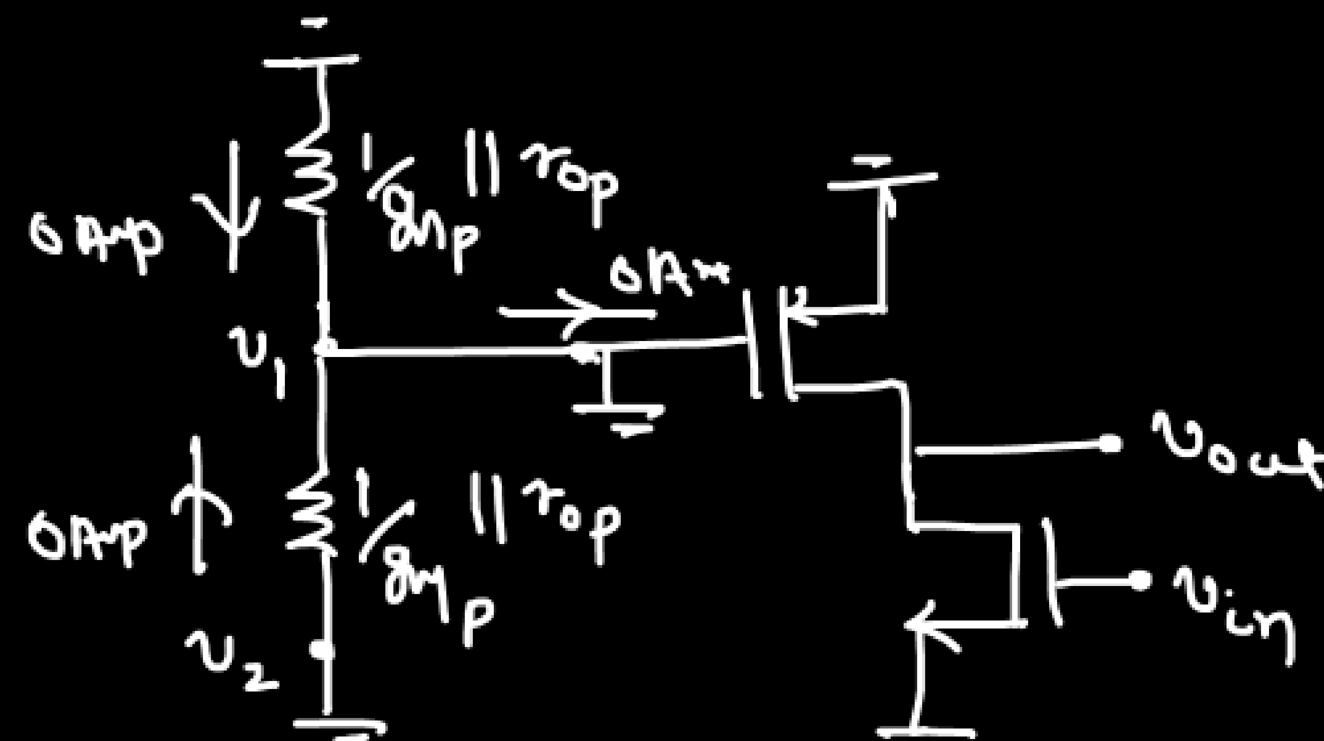
$\mu_p C_{ox} = 30\ \mu A/V^2$; $\left(\frac{W}{L}\right)_{pMOS} = 10$

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).

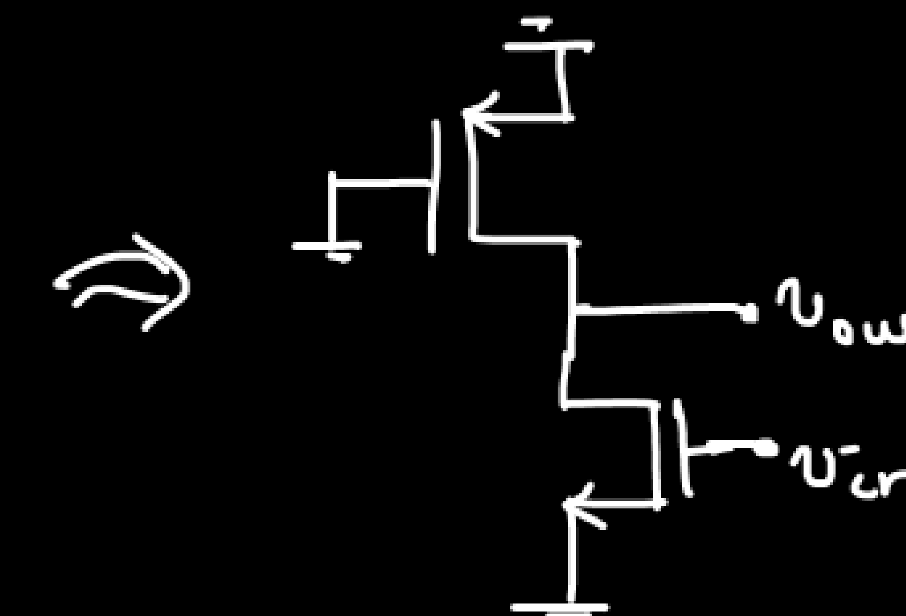




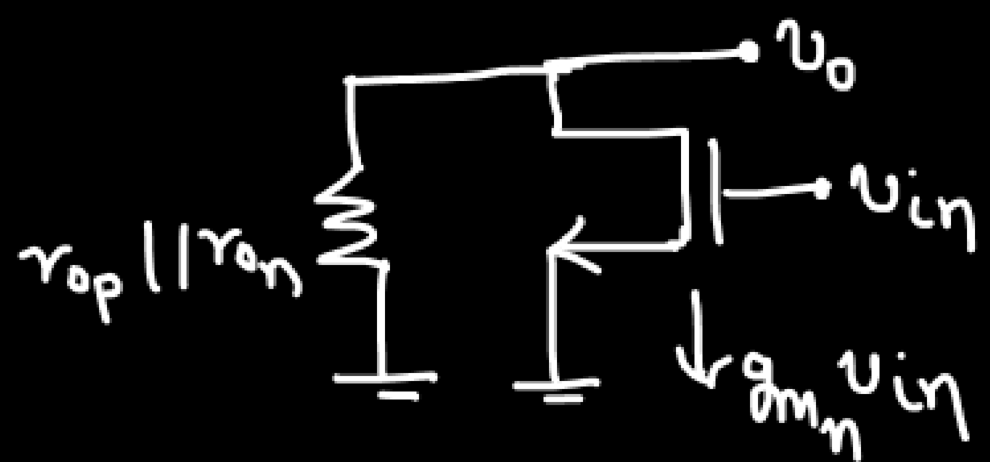
r_{op}
$g_{mp} \cdot v_1$
v_1
v_1
v_2
r_{op}
v_{out}
v_{in}



$1/g_{mp} \parallel r_{op}$
0 Amp
0 Amp
v_1
0 Amp
$1/g_{mp} \parallel r_{op}$
v_2
v_{out}
v_{in}



v_{out}
v_{in}



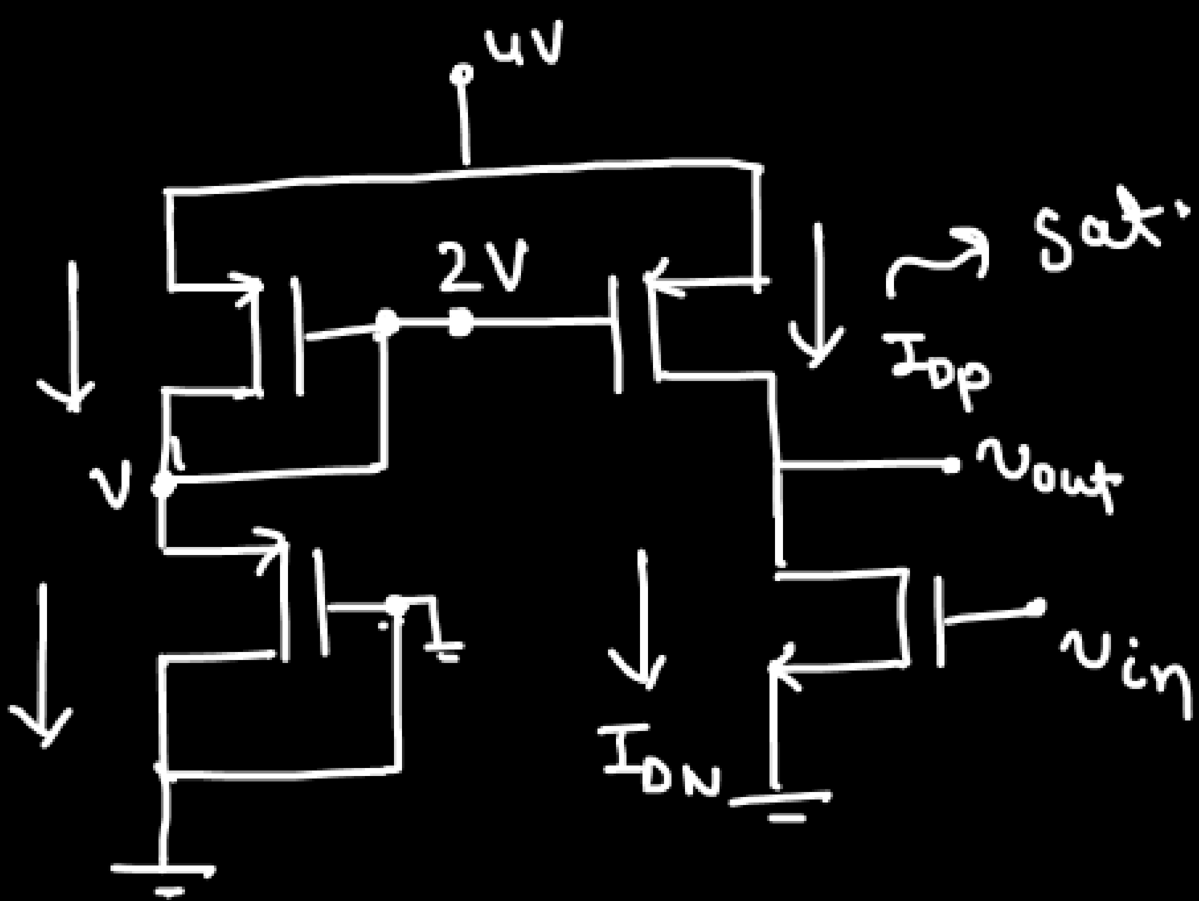
$$\boxed{\frac{v_o}{v_i} = -g_{m_n}\left[r_{op} \| r_{on}\right]}$$

$r_{op} = r_{on} = 6\,M\Omega$

$$\boxed{g_{m_n} = ?}$$

$$\boxed{g_{m_n} = \sqrt{\frac{2\mu_n C_{ox} W}{L} I_{D_N}}}$$

$I_{D_N} = ?$



$$\frac{\mu_p C_{ox} W}{2L}\left[4-V_a-1\right]^2 = \frac{\mu_p C_{ox} W}{2L}\left[V_a-1\right]^2 \qquad \{\lambda \to \text{very small}\}$$

$$3-V_a = V_a - 1$$

$$\boxed{V_a = 2V}$$

$$I_{Dp} = \frac{\mu_p C_{ox} W}{2L} (V_{SG} - V_T)^2$$

$$I_{Dp} = \frac{300\mu}{2} (2 - 1)^2$$

$$I_{Dp} = 150\mu \text{ Amp.} = I_{DN}$$

$$g_{m_n} = \sqrt{2 \times 300\mu \times 150\mu} = 300\mu S$$

$$A_V = -g_{mp} [r_{op} \| r_{on}] \qquad r_{op} = r_{oN} = 6M\Omega$$

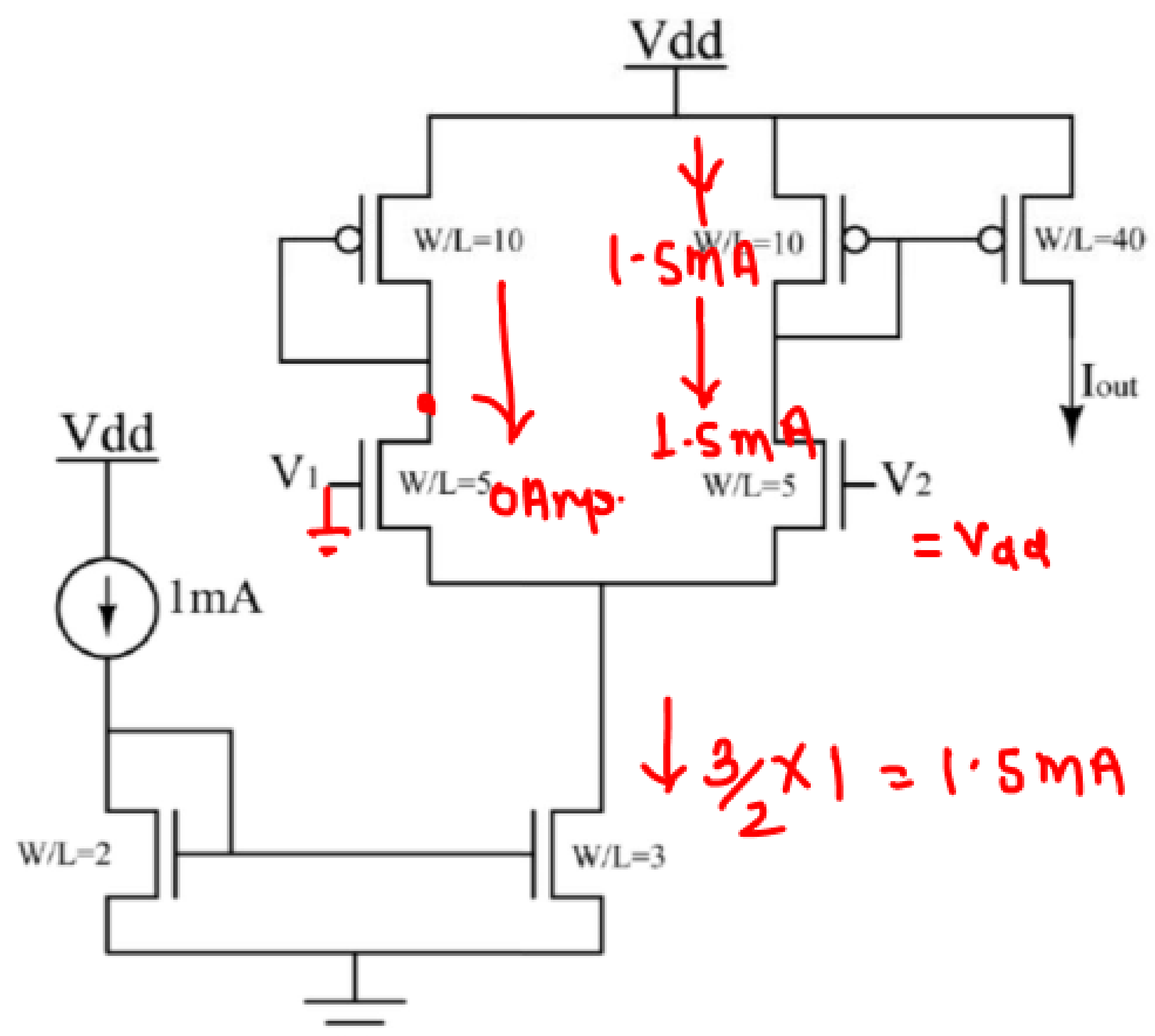
$$= -300\mu \times [6M \| 6M]$$

$$= -3 \times 10^{-4} \times 3 \times 10^6 = -900$$

$$\boxed{A_V = -900 \, V/V}$$

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).

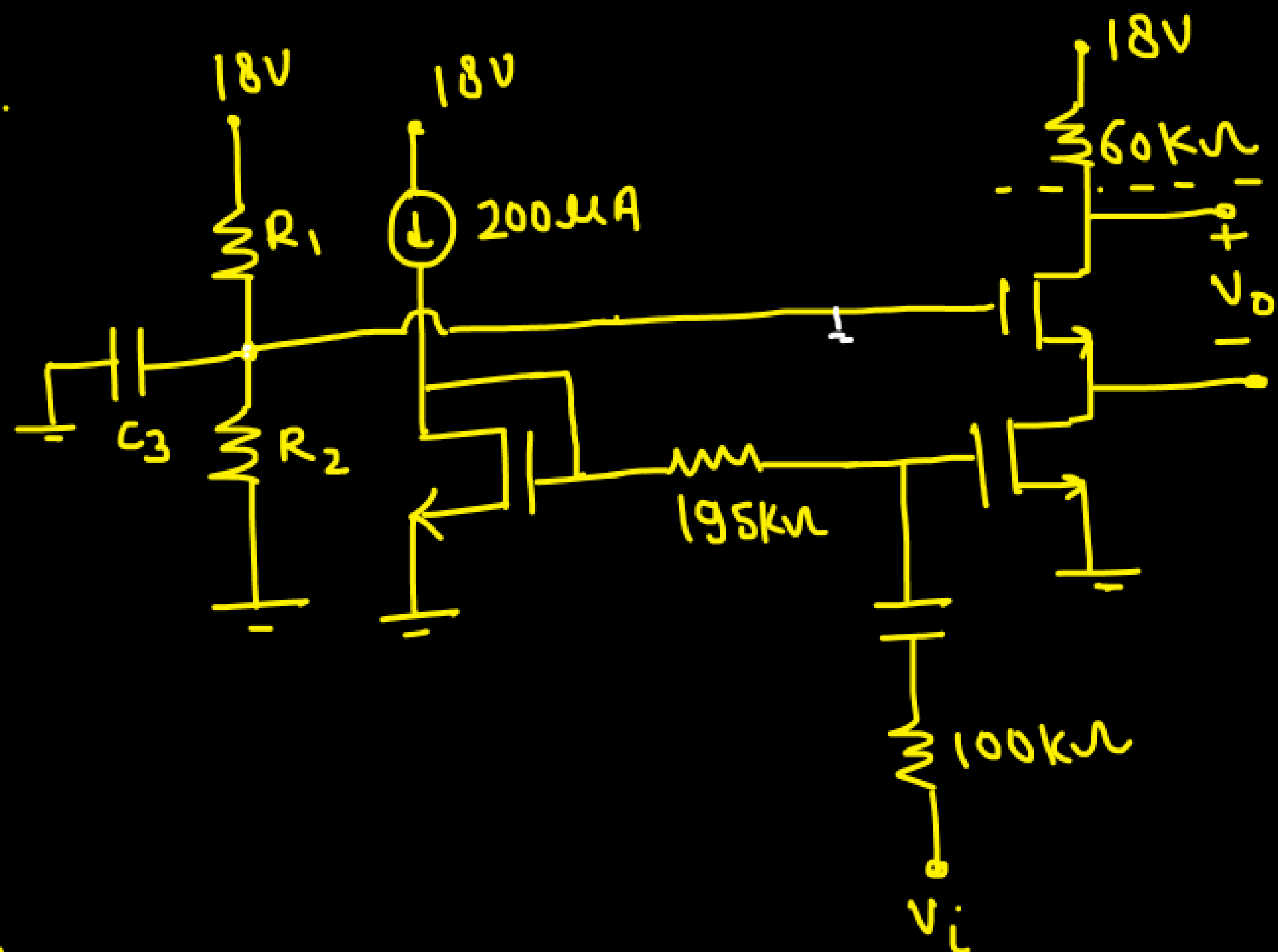


$\frac{40}{10} \times 1.5mA$

$= 6mA$

Assignment-9 [Fusion_Special]

Q.



(a) Find small signal voltage gain $\frac{v_o}{v_i}$. ($\lambda = 0$)

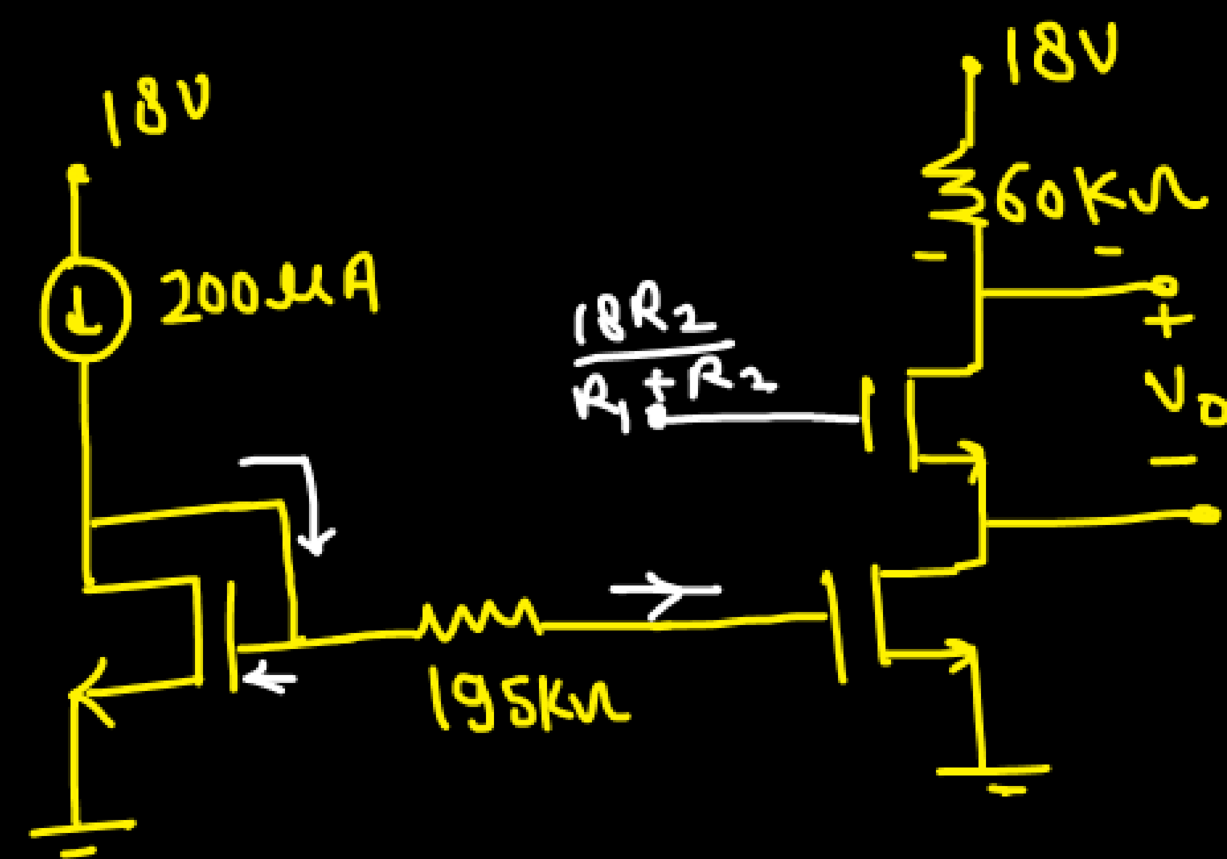
(b) Find small signal R_o. ($\lambda = 0.05\,V^{-1}$)

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:-

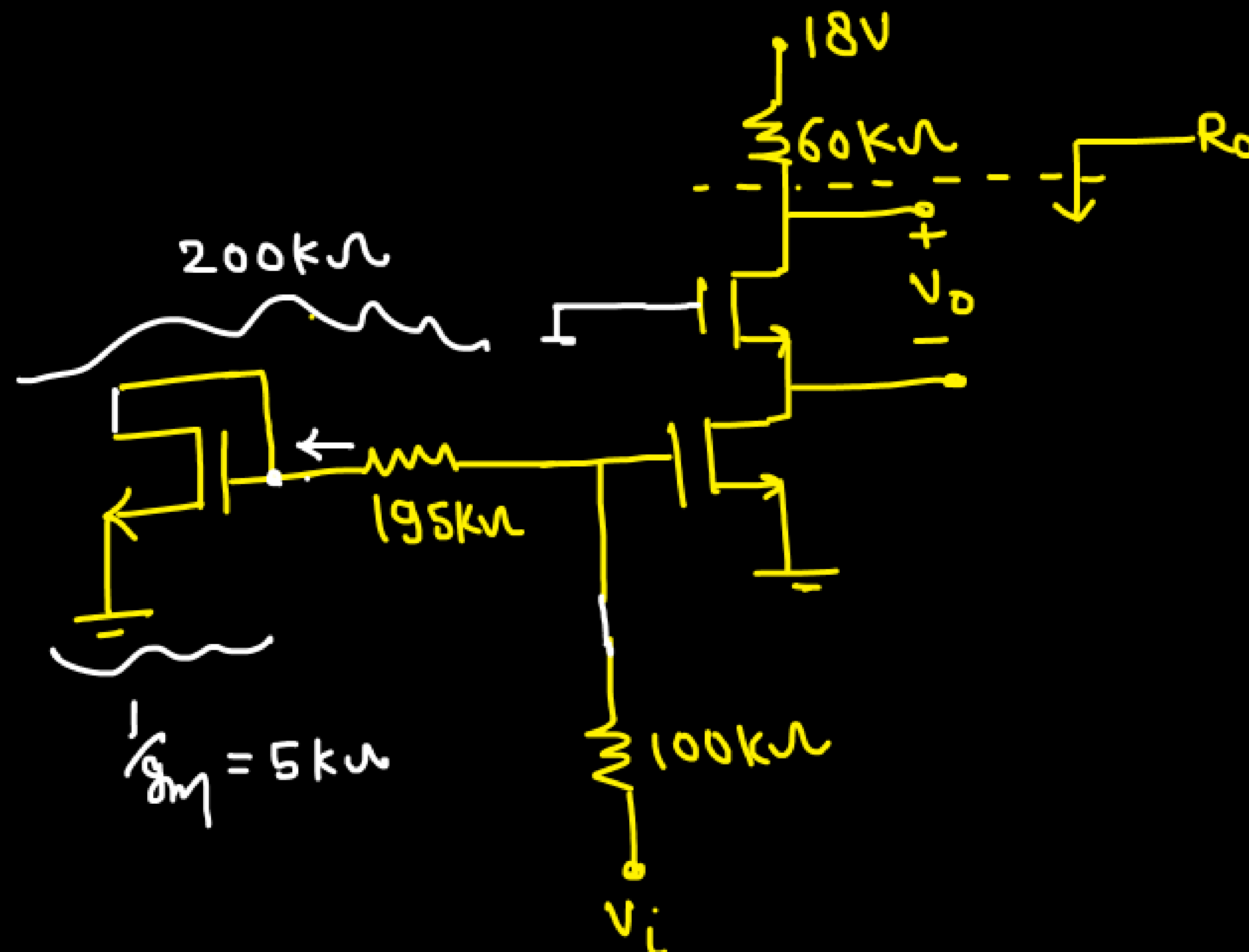


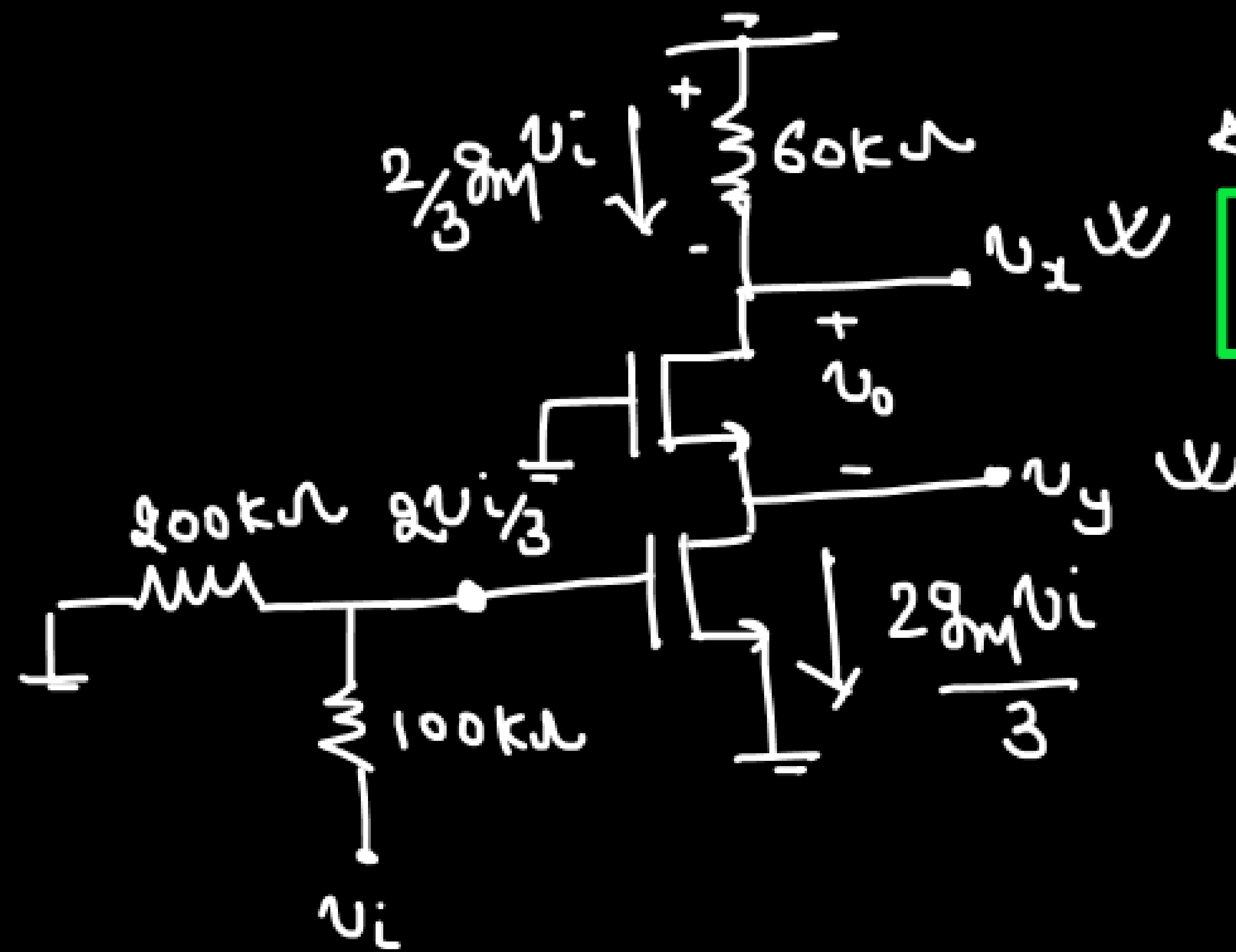
$$I_D = 200\mu A$$

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

$$\Rightarrow \boxed{\begin{aligned} g_m &= 200\mu S \\ 1/g_m &= 5k\Omega \end{aligned}}$$

Ac Analysis:-





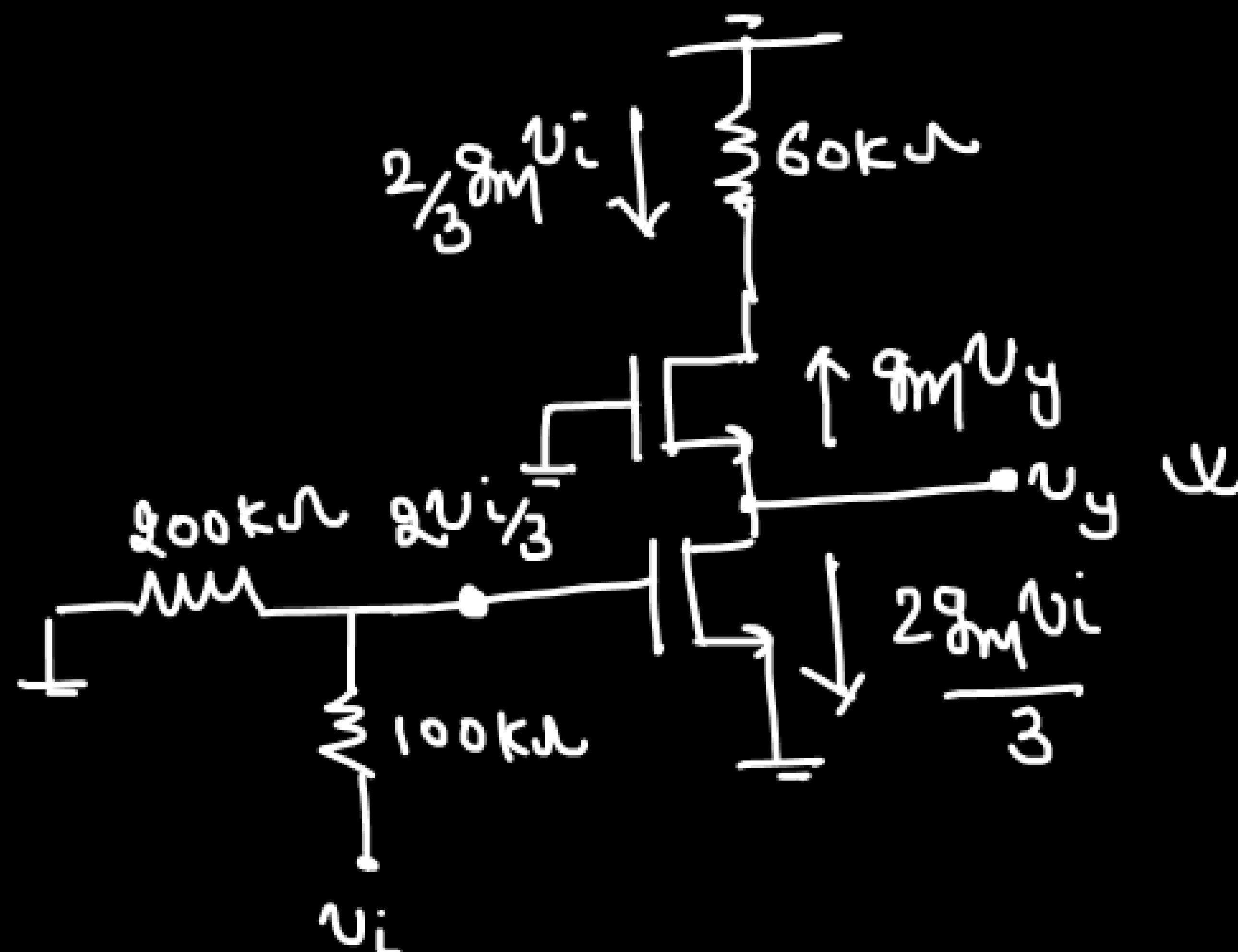
$$\boxed{v_o = v_x - v_y}$$

$$\boxed{v_o = -\tfrac{2}{3} g_m v_i \times 60k\Omega}$$

$$v_x = -\tfrac{2}{3} g_m v_i \times 60k\Omega$$

$$= -\tfrac{2}{3} \times 200\mu \times 60k \times v_i$$

$$\boxed{v_x = -8 v_i}$$



$$g_m v_y = -\frac{2}{3} g_m v_i$$

$$\boxed{v_y = -\frac{2}{3} v_i}$$

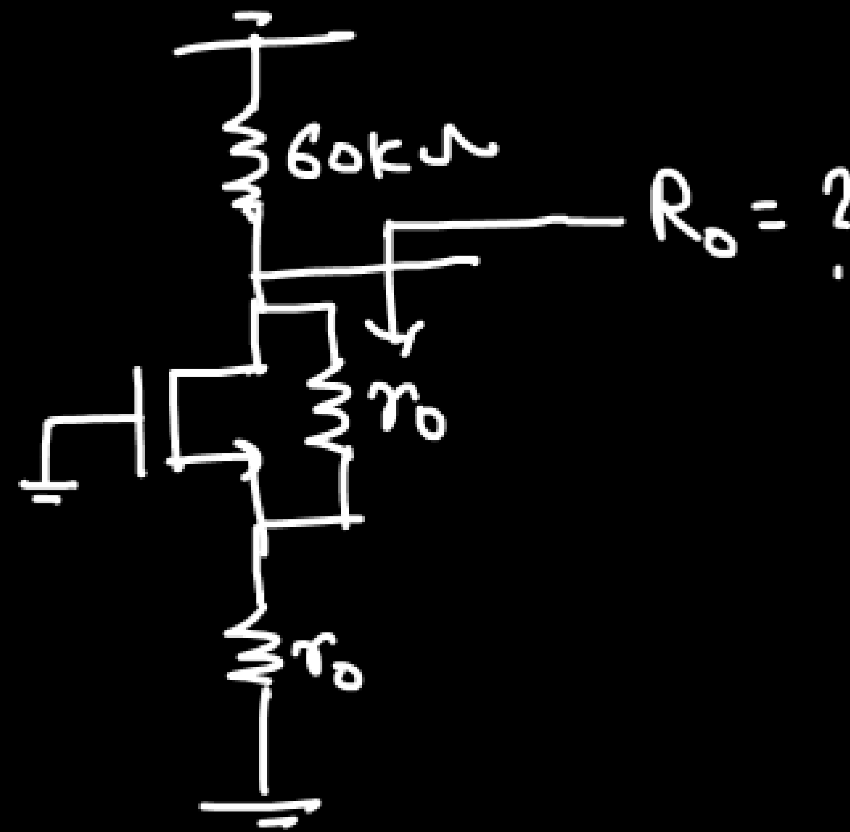
$$v_o = v_x - v_y$$

$$= -8v_i + \frac{2}{3} v_i$$

$$v_o = -7.33 v_i$$

$$\boxed{\frac{v_o}{v_i} = -7.33}$$

$\underline{\underline{R_o :-}}$



$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.05 \times 200\mu}$$

$$\boxed{r_o = 100k\Omega}$$

$$R_o = g_m r_o r_o + r_o + r_o$$

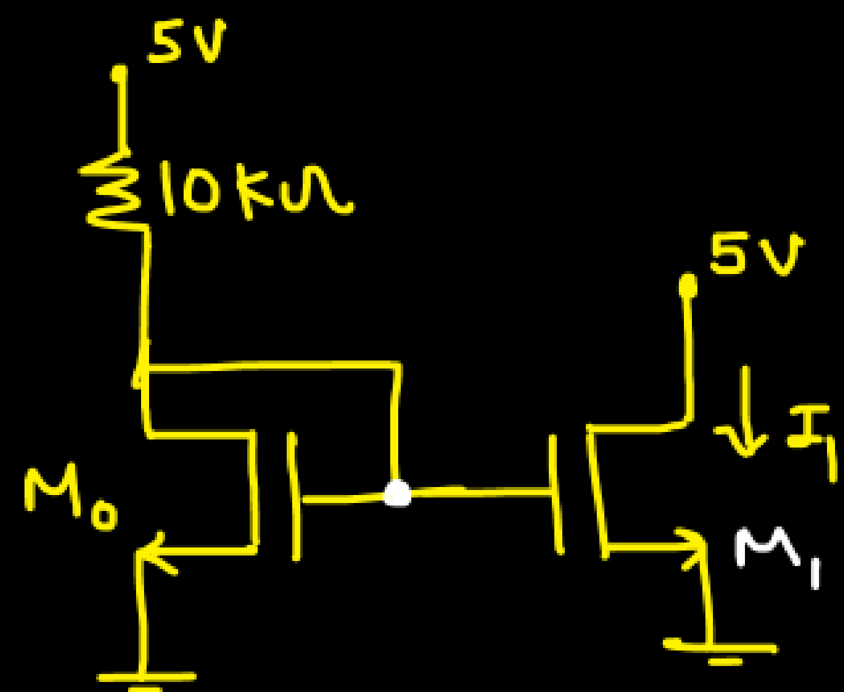
$$= g_m r_o^2 + 2r_o$$

$$= 200\mu \times 10^{10} + 2 \times 10^5$$

$$\boxed{R_o = 2.2 M\Omega}$$

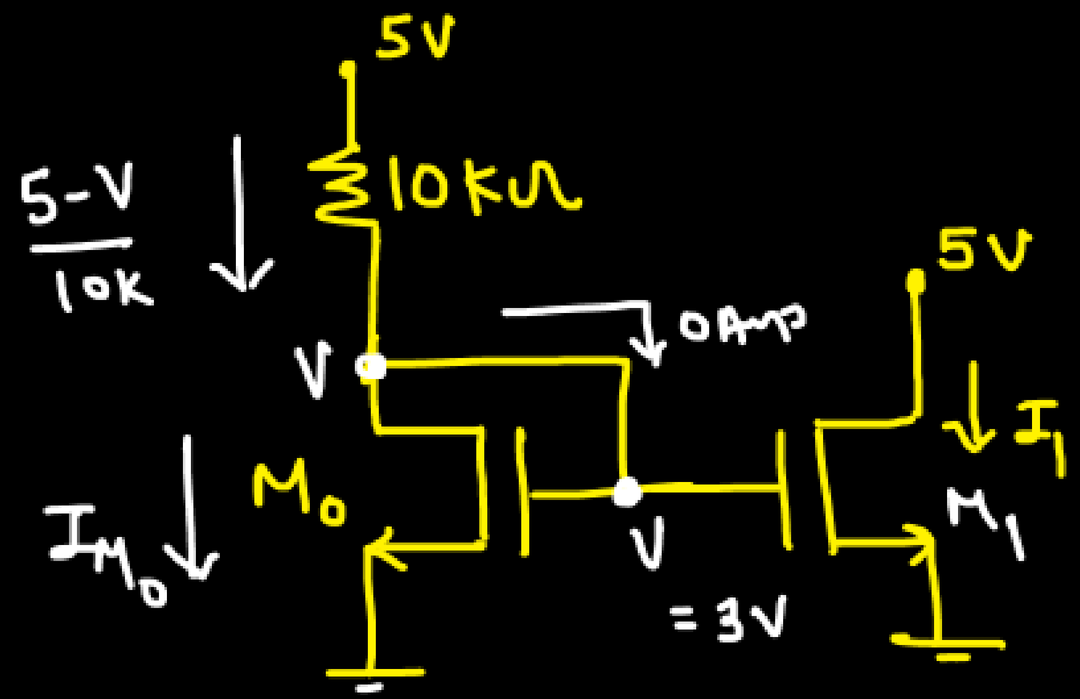
Q. M_0 and M_1 are perfectly Matched.

(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)

$$I_{M_0} = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2$$

$$\frac{5-V}{10k} = \frac{100\mu}{2}(V-1)^2$$

$$5 - V = (V-1)^2/2$$

$$10 - 2V = V^2 + 1 - 2V$$

$$\boxed{V = 3\,\text{Volt}}$$

$$I_{M_0} = \frac{5-3}{10k} = \frac{2}{10K} = 200\,\mu A = I_1$$

$M_1 \rightarrow$

$V_{DS} = 5V$

$V_{GS} = 3V$

$V_{ov} = 2V$

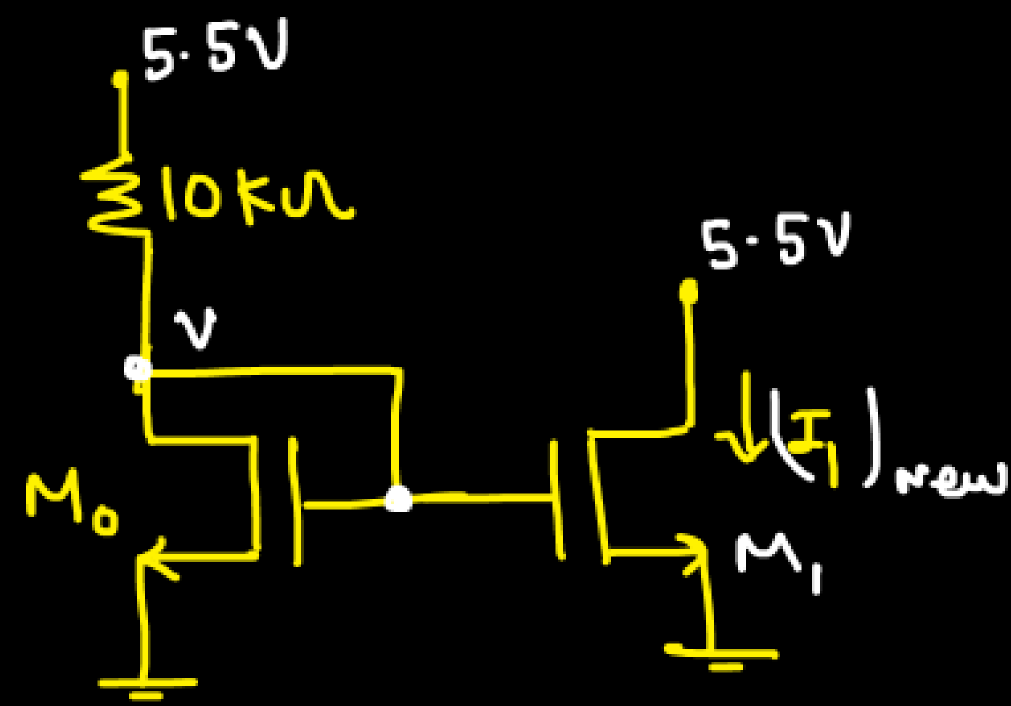
$\Downarrow$

Sat.

$$\boxed{I_1 = 200\,\mu A}$$

Ans

M-I



$$\Rightarrow \frac{5.5-V}{10K} = \frac{100\mu}{2}(V-1)^2$$

$$11-2V = V^2+1-2V$$

$$V^2=10$$

$$V = 3.16 \text{ Volt}$$

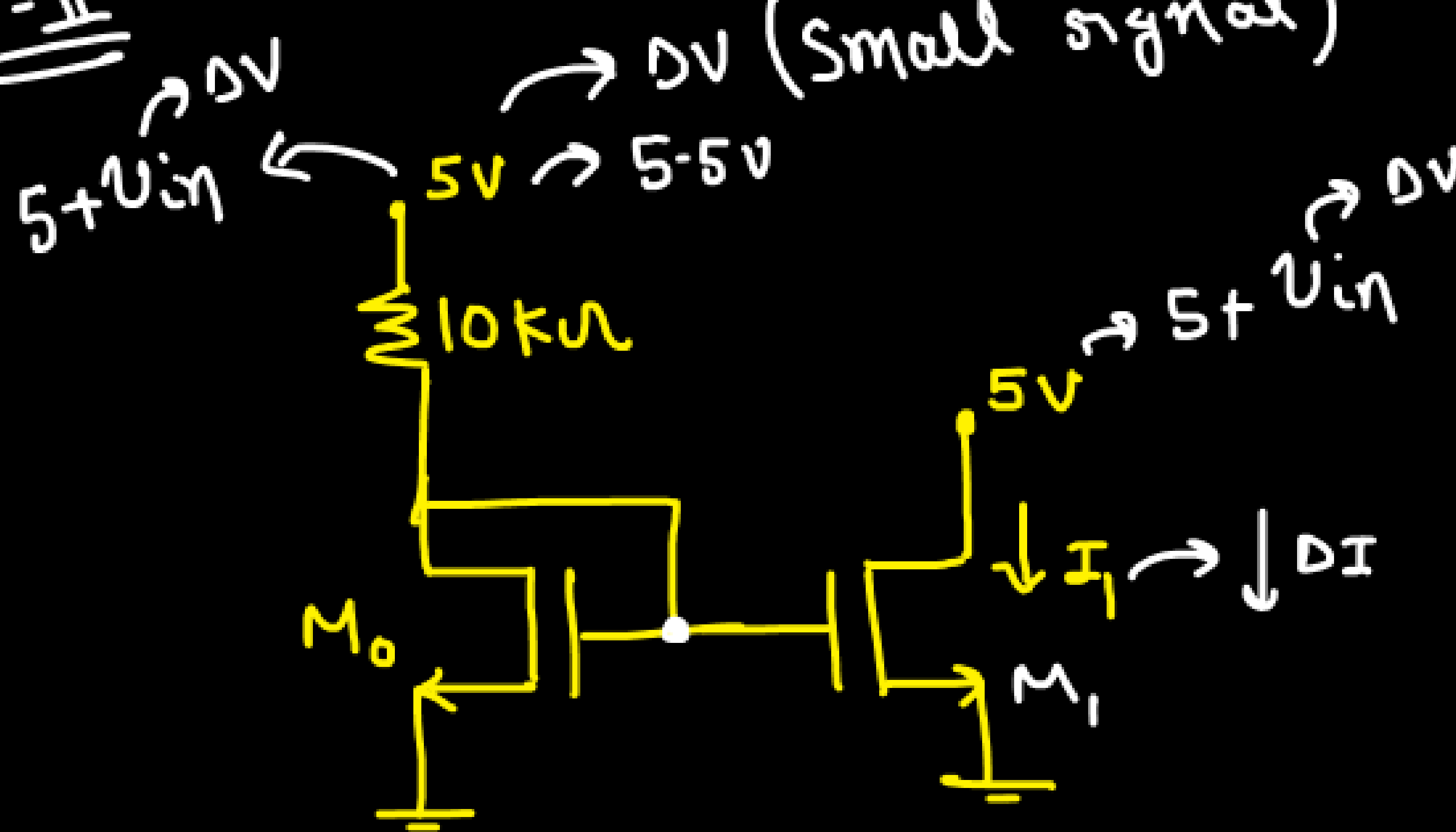
$$(I_{M_0})_{new} = (I_1)_{new} = \frac{5.5-3.16}{10K}$$

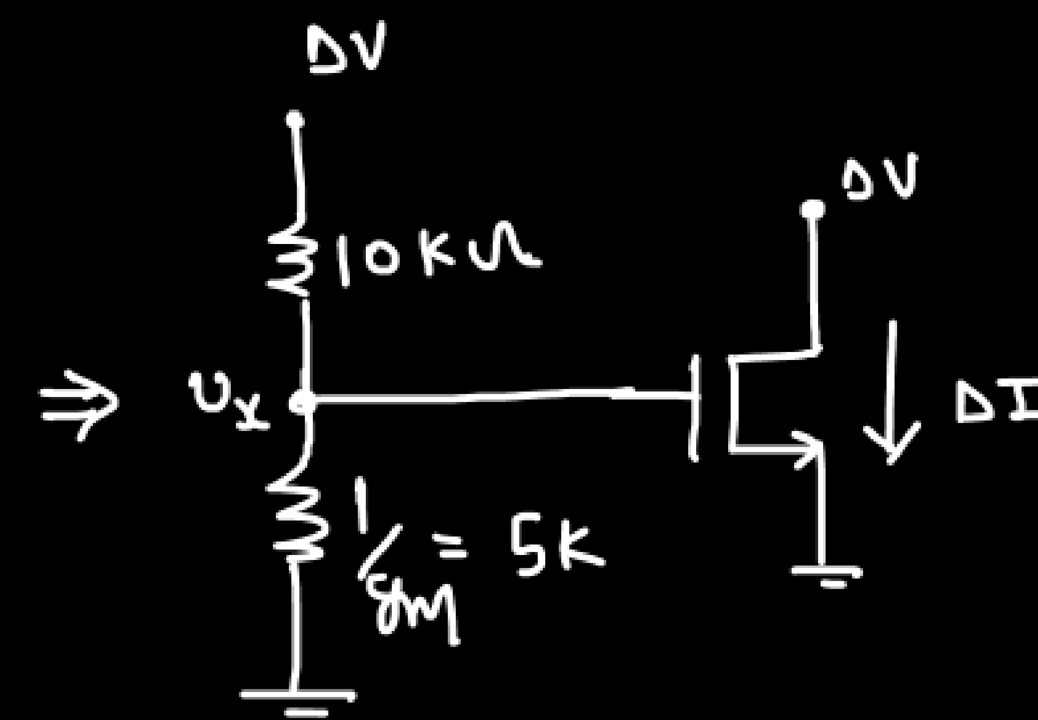
$$\boxed{(I_1)_{new} = 233\,\mu A}$$

★★

$$\boxed{\Delta I = 233\mu - 200\mu = 33\,\mu Amp}$$

M-II





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

$$= \sqrt{2 \times 100\mu \times 200\mu}$$

$$g_m = 200\mu S$$

$$1/g_m = 5k\Omega$$

$$v_x = \frac{5k}{5k+10k} \times \Delta V = \frac{\Delta V}{3}$$

$$\Delta I = g_m v_x = \frac{g_m \Delta V}{3} = \frac{200\mu}{3} \Delta V$$

$$\boxed{\Delta I = \frac{200\mu}{3} \Delta V}$$

Here; $\Delta V = 5.5 - 5 = 0.5V$

$$\Delta I = \frac{200\mu}{3} \times 0.5$$

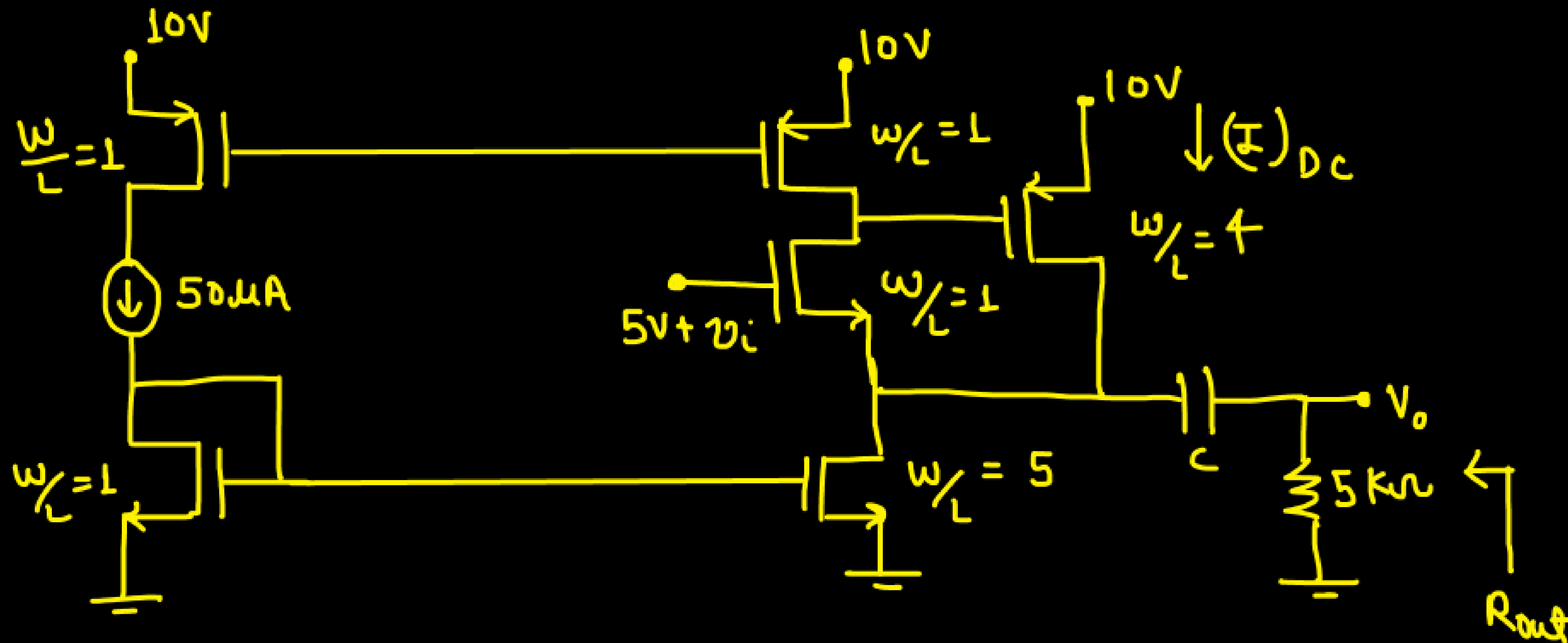
$$\boxed{\Delta I = 33.33\,\mu\text{Amp.}}$$ **

For supply,

(i) $5.1V \Rightarrow \Delta I = \frac{200\mu}{3} \times 0.1 = 6.66\,\mu\text{Amp.}$

(ii) $5.3V \Rightarrow \Delta I = \frac{200\mu}{3} \times 0.3 = 20\,\mu\text{Amp.}$

Q.



$\mu_n C_{ox} = 100\,\mu A/V^2$, $\mu_p C_{ox} = 25\,\mu A/V^2$

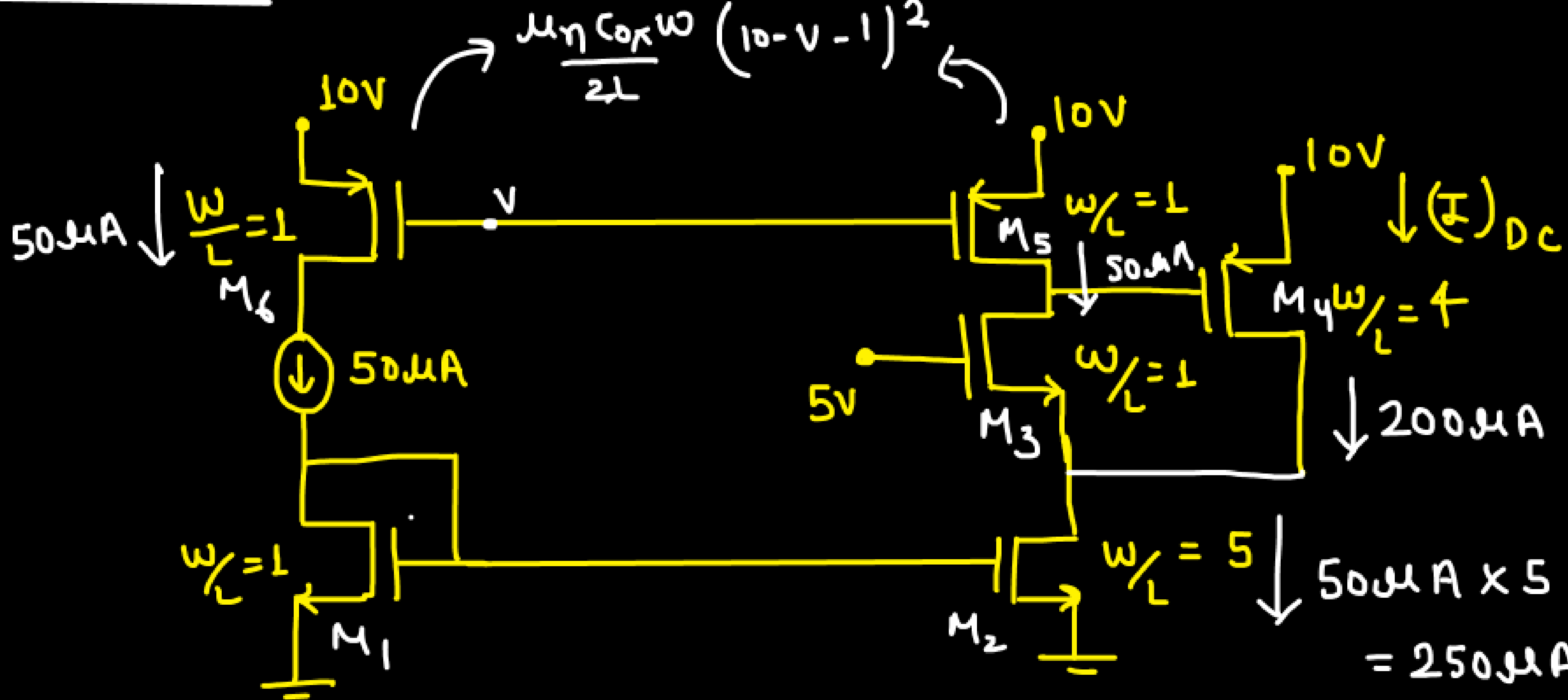
$V_{TH} = 1V$ Given → All Trs are biased in sat.

(a) Determine I_{DC}

(b) Find small signal voltage gain

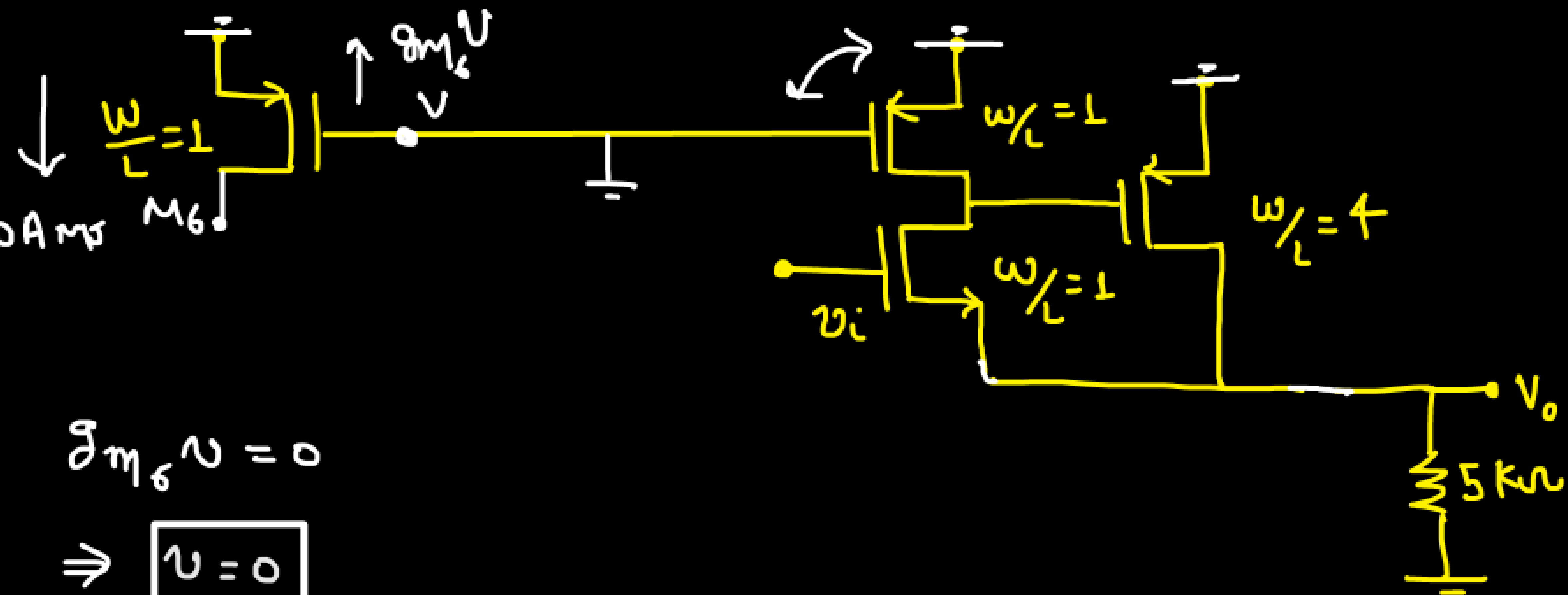
(c) Find small signal R_{out}.

DC Analysis:-



$$\boxed{(I_{DC}) = 200\mu A}$$

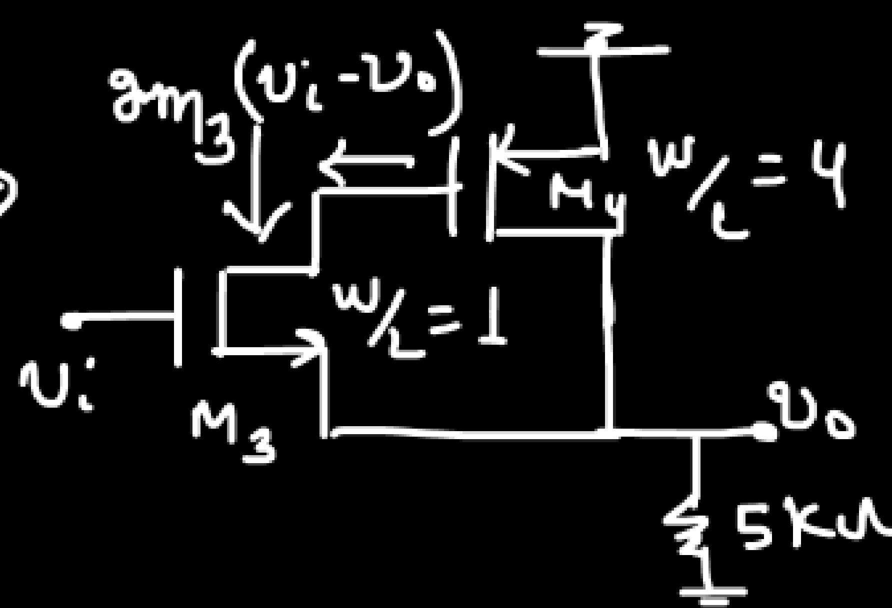
AC Analysis:-



$$g_{m_6} v = 0$$

$$\Rightarrow \boxed{v = 0}$$

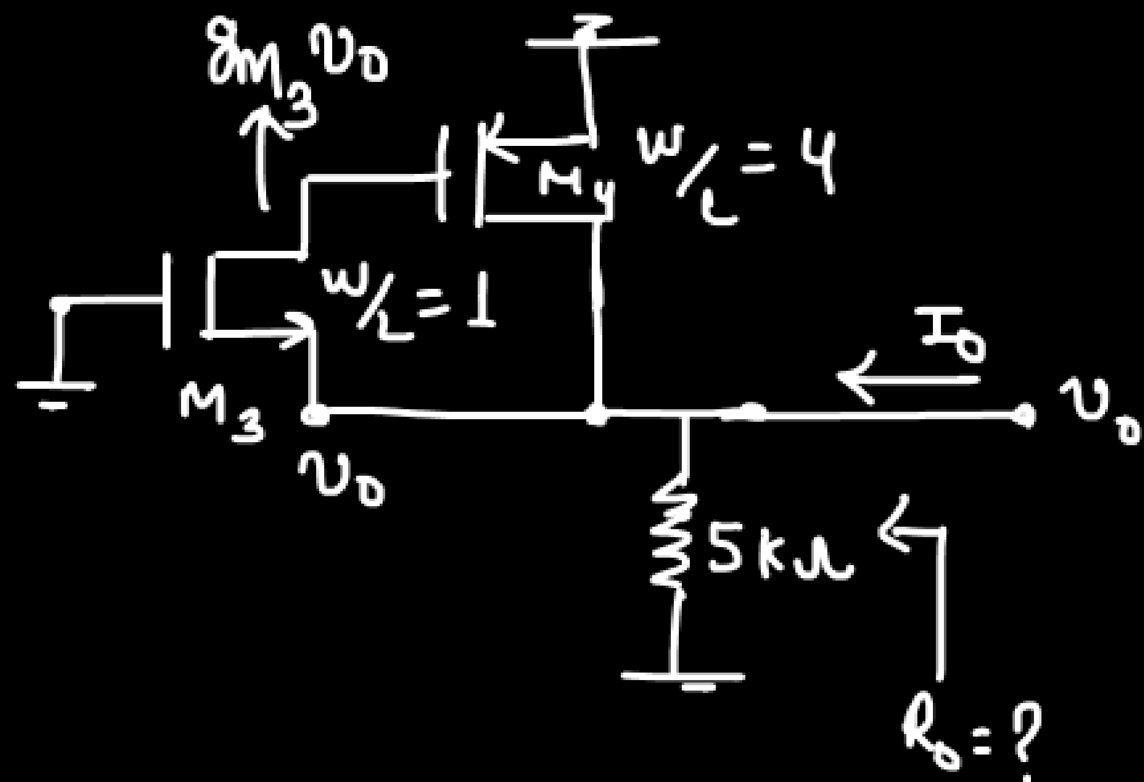
$\Rightarrow$



$$g_{m_3}(v_i - v_o) = 0$$

$$v_o = v_i$$

$$\boxed{\frac{v_o}{v_i} = 1}$$ ANS.



$$\boxed{\frac{v_o}{I_o} = R_o}$$

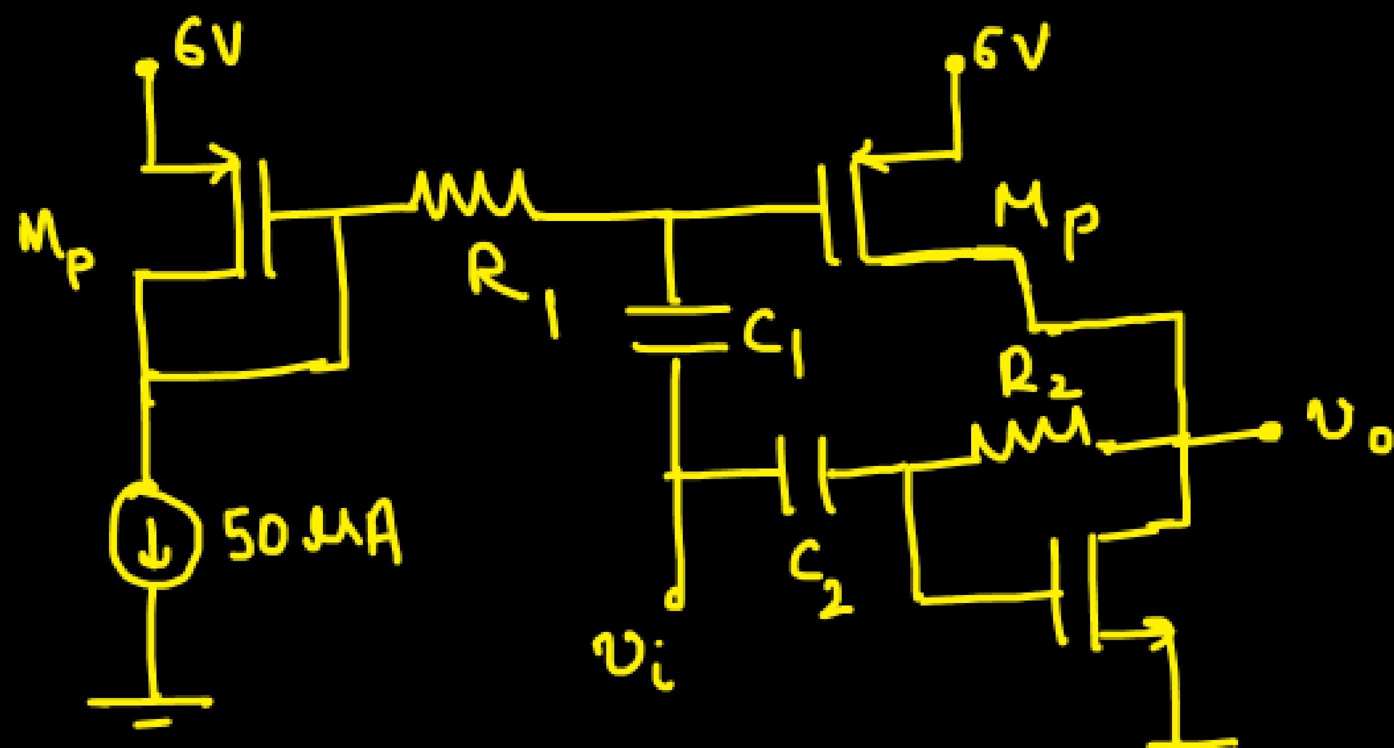
$$g_{m_3} v_o = 0$$

$$v_o = 0$$

$$\boxed{R_o = \frac{0}{I_o} = 0\,\Omega}$$

$5\,k\Omega$

Q.



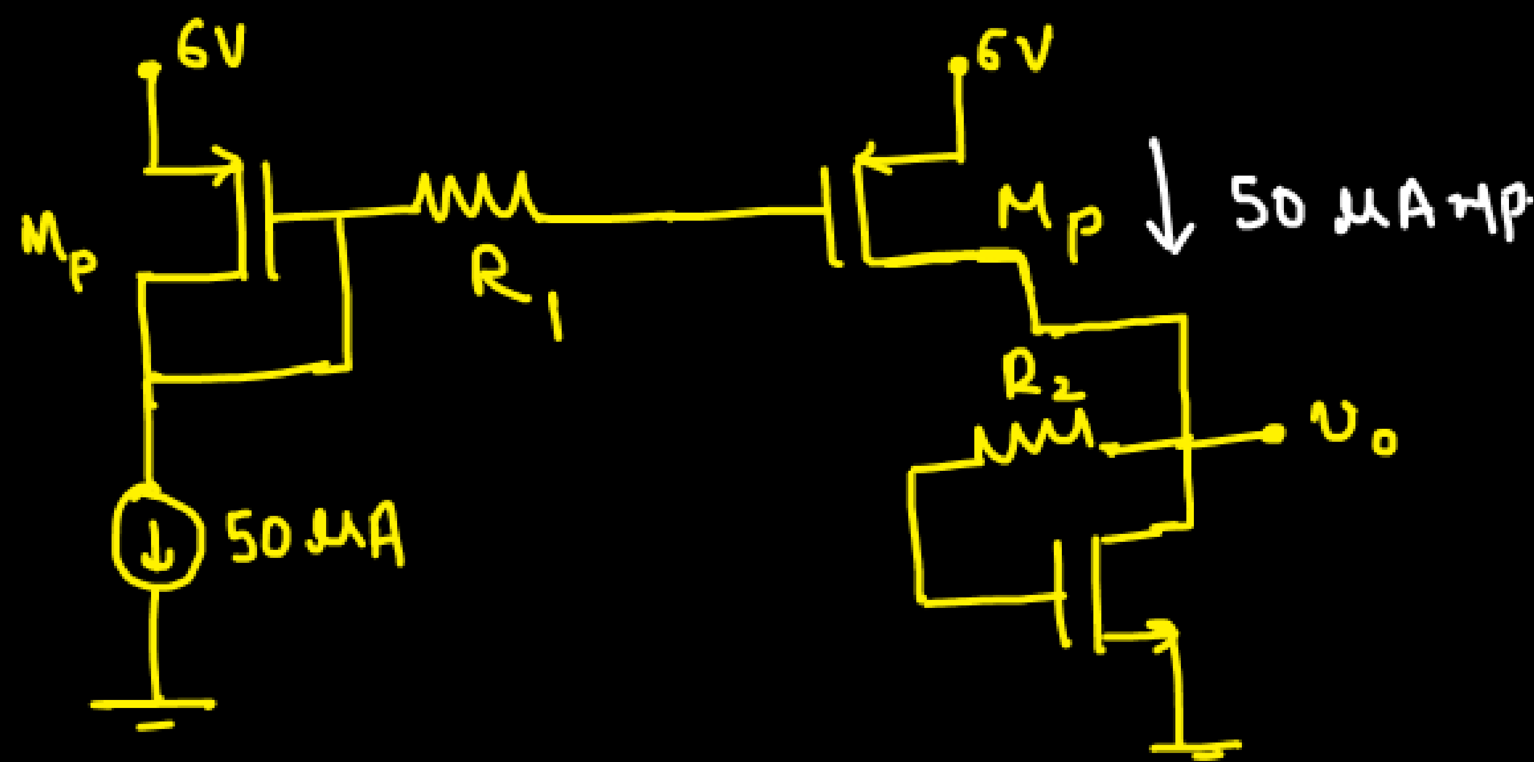
Given → R_1, R_2 values are very large.

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:-



$$g_{m_p} = \sqrt{2 \times \frac{\mu_p C_{ox} W}{L} I_D} = \sqrt{2 \times 400\,\mu \times 50\,\mu} = 200\,\mu S$$

$$g_{m_n} = \sqrt{2 \times \frac{\mu_n C_{ox} W}{L} I_D} = \sqrt{2 \times 400\,\mu \times 50\,\mu} = 200\,\mu S$$

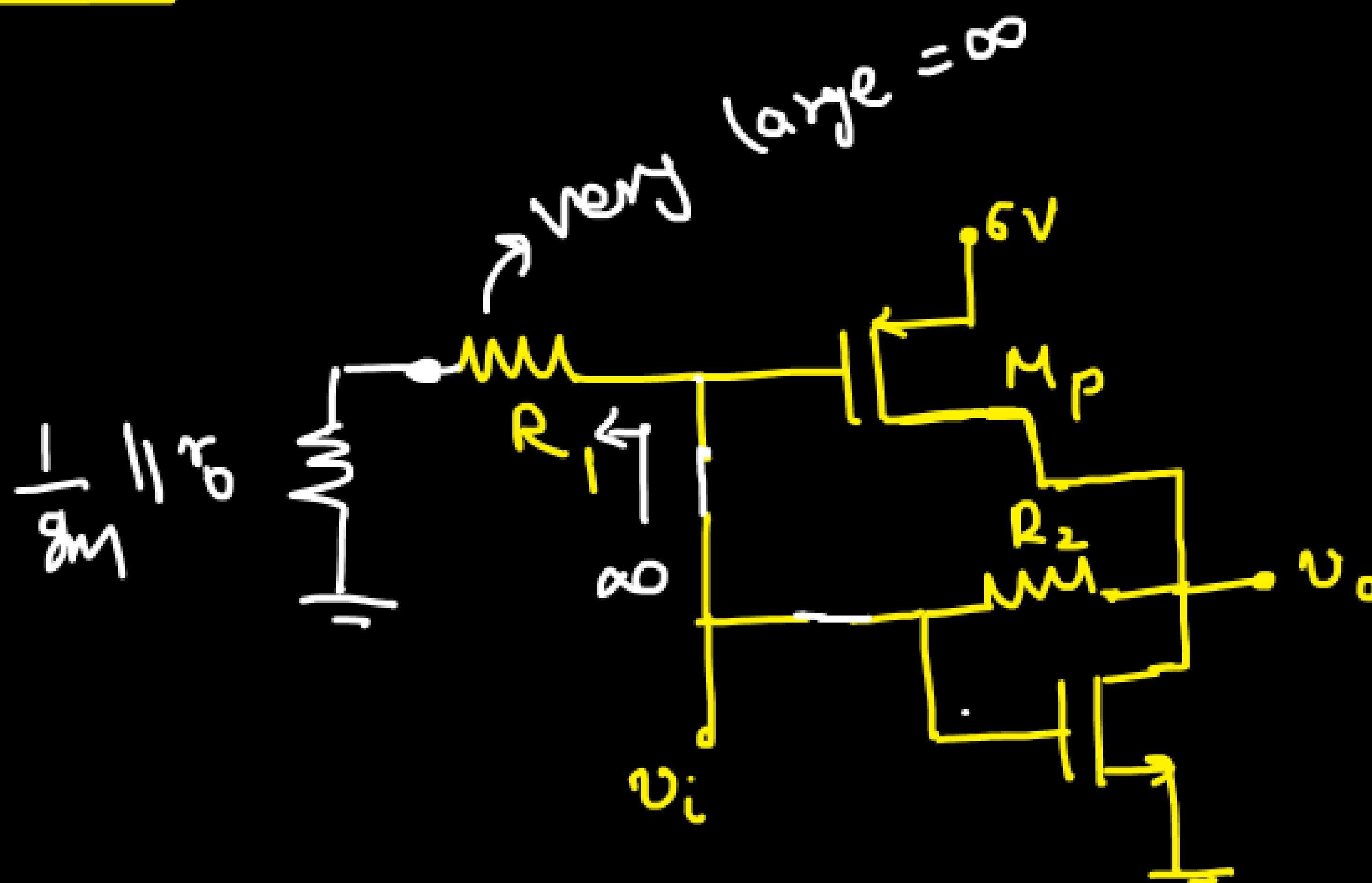
$$\boxed{g_{m_p} = g_{m_n} = g_m = 200\,\mu S}$$

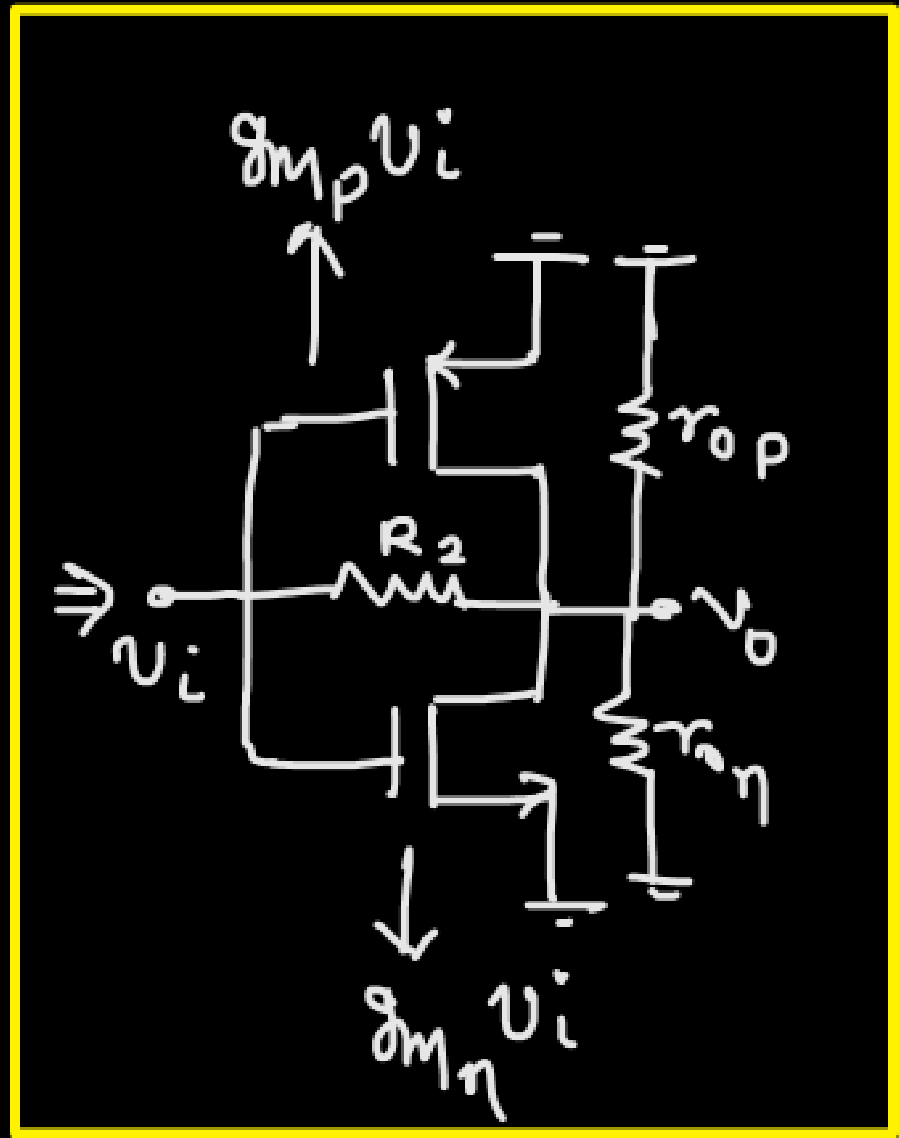
$$r_{op} = \frac{1}{\lambda_p I_D} = \frac{1}{0.05 \times 50\mu} = 400\,k\Omega$$

$$r_{on} = \frac{1}{\lambda_n I_D} = \frac{1}{0.05 \times 50\mu} = 400\,k\Omega$$

$$\boxed{r_{op} = r_{on} = 400\,k\Omega = r_o}$$

AC Analysis:-





$$\frac{v_o}{r_{op}} + \frac{v_o}{r_{on}} + g_{m_p} v_i + g_{m_n} v_i = 0$$

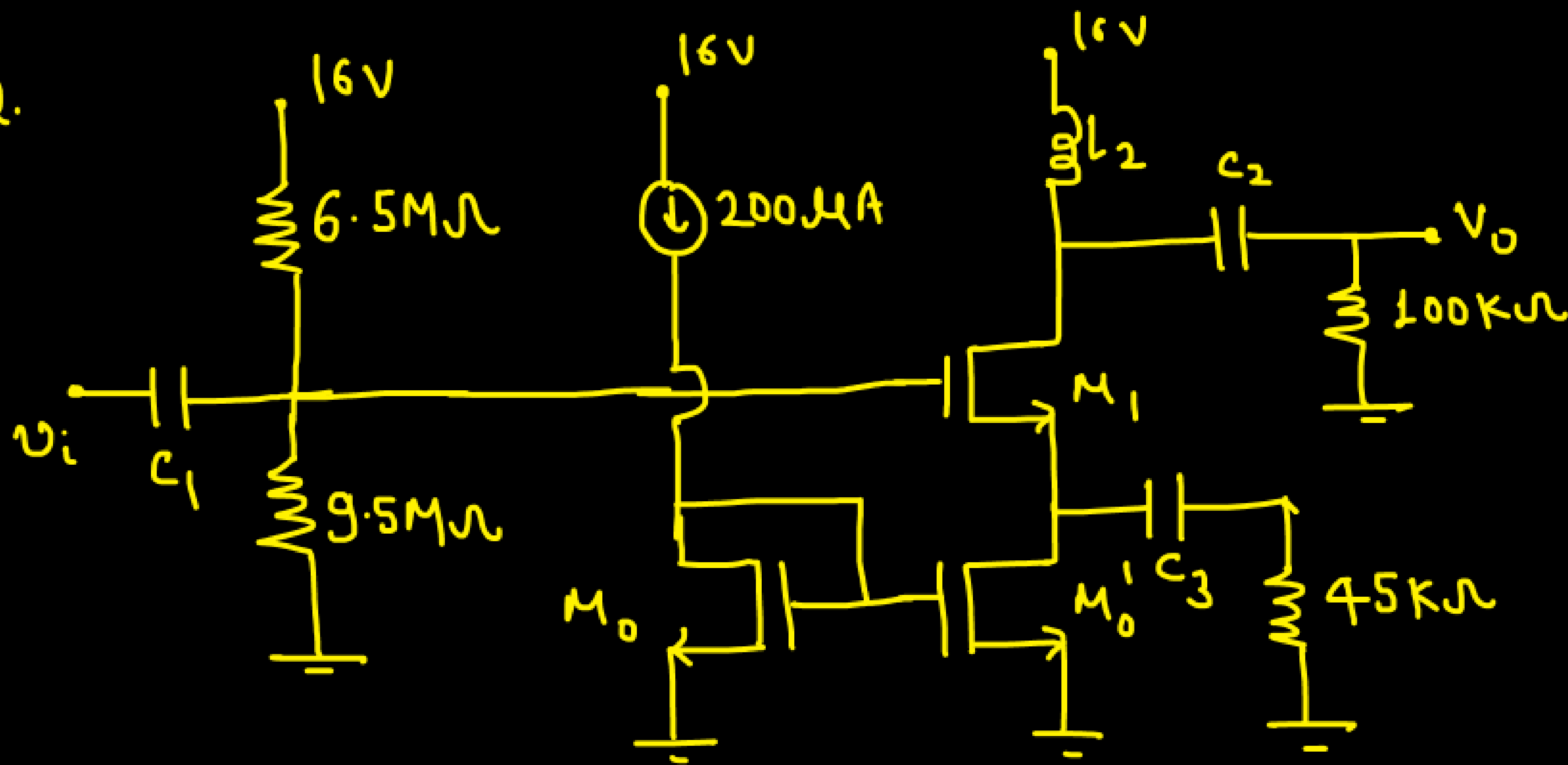
$$\frac{v_o}{r_{op} \| r_{on}} = -(g_{m_p} + g_{m_n}) v_i$$

$$\frac{v_o}{v_i} = -(g_{m_p} + g_{m_n})(r_{op} \| r_{on})$$

$$\Rightarrow \frac{v_o}{v_i} = -400 \times 10^{-6} \times 200 \times 10^{3} = \underline{\underline{-80}}$$

Ans.

Q.



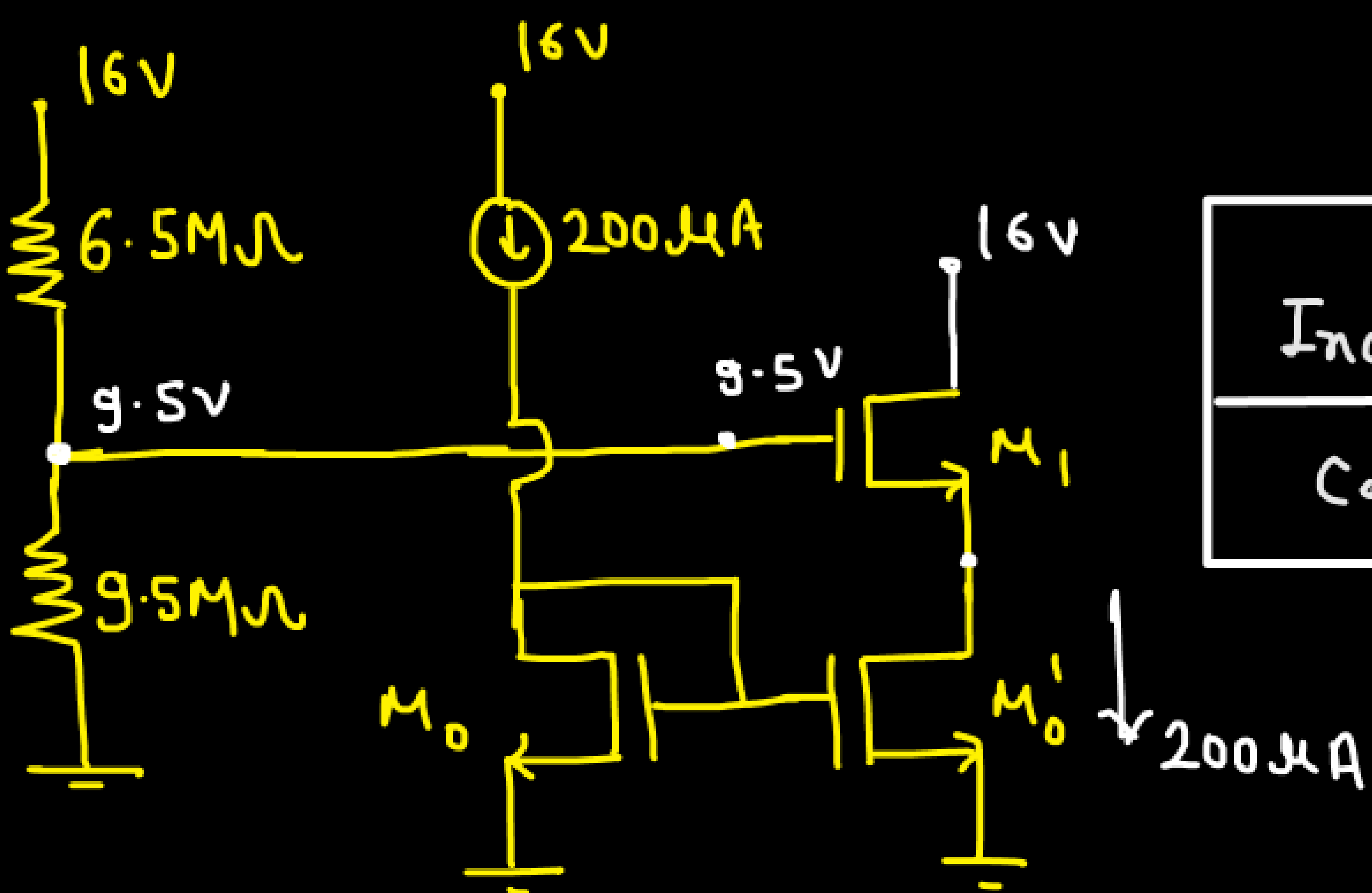
(a) Determine v_i for which M_1 enters into Triode region.

(b) Determine v_i for which M_0' 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.

$$I_{M_0'} = I_{M_1} = 200\mu$$

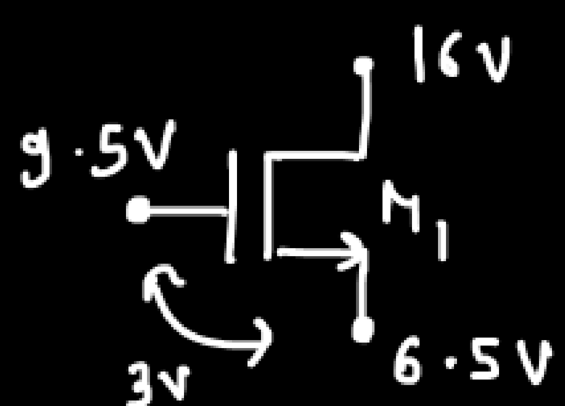
$$200\mu = \frac{100\mu}{2}\left(V_{GS} - 1\right)^2$$

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

For M_0' and M_1 $V_{GS} = 3V$

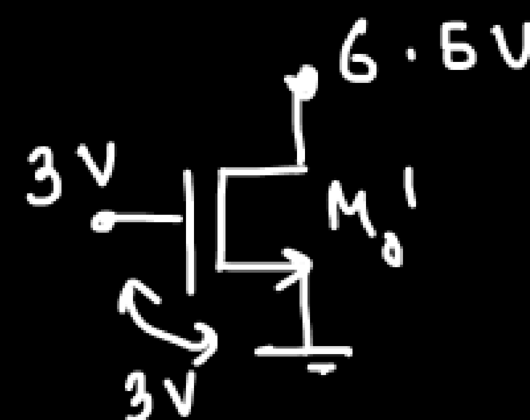
$$g_m = \frac{2I_D}{V_{GS} - V_T} = \frac{2 \times 200\mu}{3-1}$$

$$= 200\mu S$$



$\Downarrow$

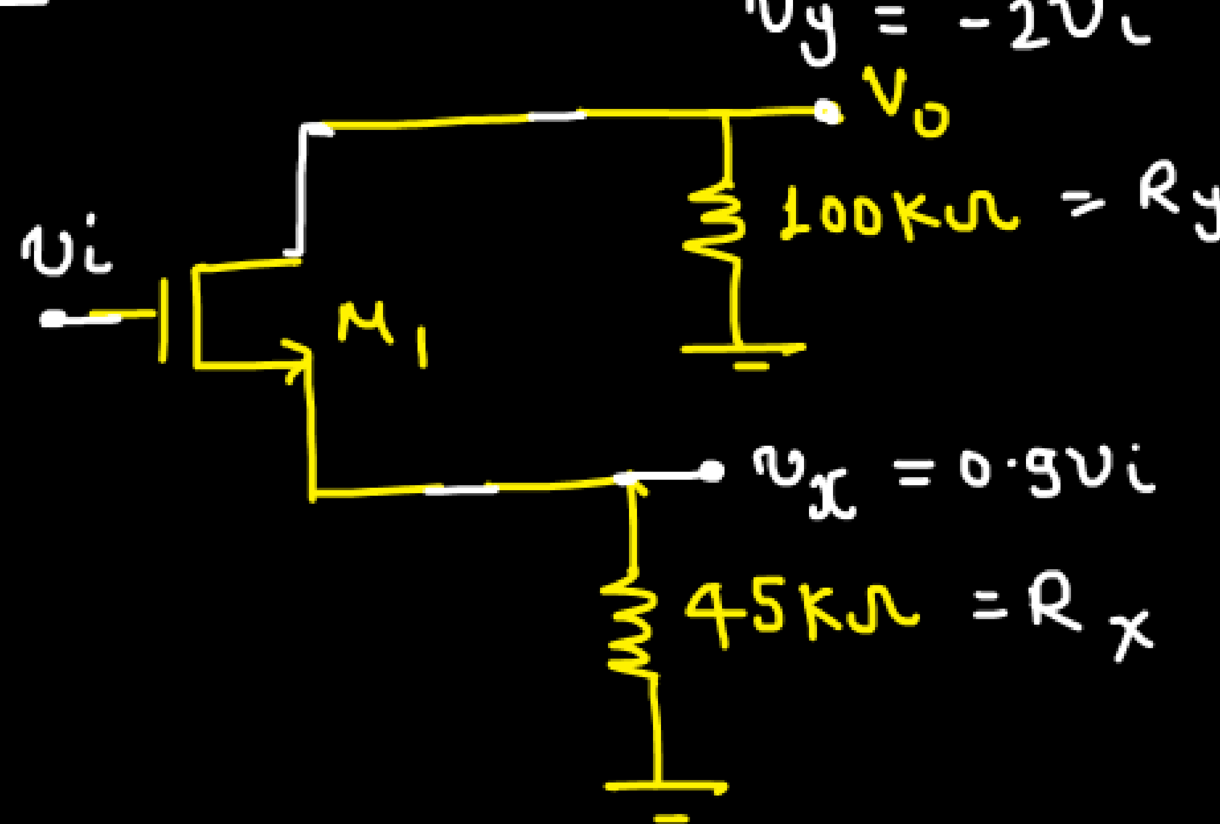
Sat.



$\Downarrow$

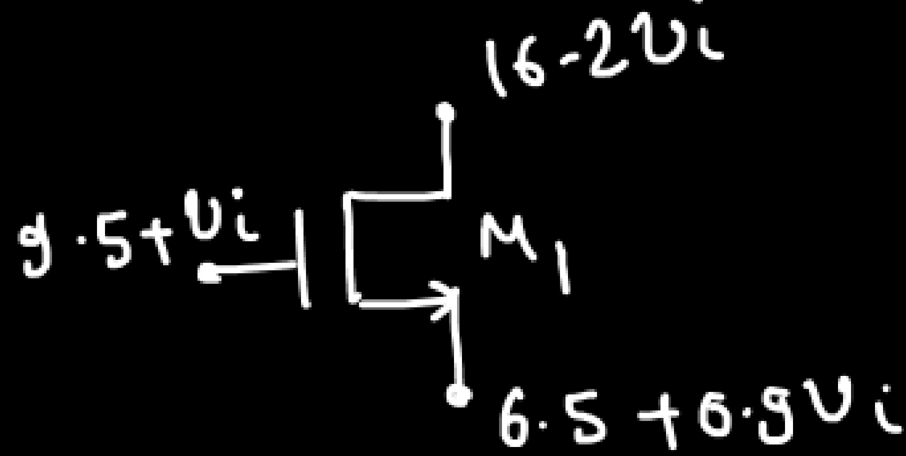
Sat.

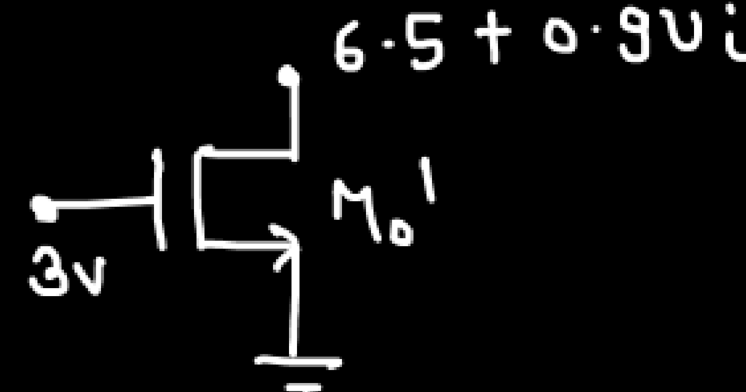
Ac Analysis:-



$$v_x = \frac{R_x}{R_x + 1/g_m} v_i = \frac{g_m R_x}{1 + g_m R_x} v_i = \frac{200\mu \times 45K}{1 + 200\mu \times 45K} v_i = 0.9 v_i$$

$$v_y = \frac{-g_m R_y}{1 + g_m R_x} v_i = \frac{-200\mu \times 100k}{1 + 200\mu \times 45K} v_i = \frac{-20}{10} v_i = -2v_i$$





(a) For M_1 to go into Triode:-

$$V_{DS} \leq V_{GS} - V_T$$

$$V_D - \cancel{V_S} \leq V_G - \cancel{V_S} - V_T$$

$$V_D \leq V_G - V_T$$

$$16 - 2v_i \leq 9.5 + v_i - 1$$

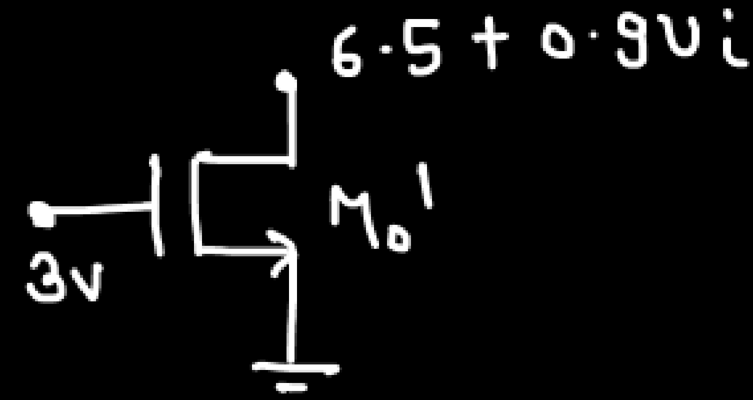
$$16 - 2v_i \leq 8.5 + v_i$$

$$\Rightarrow 7.5 \leq 3v_i$$

$$\boxed{v_i \geq 2.5V}$$

@ $v_i = 2.5V \Rightarrow$ Tr goes into triode.

(c) For M_0'



For cut off:-

$$v_{DS} \le 0$$

$$6.5 + 0.9v_i \le 0$$

$$0.9v_i \le -6.5$$

$$\boxed{v_i \le -7.28V}$$

For Triode,

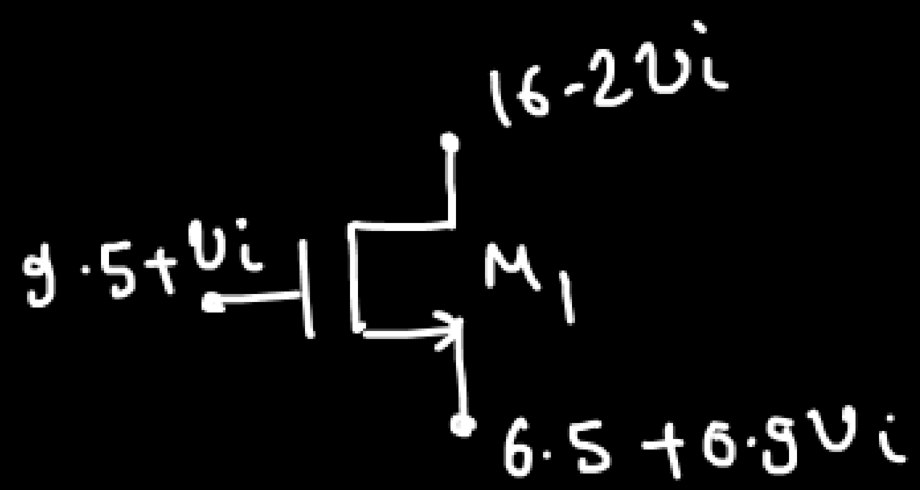
$$6.5 + 0.9v_i \le 3-1$$

$$6.5 + 0.9v_i \le 2$$

$$0.9v_i \le -4.5$$

$$\boxed{v_i \le -5}$$

@ $v_i = -5V \Rightarrow$ Tr M_0' goes into Triode region



for cut off M_1

(1) $V_{DS} \leq 0$

$$16-2v_i-6.5-0.9v_i \leq 0$$

$$9.5-2.9v_i \leq 0$$

$$2.9v_i \geq 9.5$$

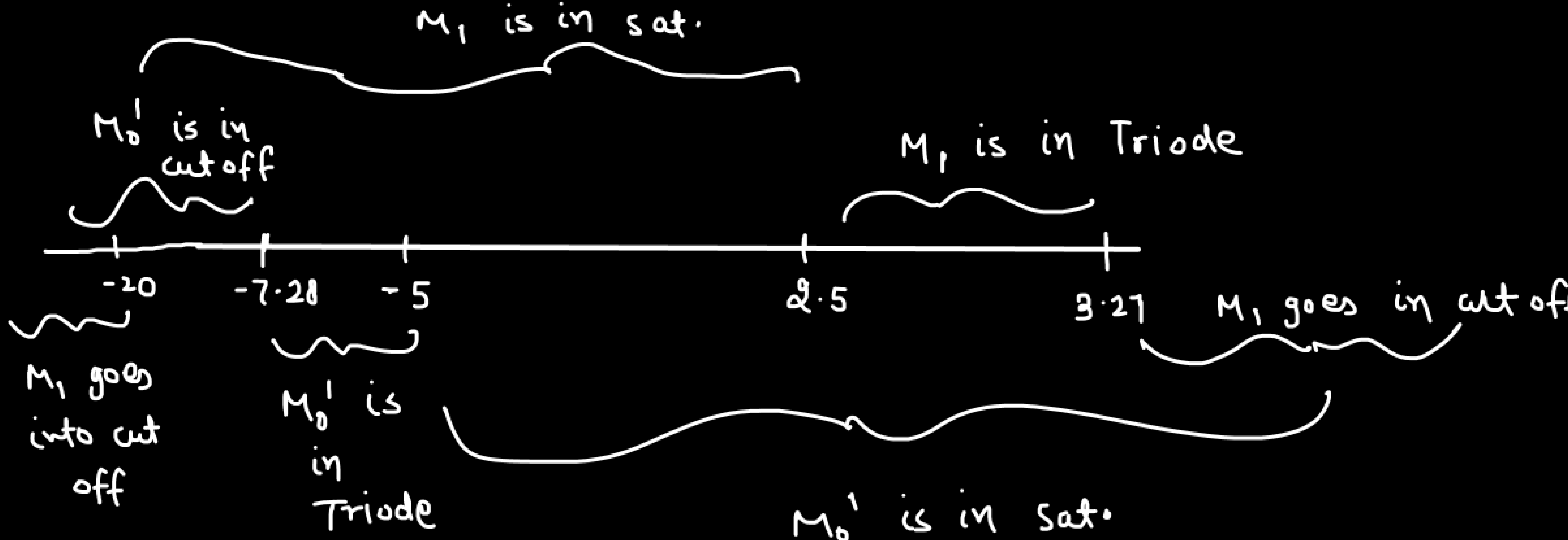
$$v_i \geq 3.27\,V$$

(2) $V_{GS} \leq V_T$

$$9.5+v_i-6.5-0.9v_i \leq 1$$

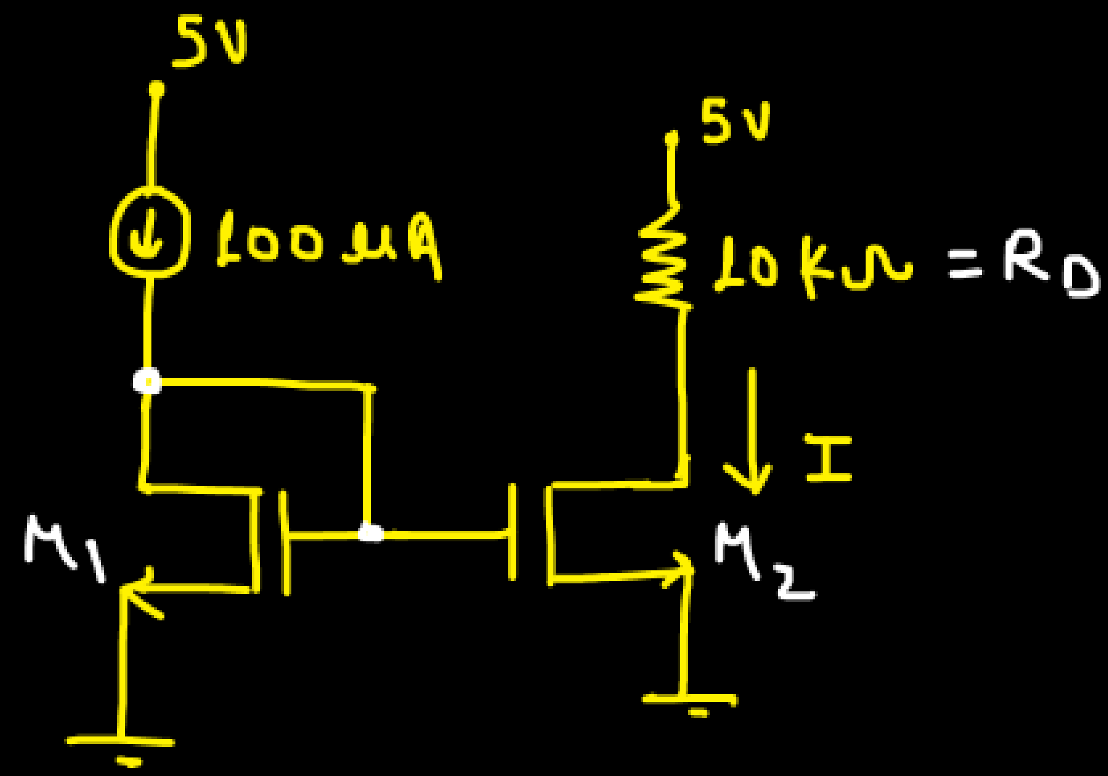
$$3+0.1v_i \leq 1$$

$$v_i \leq -20\,V$$



M_1 is in sat.
M_0' is in cutoff
M_1 is in Triode
-20
-7.28
-5
2.5
3.27
M_1 goes in cutoff
M_1 goes into cut off
M_0' is in Triode
M_0' 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

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

$$\lambda \neq 0$$

$$I_{M_1} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS_1})$$

$$I_{M_2} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS_2})$$

{let M_2 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 $V_{GS} = V_{DS} = 3$

$\lambda V_{DS} = 0.01 \times 3 = 0.03 << \underline{\underline{1}} \Rightarrow$ 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}]

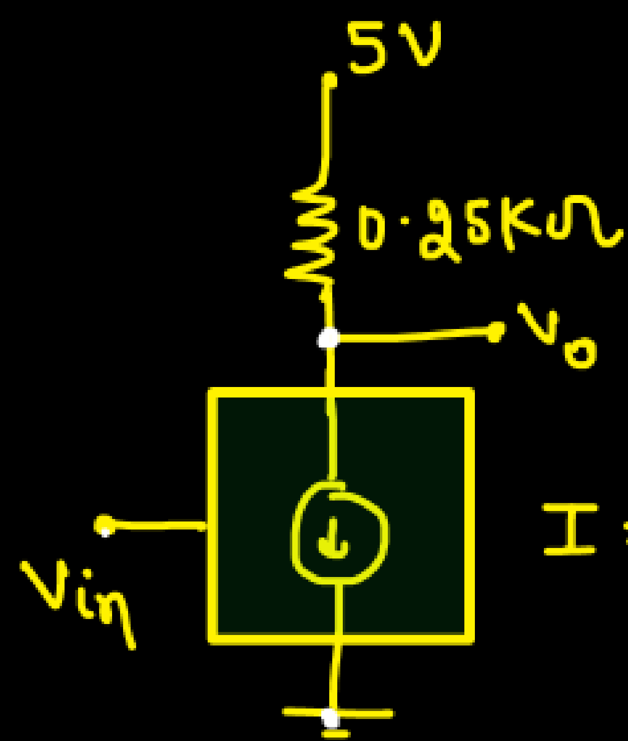
if $R_D = 10\,k\Omega \Rightarrow I_{M_2} > 100\,\mu Amp.$

$[V_{DS_2} > V_{DS_1}]$

if $R_D = 25\,k\Omega \Rightarrow I_{M_2} < 100\,\mu Amp.$

$[V_{DS_2} < V_{DS_1}]$

Q.



$I = [V_{in}^2 + 2V_{in} + 1][1 + 0.05V_0]$ mA

Yellow-box is a three terminal element. $V_{in-Q} = 1V$

Find small signal voltage gain $\frac{v_{in}}{v_0} = ?$ (Approx)

(a) -0.95

(b) -19.5

(c) -49.5

(d) -99.5

→ For MOS:-

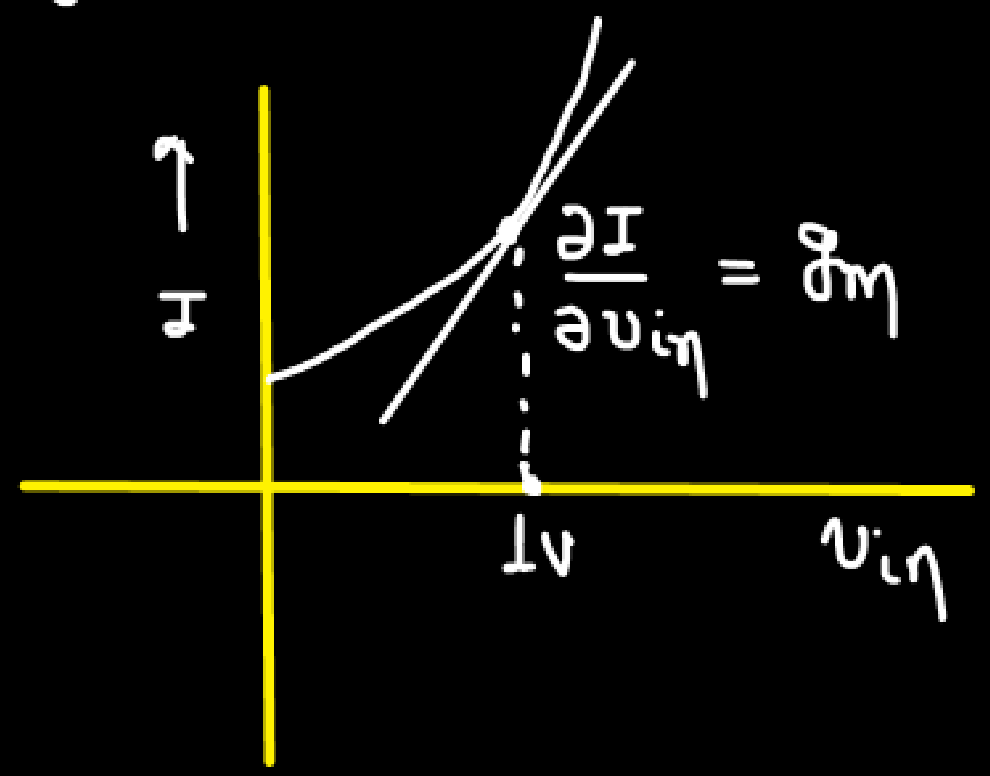
$$I_D = k_n [V_{GS} - V_T]^2 [1 + \lambda V_{DS}]$$

For given problem,

$$I = [V_{in}^2 + 2V_{in} + 1][1 + 0.05 V_0] \text{ mA}$$

$$g_m = \frac{\partial I}{\partial V_{in}} = 2V_{in} + 2 \text{ mA} \quad \left\{ \text{Assuming } 1 + 0.05 V_0 <<< 1 \right\}$$

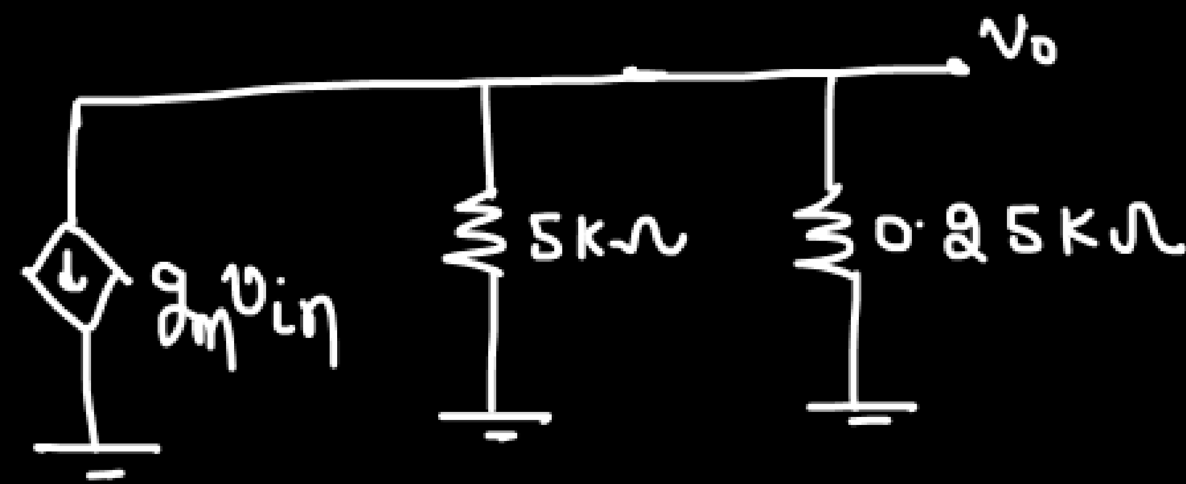
$$\boxed{(g_m)_{V_{in} = 1V} = 4 \text{ mS}}$$



$$r_0 = \frac{1}{\frac{\partial I}{\partial V_0}} = \frac{10^3}{(V_{in}^2 + 2V_{in} + 1)(0.05)}$$

$$\boxed{(r_o)_{v_{in\text{-}Q}=1} = \frac{10^3}{4\times 0.05} = 5\,K\Omega}$$

Small signal current



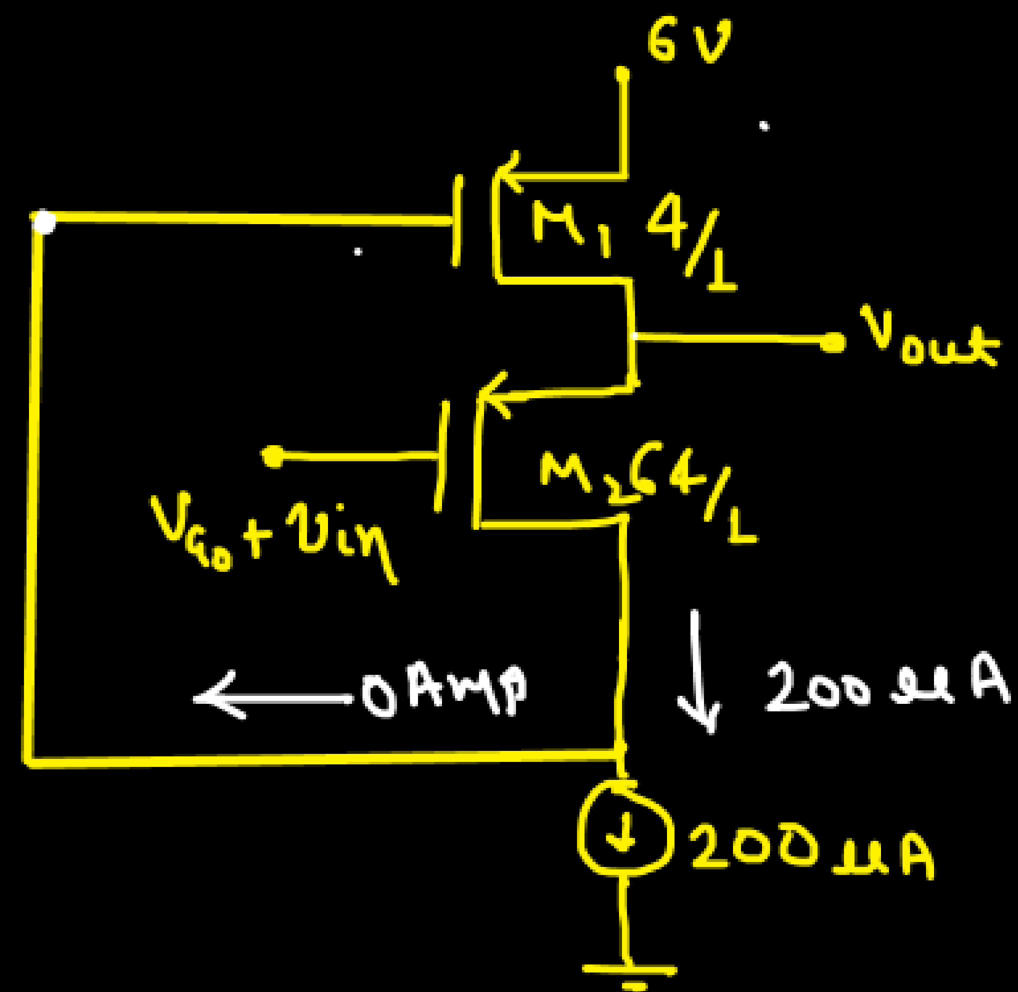
$$v_o = -g_m\,(5K \,||\, 0.25K)\,v_{in}$$

$$= -4m \times 0.238K \times v_{in}$$

$$\boxed{\frac{v_o}{v_{in}} = -0.95\, V/V}$$

Ans.

Q.



$\mu_p C_{ox} = 25\ \mu A/V^2$

$V_T = 1V$

$v_{in} = V_p \cos(\omega t)$

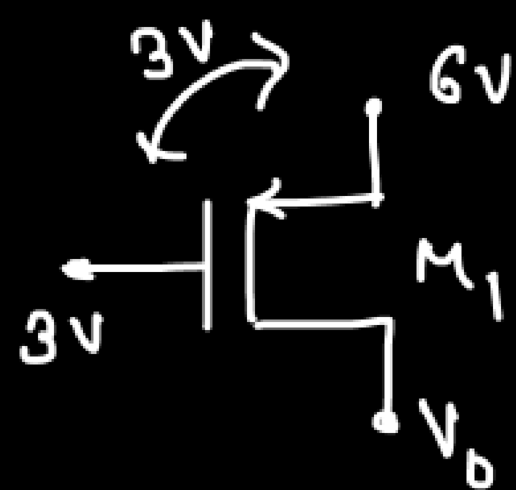
V_{G0} is set such that it maximizes V_p that can be applied while keeping all the Tr. in sat. region.

(a) Find optimum value of V_{G0} (b) Find max value of V_p.

$I_{M_1} = 200\mu A$

$$\Rightarrow 200\mu = \frac{25\mu \times 4}{2}\left(V_{SG_{M_1}} - 1\right)^2$$

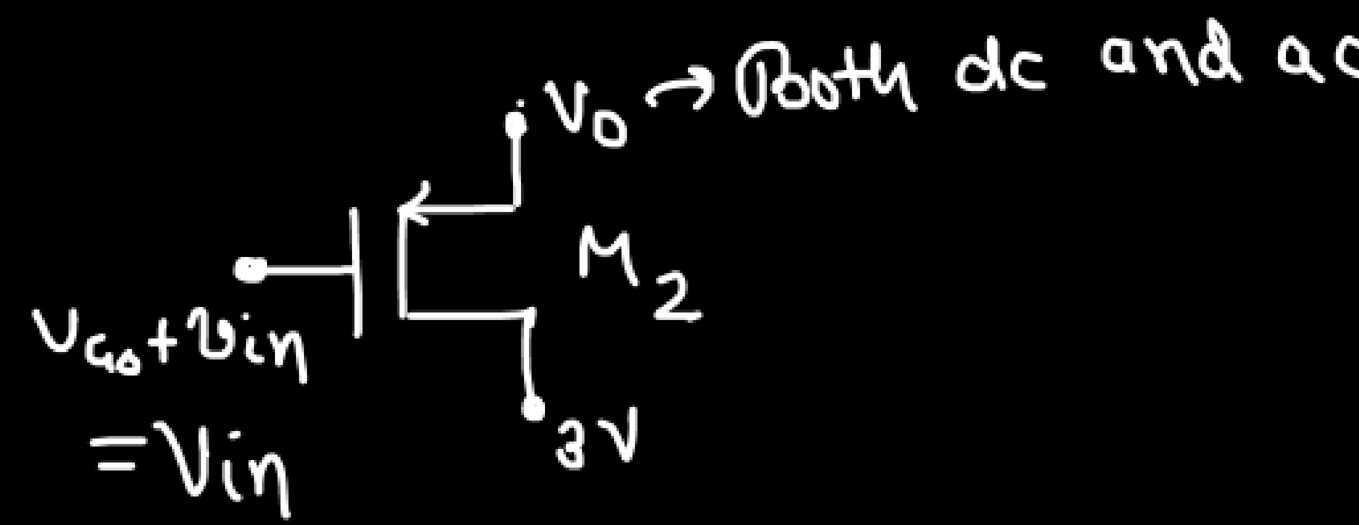
$$\boxed{V_{SG_{M_1}} = 3V}$$



$I_{M_2} = 200\mu A$

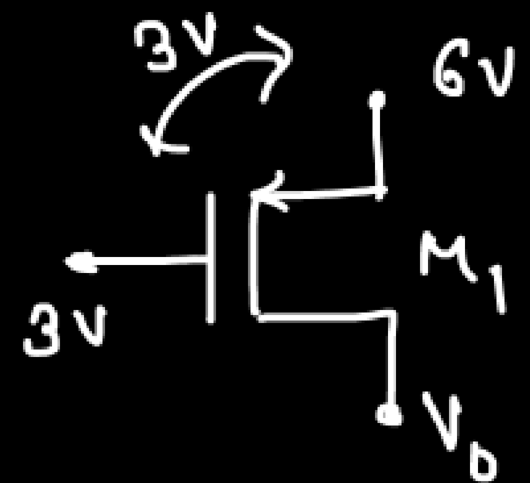
$$\Rightarrow 200\mu = \frac{25\mu \times 64}{2}\left(V_{SG_{M_2}} - 1\right)^2$$

$$\boxed{V_{SG_{M_2}} = 1.5V}$$



$$V_0 - V_{in} = 1.5$$

$$\boxed{V_0 = 1.5 + V_{in}}$$



For sat.

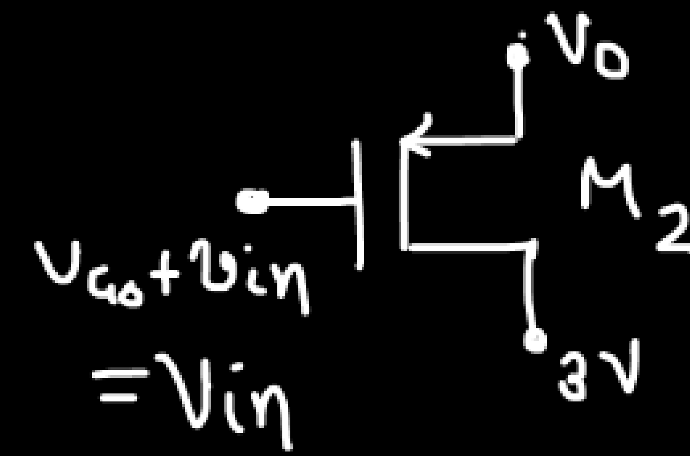
$$6 - V_0 \geq 6 - 3 - 1$$

$$6 - V_0 \geq 2$$

$$V_0 \leq 4$$

$$1.5 + V_{in} \leq 4$$

$$\boxed{V_{in} \leq 2.5V}$$



$$V_0 - 3 \geq V_0 - V_{in} - 1$$

$$-3 \geq -V_{in} - 1$$

$$\boxed{V_{in} \geq 2}$$

2·3   0·2

$$V_{in} = V_{G0} + v_{in}$$

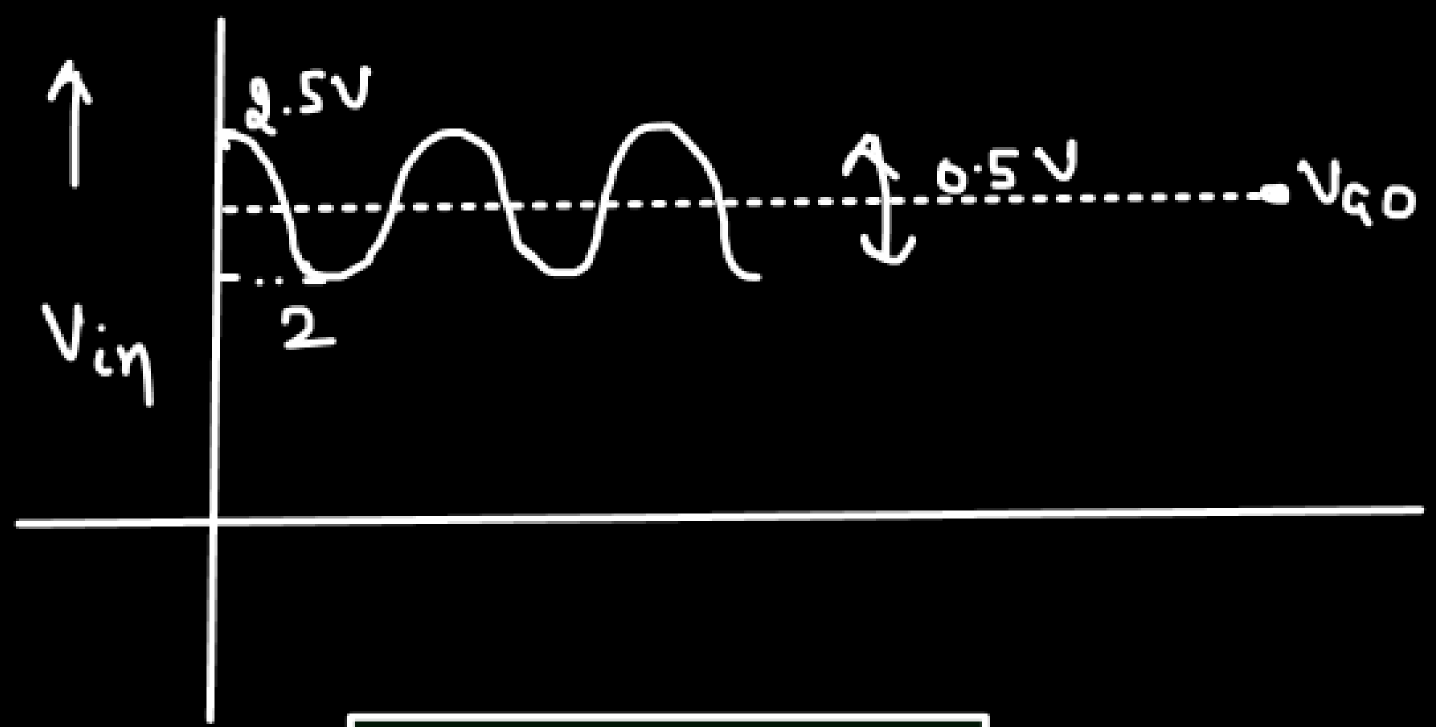
$$= V_{G0} + V_p \cos\omega t$$

$$(V_{in})_{max} = V_{G0} + V_p \quad , \quad (V_{in})_{min} = V_{G0} - V_p$$

$V_{GO} - V_p = 2$

$V_{GO} + V_p = 2.5$

$\boxed{V_{GO} = 2.25\,V}$ Ans , $\boxed{V_p = 0.25\,V}$ Ans.

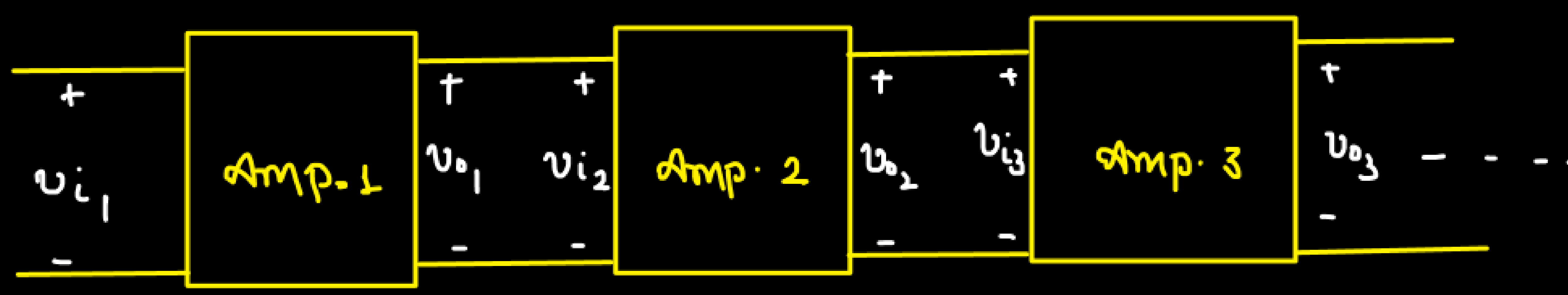


$$\boxed{\begin{array}{c} 2 < V_{GO} < 2.5 \\ \downarrow \qquad\qquad \downarrow \\ 0.5 > V_p > 0 \end{array}}$$

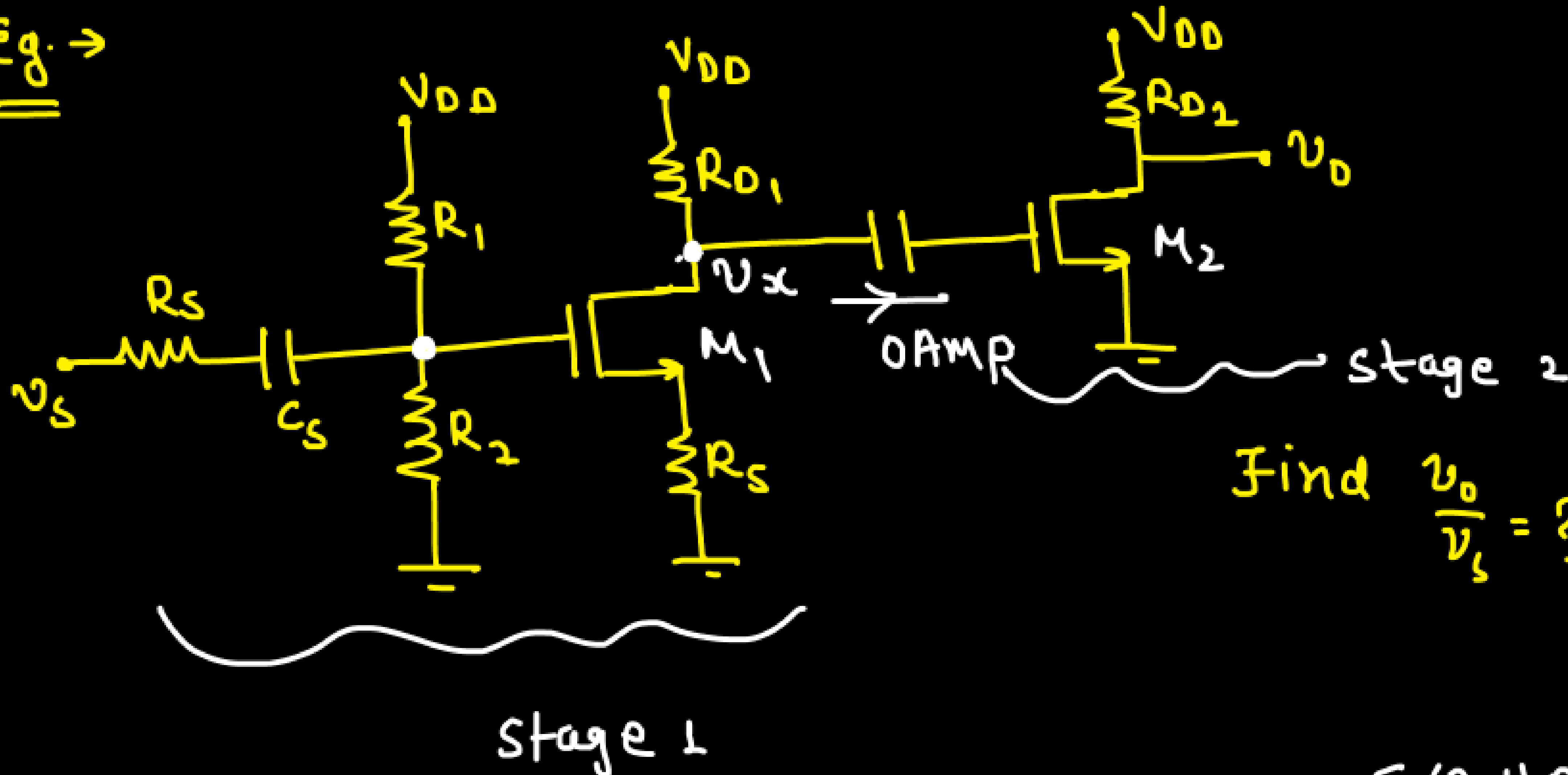
⇒ Some Miscellaneous Topics :-

★ 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 $\dfrac{v_o}{v_s} = ?$

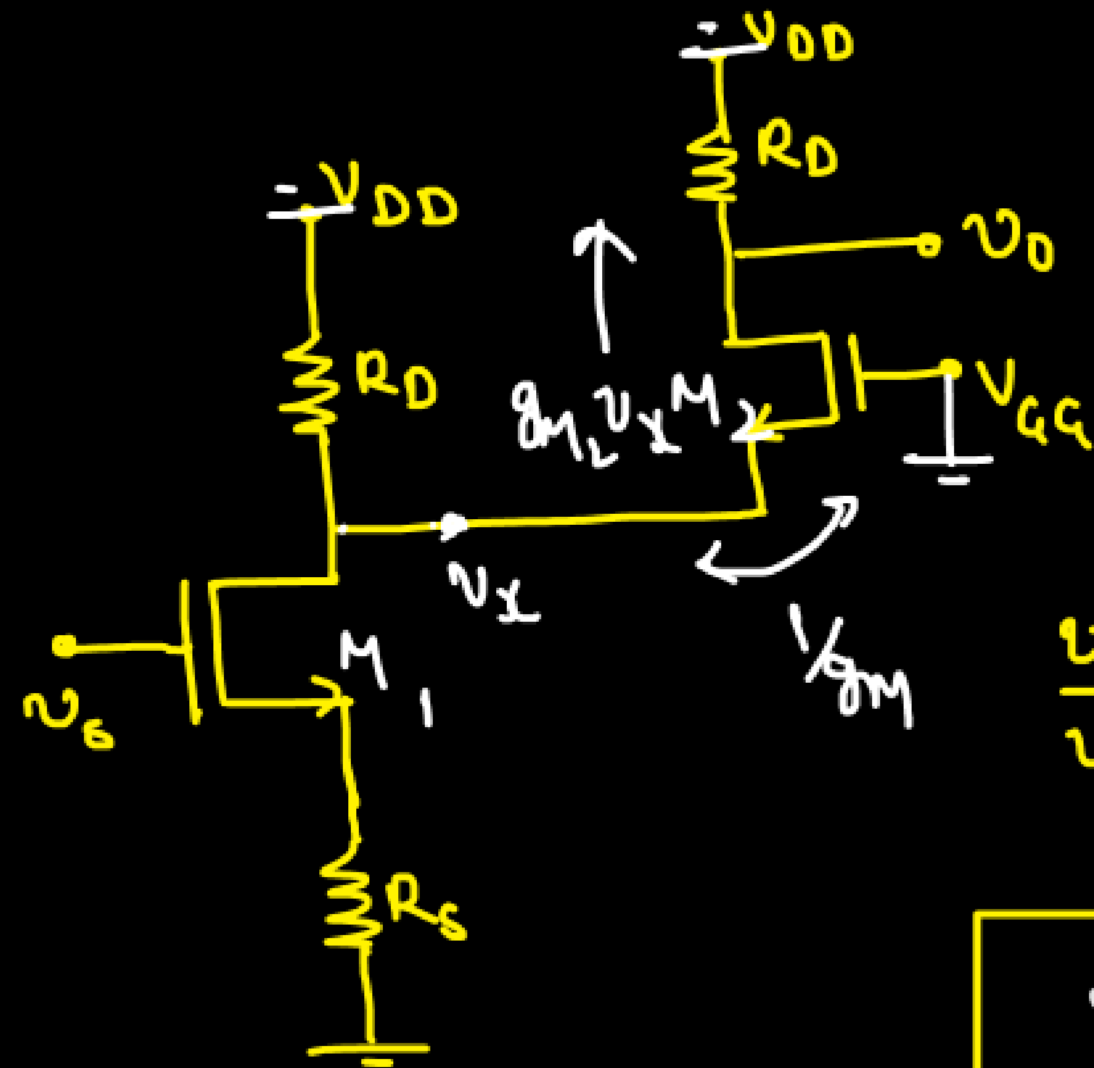
$$\frac{v_x}{v_s} = \frac{-g_{m_1} R_{D_1}}{1+g_{m_1} R_S}\left[\frac{(R_1 \| R_2)}{(R_1 \| R_2) + R_S}\right] \quad \text{— (1)}$$

$$\frac{v_o}{v_x} = -g_{m_2} R_{D_2} \quad \text{— (2)}$$

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]

$$\boxed{\frac{v_x}{v_s} = \frac{-g_m R_D}{1 + g_m R_S}}$$ X

$$\frac{v_x}{v_s} = \frac{-g_{m_1}\left[R_D \| \frac{1}{g_{m_2}}\right]}{1 + g_{m_1} R_S} \longrightarrow ①$$

$$\frac{v_x}{v_0} = ?$$

$$v_0 = g_{m_2} v_x R_D$$

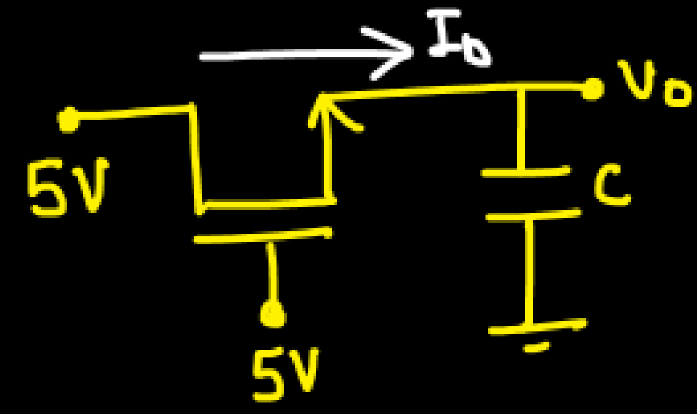
$$\frac{v_0}{v_x} = g_{m_2} R_D \quad \text{—} \quad (2)$$

$$\boxed{\frac{v_0}{v_s} = -g_{m_2} R_D \times \frac{g_{m_1}\left[R_D \,\|\, \frac{1}{g_{m_2}}\right]}{1 + g_{m_1} R_S}}$$

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

$\Downarrow$

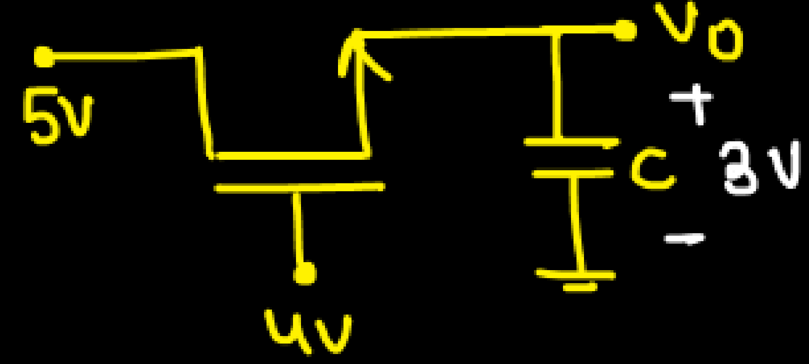
① $V_{GS} \geq V_T$ $\Rightarrow$ $5 - V_0 \geq 1$ $\Rightarrow$ $\boxed{V_0 \leq 4}$

② $V_{DS} \geq 0$ $\Rightarrow$ $5 - V_0 \geq 0$ $\Rightarrow$ $\boxed{V_0 \leq 5}$

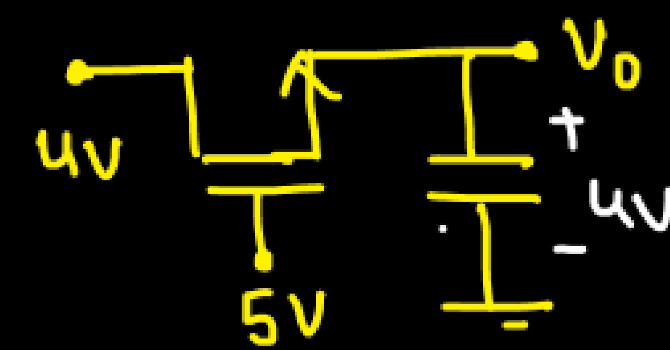
$\Rightarrow$ $\boxed{V_0 \leq 4V}$

$\Downarrow$

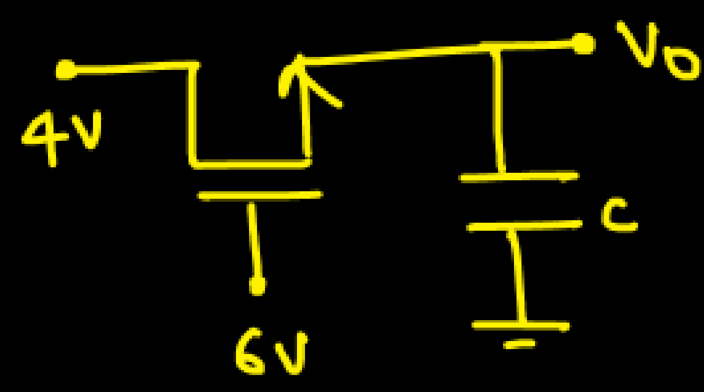
$$\boxed{(V_0)_{s.s.} = 4V}$$



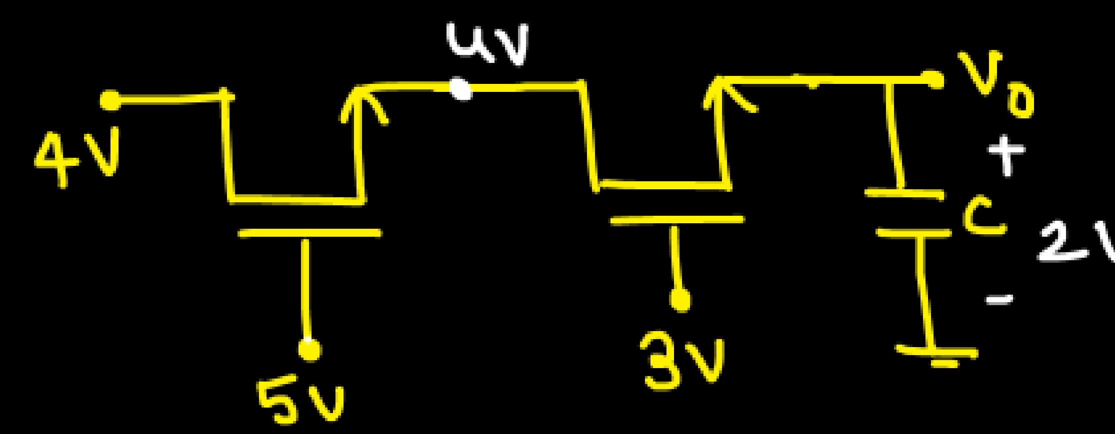
(b)



(c)



(D)



(E)

$V_{GS} \geq V_T$ — 1

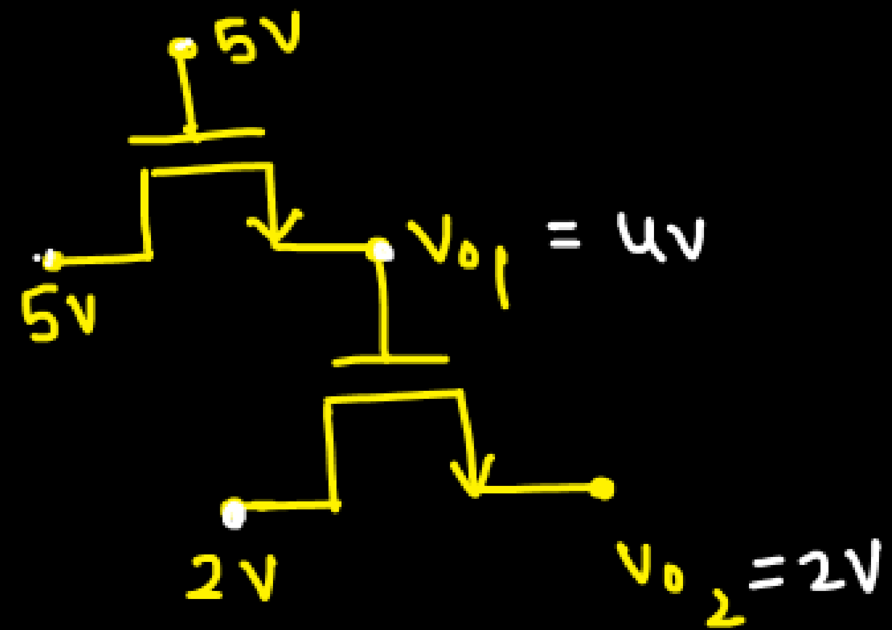
$6 - V_0 \geq 1$

$\boxed{V_0 \leq 5V}$

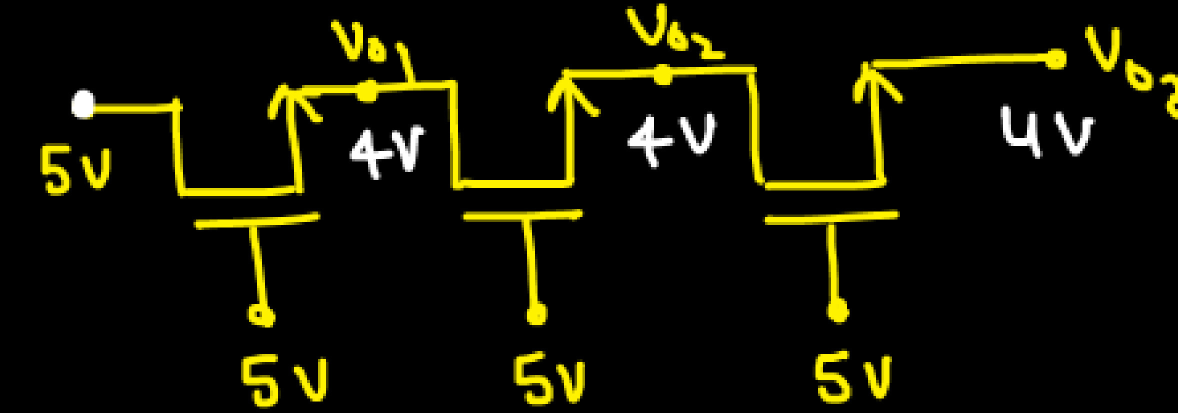
$V_{DS} \geq 0$ — 2 $\Rightarrow \boxed{V_0 = 4V}$

$4 - V_0 \geq 0$

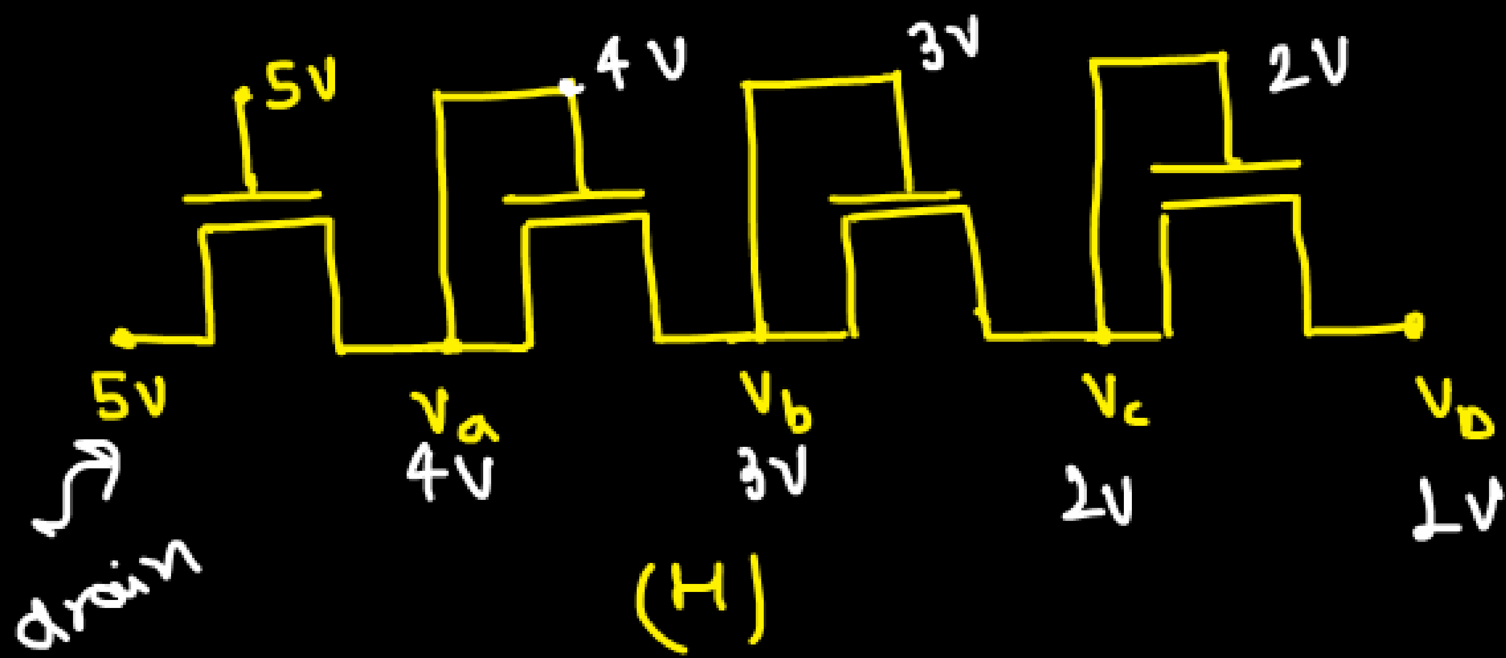
$\boxed{V_0 \leq 4V}$



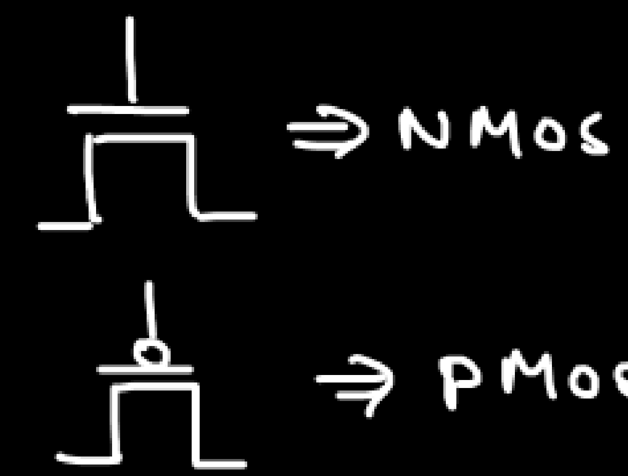
(F)



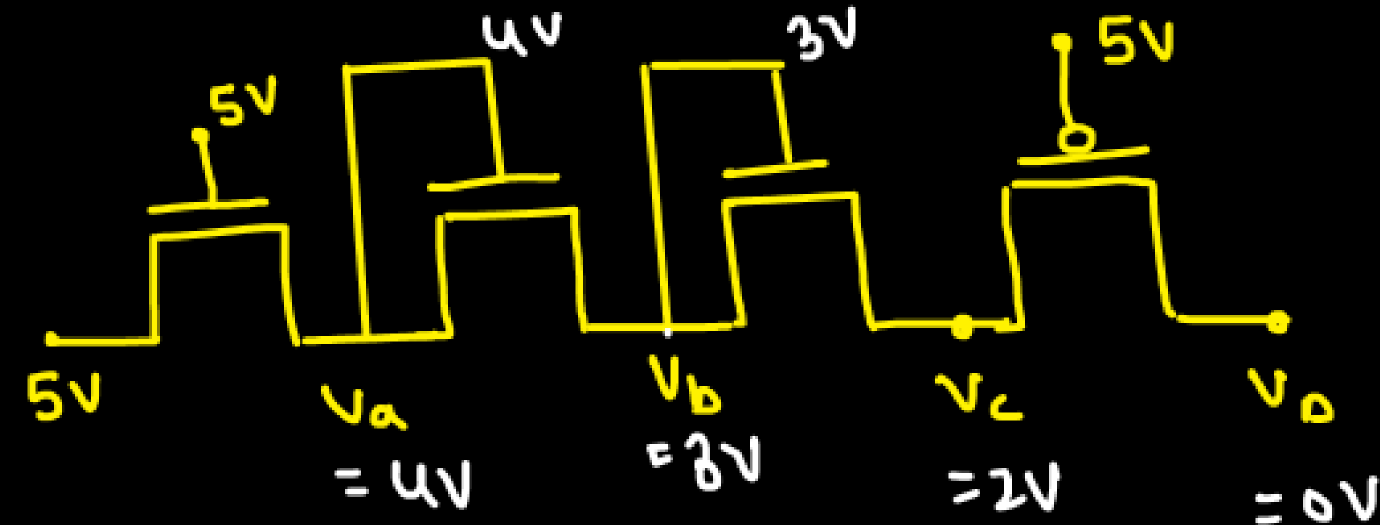
(G)

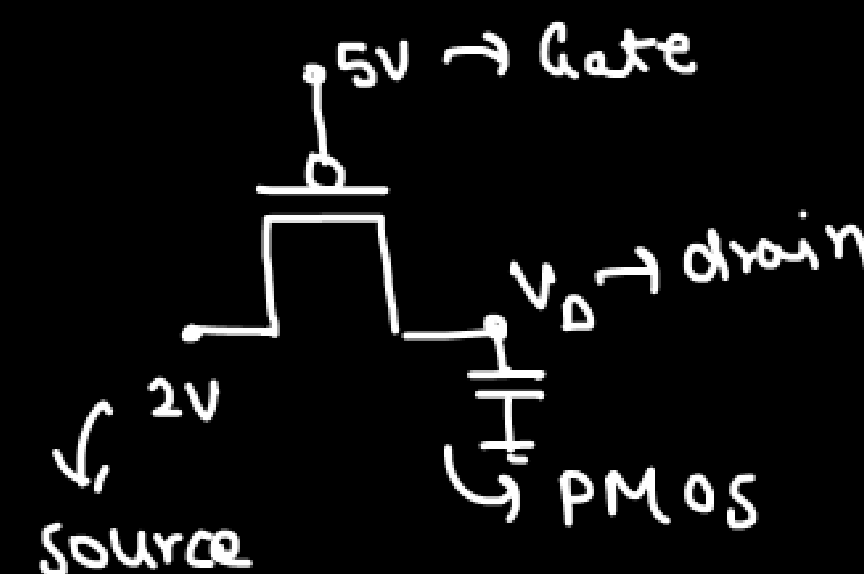


5V
4V
3V
2V
5V
drain
Va
4V
Vb
3V
Vc
2V
VD
2V
(H)



⇒ NMos
⇒ PMos





h.p → source

l.p → Drain

⇓

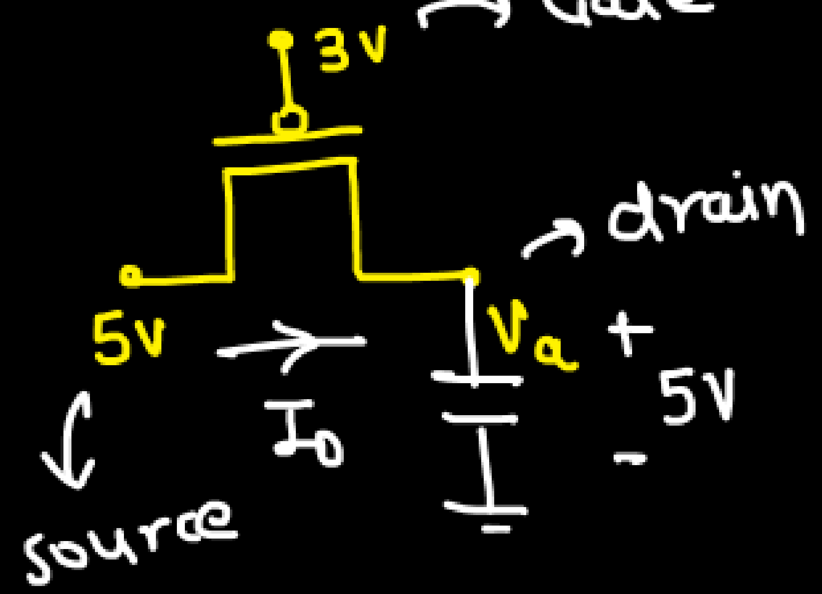
$V_{sg} = 2 - 5 = -3V$

⇓

MOS is off

⇓

No charging for V_D



$V_{SG} = 5 - 3 = 2V > V_T \Rightarrow$ always

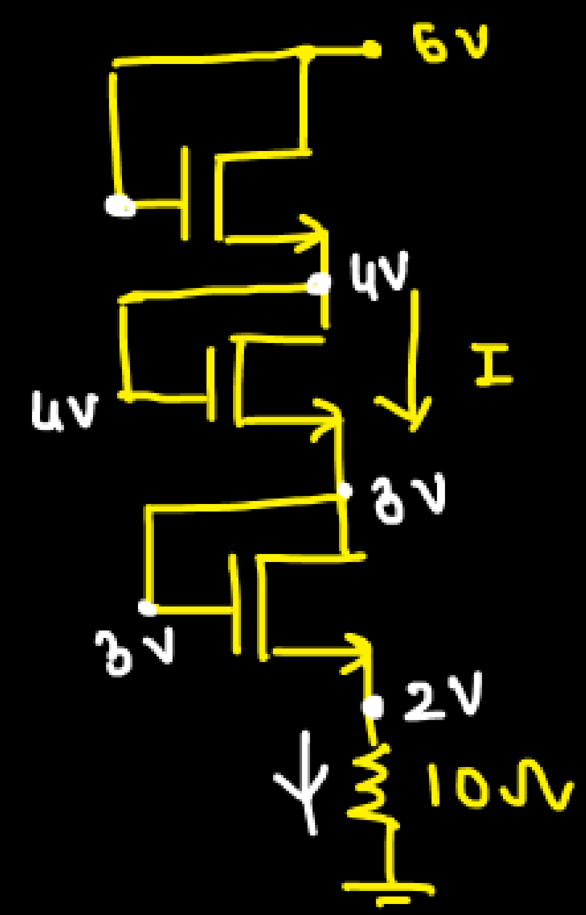
Tr can turn off only when

$V_{SD} = 0$

$5 - V_0 = 0$

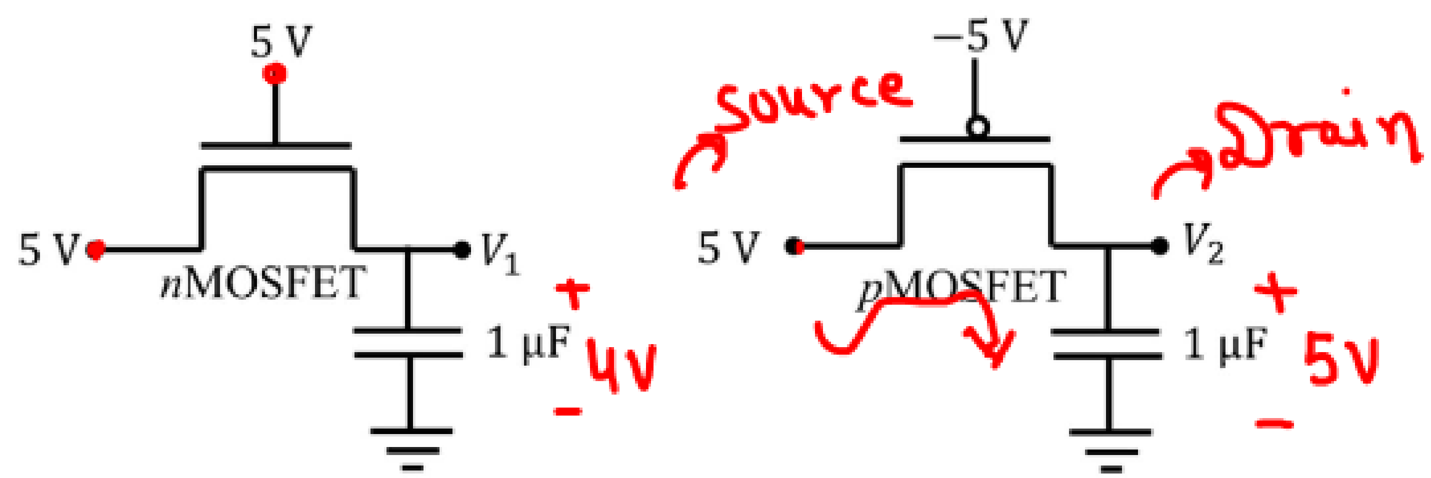
$$\boxed{(V_0)_{s.s} = 5V}$$

Q.



steady state I = ?

$$\boxed{I = \frac{2}{10} = 0.2 \text{ Amp.}}$$

Q.20	The ideal long channel *n*MOSFET and *p*MOSFET 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)	$V_1 = 5\text{ V}, \quad V_2 = 5\text{ V}$
(B)	$V_1 = 5\text{ V}, \quad V_2 = 4\text{ V}$
(C)	$V_1 = 4\text{ V}, \quad V_2 = 5\text{ V}$
(D)	$V_1 = 4\text{ V}, \quad V_2 = -5\text{ V}$

$V_{sg} = 5 - (-5) = 10\text{V}$

$\Downarrow$

Tr $\underline{\underline{\text{ON}}}$

Frequency Response of MOS

Pre-requisites :-

Transfer f^n, pole, zero, Bode plot.

Analog VLSI Mastery : Cohort (0-10) || Himanshu Agarwal || PrepFusion
Himanshu Agarwal · Playlist

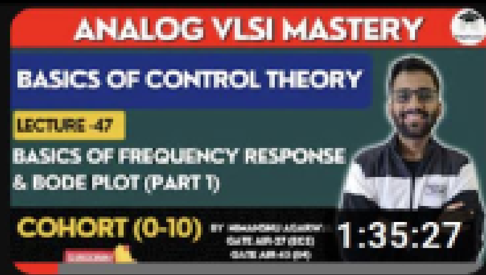
Analog VLSI Mastery : Cohort (0-10) || Free YouTube Course || Himanshu Agarwal || @PrepFusion_GA... • 12:03
Day to Day Roadmap to Complete Analog VLSI Mastery : Cohort (0-10) • 10:21

VIEW FULL PLAYLIST

42 

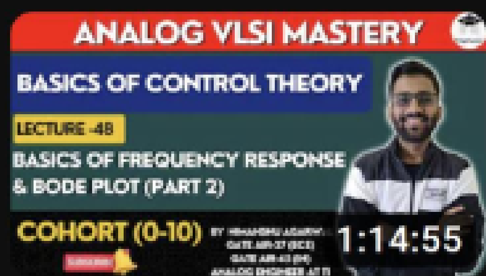
Basics of Control Systems in Electrical Circuits || Network Analysis || GATE 2025-26 || PrepFusion
PrepFusion - GATE • 493 views • 2 months ago

2x

49 

Basics of Frequency Response & Bode Plot (Part 1) || Analog VLSI Mastery (Cohort 0-10)

Himanshu Agarwal • 708 views • 2 months ago

50 

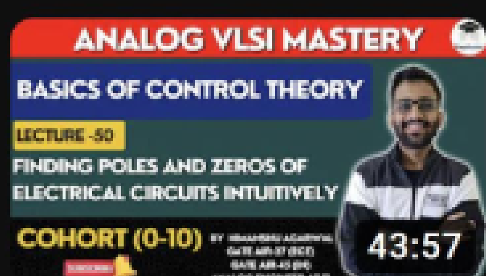
Basics of Frequency Response & Bode Plot (Part 2) || Analog VLSI Mastery (Cohort 0-10)

Himanshu Agarwal • 323 views • 2 months ago

51 

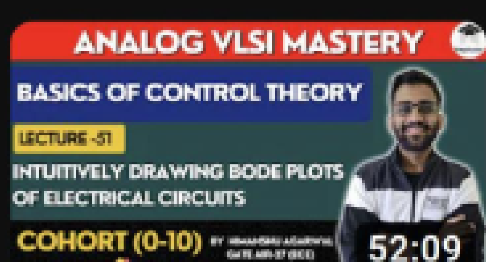
Basics of Analog Filters || Analog VLSI Mastery (Cohort 0-10) || Himanshu Agarwal

Himanshu Agarwal • 688 views • 2 months ago

52 

Finding Poles and Zeros of Electrical Circuits Intuitively || Analog VLSI Mastery (Cohort 0-10)

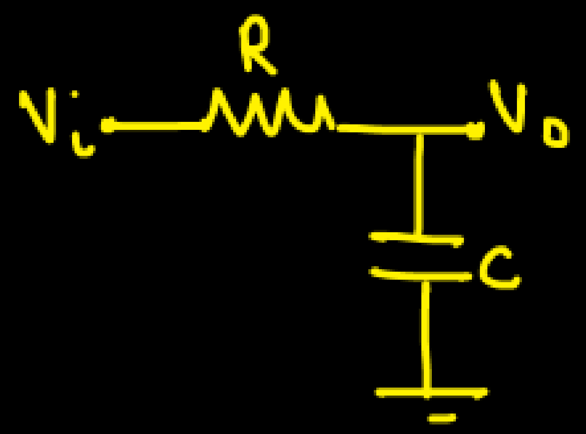
Himanshu Agarwal • 418 views • 2 months ago

53 

Intuitively Drawing Bode Plots of Electrical Circuits || Analog VLSI Mastery (Cohort 0-10)

Himanshu Agarwal • 364 views • 2 months ago

Q. Draw the bode plot for given RC ckt.



$R = 2\,\Omega$

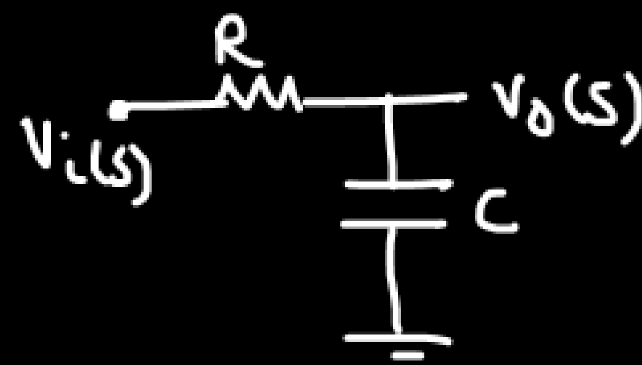
$C = 1F$

For which value of V_i ckt will have the max^m attenuation?
and min^m

$V_i = 50mV \sin\left(\frac{t}{4}\right) \rightarrow 0.25$ rad/sec

$V_i = 50mV \sin(2t) \rightarrow 2$ rad/sec

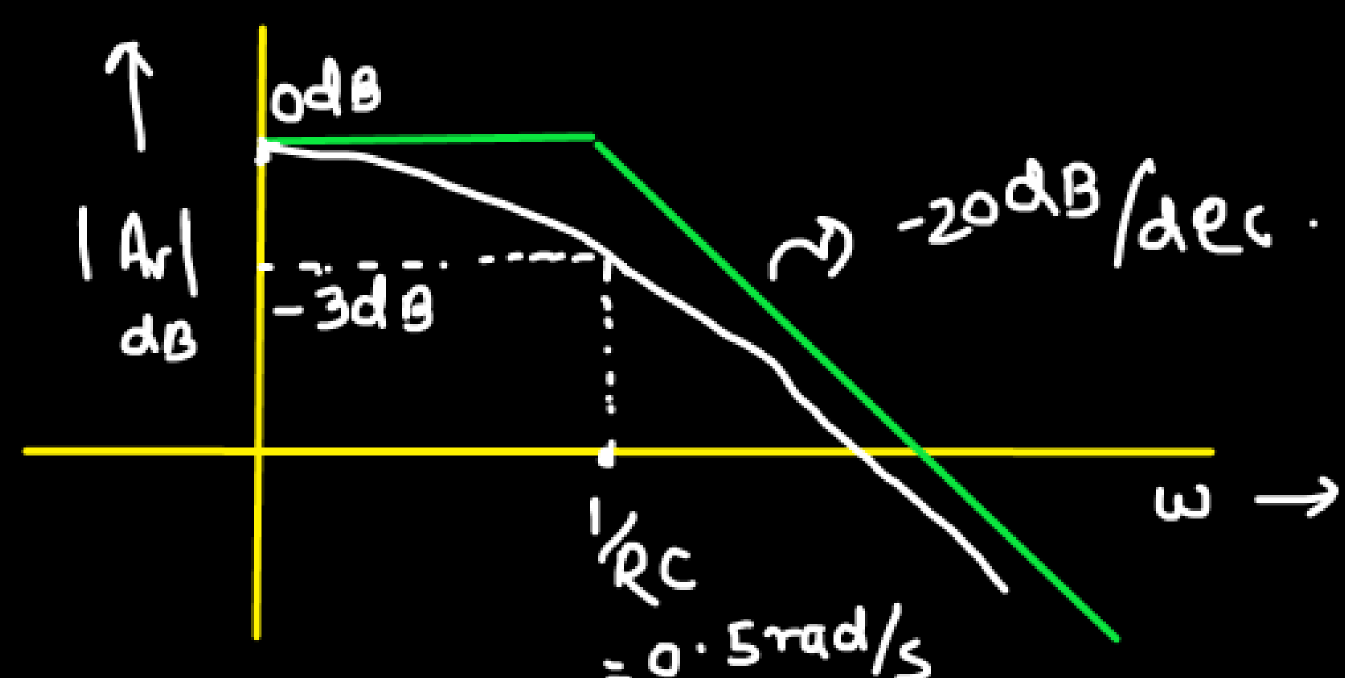
$V_i = 50mV \sin(20t) \rightarrow 20$ rad/sec

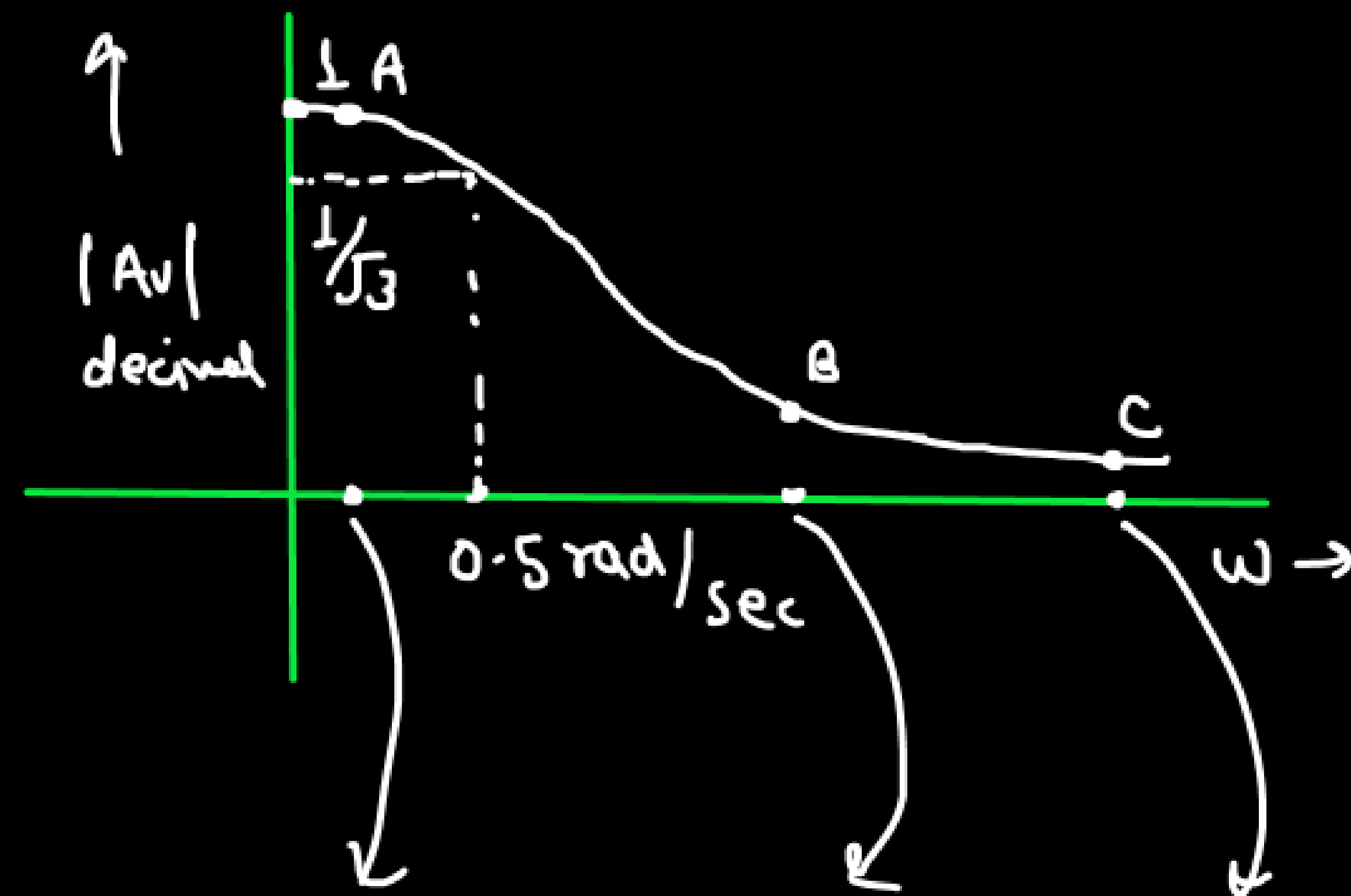


$$\boxed{\frac{V_o(s)}{V_i(s)} = \frac{1}{1+RCs}}$$

$\omega_p = \frac{-1}{RC}$, $\omega_z = \infty$

$\omega_p = \frac{-1}{2\times 1} = -0.5\ \text{rad/sec}$





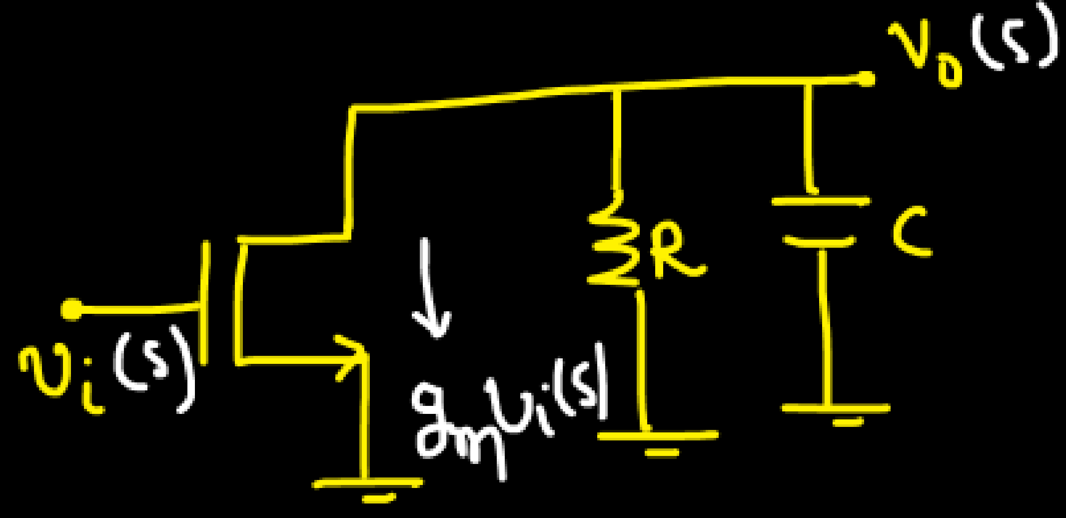
0.25 rad/sec 2 rad/sec 20 rad/sec

$$\left(\frac{V_o}{V_i}\right)_{0.25\, r/sec.} > \left(\frac{V_o}{V_i}\right)_{2\, rad/se} > \left(\frac{V_o}{V_i}\right)_{20\, rad/sec.}$$

$\Downarrow$ max gain $\Rightarrow$ min attenuation

$\Downarrow$ min gain = max^m attenuation

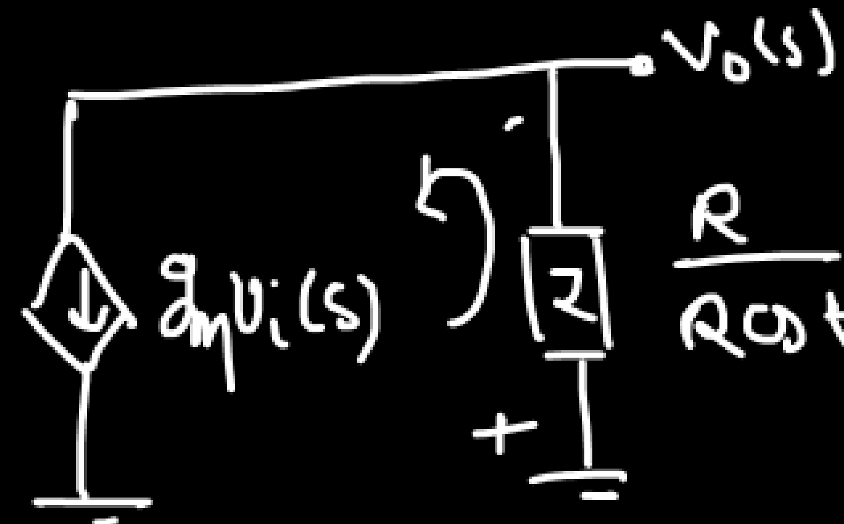
Q. Plot the frequency response.



(a)

$$\frac{v_o(s)}{v_i(s)} = ?$$

→

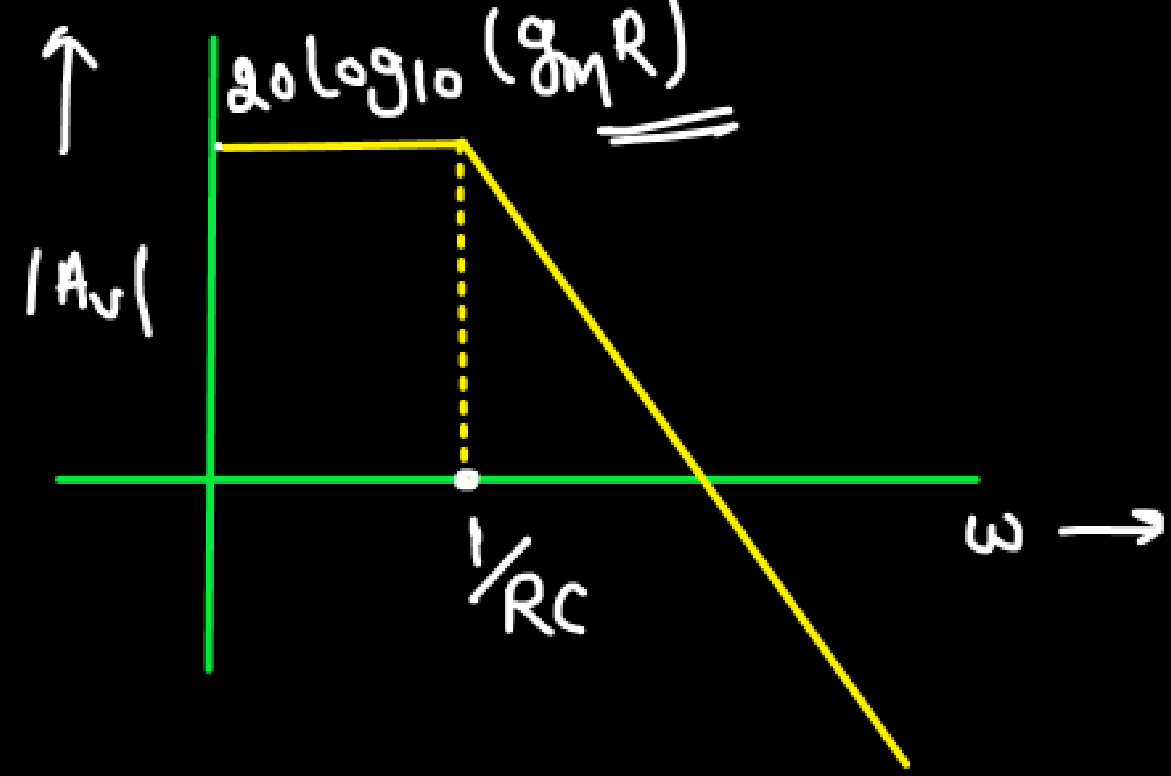


$$\frac{R}{RCs+1}$$

$$v_o(s) = -\frac{g_m \times R}{RCs+1} v_i(s)$$

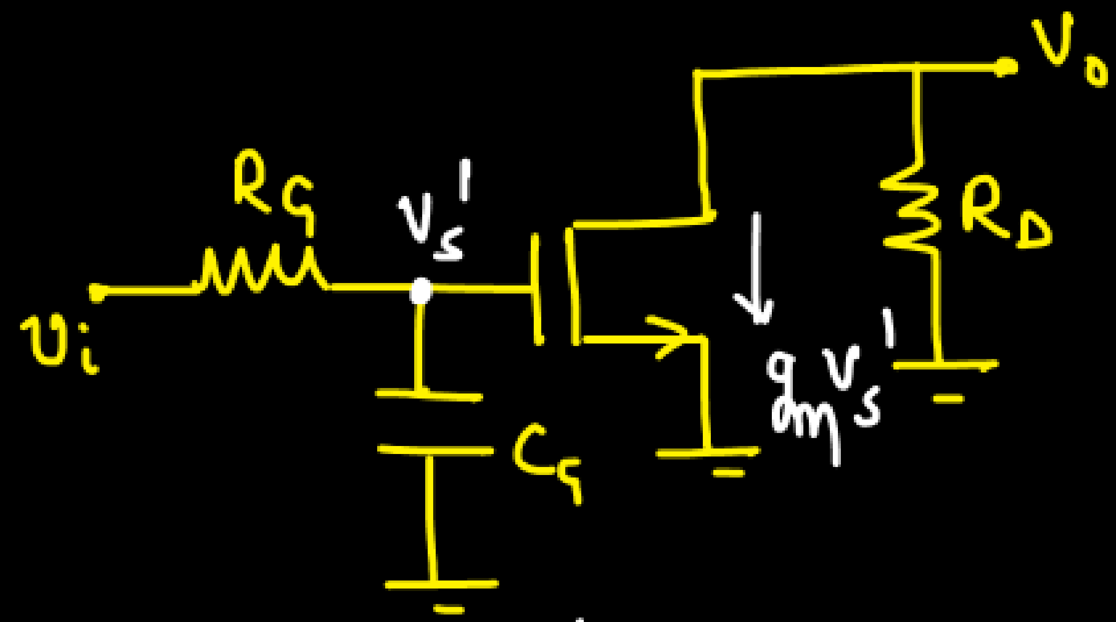
$$\frac{v_o(s)}{v_i(s)} = \frac{-g_m R}{RCs+1}$$

$$\omega_p = -\frac{1}{RC} \qquad |a\,(\text{DC gain})| = g_m R$$



Let's assume $v_i(s) = 20mV \sin(\omega_i t)$

For better amplification, $\boxed{\omega_i << \frac{1}{RC}}$

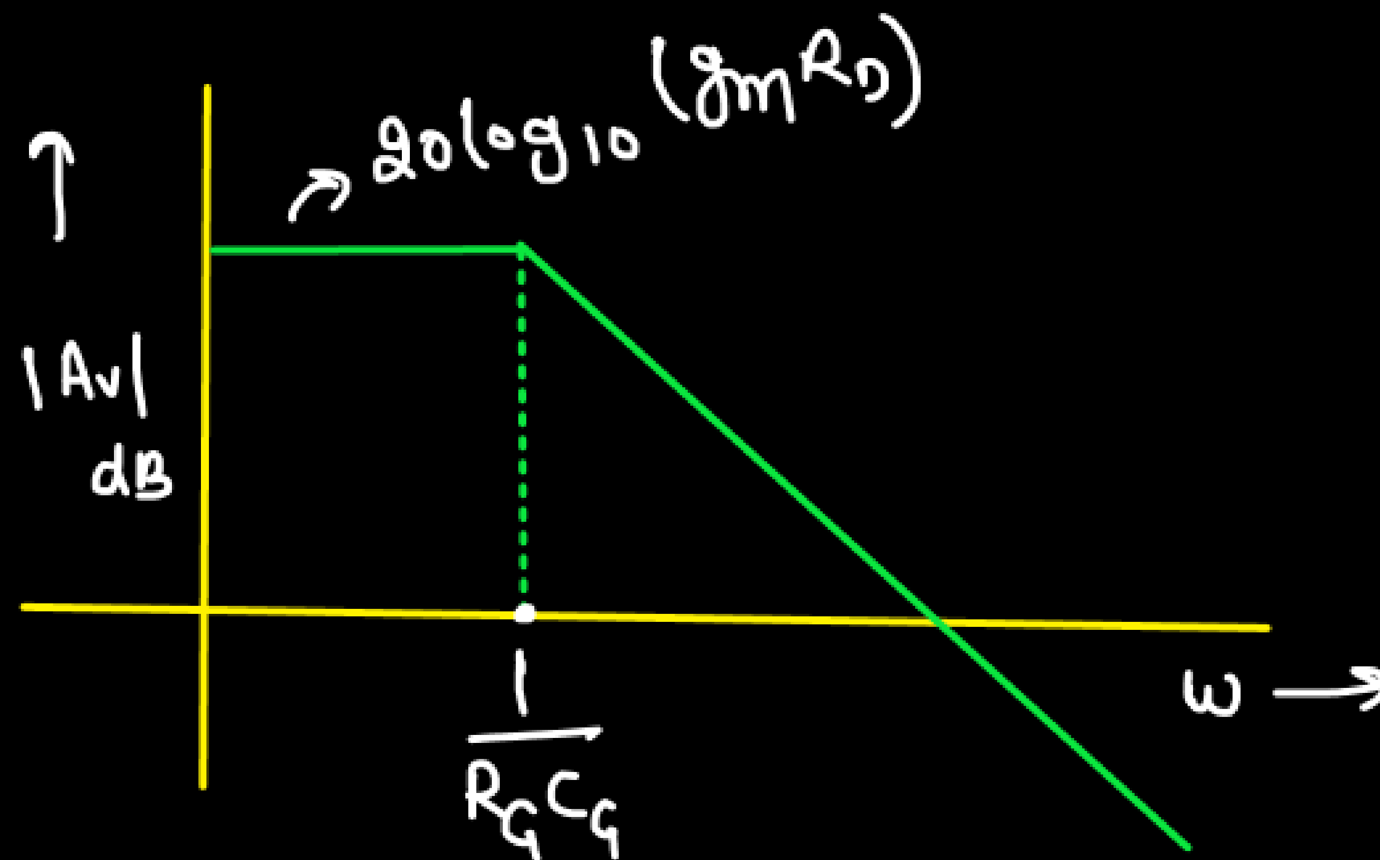


(b)

$$V_0 = -g_m R_D V_s' \quad \text{—} \ (1)$$

$$V_s' = \frac{\frac{1}{C_G s}}{\frac{1}{C_G s} + R_G} v_i = \frac{1}{R_G C_G s + 1} v_i$$

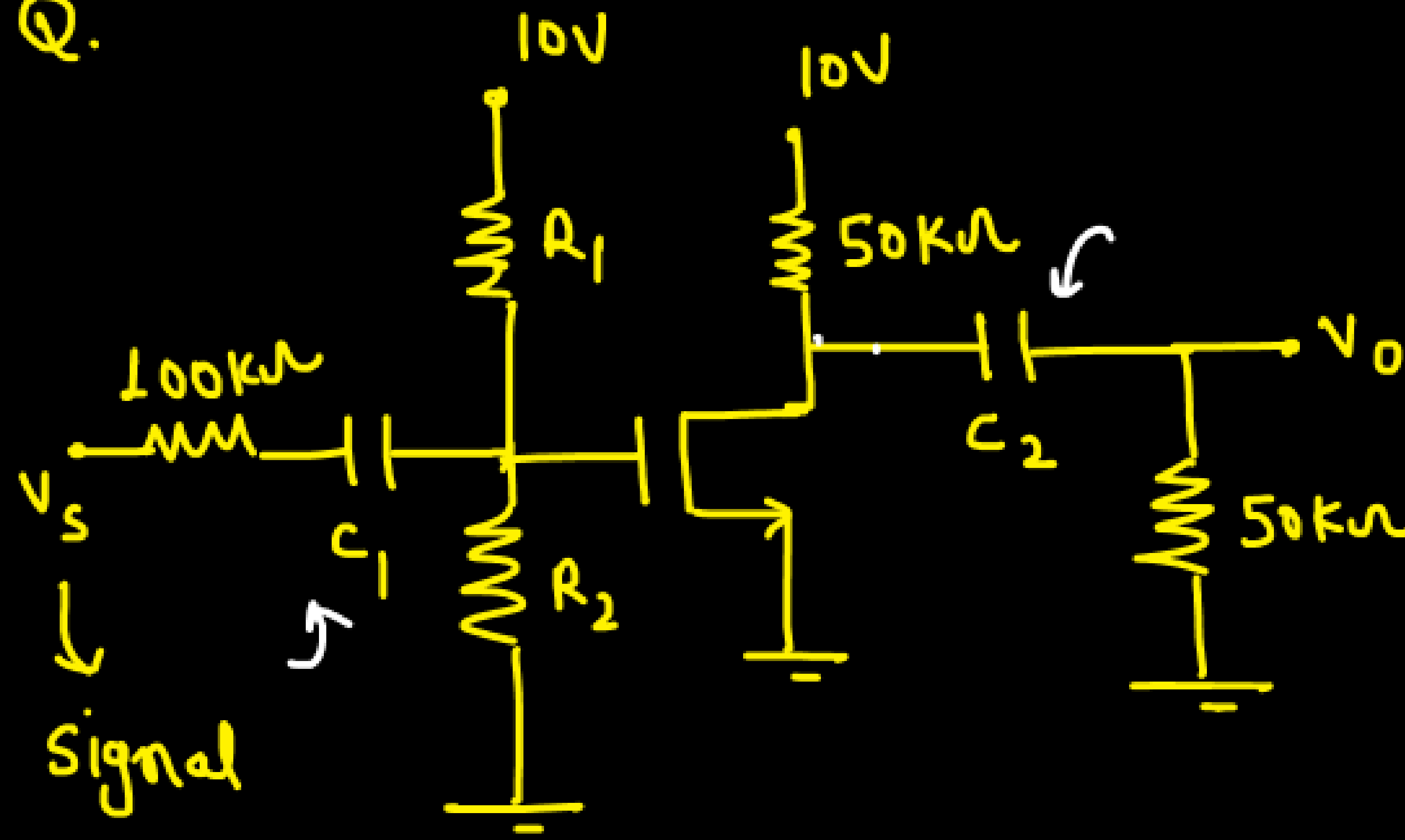
$$\boxed{\frac{V_0}{V_i} = \frac{-g_m R_D}{R_G C_G s + 1}}$$



$$V_i = V_m \sin(\omega_i t)$$

$$\boxed{\omega_i \ll \frac{1}{R_G C_G}} \Rightarrow \text{For better Amplification}$$

Q.



Signal freq. = 10KHz

$C_1, C_2 \rightarrow$ coupling cap.

$R_1 = 260k\Omega$

$R_2 = 740k\Omega$

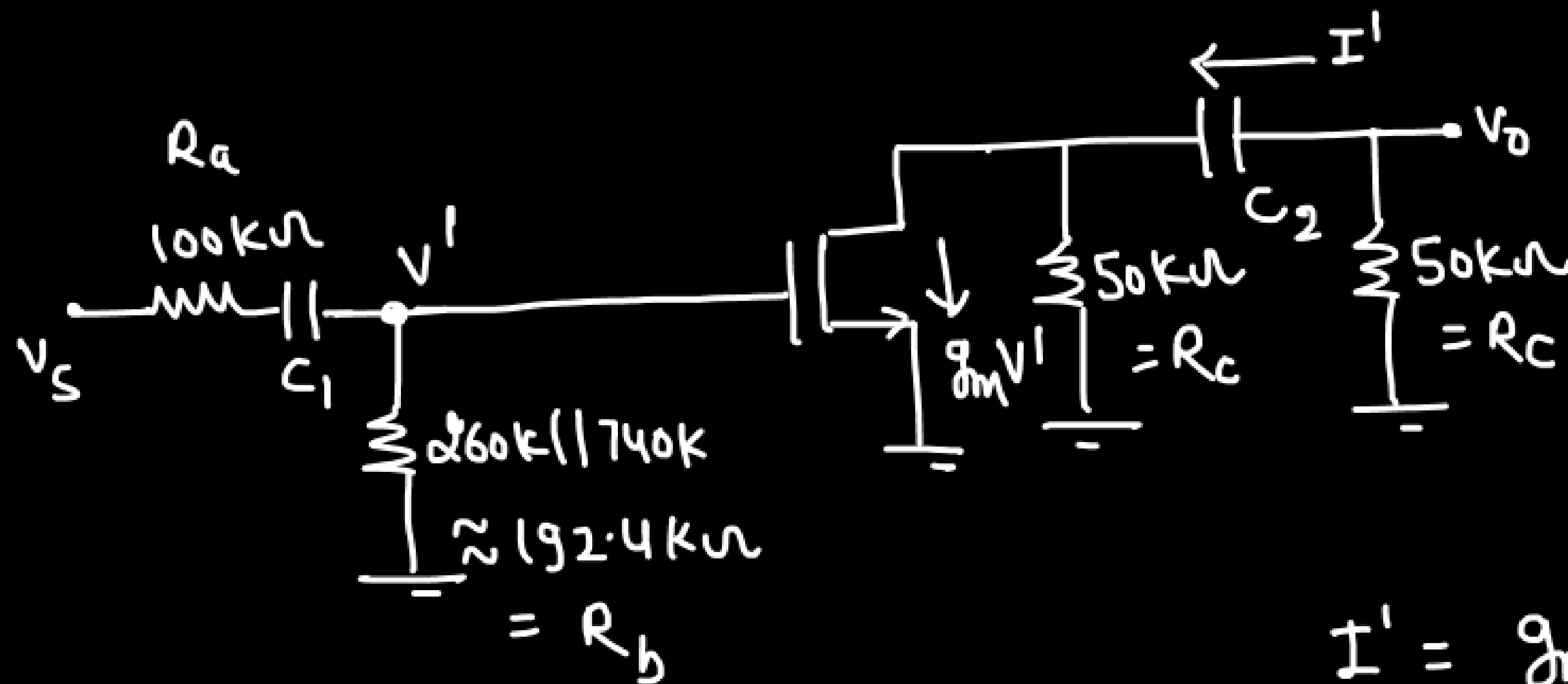
MOS is biased in sat.

How large you should choose C_1 and C_2 such that both cap. acts as short ckt @ signal freq.

$C_1 >> C_{o_1}$

$C_2 >> C_{o_2}$

Determine C_{o_1} and C_{o_2}.



$$I' = g_m V' \times \frac{R_c}{R_c + R_c + \frac{1}{C_2 s}}$$

$$V' = \frac{R_b}{R_b + R_a + \frac{1}{C_1 s}} V_s(s)$$

$$I' = g_m V' \times \frac{R_c C_2 s}{2 R_c C_2 s + 1} \quad — (2)$$

$$\boxed{V' = \frac{R_b C_1 s}{(R_b + R_a) C_1 s + 1} V_s(s)} \quad — (1)$$

$$V_o = -I' R_c \quad — (3)$$

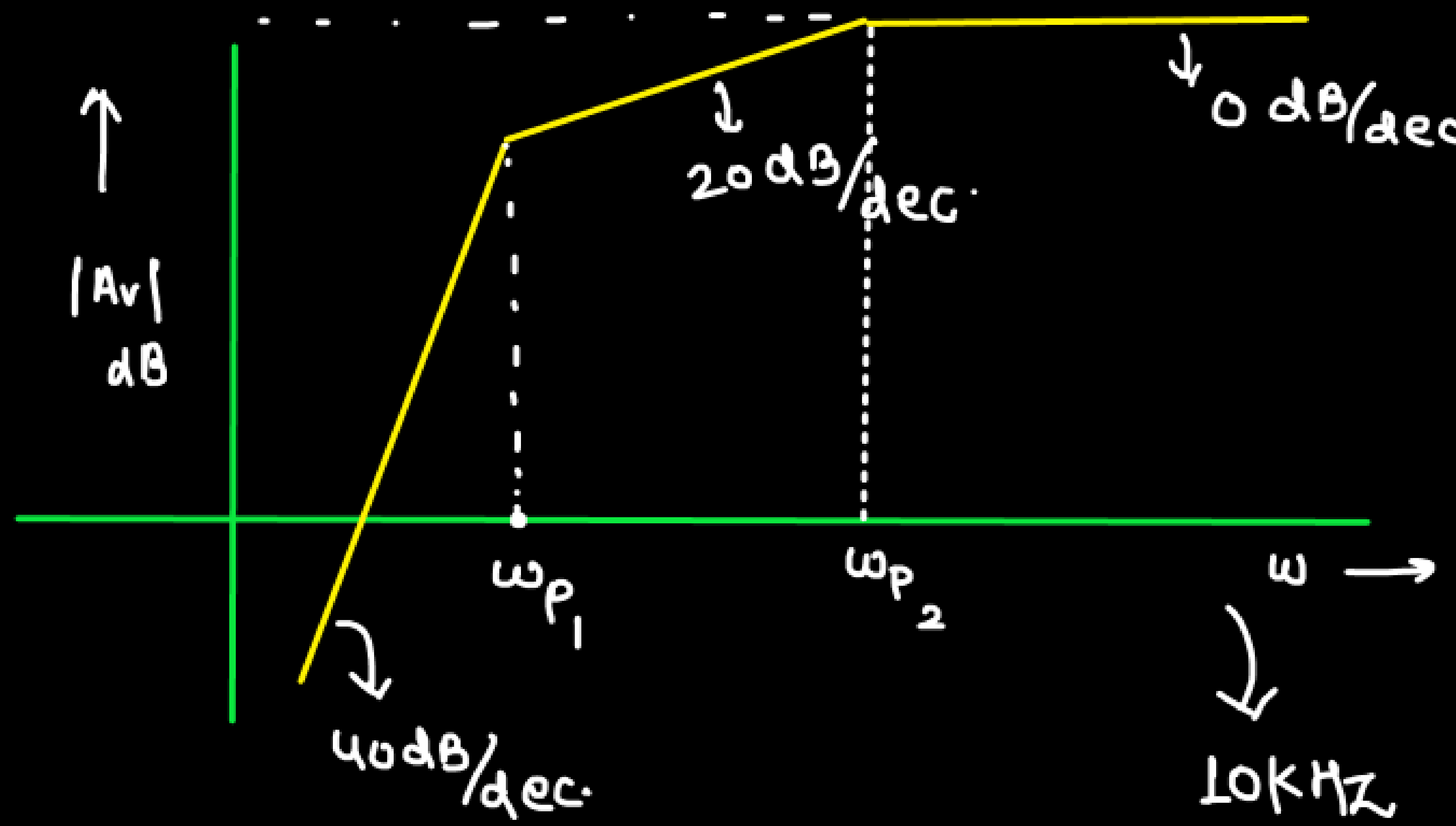
$$V_o(s) = \frac{-g_m R_c C_2 S}{2R_c C_2 S + 1} \times \frac{R_b C_1 S}{(R_b + R_a) C_1 S + 1} V_i(s)$$

$$\boxed{A_v(s) = \frac{V_o(s)}{V_i(s)} = \frac{-g_m R_c R_b C_1 C_2 S^2}{(2R_c C_2 S + 1)\left[(R_b + R_a) C_1 S + 1\right]}}$$ Ans.

$$\omega_{z_1} = \omega_{z_2} = 0$$

$$\boxed{\omega_{p_1} = \frac{-1}{2R_c C_2}} , \quad \boxed{\omega_{p_2} = \frac{-1}{(R_b + R_a) C_1}}$$

$$\omega_p = \frac{-1}{100K \times C_2} \qquad \omega_p = \frac{-1}{292.4K \times C_1}$$



$= 20k\pi \, rad/sec.$

$\omega_{p_1} < 20k\pi$ $\qquad$ $\omega_{p_2} < 20k\pi$

$\frac{1}{100k \times C_2} < 20k\pi$ $\qquad$ $\frac{1}{292.4k \times C_1} < 20k\pi$

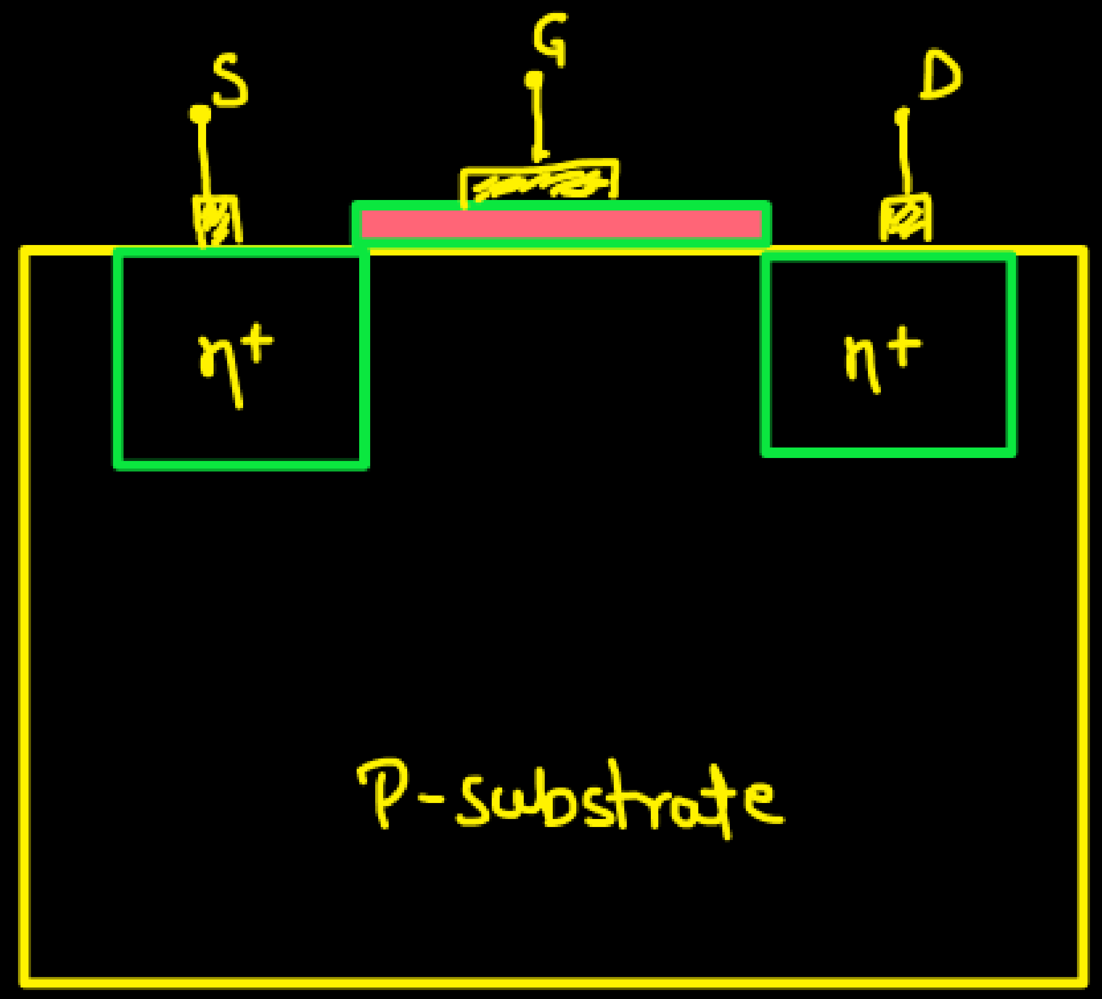
$\boxed{C_2 > 159\,pF}$ $\rightarrow C_{o_2}$ $\qquad$ $\boxed{C_1 > 54.4\,pF}$ $\rightarrow C_{o_1}$

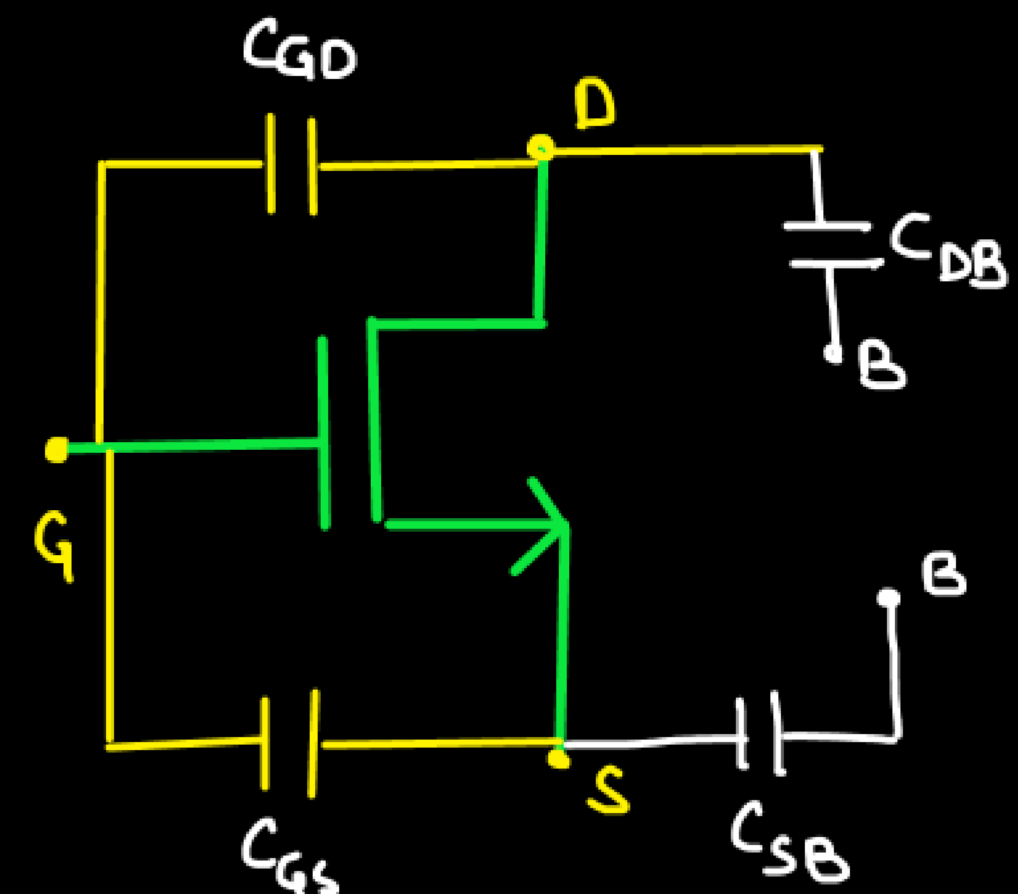
Generally c_2 should be 1590 pF $\quad [c_1, c_2 = 10C_0]$

c_1 should be 544 pF

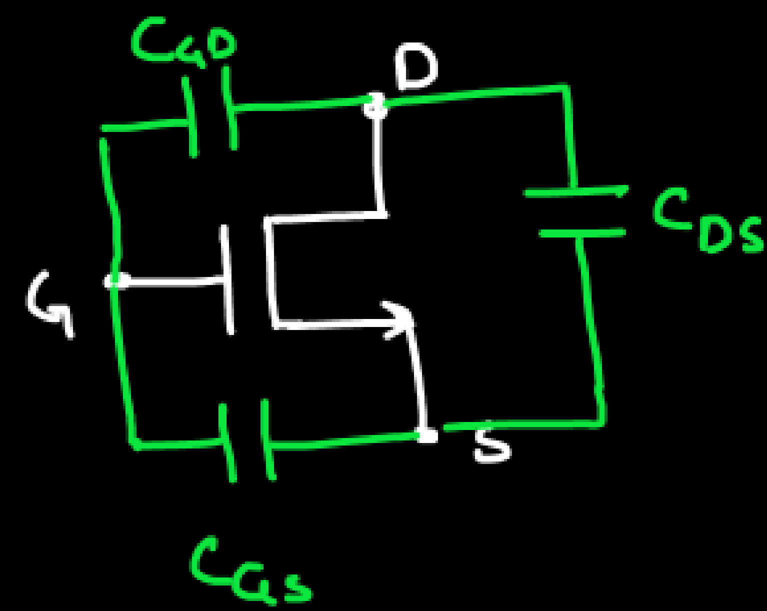
NOT Imp.

⇒ High Freq. Model of MOS:-





☆☆ $\Rightarrow$



$\rightarrow$ +nt @ Higher freq.

$$\boxed{C_{GS}, C_{GD}, C_{DS} \rightsquigarrow \text{pF, fF Range (small)}}$$

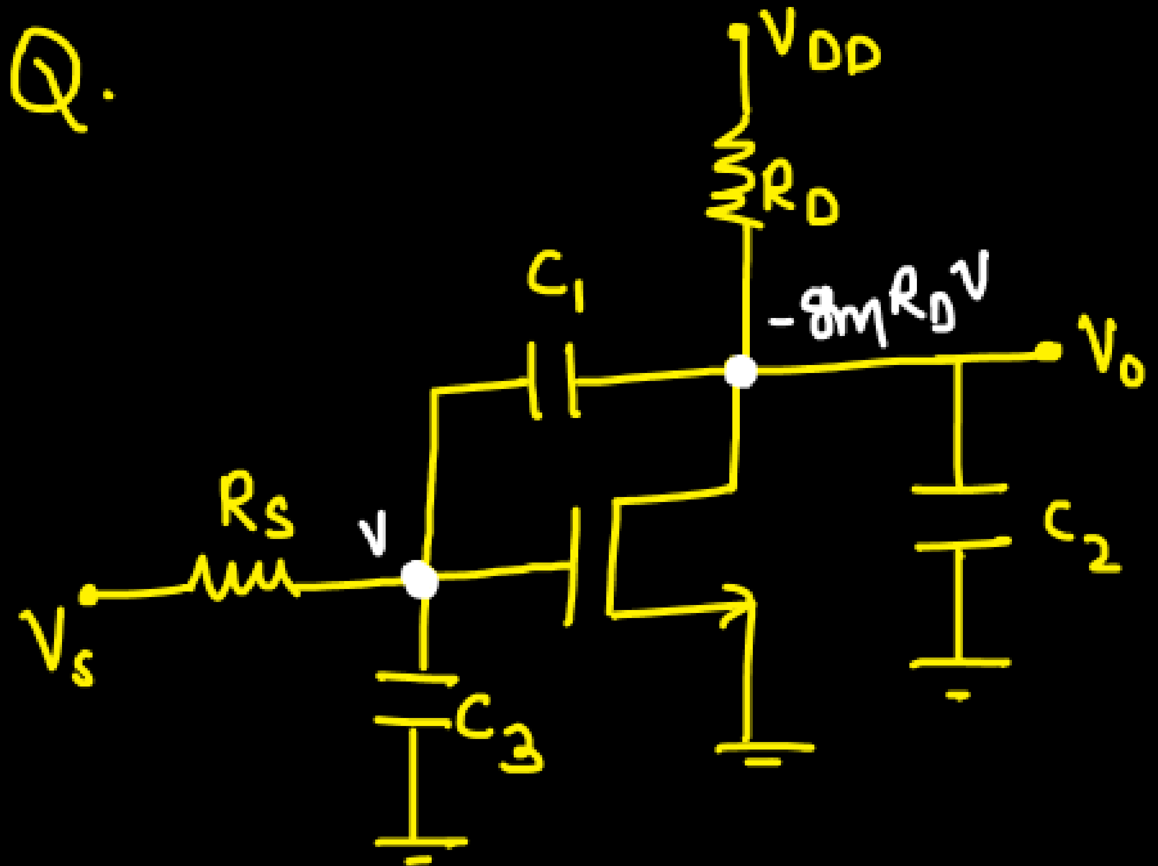
@ Low freq. $\Rightarrow \dfrac{1}{C_{GDS}} = \dfrac{1}{\text{very low} \times \text{very low}} = \dfrac{1}{0} = \infty \Rightarrow$ O.C.

@ High freq. $\Rightarrow \dfrac{1}{C_{GDS}} = \dfrac{1}{\text{very low} \times \text{very High}} = \dfrac{1}{\text{considerable}} \Rightarrow$ stays in action

$\Rightarrow$ @ Low and Mid Freq., Parasitic / Internal / J^n cap. are open ckt.

@ High freq., They come in action

Q.

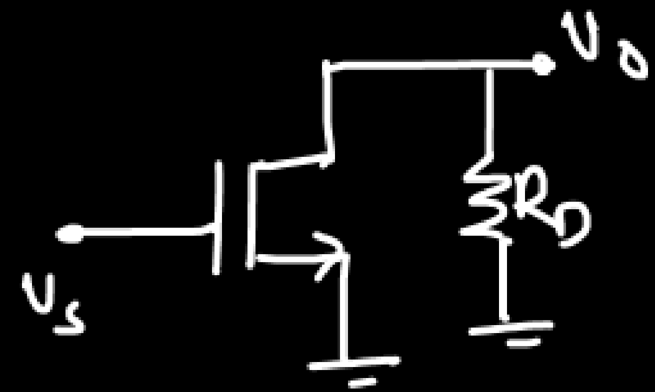


Given that C_1, C_2 & C_3 are parasitic cap.

[C_1, C_2, C_3 → very low value pf]

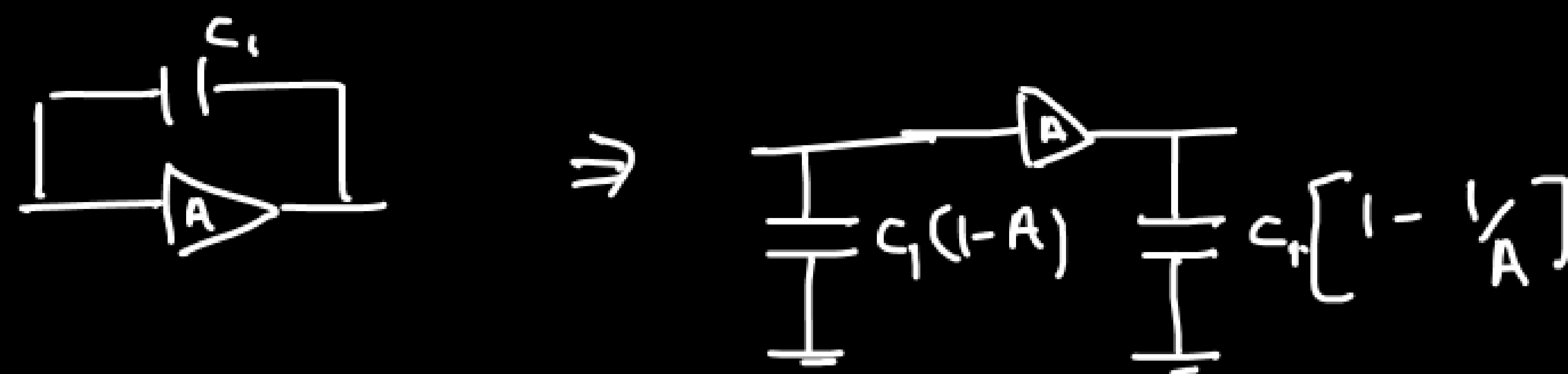
Draw the freq. response.

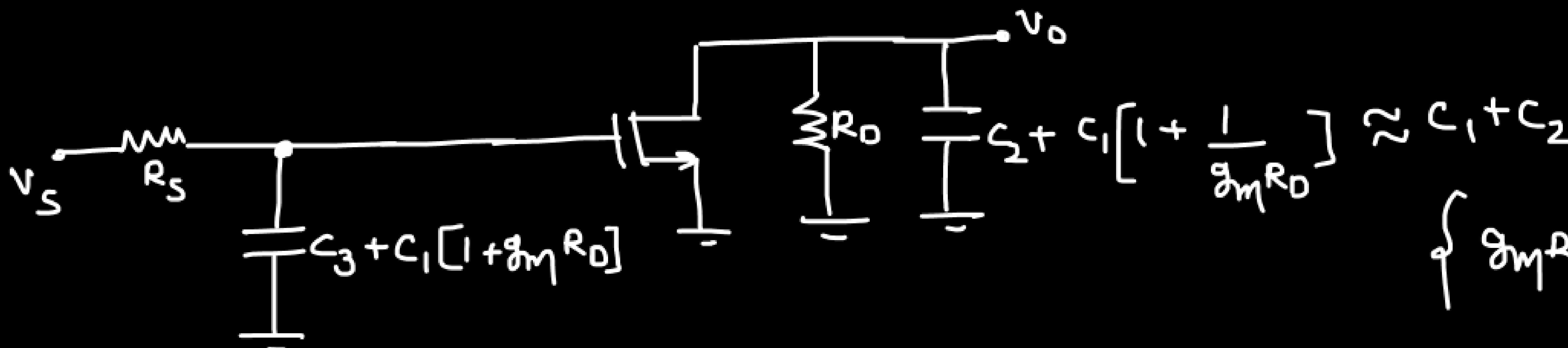
Dc gain:-



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

Applying Miller's Theorem :-





$\{g_m R_D >> 1\}$

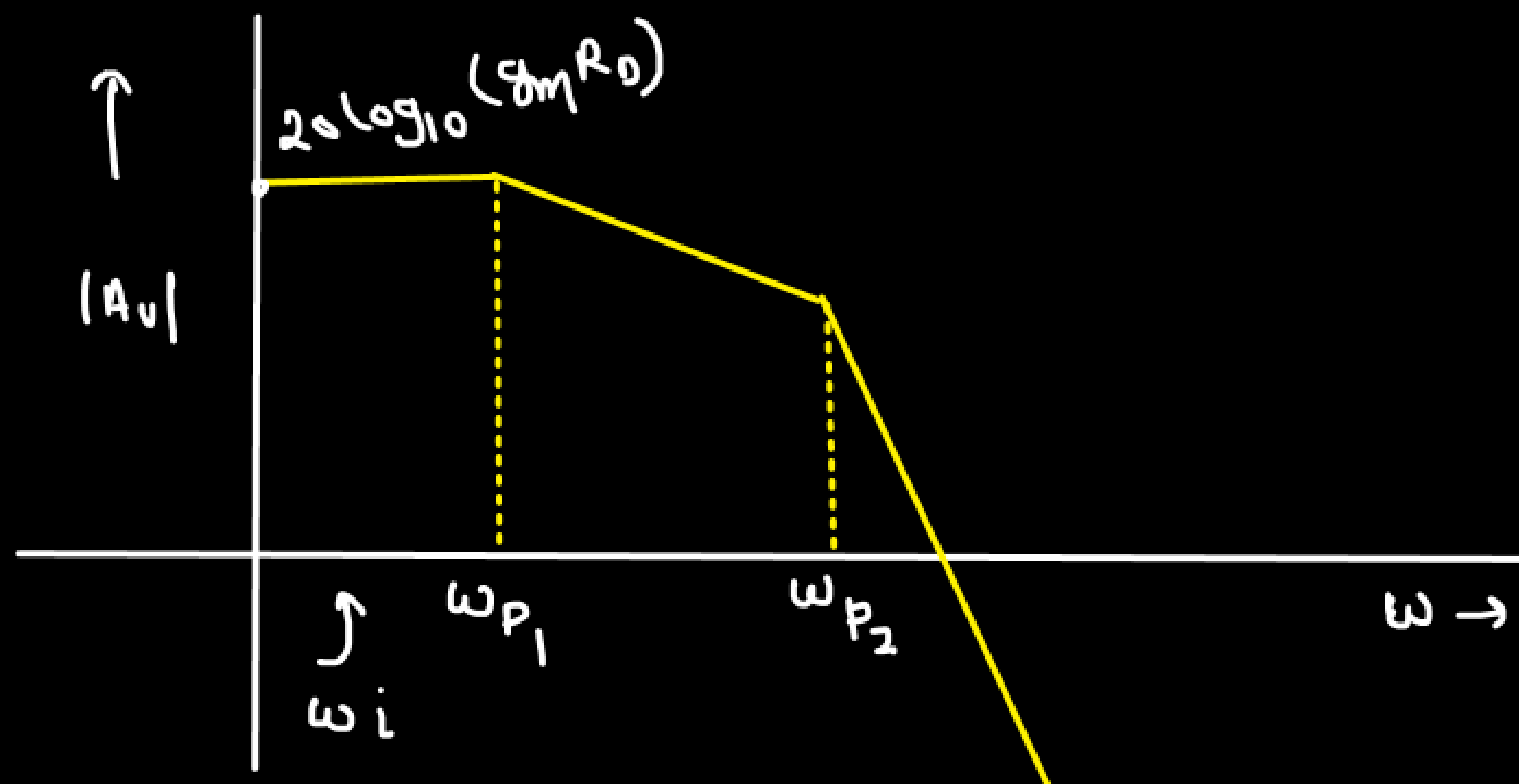
$$\boxed{\frac{V_o(s)}{V_s(s)} = \frac{-g_m R_D}{\{[C_3 + C_1(1+g_m R_D)]R_s s + 1\}\{R_D(C_1+C_2)s + 1\}}}$$

$\omega_{z_1} = \infty$

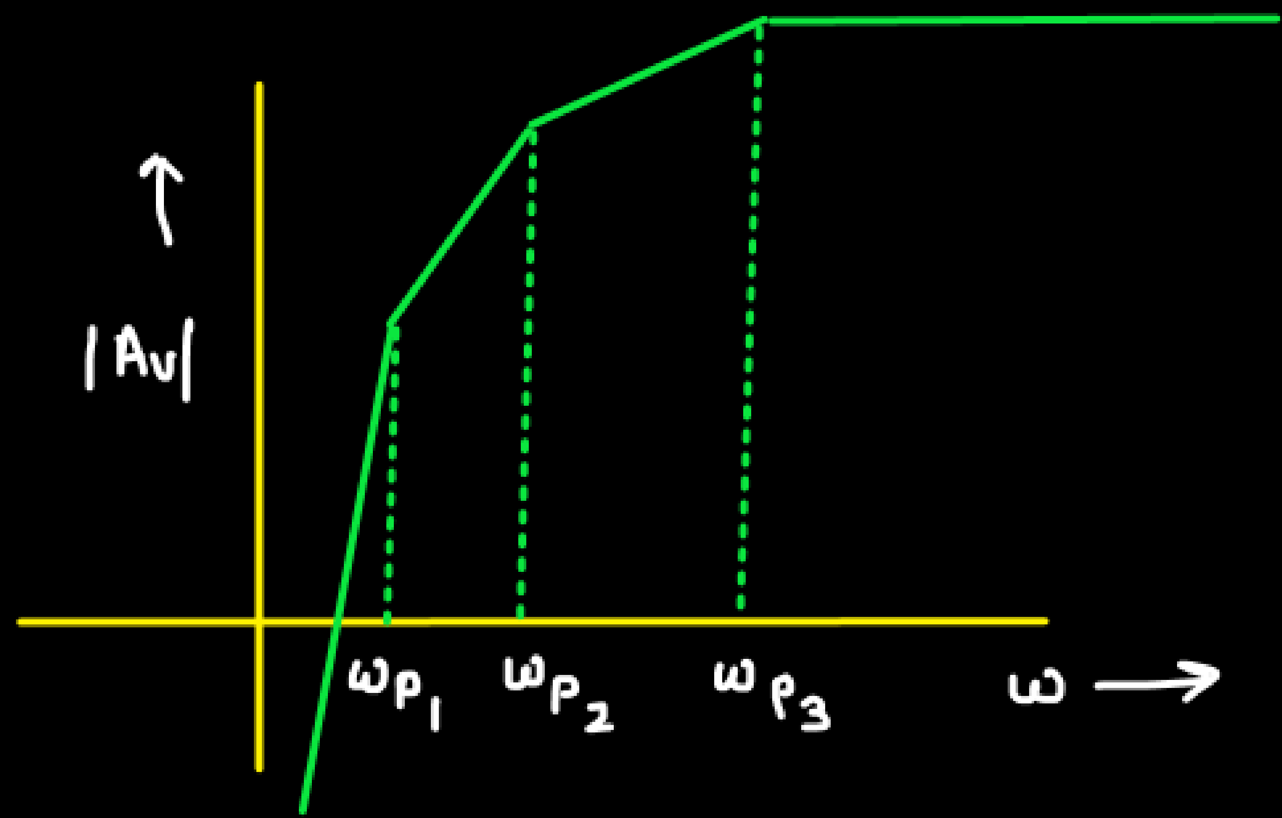
$\omega_{z_2} = \infty$

$$\omega_p = \frac{-1}{R_D(C_1+C_2)}$$

$$\omega_p = \frac{-1}{[C_3 + C_1(1+g_m R_D)]\,R_S}$$

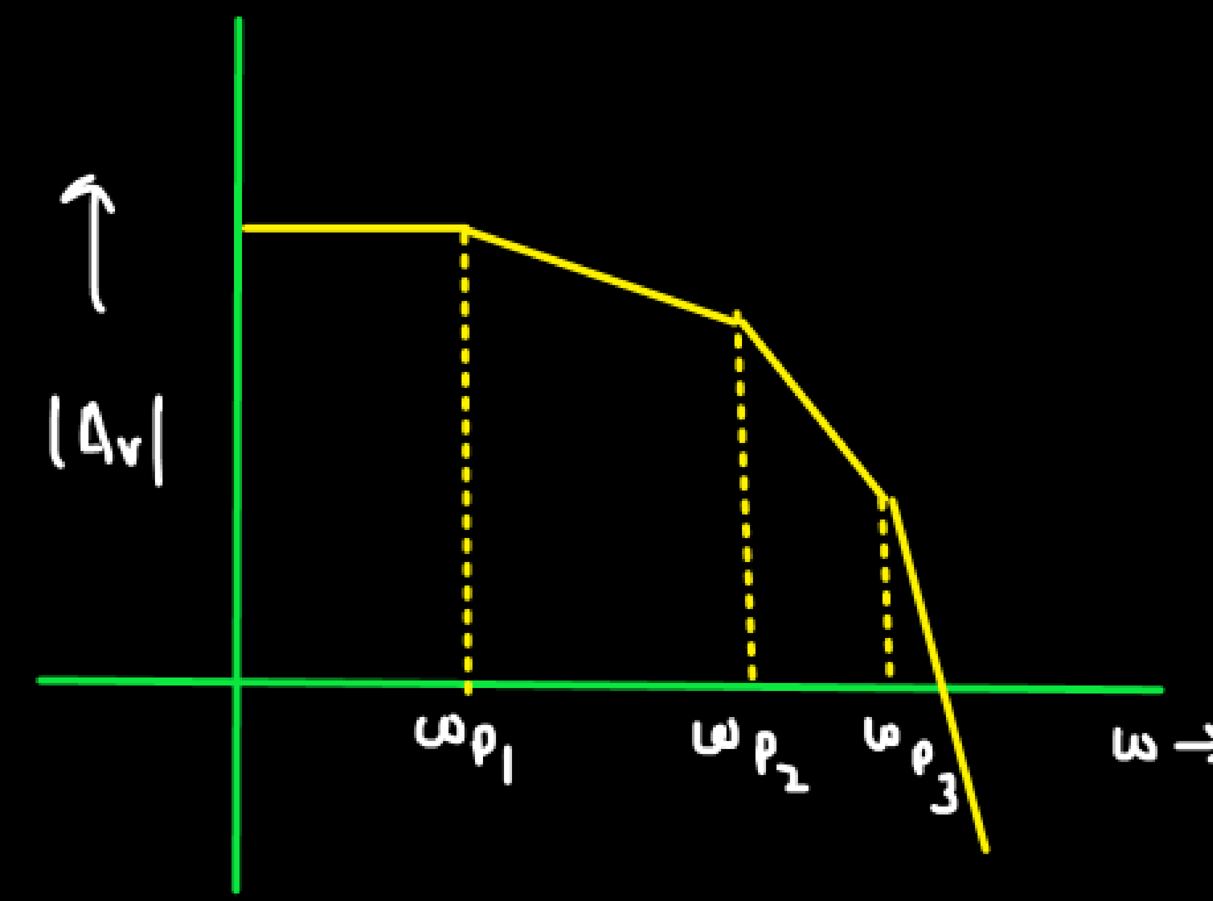


N.B. →



⇓

$\boxed{\text{3-dB cut-off freq.} = \omega_{p_3}}$



$\boxed{\text{3-dB cut-off freq.} = \omega_{p_1}}$

Low freq. Model of MOS:-

$\Downarrow$

$\boxed{\begin{array}{c}\underbrace{\text{coupling cap.}}\text{ will be in action} \\ \Downarrow \\ (\eta f \text{ or } \mu f \rightarrow \underline{\underline{\text{High}}})\end{array}}$

@ low freq. $\Rightarrow \dfrac{1}{C_c S} = \dfrac{1}{\text{High} \times \text{low}} = \dfrac{1}{\text{consider}}$ = will be in action

@ High freq. $\Rightarrow \dfrac{1}{\text{High} \times \text{High}} = \dfrac{1}{\infty} = 0$ = cap. will act as s.c.

$\Rightarrow$ @ low freq. $\Rightarrow$ coupling cap. are in action

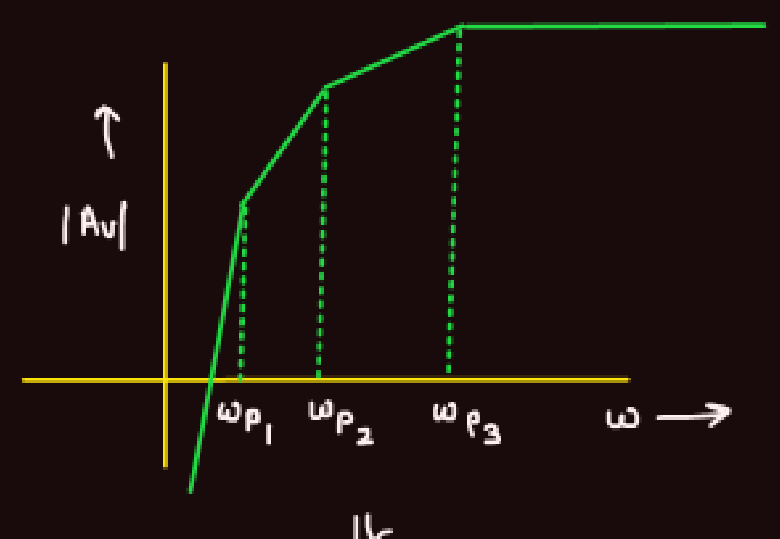
$\Rightarrow$ @ High freq. & Mid freq. $\Rightarrow$ coupling cap. is s.c.

Conclusion:-

(a) Coupling cap:-

- Will be in action @ low freq.
- Response will be of HPF.
- Will act as s.c. @ High and Mid freq.

Coupling ⇒ Low freq. ⇒ H.P.F. ⇒ 3-dB cut off freq. will be Highest Pole



⇒ @ low freq.

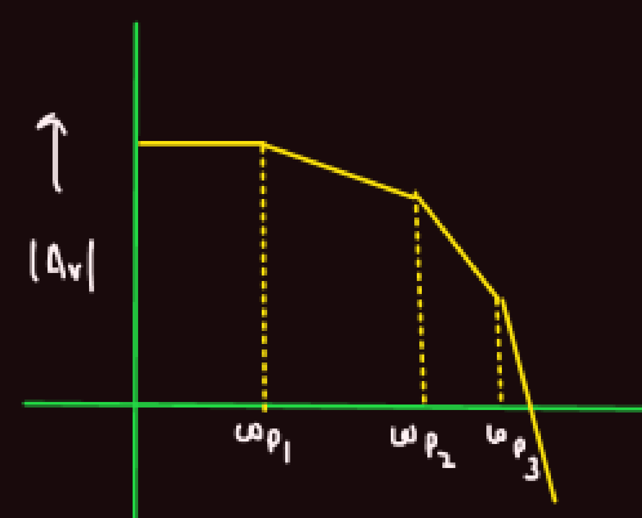
(b) Parasitic / Internal / J^n cap. -

↳ will be in action @ High freq.

↳ Response will be of LPF

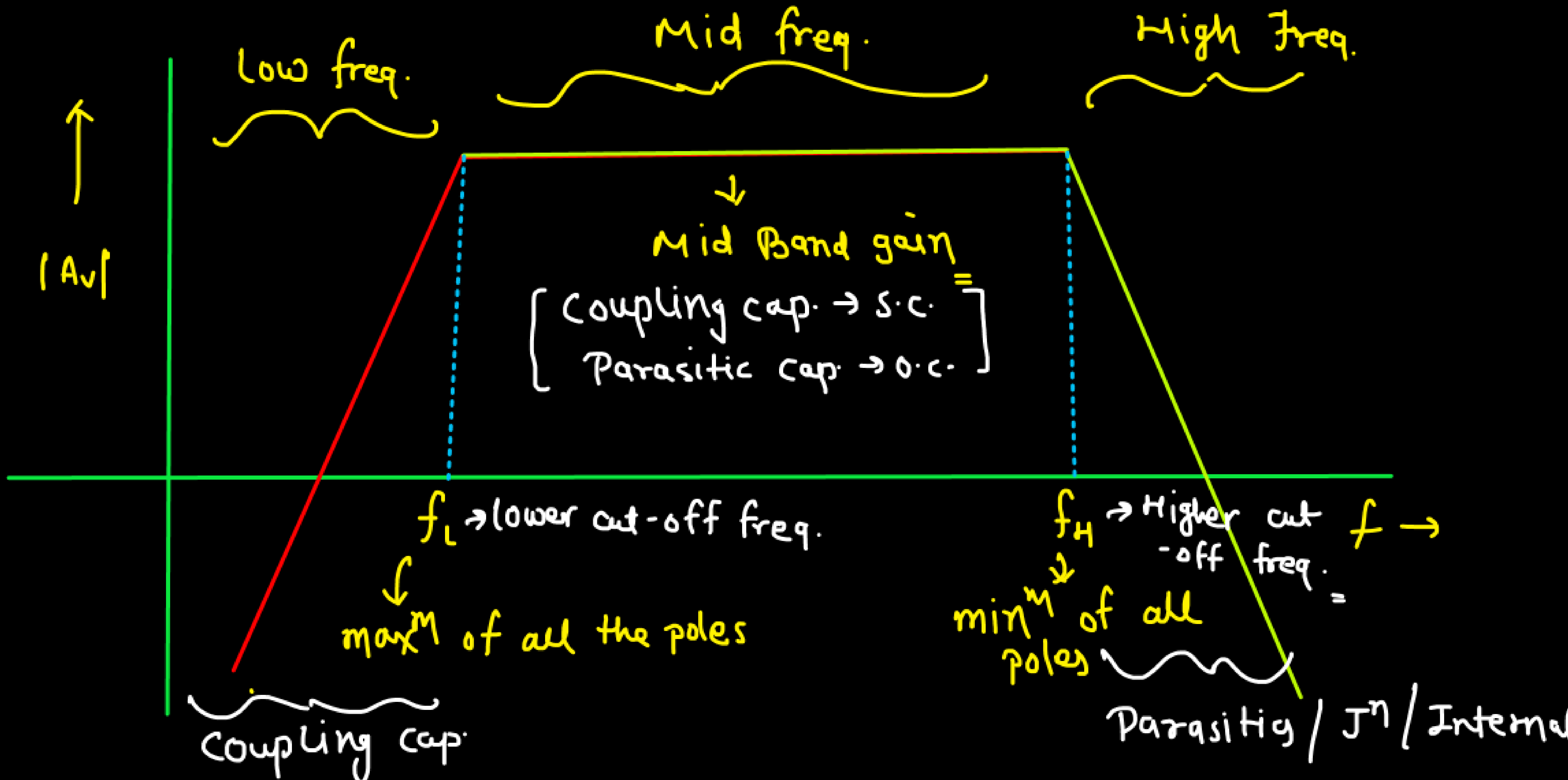
↳ Will act as o.c. @ low and Mid freq.

Para / Intern / J^n cap. ⇒ High freq. ⇒ LPF ⇒ Cut-off freq. will be min pole.



⇒ @ High freq.

⇒ Freq. Response of a RC Coupled MOS Amp:-



⇒ **How to find a pole in MOS ckt.**

① find the order of the ckt.

② Nullify the i/p and find equivalent resistance across cap. [consider the other cap. shorted]

$$\boxed{\omega_p = \frac{1}{C R_{eq}}}$$

⇒ **How to find a zero in MOS ckt:.**

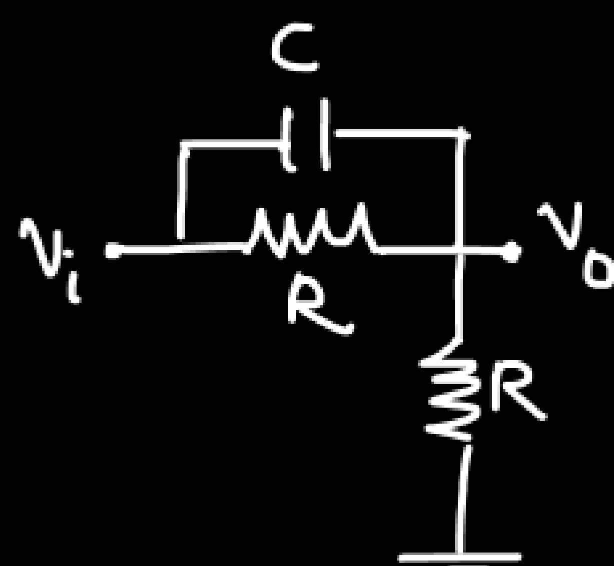
① NO Hard and fast rule. Do intelligent analysis.

$$\boxed{T(s) = \frac{A\left(\frac{s}{z_1}+1\right)\left(\frac{s}{z_2}+1\right) - - - \left(\frac{s}{z_n}+1\right)}{\left(\frac{s}{p_1}+1\right)\left(\frac{s}{p_2}+1\right) - - - \left(\frac{s}{p_n}+1\right)}}$$

⇒ A = dc gain (ω = 1)

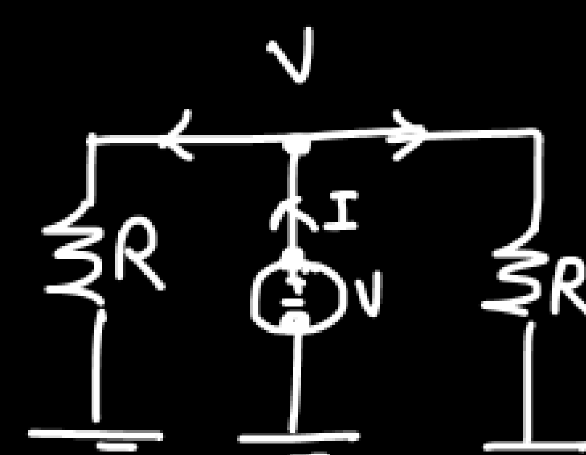
$$\boxed{\begin{array}{l} @\ s = -z_1 \Rightarrow T(s) = 0 \\ @\ \text{zero},\ \text{T.F. becomes zero}.\ \dfrac{V_o(s)}{V_i(s)} \to 0 \Rightarrow V_o(s) \to 0 \end{array}}$$

Eg. →



① order = 1^{st}

② poles →

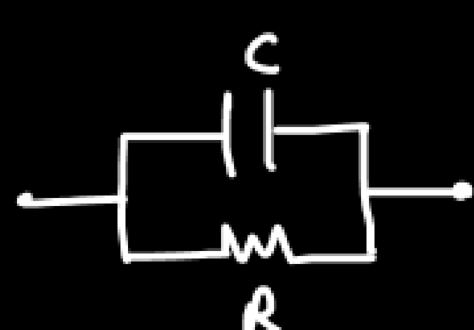


$\Rightarrow R_{eq} = R/2$

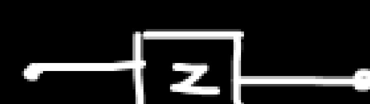
$C_{eq} = C$

$$\boxed{\omega_p = \frac{-1}{\frac{R}{2}C} = \frac{-2}{RC}}$$

③ zero →

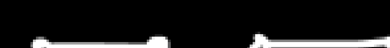


$\equiv$



$= \dfrac{R}{RCs+1} = 0$

$\Rightarrow$



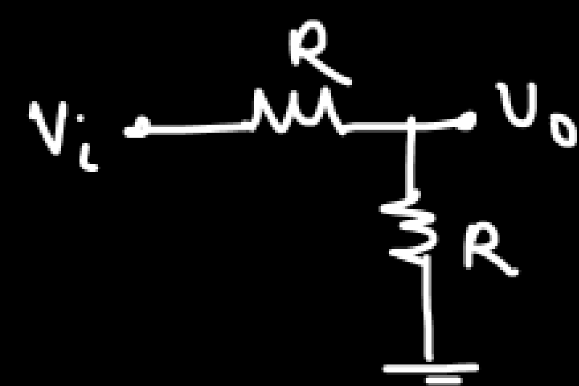
$$\boxed{s_z = -1/RC}$$

$$T.F. = \frac{A(SRC+1)}{\left(\frac{SRC}{2}+1\right)} = \frac{2A(SRC+1)}{(SRC+2)}$$

@ $\omega = 0$ $\quad T.F. = A$

in the given ckt

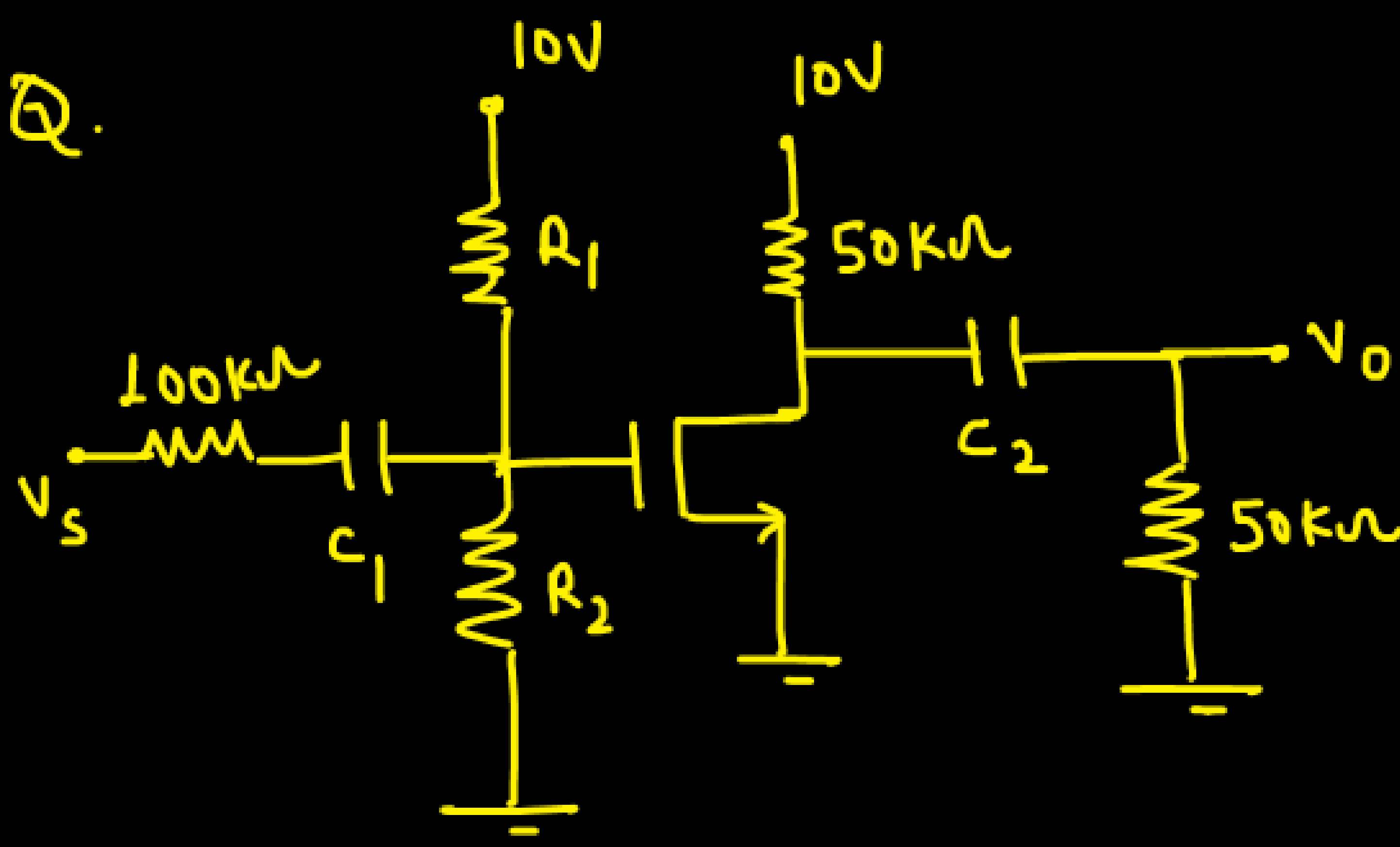
@ $\omega = 0$



$$\frac{V_o}{V_i} = \frac{1}{2} = A$$

$$\boxed{T.F. = T(s) = \frac{SRC+1}{SRC+2}}$$

Q.



Low freq. operation

(a) Determine the order of ckt.

(b) Find the location of poles.

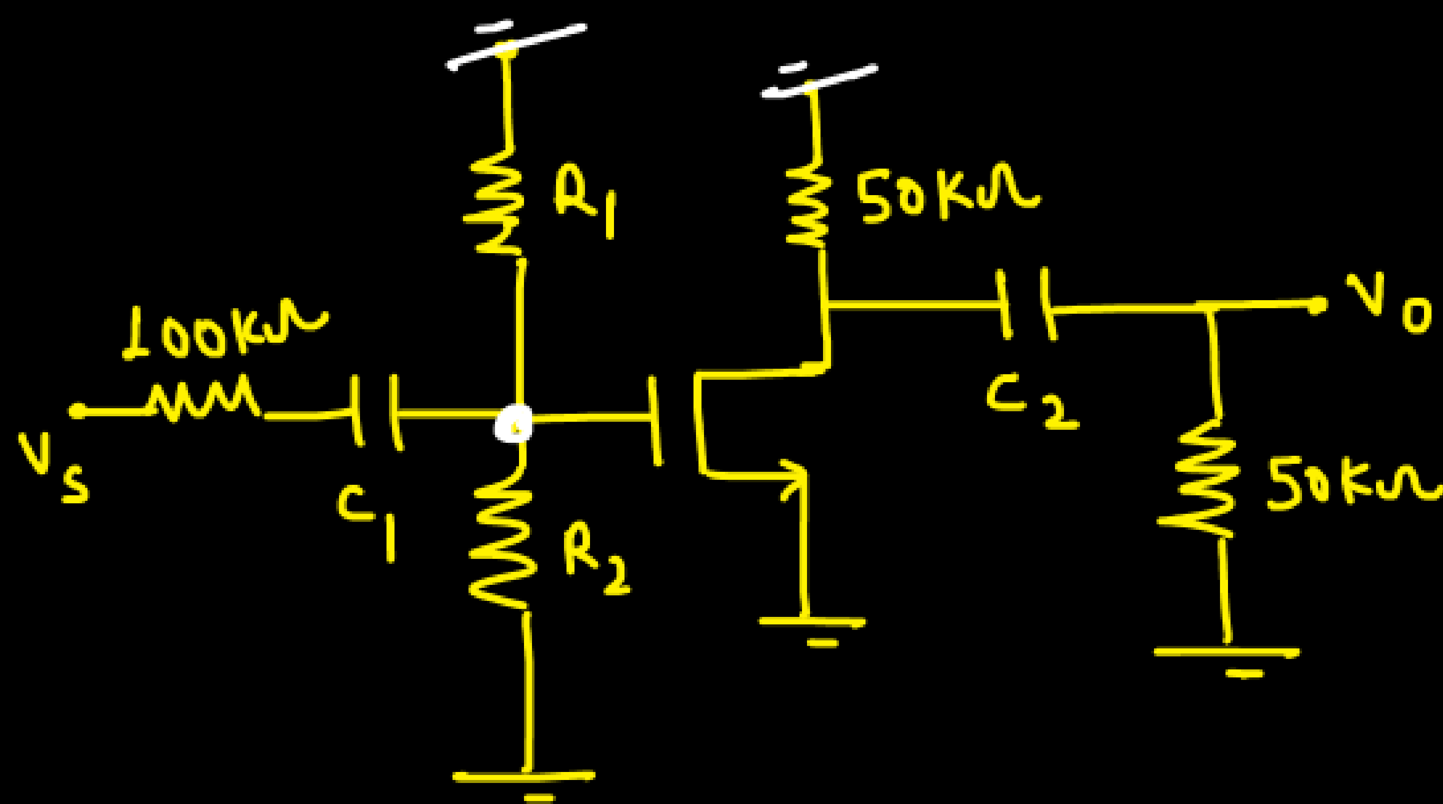
(c) Determine 3-dB cut-off freq. (kHz)

$R_1 = 260\,k\Omega$

$R_2 = 740\,k\Omega$

$C_1 = 100\,pF$

$C_2 = 200\,pF$

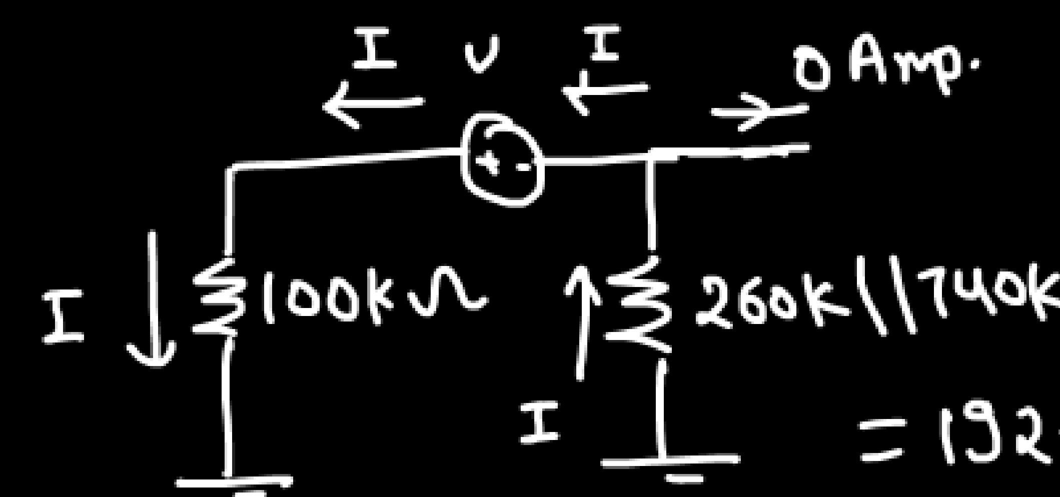


① order = 2^{nd}

② poles :-

$\boxed{\text{Pole because of } C_1}$

→ s.c. C_2 , s.c. input v_s



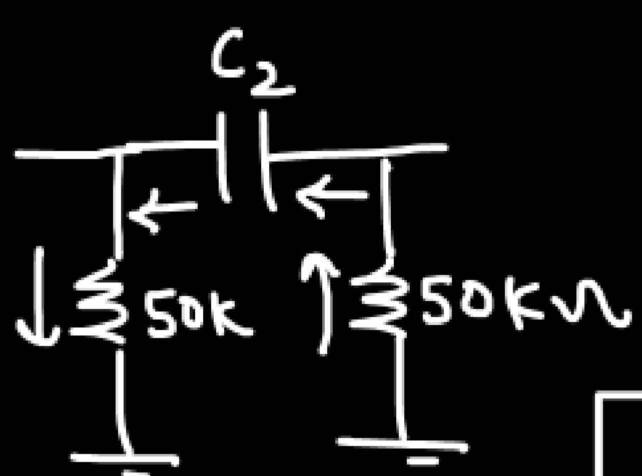
$= 192.4\,k\Omega$

$C_{eq} = C_1 = 100pf = 10^{-10} f$

$R_{eq} = 192.4 + 100 = 292.4\ k\Omega$

$$\boxed{\omega_{p_1} = \frac{1}{R_{eq} C_1} = 34.2\ K\,rad/sec.}$$

$\boxed{\text{Pole because of } C_2}$



$R_{eq} = 100k\Omega$

$C_2 = 100\,pf$

$$\boxed{\omega_{p_2} = \frac{1}{R_{eq} C_2} = 100\,k\,rad/sec.}$$

$$3\text{-dB cut-off freq.} = \max{}^{m}(\omega_{p_1}, \omega_{p_2})$$
$$= 100k \text{ rad/sec.}$$

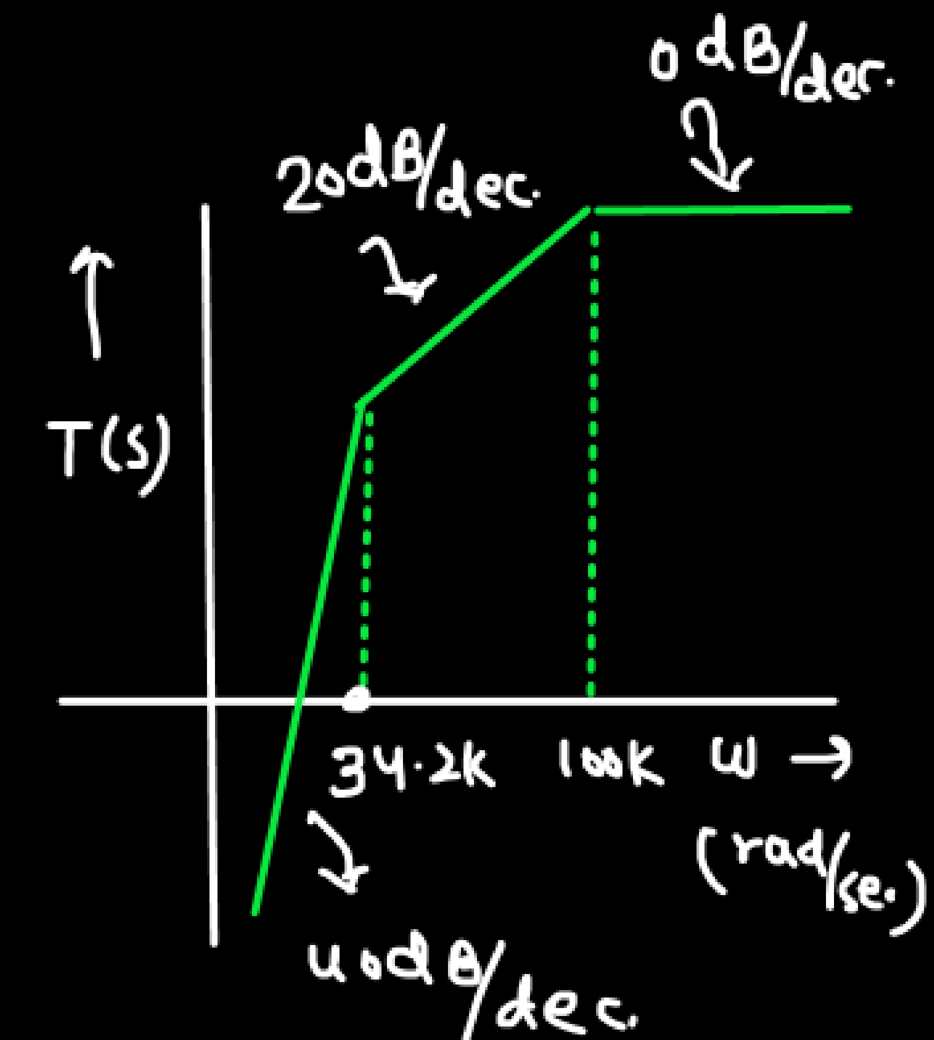
$$\boxed{\omega_{dB} = 15.91 \text{ kHz}}$$

@ $\omega = 0$, Because of C_2, v_o is zero

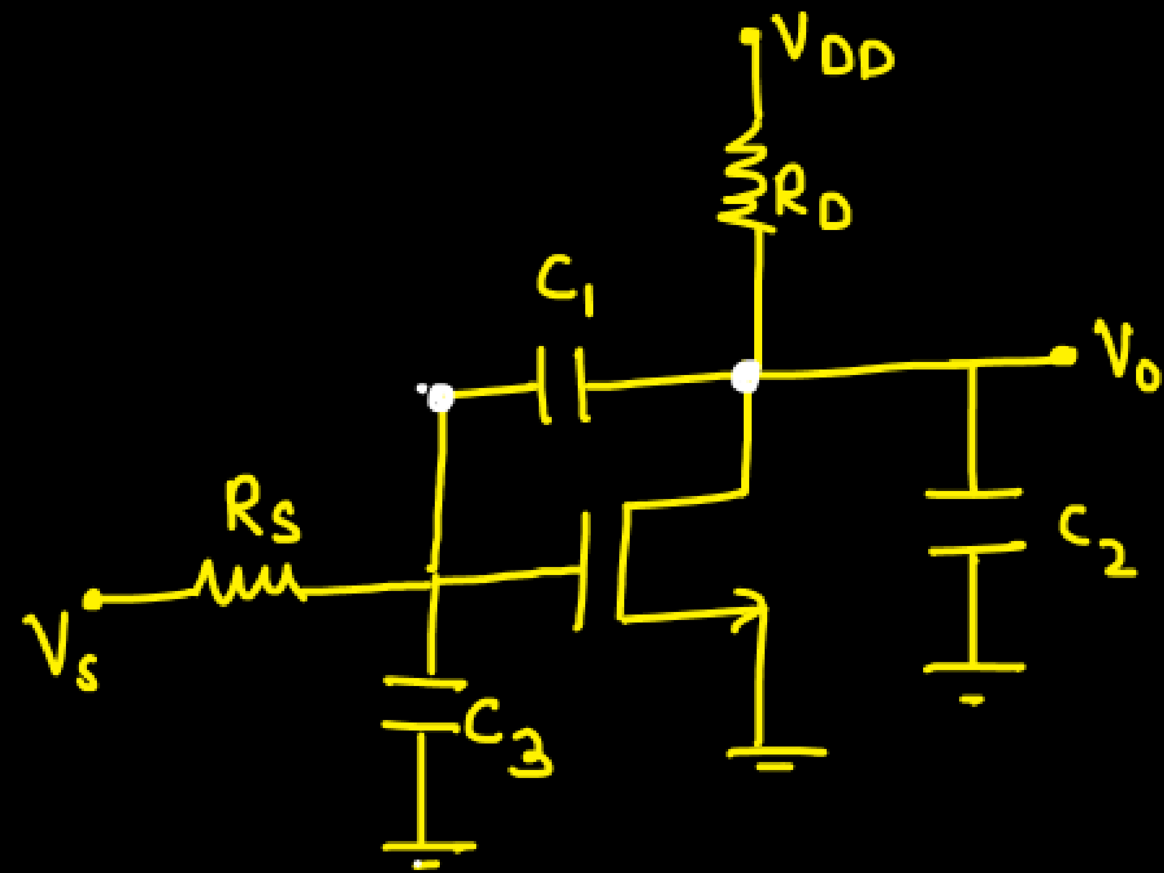
@ $\omega = 0$, Because of C_1, v_o is zero

$\Rightarrow$ you have two zeros @ $\omega = 0$

$$\boxed{T(s) = \frac{K s^2}{\left(\frac{s}{34.2k}+1\right)\left(\frac{s}{100k}+1\right)}}$$



Q.



Given that C_1, C_2 & C_3 are parasitic cap.

[C_1, C_2, C_3 → very low value. pF]

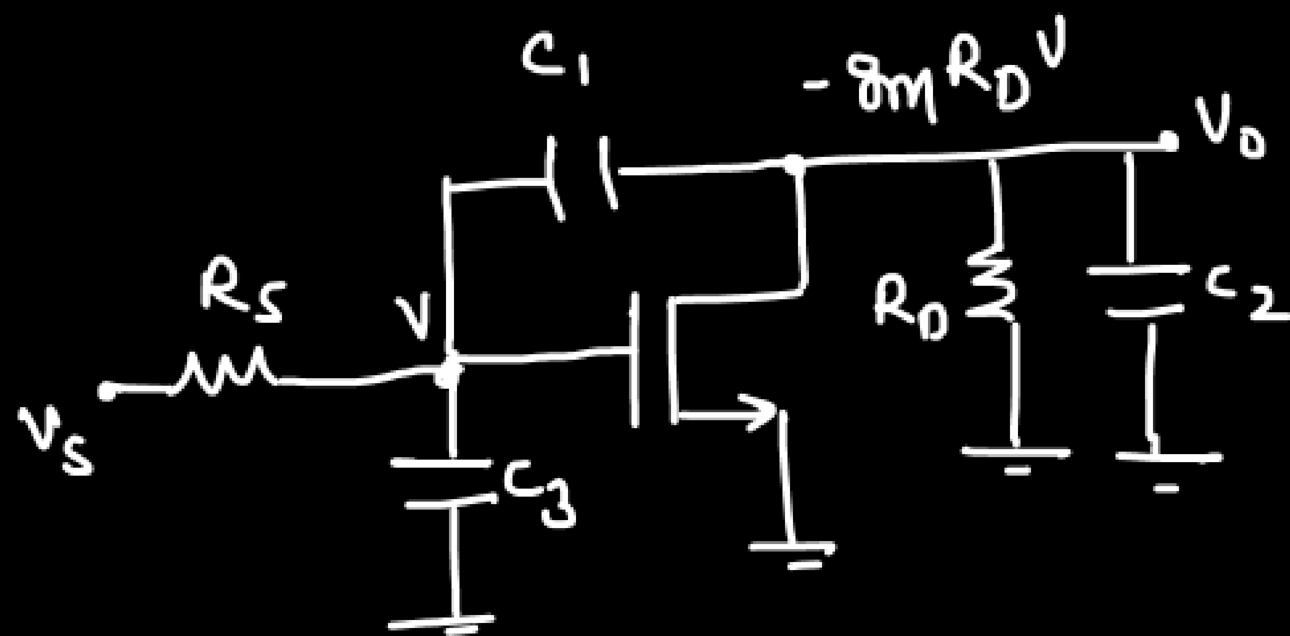
(a) Determine the order of the ckt.

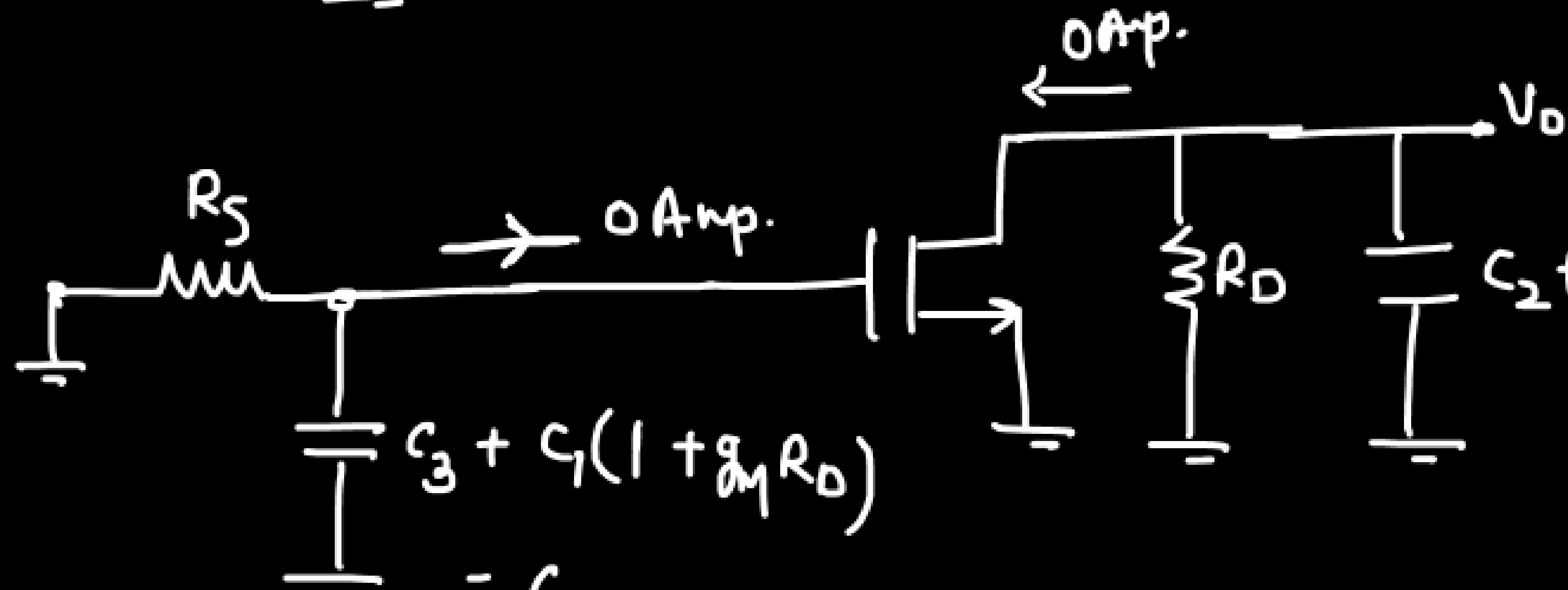
(b) Determine the location of poles.

(c) Draw freq. response.

(d) Tell 3-dB cut-off freq.

(a) 2nd order





$$C_3 + C_1(1 + g_m R_D) = C_a$$

$$C_2 + C_1\left[1 + \frac{1}{g_m R_D}\right] \approx C_1 + C_2 = C_b$$

$$\boxed{\omega_{p_1} = \frac{1}{R_S C_a}}$$

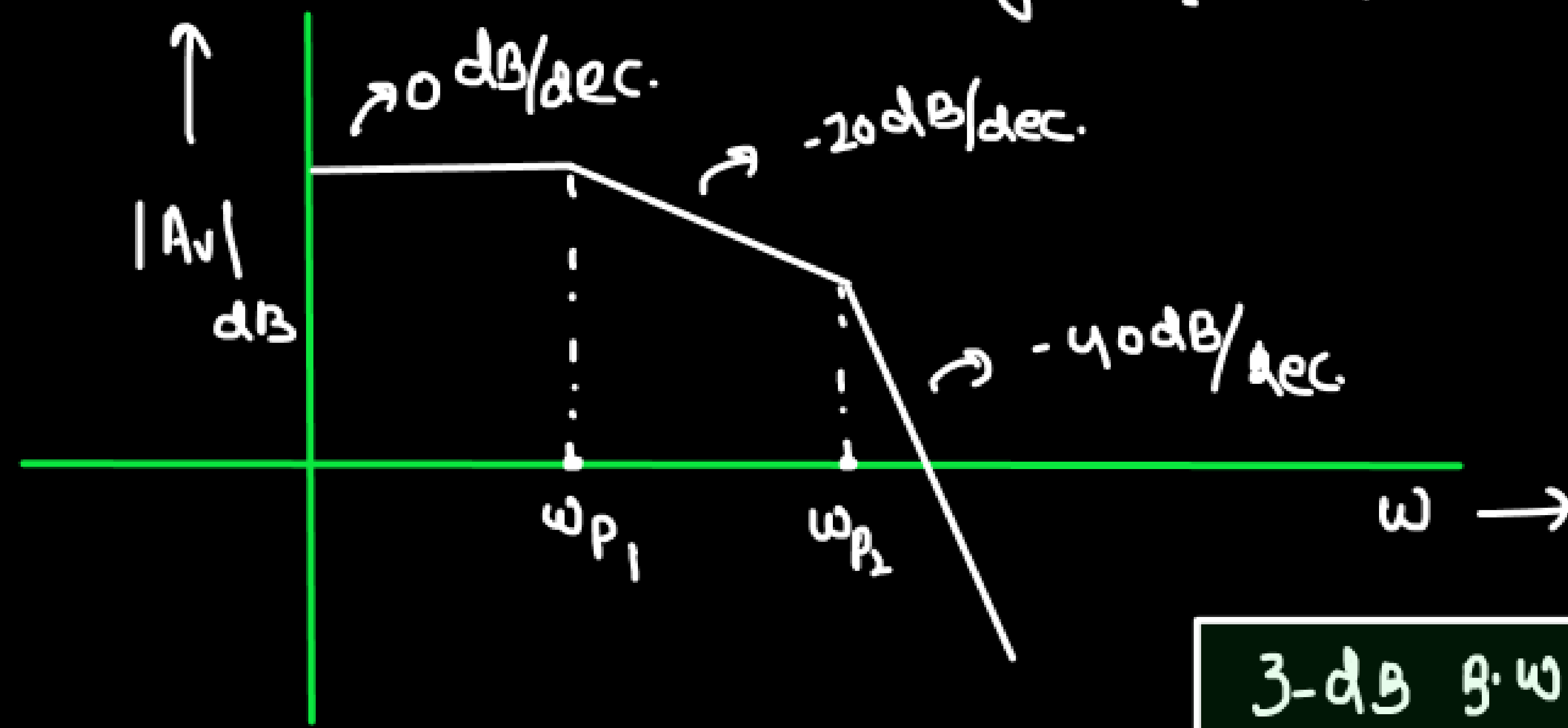
$$\boxed{\omega_{p_2} = \frac{1}{R_D C_b}}$$

Because of C_2, @ $\omega = \infty$, $V_o = 0$ $\Rightarrow$ zero @ ∞

Because of C_3, @ $\omega = \infty$, $V_o = 0$ $\Rightarrow$ zero @ ∞

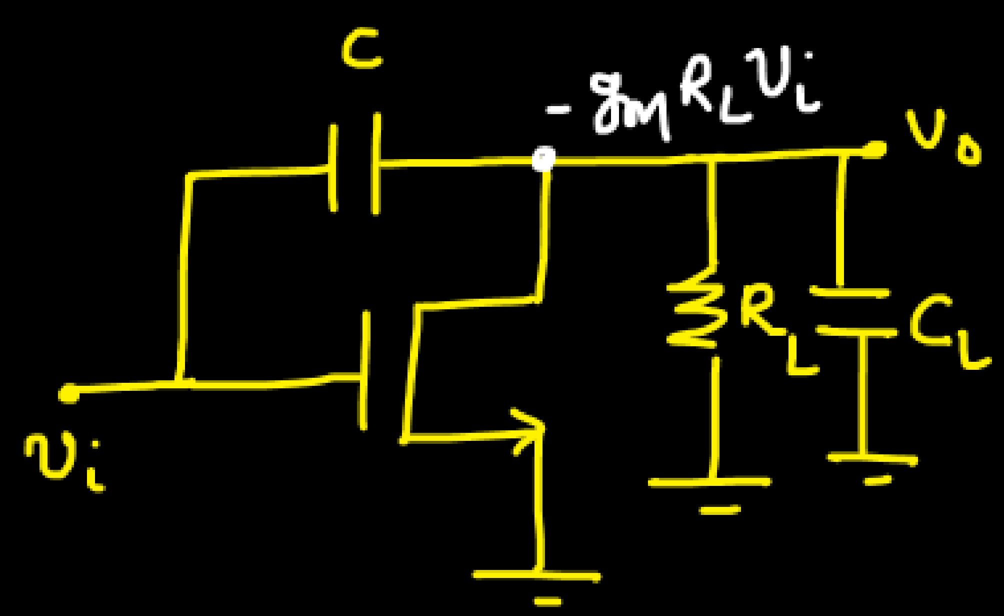
$$\boxed{T.F. = \frac{-g_m R_D}{\left\{sR_S\left[C_3 + C_1\left(1 + g_m R_D\right)\right] + 1\right\}\left\{sR_D\left(C_1 + C_2\right) + 1\right\}}}$$

considering $\omega_{p_2} > \omega_{p_1}$



$$\boxed{3\text{-dB B.W.} = \omega_{p_1}}$$

③



Q. Draw Bode plot. Considering

(a) $R_L C_L >> \frac{C}{g_m}$

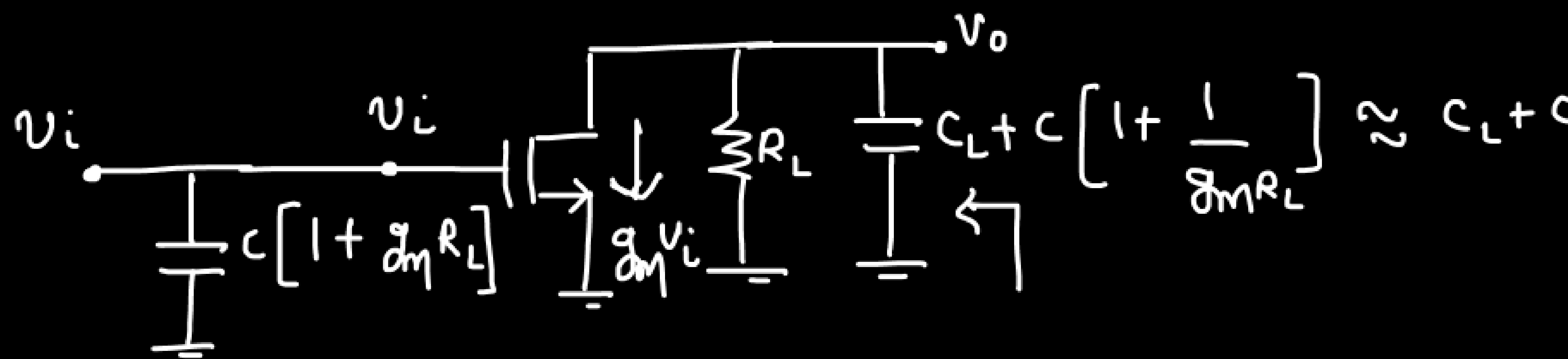
(b) No cond^n

⇒ Compare your results.

⇒ 1st order

(a) Since, C is very low

$\Rightarrow$ I can apply millers Theorem



$$\boxed{A_V = G_m R_{out}}$$

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

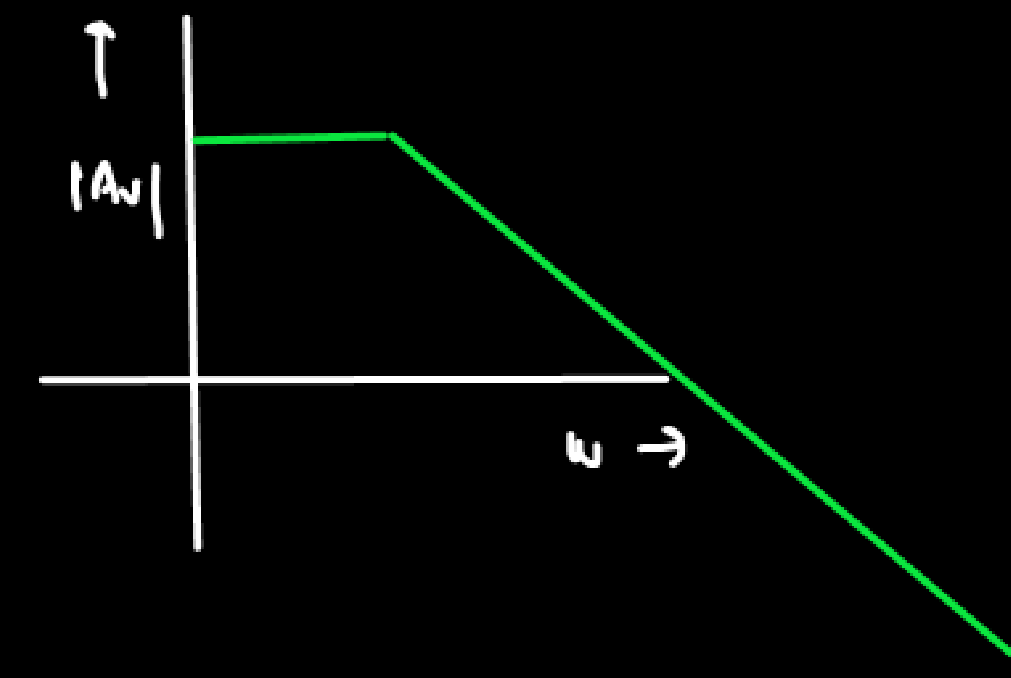
$$\boxed{R_{out} = R_L \parallel \frac{1}{(C_L+C)s}}$$

$$\boxed{A_V = -g_m\left[R_L \parallel \frac{1}{(C_L+C)s}\right]}$$

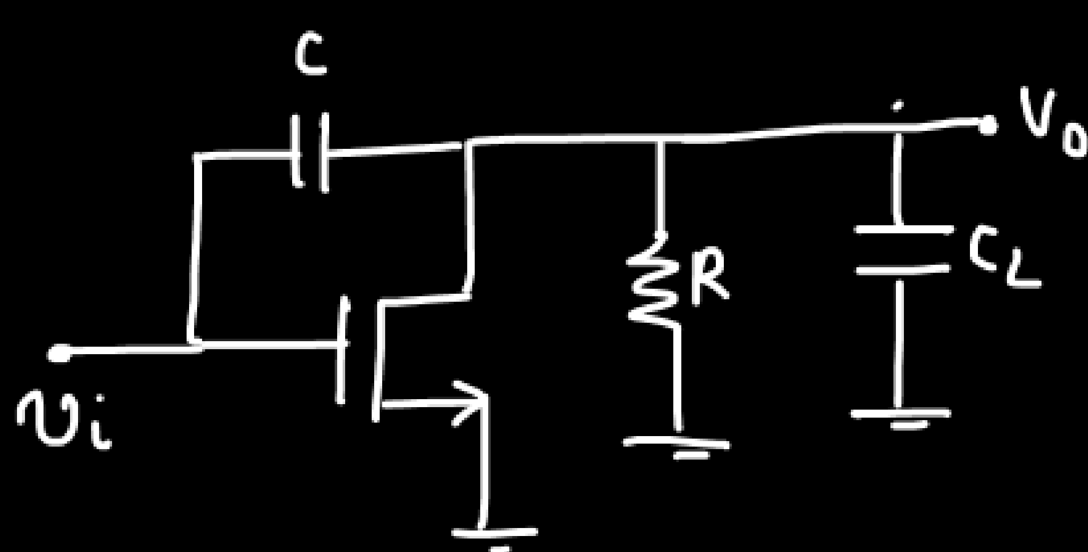
$$A_v = \frac{-g_m R_L}{R_L[C_L + C]s + 1}$$

$$\boxed{\omega_p = \frac{-1}{R_L[C_L + C]}}$$

$$\boxed{\omega_z = \infty}$$



(b)



$$G_m = ?$$

$$I_{out} = -[g_m v_i - v_i C s]$$

$$\boxed{\frac{I_{out}}{v_{in}} = G_m = -[g_m - Cs]}$$

$$R_{out} = R_L \,||\, \frac{1}{(C_L + C)s}$$

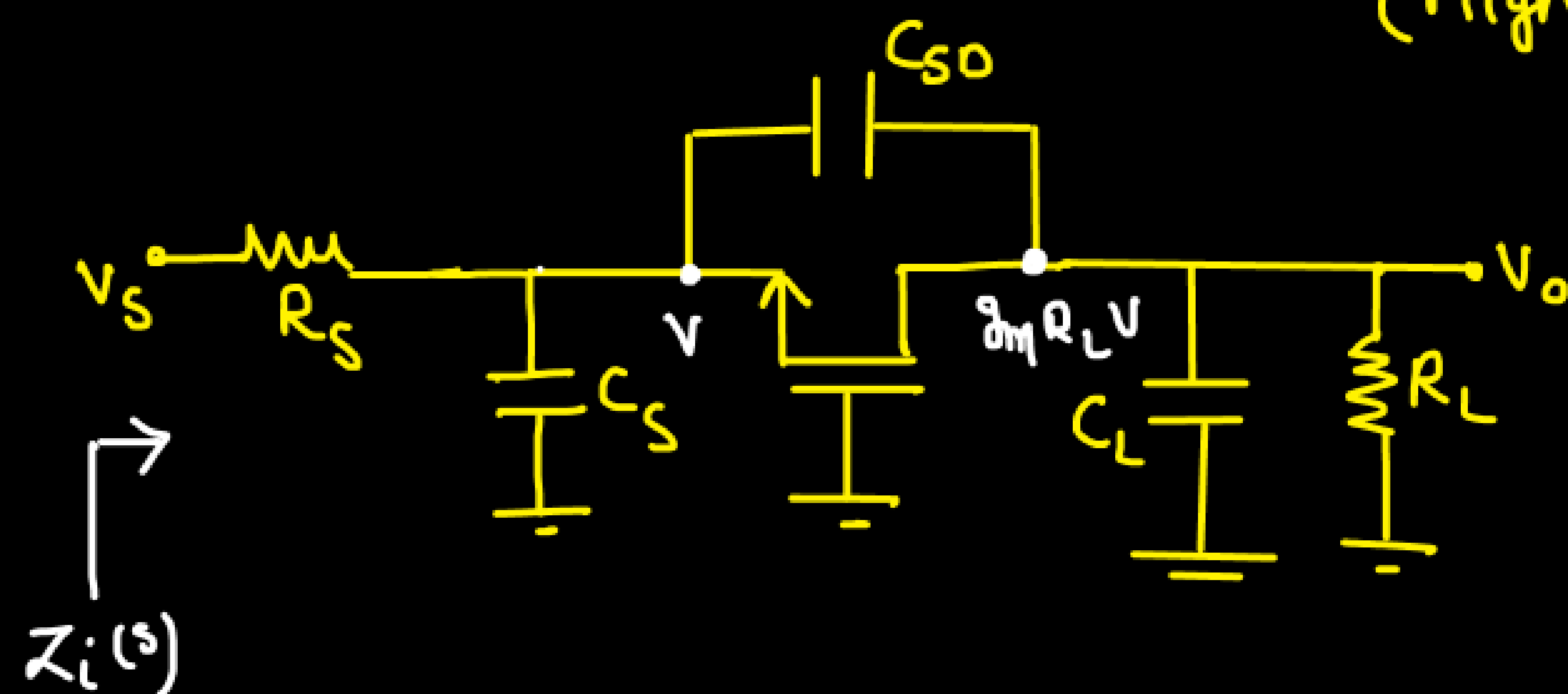
$$A_v = \left[-g_m + Cs\right]\left[\frac{R_L}{R_L(C_L+C)s+1}\right]$$

$$\boxed{A_v = \frac{-\left[g_m - Cs\right]R_L}{R_L(C_L+C)s+1}}$$

$$\boxed{\omega_p = \frac{-1}{R_L(C_L+C)}} \quad , \quad \boxed{\omega_z = \frac{g_m}{C}}$$

Frequency Response for Common Gate Amplifiers:-

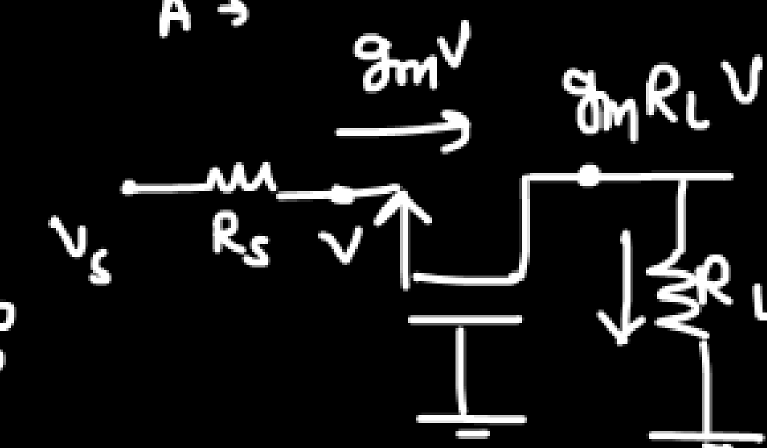
(High frequency)



$$\boxed{\text{order} = 2^{nd}}$$

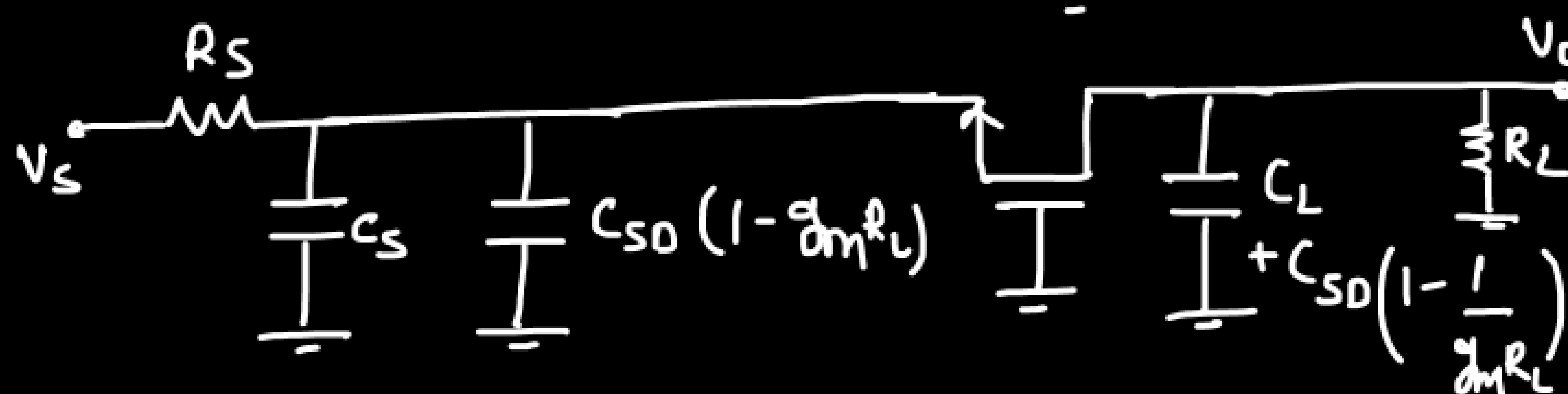
$C_{SD}, C_S, C_L \rightarrow$ Parasitics

$A \rightarrow$



$$\boxed{A = g_m R_L}$$

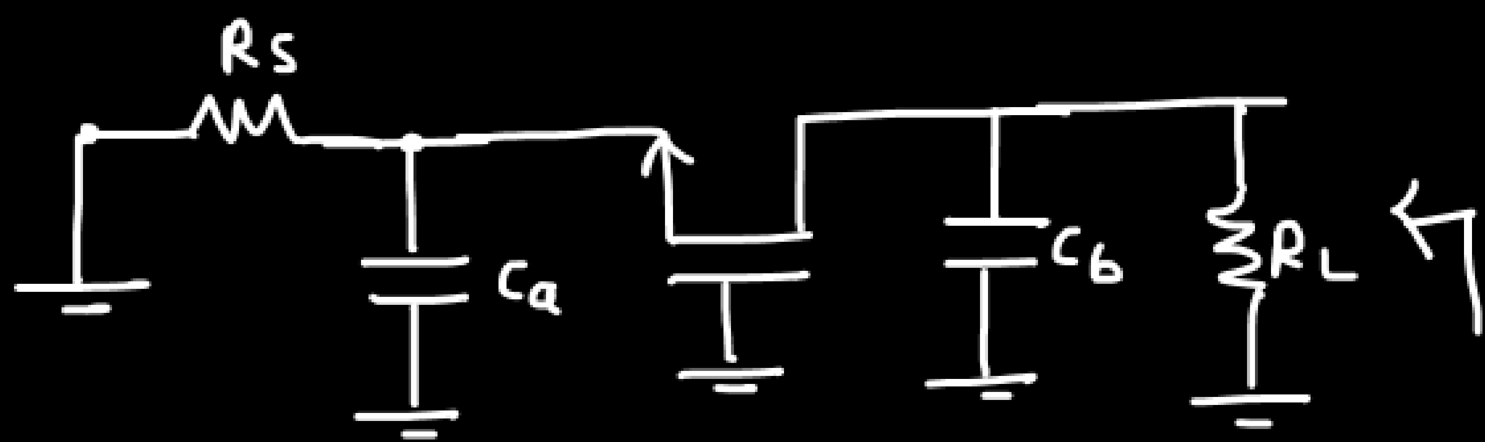
$\rightarrow$



$\simeq C_L + C_{SD}$

$$\omega_{z_1} = \infty \quad , \quad \omega_{z_2} = \infty$$

Poles:-



Equivalent resis. across

$C_b \rightarrow R_L$

$$\boxed{\omega_{p_2} \text{ or } \omega_{p_1} = \frac{1}{C_b R_L}}$$

$$C_a = C_s + C_{SD}[1 - g_m R_L]$$

$$C_b = C_s + C_{SD}\left[1 - \frac{1}{g_m R_L}\right] \approx C_s + C_{SD}$$

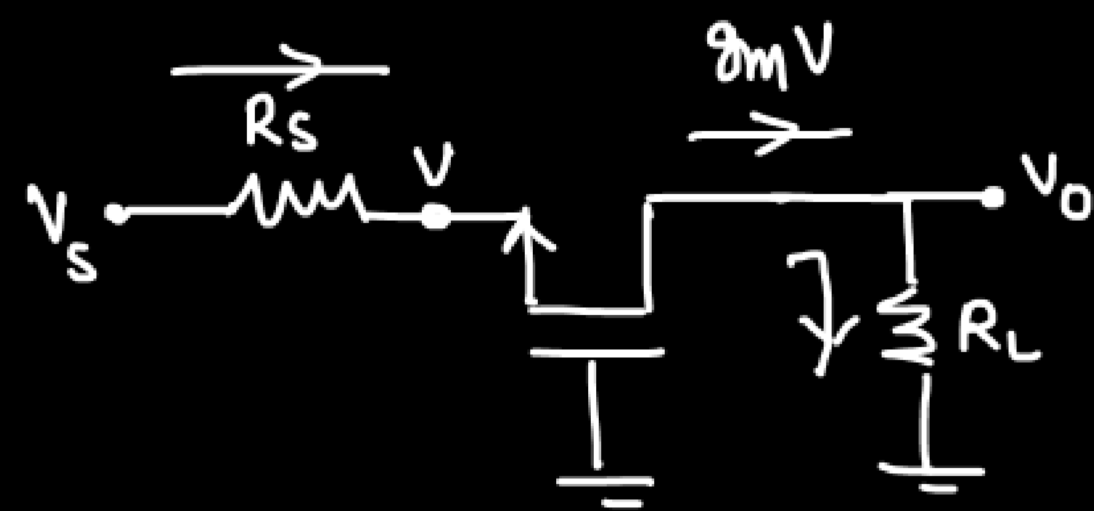
Equivalent res. across $C_a \rightarrow R_s \| 1/g_m$

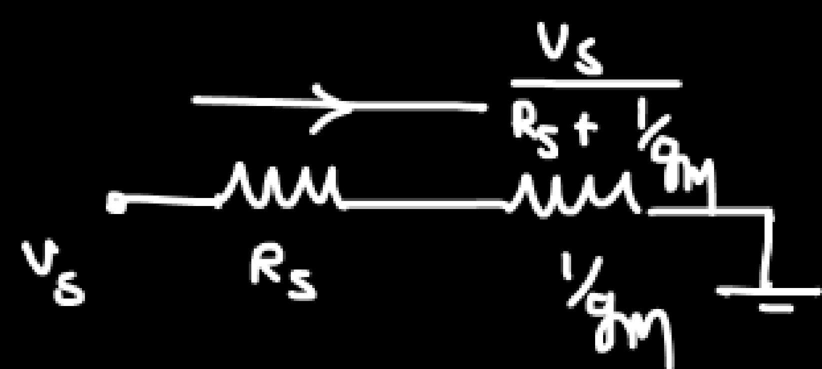
$$\boxed{\omega_{p_1} \text{ or } \omega_{p_2} = \frac{1}{C_a[R_s \| 1/g_m]}}$$

Dc gain:-

$$K = ? = \frac{V_0(\omega=0)}{V_s(\omega=0)}$$

K →

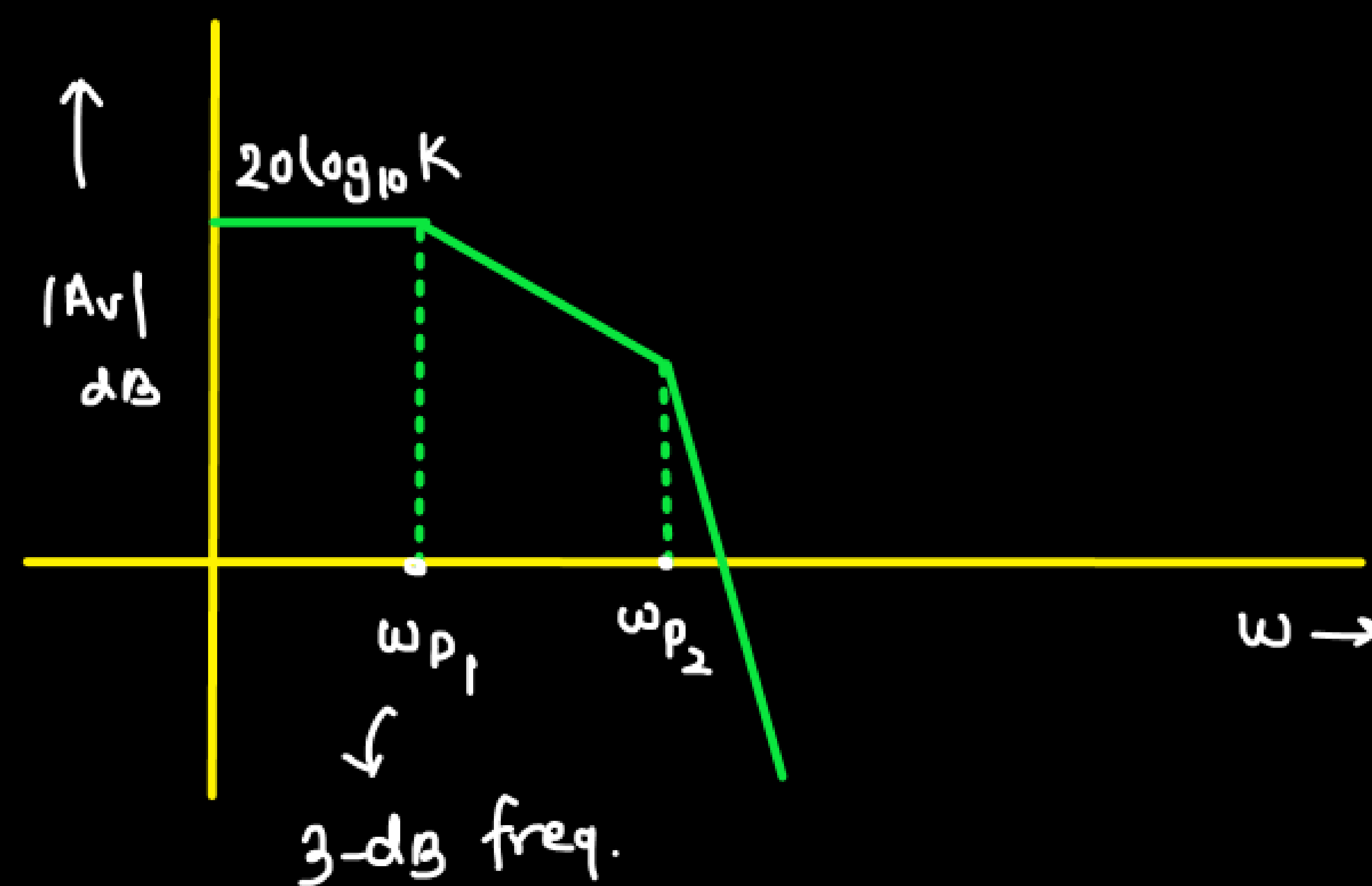




$$V_o = \frac{V_s}{R_s + 1/g_m} \times R_L$$

$$\boxed{\frac{V_o}{V_s} = \frac{g_m R_L}{1 + g_m R_S}} = K$$

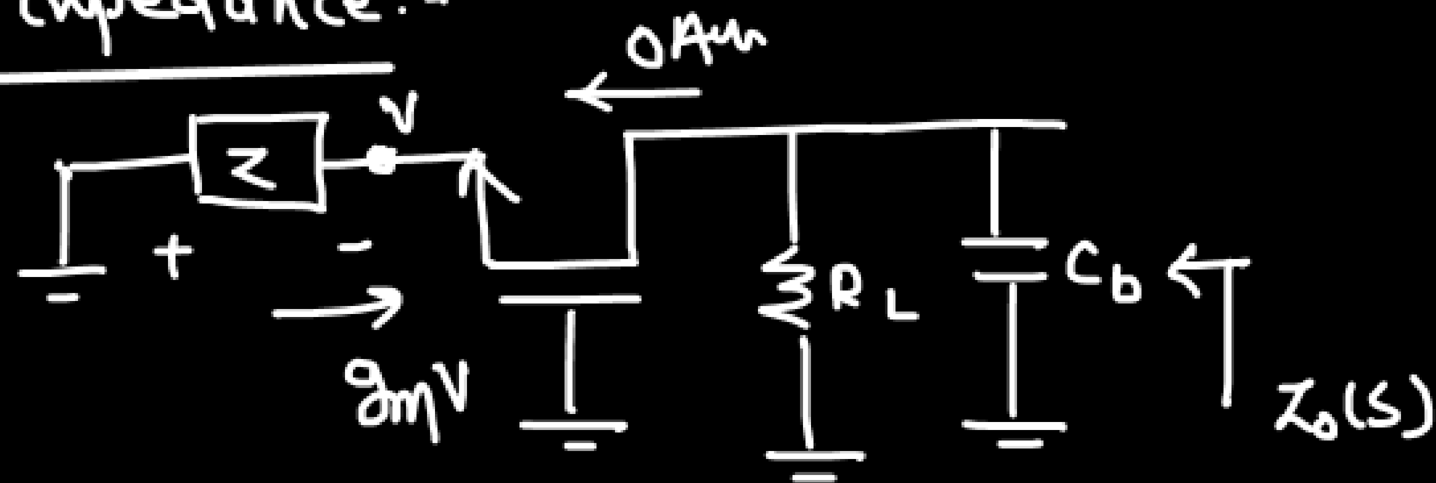
$$T(s) = \frac{K}{\left(\frac{s}{\omega_{p_1}}+1\right)\left(\frac{s}{\omega_{p_2}}+1\right)}$$



input resistance:-

$$\boxed{Z_i(s) = R_s + \frac{1}{C_a s} \parallel 1/g_m}$$

output impedance:-



**

$$\boxed{Z_o(s) = \frac{1}{C_b s} \parallel R_L}$$

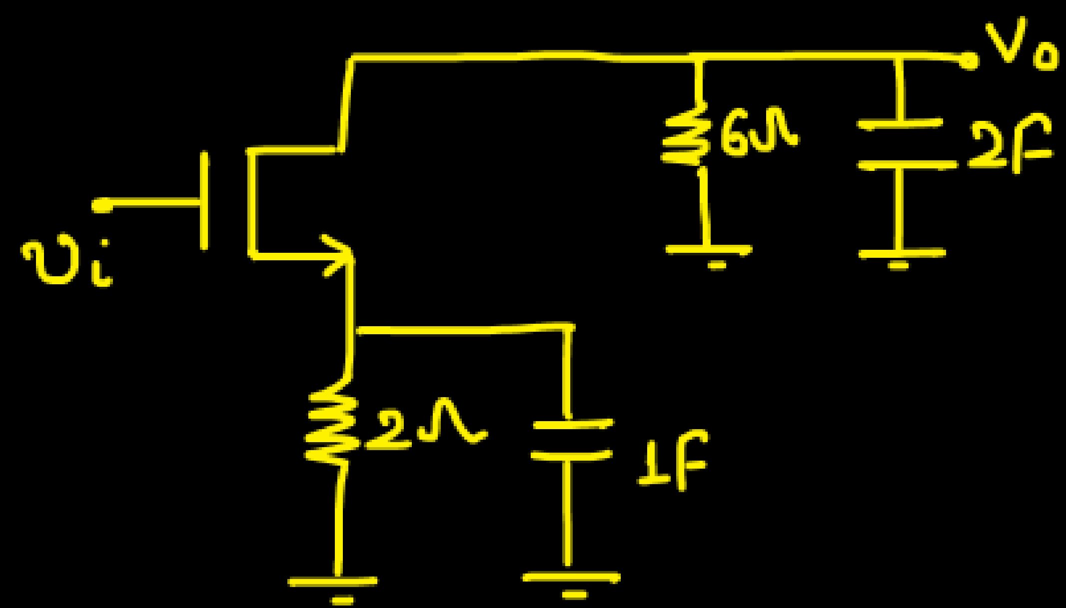
$$-g_m Z V = V$$

$$V[1 + g_m Z] = 0$$

$$\boxed{V = 0}$$

Assignment-10

Q.



Given, $g_m = 0.5\,S$

N.B. → These are not the typical values of g_m, resistance and cap.

① Find 3-dB B.W. and freq. response.

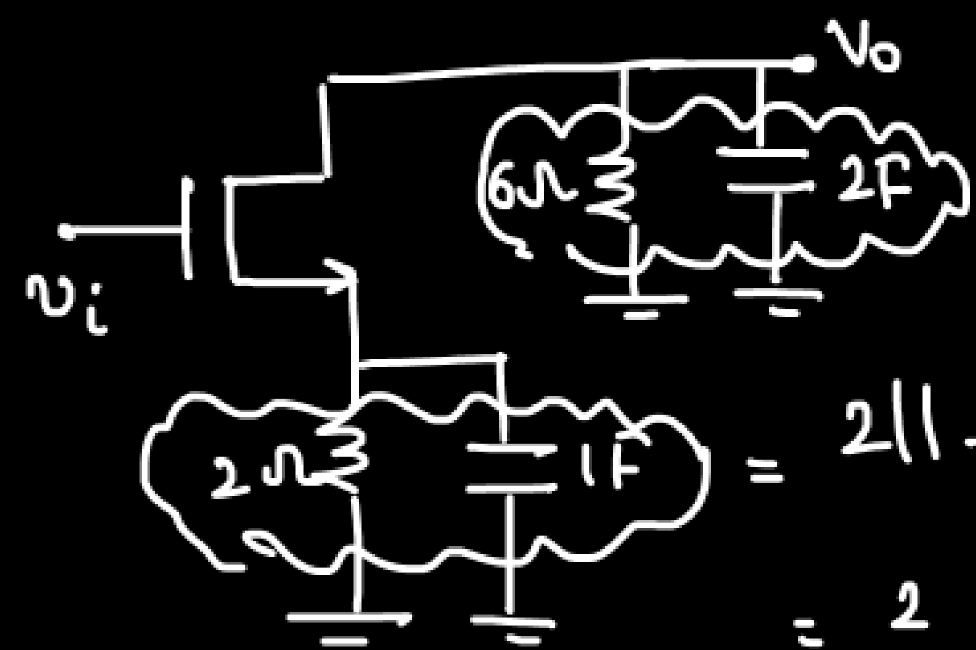
② Tell the location of poles and zeros.

③ If small signal i/p

$$v_i = 20mV \sin\left(\frac{3}{4}t\right)$$

Find v_o?

→



$$Z_L(s) = 6 \,\|\, \frac{1}{2s} = \frac{6}{12s+1}$$

$$= 2 \,\|\, \frac{1}{s} = \frac{2}{2s+1} = Z(s)$$

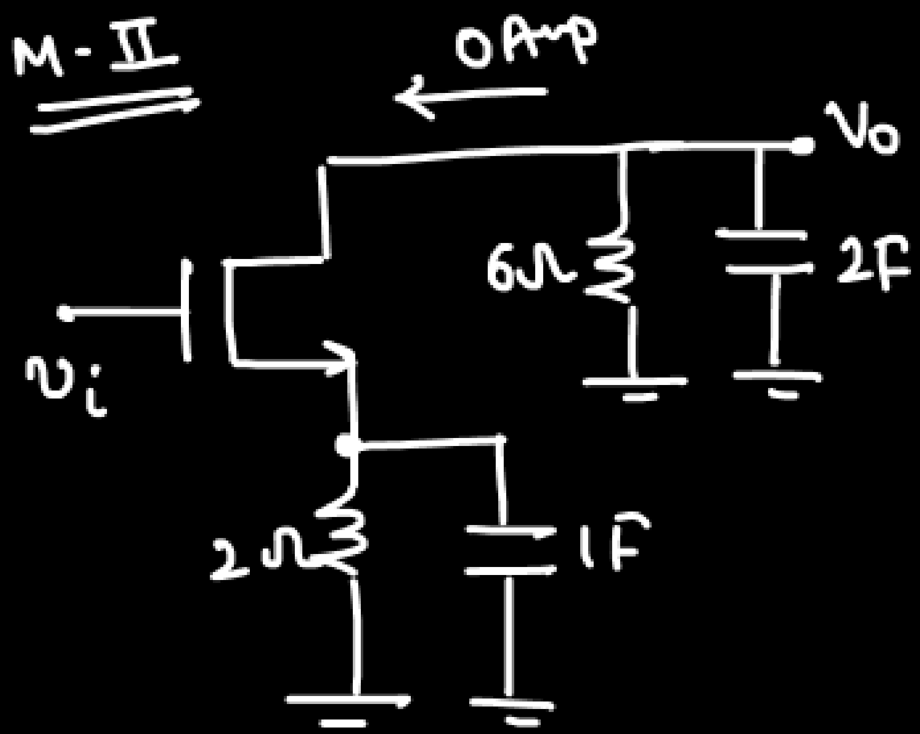
$$\frac{V_o(s)}{V_i(s)} = \frac{-g_m Z_L(s)}{1 + g_m Z(s)}$$

$$= \frac{-0.5\left(\frac{6}{12s+1}\right)}{1 + 0.5\left(\frac{2}{2s+1}\right)}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{-\frac{3}{12s+1}}{1 + \frac{1}{2s+1}} = \frac{-3(2s+1)}{(12s+1)(2s+2)}$$

$$\boxed{\frac{V_o(s)}{v_i(s)} = \frac{-1.5(2s+1)}{(12s+1)(s+1)}}$$

M-II



$\boxed{\text{order} = 2^{nd}}$

Poles:-

$$\boxed{\omega_{p_2} = \frac{1}{1F\left(2\Omega \parallel \frac{1}{g_m}\right)} = \frac{1}{1F(2\Omega \parallel 2\Omega)} = 1 \text{ rad/sec.}}$$

$$\boxed{\omega_{p_1} = \frac{1}{2F(6)} = \frac{-1}{12} \text{ rad/sec.}}$$

DC gain:-

$$\boxed{K = \frac{-g_m R_L}{1+g_m R_S} = \frac{-3}{1+1} = -1.5}$$

$$\boxed{T(s) = \frac{-1.5(2s+1)}{(12s+1)(s+1)}}$$

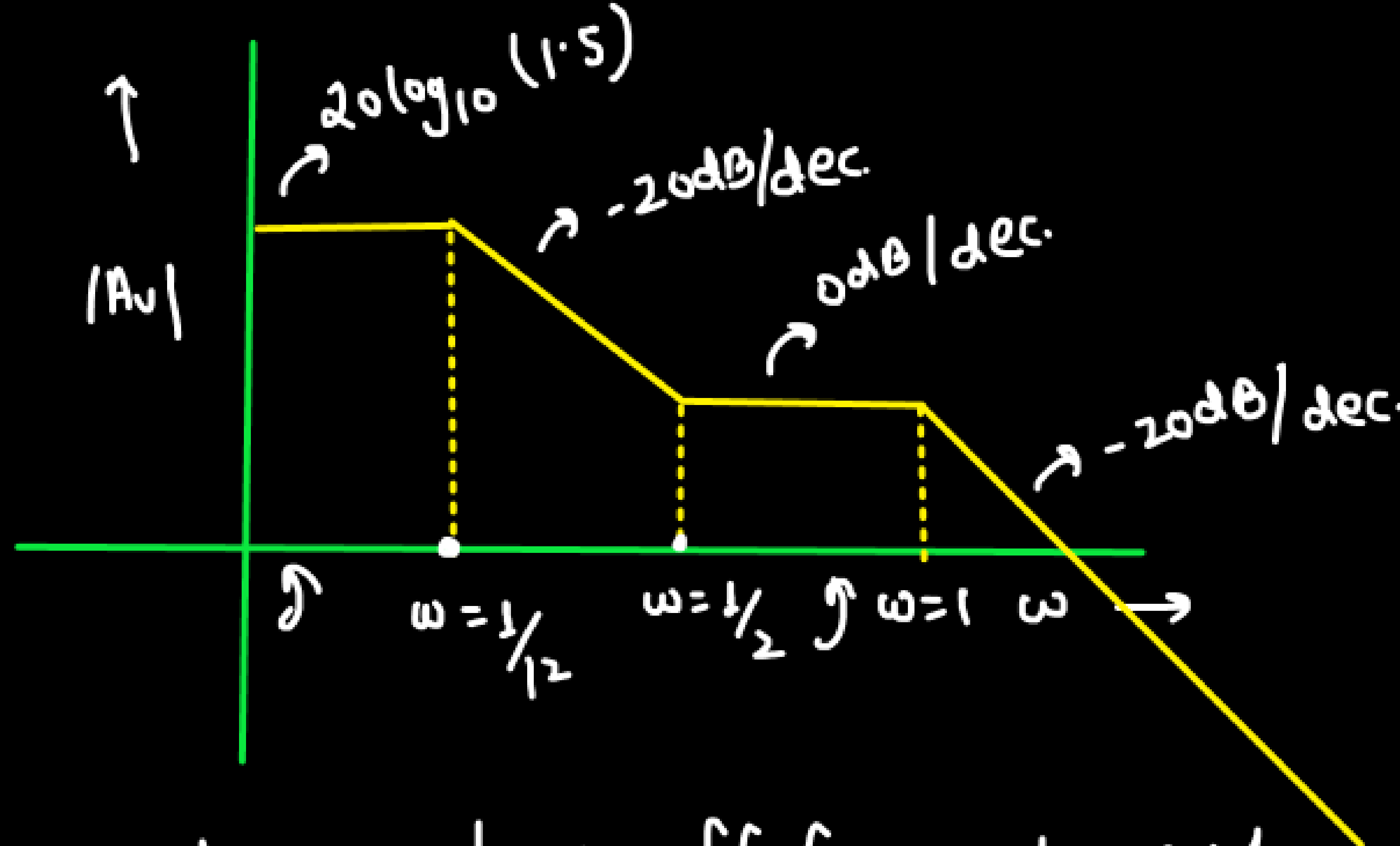
Zeros:-

$\boxed{\omega_{z_1} = \infty}$ (2F)

$\omega_{z_2} = ? \Rightarrow 2\Omega \parallel \frac{1}{1s} = \infty \Rightarrow \frac{2}{2s+1} = \frac{1}{0}$

$$\boxed{\omega_{z_2} = -1/2}$$

Freq. response:-



3-dB B.w. / cut-off freq = $\frac{1}{12}$ rad/sec.

(iii) $V_i = 20mV \sin\left(\frac{3}{4}t\right)$; $\omega_i = \frac{3}{4}$ rad/sec.

$$\frac{V_o(s)}{V_i(s)} = \frac{-1.5(2s+1)}{(12s+1)(s+1)}$$

$$20mV \sin\left(\frac{3}{4}t\right) \longrightarrow \boxed{\frac{-1.5(2s+1)}{(12s+1)(s+1)}} \longrightarrow ?$$

$$\rightarrow \quad T\left(j\tfrac{3}{4}\right) = \frac{-1.5\left(2j\times\frac{3}{4}+1\right)}{\left(12\times j\frac{3}{4}+1\right)\left(j\frac{3}{4}+1\right)} = \frac{-1.5(6j+4)\times 4}{(j36+4)(j3+4)}$$

$$\left|T\left(j\tfrac{3}{4}\right)\right| = -0.24$$

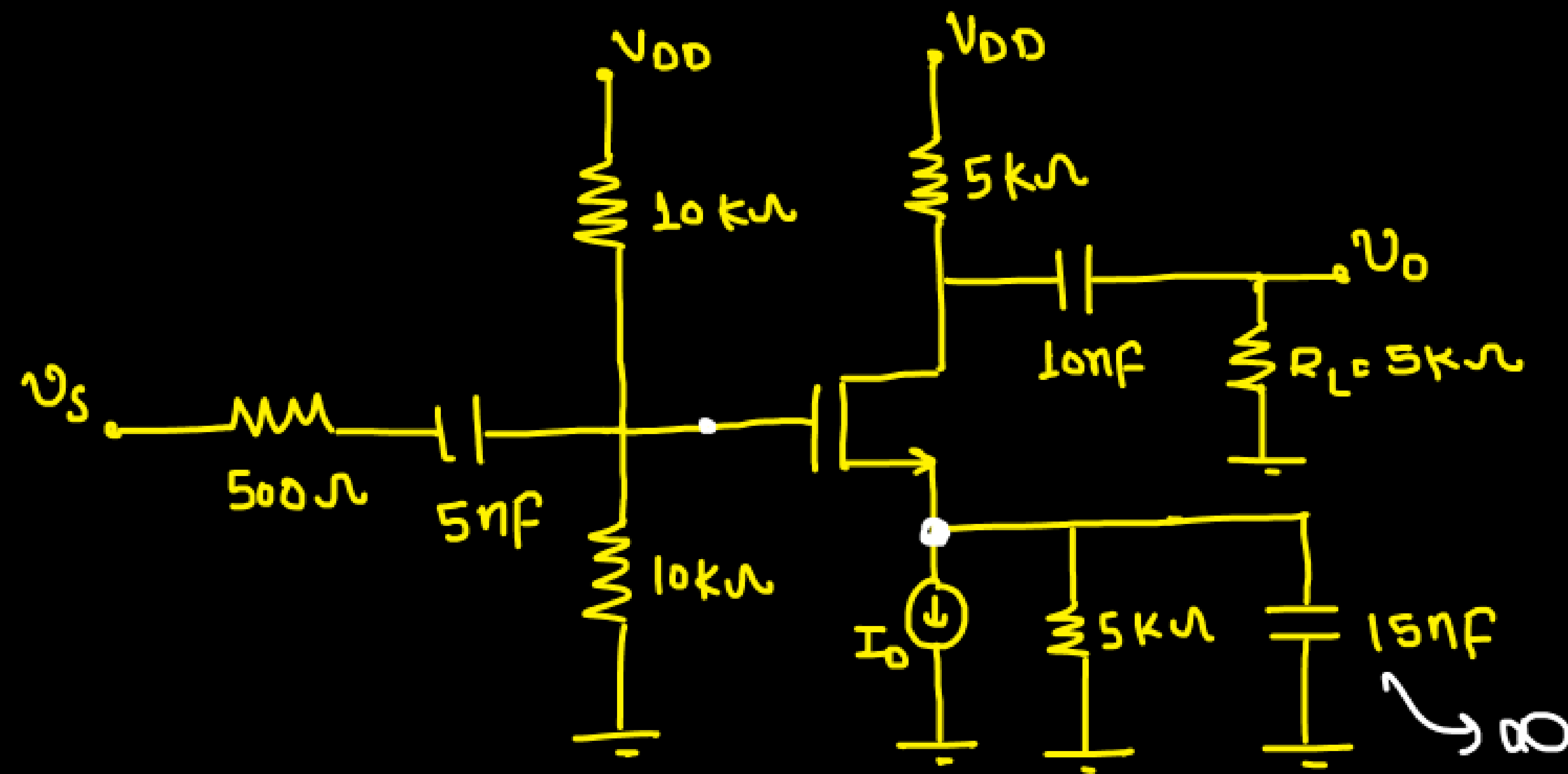
$$\angle T\left(j\tfrac{3}{4}\right) = -244.2^\circ$$

$$\left[-180^\circ + \tan^{-1}\left(\frac{6}{4}\right) - \tan^{-1}\left(\frac{36}{4}\right) - \tan^{-1}\left(\frac{3}{4}\right)\right]$$

**

$$\Rightarrow \quad \boxed{v_0(t) = 4.8mV \sin\left(\frac{3}{4}t - 244.2^\circ\right)}$$

Q.



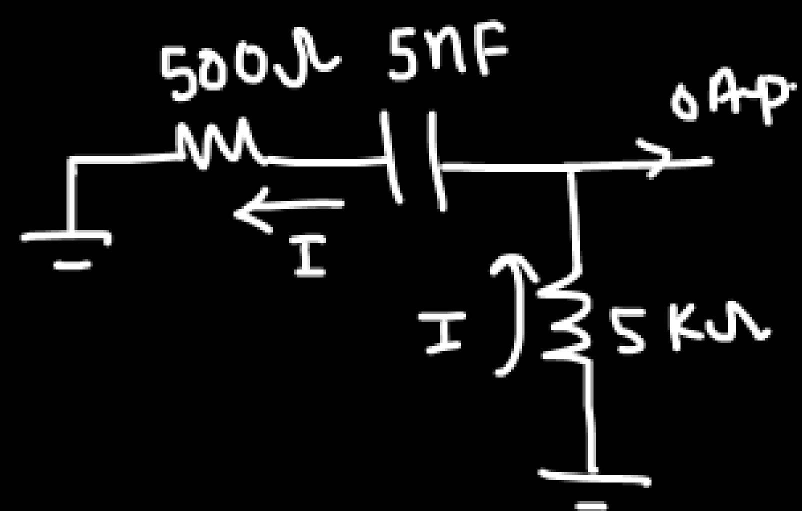
$g_m = 200\,\mu S$

(a) Find the location of poles and zeros.

(b) Find the 3-dB cut-off frequency.

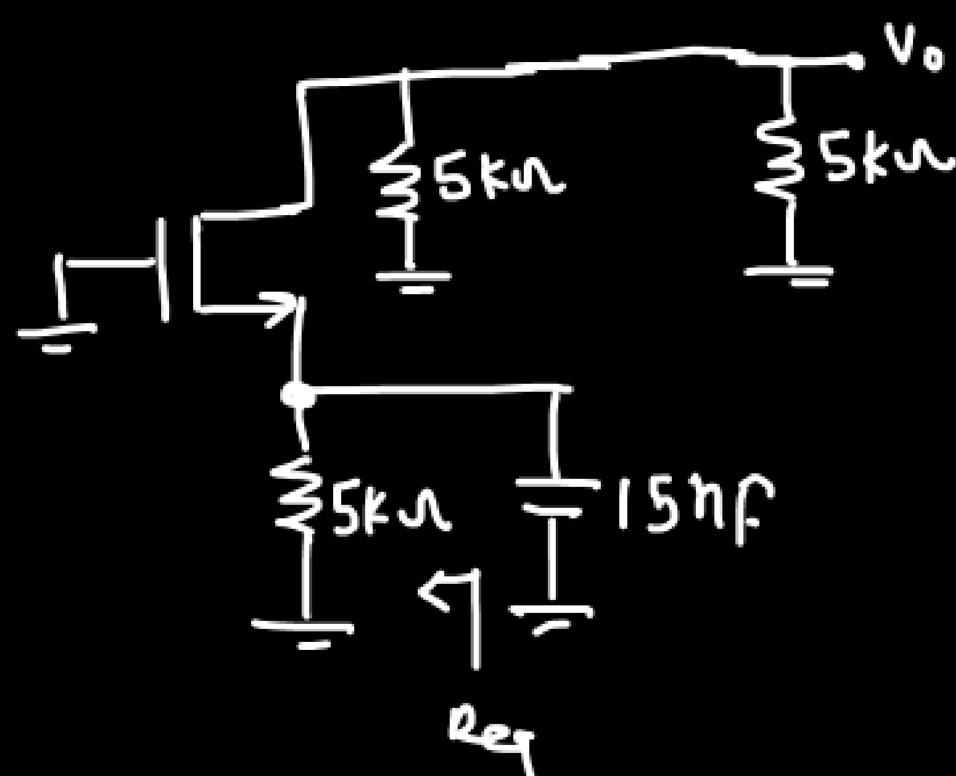
→ $\omega_{z_1} = 0$, $\omega_{z_2} = 0$ $\quad \omega_{z_3} = \dfrac{-1}{15\eta \times 5K} = -13.33\,\text{K rad/sec.}$

Req. across 5nF:-



$$\omega_{p_3} = \frac{1}{5n \times 5.5K} = -36.36\ \text{krad/sec.}$$

15nF:-



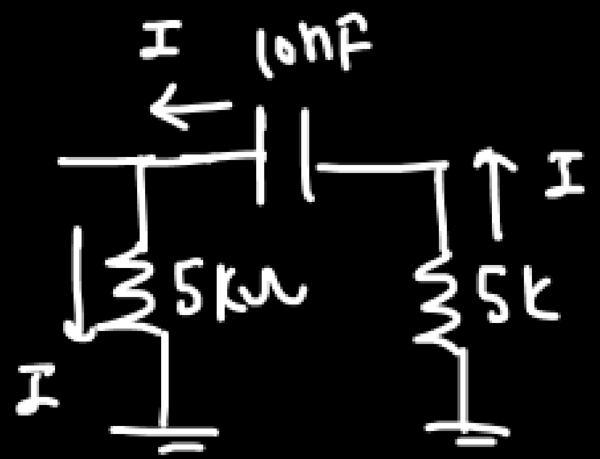
$$R_{eq} = 5K \,||\, \frac{1}{g_m} = 5K \,||\, 5K = 2.5K$$

$$[g_m = 200\,\mu S]$$

$$\omega_p = \frac{1}{15n \times 2.5K}$$

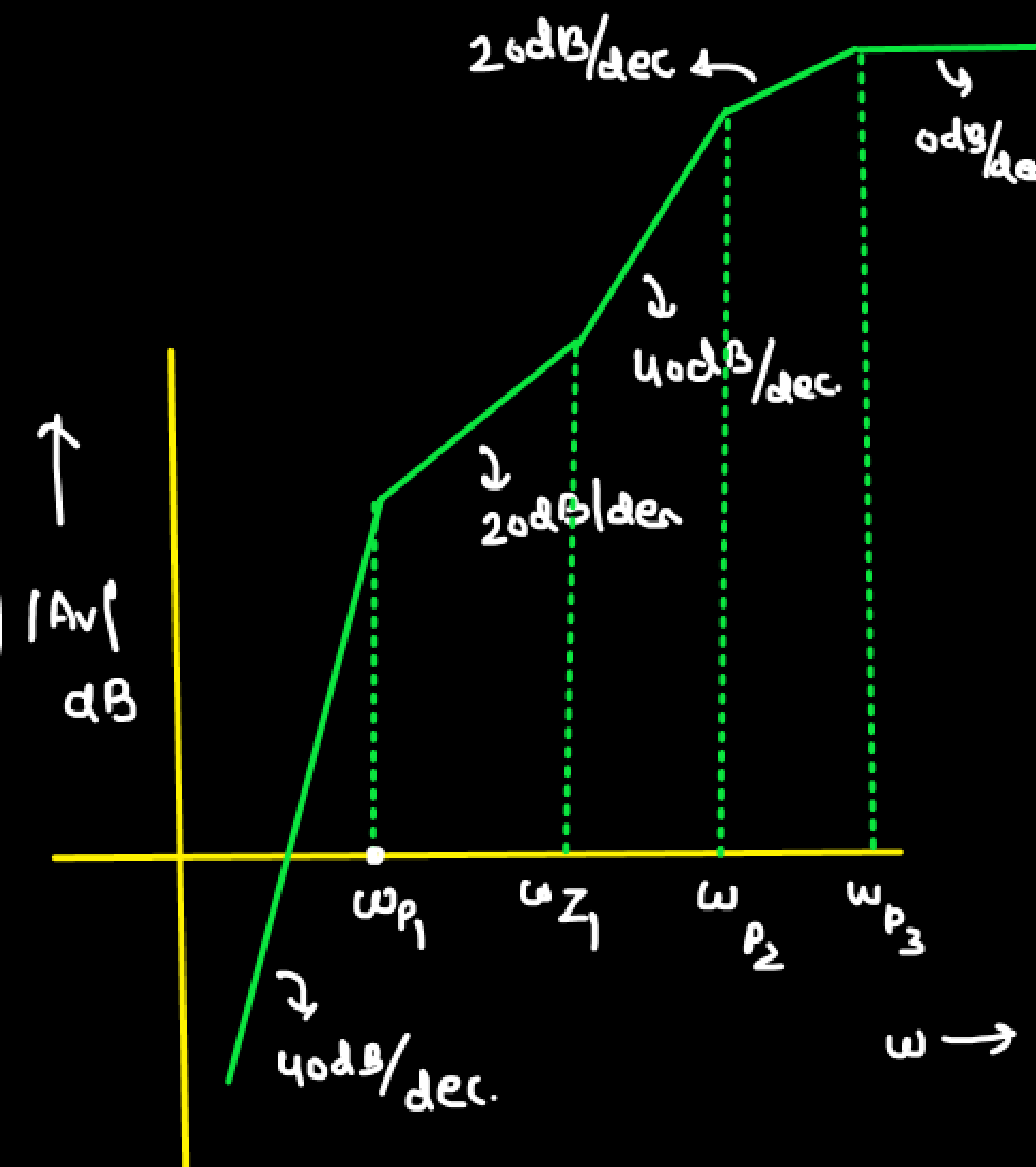
$$\omega_{p_2} = -26.67\ \text{Krad/sec.}$$

10nF :-



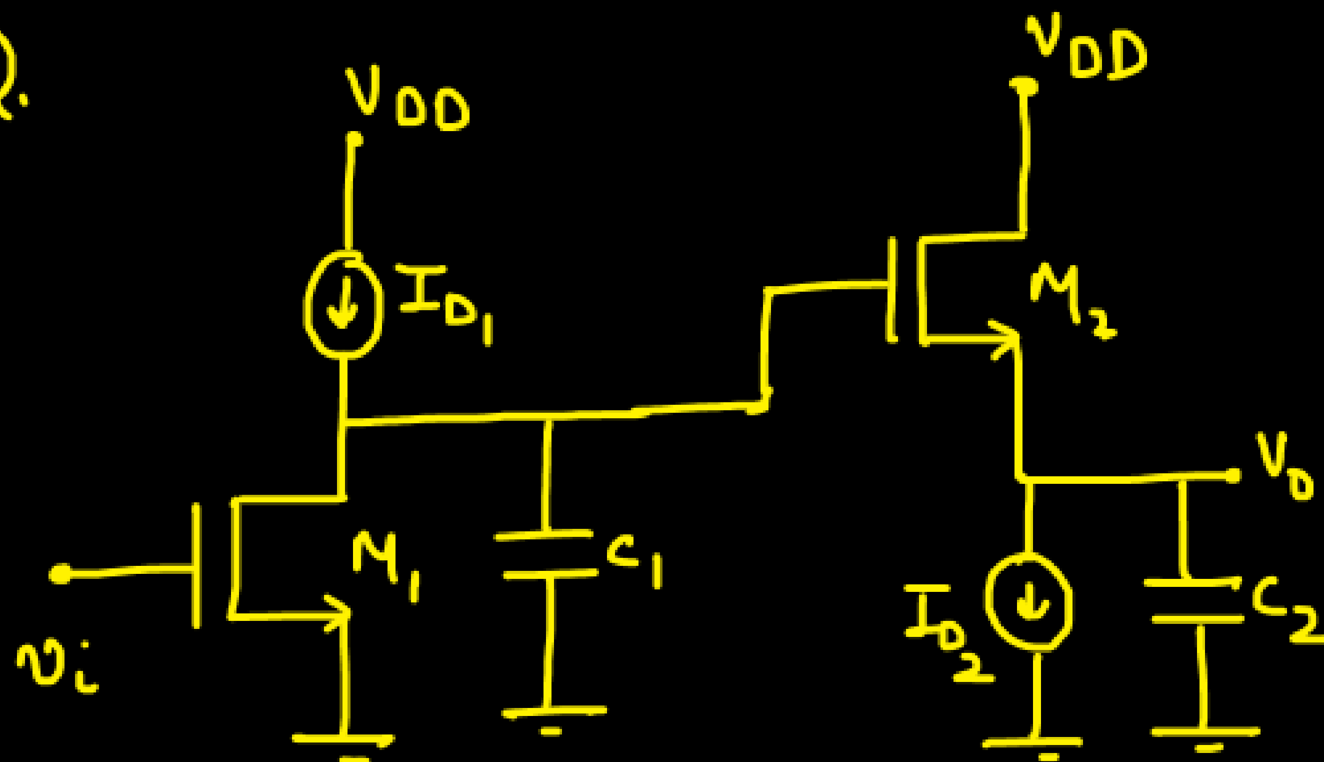
$$\omega_{p_1} = \frac{1}{10n \times 10K} = -10k\ \text{rad/sec}$$

$$T(s) = \frac{A s^2 \left(\frac{s}{13.33k} + 1\right)}{\left(\frac{s}{10k} + 1\right)\left(\frac{s}{26.67k} + 1\right)\left(\frac{s}{36.36k} + 1\right)}$$



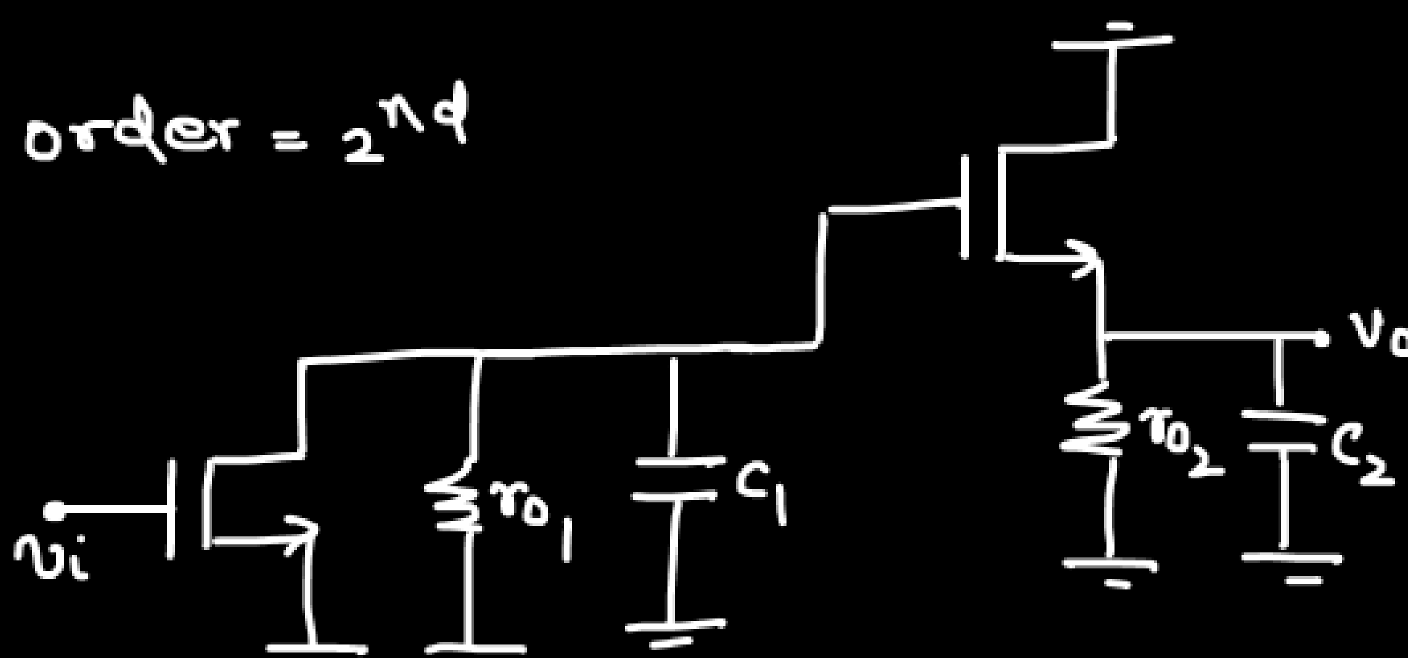
$$\boxed{\text{3-dB cut-off freq.} = 36.36\ \text{krad/sec.}}$$

Q.



Write down the frequency response intuitively.

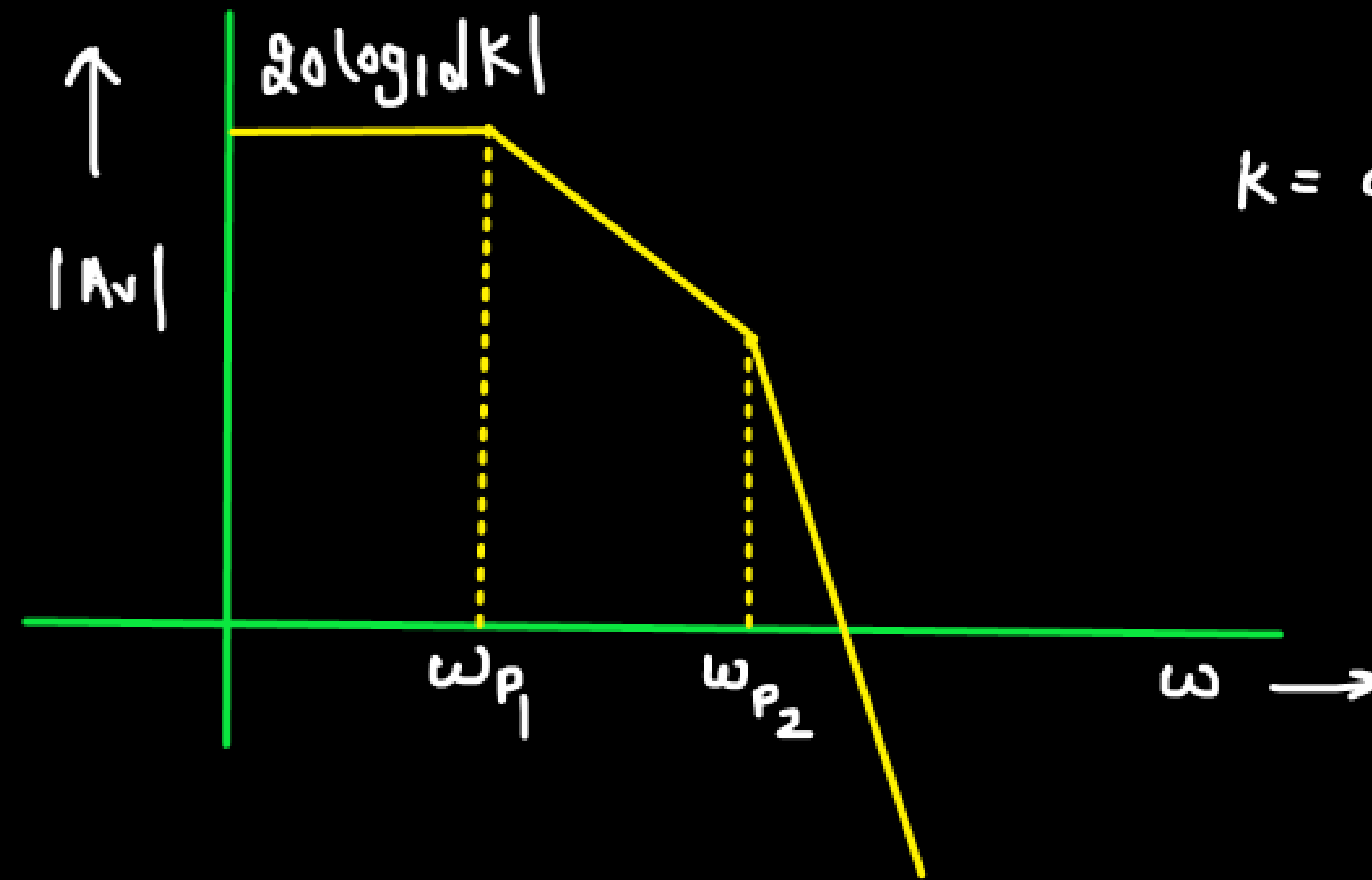
→ order = 2^{nd}



$$\omega_{p_1} \text{ or } \omega_{p_2} = \frac{-1}{r_{o_1} C_1}$$

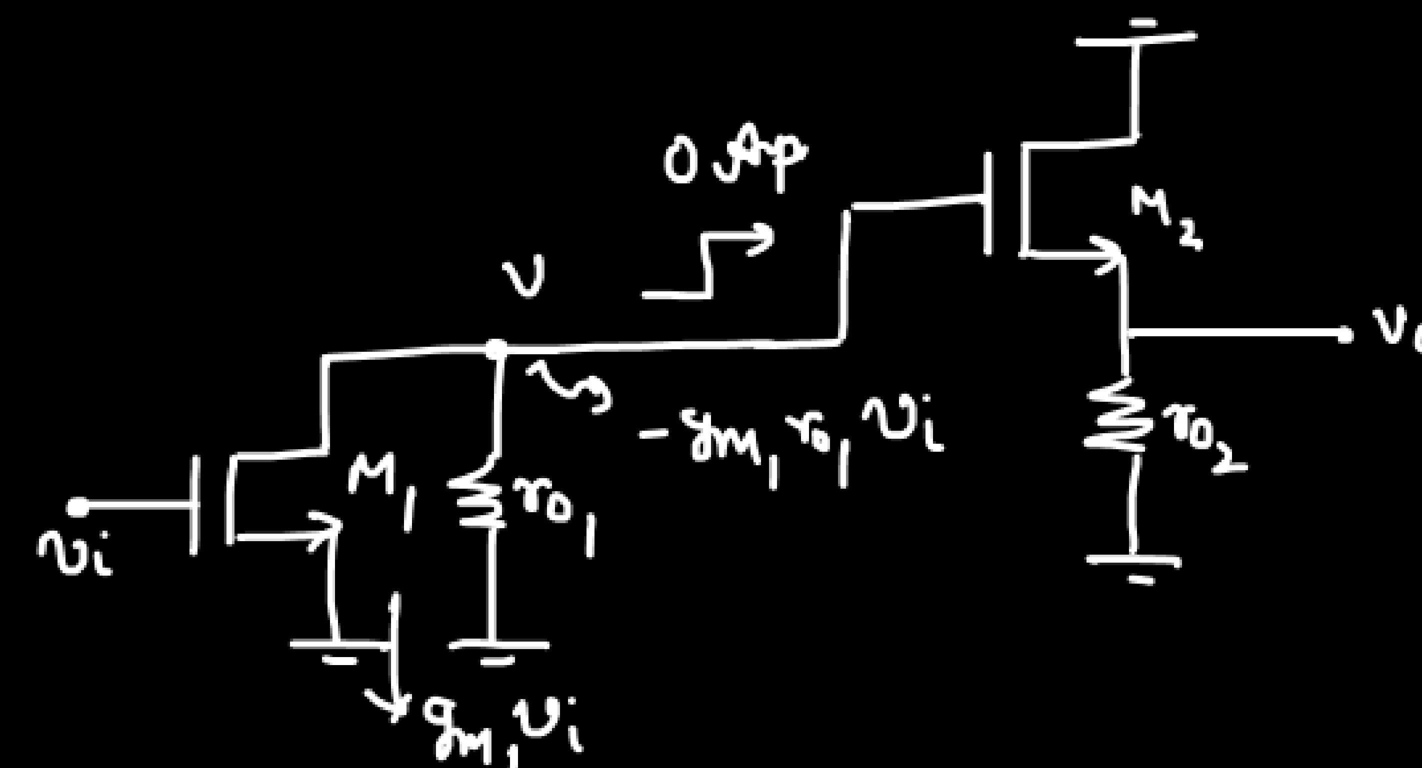
$$\omega_{p_2} \text{ or } \omega_{p_1} = \frac{-1}{C_2 \left[\frac{1}{g_{m_2}} \| r_{o_2}\right]}$$

$$\omega_{z_1} = \infty \quad , \quad \omega_{z_2} = \infty$$



k = dc gain

$$\frac{v_o}{v_i} = \frac{-g_{m_2} r_{o_2}}{1 + g_{m_2} r_{o_2}} \times g_{m_1} r_{o_1} = K$$

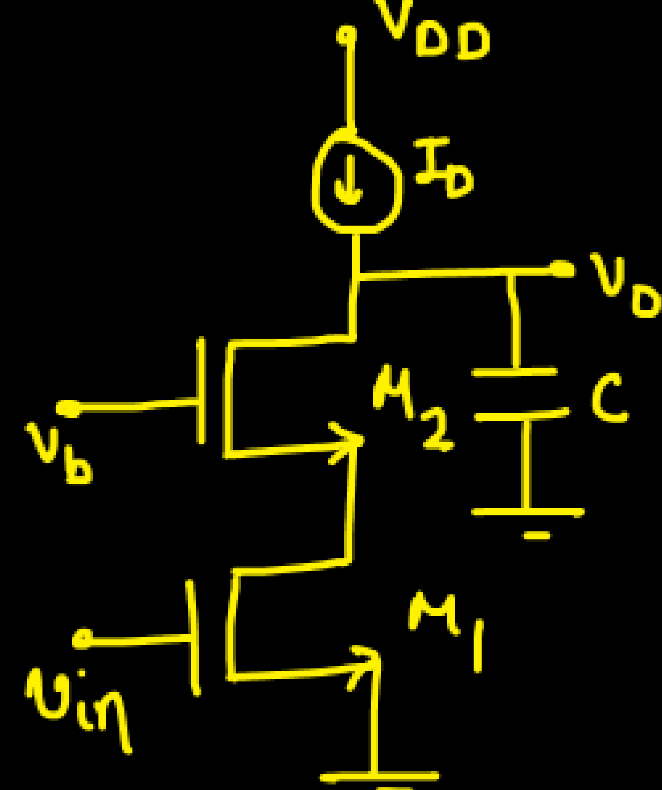


Q. Find (a) DC gain

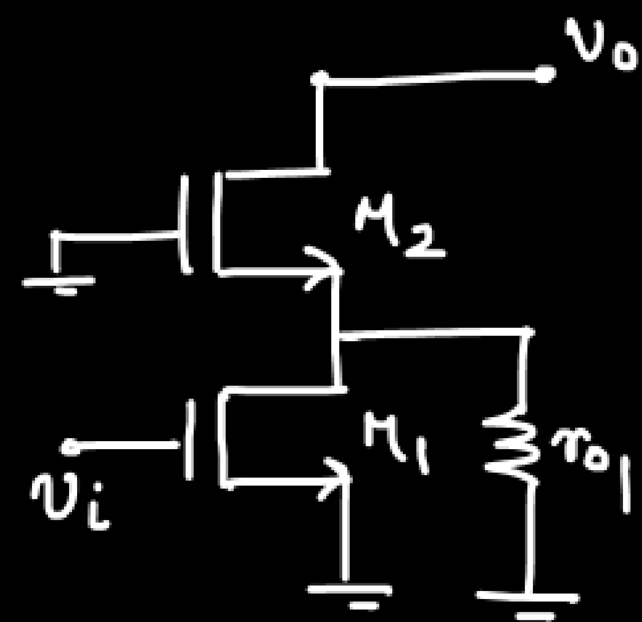
(b) 3-dB Bandwidth ($\omega_{3\text{-dB}}$)

(c) 3-dB Unity gain Bandwidth (ω_{UGB})

[Make Necessary Approximations]



(a) Dc gain (small signal gain):-



$$A_v = -G_m R_{out}$$

$$A_v \approx -g_{m1} g_{m2} r_{o2} r_{o1}$$

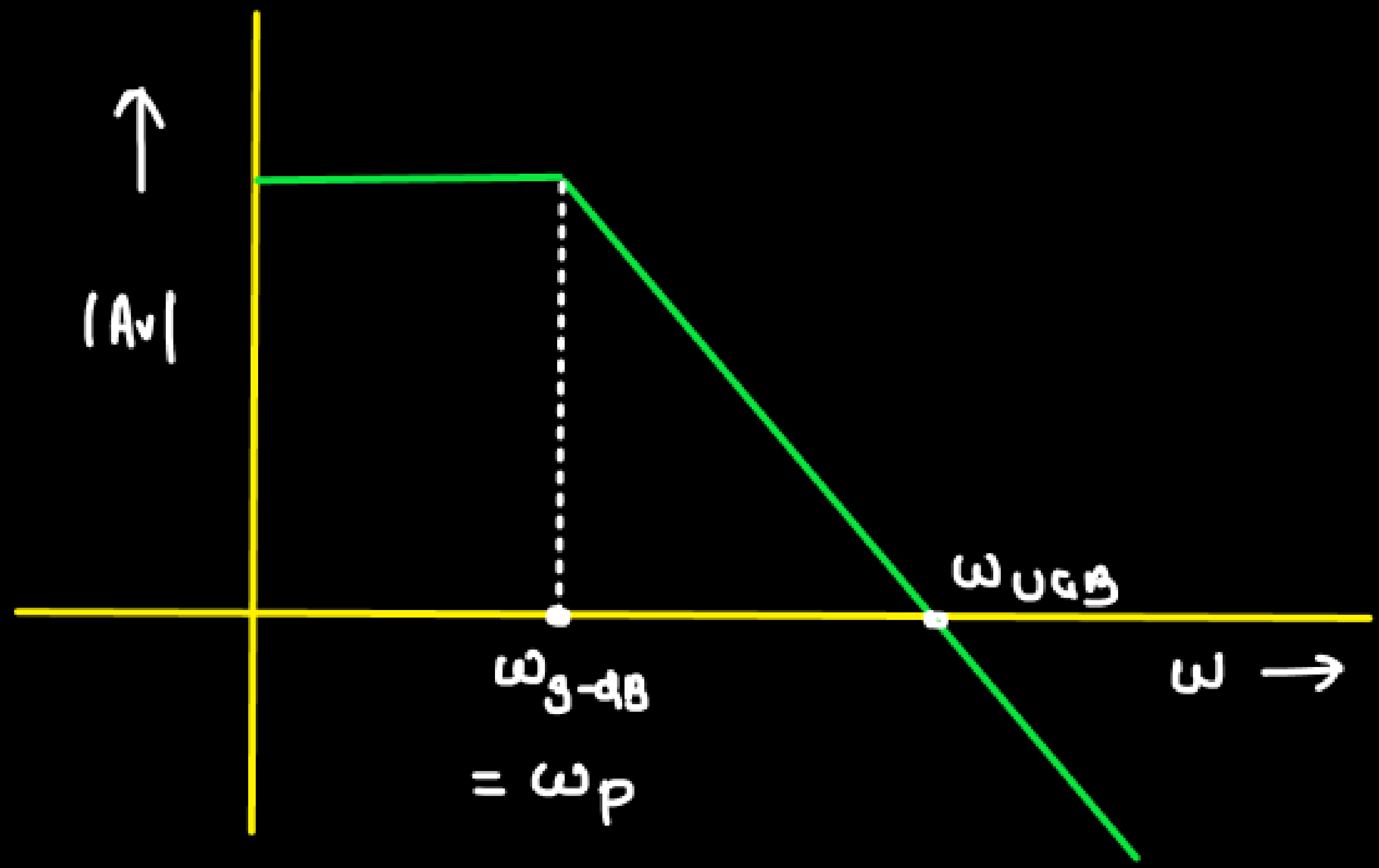
$$R_{out} = g_{m2} r_{o2} r_{o1} + r_{o2} + r_{o1}$$

(ii) 1^{st} order:-

$$\omega_z = \infty$$

$$\omega_p = \frac{-1}{C[g_{m2} r_{o2} r_{o1}]}$$

$$\boxed{T(s) = \frac{-g_{m1} g_{m2} r_{o1} r_{o2}}{1 + sC g_{m2} r_{o2} r_{o1}}}$$



$$\boxed{3\text{-dB B.W.} = \omega_p = \frac{-1}{C[g_{m_2} r_{o_2} r_{o_1} + r_{o_2} + r_{o_1}]} \approx \frac{-1}{C\, g_{m_2} r_{o_2} r_{o_1}}}$$

<u>Unity gain B.W.</u> → For a low Pass filter, the freq. @ which the gain is unity (0 dB).

(UGB)

@ $\omega = \omega_{UGB}$

$$|T(j\omega_{UGB})| = 1$$

$$\frac{g_{m_1} g_{m_2} r_{o_2} r_{o_1}}{\sqrt{1 + \omega_{UGB}^2 C^2 g_{m_2}^2 r_{o_2}^2 r_{o_1}^2}} = 1$$

$$g_{m_1}^2 g_{m_2}^2 r_{o_2}^2 r_{o_1}^2 = \omega_{UGB}^2 C^2 g_{m_2}^2 r_{o_2}^2 r_{o_1}^2$$

$$\boxed{\omega_{UGB} = \frac{g_{m_1}}{C}}$$

For a stable config. →

Gain Bandwidth product is constant.

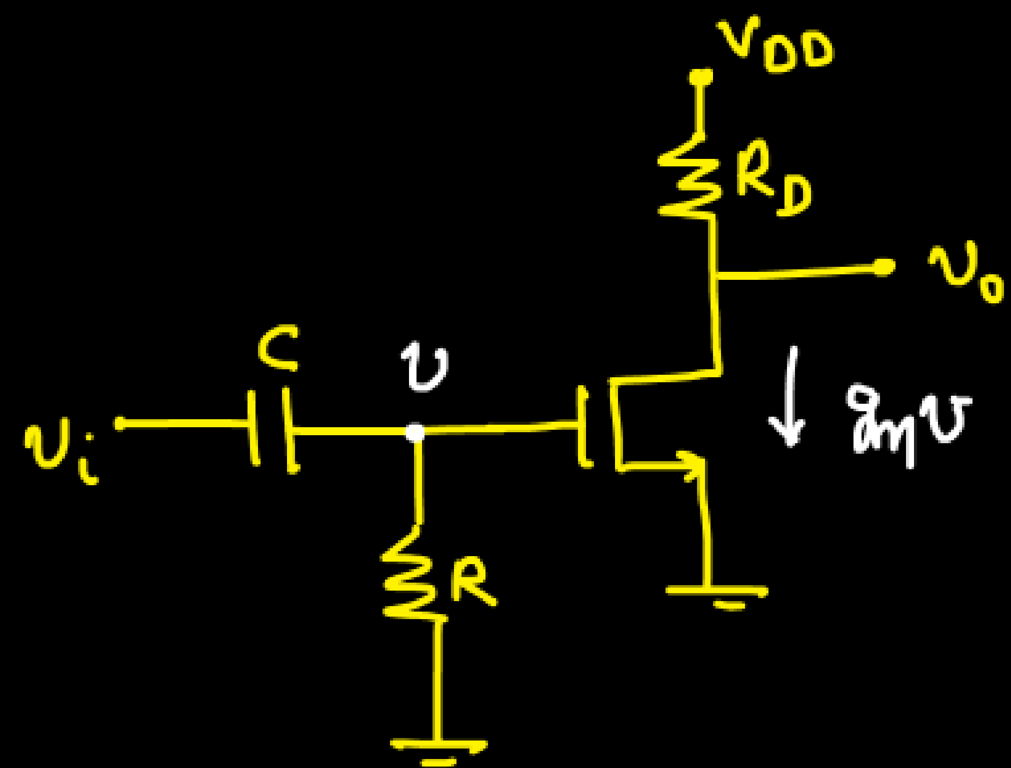
3-dB Bandwidth × DC gain = Unity gain B.W. × 1

$$\boxed{\omega_{UGB} = A_v \times \omega_{3\text{-}dB}}$$

For the given problem,

$$\boxed{\omega_{UGB} = \frac{g_{m_1} g_{m_2} r_{o_2} r_{o_1}}{C\, g_{m_2} r_{o_2} r_{o_1}} = \frac{g_{m_1}}{C}}$$

Q.



Q. (a) Find 3-dB B.W.

(b) Find 3-dB cut-off freq.

(c) Find the freq. @ which the gain is unity.

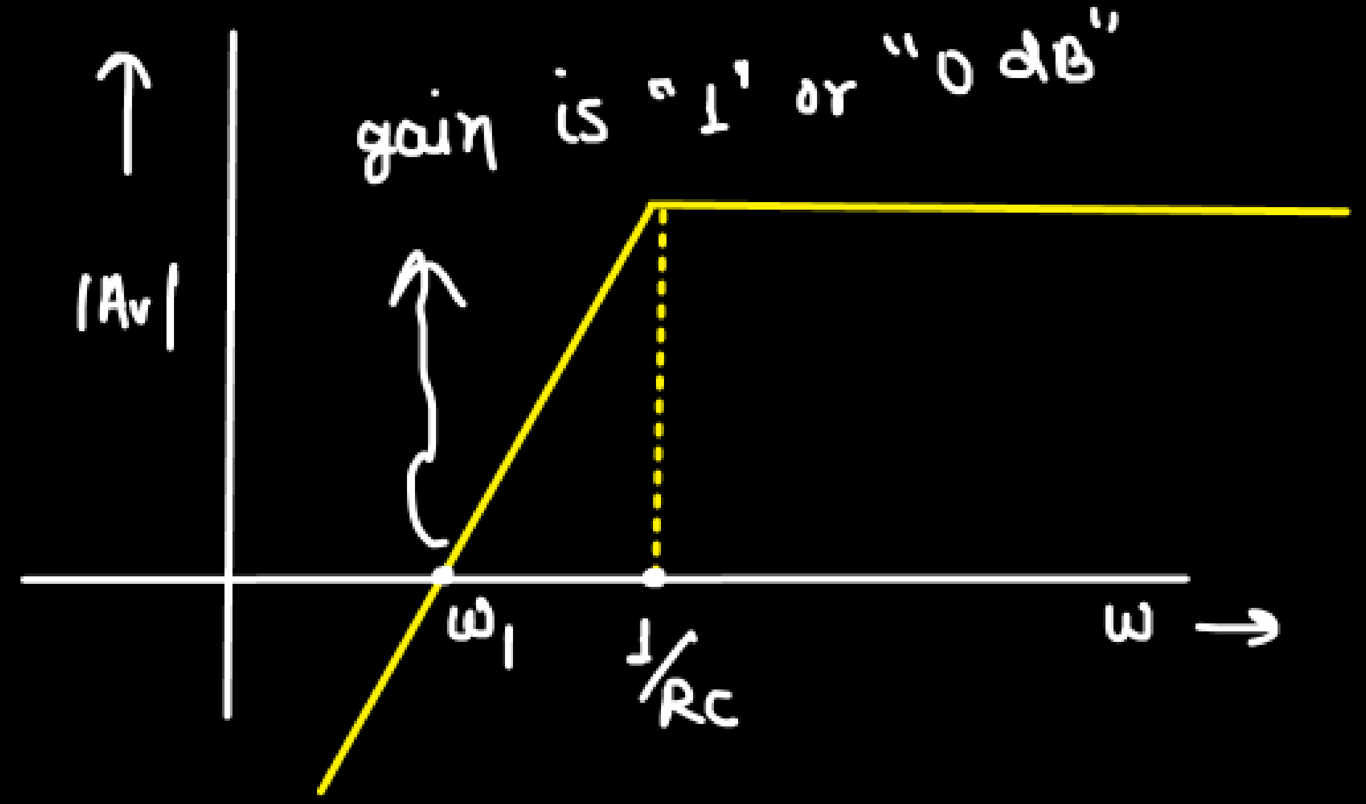
$$v_o = -g_m R_D v \longrightarrow (1)$$

$$v = \frac{Rs}{1+Rs} v_i \longrightarrow (2)$$

$$\boxed{\frac{v_o}{v_i} = -g_m R_D \left(\frac{Rs}{Rs+1}\right)}$$

$$\omega_z = 0$$

$$\omega_p = \frac{-1}{RC}$$



① 3-dB cut-off freq. = $1/RC = \omega_p$

② 3-dB B.W. = $\infty - \dfrac{1}{RC} = \infty$

$\omega_1 = ?$

@ $\omega = \omega_1$

$$|T(j\omega_1)| = 1$$

$$\frac{g_m R_D \times R C \omega_1}{\sqrt{1 + \omega_1^2 R^2 C^2}} = 1$$

$$g_m^2 R_D^2 R^2 C^2 \omega_1^2 = 1 + \omega_1^2 R^2 C^2$$

$$\omega_1^2 \left[g_m^2 R_D^2 R^2 C^2 - R^2 C^2 \right] = 1$$

$$\boxed{\omega_1 = \frac{1}{RC\sqrt{g_m^2 R_D^2 - 1}}}$$

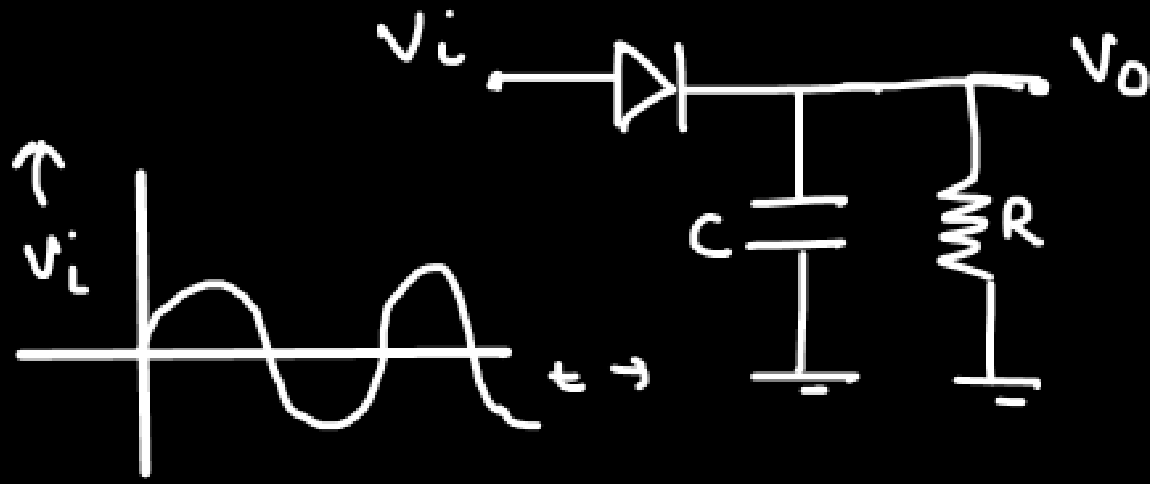
generally $g_m R_D \gg 1$

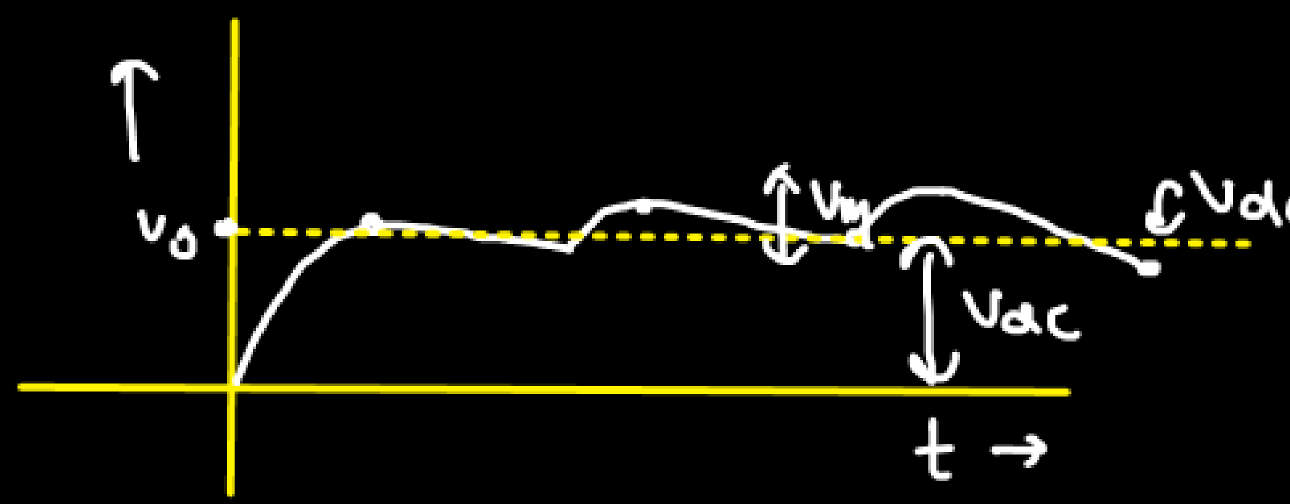
$$\boxed{\omega_1 \approx \frac{1}{RC \times g_m R_D}}$$

Differential Amplifier

↳ Why do we need differential Amplifier?

* Generally the dc supply we use, have some small ripple.

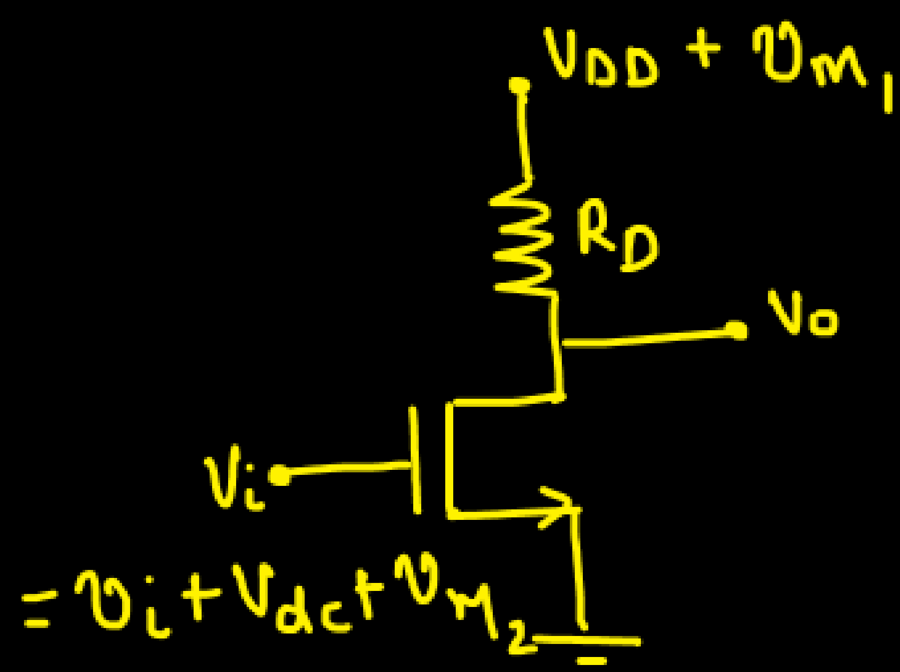




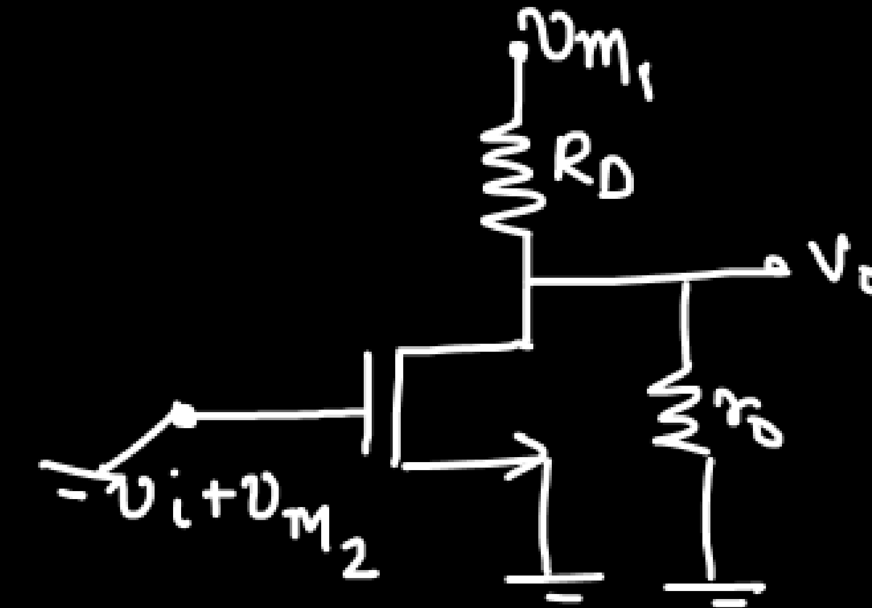
$$\boxed{V_o = \underbrace{V_{dc}}_{\text{dc o/p}} + \underbrace{v_m}_{\text{ripple (small signal noise)}}}$$

This supply will be fed to the Transistors.

Q. All the supplies have some ripples (v_{m_1}, v_{m_2}).
Find small signal o/p.



$\Rrightarrow$



$$v_o = -g_m(v_i + v_{m_2})(R_D \| r_o) + \frac{r_o}{r_o + R_D} v_{m_1}$$

$$v_o = -g_m(R_D \| r_o) v_i - g_m(R_D \| r_o) v_{m_2} + \frac{r_o}{r_o + R_D} v_{m_1}$$

$$\boxed{v_o = \underbrace{-g_m(R_D \| r_o)v_i}_{\text{desired}} \underbrace{- g_m(R_D \| r_o)v_{m_2} + \frac{r_o}{r_o+R_D}v_{m_1}}_{\text{NOISE}}}$$

To eradicate the noise part, we use differential amp.

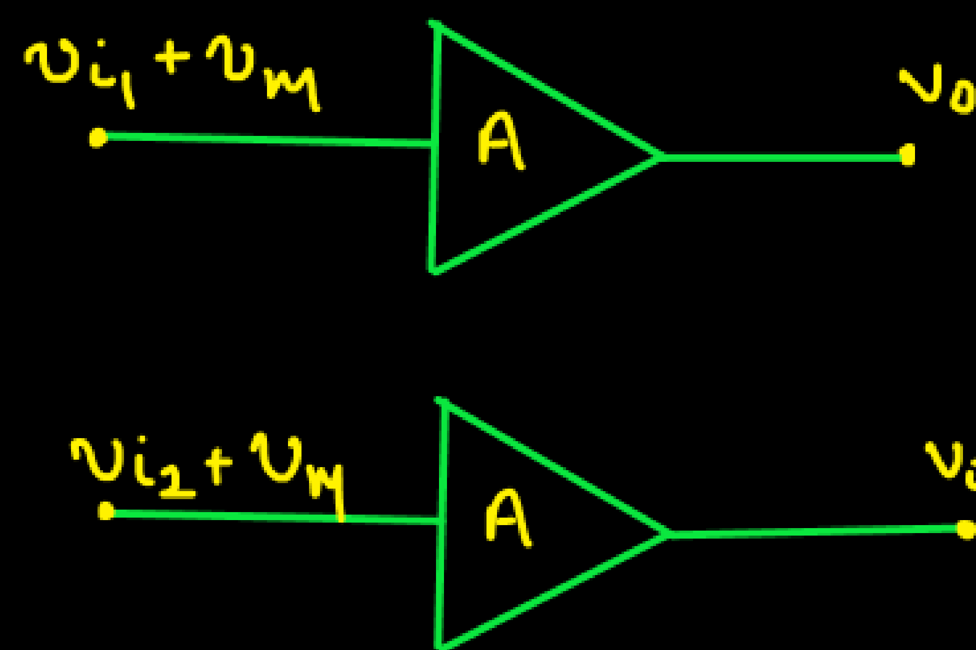
Basic Idea :-

↳ At input, you have "signal + Noise"

↳ At output, you have "signal + Noise"

you want Amplified O/P, but no noise ⇒

$$[v_0 = \underline{A} v_i]$$



$$v_{o_1} = A v_{i_1} + A v_m$$

$$-$$

$$v_0 = v_{o_2} - v_{o_1} = A(v_{i_2} - v_{i_1}) + A v_m - A v_m$$

$$+$$

$$v_{o_2} = A v_{i_2} + A v_m$$

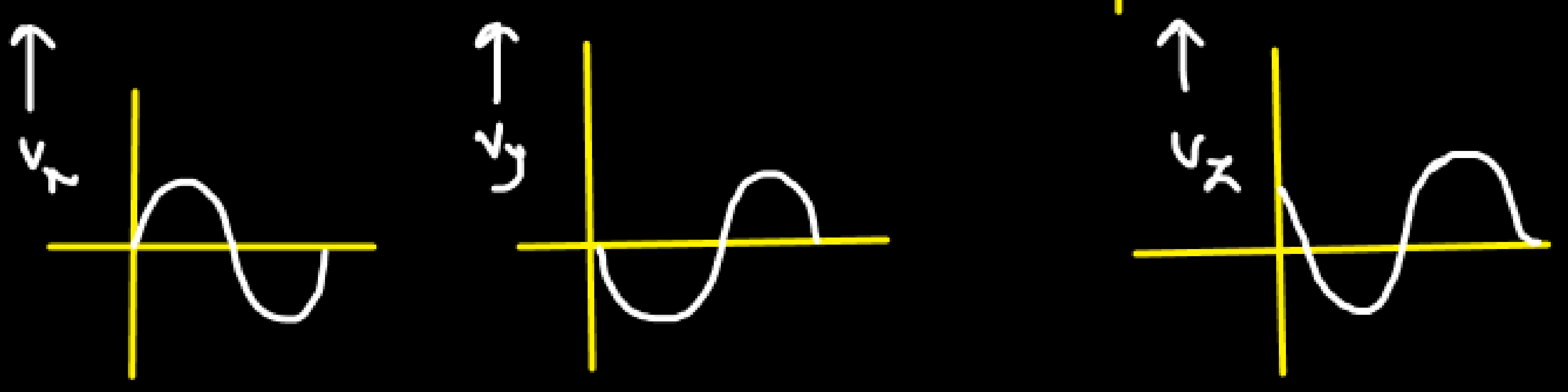
$$\boxed{v_0 = A(v_{i_2} - v_{i_1})}$$

if $v_{i_2} = v_i/2$ and $v_{i_1} = -v_i/2$

$\boxed{v_0 = A v_i}$ ⇒ desired o/p

Here v_{i_2} and v_{i_1} are differential signals.

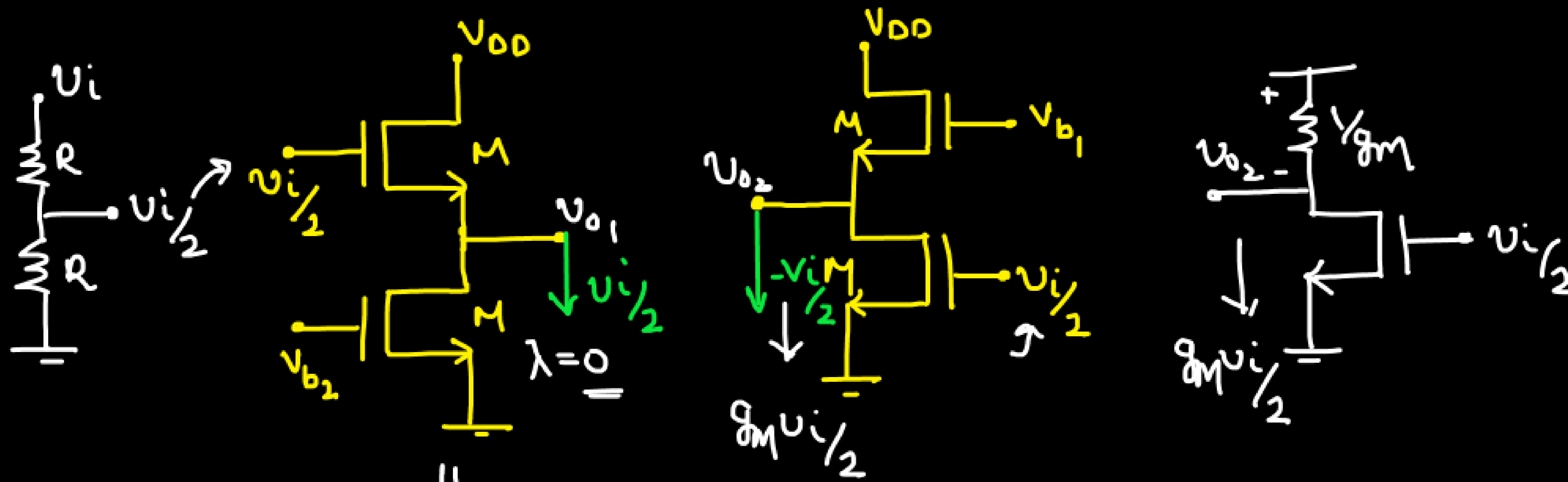
- → Same amplitude
- → same dc level
- → opposite in phase



⇒ v_x & v_y are differential signals.

⇒ v_x & v_z are not differential signals.

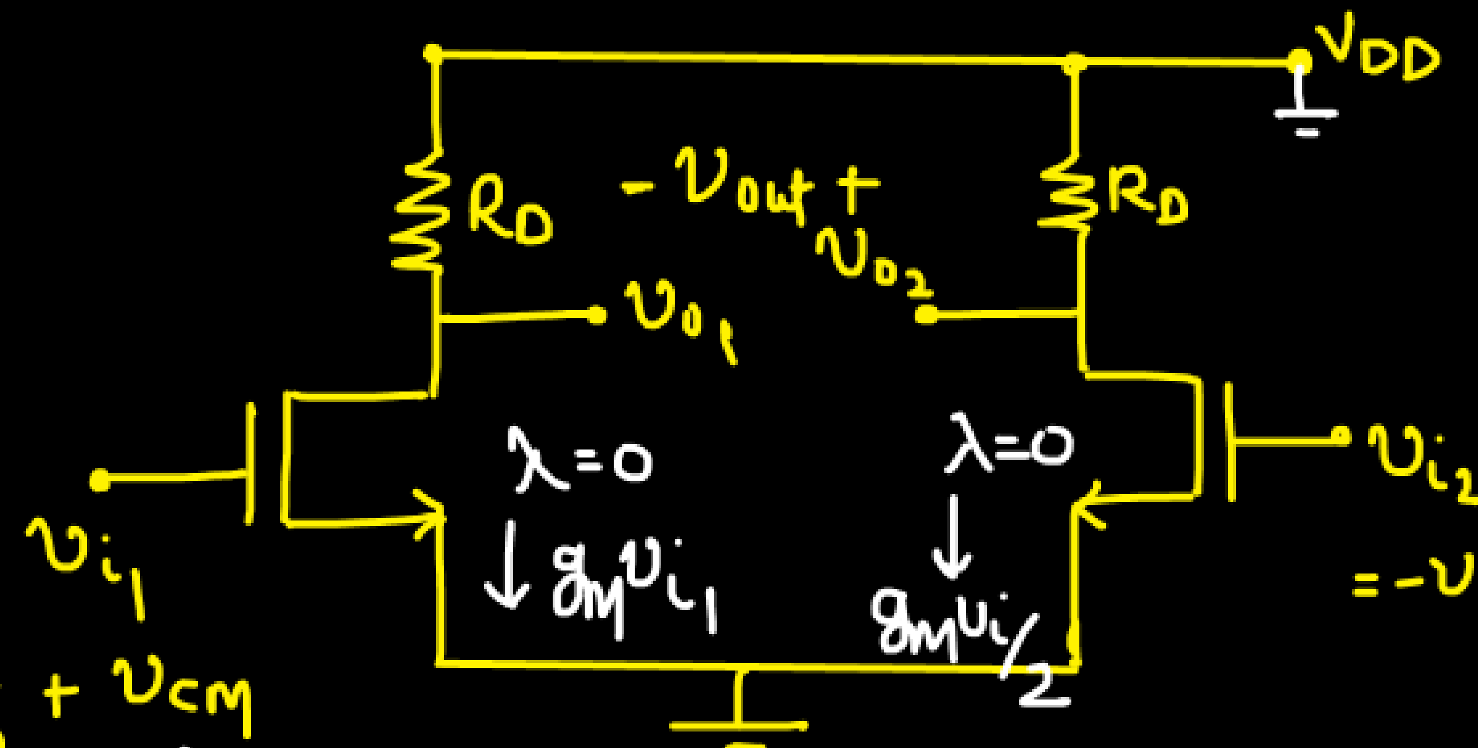
How to generate differential signal:-



$$g_m\left(\frac{v_i}{2} - v_{o1}\right) = 0 \qquad\qquad v_{o2} = -g_m v_i/2\left[\frac{1}{g_m}\right]$$

$$\boxed{v_{o1} = v_i/2} \qquad\qquad \boxed{v_{o2} = -v_i/2}$$

Differential Amplifier:-



$v_{i_1} = \underbrace{v_i/2}_{\text{small signal i/p}} + \underbrace{v_{cm}}_{\text{small signal Noise}}$

$v_{i_2} = -v_i/2 + v_{cm}$

$$v_{o_1} = -g_m R_D v_{i_1}$$

$$= -g_m R_D \left[v_i/2 + v_{cm}\right]$$

$$\boxed{v_{o_1} = -g_m R_D \frac{v_i}{2} - g_m R_D v_{cm}}$$

$$v_{o_2} = -g_m R_D v_{i_2}$$

$$= -g_m R_D \left[-\frac{v_i}{2} + v_{cm}\right]$$

$$\boxed{v_{o_2} = g_m R_D v_i/2 - g_m R_D v_{cm}}$$

$$v_o = v_{o_2} - v_{o_1}$$

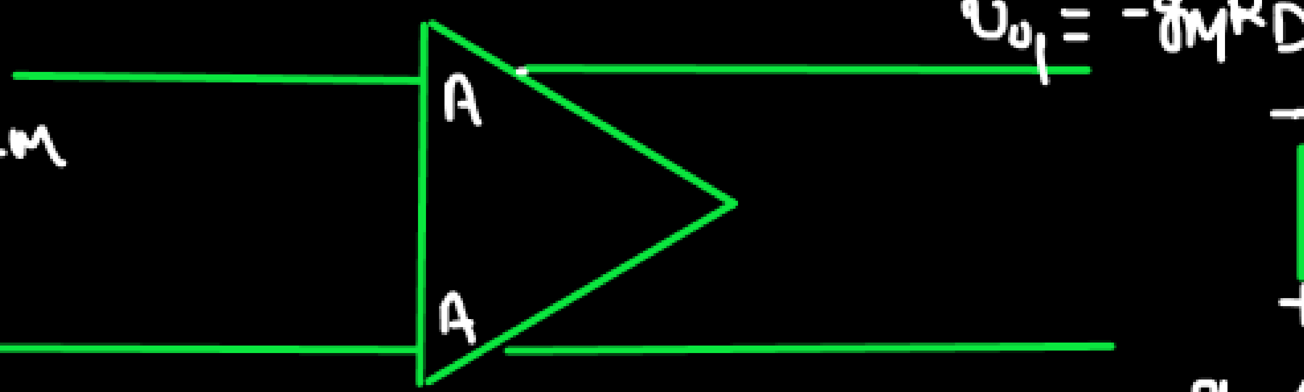
$$= g_m R_D \frac{v_i}{2} - g_m R_D v_{cm} - \left[-g_m R_D \frac{v_i}{2} - g_m R_D v_{cm} \right]$$

$$v_o = g_m R_D v_i$$

$$\boxed{\frac{v_o}{v_i} = g_m R_D}$$

$v_{i_1} = v_i/2 + v_{cm}$

$v_{i_2} = -v_i/2 + v_{cm}$

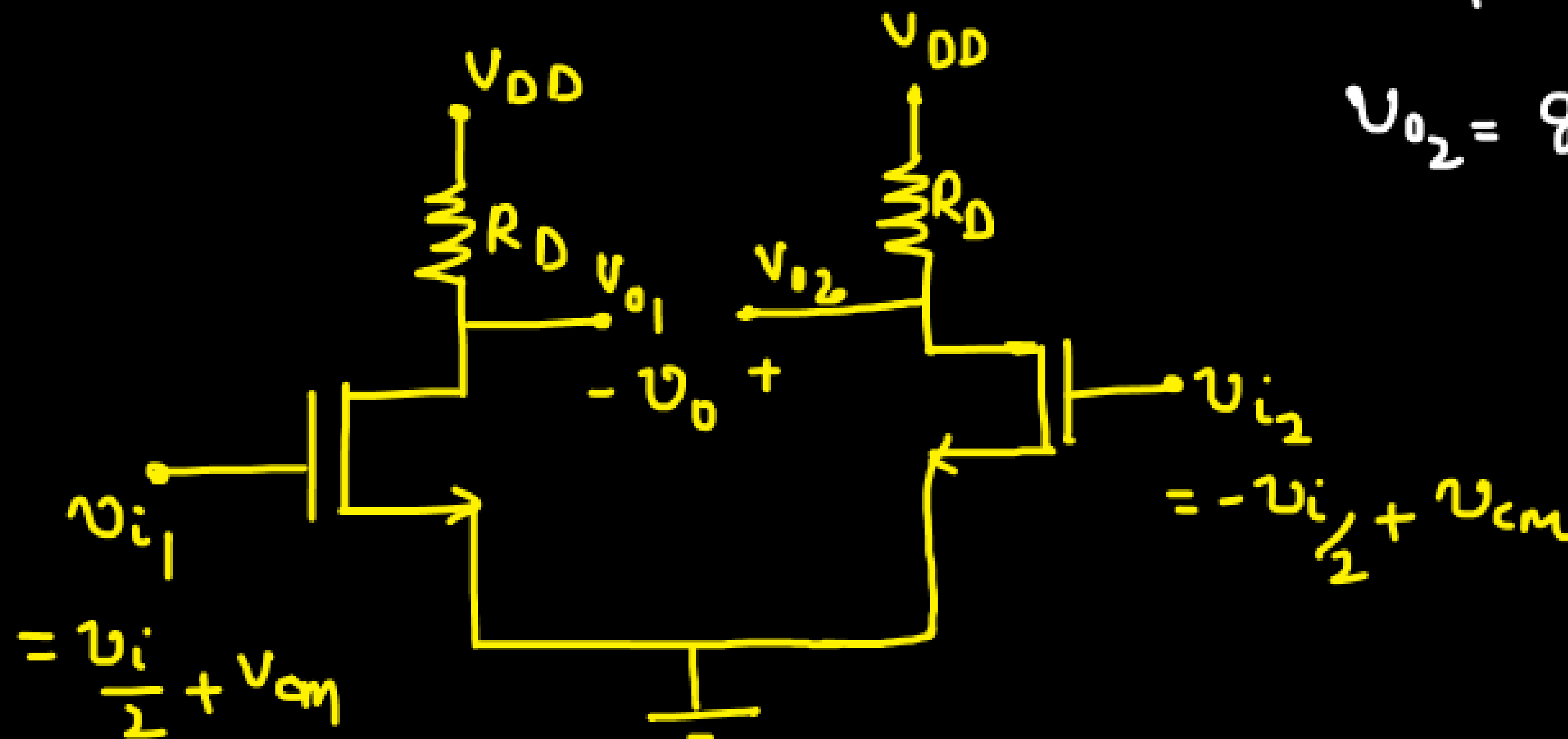


$v_{o_1} = -g_m R_D v_i/2 - g_m R_D v_{cm}$

$$\boxed{v_{out} = v_{o_2} - v_{o_1} = g_m R_D v_i}$$

$v_{o_2} = g_m R_D v_i/2 - g_m R_D v_{cm}$

Some Common Terms:-



$v_{o_1} = -g_m R_D v_i/2 - g_m R_D v_{cm}$

$v_{o_2} = g_m R_D v_i/2 - g_m R_D v_{cm}$

* differential input $(v_i)_d = v_{i_1} - v_{i_2} = v_i$

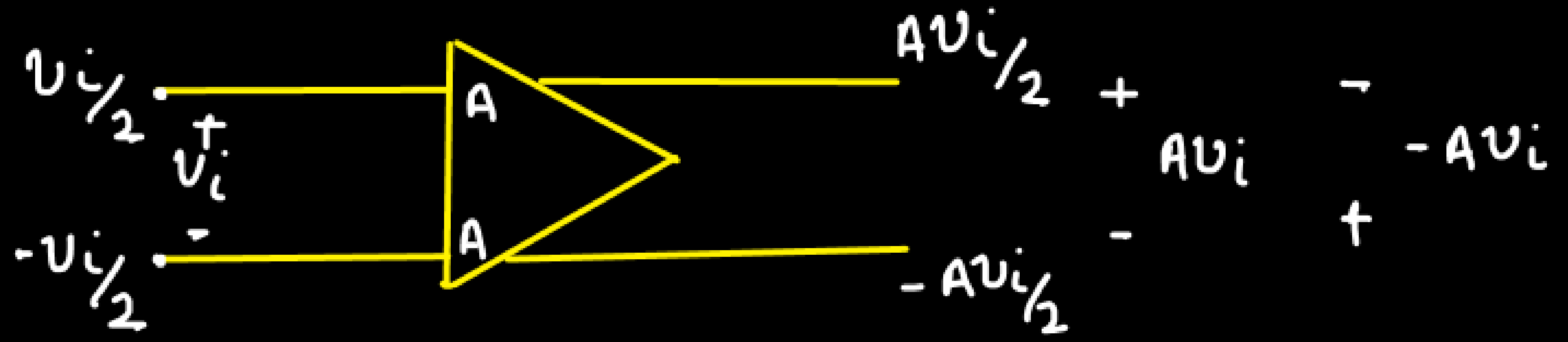
* differential output $(v_o)_d = v_{o_2} - v_{o_1} = g_m R_D v_i$

* differential gain $(A_v)_d = \frac{(v_o)d}{(v_o)i} = g_m R_D$

⇒ HOW TO FIND $\boxed{\text{Differential Gain}}$:-

Put $v_{i_1} = v_i/2$ and $v_{i_2} = -v_i/2$ $\{\text{if } v_{i_1} - v_{i_2} = v_i\}$

Calculate $v_o = v_{o_2} - v_{o_1}$ OR $v_{o_1} - v_{o_2}$



Here $A = -g_m R_D$

★ Common mode input $(v_i)_{cm} = \dfrac{v_{i_1} + v_{i_2}}{2} = \dfrac{2v_{cm}}{2} = v_{cm}$

★ Common mode output $(v_o)_{cm} = \dfrac{v_{o_1} + v_{o_2}}{2} = \dfrac{-2g_m R_D v_{cm}}{2} = -g_m R_D v_{cm}$

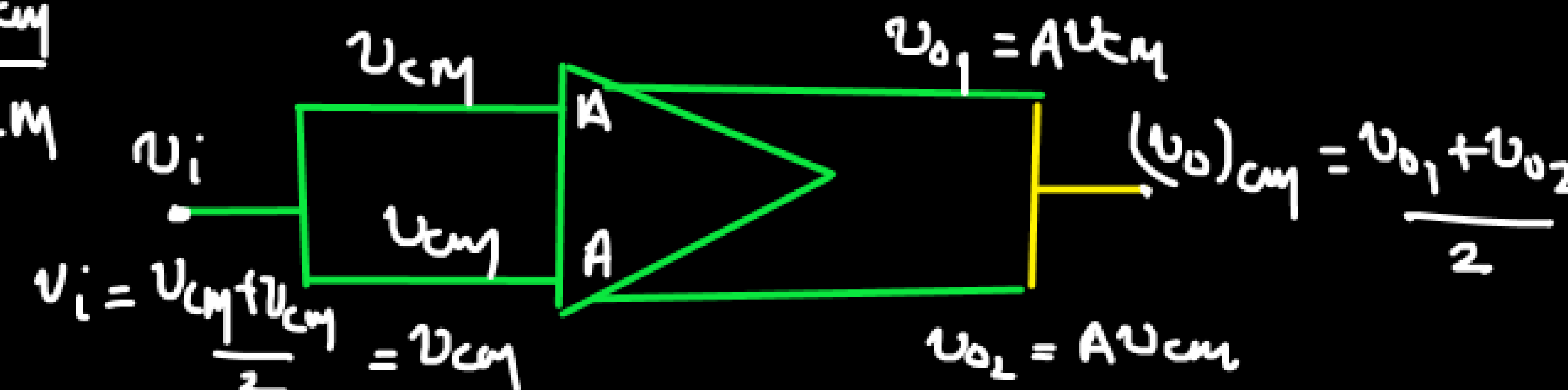
★ Common mode gain $(A_v)_{cm} = \dfrac{(v_o)_{cm}}{(v_i)_{cm}} = -g_m R_D$

HOW TO FIND $\boxed{\text{common mode gain}}$:-

→ Apply $v_{i_1} = v_{i_2} = v_{cm}$

Find v_{o_1} and v_{o_2} and take average → $(v_o)_{cm}$

$$\text{gain} = \frac{(v_o)_{cm}}{v_{cm}}$$



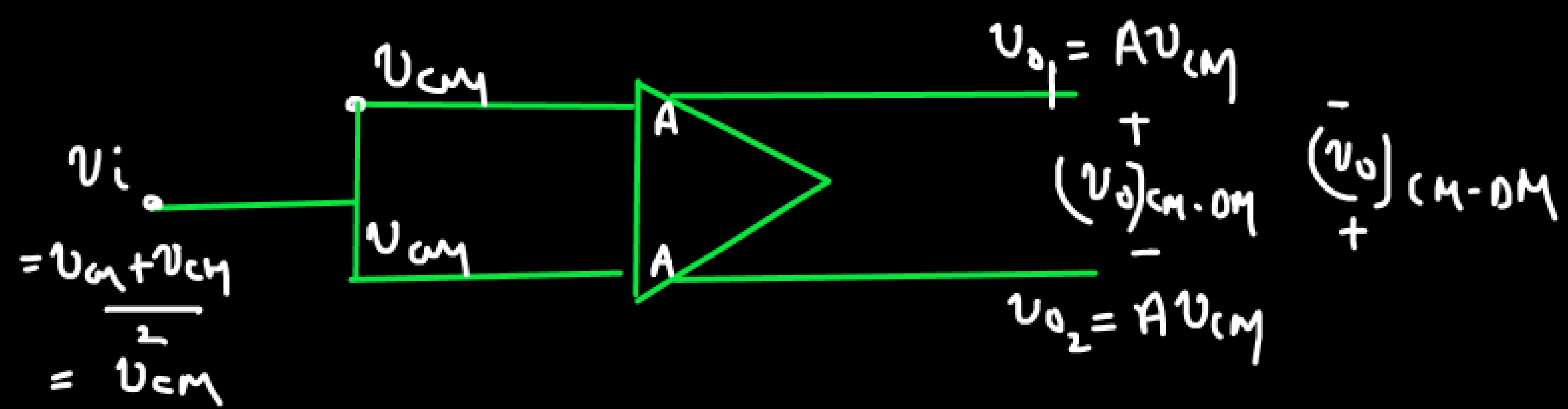
HOW TO FIND Common-Mode Differential gain :-

$$\left[(A)_{CM-DM} \right]$$

Apply $v_{i_1} = v_{i_2} = v_{CM}$

Find v_{o_1} & v_{o_2} and $(v_o)_{CM-DM} = v_{o_2} - v_{o_1}$ or $v_{o_1} - v_{o_2}$

$$(A)_{CM-DM} = \frac{(v_o)_{CM-DM}}{v_{CM}}$$



Common Mode Rejection Ratio:-

(CMRR)

Shows the ability of rejecting common mode input.

$$\boxed{CMRR = \left|\frac{(A)_d}{(A)_{CM-DM}}\right| = \left|\frac{\text{Differential gain}}{\text{Common-Mode differential gain}}\right|}$$

MORE CMRR $\Rightarrow$ Less sensitive to noise

$CMRR \to \infty \Rightarrow (A)_{CM-DM} = 0 \Rightarrow$ No noise in the o/p

Q. For the given config (a) and (b). Find

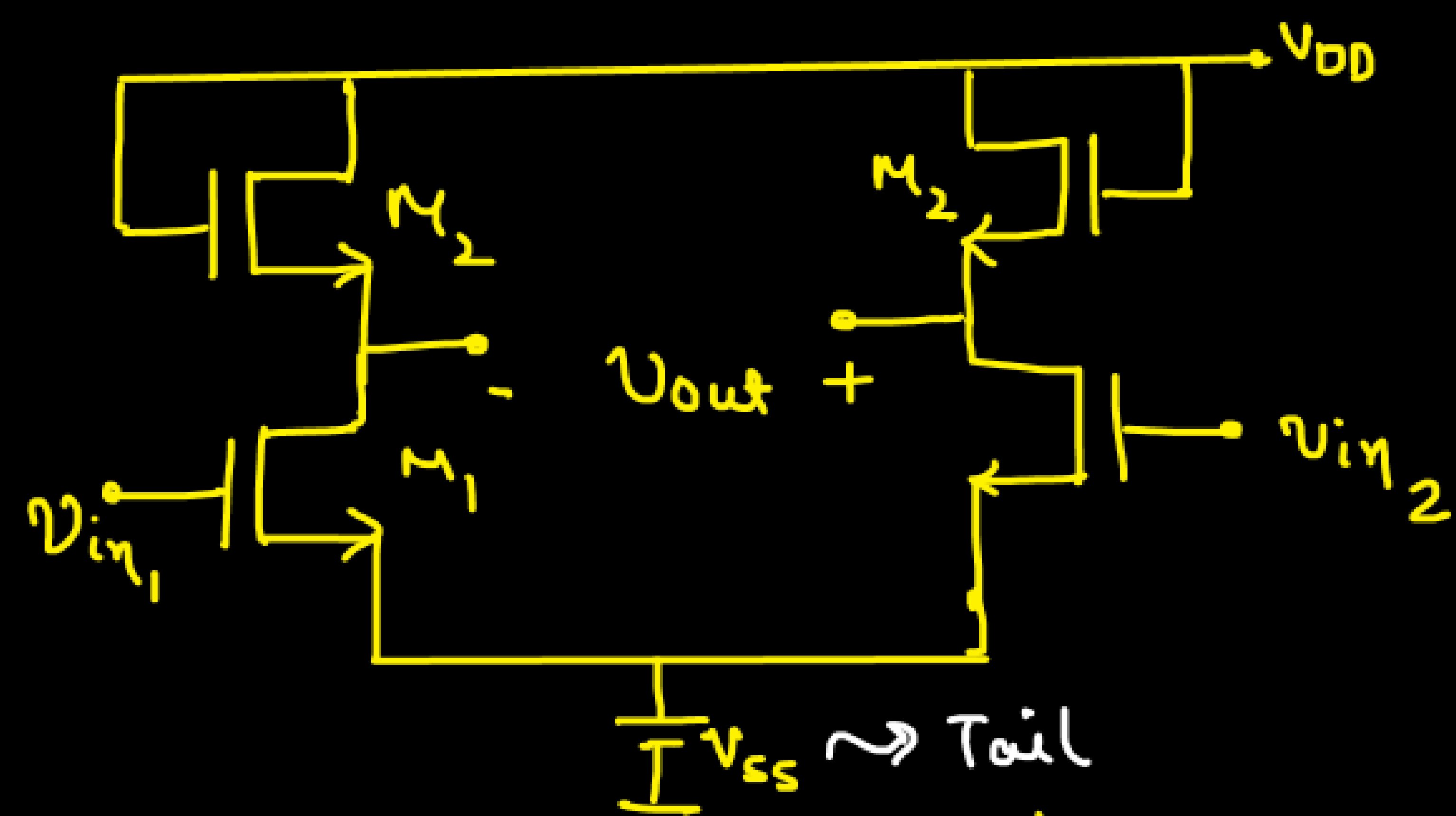
(i) Differential Gain

(ii) Common-Mode Gain

(iii) Common-Mode Differential Gain

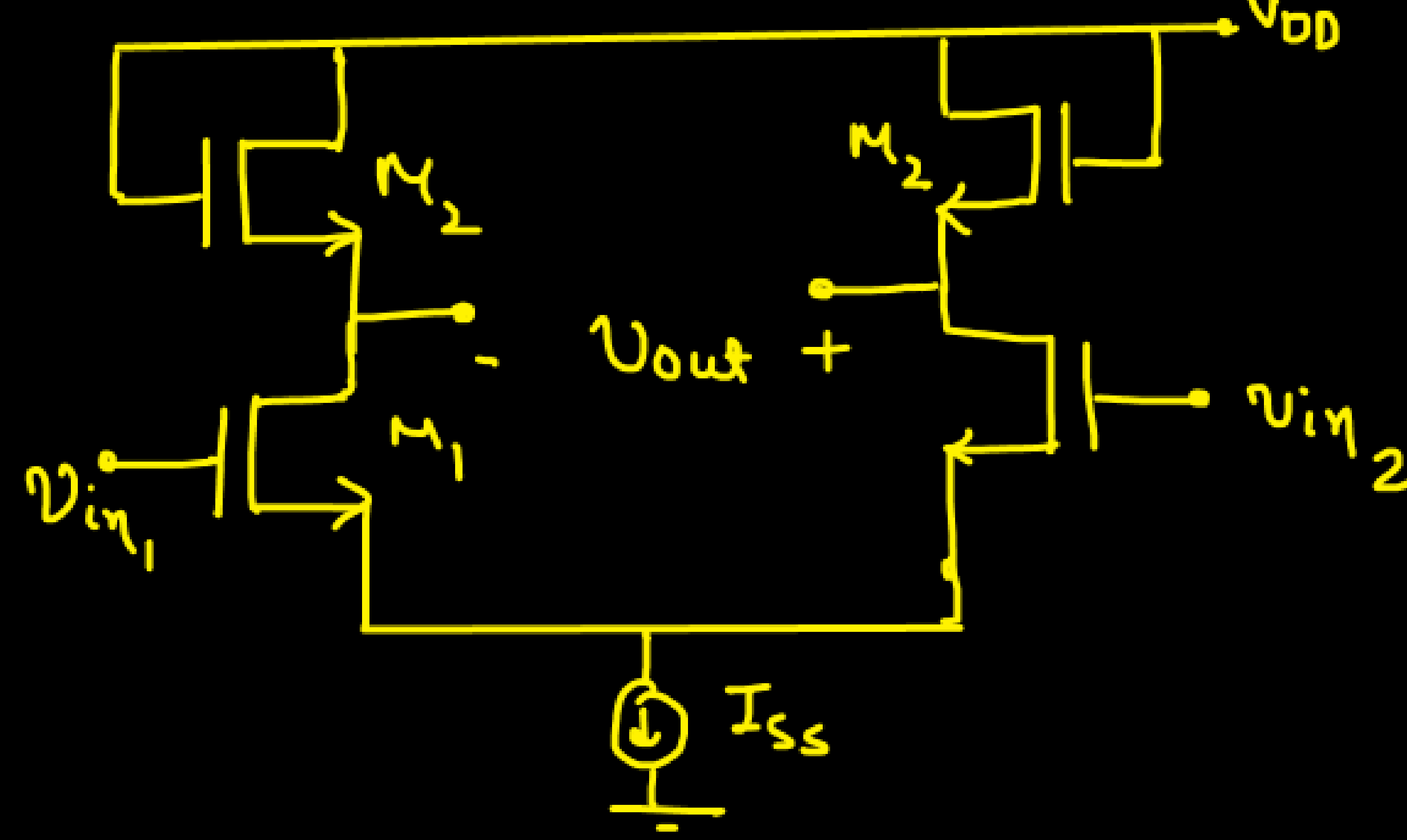
(iv) CMRR

N.B.- $\lambda \neq 0$ for M_2
$\lambda = 0$ for M_1



(a)

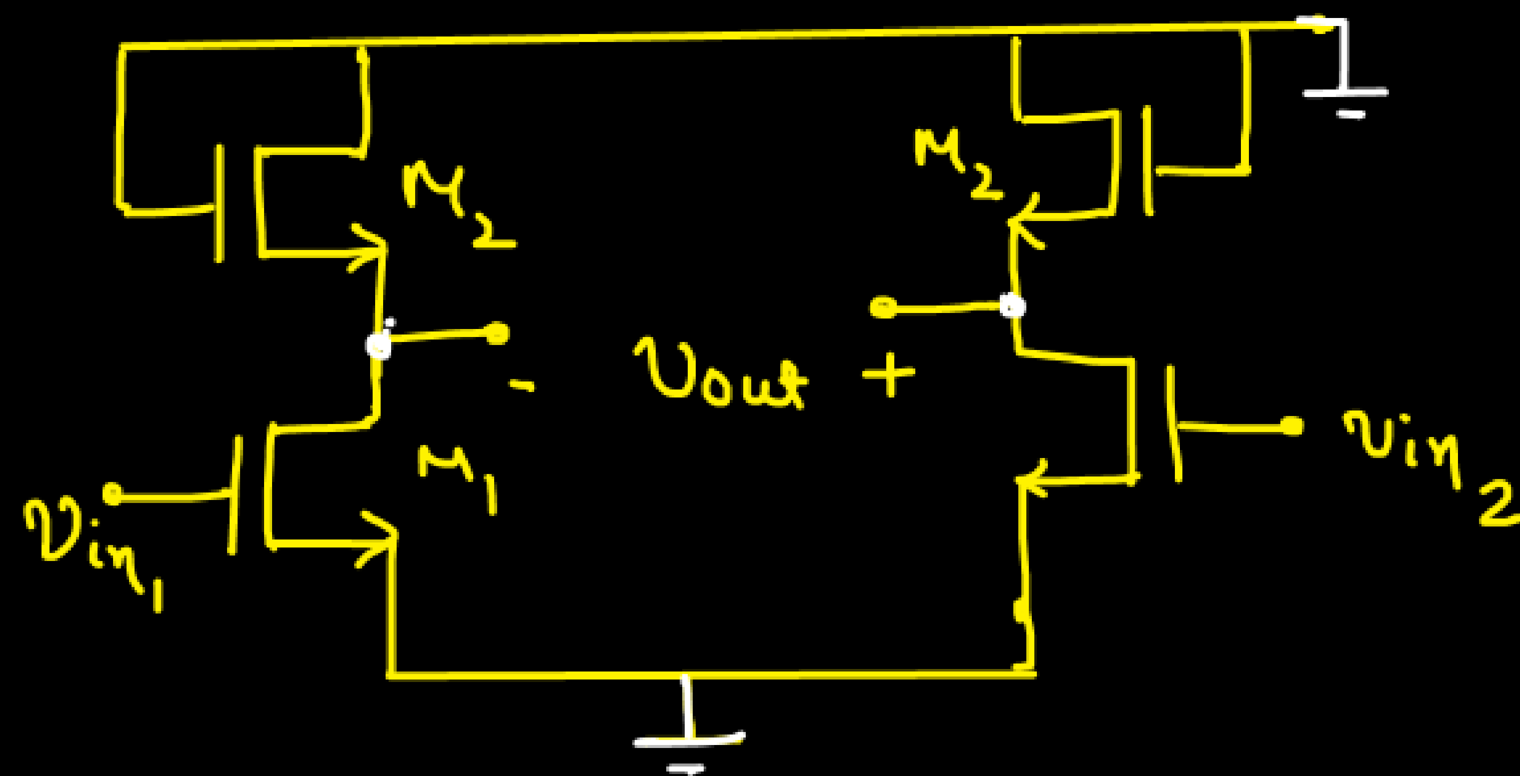
$v_{in} = v_{in_1} - v_{in_2}$



(b)

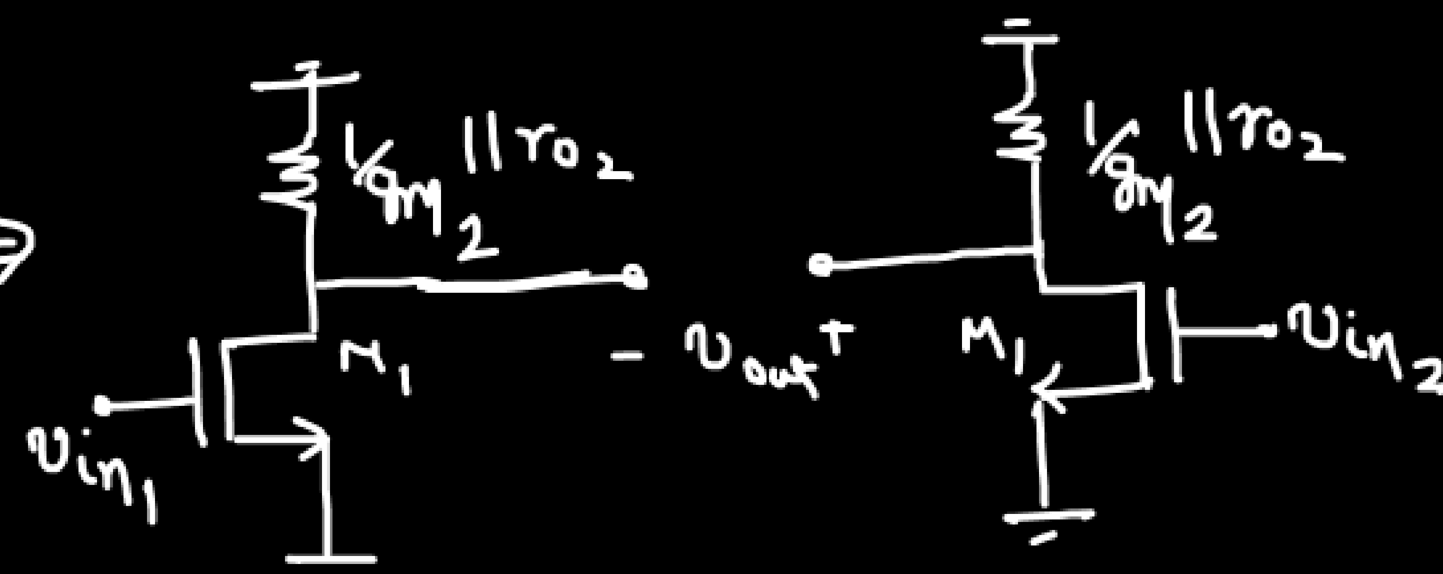
$$v_{in} = v_{in_1} - v_{in_2}$$

→



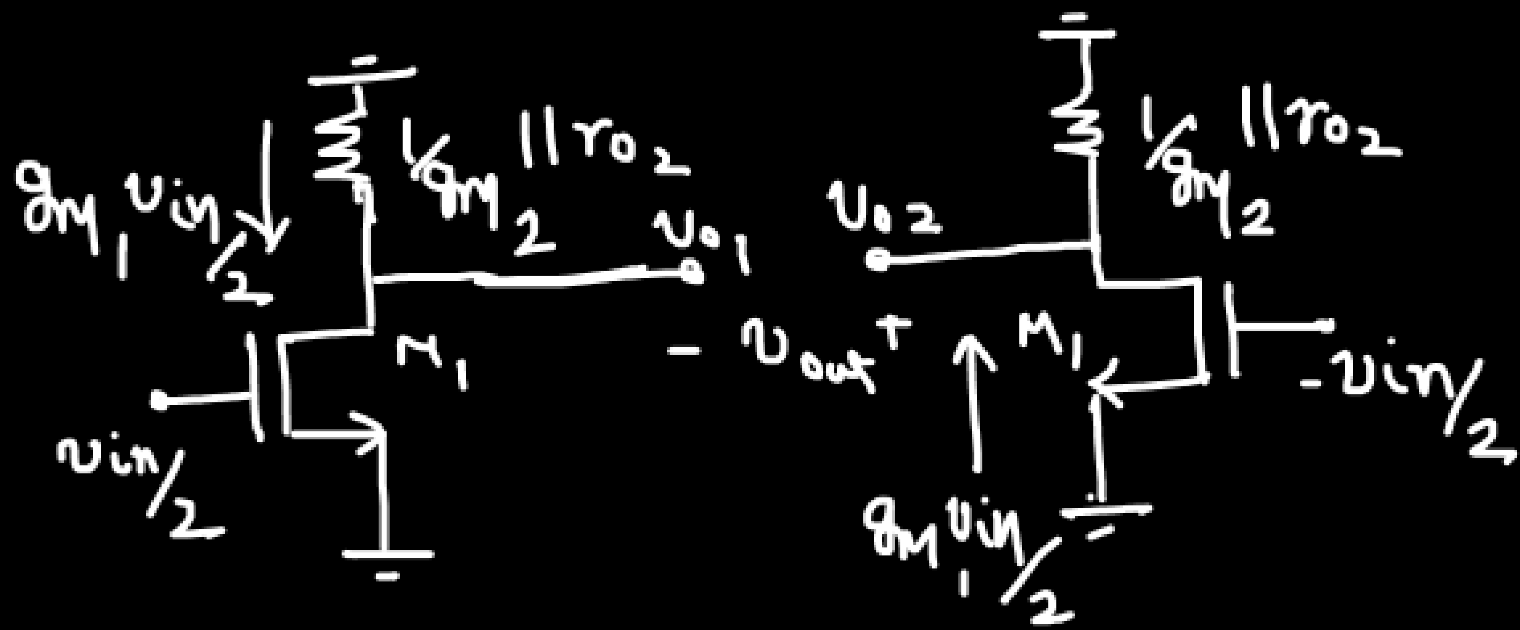
(a)

⇒



(I) <u>Differential gain:-</u>

$$v_{i_1} = \frac{v_{in}}{2} \quad , \quad v_{i_2} = -v_{in}/2 \qquad [v_{in_1} - v_{in_2} = v_{in}]$$



$$v_{o_1} = -g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right] v_{in}/2$$

$$v_{o_2} = g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right] v_{in}/2$$

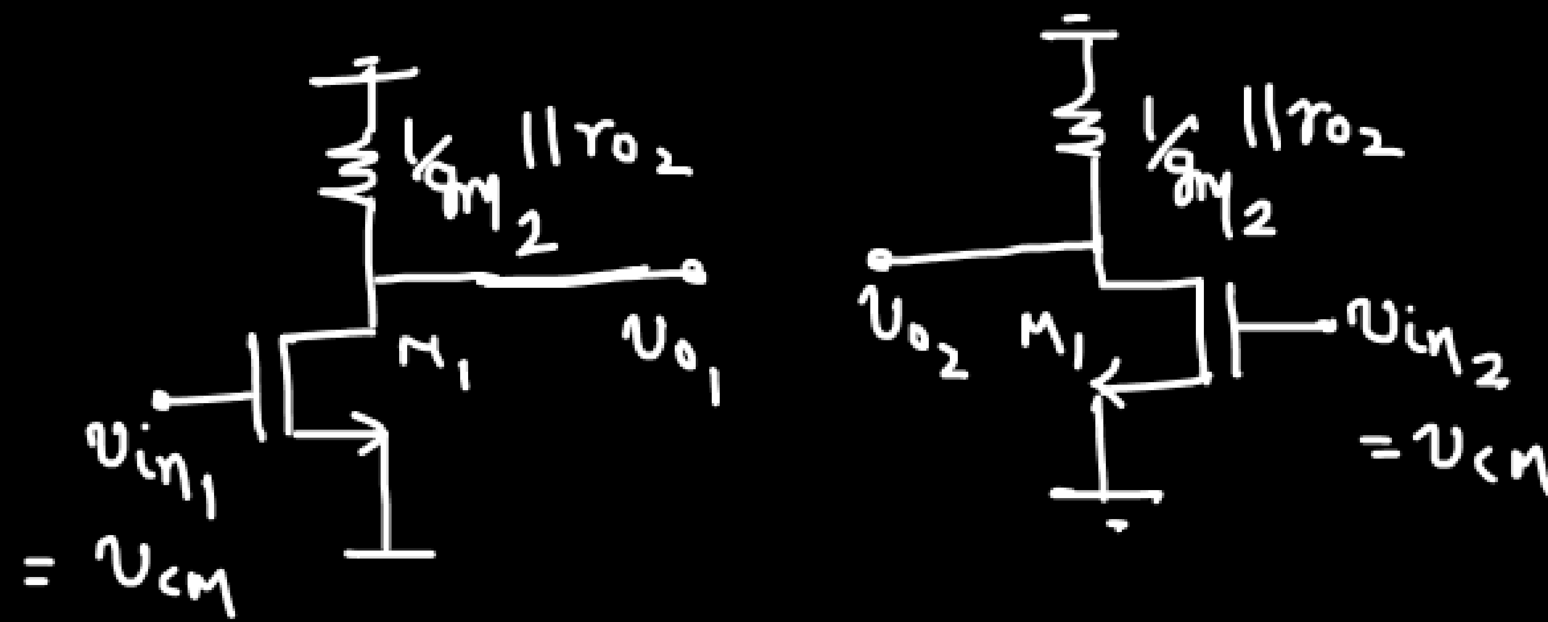
$$\Rightarrow (v_o)_d = g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right] v_{in}$$

$$\Rightarrow (v_i)_d = \frac{v_{in}}{2} - \left(-\frac{v_{in}}{2}\right) = v_{in}$$

$$\boxed{(A_v)_d = g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right]} \;*$$

(II) Common - Mode gain :-

$$v_{i_1} = v_{i_2} = v_{CM}$$



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

$$v_{o_2} = -g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right] v_{cm}$$

$$\Rightarrow \quad (v_o)_{cm} = \frac{v_{o_1} + v_{o_2}}{2}$$

$$(v_o)_{cm} = -g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right] v_{cm}$$

$$(v_i)_{cm} = \frac{v_{cm} + v_{cm}}{2} = v_{cm}$$

$$\boxed{(A_v)_{cm} = -g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right]}$$

Common Mode Differential gain:-

$$v_{i_1} = v_{i_2} = v_{CM}$$

$$v_{o_1} = -g_{m_1}\left[\frac{1}{g_{m_2}} \parallel r_{o_2}\right] v_{cm}$$

$$v_{o_2} = -g_{m_1}\left[\frac{1}{g_{m_2}} \parallel r_{o_2}\right] v_{cm}$$

$$(v_o)_{CM-DM} = v_{o_2} - v_{o_1} = 0$$

$$(v_i)_{CM-DM} = \frac{v_{cm} + v_{cm}}{2} = v_{CM}$$

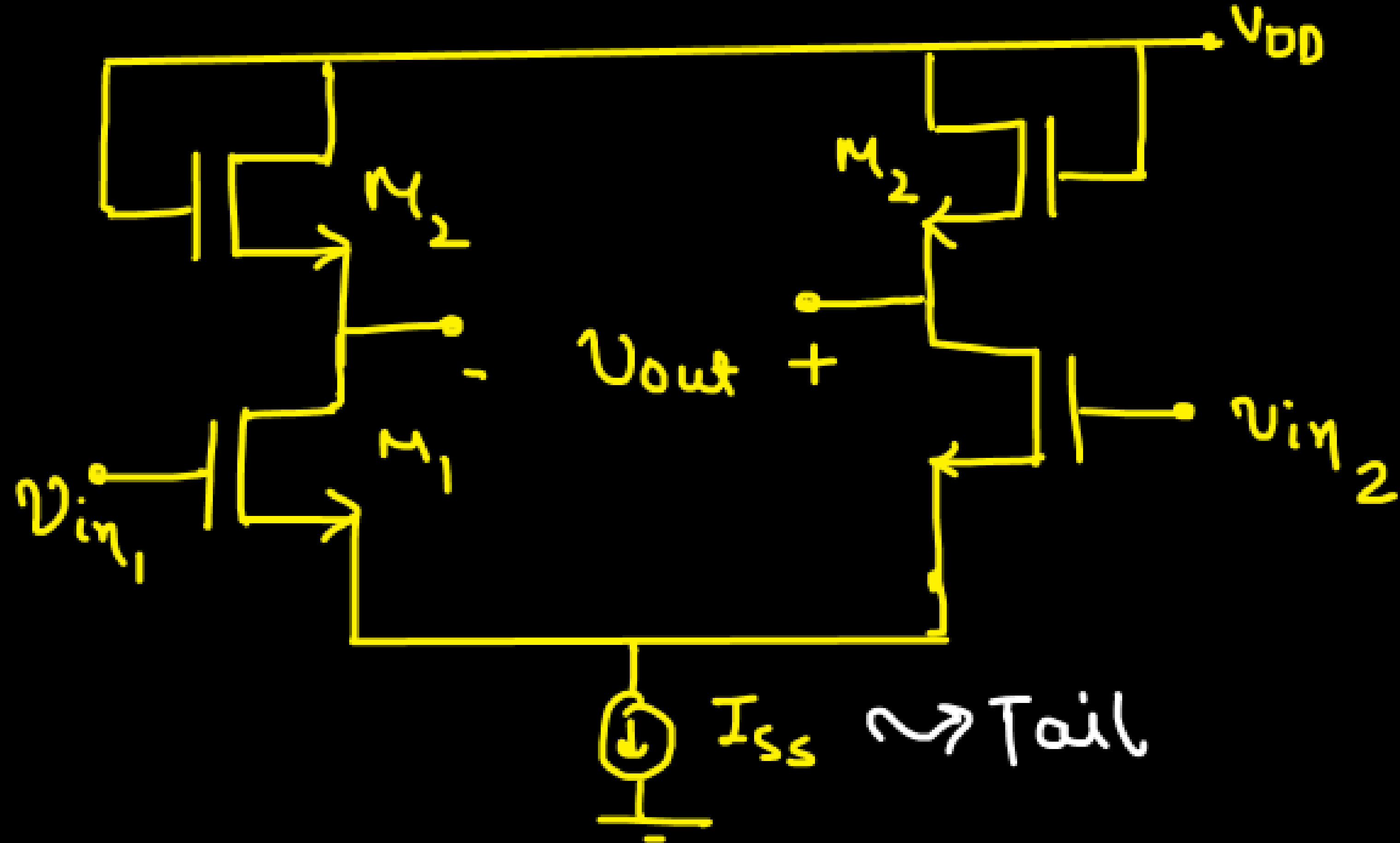
$$\boxed{(A_v)_{CM-DM} = \frac{0}{v_{cm}} = 0}$$

CMRR:-

$$CMRR = \left|\frac{(A)_d}{(A)_{CM-DM}}\right|$$

$$= \left|\frac{(A)_d}{0}\right|$$

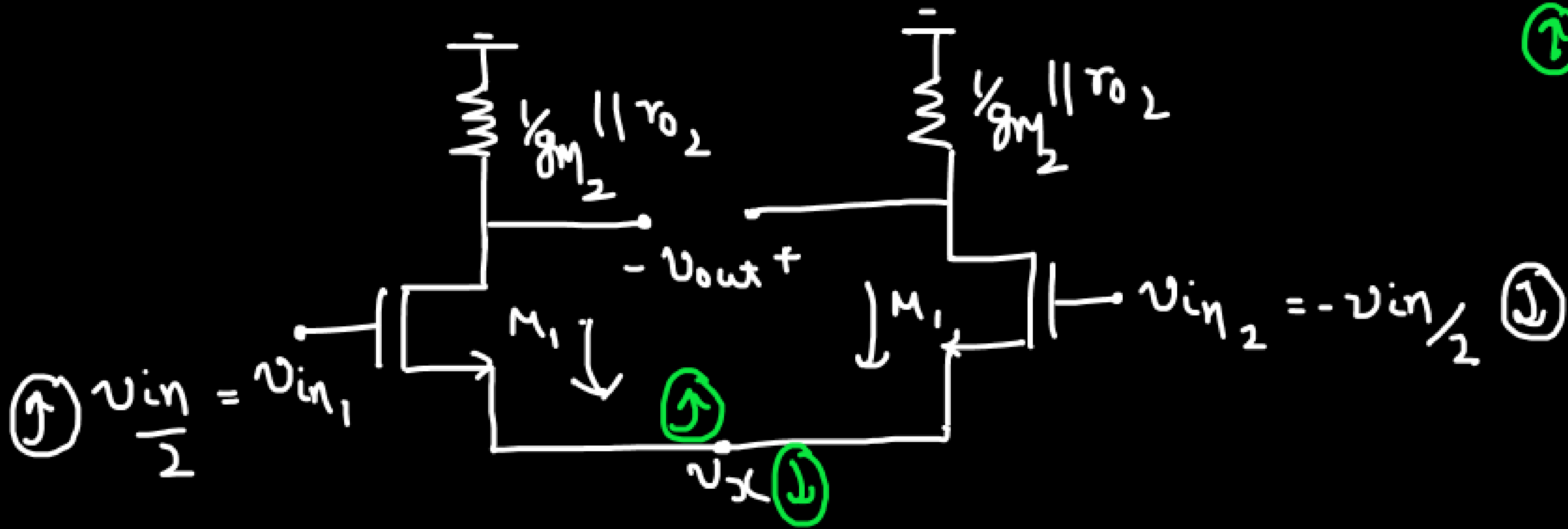
$$\boxed{CMRR = \infty}$$

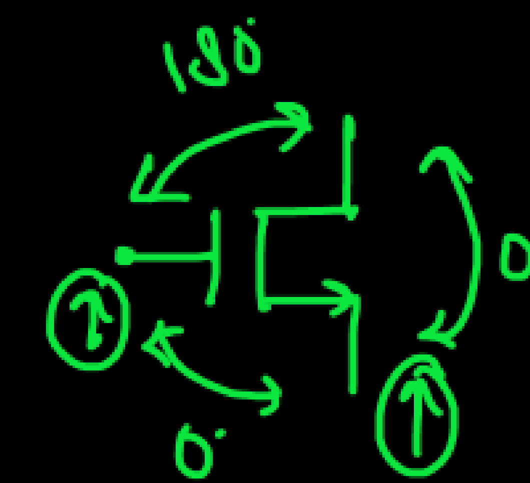


(b)

$$v_{in} = v_{in_1} - v_{in_2}$$

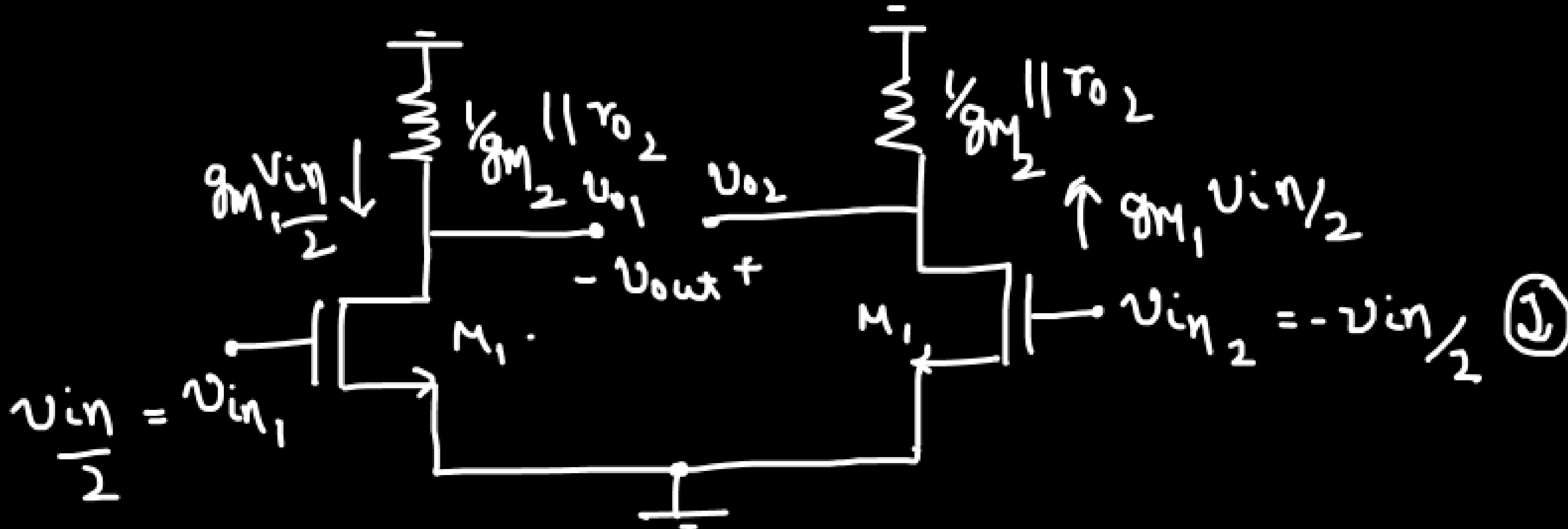
(I) Differential gain :-





$$g_m\left(\frac{v_{in}}{2} - v_x\right) = -g_m\left(-\frac{v_{in}}{2} - v_x\right)$$

$$\boxed{v_x = 0}$$



$$v_{o2} = g_{m1}\left[\frac{1}{g_{m2}} \| r_{o2}\right]\frac{v_{in}}{2}$$

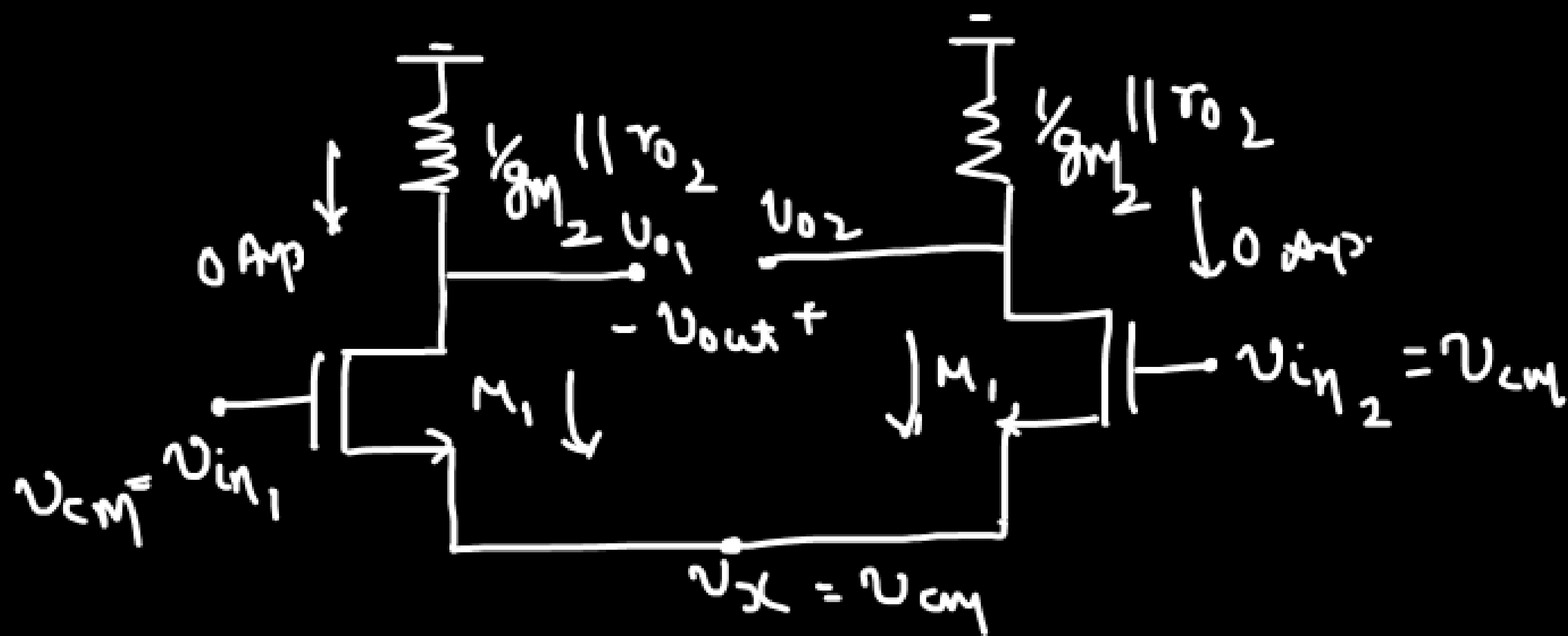
$$v_{o1} = -g_{m1}\left[\frac{1}{g_{m2}} \| r_{o2}\right]\frac{v_{in}}{2}$$

$$\boxed{A_v = g_{m1}\left[\frac{1}{g_{m2}} \| r_{o2}\right]}$$

$$(v_{out})_d = g_{m1}\left[\frac{1}{g_{m2}} \| r_{o2}\right] v_{in}$$

$$(v_{in})_d = v_{in}$$

(II) Common Mode Gain:-



$$g_{m1}(v_{cm} - v_x) = -g_{m1}(v_{cm} - v_x)$$

$$2g_{m1}(v_{cm} - v_x) = 0$$

$$\boxed{V_x = v_{cm}}$$

$$V_{o1} = V_{o2} = 0$$

$$(v_o)_{cm} = \frac{v_{o1} + v_{o2}}{2} = 0$$

$$\boxed{(A_v)_{cm} = \frac{0}{v_{cm}} = 0}$$

N.B.:- Common Mode gain shows the amount of noise present in the ckt.

It's good to have as low as common mode gain.

(III) Common-Mode Differential gain :-

$$v_{o_1} = 0$$

$$v_{o_2} = 0$$

$$(v_o)_{CM-DM} = v_{o_2} - v_{o_1} = 0$$

$$\boxed{(A)_{CM-DM} = 0}$$

N.B.:- When there is no Mismatch in Transistors

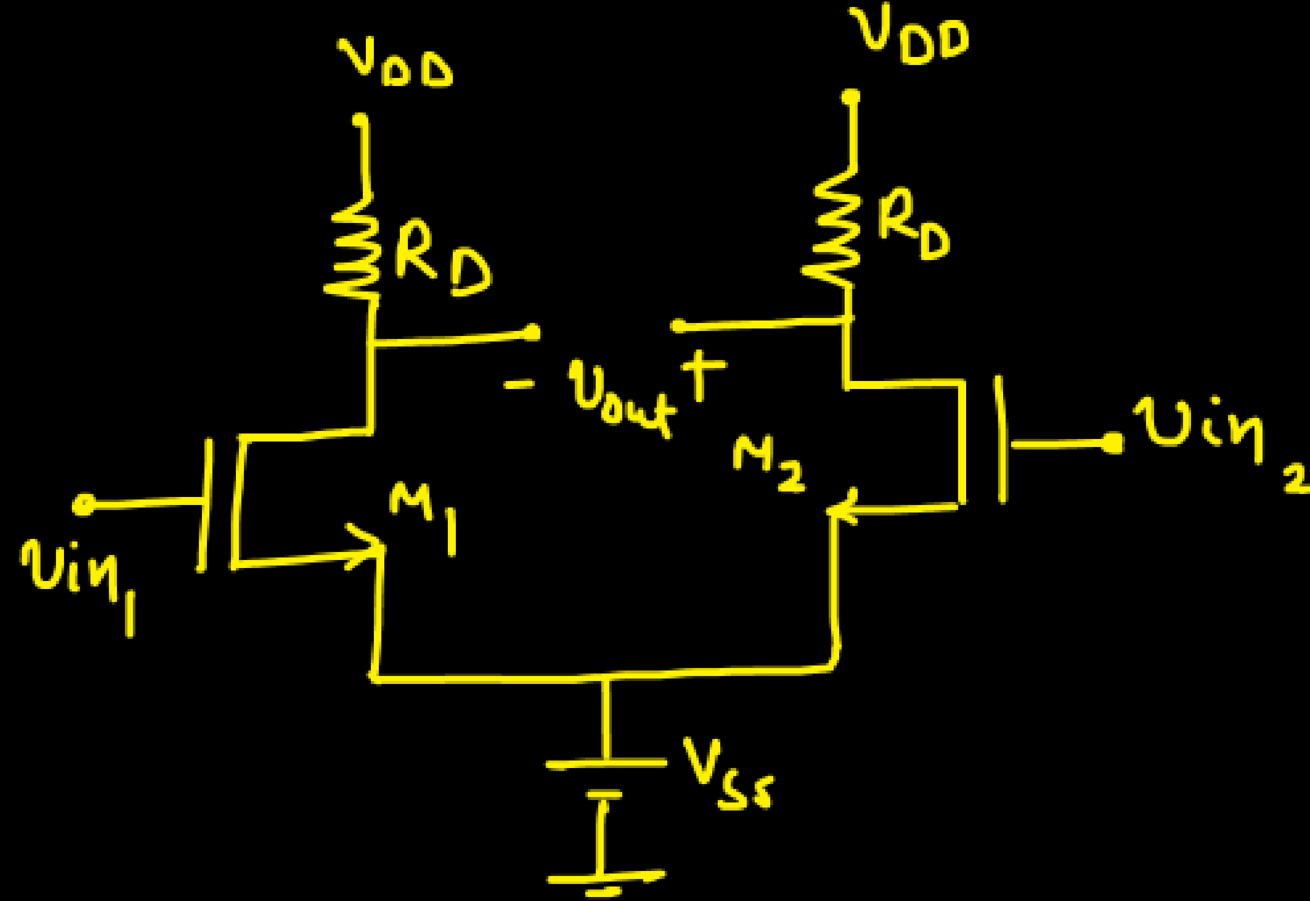
Voltage source as tail

1. $(A_v)_d = g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right]$
2. $(A_v)_{CM} = -g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right]$
3. $(A_v)_{CM-DM} = 0$

Current source as tail

1. $(A_v)_d = g_{m_1}\left[\frac{1}{g_{m_2}} \| r_{o_2}\right] \rightarrow \boxed{\text{Same}}$
2. $(A_v)_{CM} = 0 \rightarrow \boxed{\text{Advantage}}$ ★
3. $(A_v)_{CM-DM} = 0 \rightarrow \boxed{\text{Same}}$

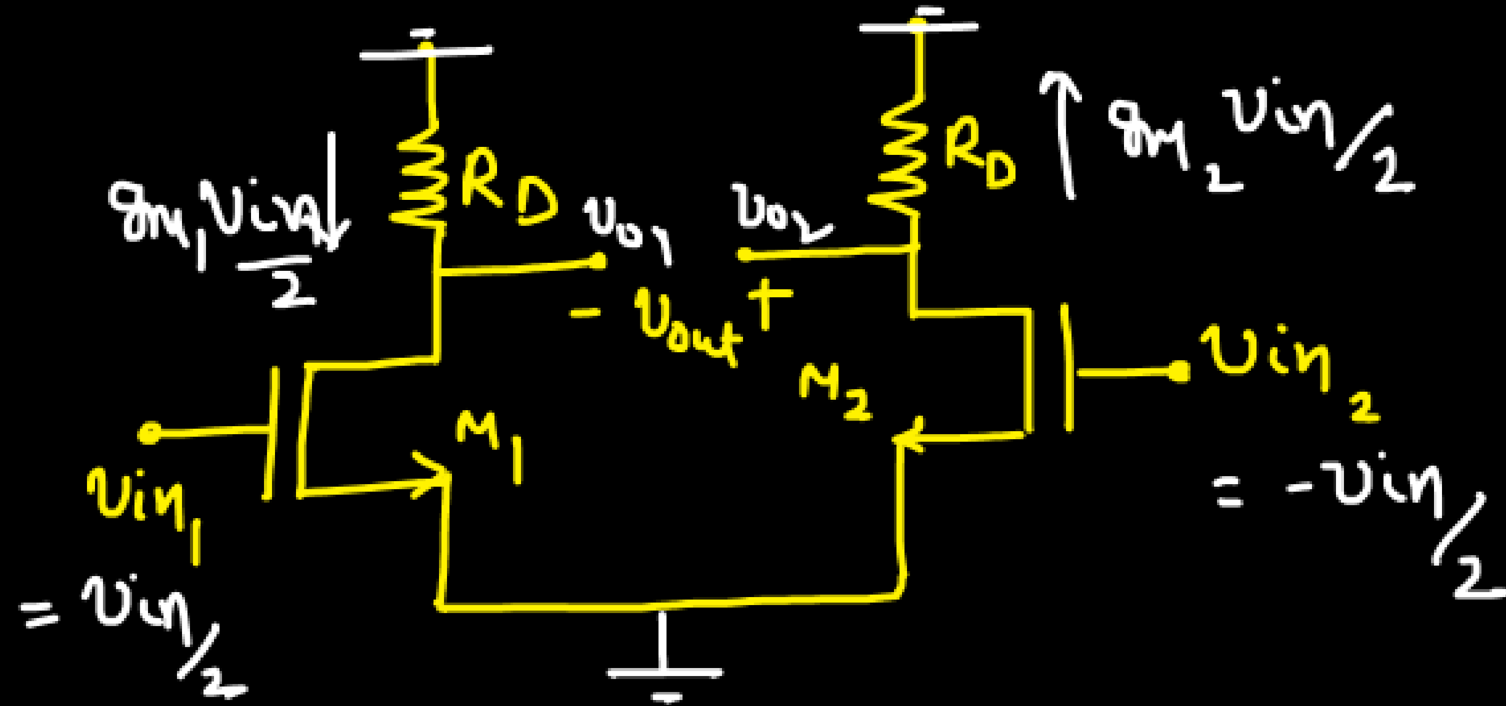
⇒ Finding the same parameters when there is mismatch:-



(a)

$V_{in} = V_{in_1} - V_{in_2}$

(a) <u>Differential gain :-</u>



$$v_{o2} = g_{m2} R_D \, v_{in}/2$$

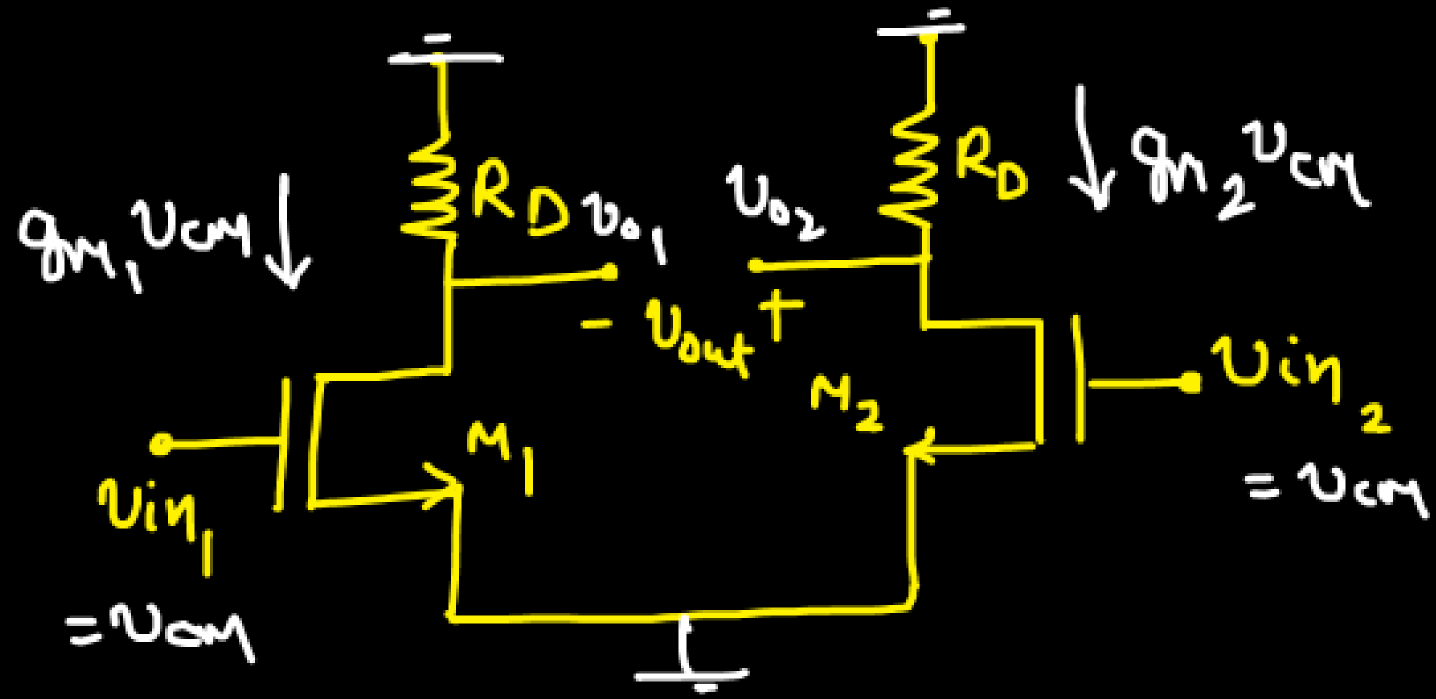
$$v_{o1} = -g_{m1} R_D \, v_{in}/2$$

$$(v_o)_d = v_{o2} - v_{o1} = (g_{m2} + g_{m1}) R_D \, v_{in}/2$$

$$(v_i)_d = v_{in}$$

$$\boxed{(A_v)_d = \left(\frac{g_{m1} + g_{m2}}{2}\right) R_D}$$

(b) Common-Mode Gain:-



$$v_{o_2} = -g_{m_2} R_D v_{cm}$$

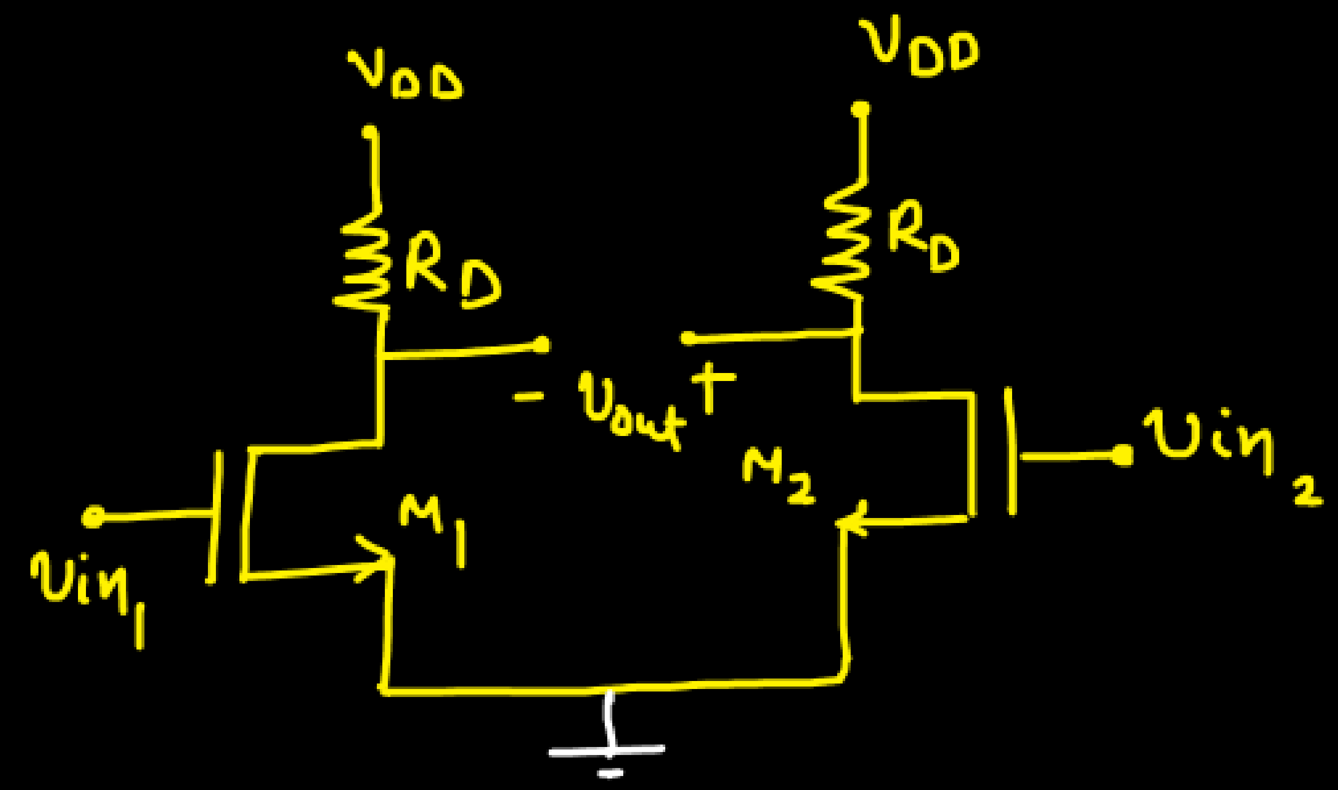
$$v_{o_1} = -g_{m_1} R_D v_{cm}$$

$$(v_o)_{cm} = -\frac{(g_{m_1} + g_{m_2})}{2} R_D v_{cm}$$

$$(v_i)_{cm} = v_{cm}$$

$$* \quad \boxed{(A_v)_{cm} = -\frac{(g_{m_1} + g_{m_2})}{2} R_D}$$

(c) Common Mode Differential Gain:-

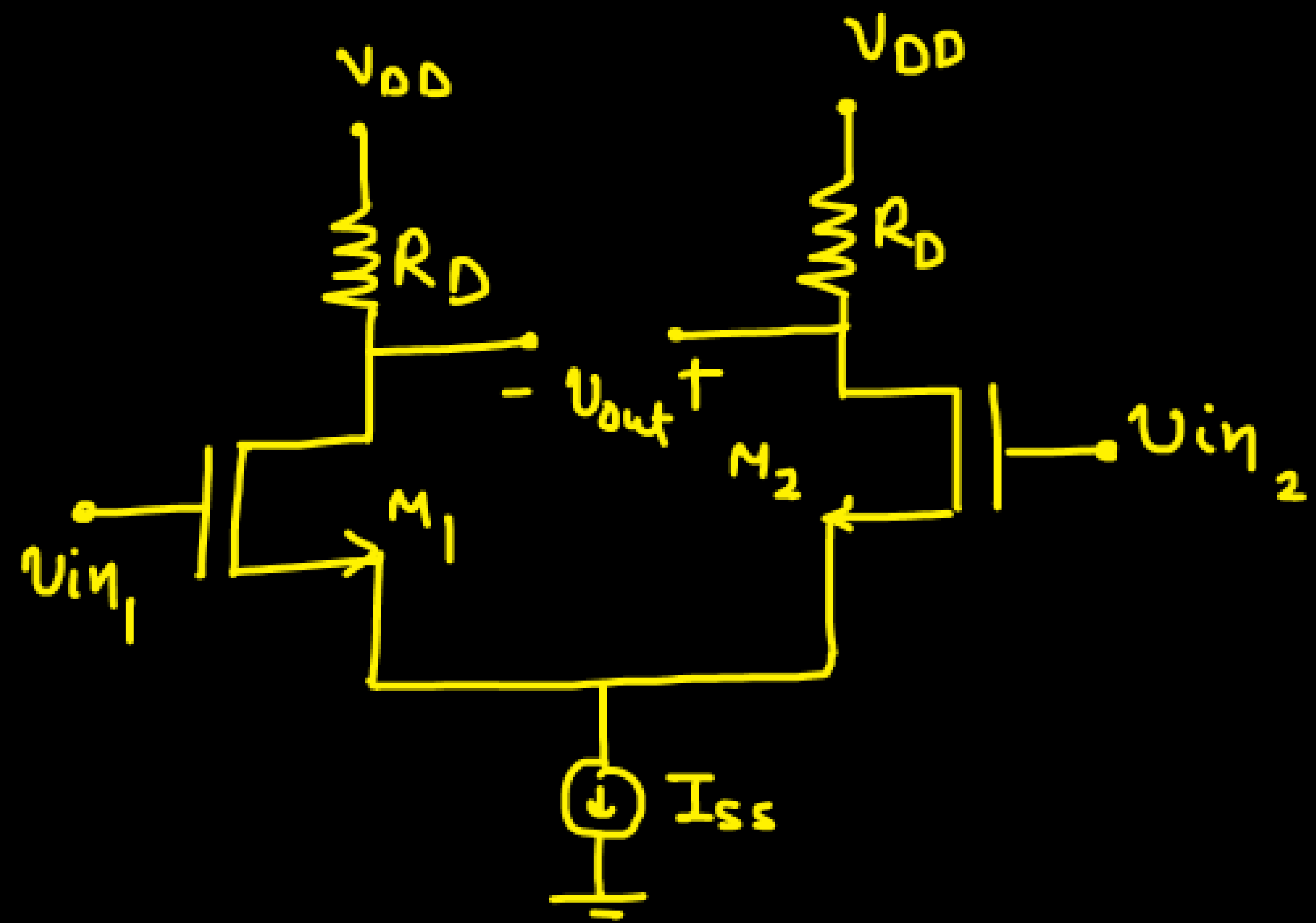


$$(v_o)_{CM-DM} = (g_{m_1} - g_{m_2}) R_D v_{CM}$$

$$(v_i)_{CM} = v_{CM}$$

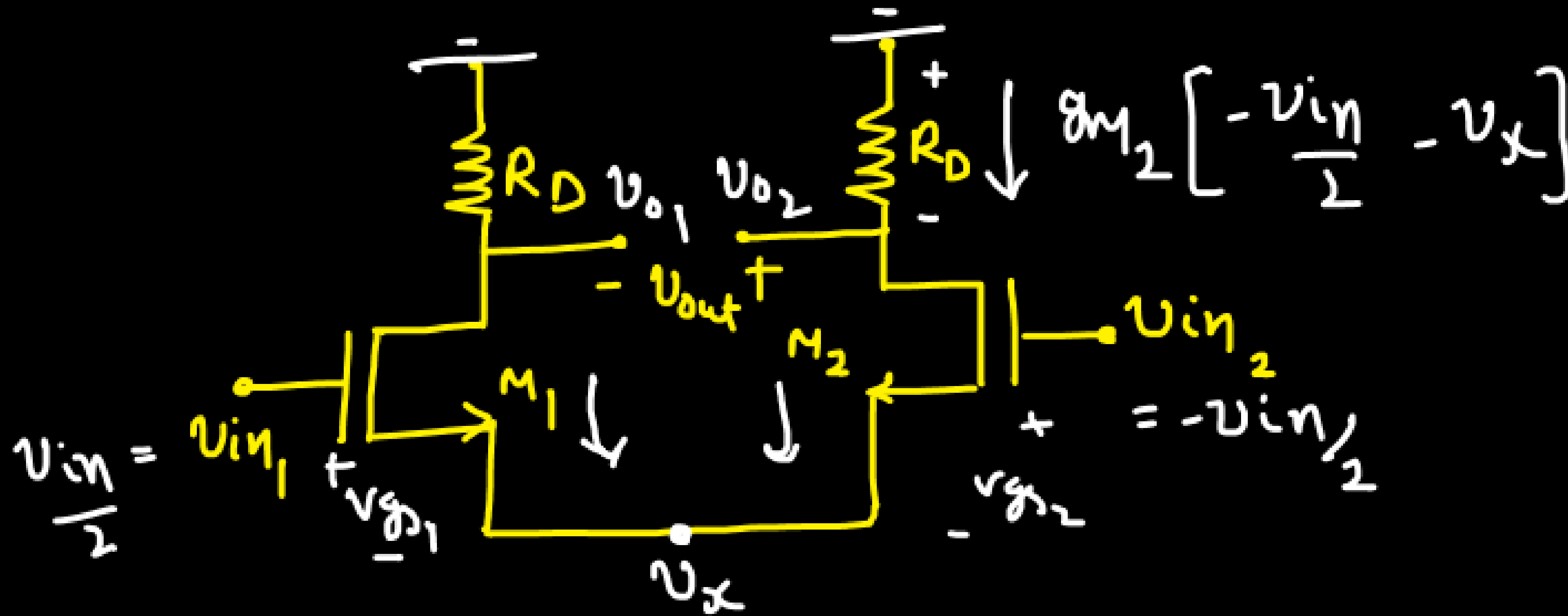
**

$$\boxed{(A_v)_{CM-DM} = (g_{m_1} - g_{m_2}) R_D}$$



(b)

(9) Differential Gain:-



$$g_{m_1}\left[\frac{v_{in}}{2} - v_x\right] = -g_{m_2}\left[-\frac{v_{in}}{2} - v_x\right]$$

$$g_{m_1}\frac{v_{in}}{2} - g_{m_1}v_x = g_{m_2}\frac{v_{in}}{2} + g_{m_2}v_x$$

$$\frac{(g_{m_1} - g_{m_2})}{g_{m_2} + g_{m_1}}\frac{v_{in}}{2} = v_x \quad \text{—— } (1)$$

$$v_{o2} = g_{m2} R_D \left[\frac{v_{in}}{2} + v_x \right]$$

$$v_{o1} = -g_{m1} R_D \left[\frac{v_{in}}{2} - v_x \right]$$

$$(v_o)_d = g_{m2} R_D \left[\frac{v_{in}}{2} + v_x \right] + g_{m1} R_D \left[\frac{v_{in}}{2} - v_x \right]$$

$$(v_o)_d = \frac{\left[g_{m2} + g_{m1} \right] R_D v_{in}}{2} + \left[g_{m2} - g_{m1} \right] R_D v_x$$

$$= \left[\frac{g_{m1} + g_{m2}}{2} \right] R_D v_{in} + \left[g_{m2} - g_{m1} \right] R_D \frac{\left[g_{m1} - g_{m2} \right]}{\left[g_{m2} + g_{m1} \right]} \frac{v_{in}}{2}$$

$$= \left\{ \frac{\left[g_{m1} + g_{m2} \right]^2 R_D - \left[g_{m2} - g_{m1} \right]^2 R_D}{g_{m1} + g_{m2}} \right\} v_{in}/2$$

$$= \frac{\left[4 g_{m_1} g_{m_2}\right]}{g_{m_1} + g_{m_2}} R_D \frac{v_{in}}{2}$$

$$(v_o)_d = \left[\frac{2 g_{m_1} g_{m_2}}{g_{m_1} + g_{m_2}}\right] R_D v_{in}$$

$$(v_i)_d = v_{in}$$

$$\boxed{(A_v)_d = \frac{2 g_{m_1} g_{m_2}}{g_{m_1} + g_{m_2}} R_D}$$

Current source as a tail:-

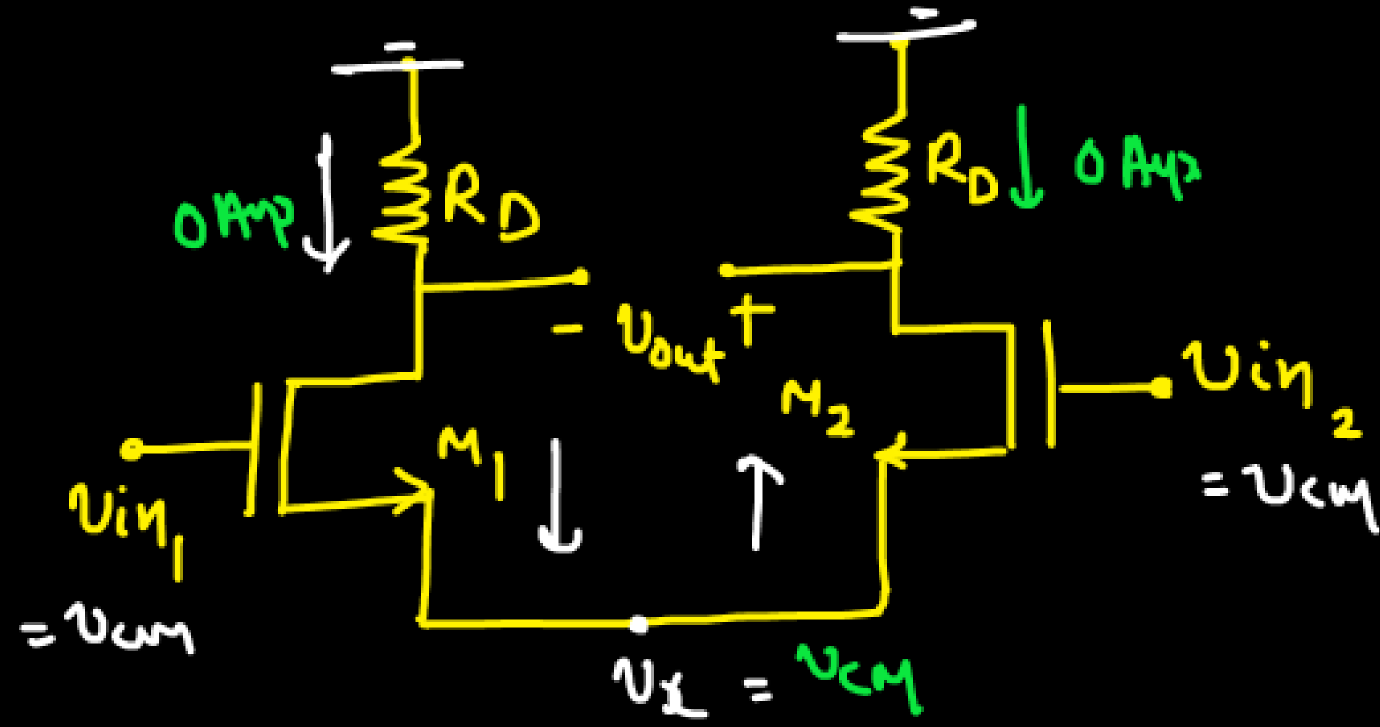
$$(A_v)_{d_{c.s.}} = \left(\frac{2 g_{m_1} g_{m_2}}{g_{m_1} + g_{m_2}}\right) R_D$$

Voltage source as a tail:-

$$(A_v)_{d_{v.s.}} = \left(\frac{g_{m_1} + g_{m_2}}{2}\right) R_D \rightarrow \text{ve Advantge}$$

$$\boxed{(A_v)_{d_{v.s.}} > (A_v)_{d_{c.s.}}} \rightarrow \text{In case of mismatch}$$

(b) Common mode gain :-



$$g_{m_1}(v_{cm} - v_x) = -g_{m_2}(v_{cm} - v_x)$$

$$(g_{m_1} + g_{m_2})v_{cm} = (g_{m_2} + g_{m_1})v_x$$

$$v_x = v_{cm}$$

$$\boxed{(A_v)_{cm} = 0}$$

$$(A_v)_{cm \to v.s.} = -\left(\frac{g_{m_1} + g_{m_2}}{2}\right) R_D$$

$$\underbrace{(A_v)_{cm \to c.s}}_{\text{Advantage}} = 0$$

(c) Common-Mode Differential Gain :-

$$v_{o_1} = v_{o_2} = 0$$

$$\boxed{(A_v)_{CM-DM} = 0}$$

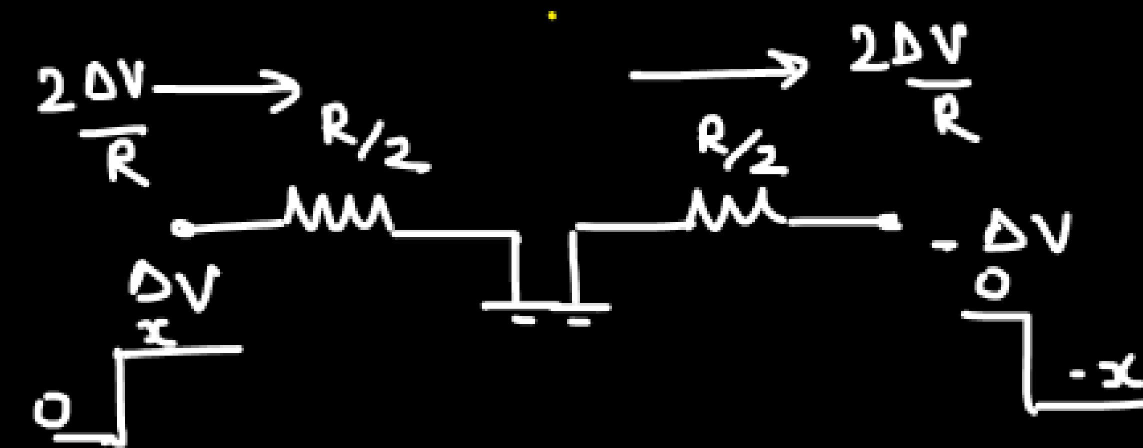
$$(A_v)_{CM-DM \to V.S} = (g_{m_1} - g_{m_2}) R_D$$

$$\underbrace{(A_v)_{CM-DM \to C.S.}}_{\text{Advantage}} = 0$$

★ Some important concepts :-

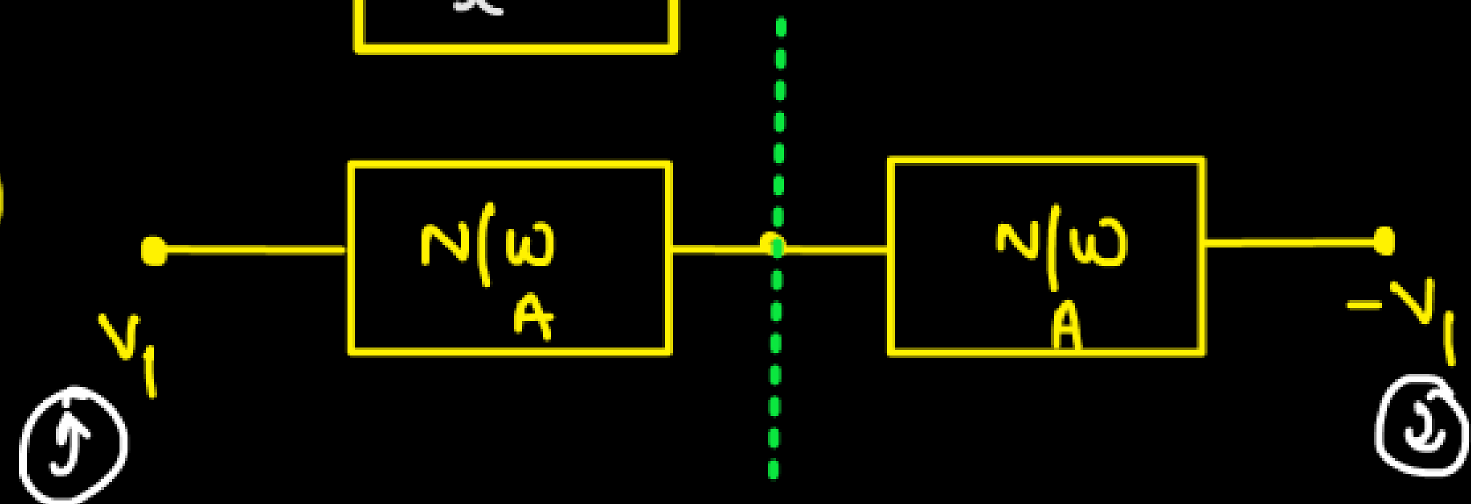
① 

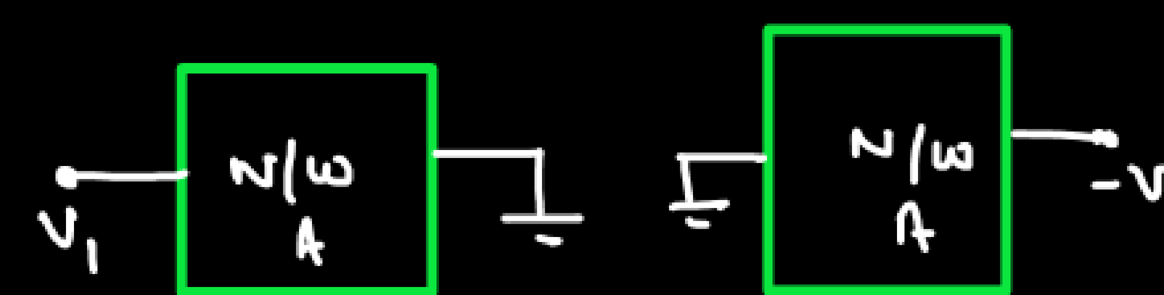
potential @ node x ?



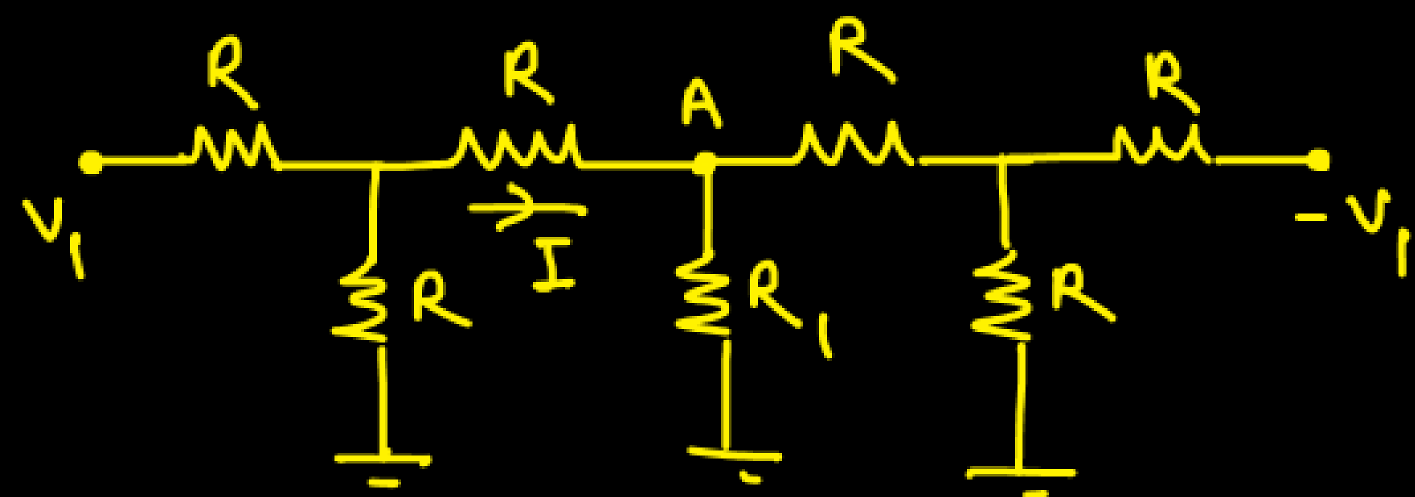
→ $$V_x = \frac{\Delta V\left(R/2\right) + (-\Delta V)\left(R/2\right)}{R}$$

$$\boxed{V_x = 0}$$

② 

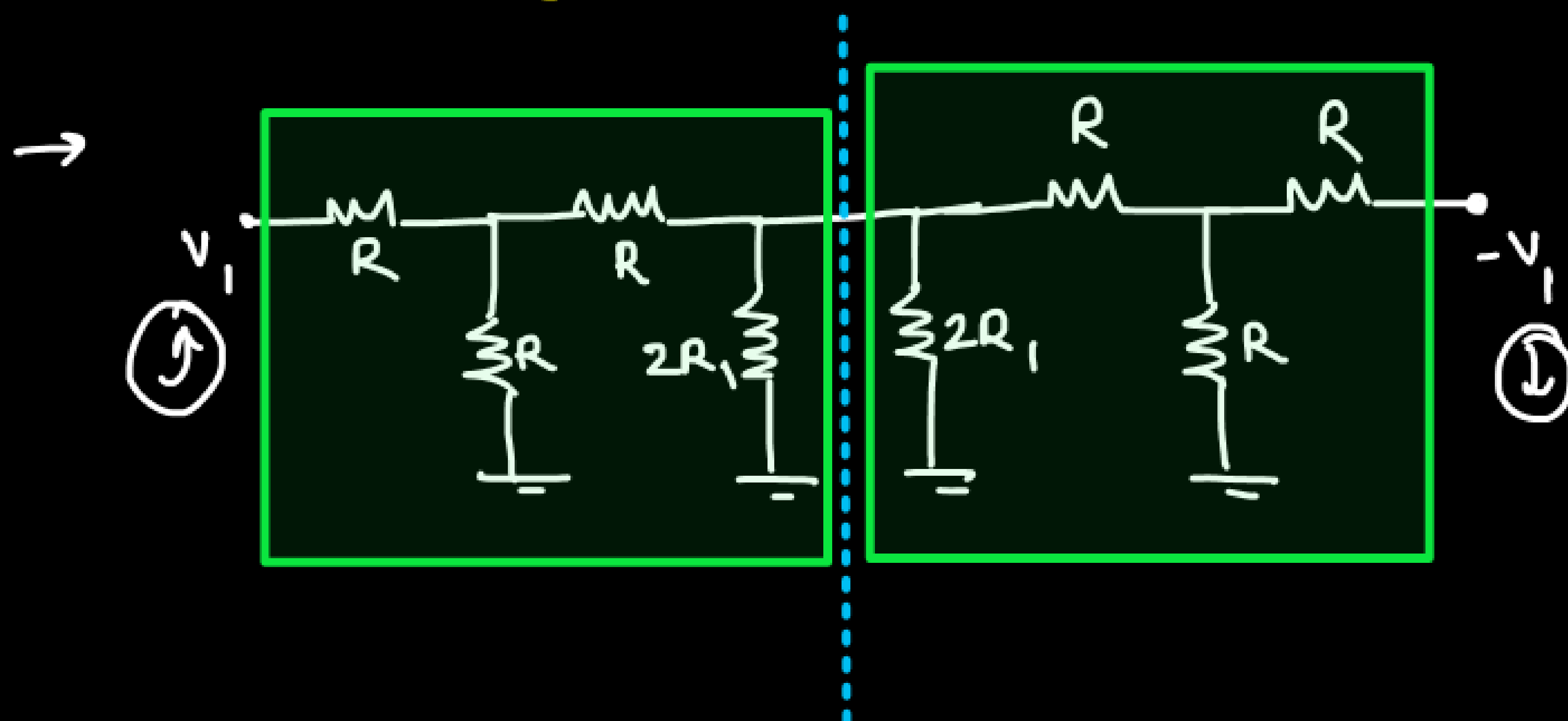
≡ 

③

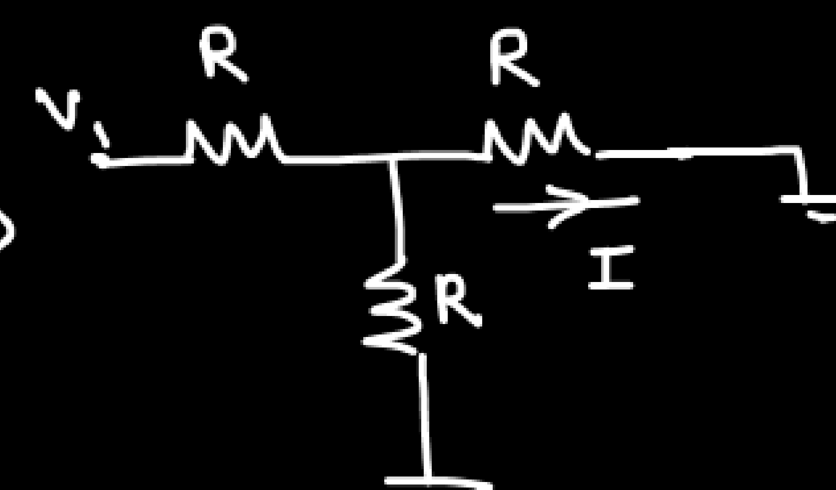


Find the potential @ node A.

Find current I.

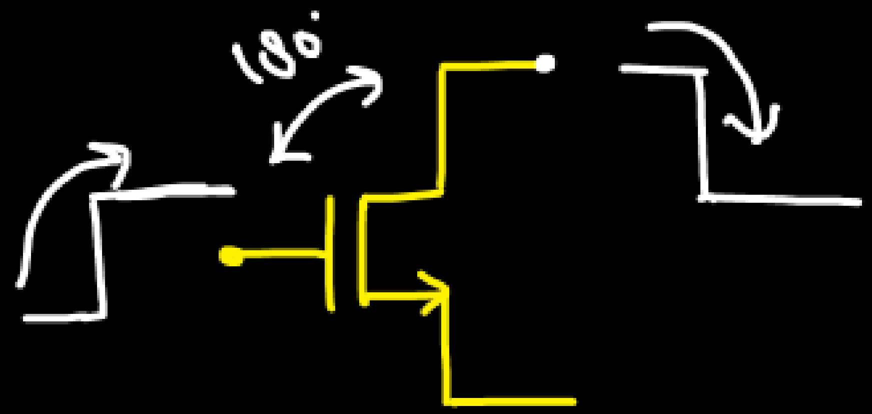


$\Rightarrow$



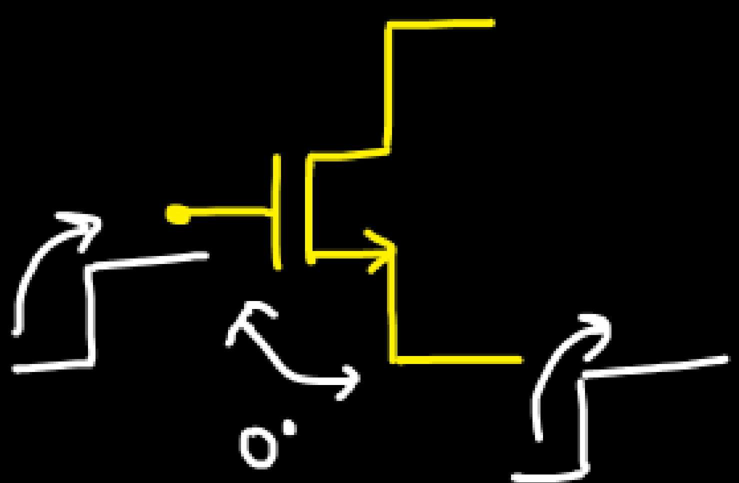
$$I = \frac{2V_1}{3R} \times \frac{1}{2} = \frac{V_1}{3R}$$

4



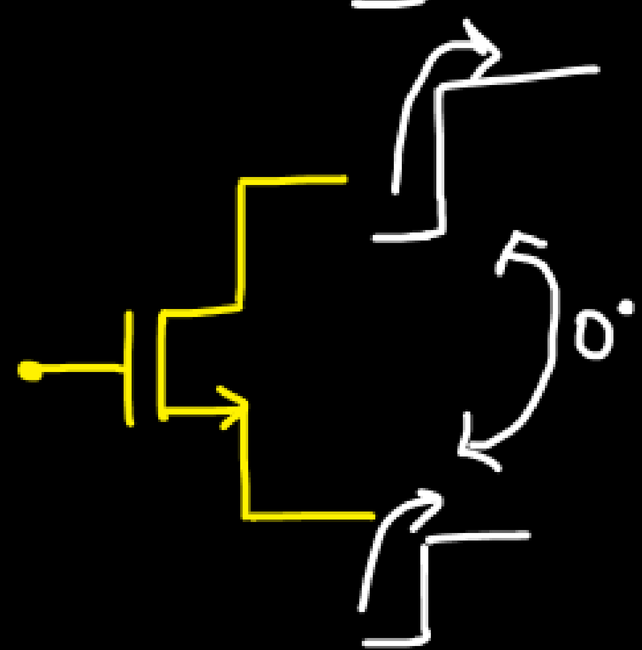
$$A_v = -g_m R_D$$

5



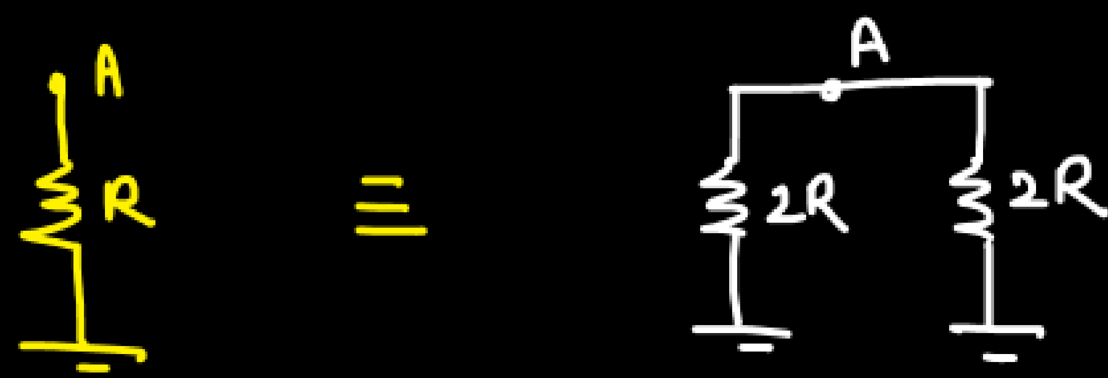
$$A_v = \frac{g_m R_S}{1 + g_m R_S}$$

6

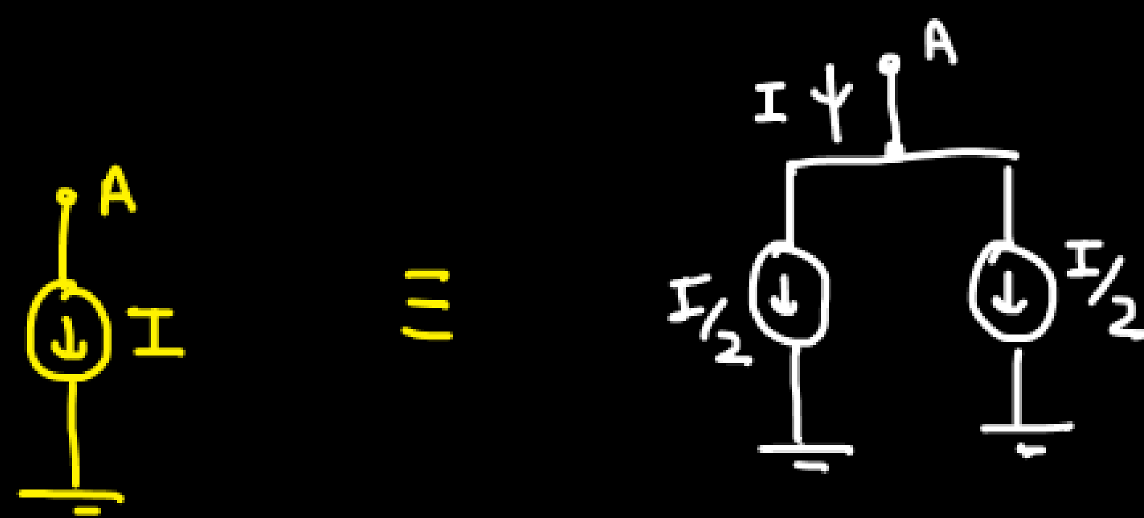


$$A_v = g_m R_D$$

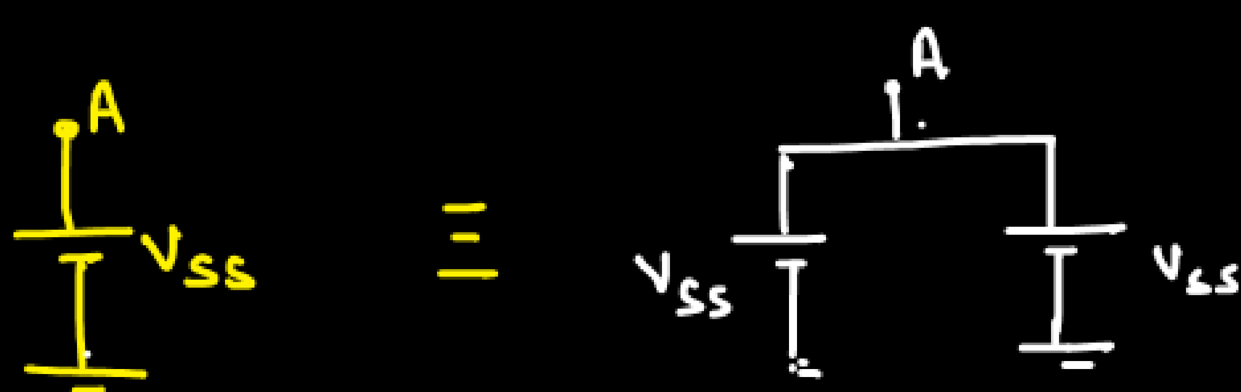
7



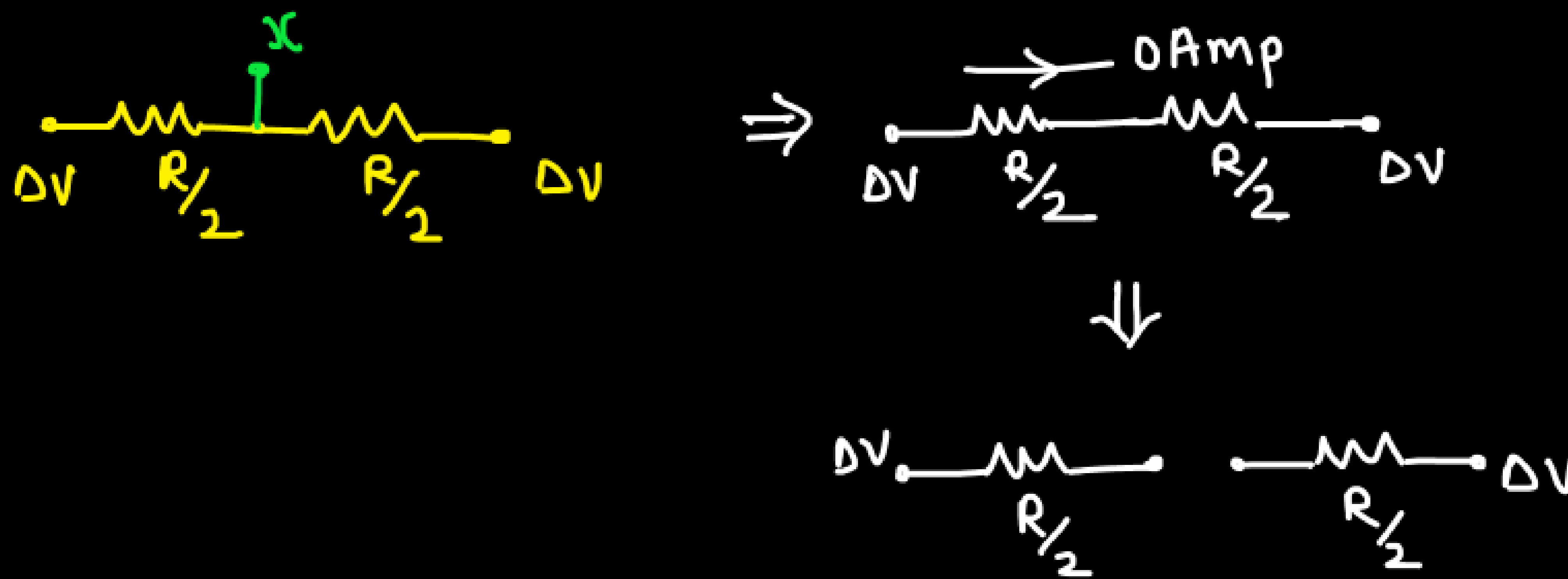
8



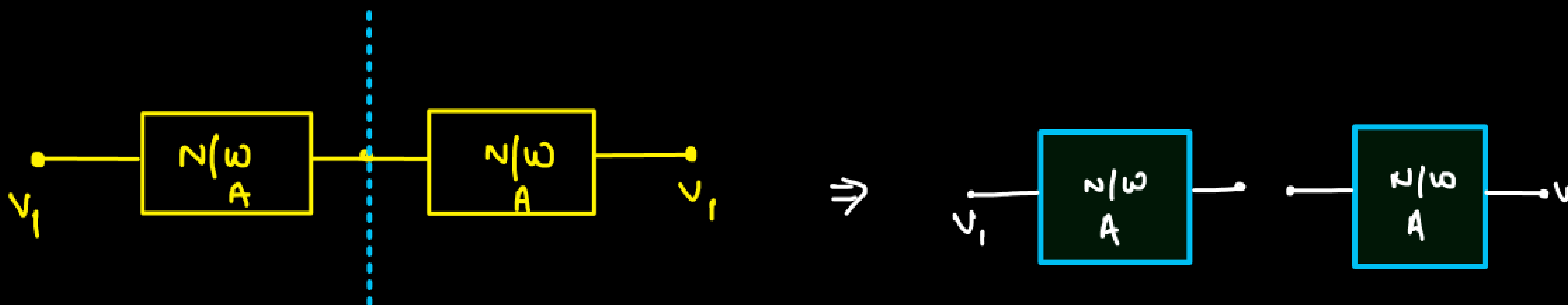
9



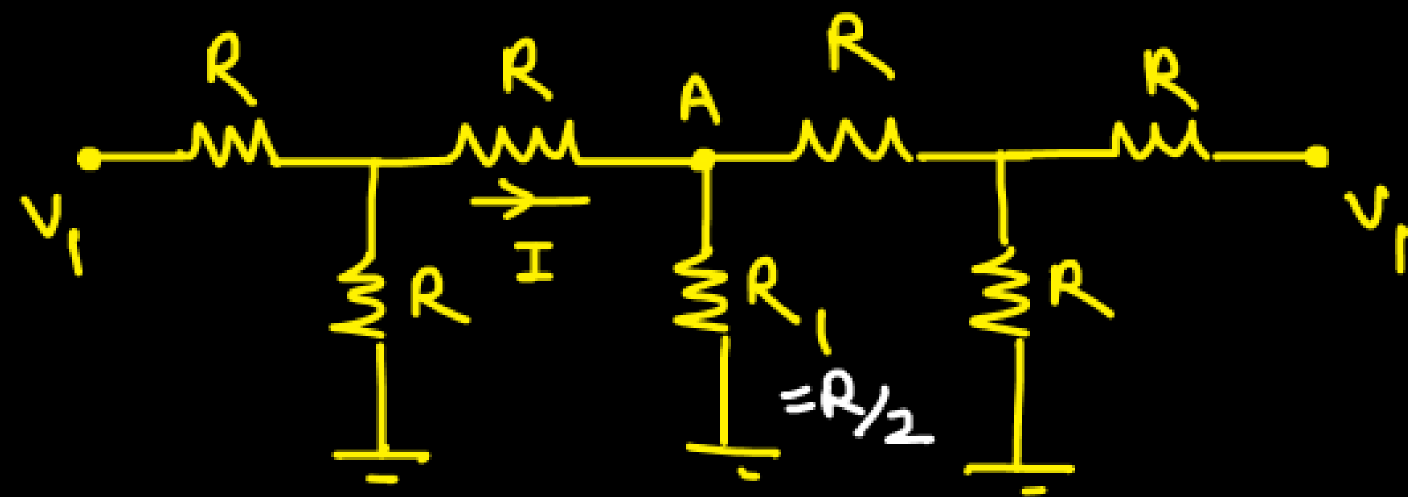
10



11



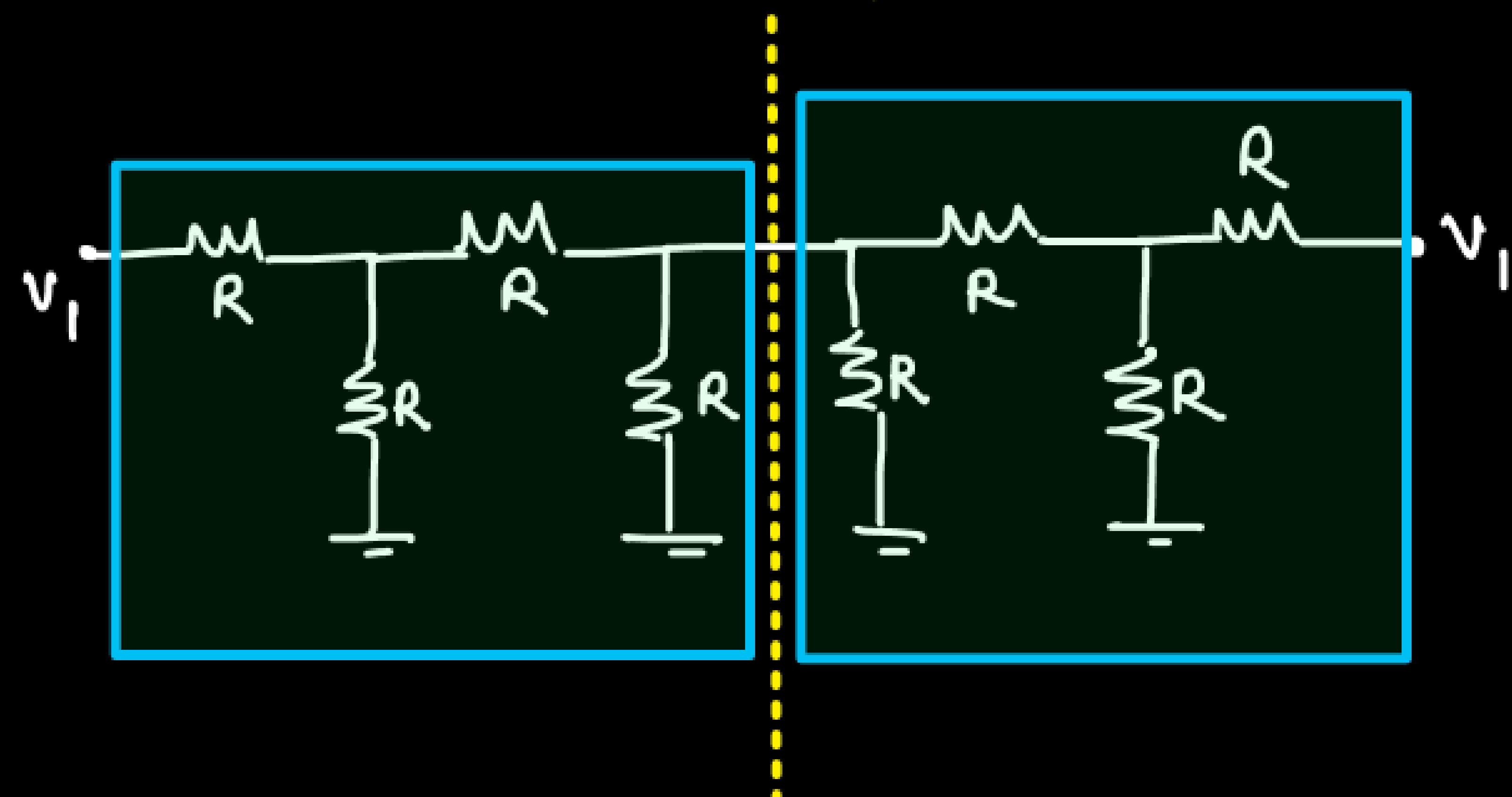
12



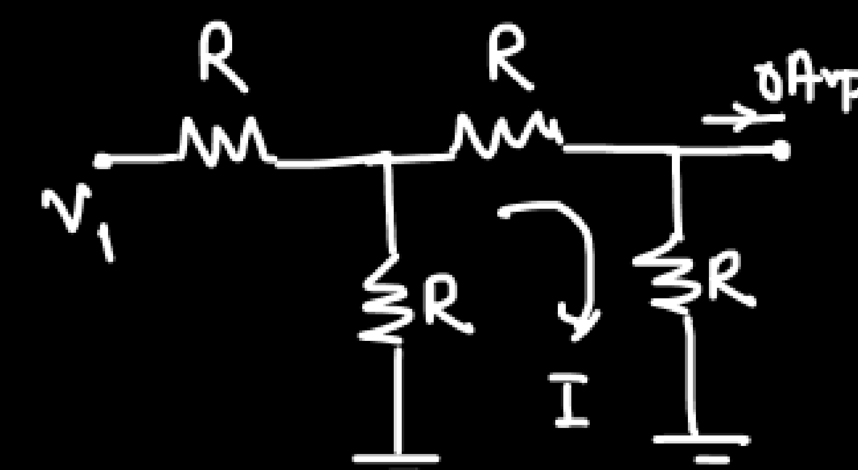
$$R_1 = R/2$$

Find current I = ?

→



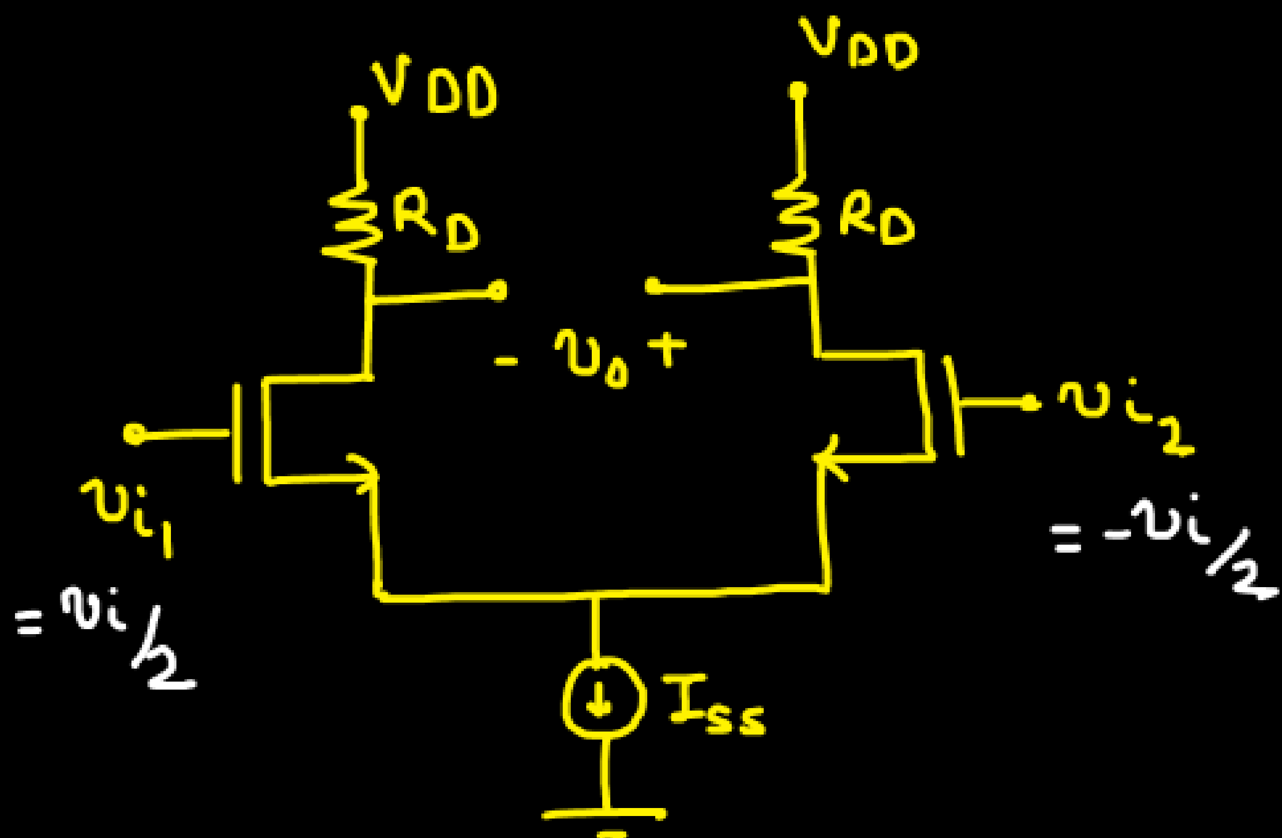
⇒



$$\boxed{I = \frac{3V_1}{5R} \times \frac{R}{3R} = \frac{V_1}{5R}}$$

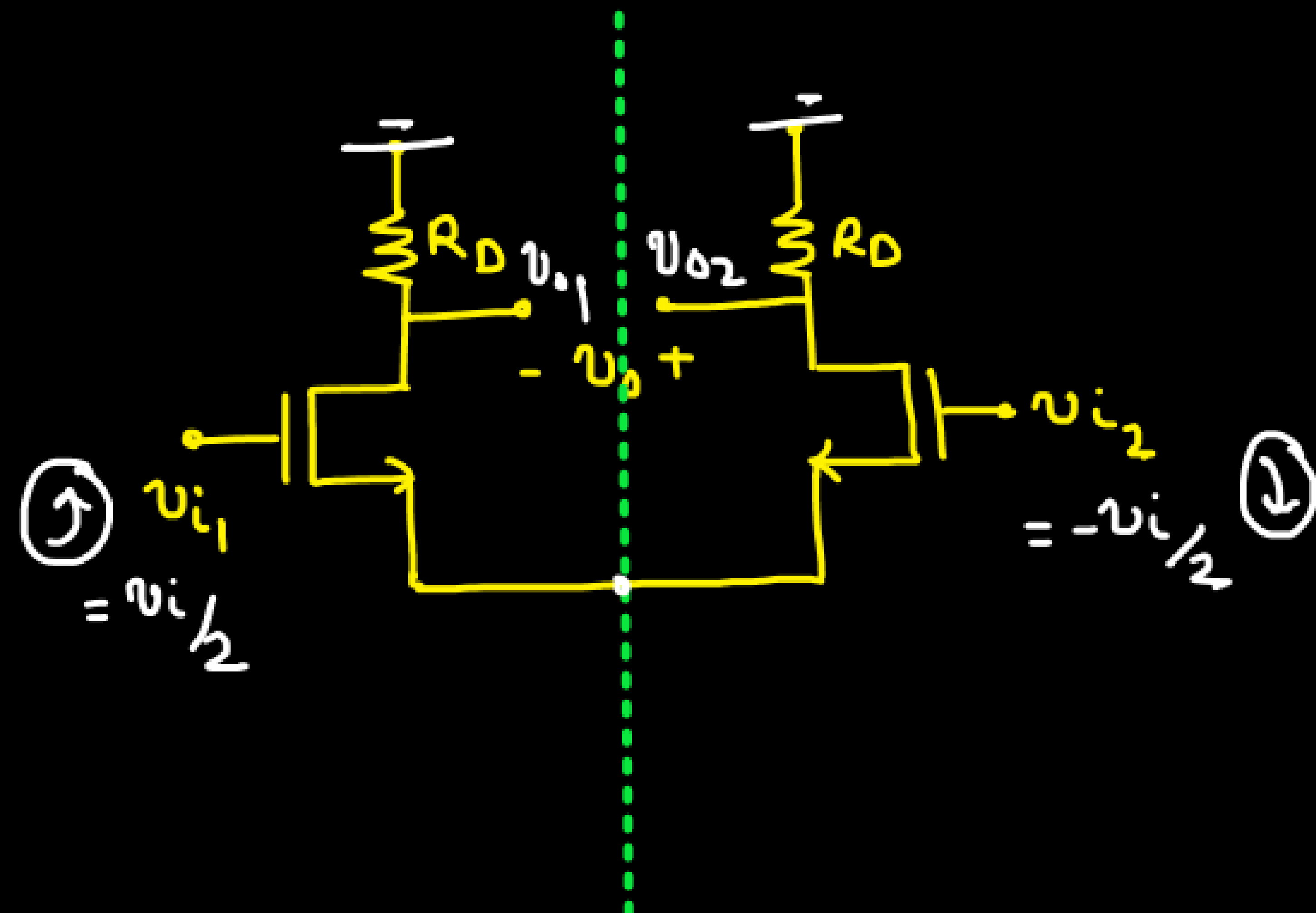
⇒ Concept of Half ckt:-

(a) For Differential Gain:-

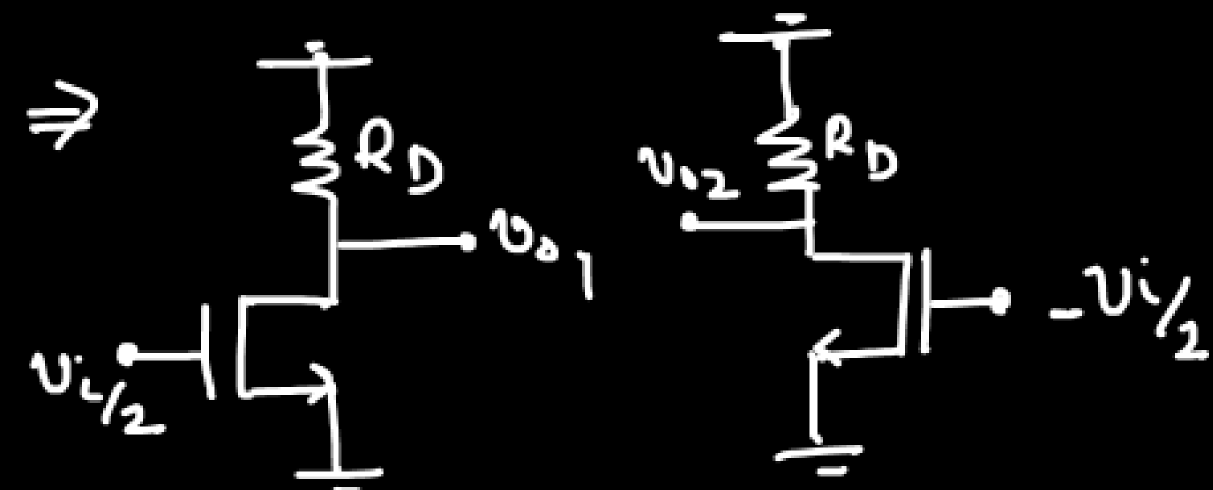


$$v_{i_1} - v_{i_2} = v_{in}$$

Small signal Model:-



$\Rightarrow$



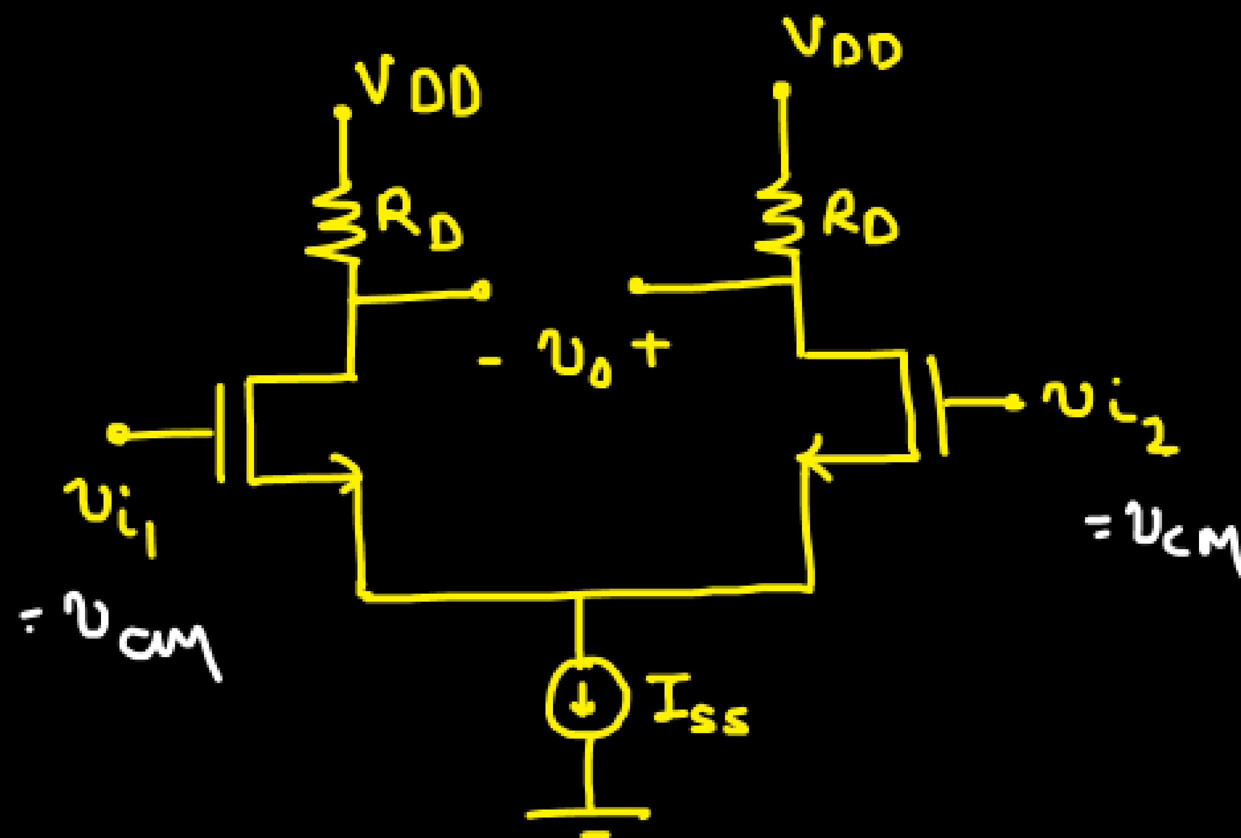
$$v_{o_1} = -g_m R_D v_i/2$$

$$v_{o_2} = g_m R_D v_i/2$$

$$v_o = g_m R_D v_i$$

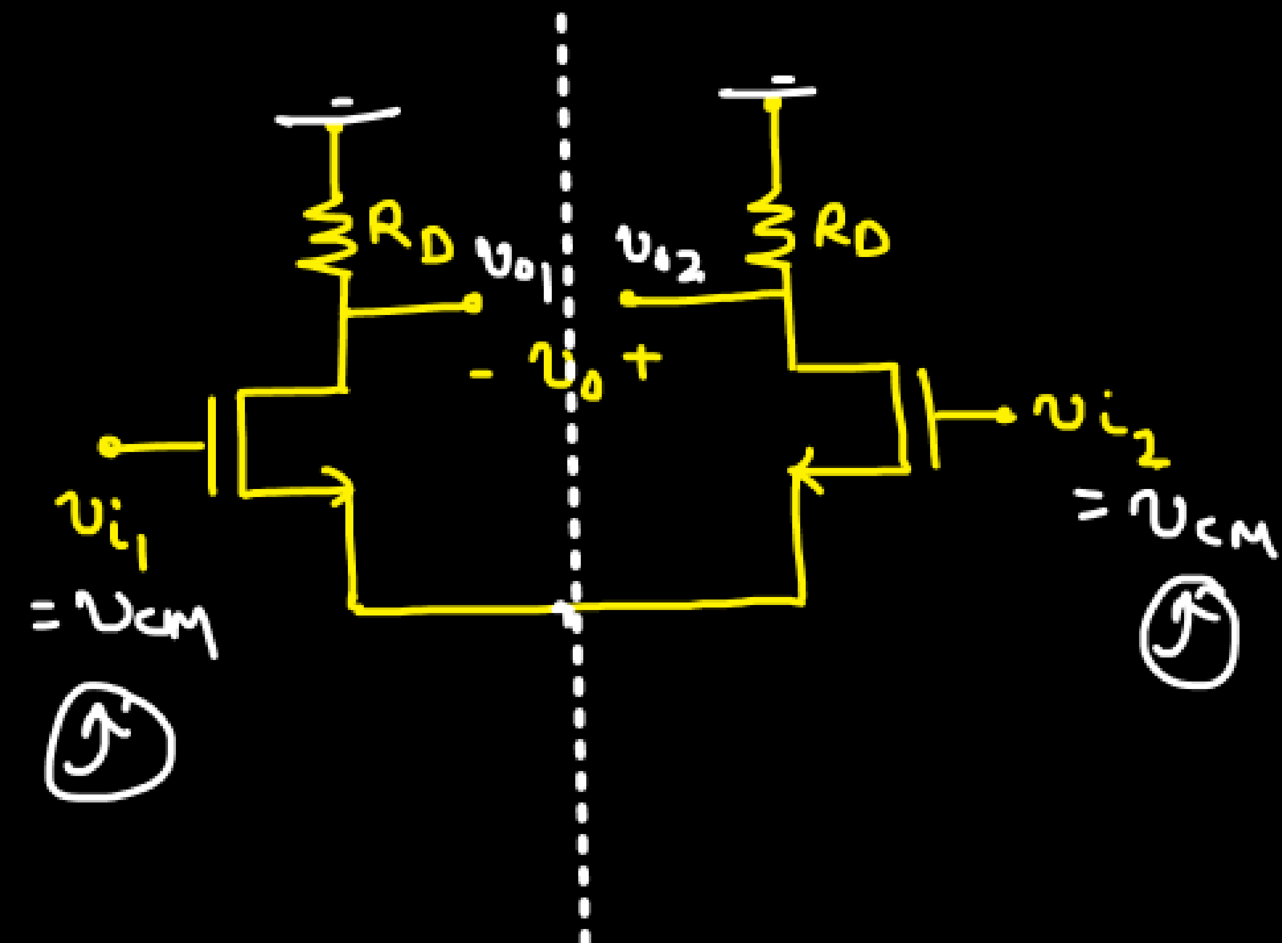
$$\boxed{(A_v)_d = g_m R_D}$$

For common Mode gain :-



$$v_{i_1} - v_{i_2} = v_{in}$$

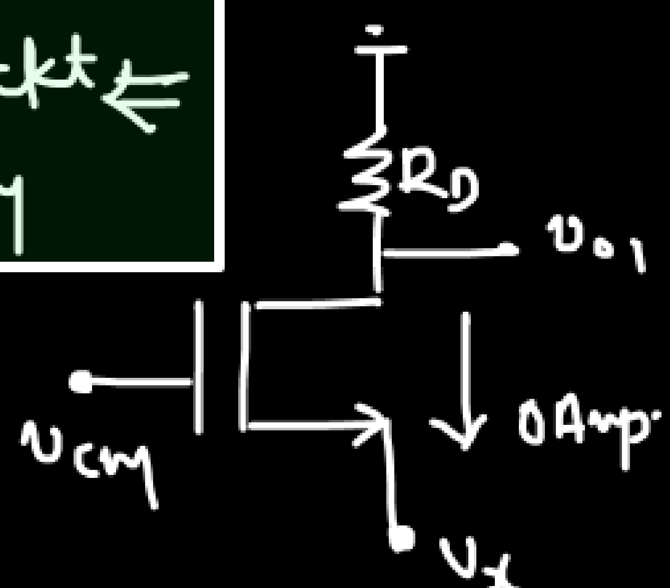
Small Signal Model :-



$$(v_o)_{CM} = \frac{v_{o2} + v_{o1}}{2}$$

$$(v_i)_{CM} = v_{CM}$$

$$\boxed{\text{Same Half ckt for CM-DM}}$$



$$v_{o1} = 0$$

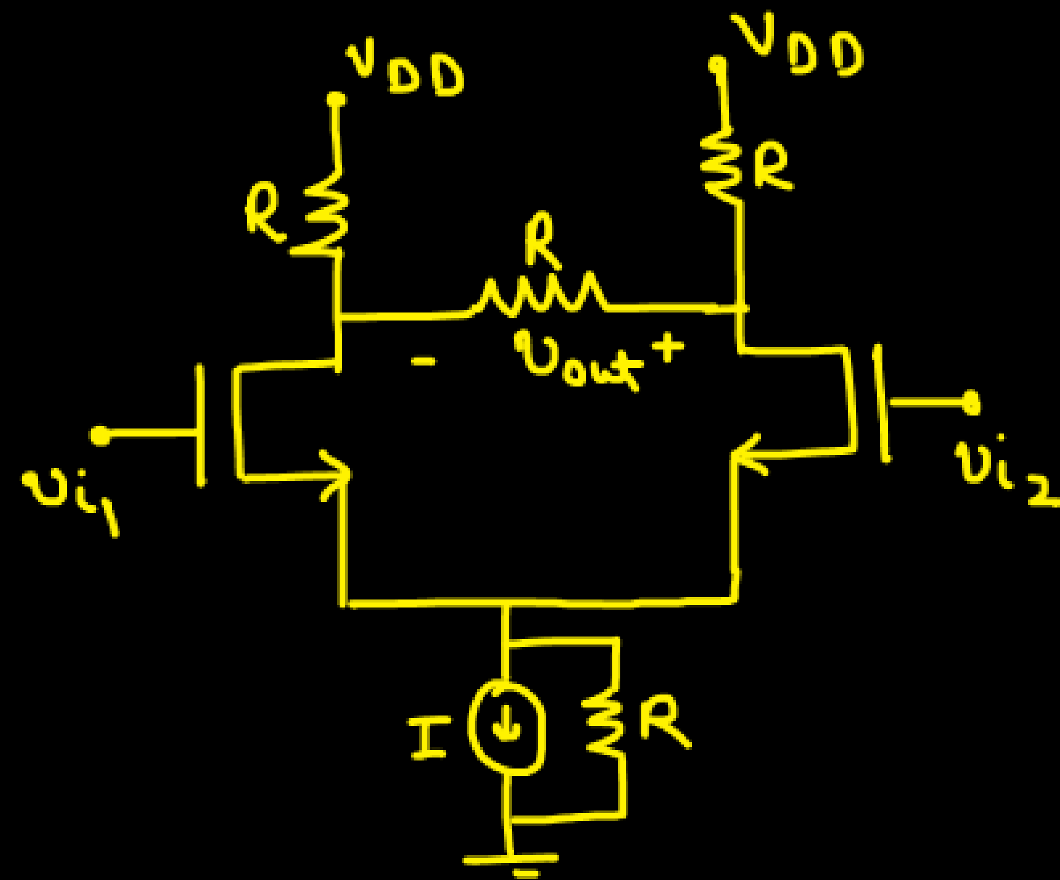
$$v_{o2} = 0$$

$$\boxed{(A_v)_{CM} = 0}$$

$$g_m(v_{CM} - v_x) = 0$$

$$\boxed{v_x = v_{CM}}$$

Q.



Find

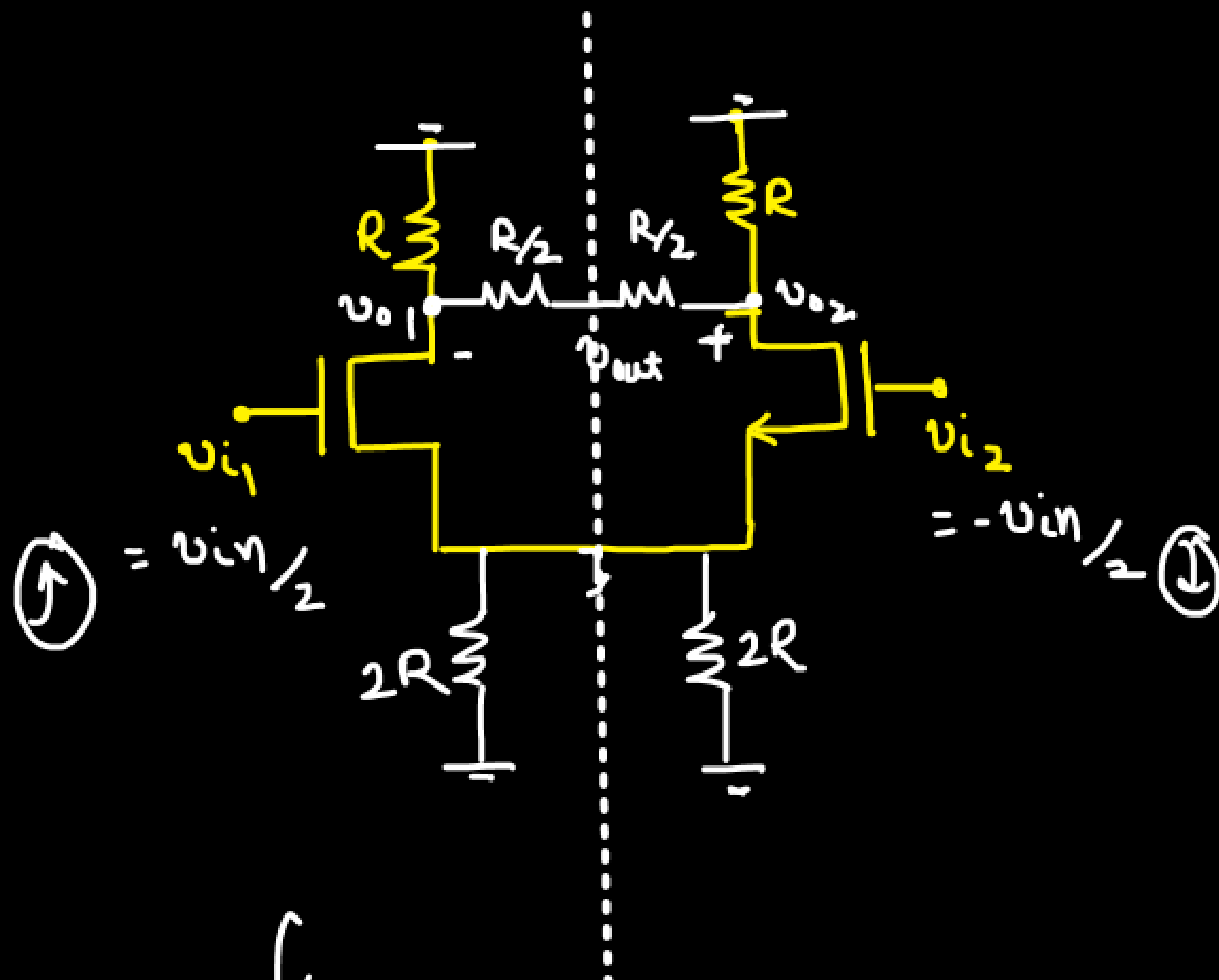
(a) Differential Gain

(b) Common-Mode Gain

(c) Common-Mode Differential Gain

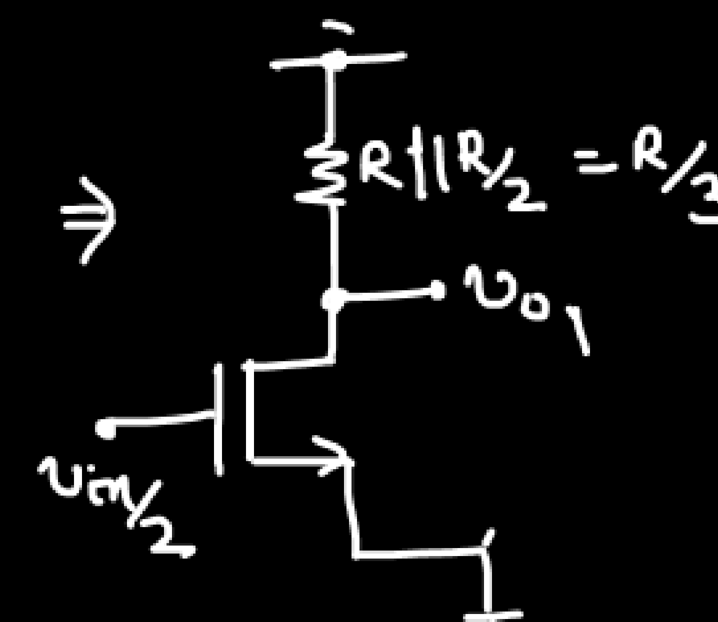
(d) CMRR

(a) Differential gain:-



$$v_{out} = v_{o2} - v_{o1}$$

$\Rightarrow$



$$v_{o1} = -g_m \frac{R}{3} \frac{v_{in}}{2}$$

$$v_{o2} = g_m \frac{R}{3} \frac{v_{in}}{2}$$

$\Leftarrow$

$$(v_o)_d = g_m \frac{R}{3} v_{in}$$

$$(v_i)_d = v_{in}$$

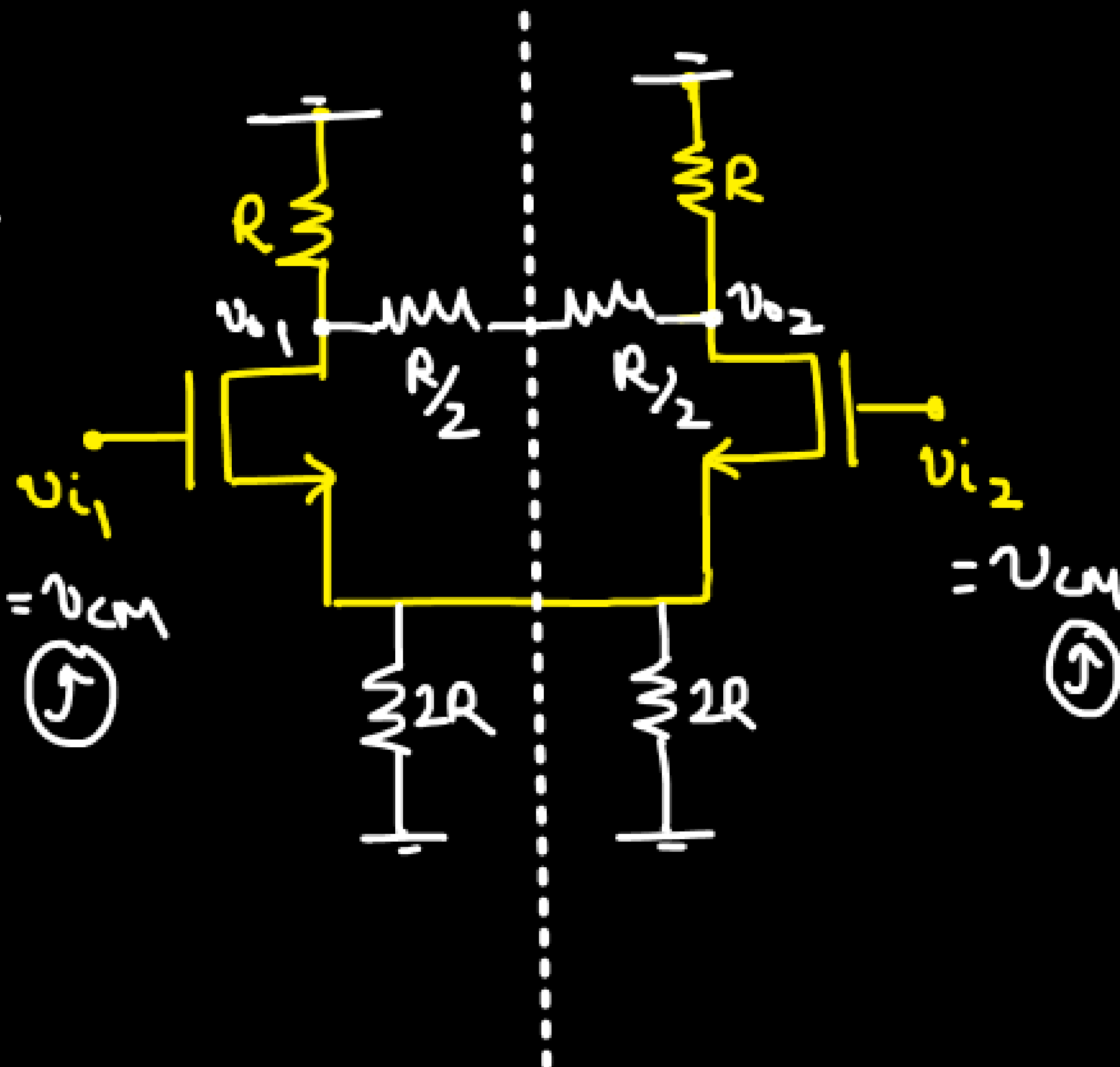
$\Leftarrow$

$$\boxed{A_v = g_m \frac{R}{3}}$$

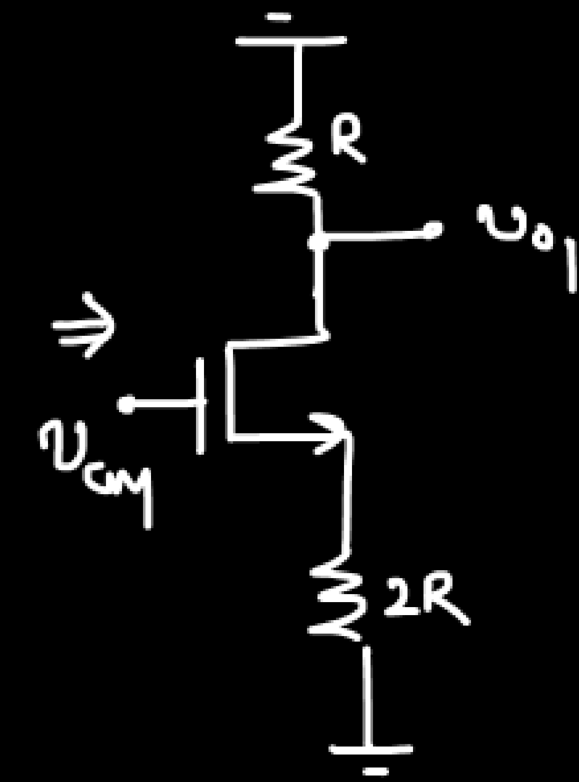
(b) Common Mode gain:-

$$(v_o)_{cm} = \frac{v_{o1} + v_{o2}}{2}$$

$$(v_i)_{cm} = v_{cm}$$



$\Rightarrow$



$$v_{o1} = \frac{-g_m R}{1 + 2g_m R} v_{cm}$$

$$v_{o2} = \frac{-g_m R}{1 + 2g_m R} v_{cm}$$

$$(v_o)_{cm} = \frac{-g_m R}{1 + 2g_m R} v_{cm}$$

$$\boxed{(A_v)_{cm} = \frac{-g_m R}{1 + 2g_m R}}$$

(c) Common Mode Differential Gain :-

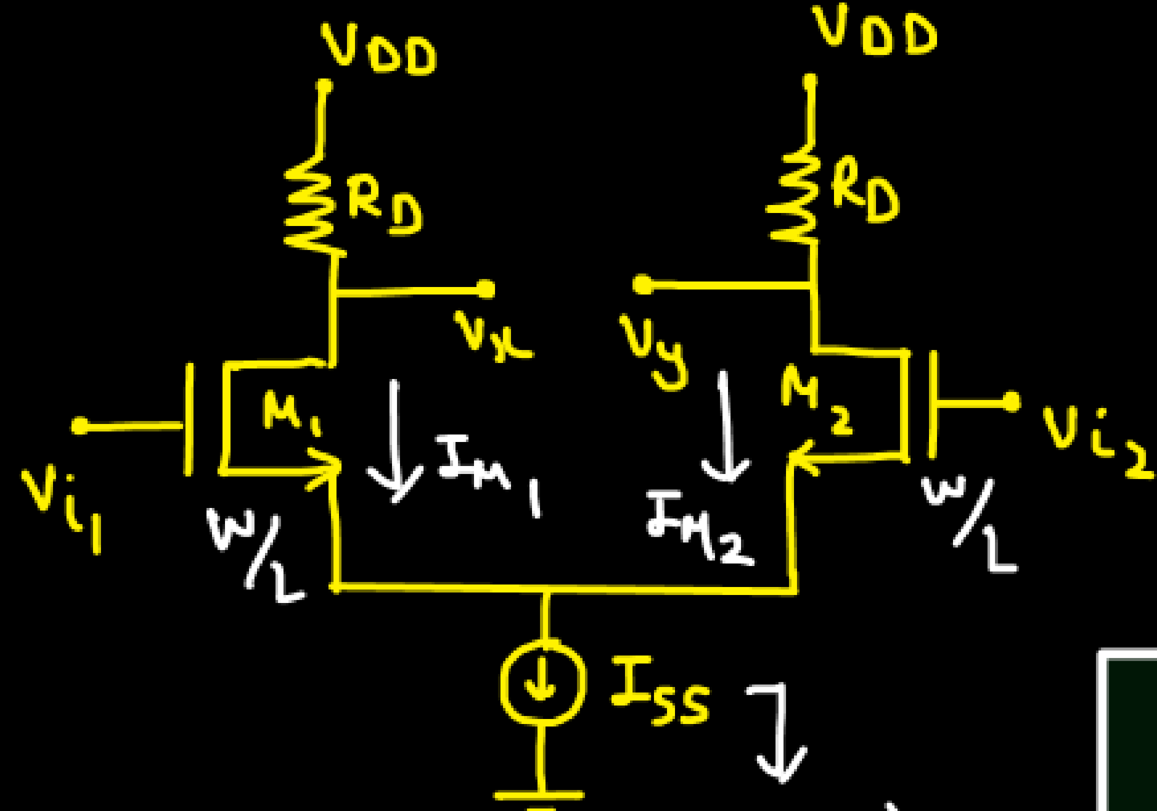
$$(v_o)_{CM-DM} = v_{o_2} - v_{o_1}$$

$$= 0$$

$$\boxed{(A_v)_{CM-DM} = 0}$$

⇒ Large Signal Analysis of differential Amplifier:-

(DC)



const.

$$I_{M_1} + I_{M_2} = I_{SS}$$

$$V_x = V_{DD} - I_{M_1} R_D$$

$$V_y = V_{DD} - I_{M_2} R_D$$

if $V_{i_1} \uparrow \Rightarrow I_{M_1} \uparrow \Rightarrow V_x \downarrow$

$\Downarrow$

$I_{M_2} \downarrow \Rightarrow V_y \uparrow$

$\Downarrow$

$V_{xy} = V_x - V_y \downarrow$

Let

@ some $V_{i_1} = V_a \Rightarrow I_{M_1} = I_{SS}$, $I_{M_2} = 0\,\text{Amp.}$

$$\boxed{V_x = V_{DD} - I_{SS} R_D}$$

$$V_y = V_{DD}$$

$$\boxed{V_{xy} = -I_{SS} R_D}$$

$$\boxed{\begin{array}{l} \text{if } v_{i_2} \uparrow \Rightarrow I_{M_2} \uparrow \Rightarrow V_y \downarrow \\ \qquad\qquad\qquad \Downarrow \\ \qquad\qquad I_{M_1} \downarrow \Rightarrow V_x \uparrow \\ \qquad\qquad\qquad \Downarrow \\ \qquad\qquad V_{xy} = V_x - V_y \uparrow \end{array}}$$

let @ some $v_{i_2} = V_b$

$\Rightarrow$

$I_{M_2} = I_{ss}$

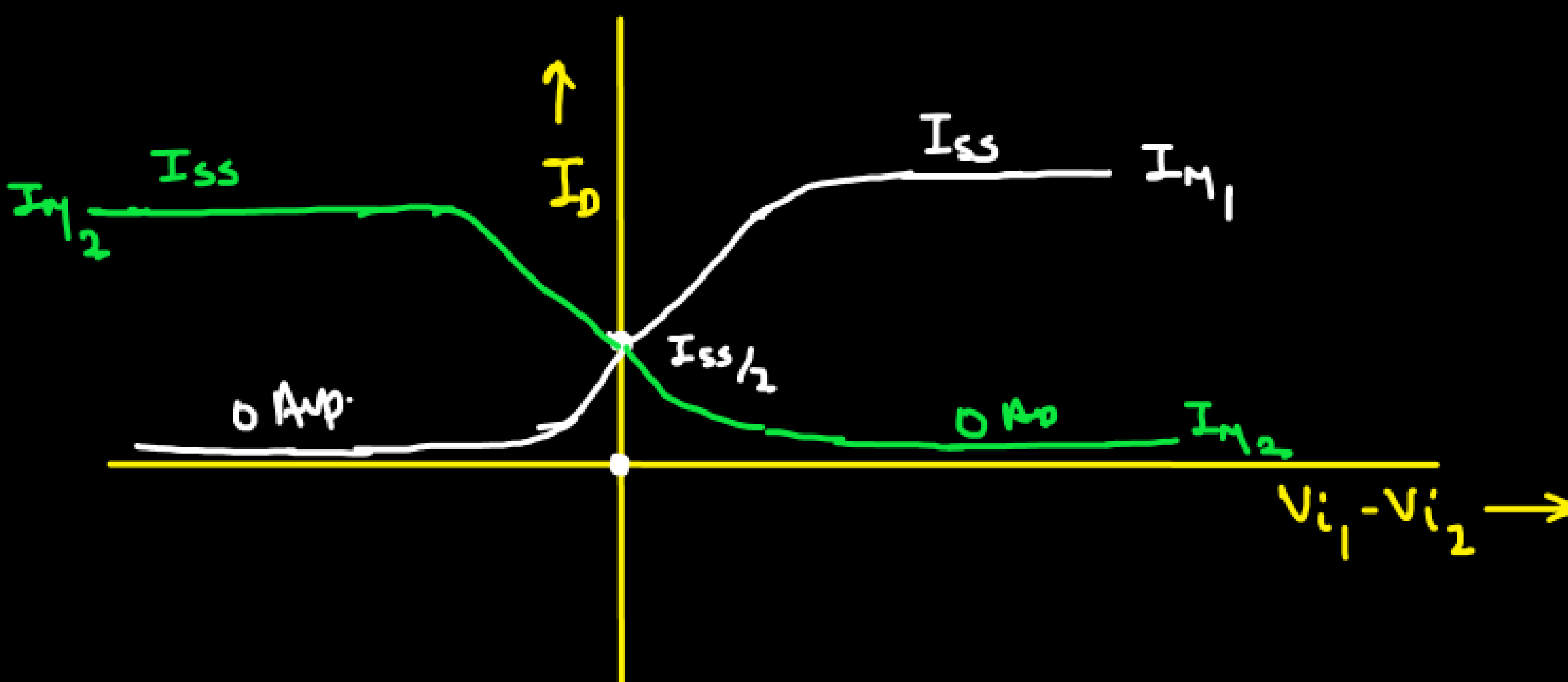
$\Downarrow$

$I_{M_1} = 0 \text{ Amp}$

$$\boxed{V_y = V_{DD} - I_{ss} R_D}$$

$V_x = V_{DD}$

$$\boxed{V_{xy} = I_{ss} R_D}$$

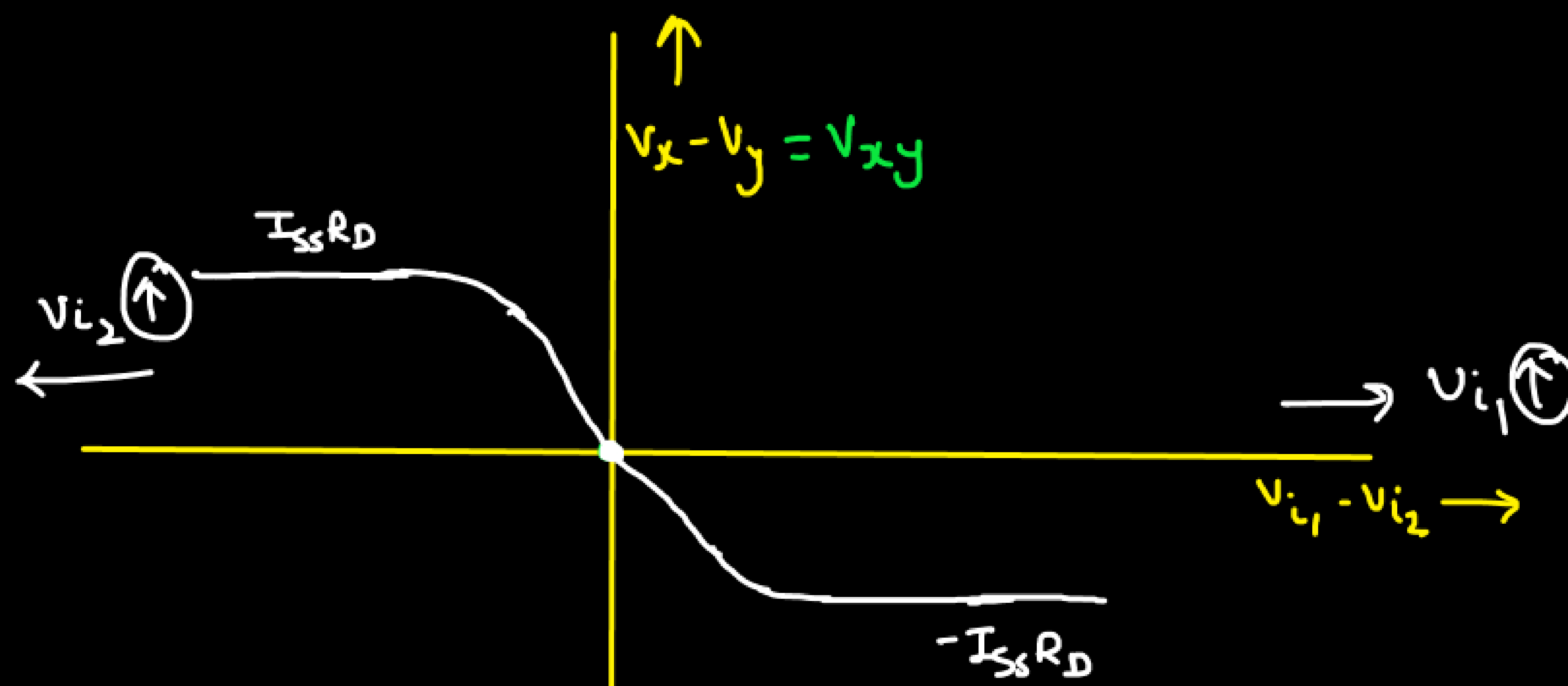


if $V_{i_1} - V_{i_2} > 0$

$\Rightarrow V_{i_1} > V_{i_2}$

if $V_{i_1} - V_{i_2} < 0$

$\Rightarrow V_{i_1} < V_{i_2}$



when $V_{i_1} - V_{i_2} = 0$

$\Rightarrow V_{i_1} = V_{i_2} \Rightarrow I_{M_1} = I_{M_2} = I_M$

$V_x = V_{DD} - I_M R_D$

$V_y = V_{DD} - I_M R_D$

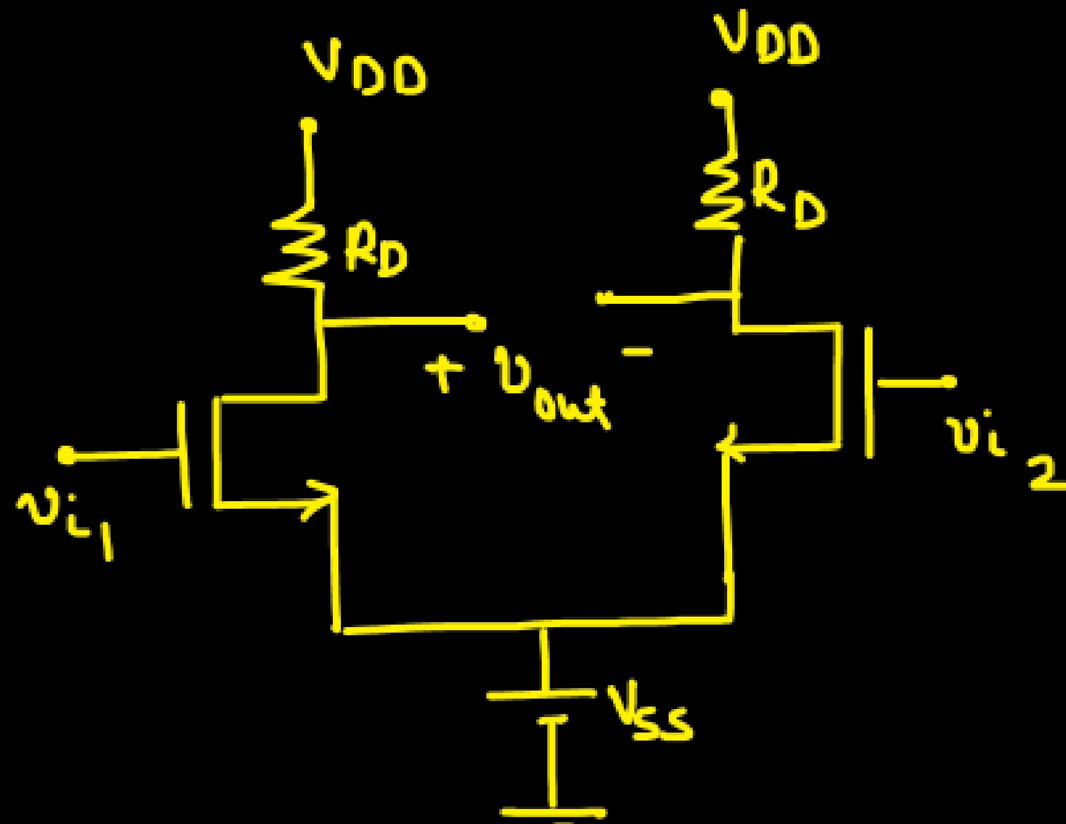
$V_{xy} = 0$

if $V_{i_1} > V_{i_2} \Rightarrow V_x < V_y \Rightarrow V_{xy} = -ve$

if $V_{i_2} > V_{i_1} \Rightarrow V_x > V_y \Rightarrow V_{xy} = +ve$

Assigment - 11

Q.



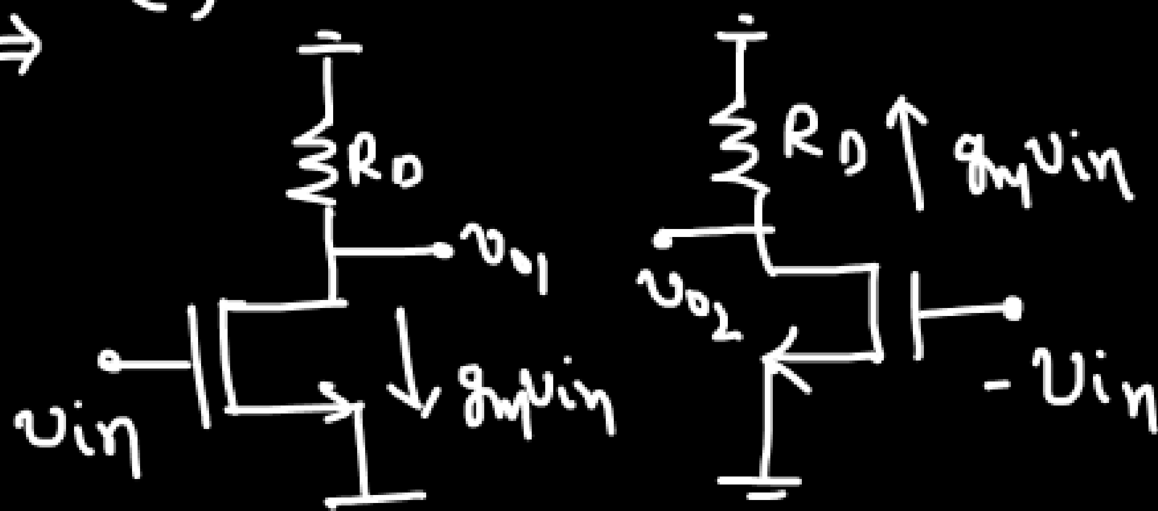
Find

(a) Differential gain

(b) Common-Mode gain

$v_{i_1} - v_{i_2} = 2v_{in}$

⇒ (a)



$v_{o_1} = -g_m R_D v_{in}$

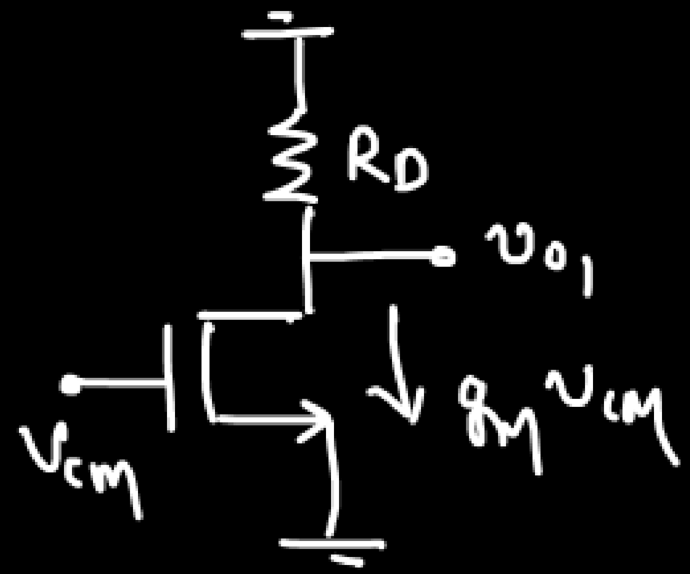
$v_{o_2} = g_m R_D v_{in}$

$(v_o)_d = v_{o_1} - v_{o_2} = -2g_m R_D v_{in}$

$(v_i)_d = 2v_{in}$

$\boxed{(A_v) = -g_m R_D}$

(b)



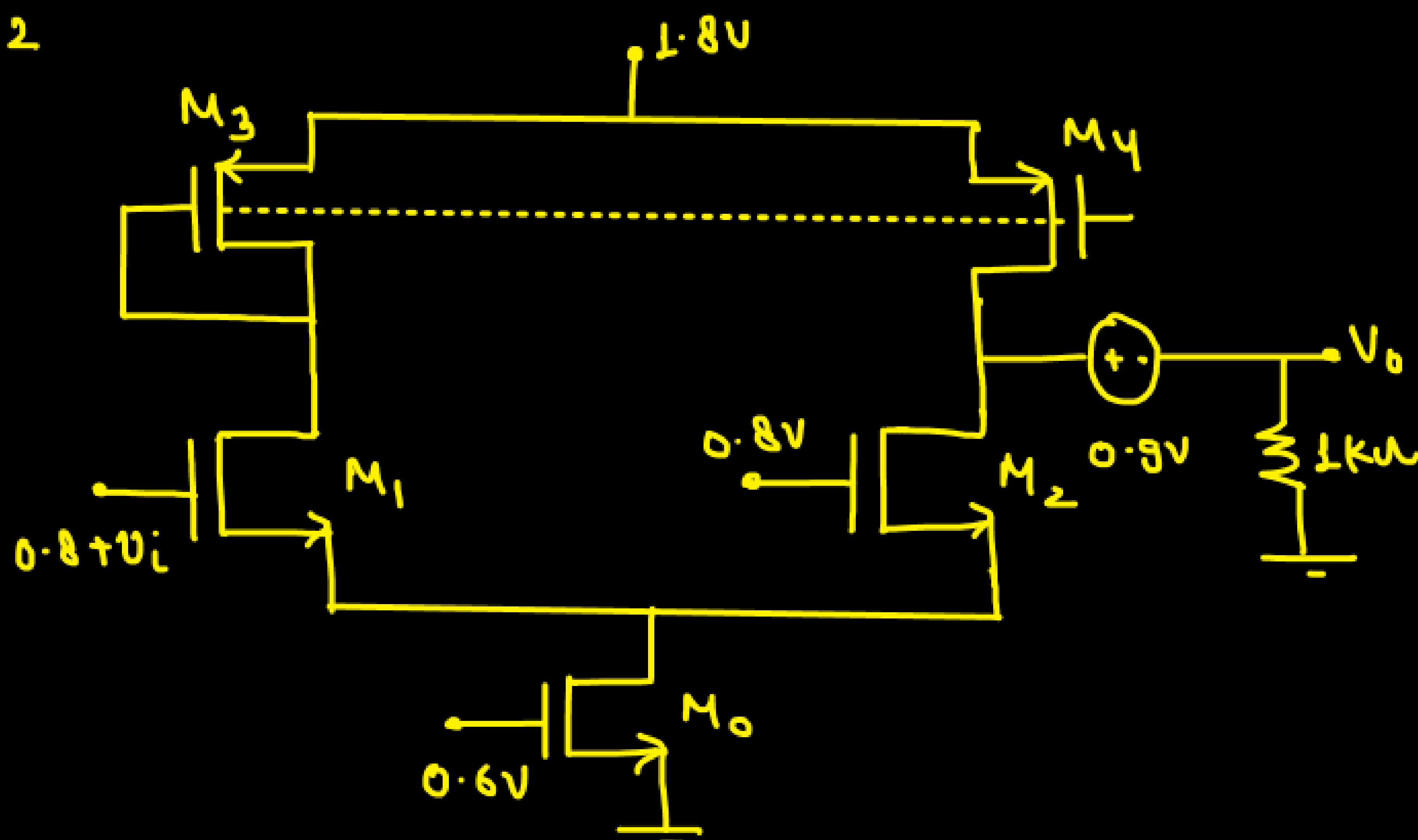
$$v_{o1} = -g_m R_D v_{cm}$$

$$v_{o2} = -g_m R_D v_{cm}$$

$$(v_o)_{cm} = -g_m R_D v_{cm}$$

$$\boxed{(A_v)_{cm} = -g_m R_D}$$

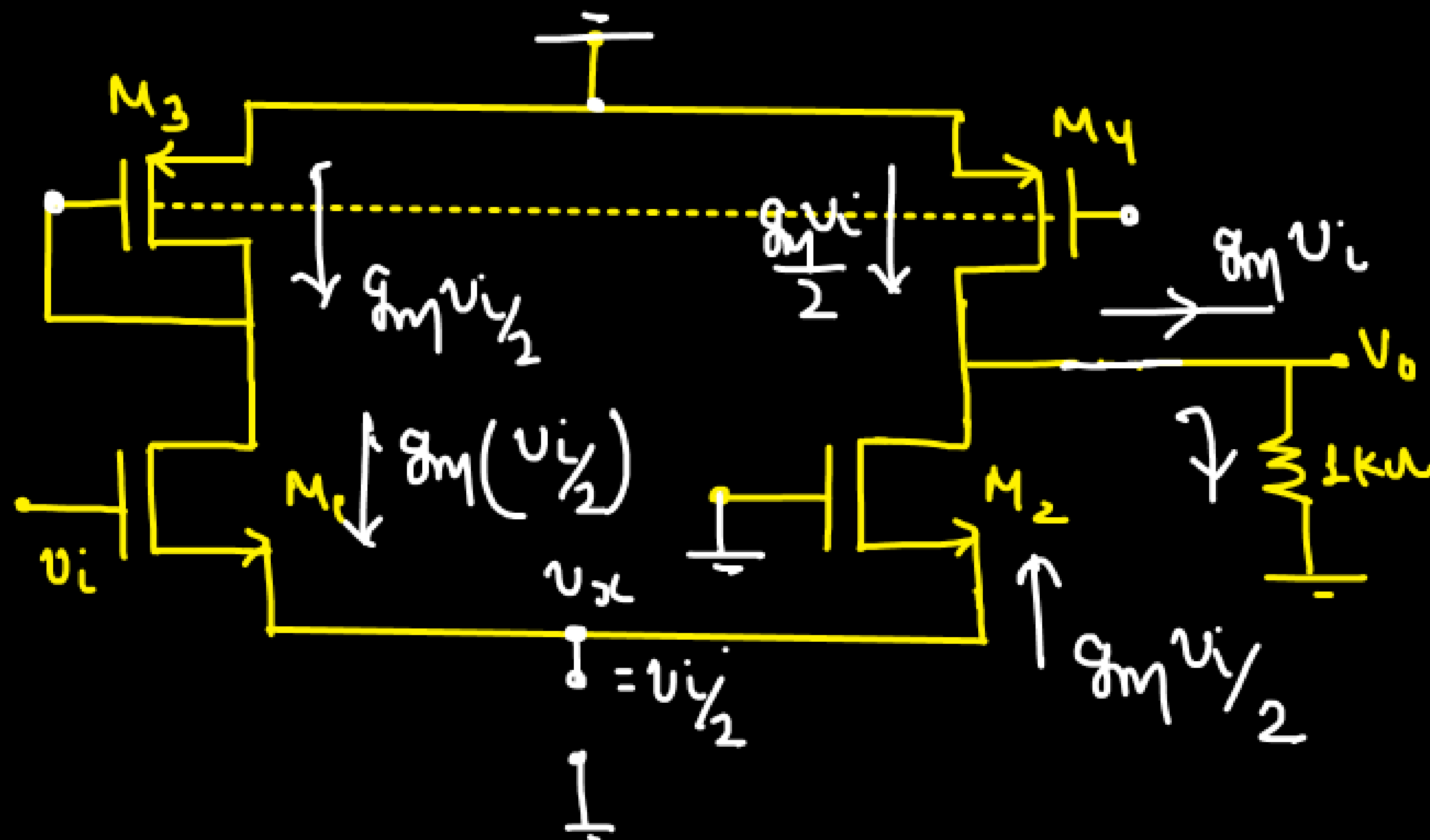
Q. 2



$M_0 - M_4$ all are biased in sat. region.

For all Transistors $g_m = 25\,mS$, $\lambda = 0$

Find small signal voltage gain. $\left(\frac{v_o}{v_i}\right)$



$$g_m(v_i - v_x) = g_m v_x$$

$$\boxed{v_x = v_{i/2}}$$

For M_3 and M_4

both g_m & v_{gs} are

same

$$\Rightarrow (i_d)_{M_3} = (i_d)_{M_4}$$

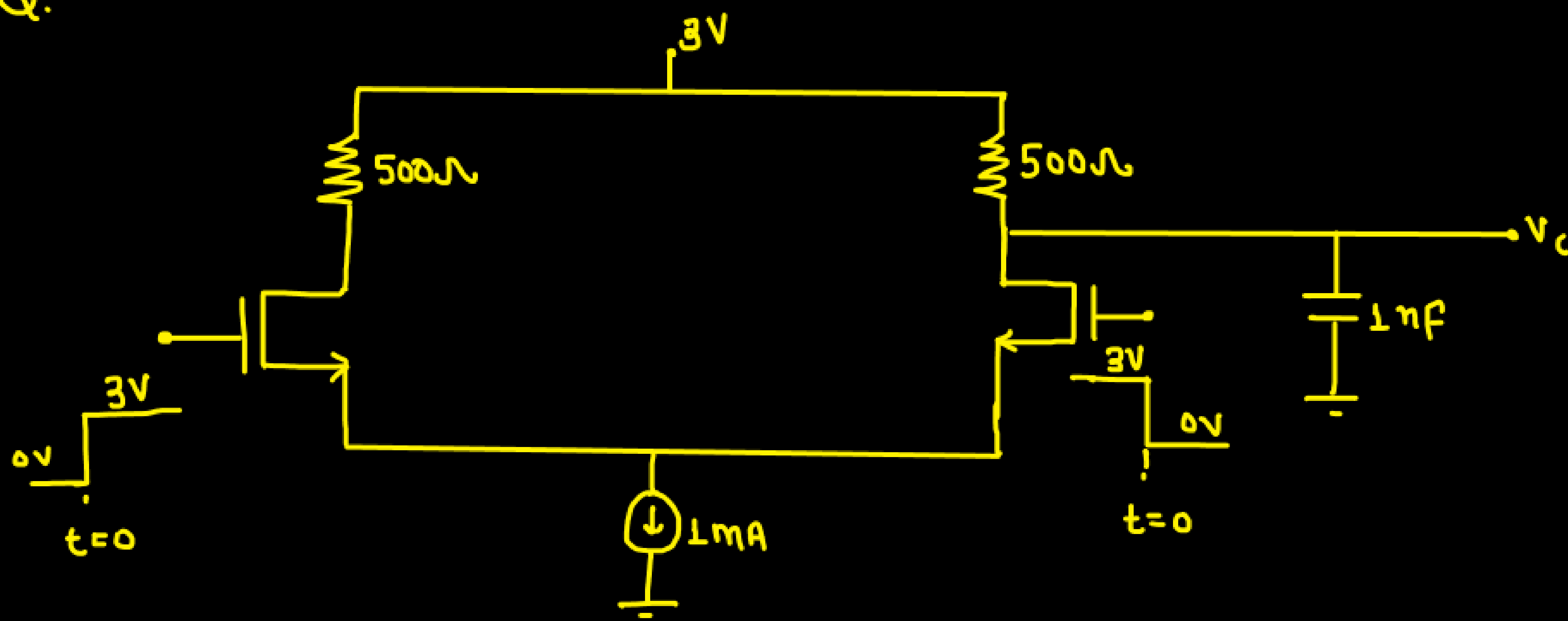
$$v_o = g_m v_i (1k\Omega)$$

$$\frac{v_o}{v_i} = 25m(1k)$$

$$\boxed{\frac{v_o}{v_i} = 25\,V/V}$$

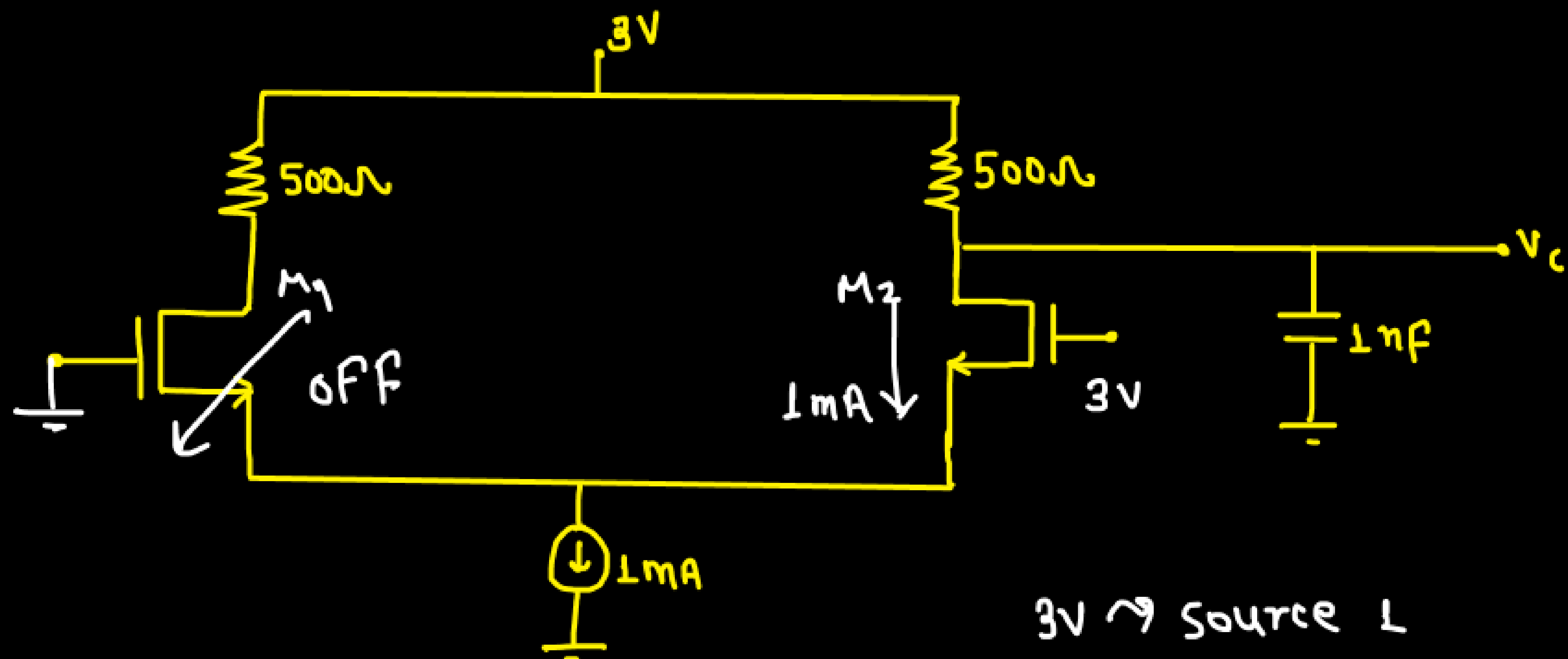
ANS.

Q.

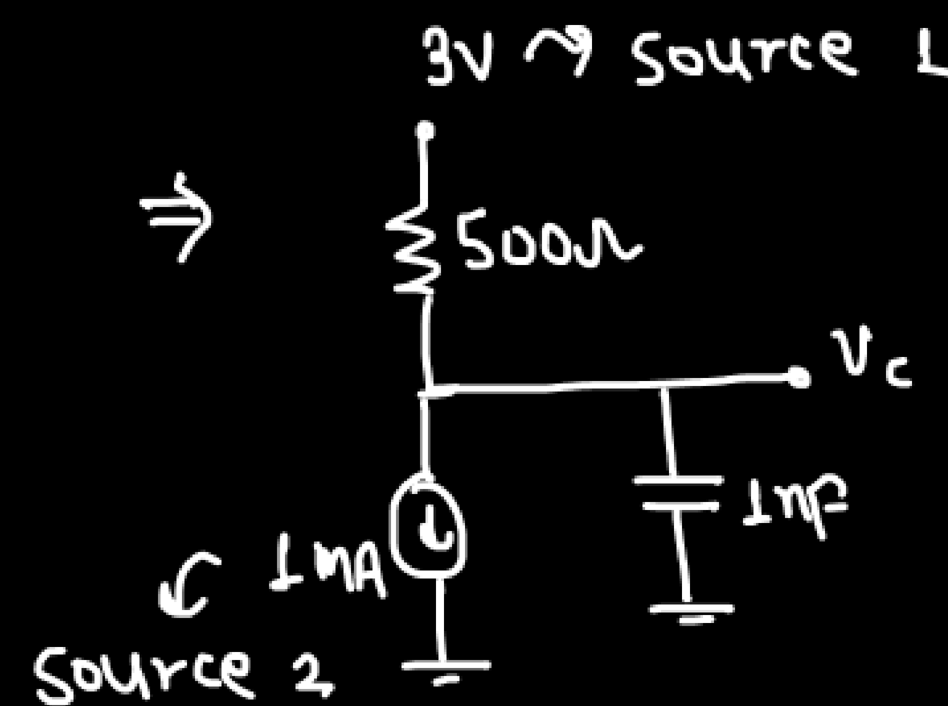


Find the time at which v_c node reaches to 2.9V

For t<0:-



⇒

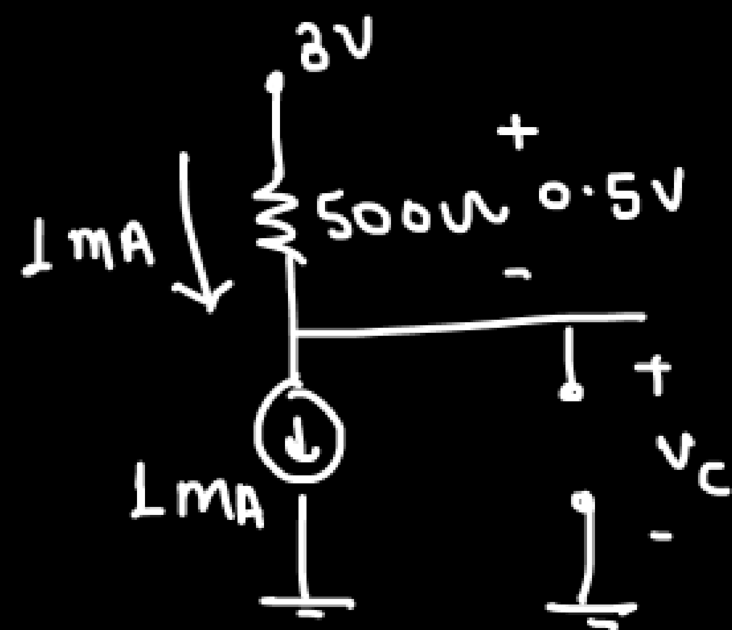


$V_c(-\infty) = 0V$

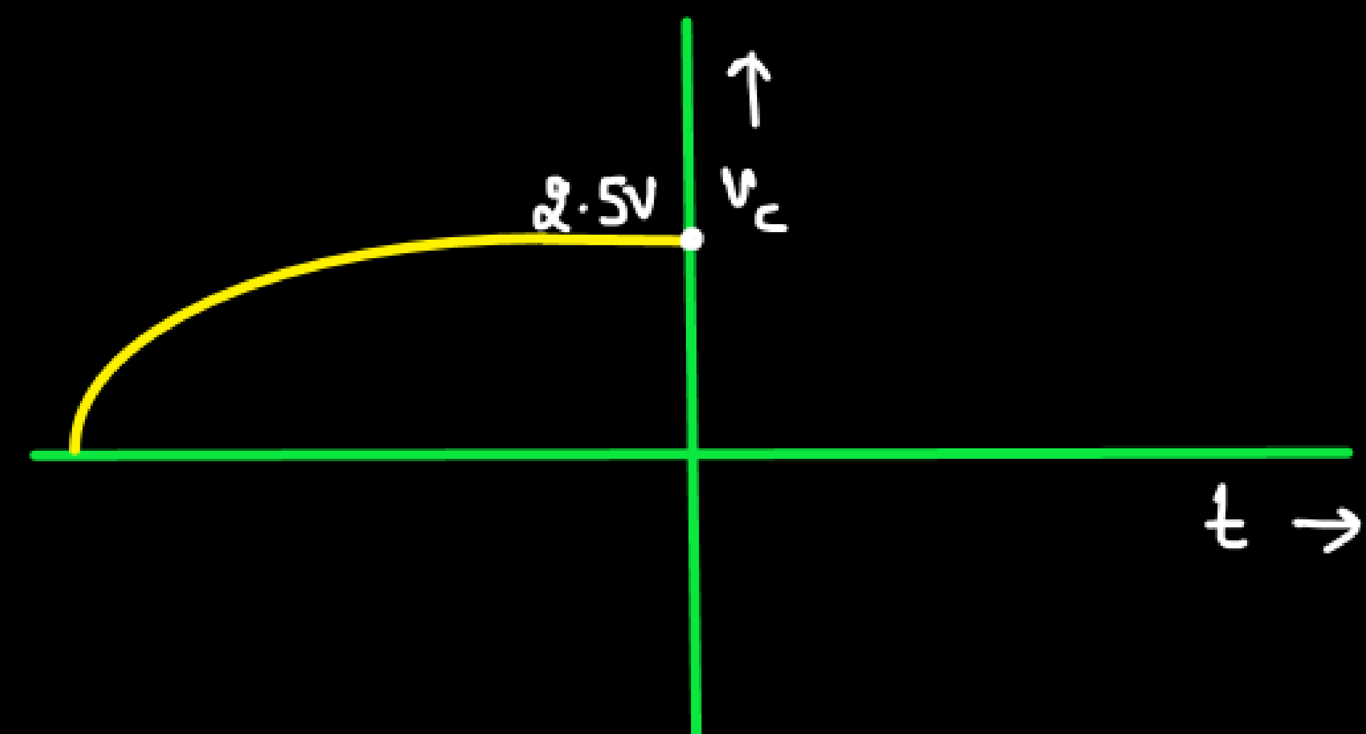
$V_c(0^-) =$

$v_c = 0^-$ (s.s.)

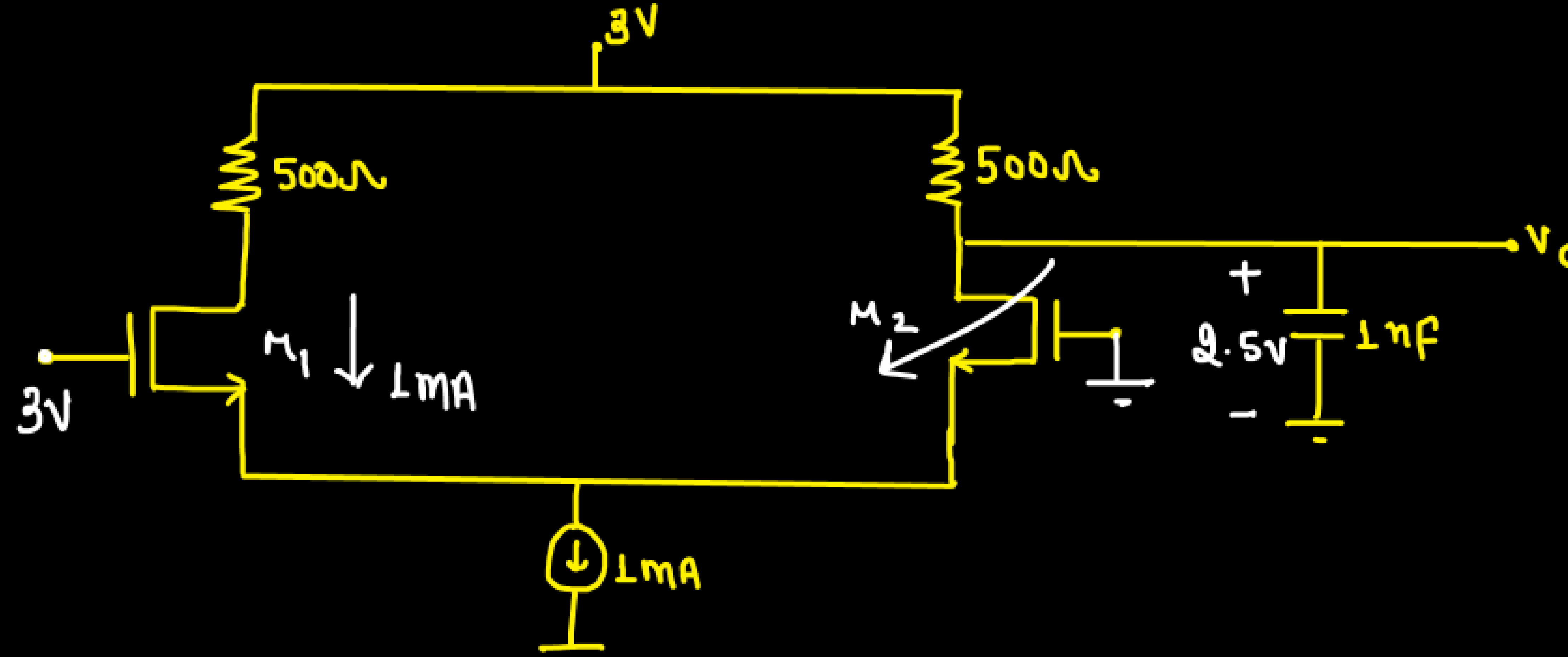
@ s.s. $\Rightarrow$ cap. o.c.



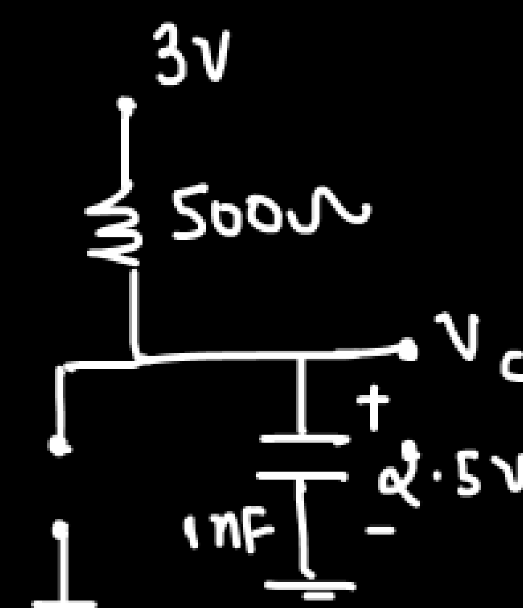
$$\boxed{v_c(0^-) = 2.5V}$$



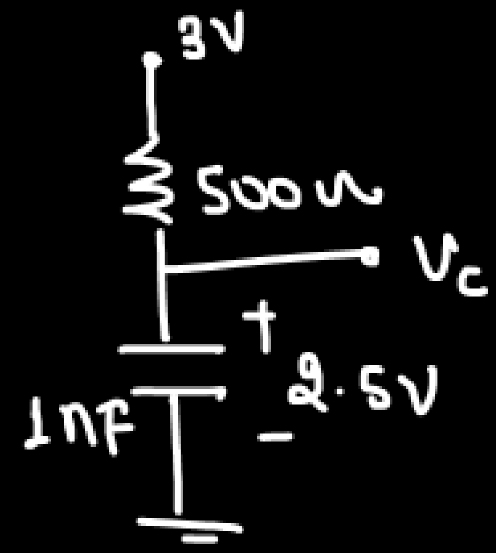
For t>0



M_2 is off



$\Rightarrow$

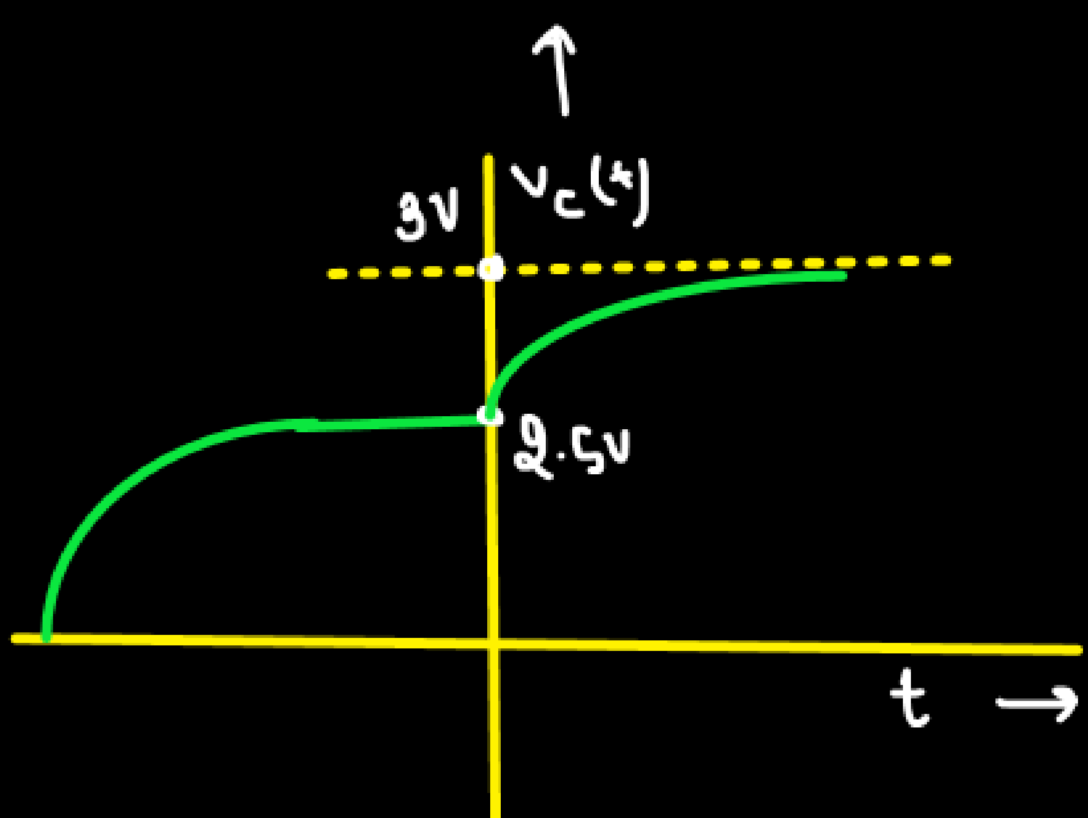


$$v_c(0^+) = 2.5V$$

$$v_c(\infty) = 3V$$

$$\tau = RC = 500 \times 1nF = 0.5\mu sec.$$

$$\boxed{v_c(t) = 3 - 0.5e^{-t/0.5\mu}}$$



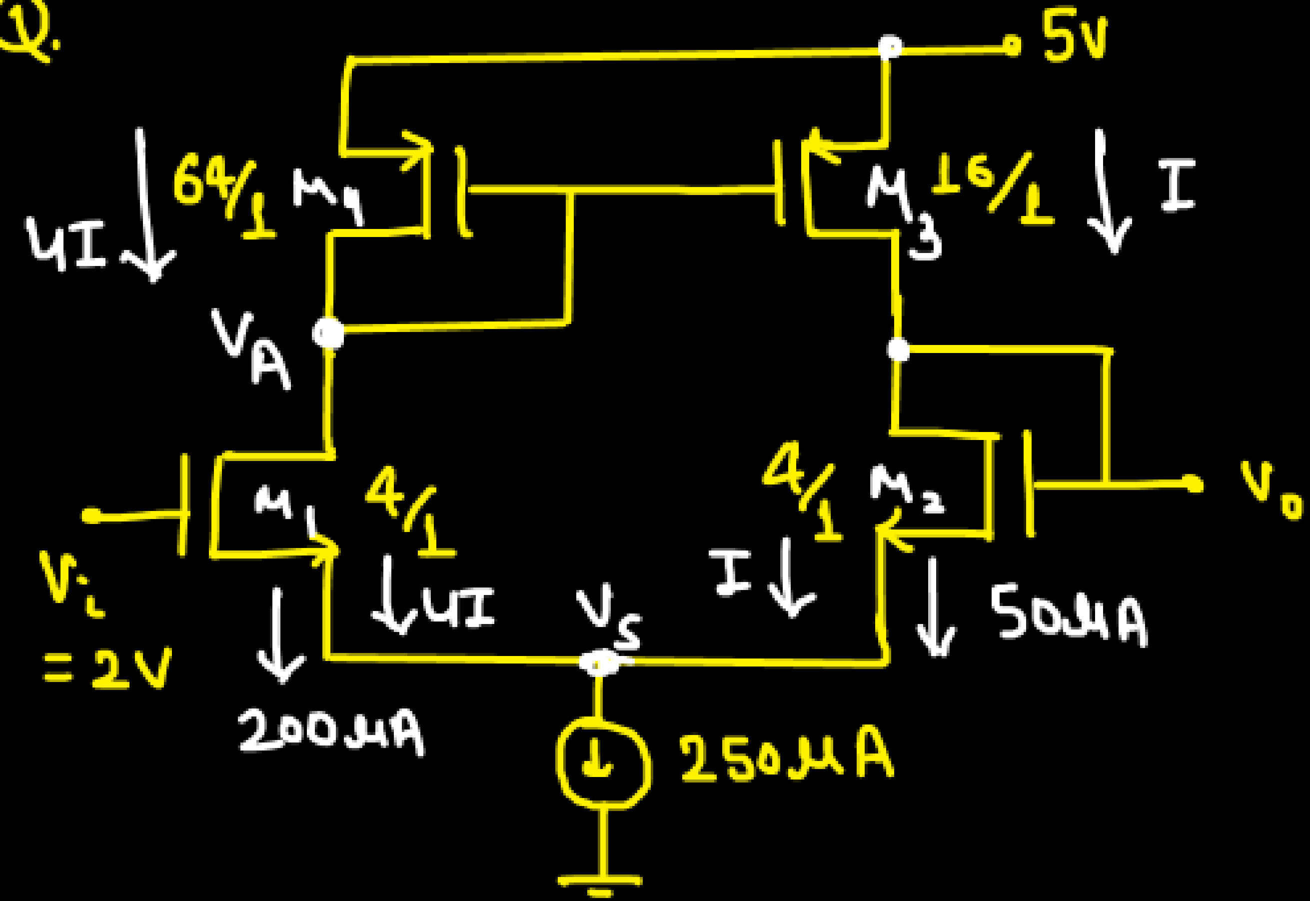
let @ $t = t_1$, $v_c(t_1) = 2.9V$

$$2.9 = 3 - 0.5e^{-t/0.5\mu}$$

$$t_1 = 0.5\ln(5)\ \mu sec.$$

$$\boxed{t_1 = 0.8\mu sec.}$$ ANS.

Q.



$\mu_n C_{ox} = 400\ \mu A/V^2$, $V_{Tn} = 0.5V$

$\mu_p C_{ox} = 100\ \mu A/V^2$, $V_{Tp} = 0.5V$

Find output voltage V_o.

M_4 and M_3 are in current Mirror. [M_3 should be in sat.]

$\boxed{\text{Assuming } M_3 \text{ to be in sat.}}$

$\Rightarrow$ M_4 and M_3 are in C.M.

$4I + I = 250\mu$

$\boxed{I = 50\mu A}$

Both M_1 and M_2 are having same source potential

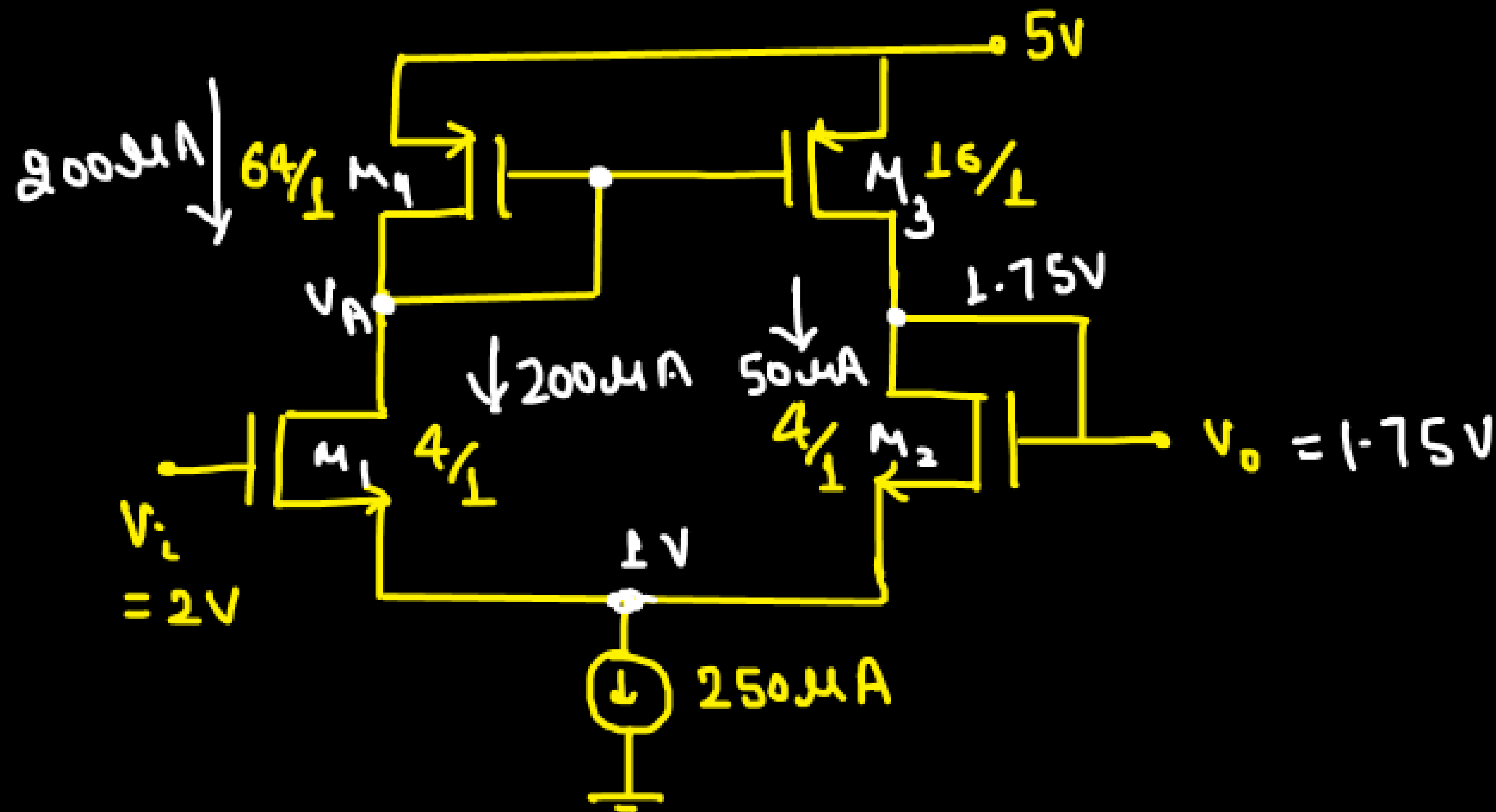
Let, M_1 is in saturation

$$I_{M_1} = 200\mu A$$

$$\Rightarrow \quad 200\mu A = \frac{400\mu \times 4}{2}(2 - V_S - 0.5)^2$$

$$0.5 = 1.5 - V_S$$

$$\boxed{V_S = 1V}$$



M_2 is in sat.

$$I_{M_2} = 50\mu A$$

$$\Rightarrow \quad 50\mu = \frac{400\mu \times 4}{2}\left[V_0 - 1 - 0.5\right]^2$$

$\boxed{V_0 = 1.75V}$ $\Rightarrow$ correct ? $\Rightarrow$ NOT SURE $\Rightarrow$ Take care of Assump.

Check:- if M_1 and M_3 are in sat. or NOT.

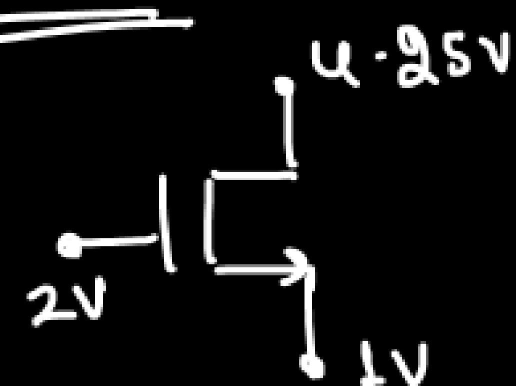
$$I_{M_4} = 200\,\mu A \quad [\text{Sat.}]$$

$$\Rightarrow 200\mu = \frac{100\mu \times 64}{2}\left[5 - V_A - 0.5\right]^2$$

$$0.25 = 4.5 - V_A$$

$$\boxed{V_A = 4.25V}$$

For M_1:-



$V_{DS} = 3.25V$

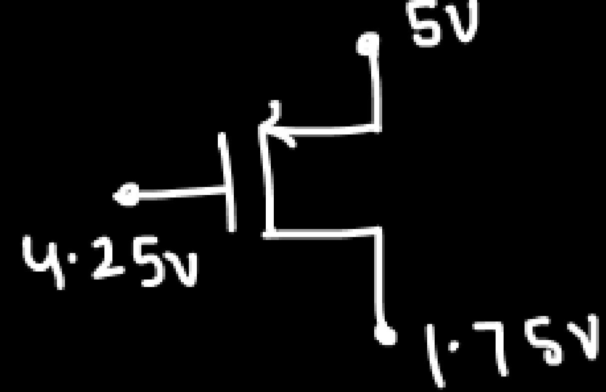
$V_{GS} = 1V$

$V_T = 0.5V$

$V_{ov} = 0.5V$

$\Rightarrow V_{DS} > V_{ov} \Rightarrow M_1$ is in sat $\Rightarrow$ Assumption correct

For M_3 :-



$V_{SG} = 0.75$

$V_T = 0.5$

$V_{ov} = 0.25$

$V_{SD} = 3.25$

$\Rrightarrow V_{SD} > V_{ov} \Rrightarrow$ sat. region

$\Downarrow$

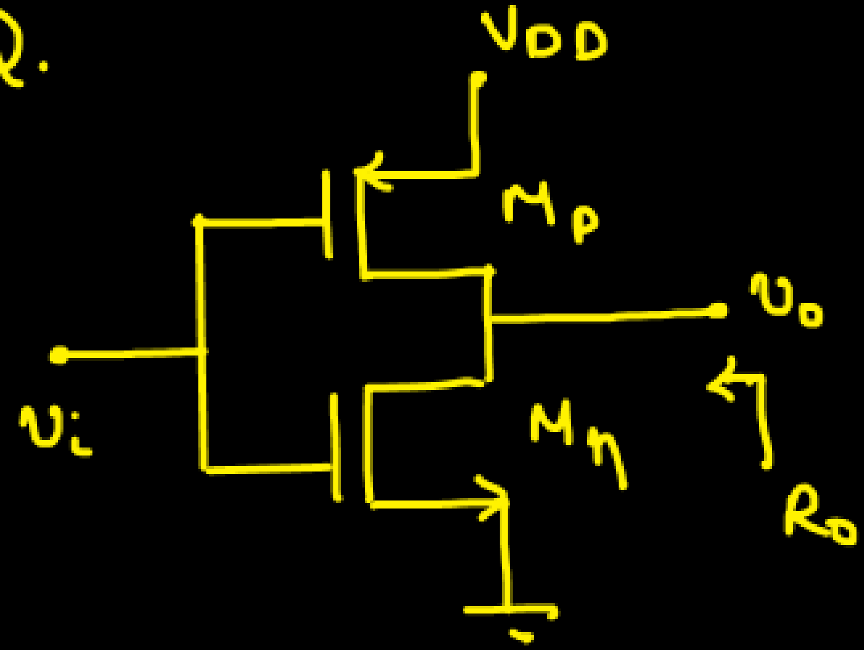
Assumption correct

$\Rrightarrow$ All Tr M_1, M_2, M_3 and M_4 are in sat.

$$\boxed{V_0 = 1.75V}$$

Ans.

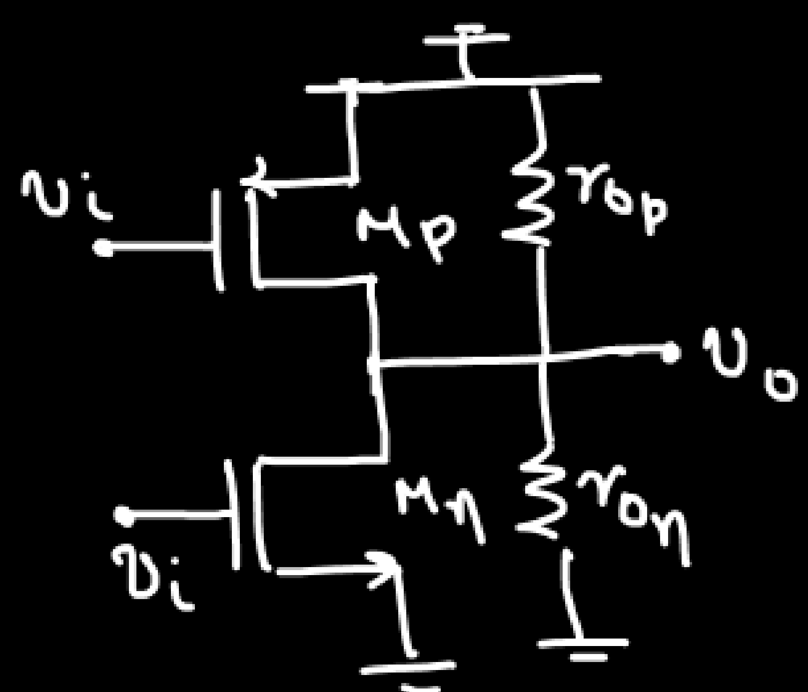
Q.



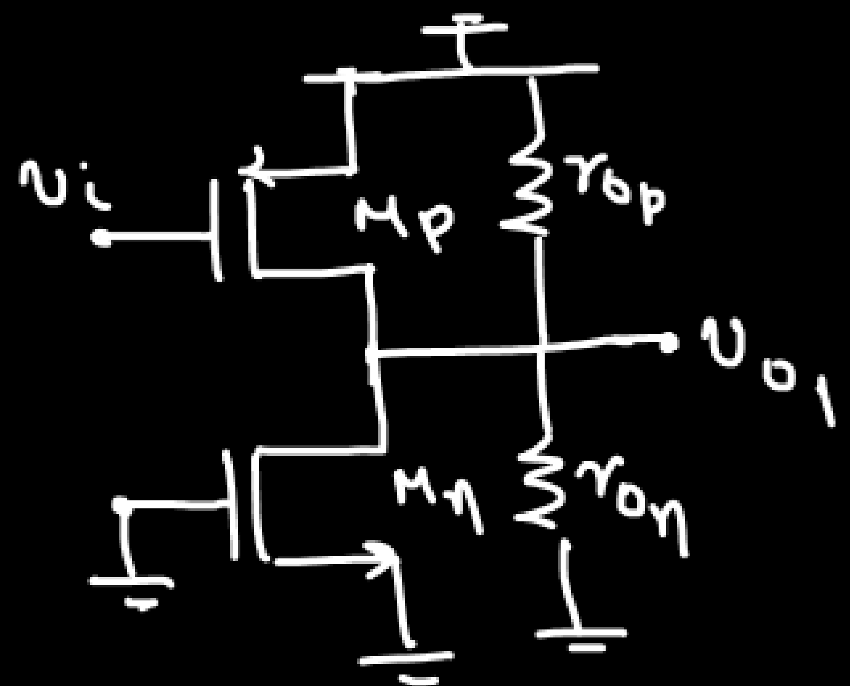
① Find the small signal voltage gain.

② Find small signal o/p resistance.

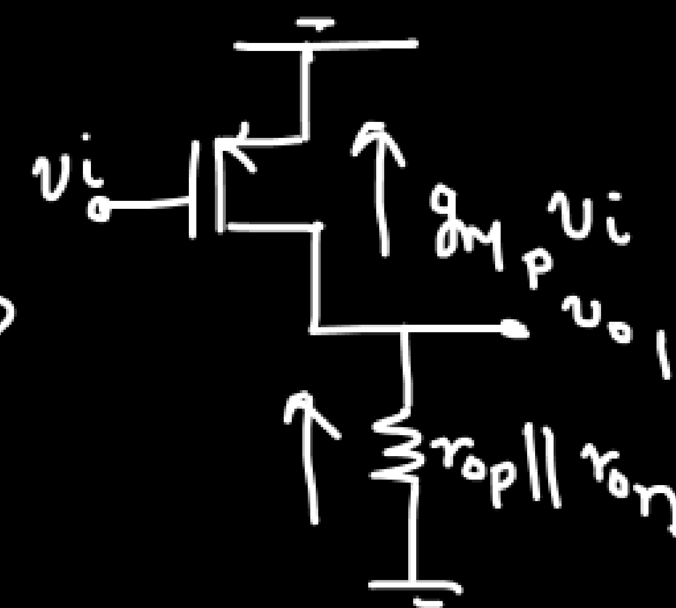
⇒



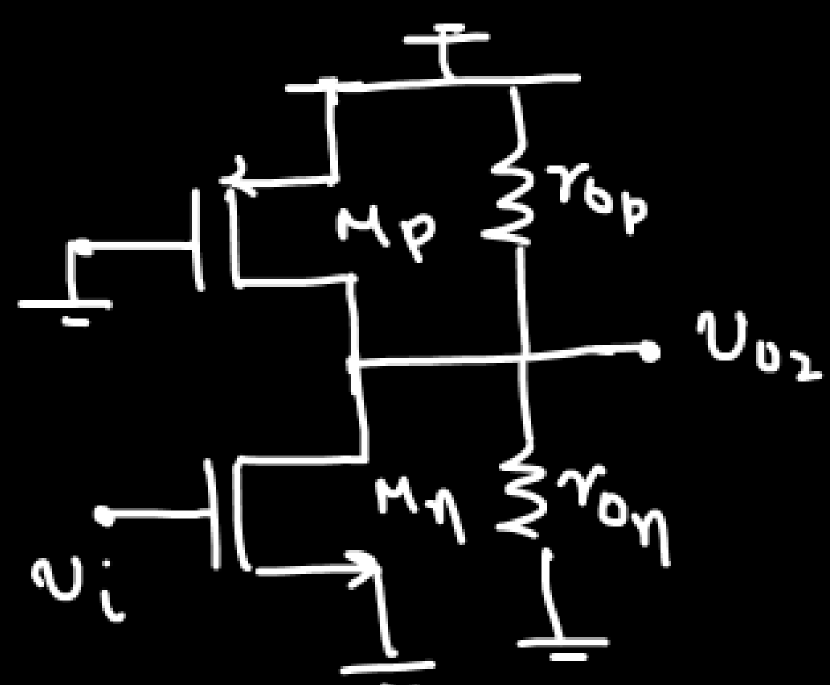
Applying superposition:-



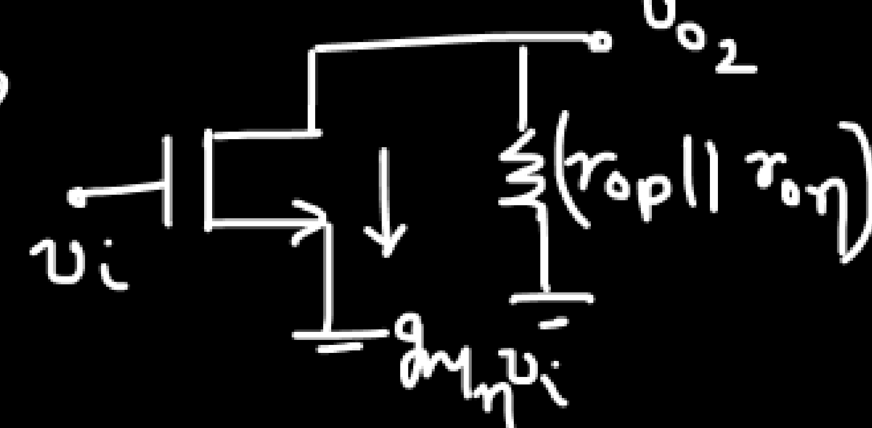
$\Rightarrow$



$$v_{o1} = -g_{mp} (r_{op} || r_{on}) v_i \quad \text{—} \ (1)$$



$\Rightarrow$



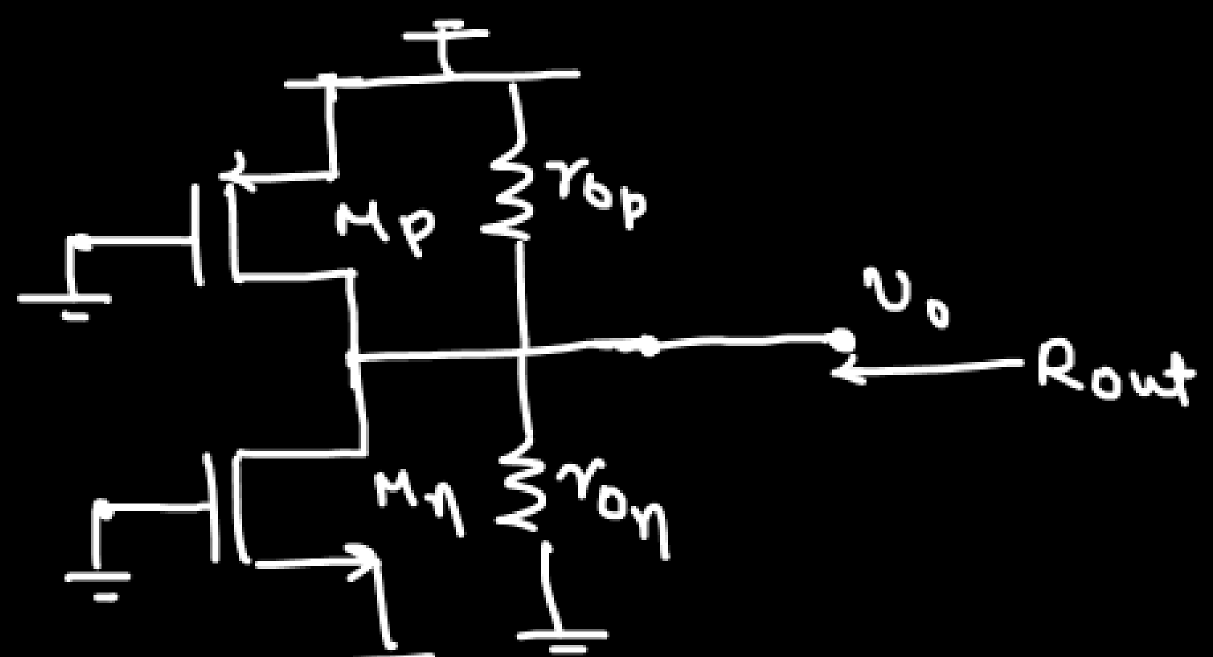
$$v_{o2} = -g_{mn} (r_{op} || r_{on}) v_{in} \quad \text{—} \ (2)$$

$$v_o = v_{o1} + v_{o2}$$

$$v_o = -(g_{m_p} + g_{m_n})(r_{op} \| r_{on})\, v_{in}$$

$$\boxed{\frac{v_o}{v_{in}} = -(g_{m_p} + g_{m_n})(r_{op} \| r_{on})}$$ ANS

<u>O/P impedance:-</u>



$$\boxed{R_{out} = r_{op} \| r_{on}}$$

Q. For a n-channel enhancement type MOS,

$$W/L = 10$$

$$\mu_n C_{ox} = 1\ \text{mA}/V^2$$

$$V_T = 1V$$

$$V_{GS} = 2 - \sin(2t)\ V$$

$$V_{DS} = 1V$$

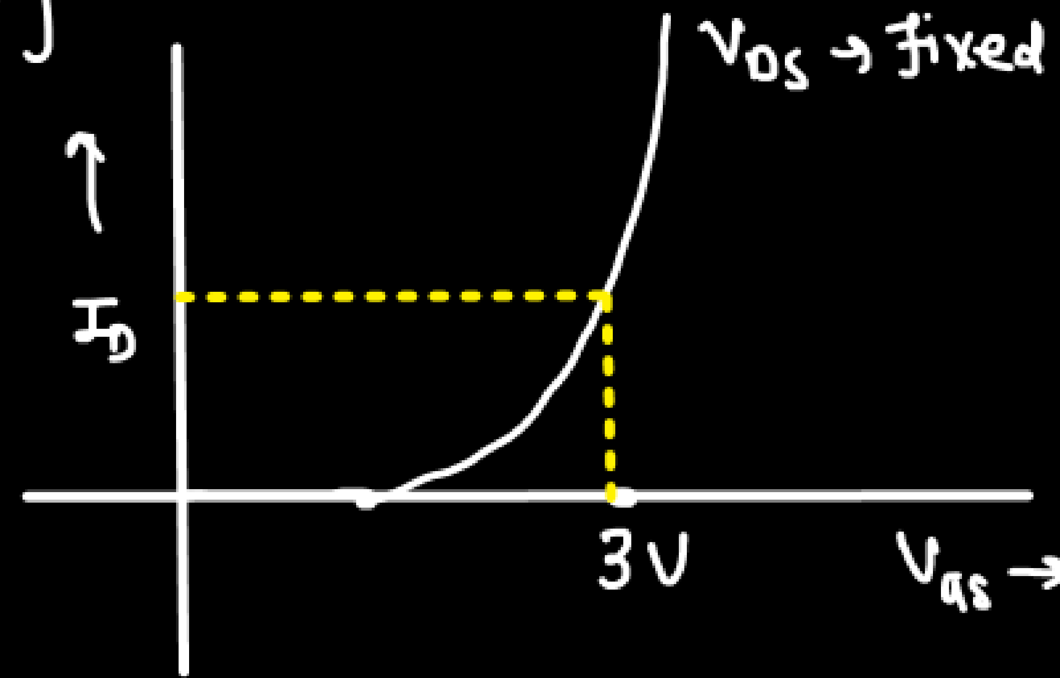
max^m value of drain to source current = ?

(a) 40 mA (b) 20 mA

(c) 15 mA (d) 5 mA

$\rightarrow$ $V_{GS} = 2 - \sin(2t)\ V \quad \{1 < V_{GS} < 3\}$

$\boxed{V_{DS} = 1V}$



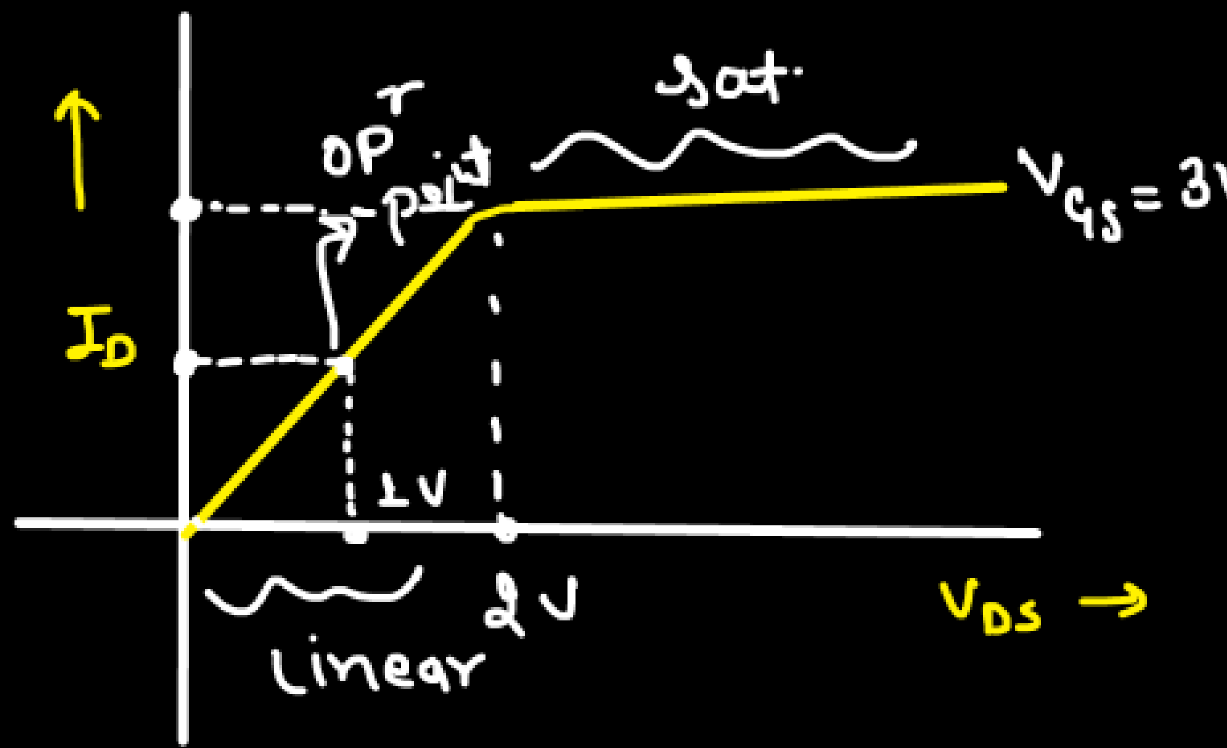
more $V_{GS} \Rightarrow$ more I_D

$(I_D)_{max} = ?$

@ $(V_{GS})_{max} \Rightarrow (I_D)_{max}$

$(V_{GS})_{max} = 2 - (-1) = 3V$

$\boxed{(I_D)_{max} = \frac{1m \times 10}{2}(3-1)^2 = 20mA}$ X



$(V_{GS})_{max} = 3V$

$V_{DS} = 1V$ ✓

$V_T = 1V$

$V_{ov} = 3-1 = 2V$ ✓

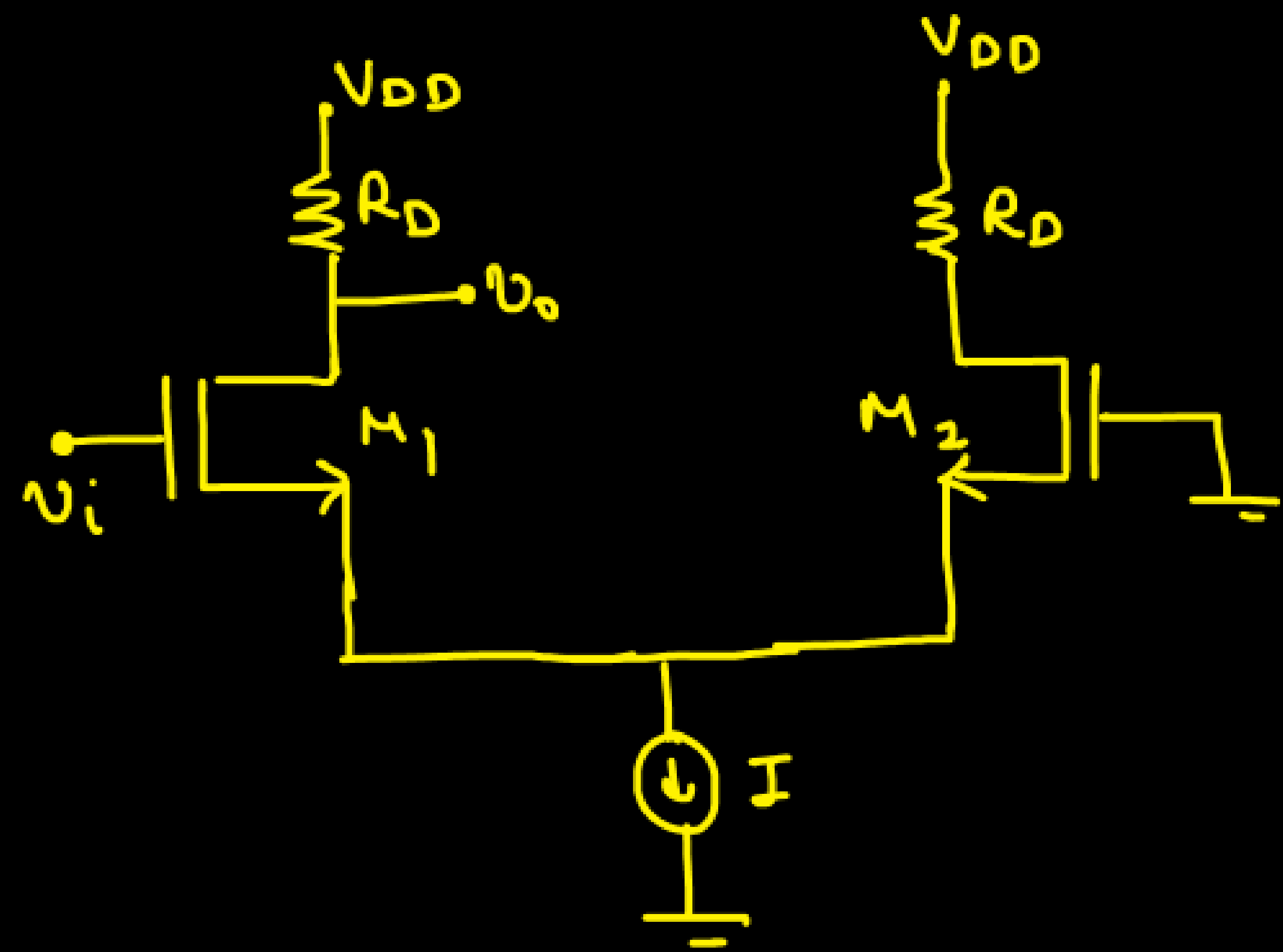
$V_{DS} < V_{ov} \Rightarrow$ MOS is working in linear region for max V_{GS}

$$(I_D)_{max} = 10m\left[(2)(1) - \frac{1^2}{2}\right]$$

$$\boxed{(I_D)_{max} = 15mA}$$ ✓

Ans.

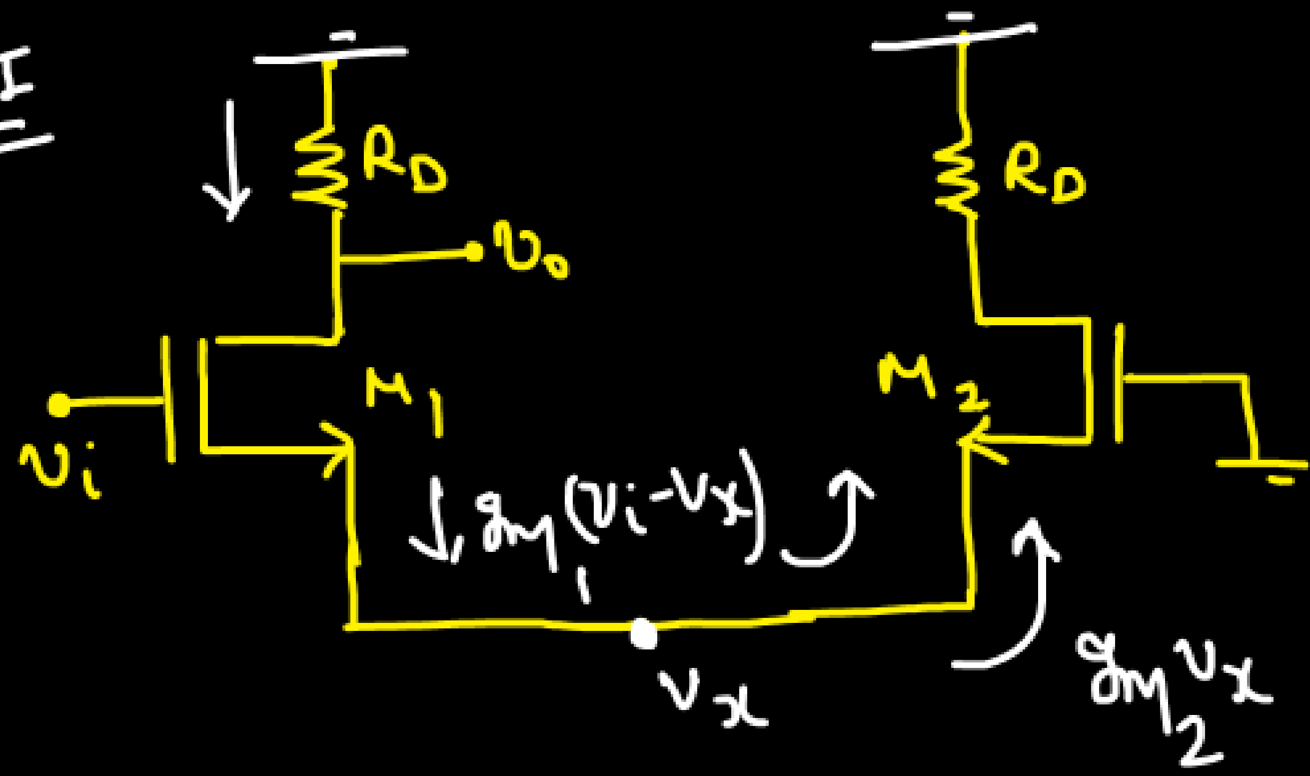
Q.



Take $\lambda = 0$

Find small signal voltage gain $\frac{v_o}{v_i}$.

→ M-I



$$\frac{v_o}{v_i} = ?$$

$$g_{m_1}(v_i - v_x) = g_{m_2} v_x$$

$$\boxed{v_x = \frac{g_{m_1}}{g_{m_1} + g_{m_2}} v_i}$$

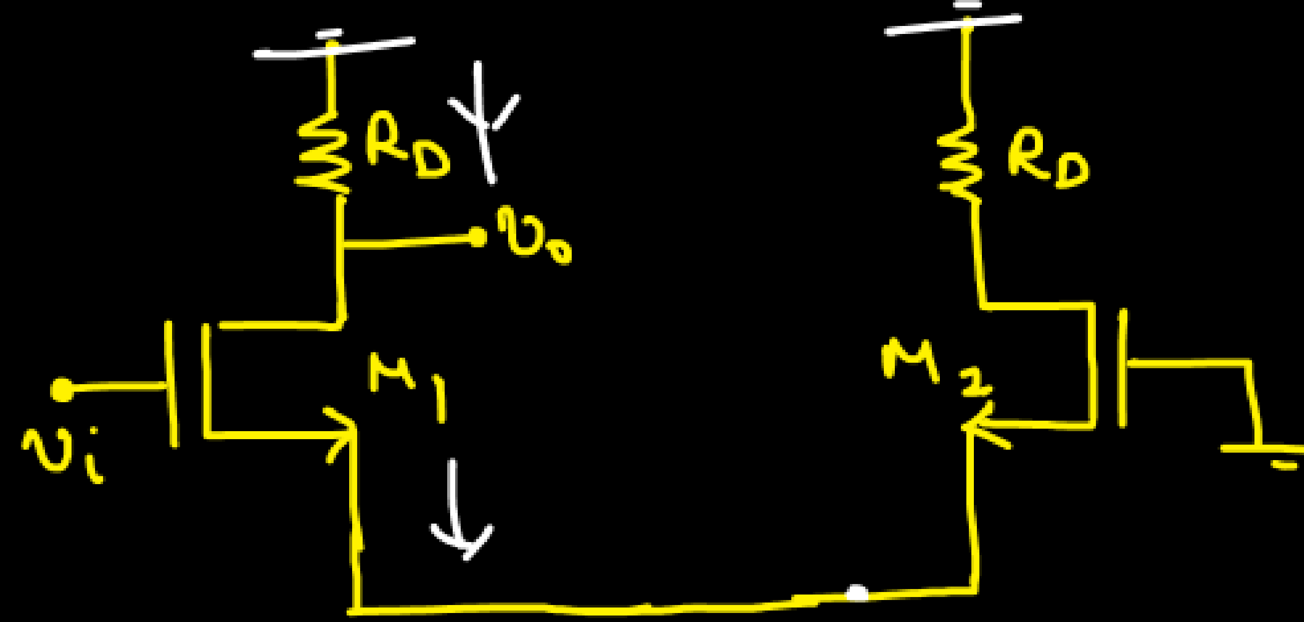
$$v_o = -g_{m_1} R_D (v_i - v_x)$$

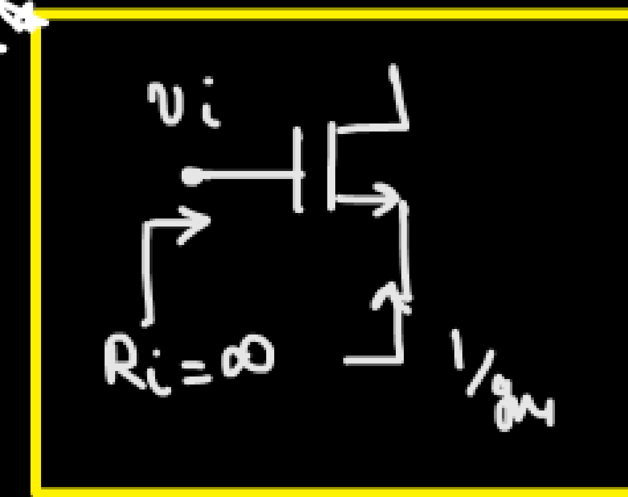
$$v_o = -g_{m_1} R_D \left(v_i - \frac{g_{m_1}}{g_{m_1} + g_{m_2}} v_i \right)$$

$$v_o = -g_{m_1} R_D \left[\frac{g_{m_2}}{g_{m_1} + g_{m_2}} \right] v_i$$

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

M - II



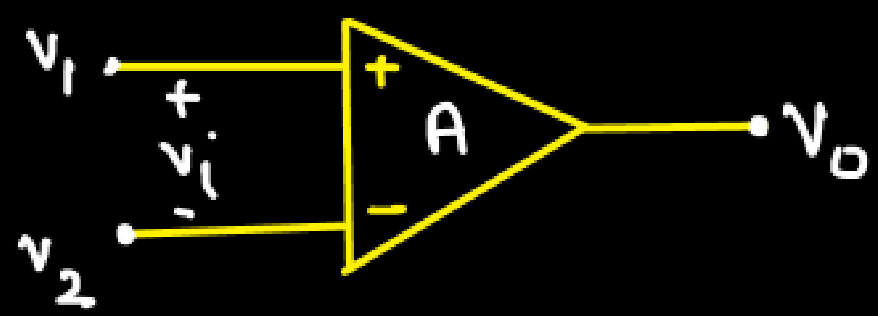


$$-\frac{v_i}{\frac{1}{g_{m_1}}+\frac{1}{g_{m_2}}} R_D = v_o$$

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

⇒ Building 2-stage OP-Amp:-

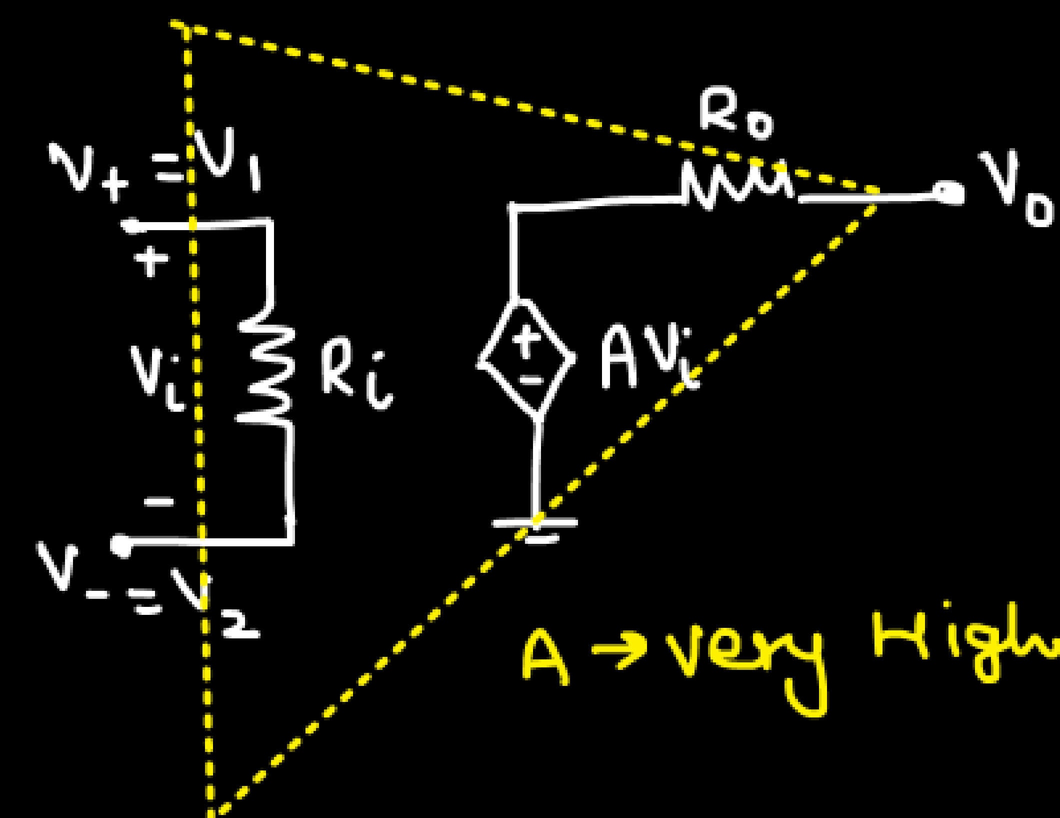
★ **What is OP-Amp?** (operational Amplifier)



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

$$V_o = A(V_1 - V_2)$$

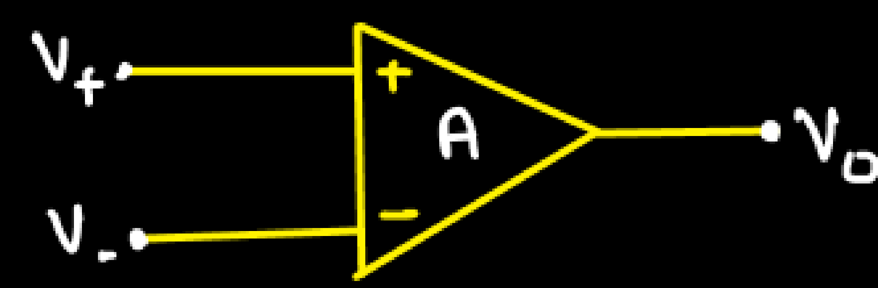
$$\boxed{V_o = \underbrace{A}_{\text{High}} V_i}$$



A → very High

R_i → very High (∞)

R_o → very low (0)



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

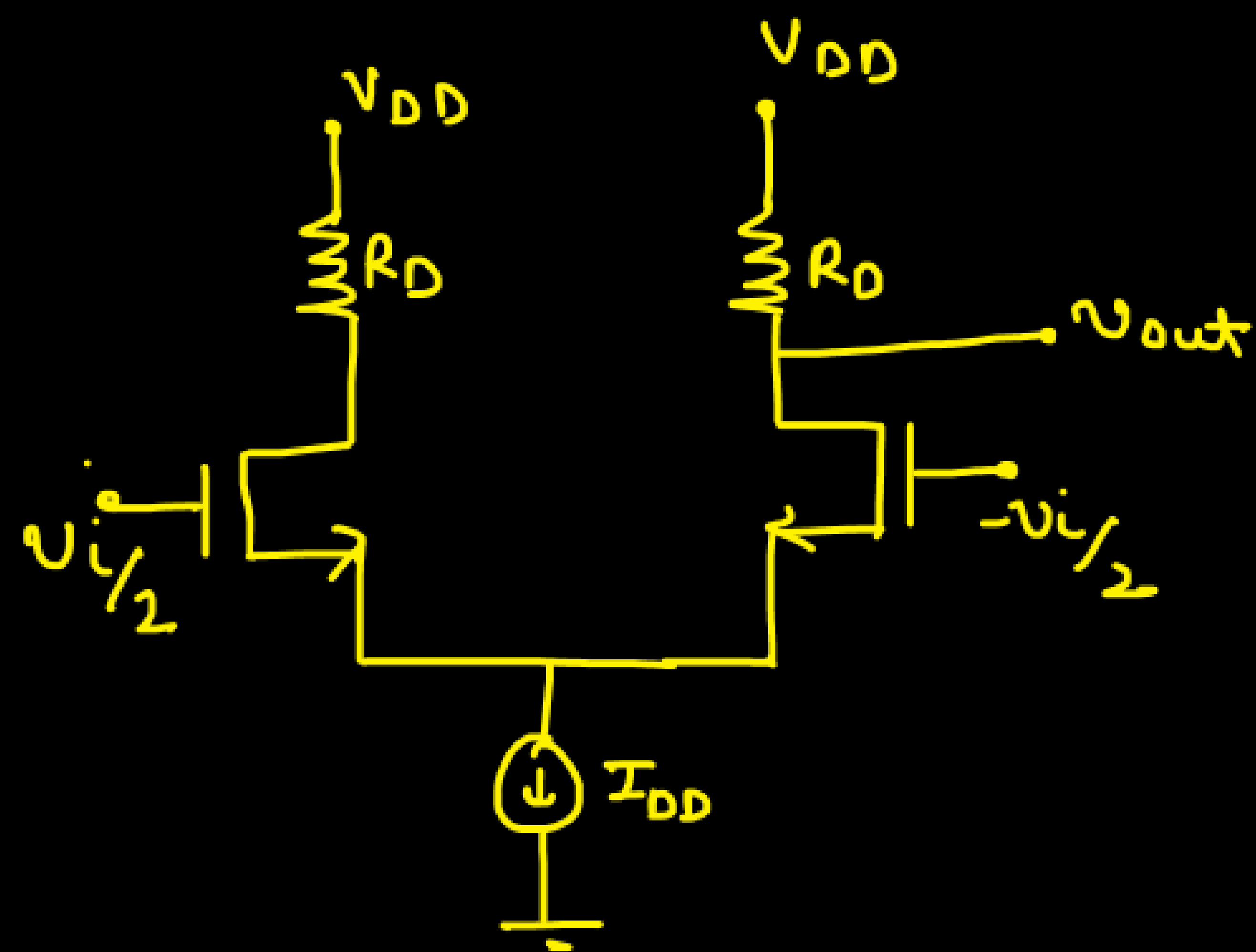
$$\boxed{\begin{array}{l} V_+ \uparrow \Rightarrow V_o \uparrow \\ V_- \uparrow \Rightarrow V_o \downarrow \end{array}}$$

Target :-

Desiging High input impedance, low o/p impedance and a High gain Amplifier.

(double ended i/p, single ended o/p)

⇒ What we have studied?

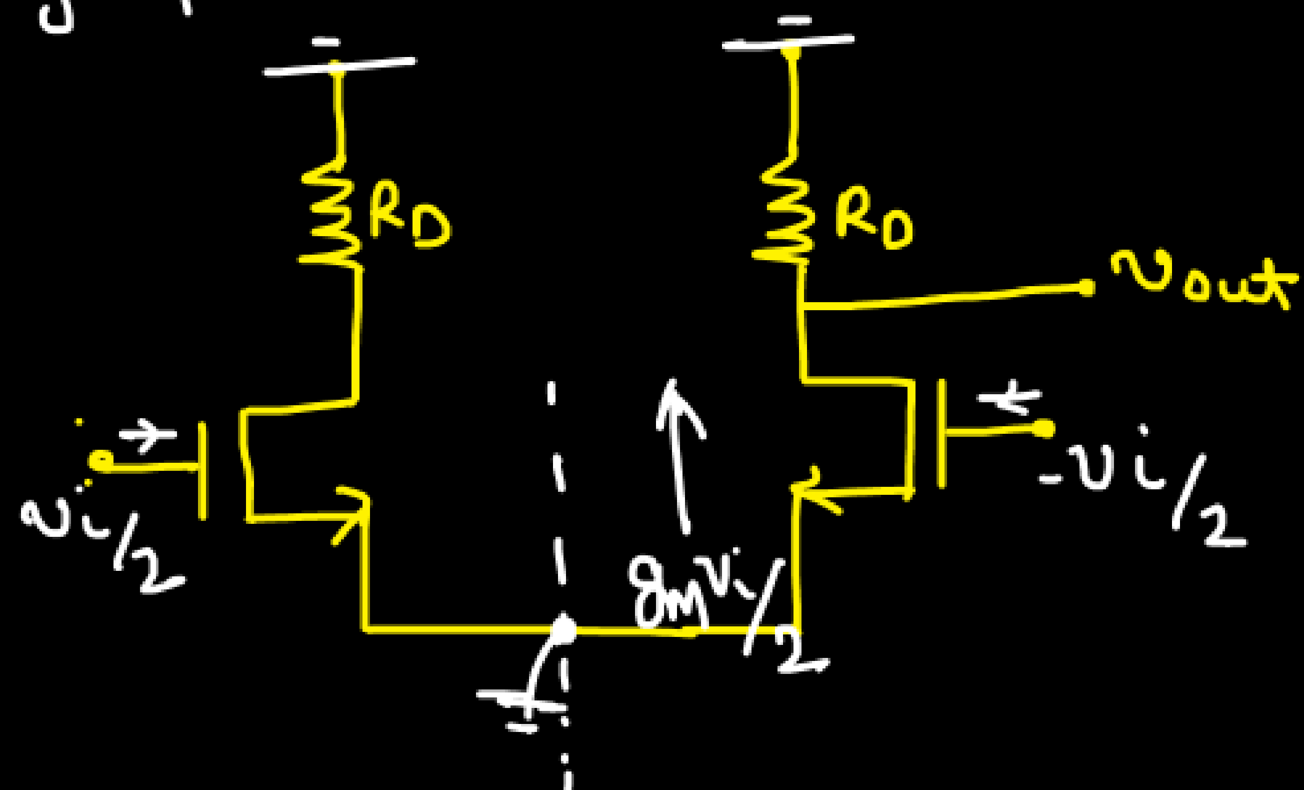


(i) gain = ? = $\frac{v_o}{v_i}$

(ii) i/p impedance = ?

(iii) o/p impedance = ?

(i) gain:-



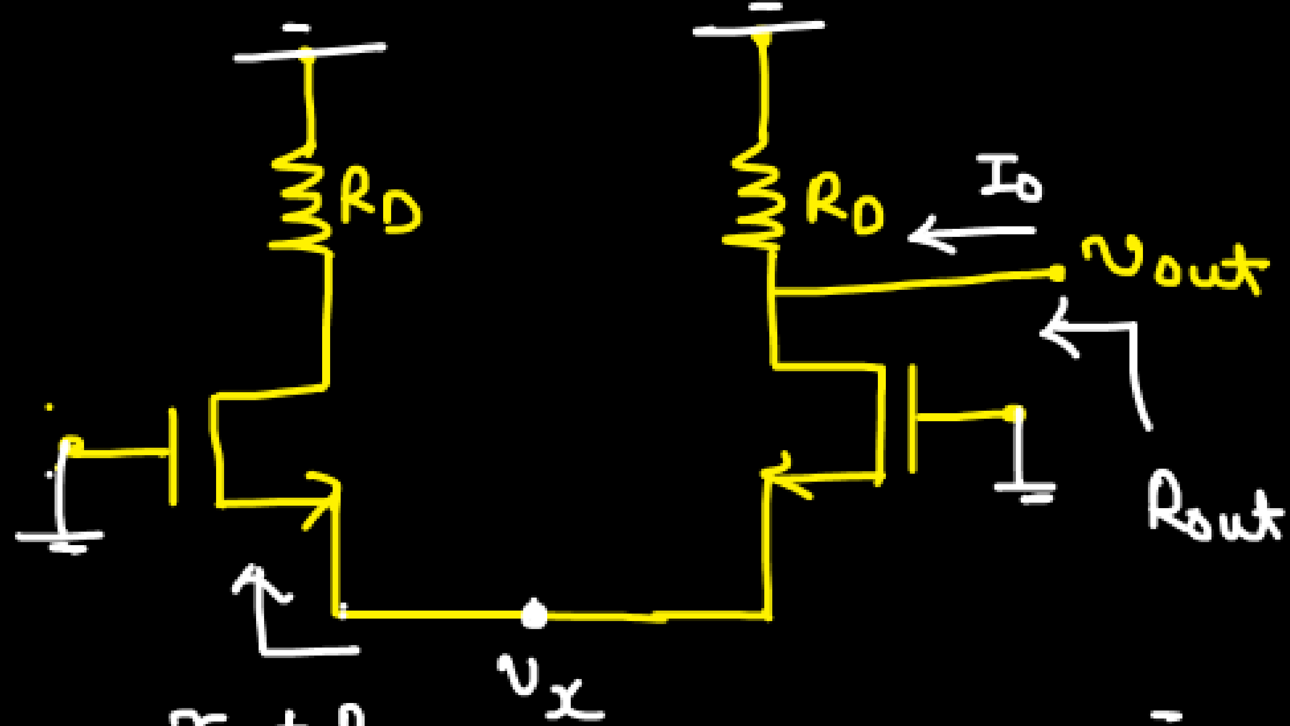
$$v_0 = \frac{g_m v_i}{2} R_D$$

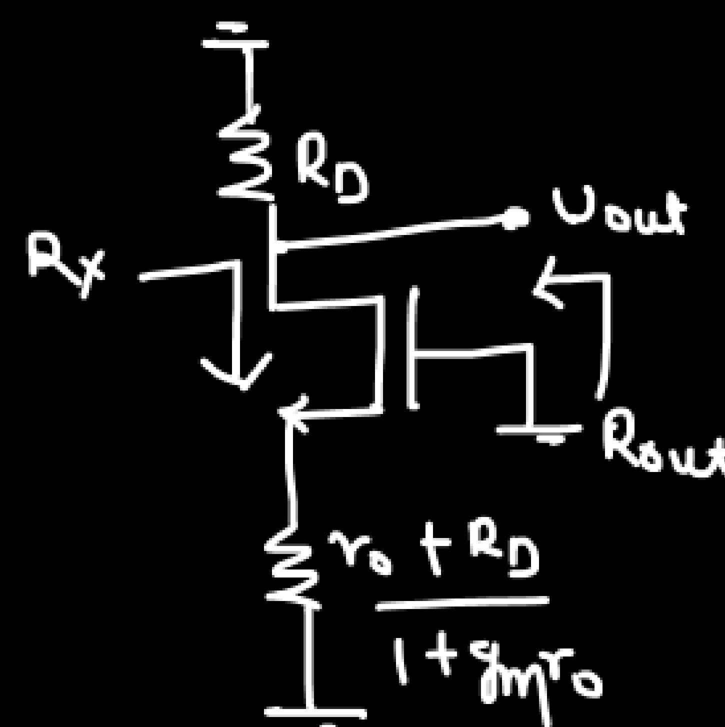
$$\boxed{\frac{v_0}{v_i} = \frac{g_m R_D}{2}} \Rightarrow \text{NOT VERY High (X)}$$

(ii) Input Impedance :-

$$\boxed{\frac{v_i}{I_i} = \frac{v_i}{0} = \infty} \Rightarrow \text{High Input Impedance } (\checkmark)$$

(iii) o/p impedance:- (Let's take $\lambda \neq 0$)





$$R_x = g_m r_o \left(\frac{r_o + R_D}{1+g_m r_o}\right) + r_o + \left(\frac{r_o + R_D}{1+g_m r_o}\right)$$

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

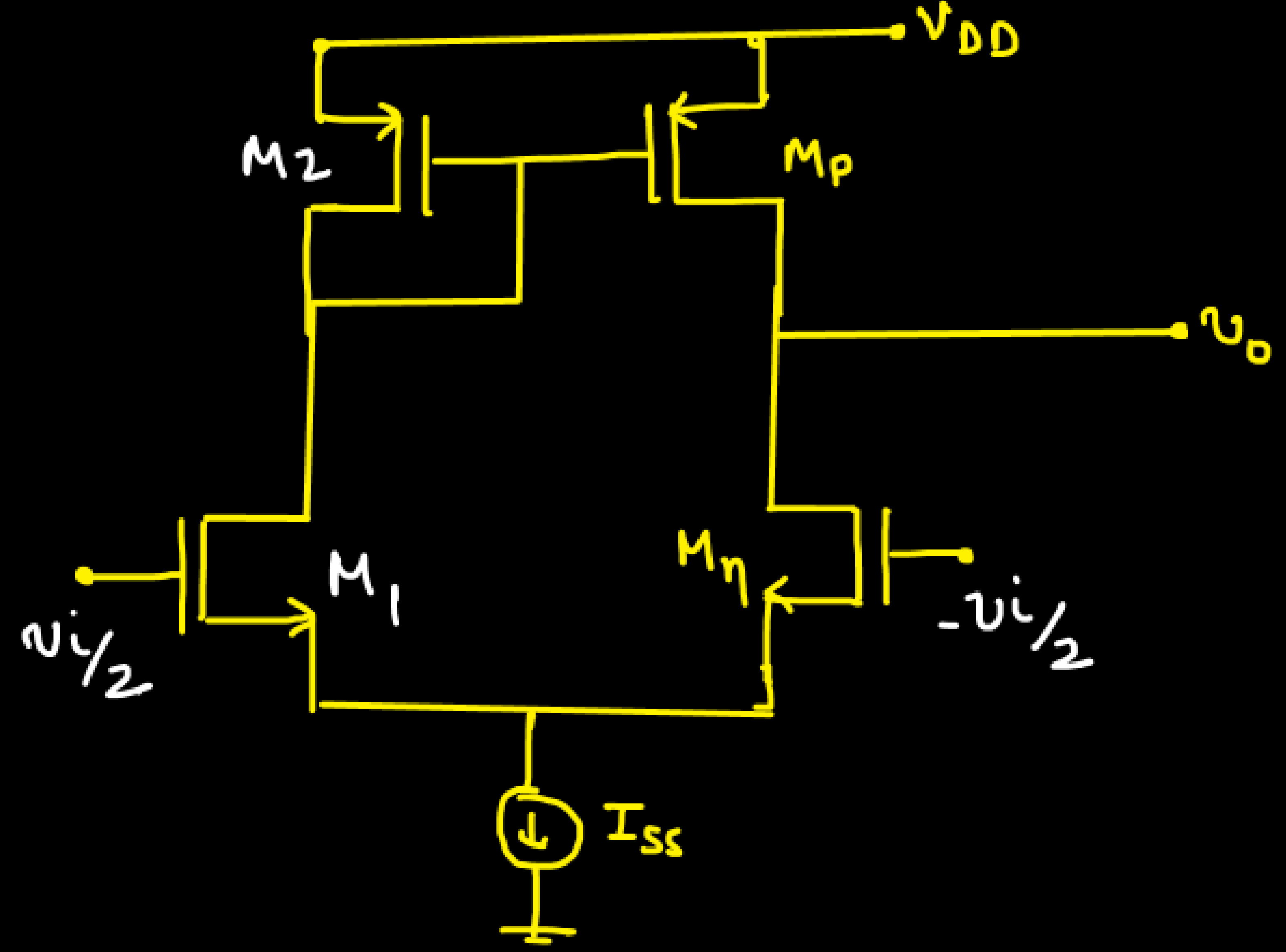
$$\boxed{R_x = 2r_o + R_D}$$

$$R_{out} = R_x \| R_D$$

$$\boxed{R_{out} = (2r_o + R_D) \| R_D}$$

$$\approx R_D \Rightarrow \text{low } (\checkmark)$$

Differential Amplifier with active load :-

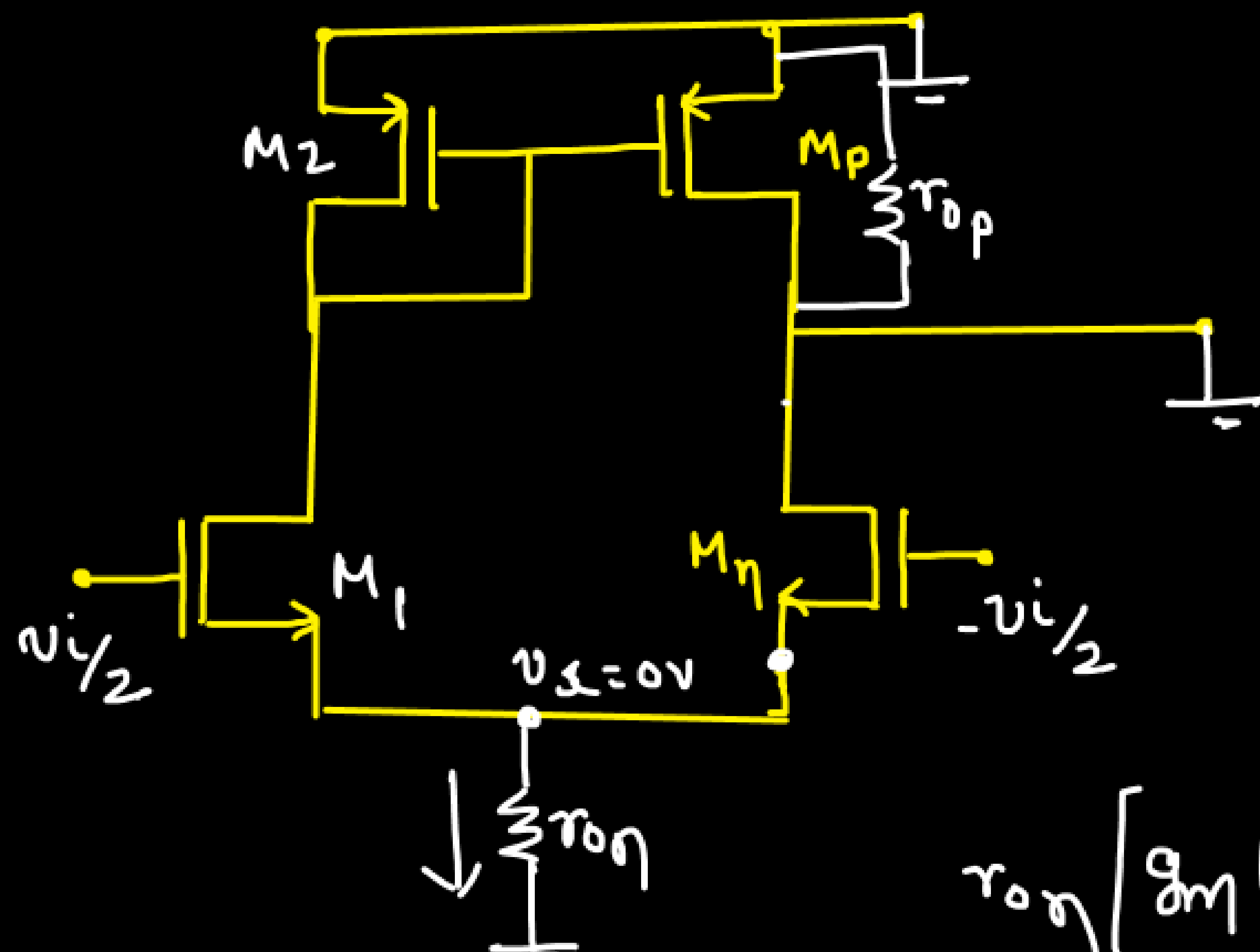


For ease of calculation, we will take $\lambda = 0$ for M_1 & M_2

$\lambda \neq 0$ for M_n & M_p

Voltage Gain:-

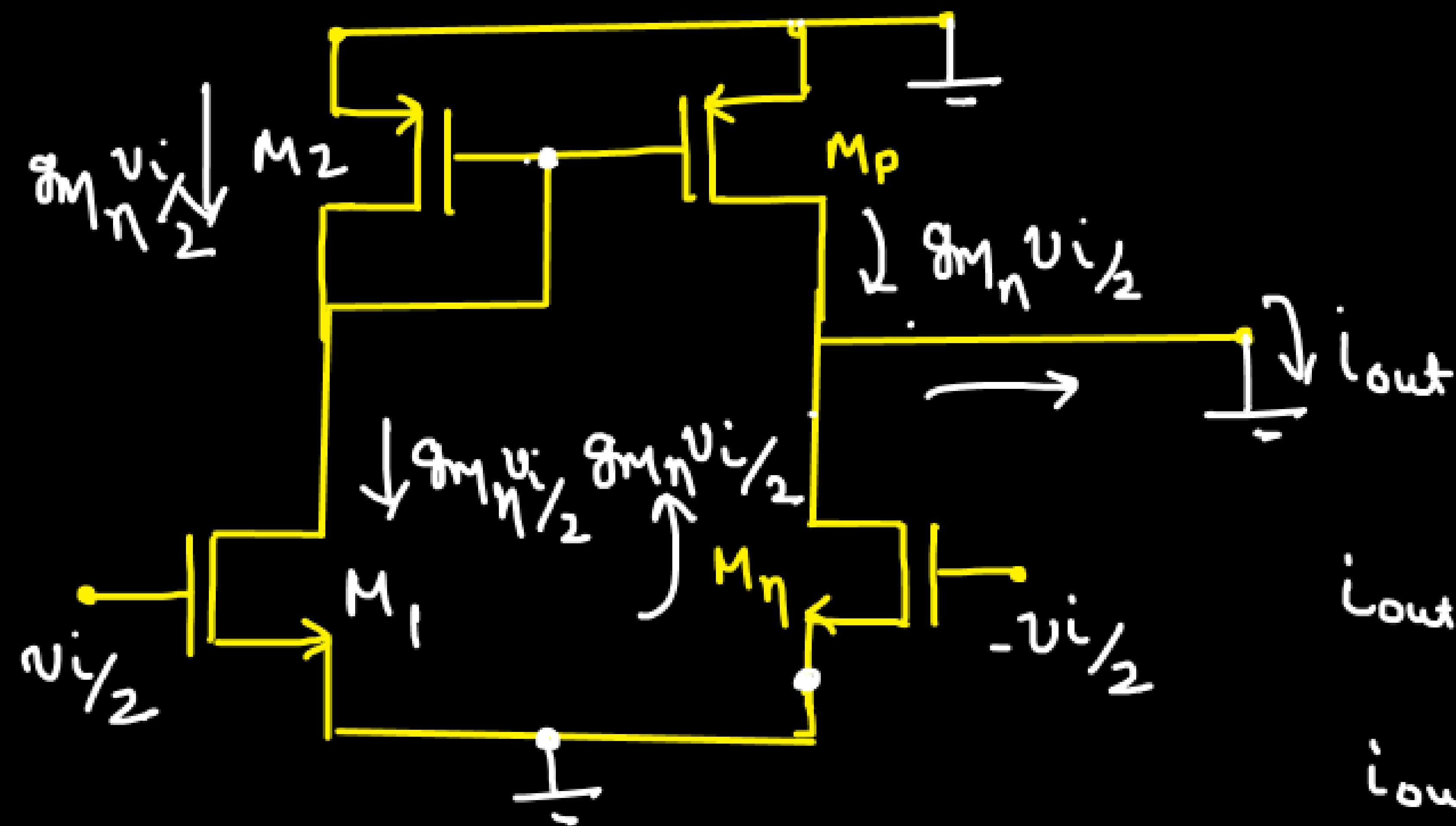
$G_m \rightarrow$



$$r_{on}\left[g_m\left(\frac{v_i}{2} - v_x\right) + g_m\left(\frac{-v_i}{2} - v_x\right)\right] = v_x$$

$$-2g_m r_{on} v_x = v_x$$

$$v_x\left[1 + 2g_m r_{on}\right] = 0 \Rightarrow \boxed{v_x = 0}$$

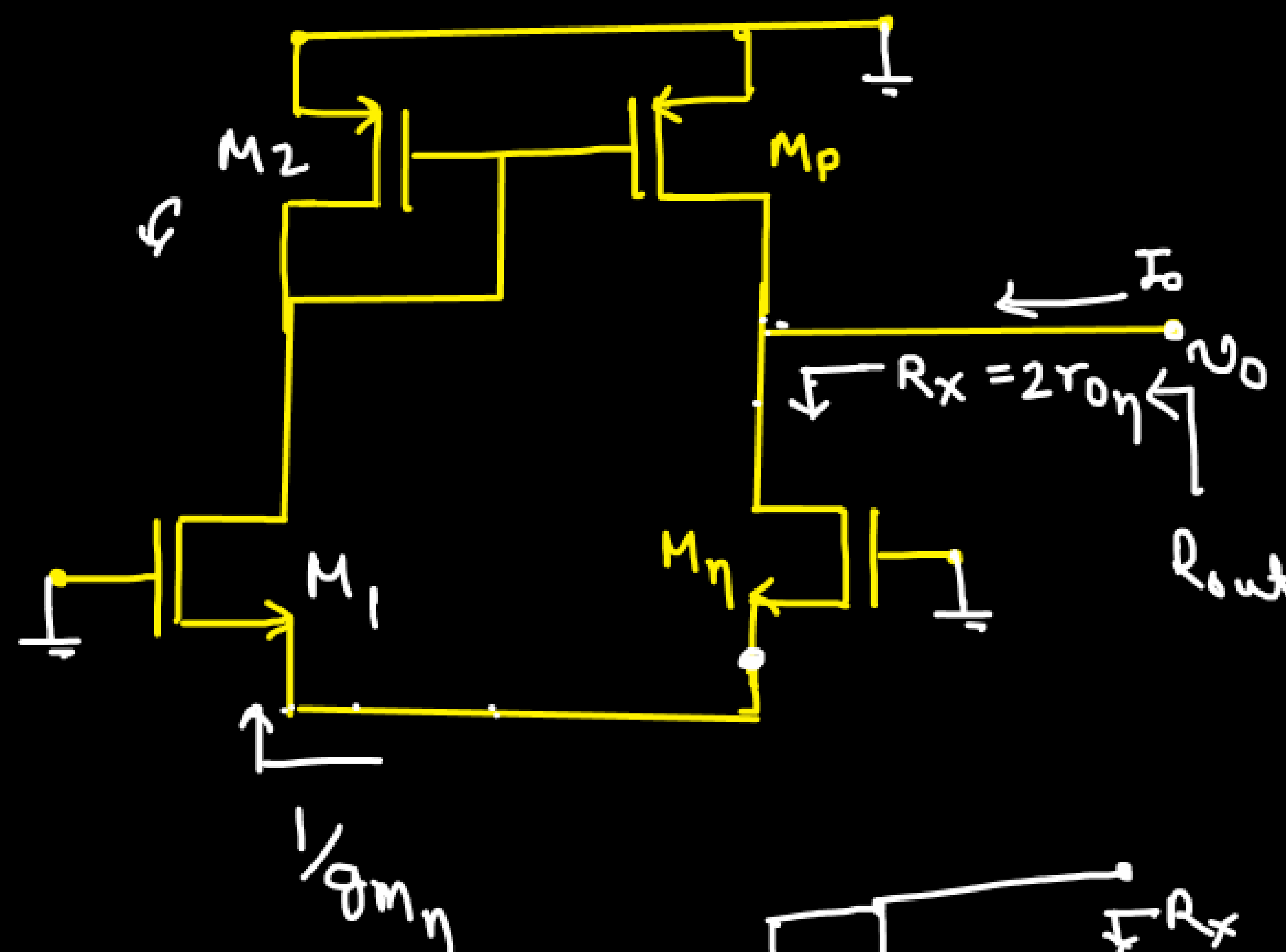


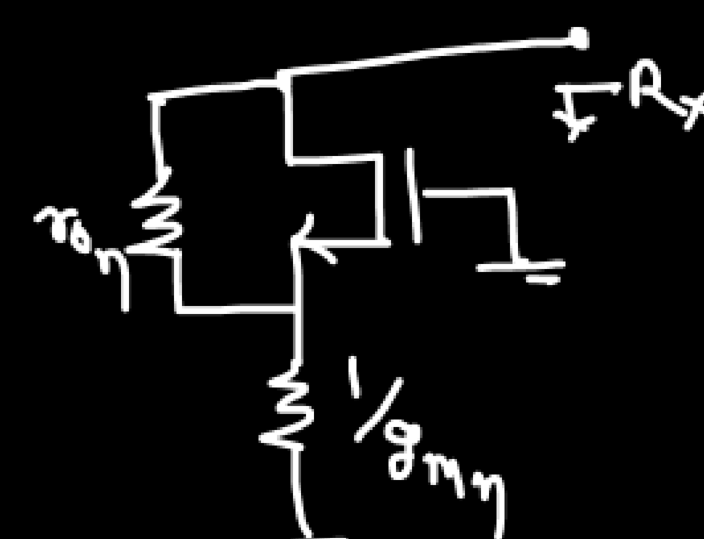
$$i_{out} = g_{m_n} v_i/2 + g_{m_n} v_i/2$$

$$i_{out} = g_{m_n} v_i$$

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

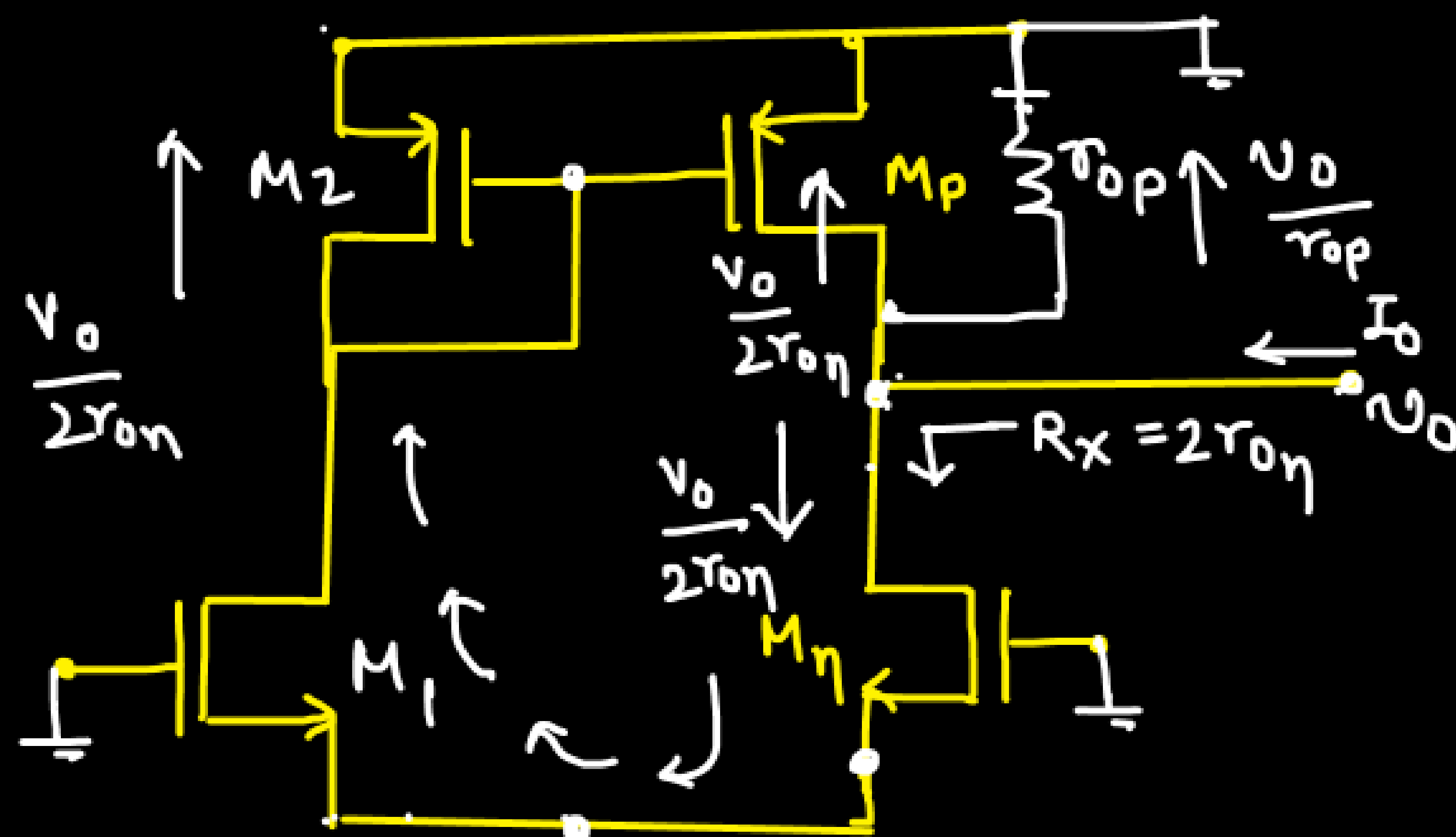
Rout :-





$$R_x = g_{m_n} r_{on} \times \frac{1}{g_{m_n}} + r_{on} + \frac{1}{g_{m_n}}$$

$$\boxed{R_x = 2r_{on} + \frac{1}{g_m} \approx 2r_{on}}$$



$$\frac{v_o}{r_{op}} + \frac{v_o}{2r_{on}} + \frac{v_o}{2r_{on}} = I_o \quad \Rightarrow \quad \frac{v_o}{r_{op}} + \frac{v_o}{r_{on}} = i_o$$

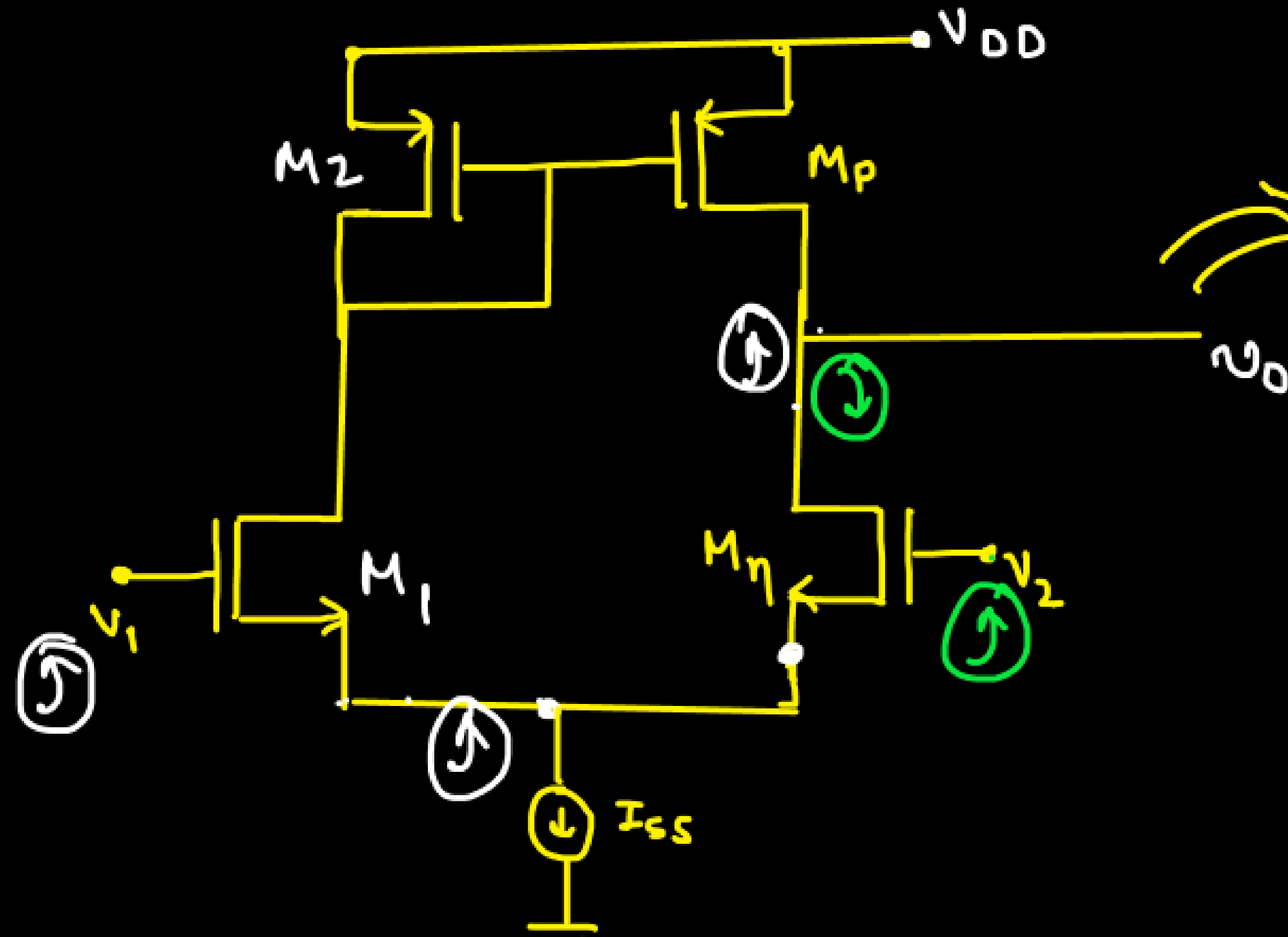
$$\boxed{\frac{v_o}{i_o} = R_{out} = r_{op} \,||\, r_{on}}$$

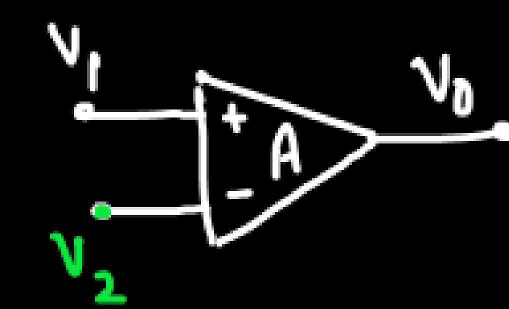
$\rightsquigarrow$ High (<u>NOT Desired</u>)

$$\boxed{A_v = g_{m_n}(r_{op} \| r_{on})} \Rightarrow \text{High (desired)}$$

Input impedance $\boxed{R_i = \infty} \Rightarrow$ High (desired)

$\boxed{\text{Matter of concern} \Rightarrow \text{o/p impedance}}$

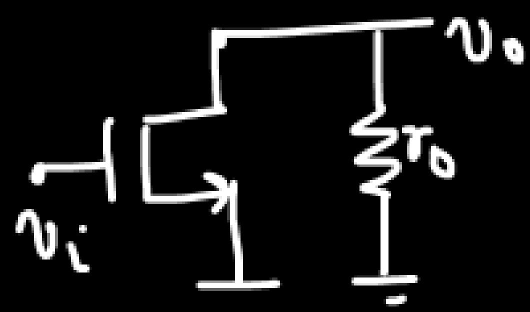
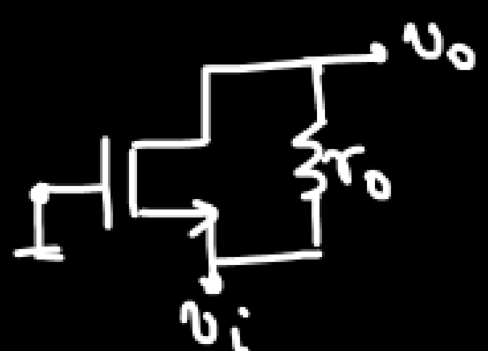
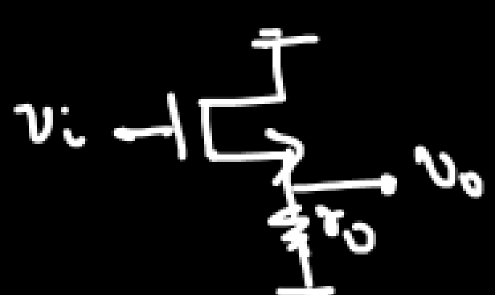


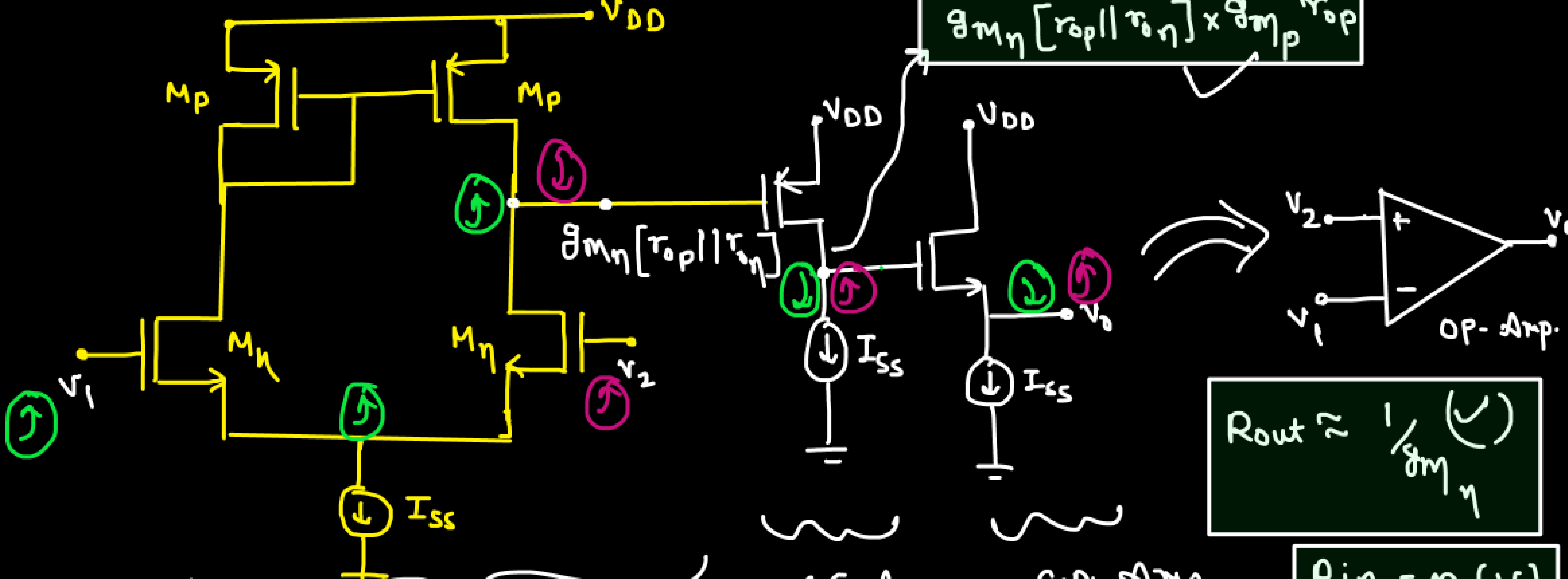


NOT an op-Amp

$V_1 \uparrow \Rightarrow V_0 \uparrow \Rightarrow V_1 = V_+$

$V_2 \uparrow \Rightarrow V_0 \downarrow \Rightarrow V_2 = V_-$

	Gain	o/p impedance
① Common Source 	$-g_m r_o$	$r_o \rightarrow$ High
② Common Gate 	$1 + g_m r_o$	$r_o \rightarrow$ High
③ Common drain 	$\dfrac{g_m r_o}{1+g_m r_o}$ ≈ 1	$r_o \parallel \dfrac{1}{g_m} \approx \dfrac{1}{g_m} \rightarrow$ low



Gain =

$$g_{m_n}[r_{op}||r_{on}] \times g_{m_p} r_{op}$$

$R_{out} \approx 1/g_{m_n}$ (✓)

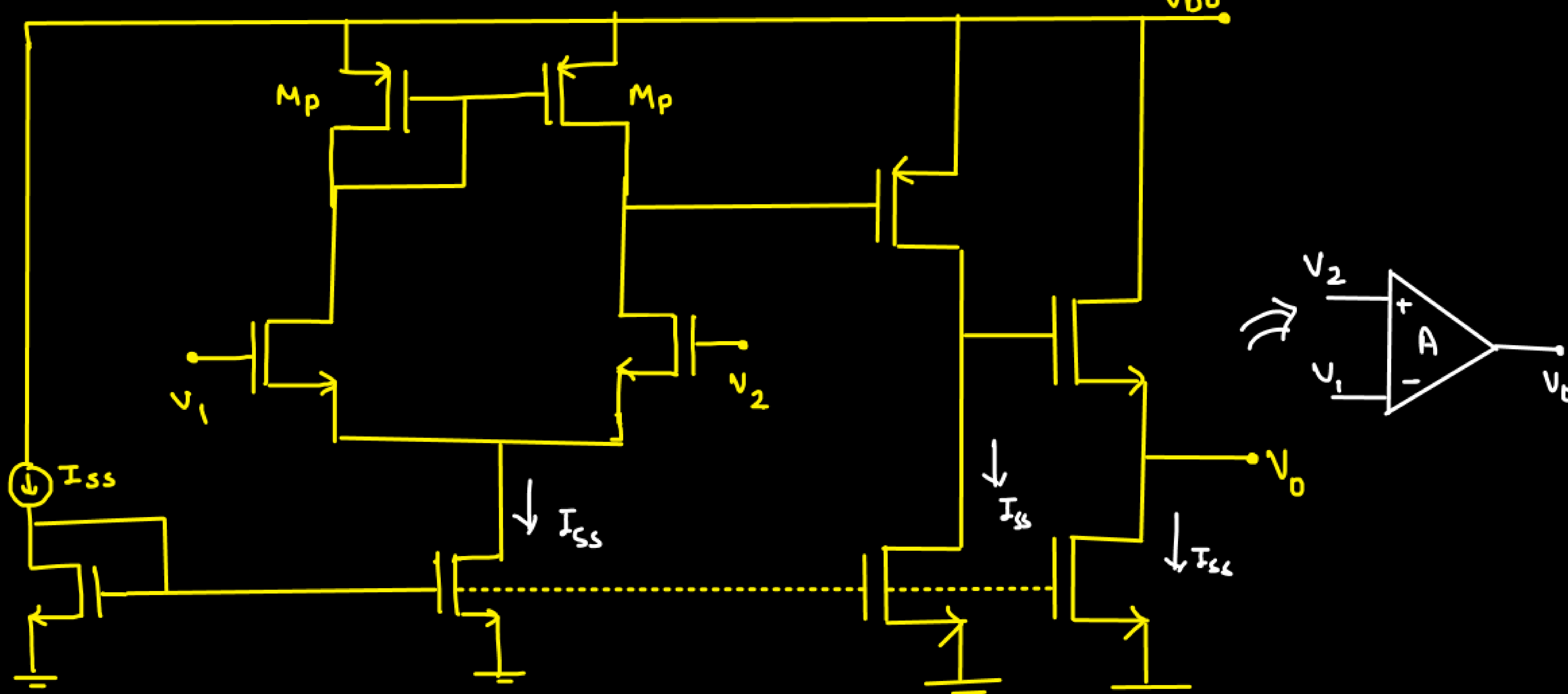
$R_{in} = \infty$ (✓)

Diff. Amp with active load

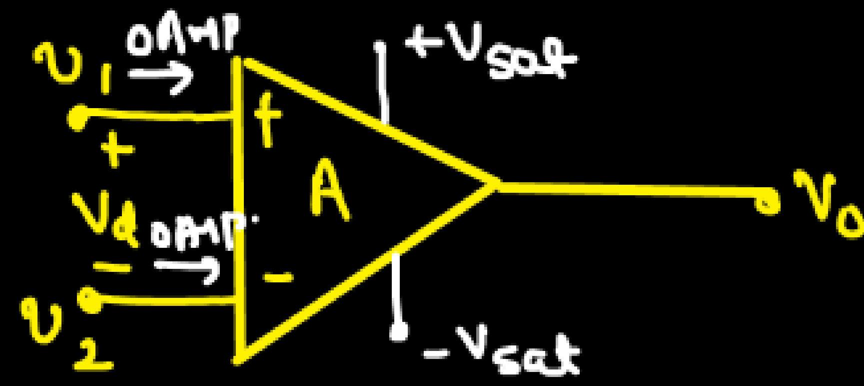
C.S. Amp. (To increase gain)

C.D. Amp. (lower o/p impedance)

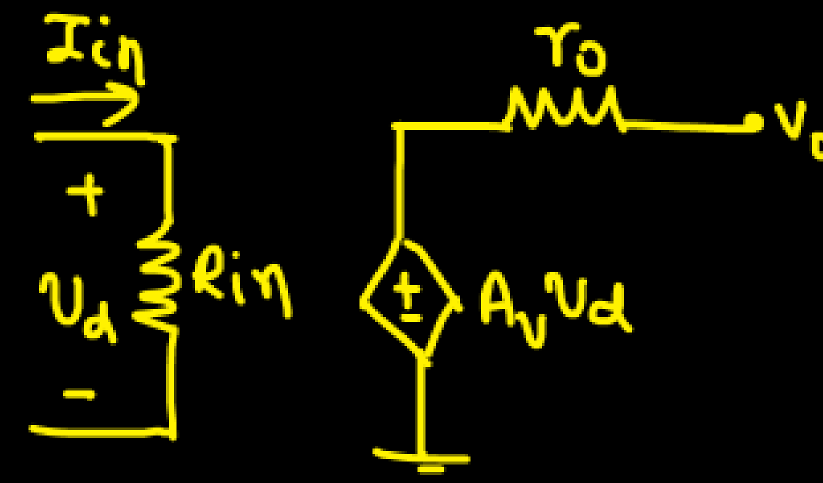
Final design:-



Some Basics of OP-Amp:-



⇒



$V_o = A V_d$

$-V_{sat} < V_o < +V_{sat}$

$-V_{sat} < A V_d < +V_{sat}$

$$\boxed{\frac{-V_{sat}}{A} < V_d < \frac{+V_{sat}}{A}}$$

$$\boxed{V_o = A(V_1 - V_2)}$$

$V_+ = V_1 \uparrow \Rightarrow V_o \uparrow$

$V_- = V_2 \uparrow \Rightarrow V_o \downarrow$

For an ideal op-Amp ⇒

$$\boxed{\begin{aligned} R_{in} &= \infty \\ I_{in} &= 0 \\ r_o &= 0 \\ A_v &= \infty \end{aligned}}$$

$CMRR = \infty$

slew rate $= \infty$

☆ For an OP-Amp, O/P can never go above +ve sat. voltage and can never go below -ve sat. voltage

Let, $A = 10^3\ V/V$; $\pm V_{sat} = \pm 5V$

(i) $V_d = 1mV$

$$V_o = AV_d = 10^3 \times 1mV = 1V \checkmark$$

(ii) $V_d = -3mV$

$$V_o = -3m \times 10^3 = -3V \checkmark$$

(iii) $V_d = -5mV$

$$V_o = -5m \times 10^3 = -5V \checkmark$$

(iv) $V_d = 7mV$

$$V_o = 7m \times 10^3 = 7V \times \Rightarrow 5V \checkmark$$

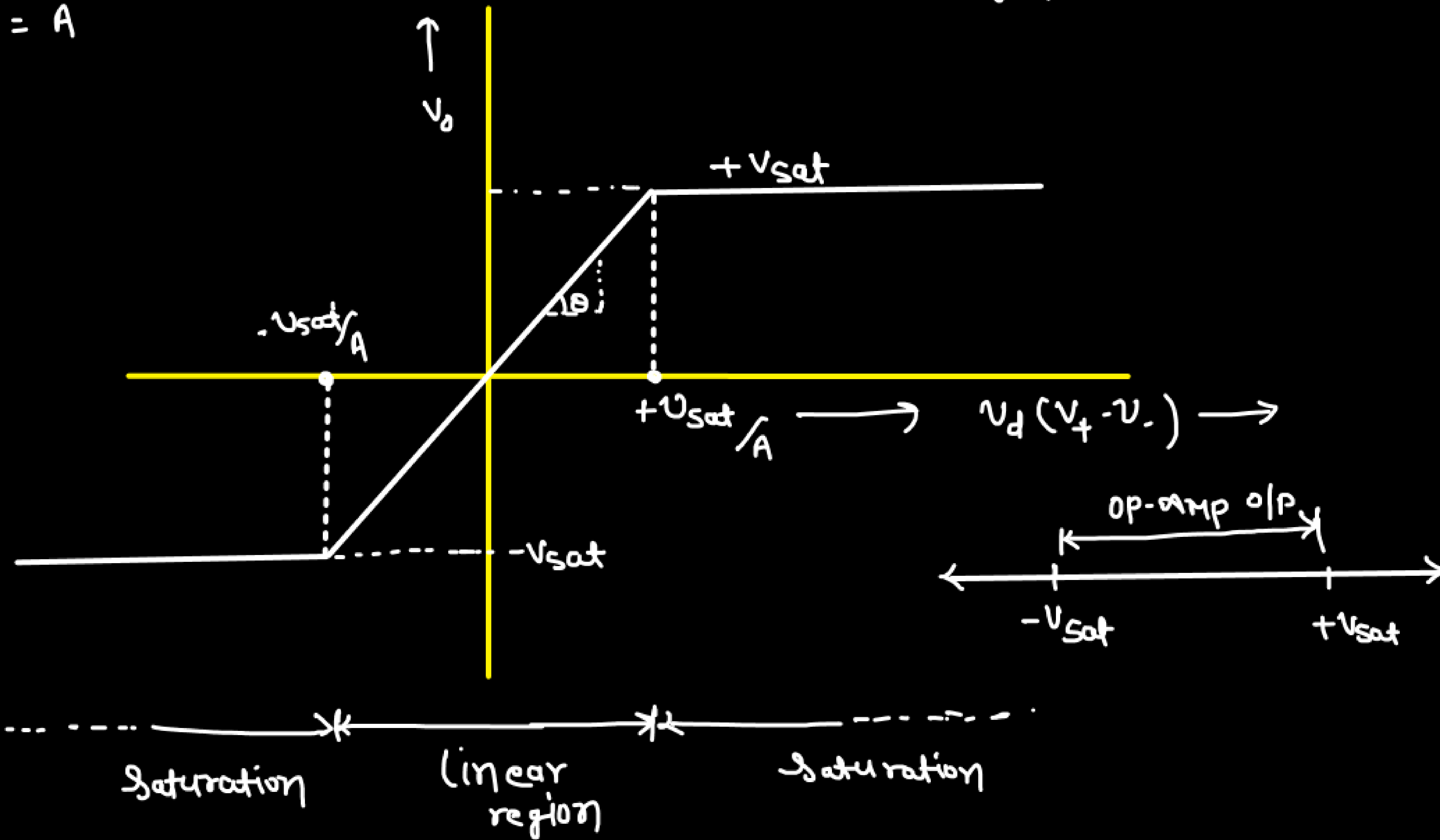
(v) $V_d = -6mV$

$$V_o = -6m \times 10^3$$
$$= -6V \times$$
$$\Rightarrow -5V$$

$v_0 = A v_d$

$\frac{v_0}{v_d} = A$

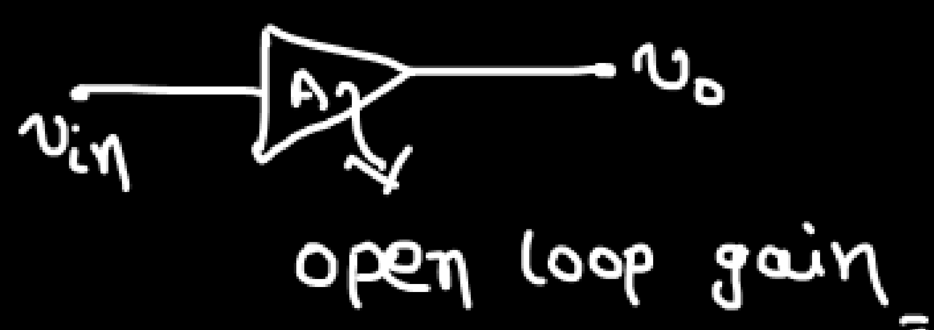
$\tan\theta = A$



Feedback:-

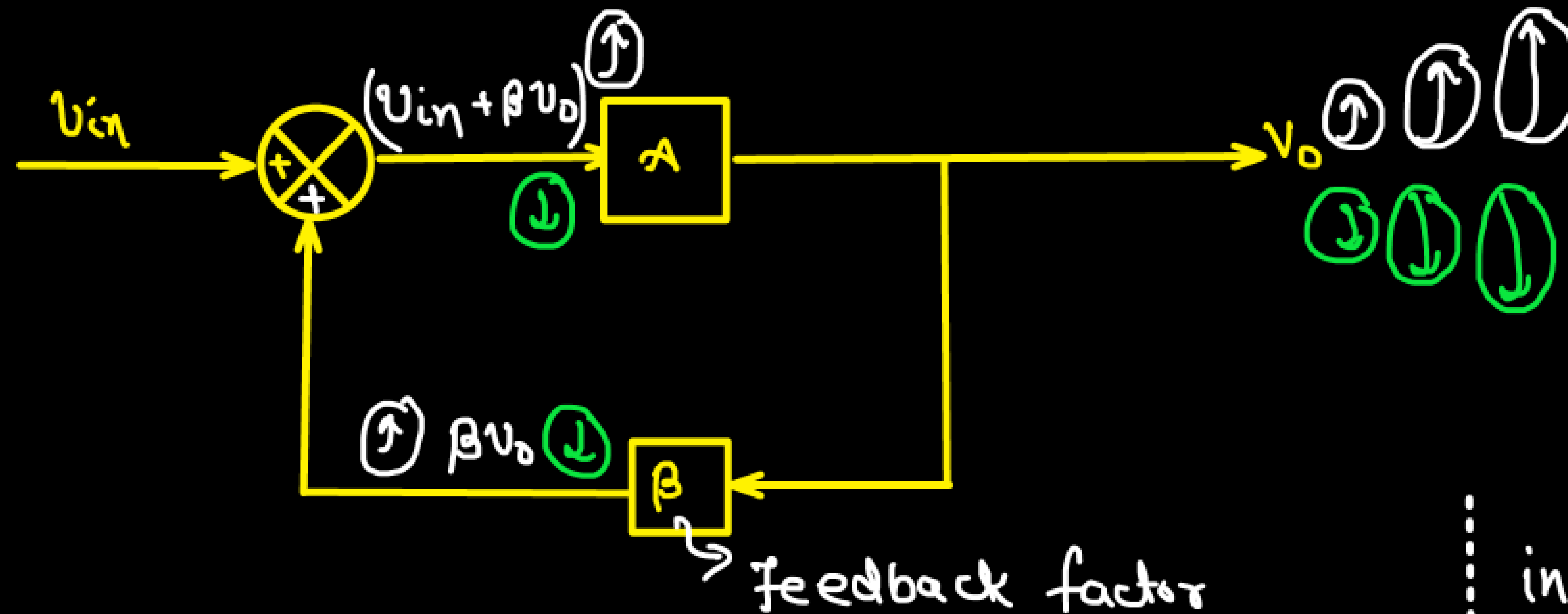
Taking a fraction of the o/p of an amplifier and connecting it back to the i/p. This fed-back signal can be connected in a way that it either adds to the normal input or subtracts from it.

System w/o any feedback:-



$$v_o = A v_{in}$$

① Positive feedback :-



$$v_0 = A(v_{in} + \beta v_0)$$

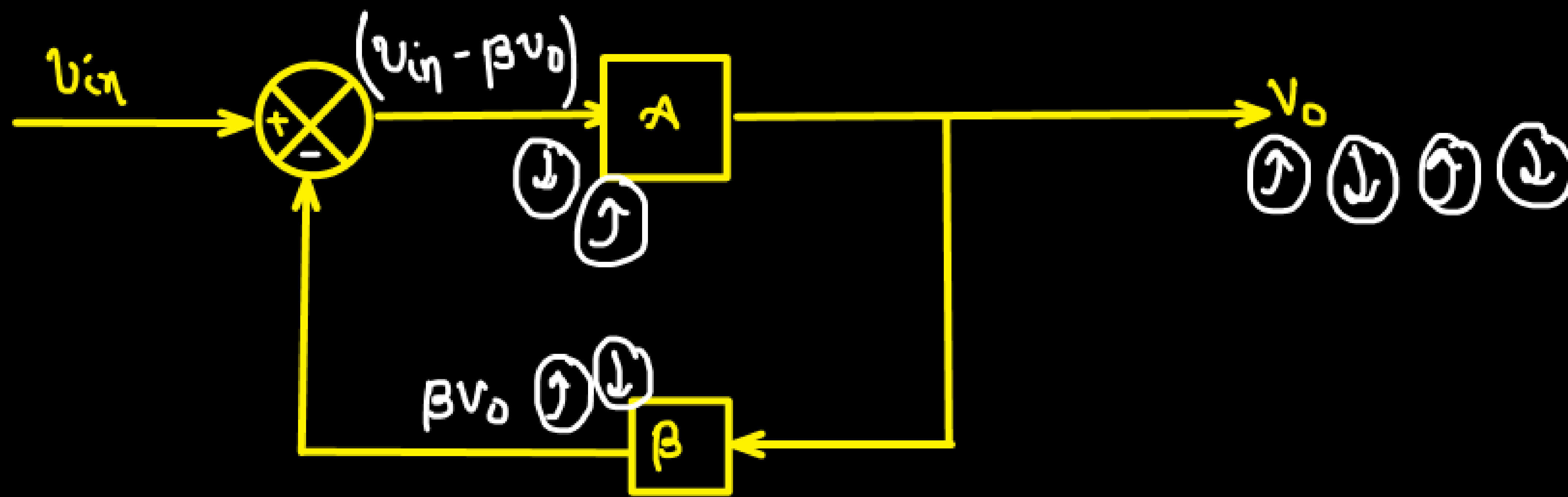
$$v_0 - A\beta v_0 = A v_{in}$$

$$\boxed{\frac{v_0}{v_{in}} = \frac{A}{1 - A\beta}} \rightarrow \text{closed loop gain}$$

in positive f/b, if o/p increases, then it keeps on increasing and results in unstable o/p.

Positive f/b s/s are unstable.

② Negative feedback :-



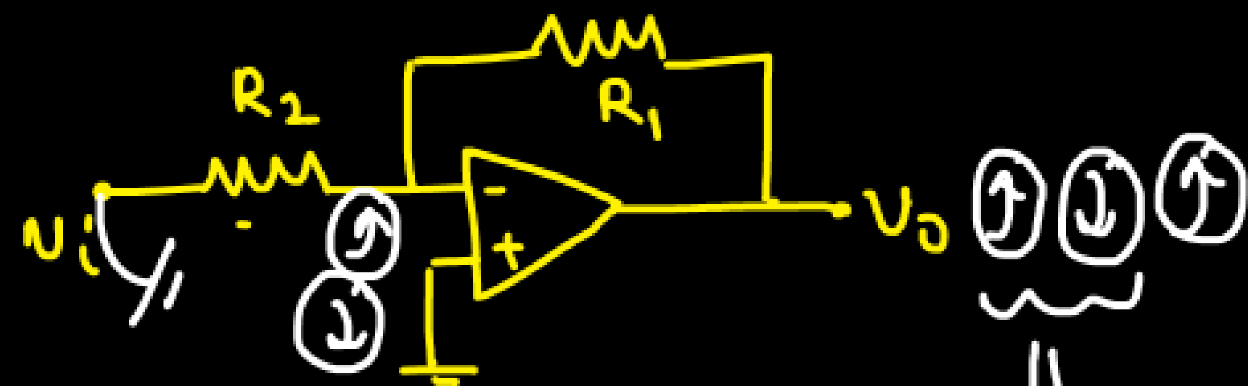
$$(v_{in} - \beta v_o) A = v_o$$

$$\boxed{\frac{v_o}{v_i} = \frac{A}{1 + A\beta}}$$ → closed loop gain

in negative f/b, you get a stable o/p.

Eg →

①



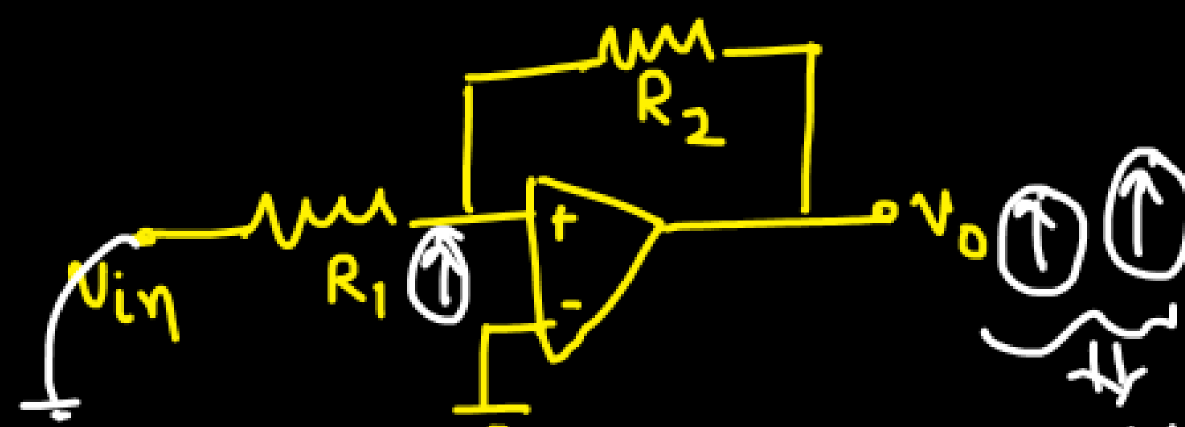
(a)

Negative f/b

$$v_0 = A(v_+ - v_-)$$

when you check the type of f/b, Nullify the i/p

②

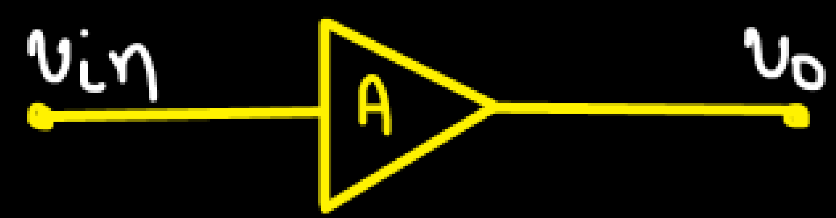


Positive f/b

$$v_0 = A(v_+ - v_-)$$

* Advantages of feedback:-

1. Gain stability:-



open-loop

$$v_o = A v_{in}$$

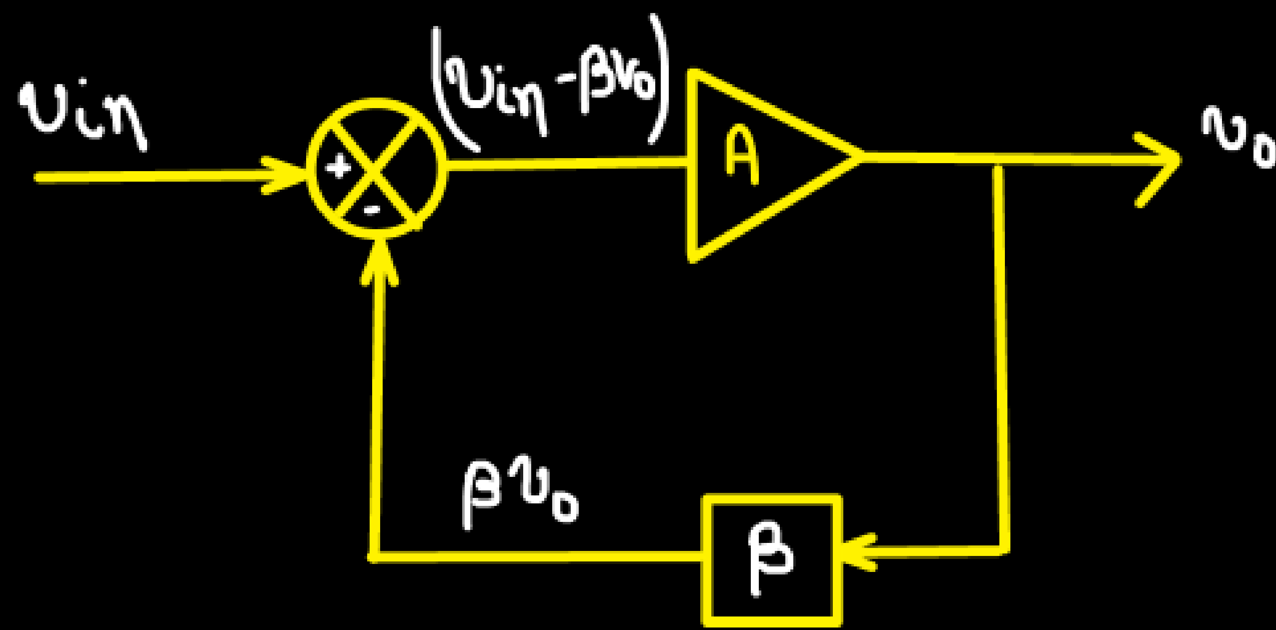
Let's assume, your gain $A = 10^3 \rightarrow 10^4$

Let; $v_{in} = 1mV$

$$v_o = A v_{in}$$

$$= 1V \rightarrow 10V$$

Introducing negative f/b :-



$$v_o = A(v_{in} - \beta v_o)$$

$$\frac{v_o}{v_{in}} = \frac{A}{1 + A\beta}$$

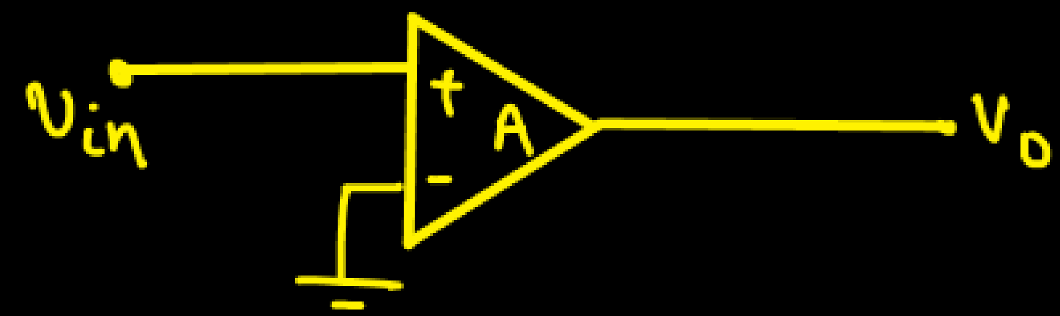
β is designed such that $A\beta >> 1$

$$\boxed{\frac{v_o}{v_{in}} \approx \frac{A}{A\beta} \approx \frac{1}{\beta}} \Rightarrow \text{constant}$$

$\Rightarrow$ Here you are getting a constant gain.

Example:-

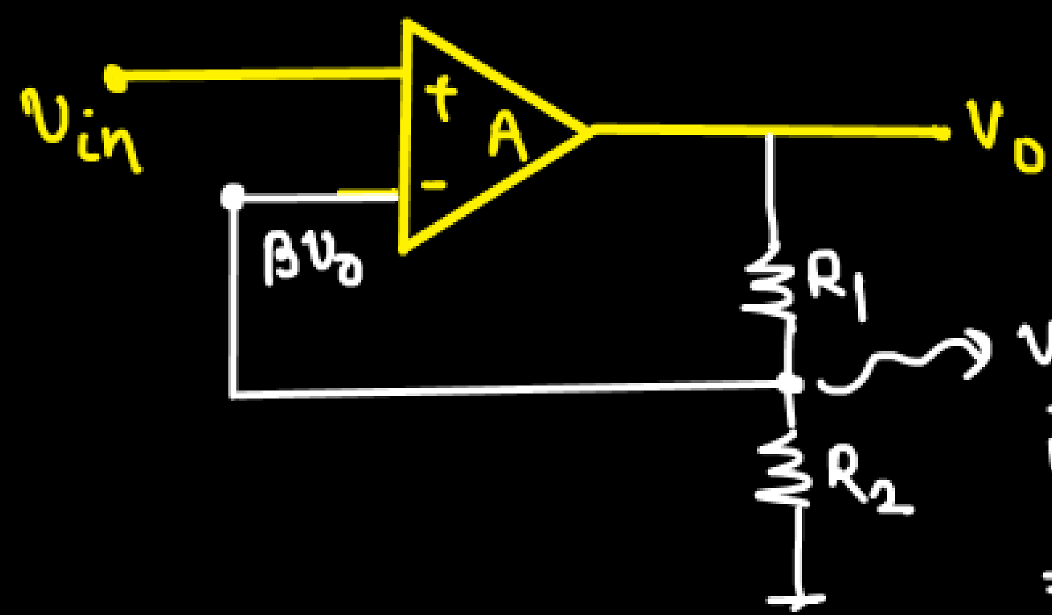
Before f/b:-



$\boxed{v_o = A v_{in}}$

if $A \to$ variable, then $v_o \to$ variable

After f/b:-



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

$$\Rightarrow \beta = \frac{R_2}{R_1 + R_2}$$

$$(v_{in} - \beta v_o) A = v_o$$

$$\frac{v_o}{v_{in}} = \frac{A}{1 + A\beta}$$

$$\boxed{\frac{v_o}{v_{in}} \approx \frac{1}{\beta} = 1 + \frac{R_1}{R_2}}$$

⇒ loop gain :-

$$(A_v)_{w/o\ f/b} = A \rightarrow \text{open loop gain}$$

$$(A_v)_{\text{with neg } f/b} = \frac{A}{1-A\beta} \rightarrow \text{closed loop gain}$$

$$\boxed{A\beta = \text{loop gain}}$$

Q. An Amplifier is connected in negative f/b. if the percentage change is open loop gain is 10% then what will be the % change in closed loop gain. loop gain is 99.

→

$$\text{closed loop gain } A_{CL} = \frac{A_{OL}}{1+A_{OL}\beta} \quad \text{---} \; 1$$

$$\frac{DA_{OL}}{A_{OL}} \times 100\% = 10\%$$

$$\frac{DA_{OL}}{A_{OL}} = 0.1$$

$$\frac{DA_{CL}}{A_{CL}} = ?$$

$$A_{CL} = \frac{A_{OL}}{1 + A_{OL}\beta}$$

$$DA_{CL} = \frac{(1 + A_{OL}\beta)\, DA_{OL} - A_{OL}\beta\, DA_{OL}}{(1 + A_{OL}\beta)^2}$$

$\beta \to$ constant

$$DA_{CL} = \frac{DA_{OL}}{(1 + A_{OL}\beta)^2}$$

$$\frac{DA_{CL}}{A_{CL}} = \frac{DA_{OL}\,(1 + A_{OL}\beta)}{(1 + A_{OL}\beta)^2 \times A_{OL}}$$

$$\left\{ A_{CL} = \frac{A_{OL}}{1 + A_{OL}\beta} \right\}$$

**

$$\boxed{\frac{DA_{CL}}{A_{CL}} = \frac{DA_{OL}/A_{OL}}{(1 + A\beta)}}$$

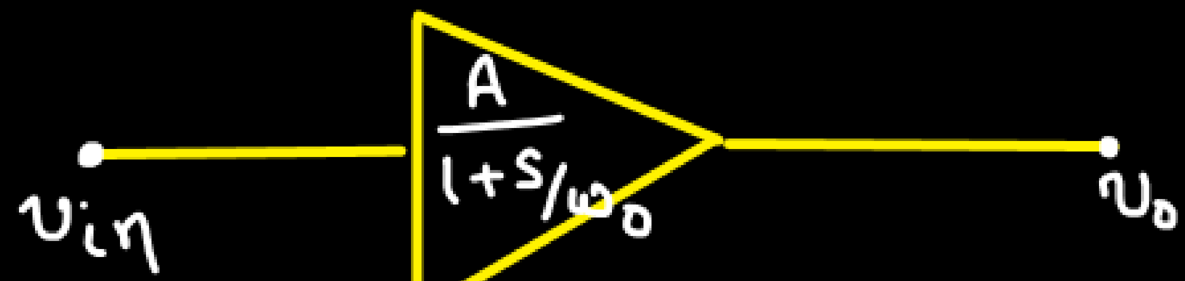
Given $A\beta = 99$

$$\frac{\Delta A_{CL}}{A_{CL}}\% = \frac{\Delta A_{OL}/A_{OL}\,\%}{1+99}$$

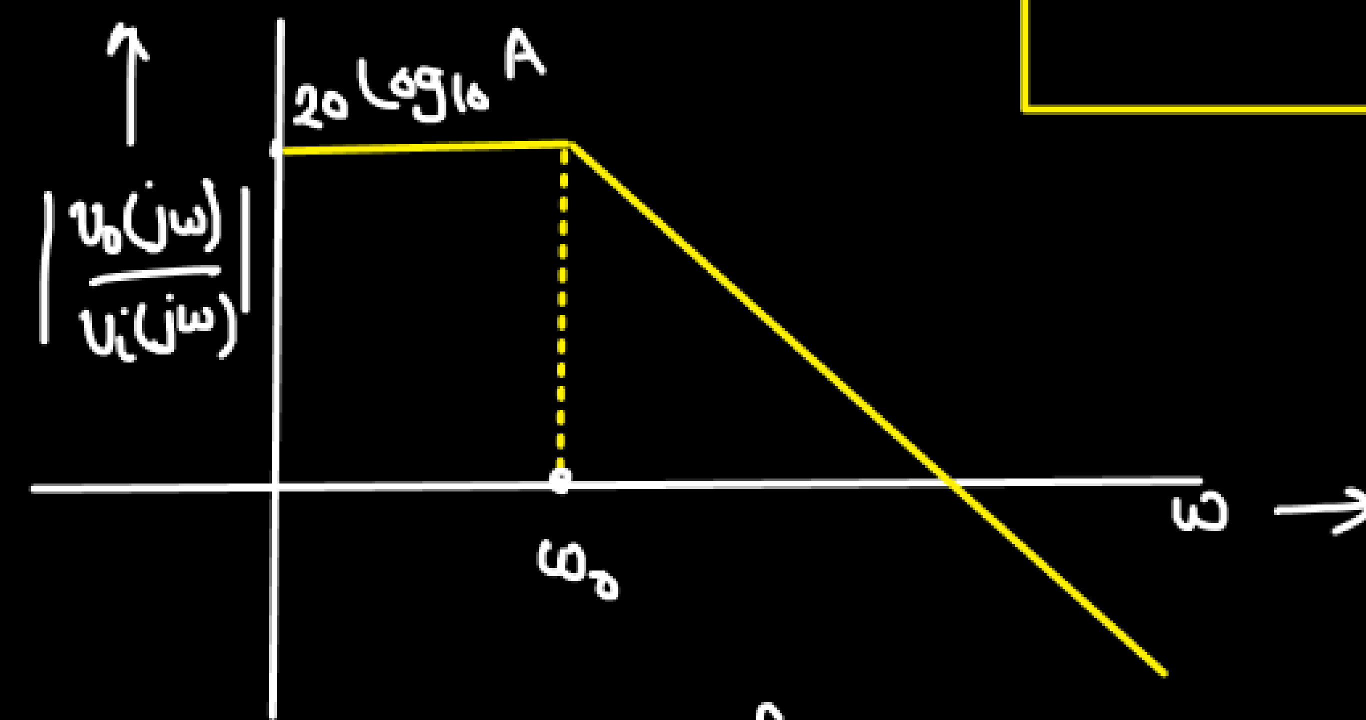
$$= \frac{10\,\%}{100}$$

$$\boxed{\frac{\Delta A_{CL}}{A_{CL}} = 0.1\,\%}$$

2. Increase in B.W. -

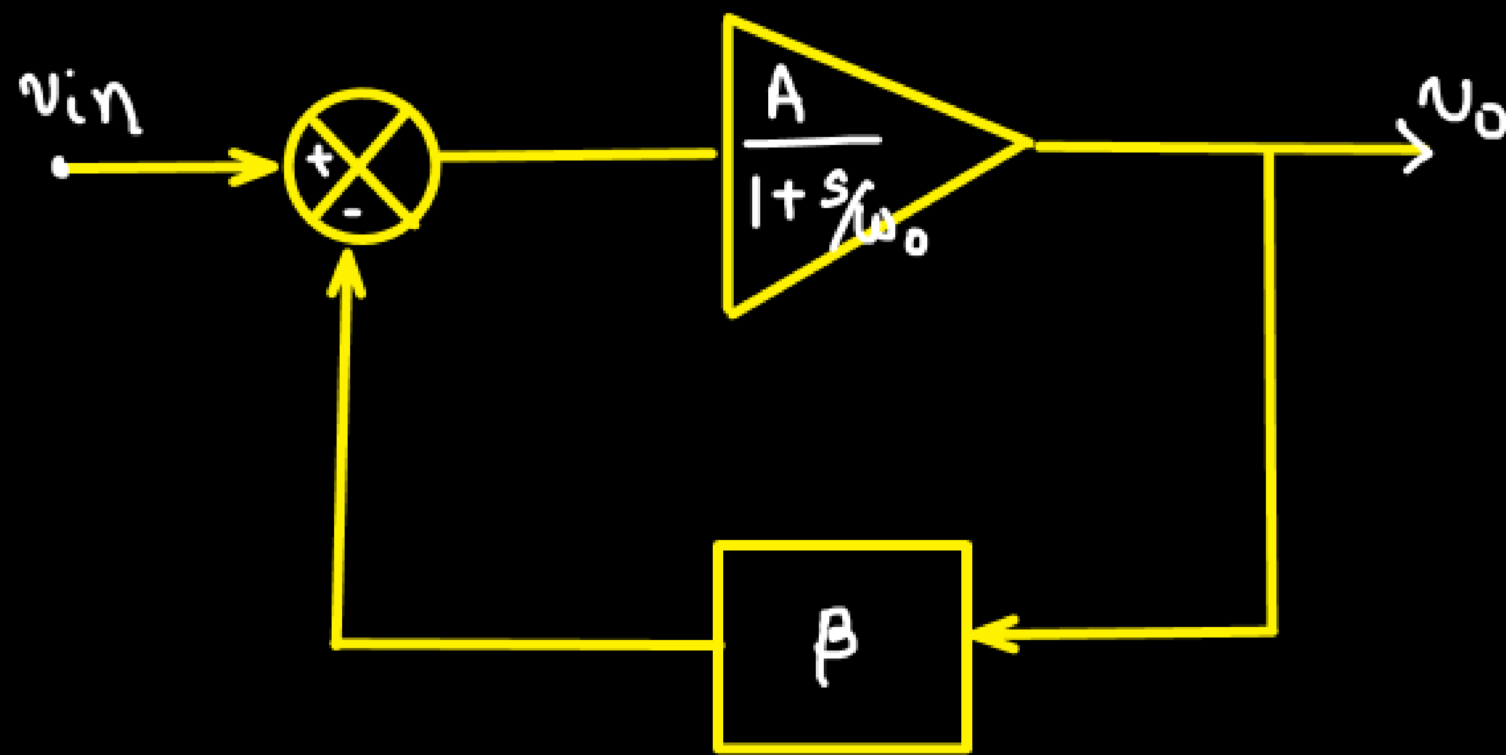


$$\boxed{v_0(s) = \frac{A}{1+S/\omega_0} v_i(s)}$$



B.W = ω_0 {getting a good gain}

Introducing feedback:-



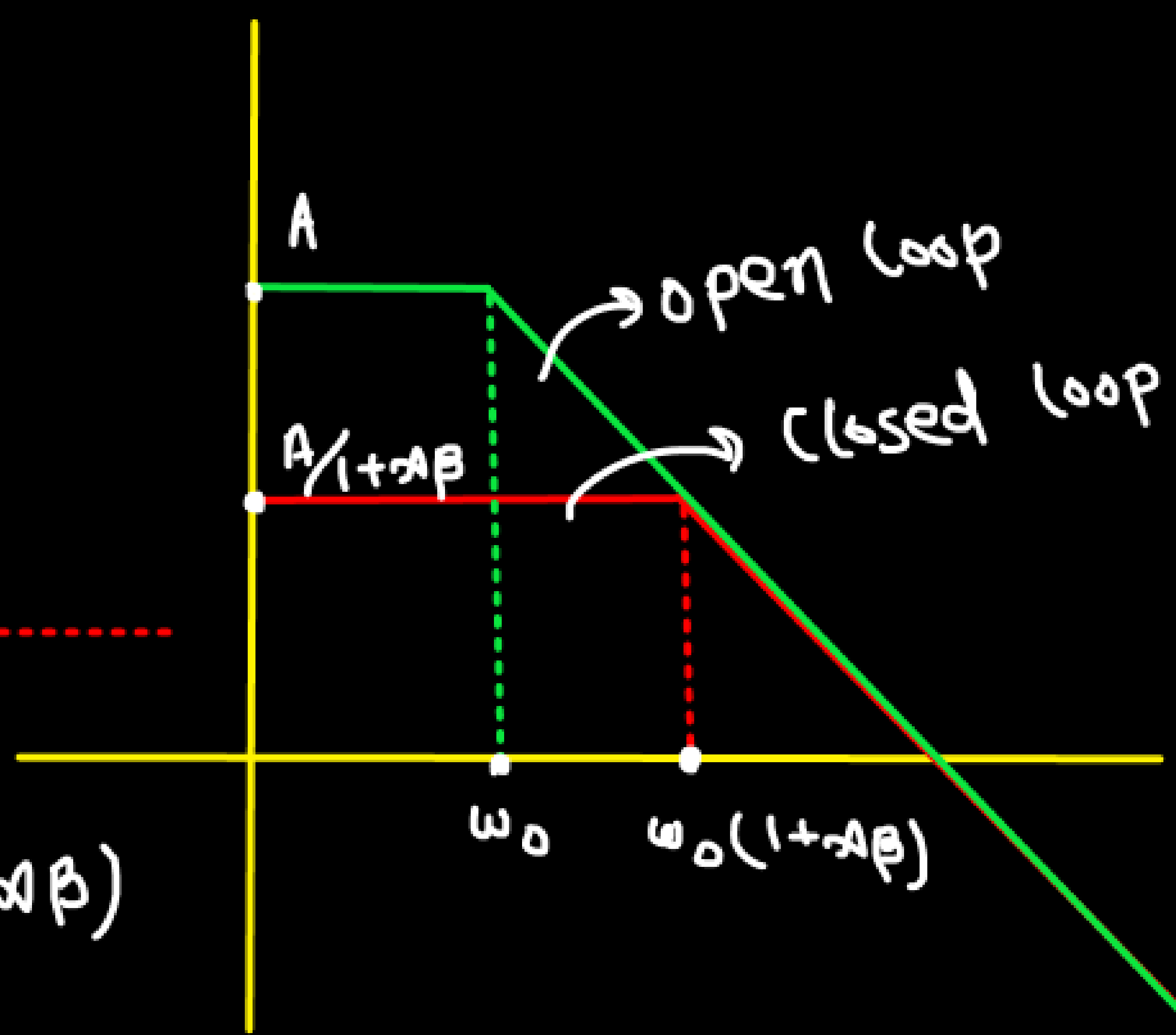
$$\boxed{\frac{v_o(s)}{v_i(s)} = \frac{\dfrac{A}{1+s/\omega_0}}{1+\dfrac{A\beta}{1+s/\omega_0}} = \frac{A}{A\beta+1+s/\omega_0} = \frac{A\omega_0}{s+\omega_0(1+A\beta)}}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{A\omega_0}{s+\omega_0(1+A\beta)}$$

$$\boxed{\frac{V_o(s)}{V_i(s)} = \frac{A/1+A\beta}{\frac{s}{\omega_0(1+A\beta)}+1}}$$

$$\text{dc gain} = \frac{A}{1+A\beta}$$

$$\text{Bandwidth} = \omega_0(1+A\beta)$$



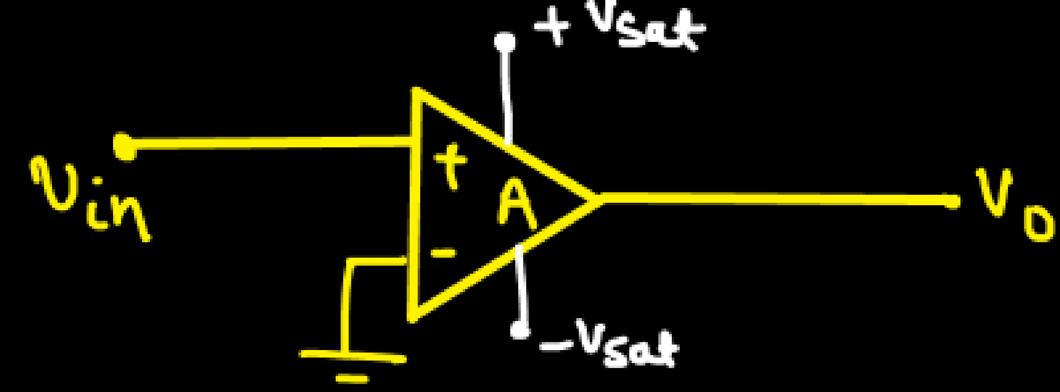
For open loop:- DC gain $= A$, $B.W. = \omega_0$

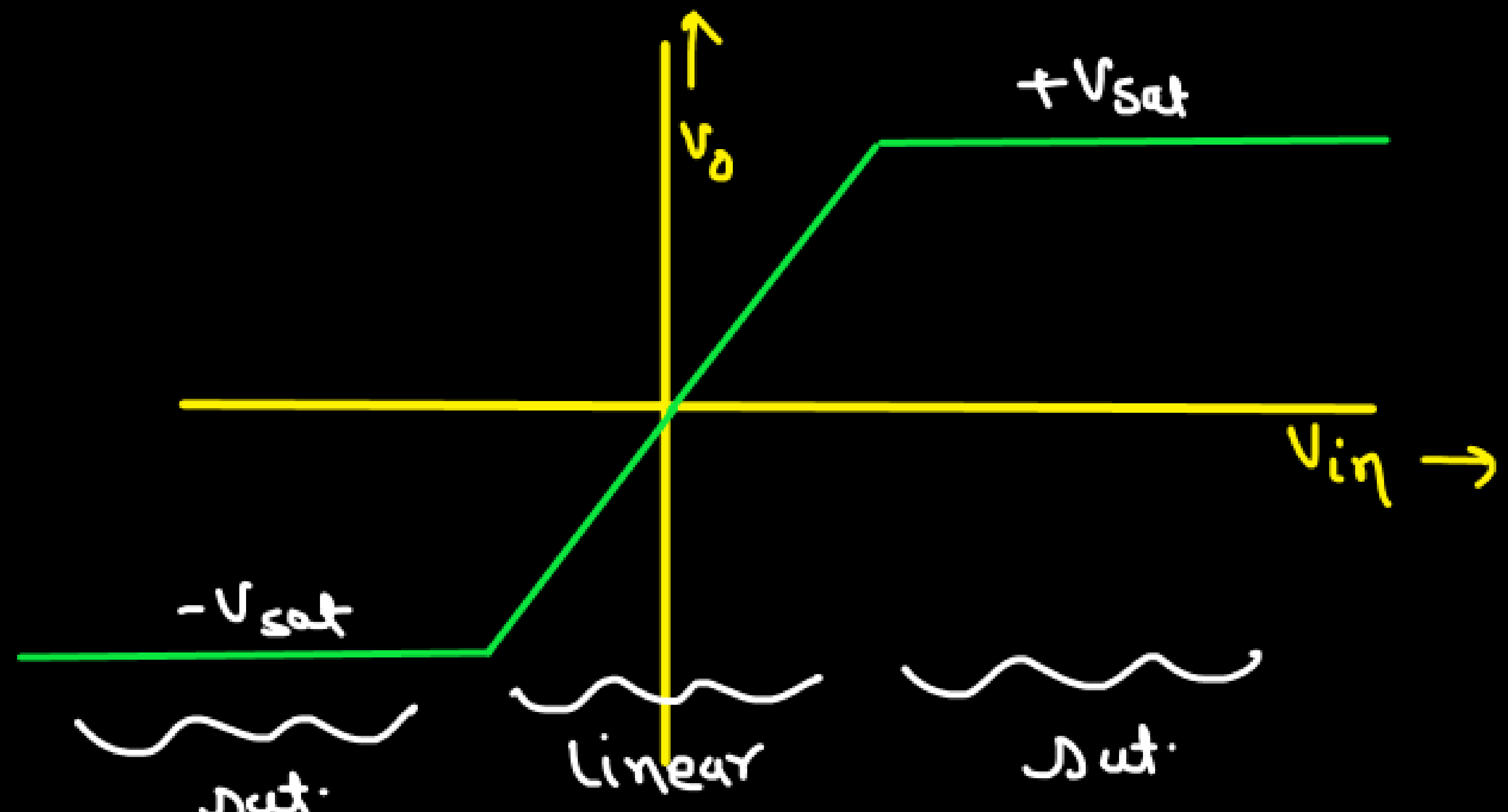
For closed loop:- DC gain $= \dfrac{A}{1+A\beta}$, $B.W. = \omega_0(1+A\beta)$

in both cases $\boxed{G.B.W. = A\omega_0}$

(iii) Increase in linearity:-

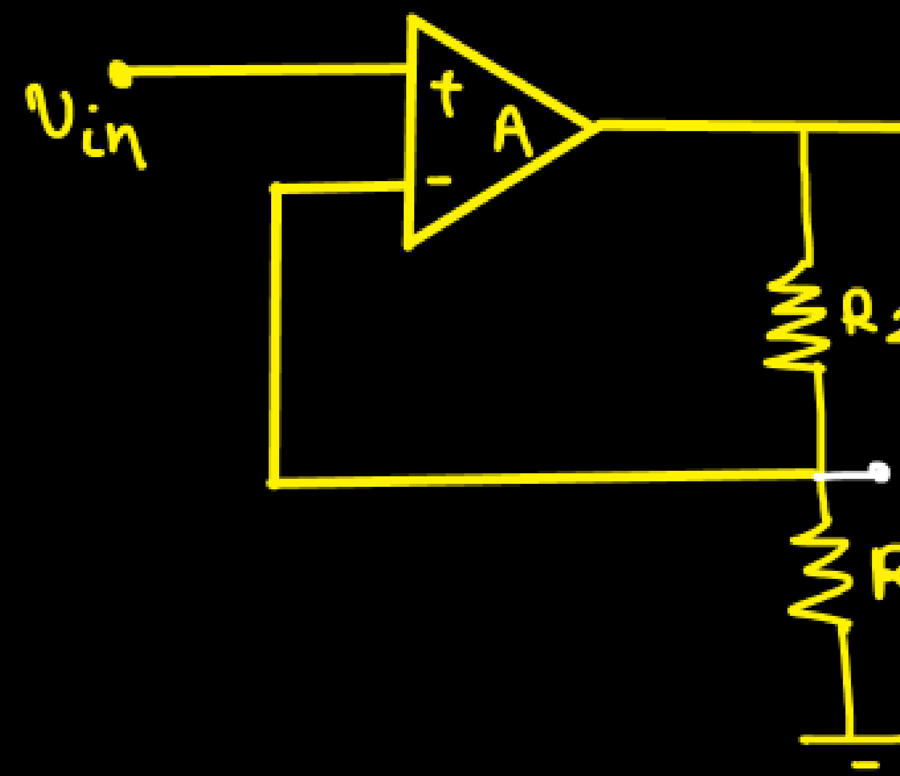
Before f/b:-





linearity ↓

After f/b:-

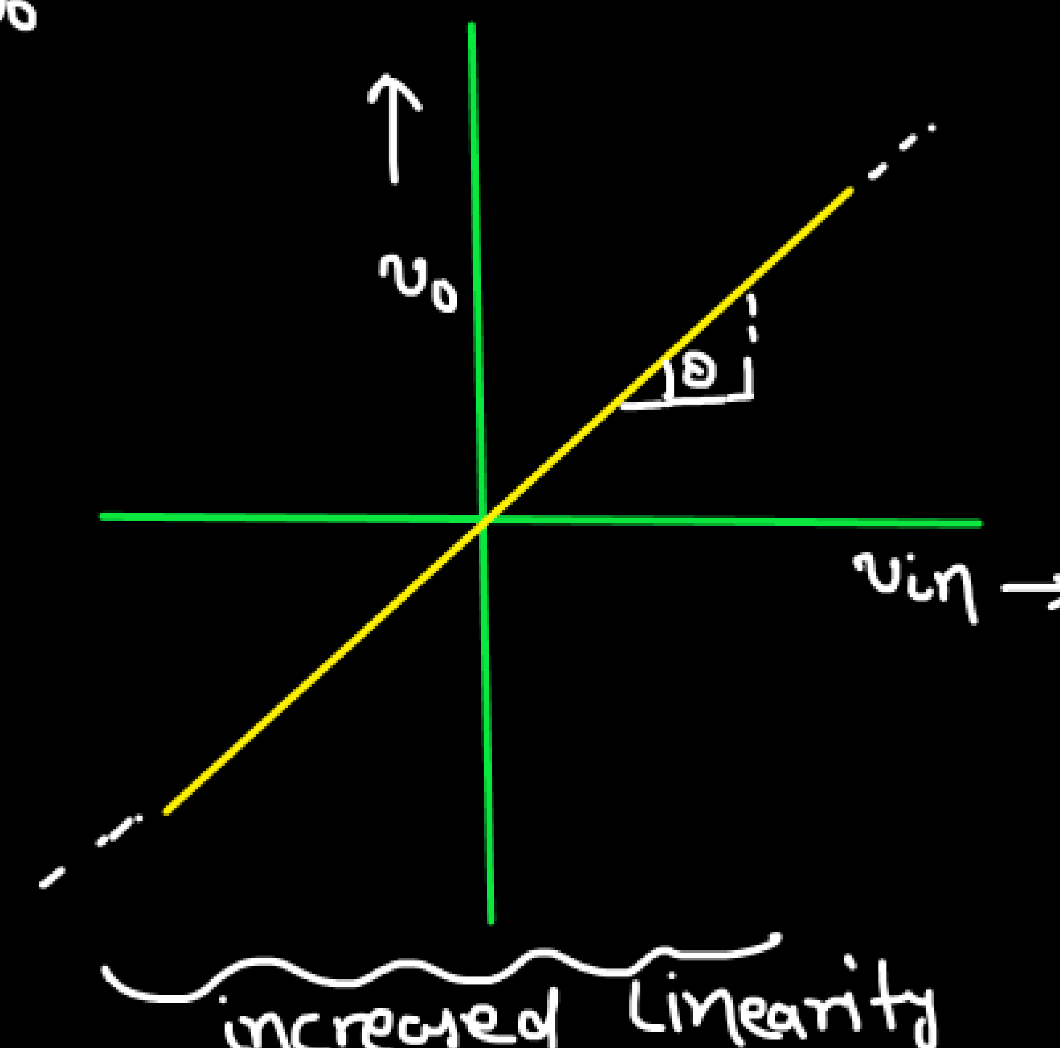


$$\beta v_o = \frac{R_1}{R_1+R_2} v_o$$

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

$$\frac{v_o}{v_{in}} = \frac{A}{1+A\beta} \approx \frac{1}{\beta} = 1+\frac{R_2}{R_1}$$

$$\boxed{v_o = \left(1+\frac{R_2}{R_1}\right) v_{in}}$$



⇒ In Negative f/b:-

① s/s → stable [Gain is constant]

② Gain → Reduces

③ B.W. → Increases

④ linearity → Increases

⑤ Time constant → decreases [$B.W. \propto \frac{1}{\tau}$]

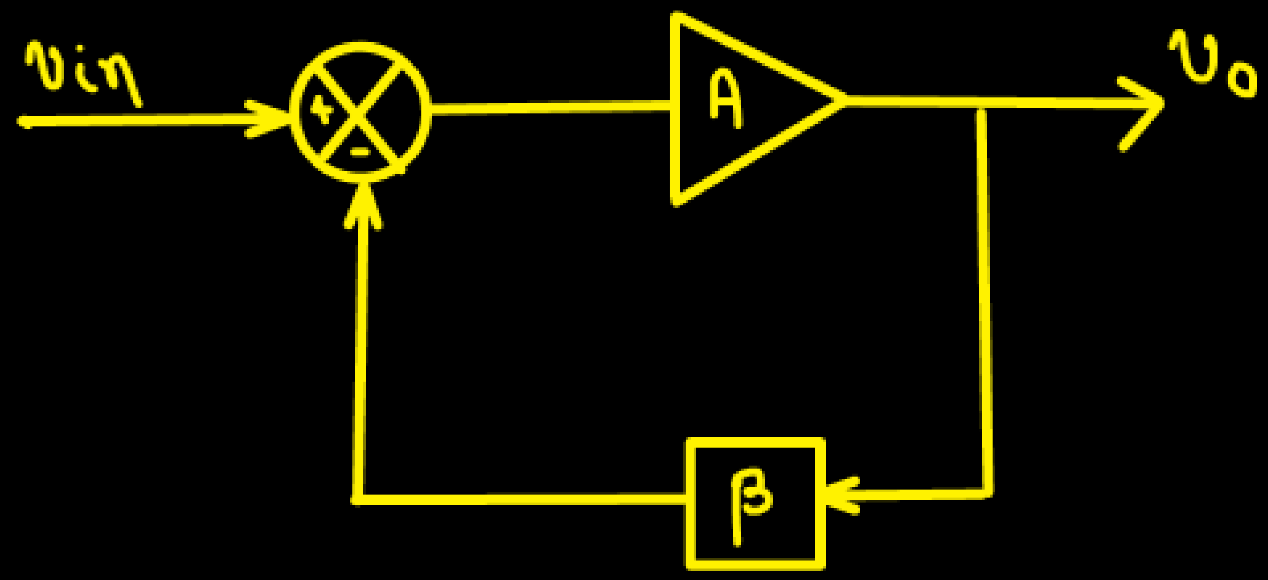
* open loop gain = A

After f/b:-

(i) Closed loop gain (Neg f/b) $= \dfrac{A}{1+A\beta} = \dfrac{\text{open loop gain}}{1+\text{loop gain}}$

(ii) Closed loop gain (pos f/b) $= \dfrac{A}{1-A\beta} = \dfrac{\text{open loop gain}}{1+\text{loop gain}}$

★ How to find loop gain ?

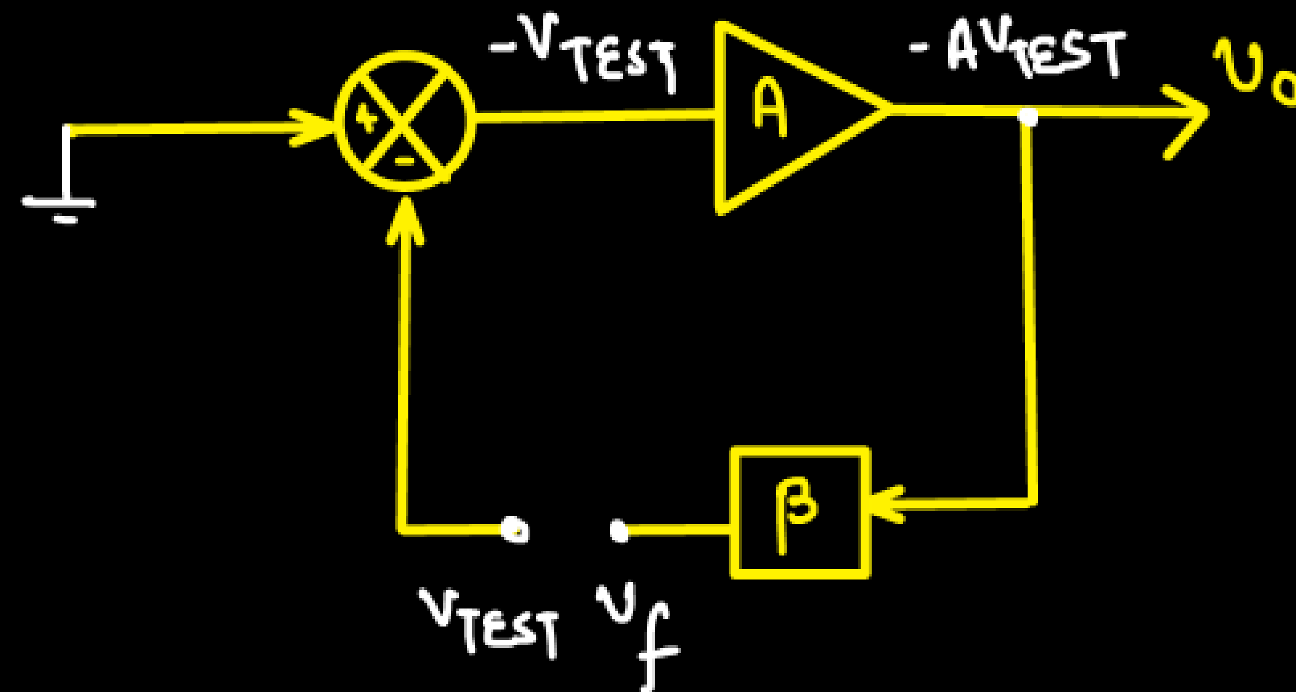


(i) Nullify the i/p.

(ii) Break the loop in feedback path.

(iii) Mark the open end as v_f and v_{TEST}. (V_{TEST} should go towards the input side)

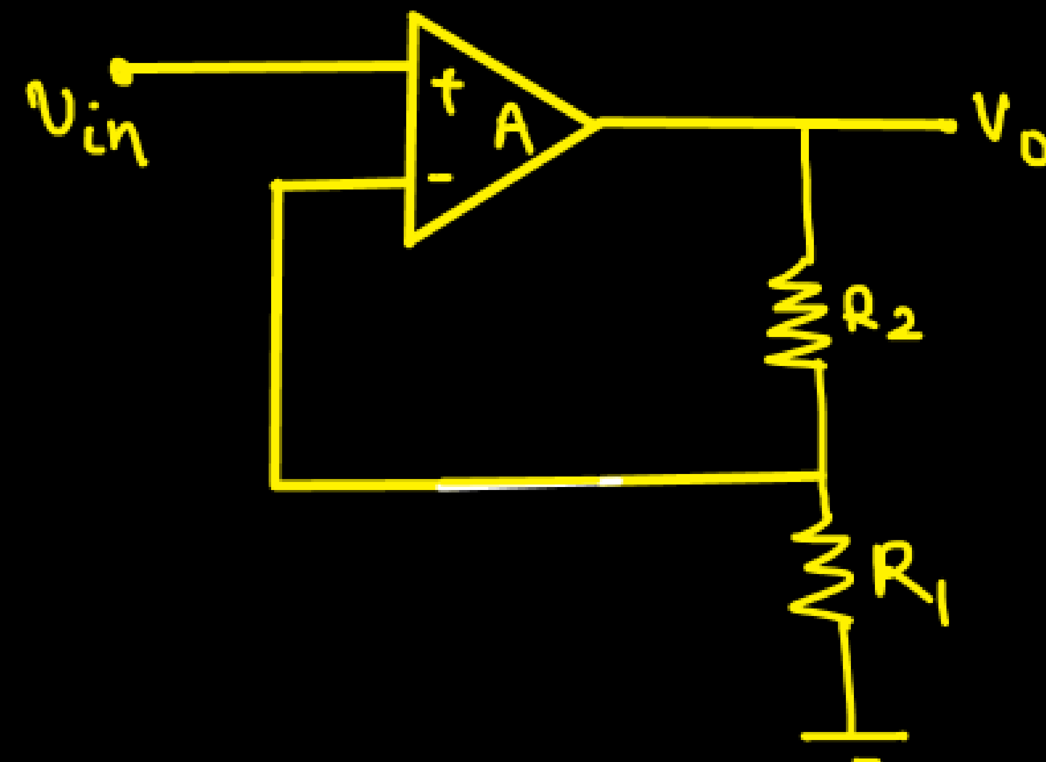
(iv) loop gain $A\beta = -\dfrac{V_f}{V_{TEST}}$



$$v_f = -\beta(Av_{TEST})$$

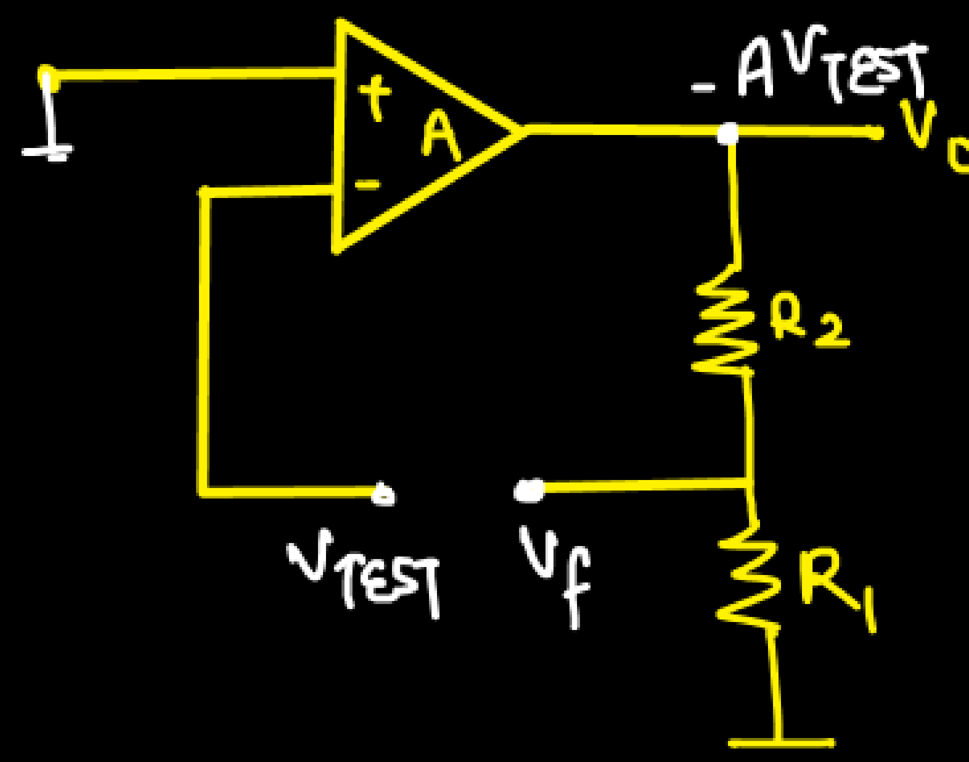
$$\boxed{\frac{-v_f}{v_{TEST}} = A\beta}$$

Example:



loop gain = ?

→



$$-AV_{TEST} \times \frac{R_1}{R_1+R_2} = V_f$$

$$-\frac{V_f}{V_{TEST}} = \boxed{\text{loop gain} = \frac{AR_1}{R_1+R_2}}$$

Types of Amplifiers:-

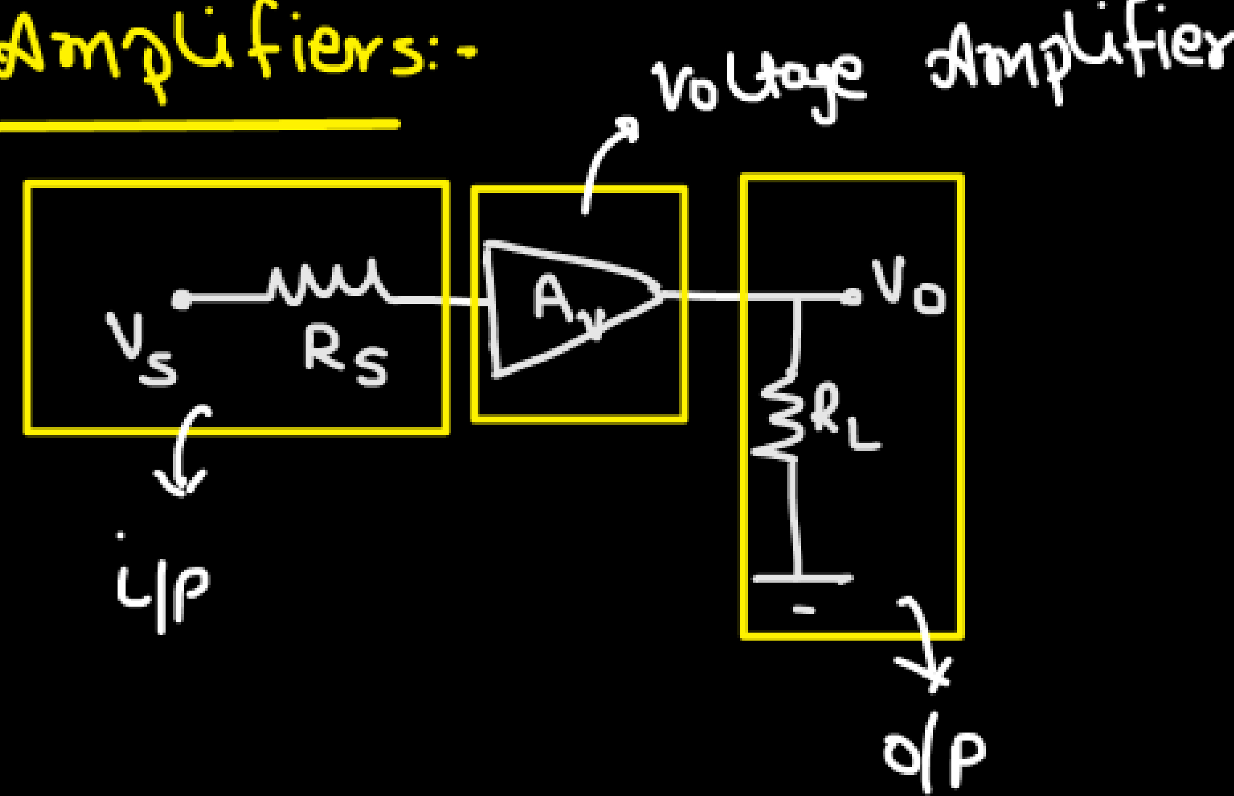
(i) Voltage Amplifiers:-

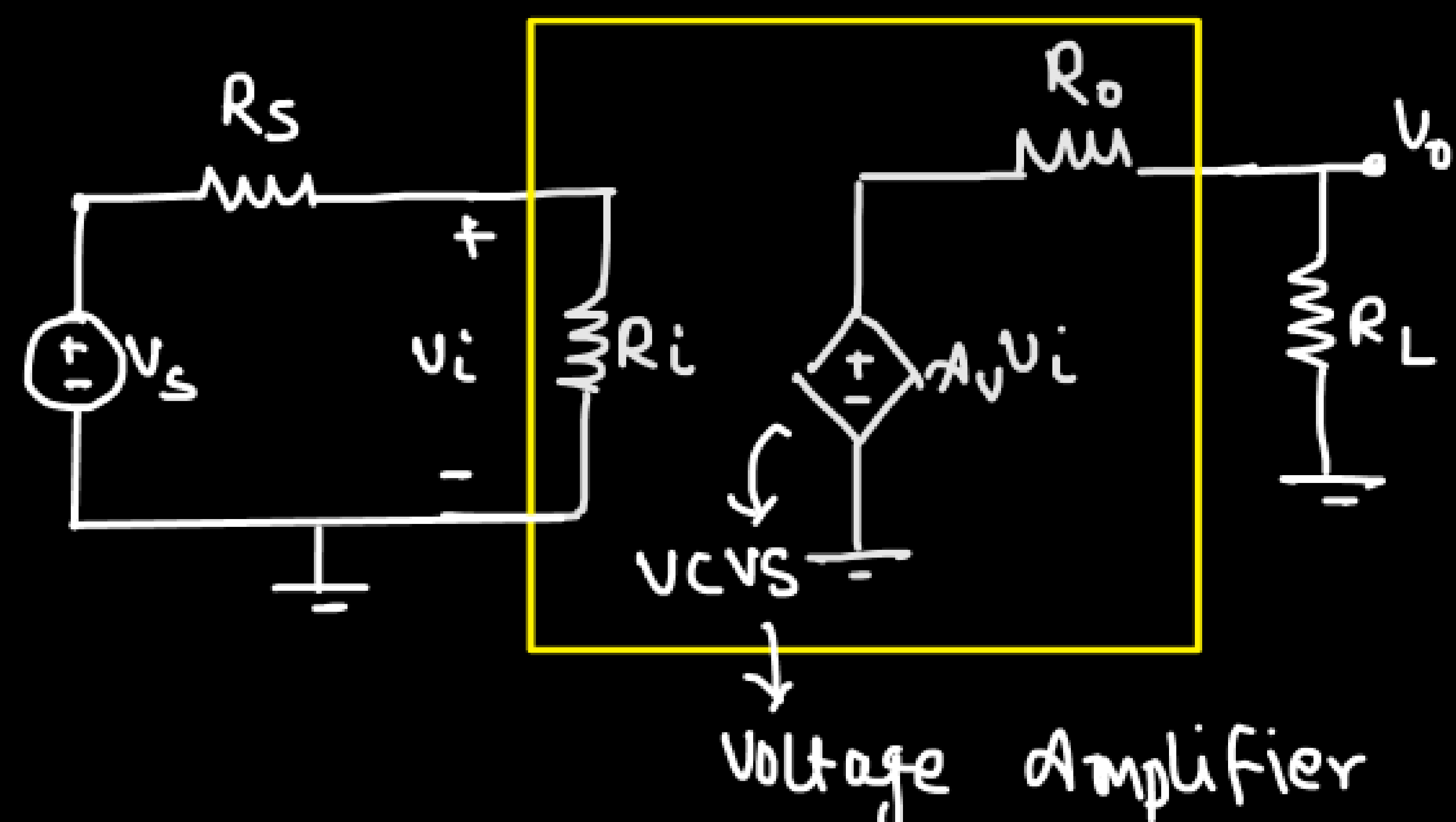
(ii) Transresistance Amplifiers:-

(iii) Transconductance Amplifiers:-

(iv) Current Amplifiers:-

(i) Voltage Amplifiers:-





$$v_i = \frac{R_i}{R_i + R_s} V_s$$

$$V_o = \frac{A_v \times v_i \times R_L}{R_L + R_o}$$

$$V_o = A_v \left[\frac{R_i}{R_i + R_s}\right] V_s \times \frac{R_L}{R_L + R_o}$$

$$\boxed{\frac{V_o}{V_s} = A_v\left[\frac{R_i}{R_i+R_s}\right]\left[\frac{R_L}{R_L+R_o}\right]}$$

**

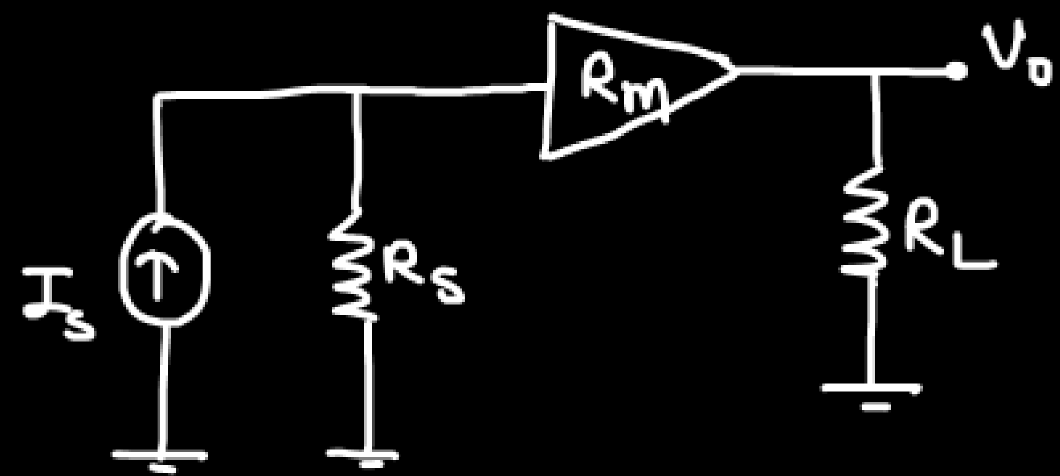
For an ideal voltage Amplifier :- $\boxed{\begin{array}{l} R_i = \infty \\ R_o = 0 \end{array}}$ $\begin{array}{l} \rightarrow \text{High} \\ \rightarrow \text{low} \end{array}$

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

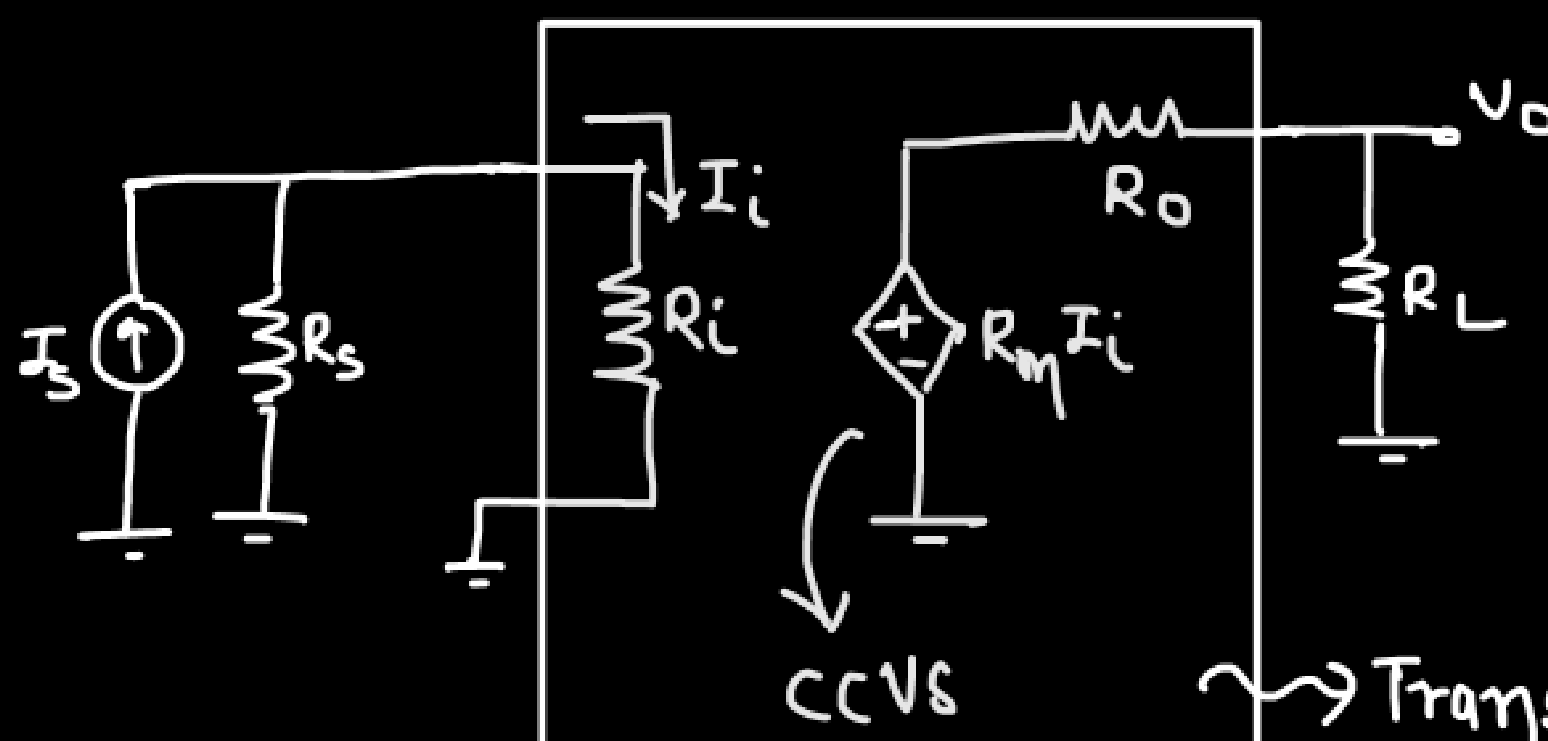
$$\boxed{\frac{V_o}{V_s} = A_v}$$

Unit of $A_v = V/V$

(ii) Trans-resistance Amplifier :-



$$R_m = \frac{\text{Volt}}{\text{Ampere}} = \text{ohm}$$



$\rightsquigarrow$ Trans-resistance Amplifier

$$I_i = \frac{R_s}{R_s + R_i} I_s$$

$$V_o = \frac{R_L}{R_L + R_o} \times R_m I_i$$

$$V_o = (R_m)\left(\frac{R_L}{R_L+R_o}\right)\left(\frac{R_s}{R_s+R_i}\right) I_s$$

$$\boxed{\frac{V_o}{I_s} = (R_m)\left(\frac{R_L R_s}{(R_L+R_o)(R_s+R_i)}\right)}$$

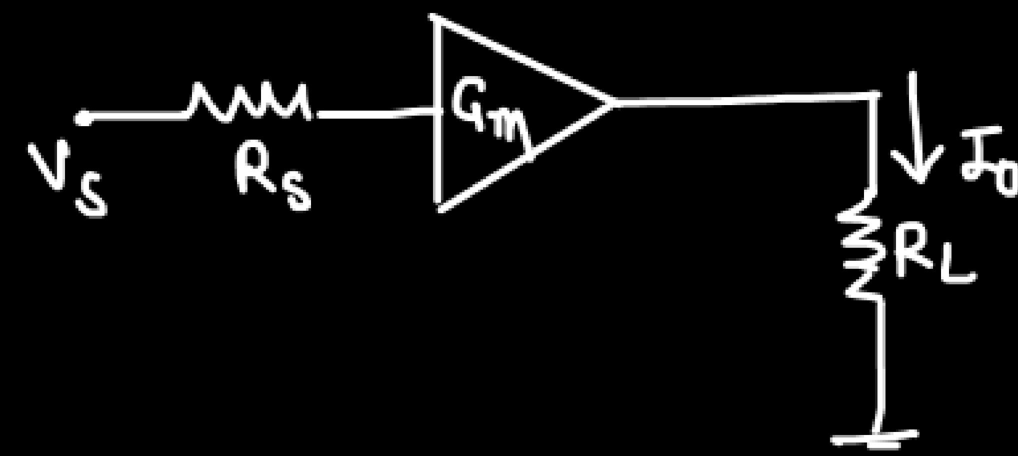
For ideal Transresistance Amplifier, $\boxed{\begin{array}{l} R_i = 0\,\Omega \\ R_o = 0\,\Omega \end{array}}$ → low → low

if $R_i=0$ and $R_o=0$

$$\boxed{\frac{V_o}{I_s} = R_m}$$

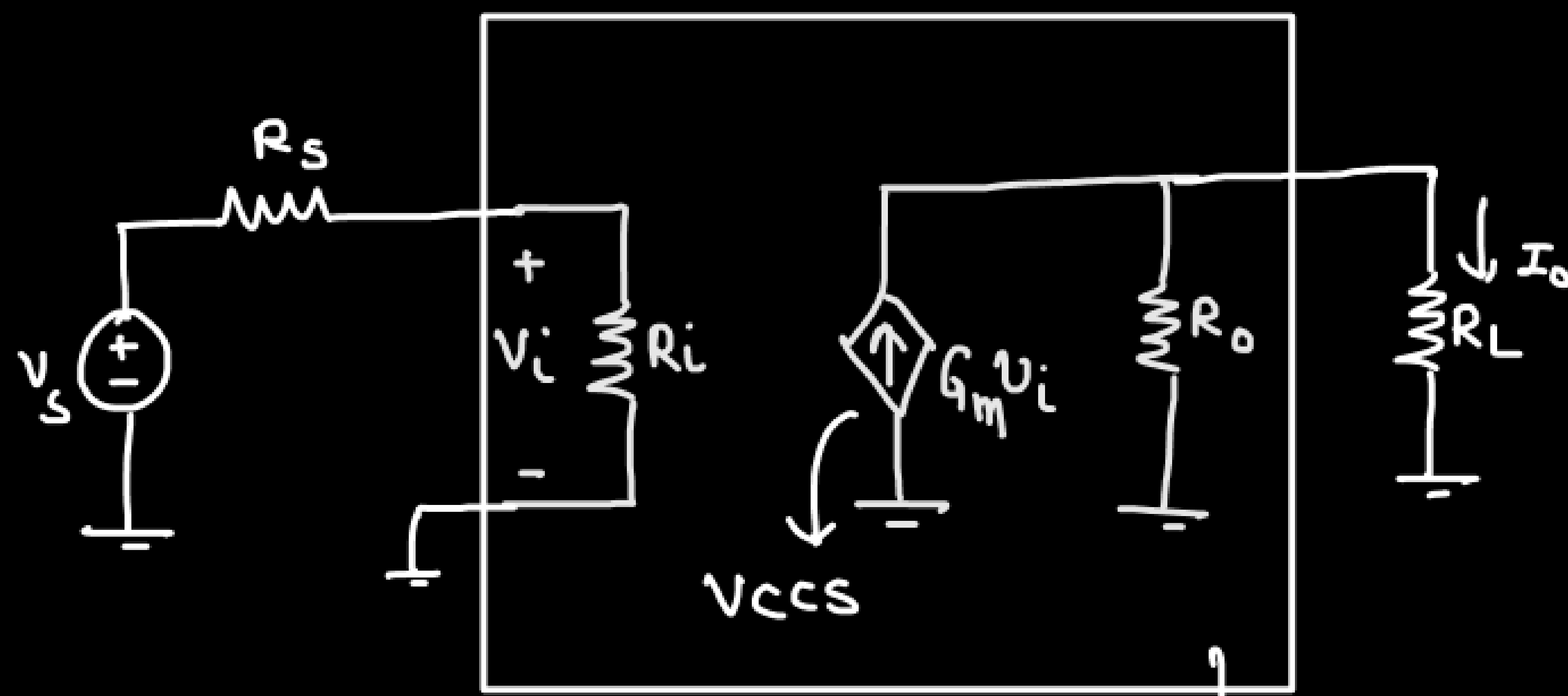
$\boxed{\text{unit of } R_m \rightarrow \text{ohm}}$

(iii) Transconductance Amplifier :-



$$G_m \rightarrow \frac{\text{Current}}{\text{Voltage}} = \frac{A}{V}$$

$$= \text{mho} = S$$



Transconductance amplifier

$$v_i = \frac{R_i}{R_i + R_s} V_s$$

$$I_o = \frac{R_o}{R_o + R_L} \times G_m v_i$$

$$I_o = (G_m)\left(\frac{R_o}{R_o+R_L}\right)\left(\frac{R_i}{R_i+R_s}\right)V_s$$

$$\boxed{\frac{I_o}{V_s} = G_m\left(\frac{R_o}{R_o+R_L}\right)\left(\frac{R_i}{R_i+R_s}\right)}$$

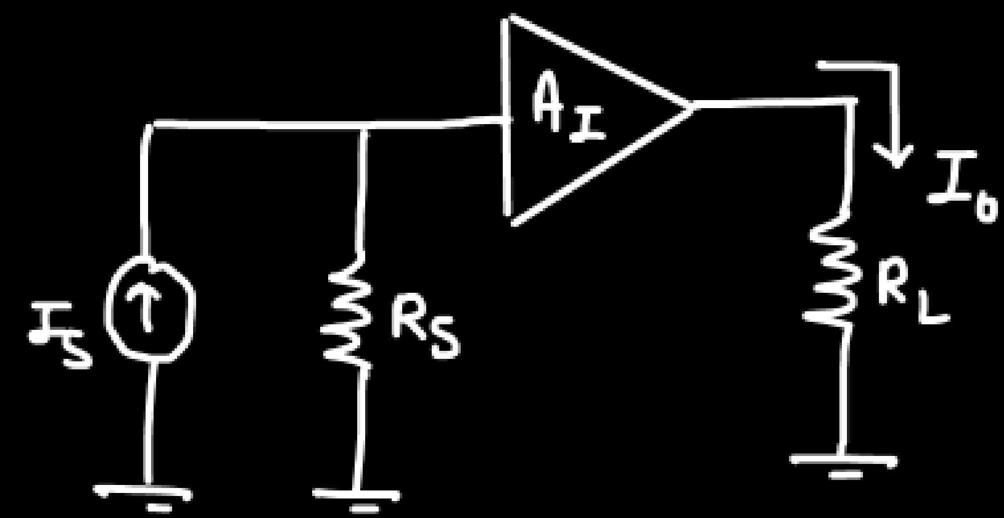
For ideal Transconductance Amplifier ; $\boxed{\begin{array}{l} R_i = \infty \\ R_o = \infty \end{array}}$

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

$$\boxed{\frac{I_o}{V_s} = G_m}$$

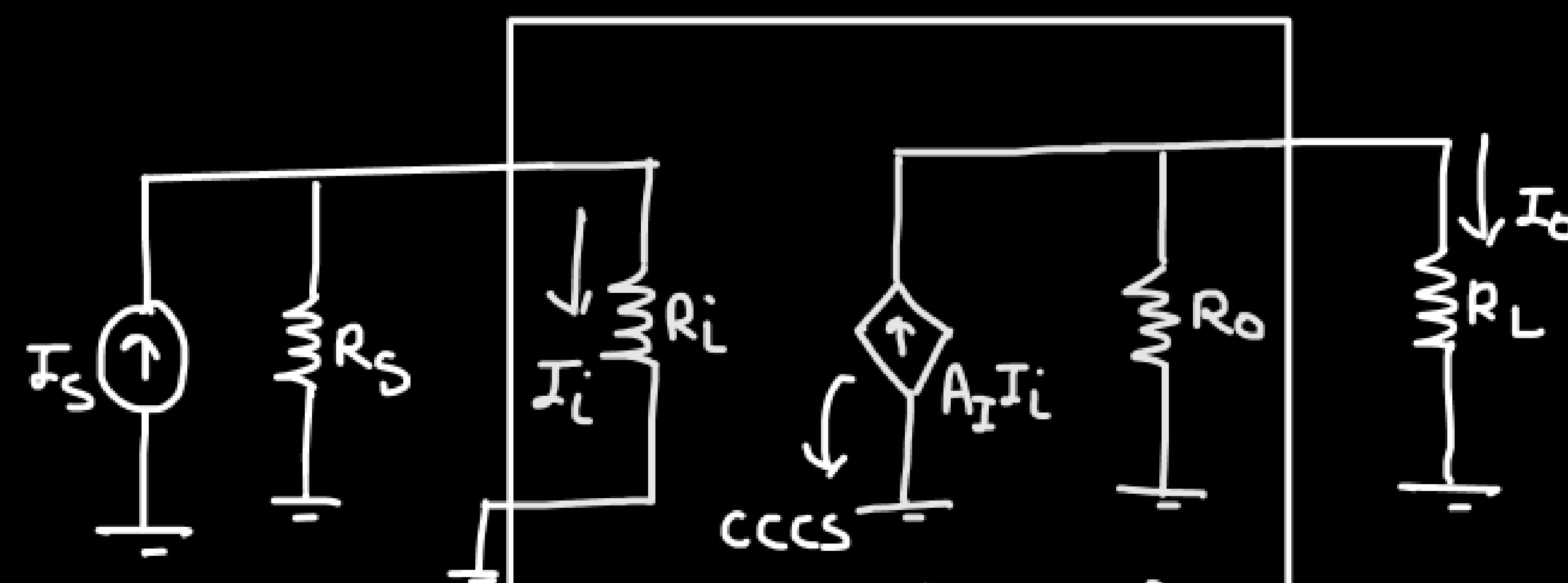
Unit of $G_m \rightarrow$ mho/s

(iv) Current Amplifier :-



$$I_i = \frac{R_S}{R_S + R_i} I_S$$

$$I_o = \frac{R_o}{R_o + R_L} A_I I_i$$



Current Amplifier

$$I_o = A_I \left(\frac{R_o}{R_o + R_L} \right) \left(\frac{R_s}{R_s + R_i} \right) I_s$$

$$\boxed{\frac{I_o}{I_s} = A_I \left(\frac{R_o}{R_o + R_L} \right) \left(\frac{R_s}{R_s + R_i} \right)}$$

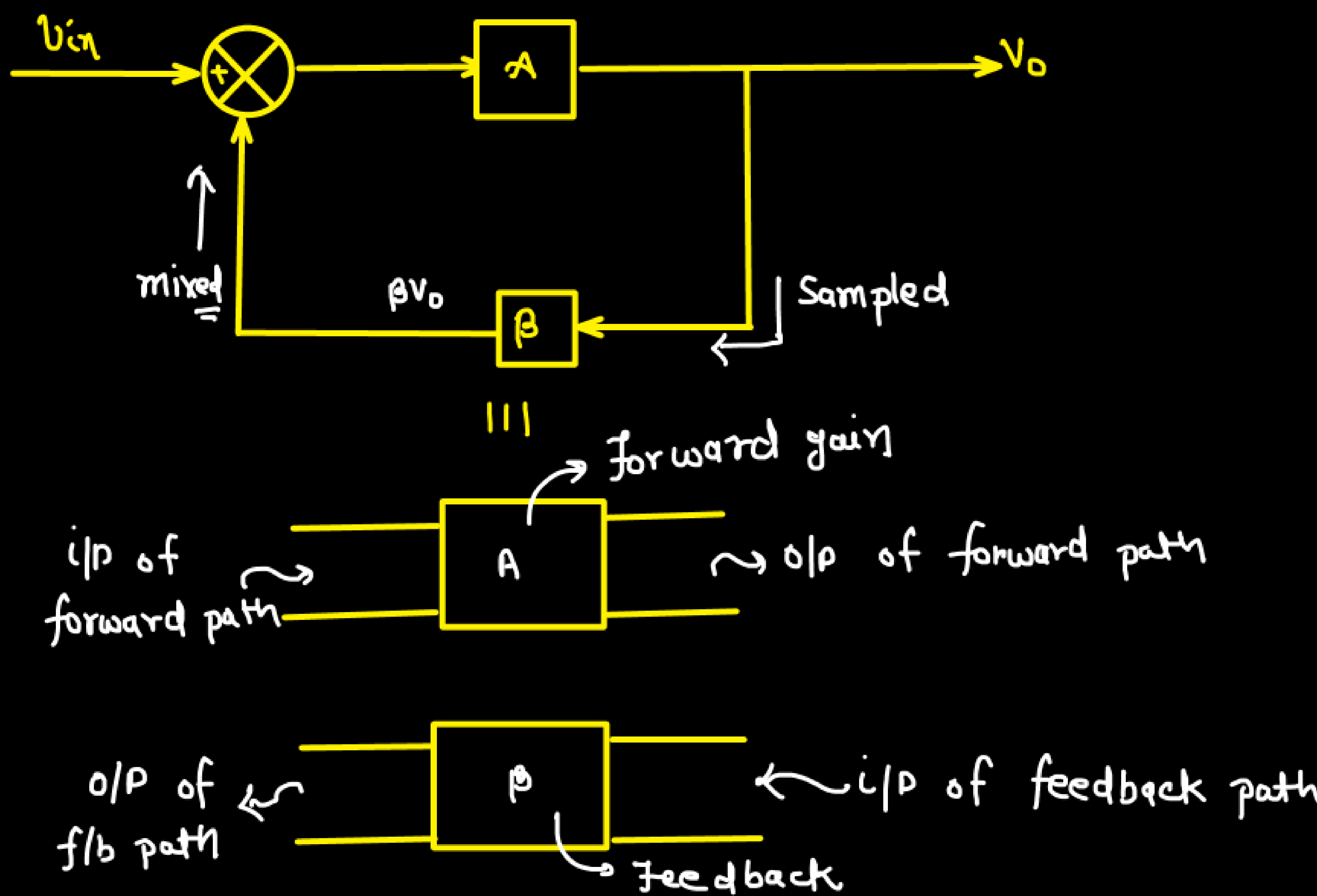
For ideal current Amplifier, $\boxed{\begin{aligned} R_i &= 0 \\ R_o &= \infty \end{aligned}}$

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

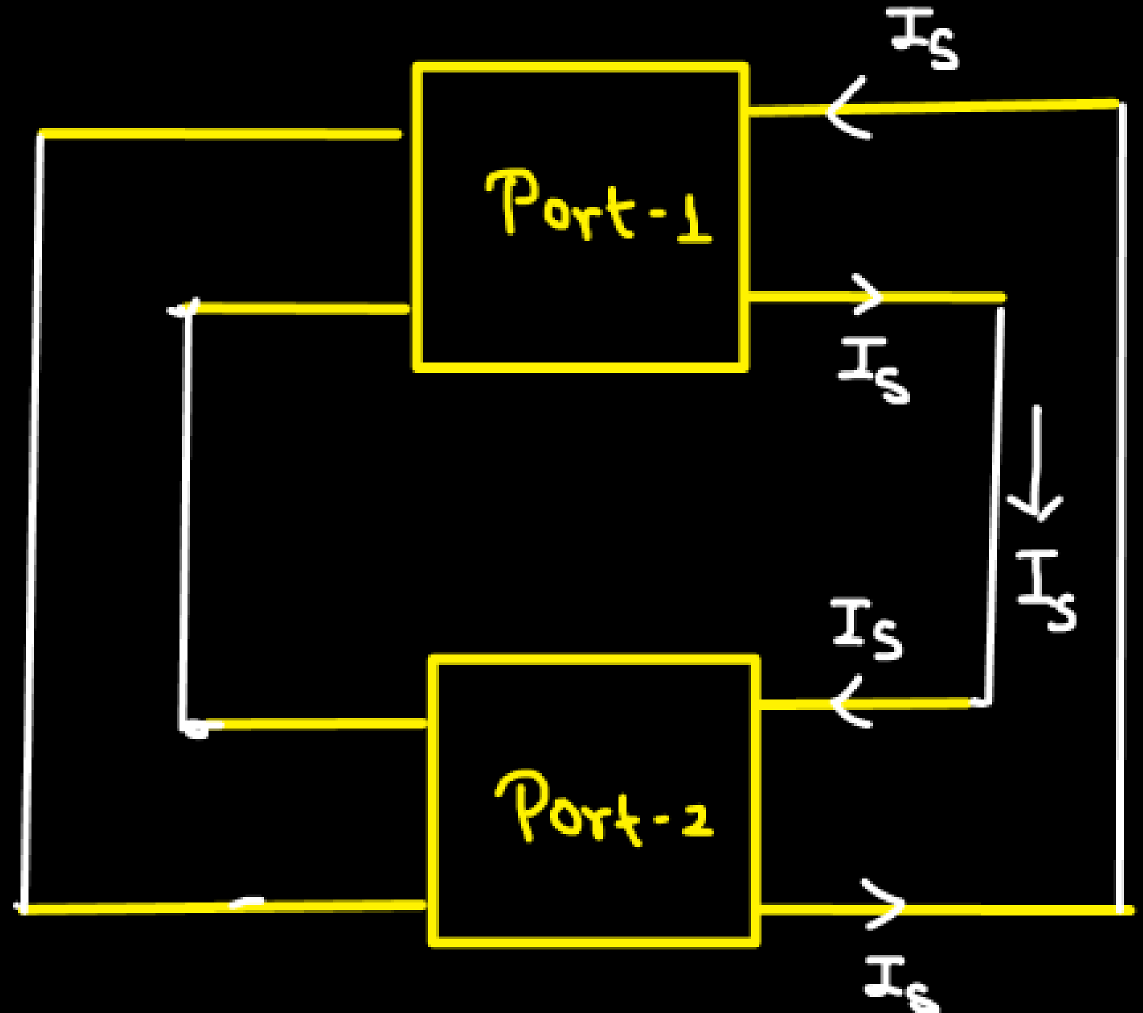
$$\boxed{\frac{I_o}{I_s} = A_I}$$

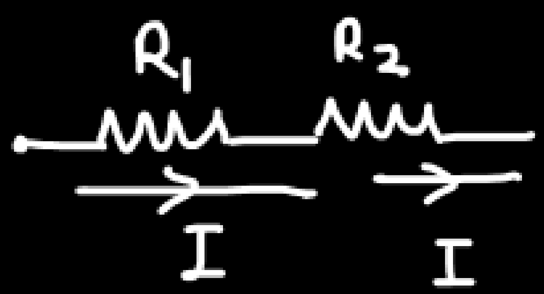
Type of Amplifier	Input Resistance	Output Resistance
(i) Voltage Amplifier	∞	0
(ii) Transresistance Amp.	0	0
(iii) Transconductance Amp	∞	∞
(iv) Current Amplifier	0	∞

Alternative feedback Model:-



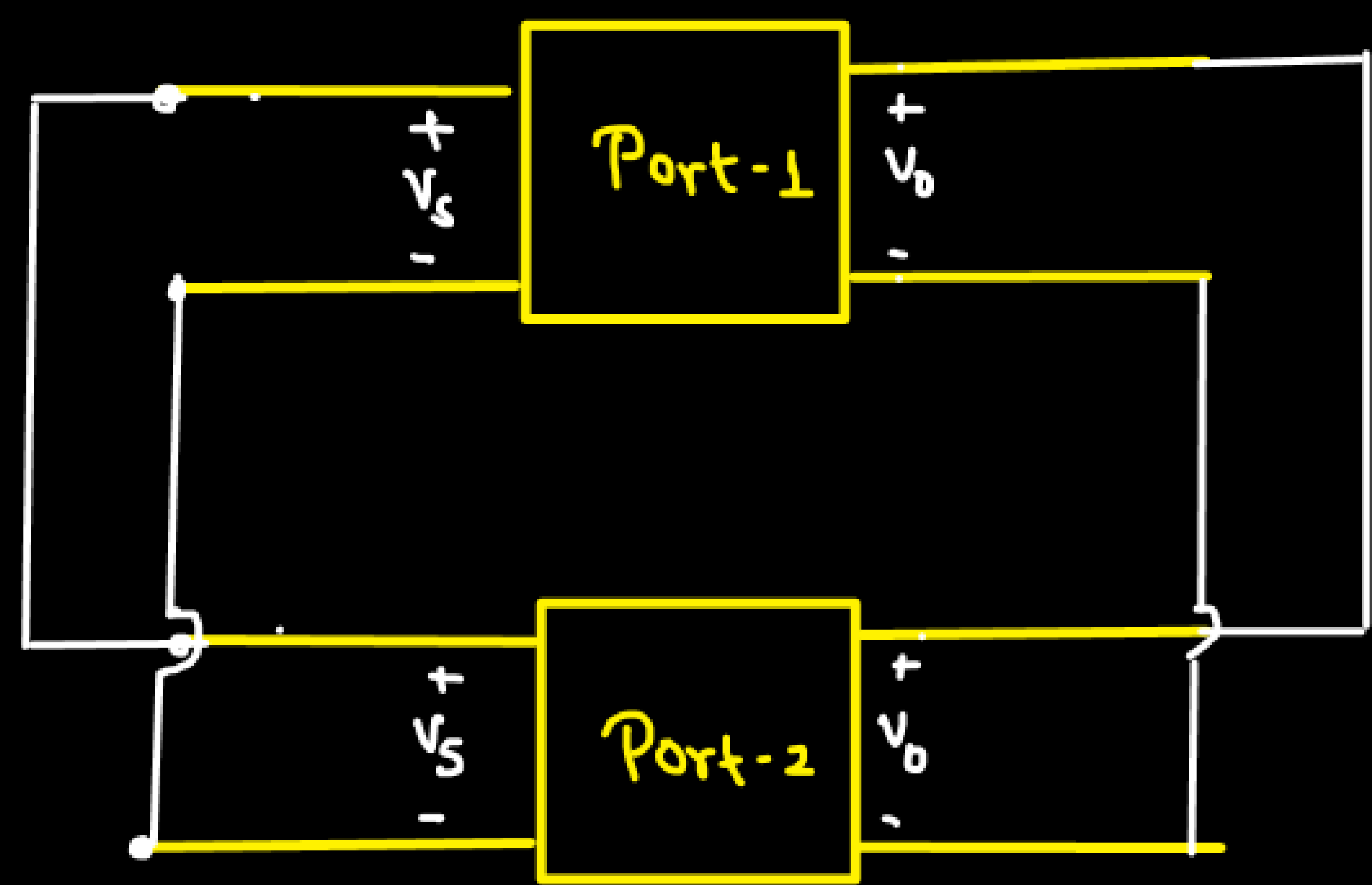
☆ Series Connection of 2- Two port N/w:-

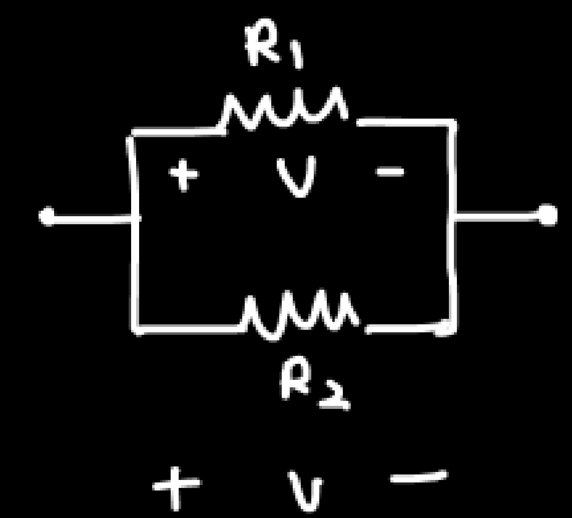




✱ Parallel connection of 2 - Two port N/w :-

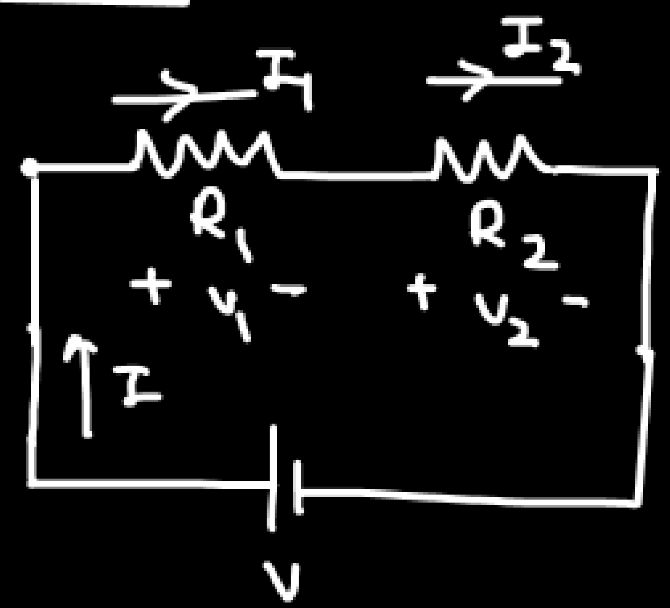
(Shunt)





☆ Important points to remember:-

1. Series Connection:-

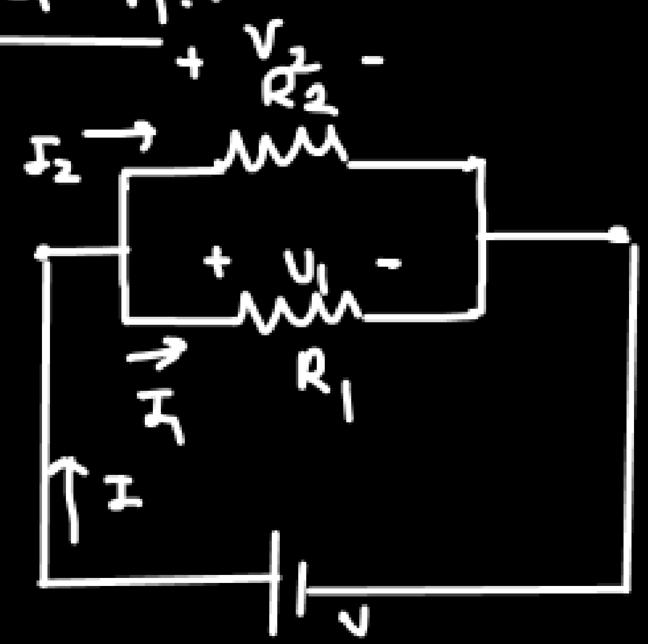


$I = I_1 = I_2 \rightarrow$ current same

$V = V_1 + V_2 \rightarrow$ voltage mixed

$\boxed{\text{series = current sampled, voltage mixed}}$

2. Parallel Connection:-
(Shunt)

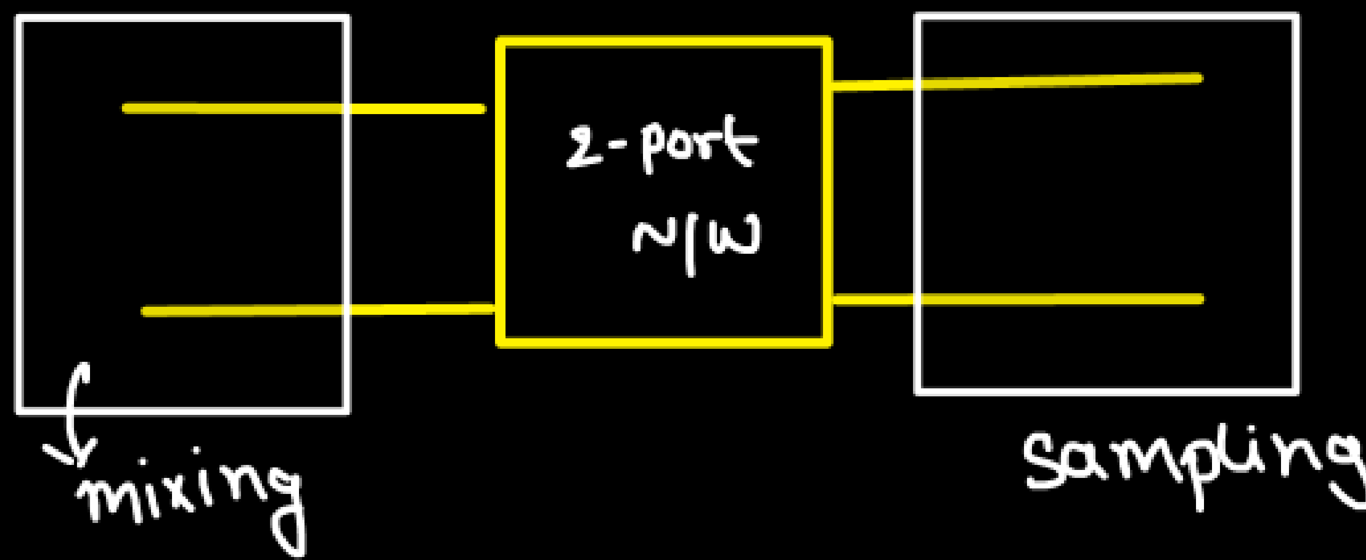


$V = V_1 = V_2 \rightarrow$ voltage same

$I = I_1 + I_2 \rightarrow$ current mixed

$\boxed{\text{Parallel = Voltage sampled, current mixed}}$

For a two port N/W:-



★ Decode the following:-

1. Voltage sampling → Shunt connection
2. Current Mixing → Shunt connection
3. Voltage Mixing → Series connection
4. Current Sampling → Series connection

(5) Series connection → Current Sampling, Voltage mixing

(6) Shunt connection → Voltage Sampling, Current mixing

(7) Series connection at input → Voltage mixing

(8) Series connection at output → Current sampling

(9) Shunt connection at input → current mixing

(10) Shunt connection at output → Voltage sampling

Conclusion:-

(1) i/p → mixing, o/p → sampling

(2) Series → Current sampling, Voltage mixing

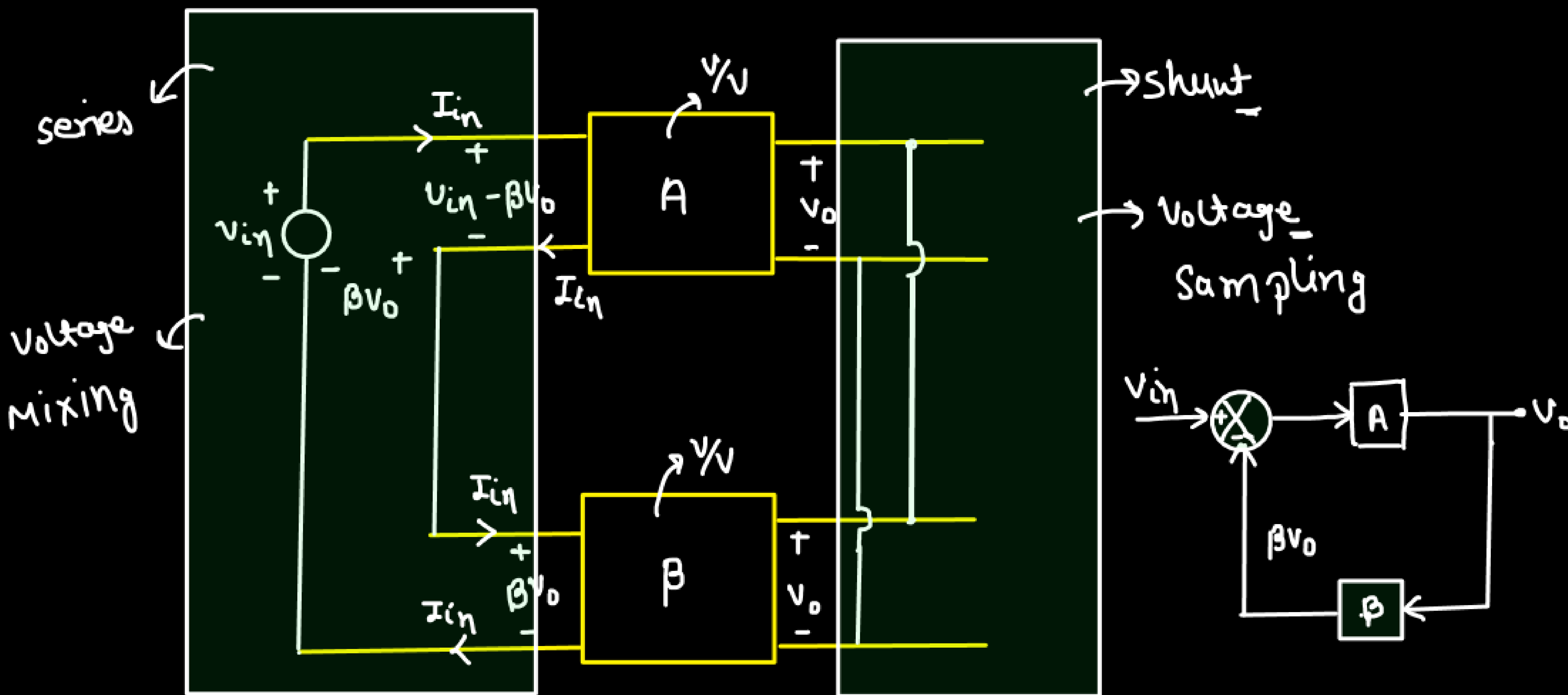
(3) Shunt → Voltage sampling, Current mixing

⇒ **Feedback Topologies :-**

o/p - i/p	i/p - o/p	o/p - i/p
① Voltage - Voltage /	Series - Shunt /	Voltage - Series
② Voltage - Current /	Shunt - Shunt /	Current - Shunt
③ Current - Voltage /	Series - Series /	Voltage - Series
④ Current - Current /	Shunt - Series /	Current - Series

★ Voltage - Voltage Feedback Topology :-

(Series - Shunt) ↳ From o/p voltage is sensed and fed back to the i/p

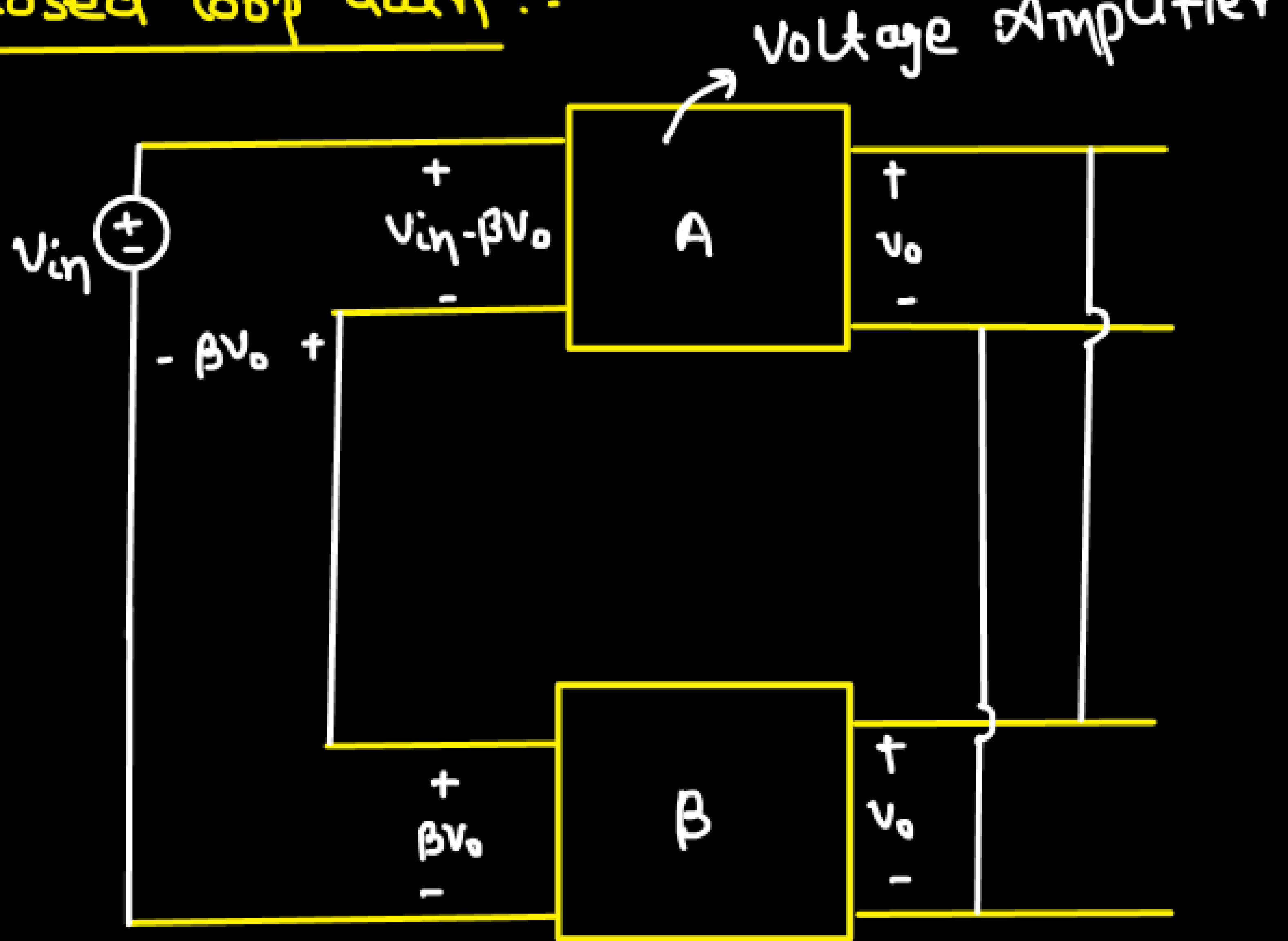


open loop gain = A

open loop input resistance = R_{in}

open loop output resistance = R_o

① Closed loop Gain :-

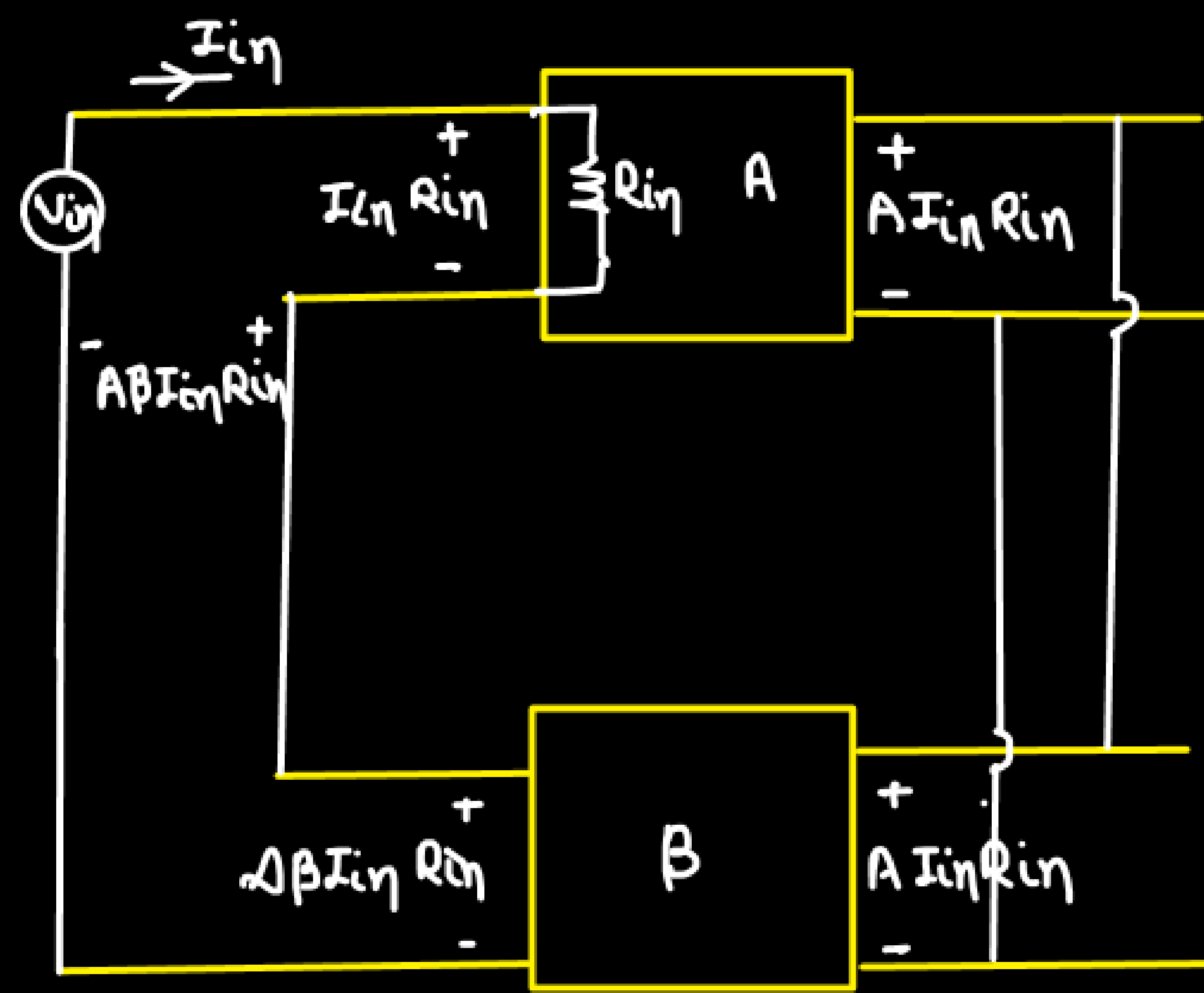


$$CLG = \frac{v_{in}}{v_o} = (A_v)_f$$

$$A(v_{in} - \beta V_o) = v_o$$

$$\boxed{\frac{v_o}{v_{in}} = (A_v)_f = \frac{A}{1 + A\beta}}$$

② Closed loop input impedance :-

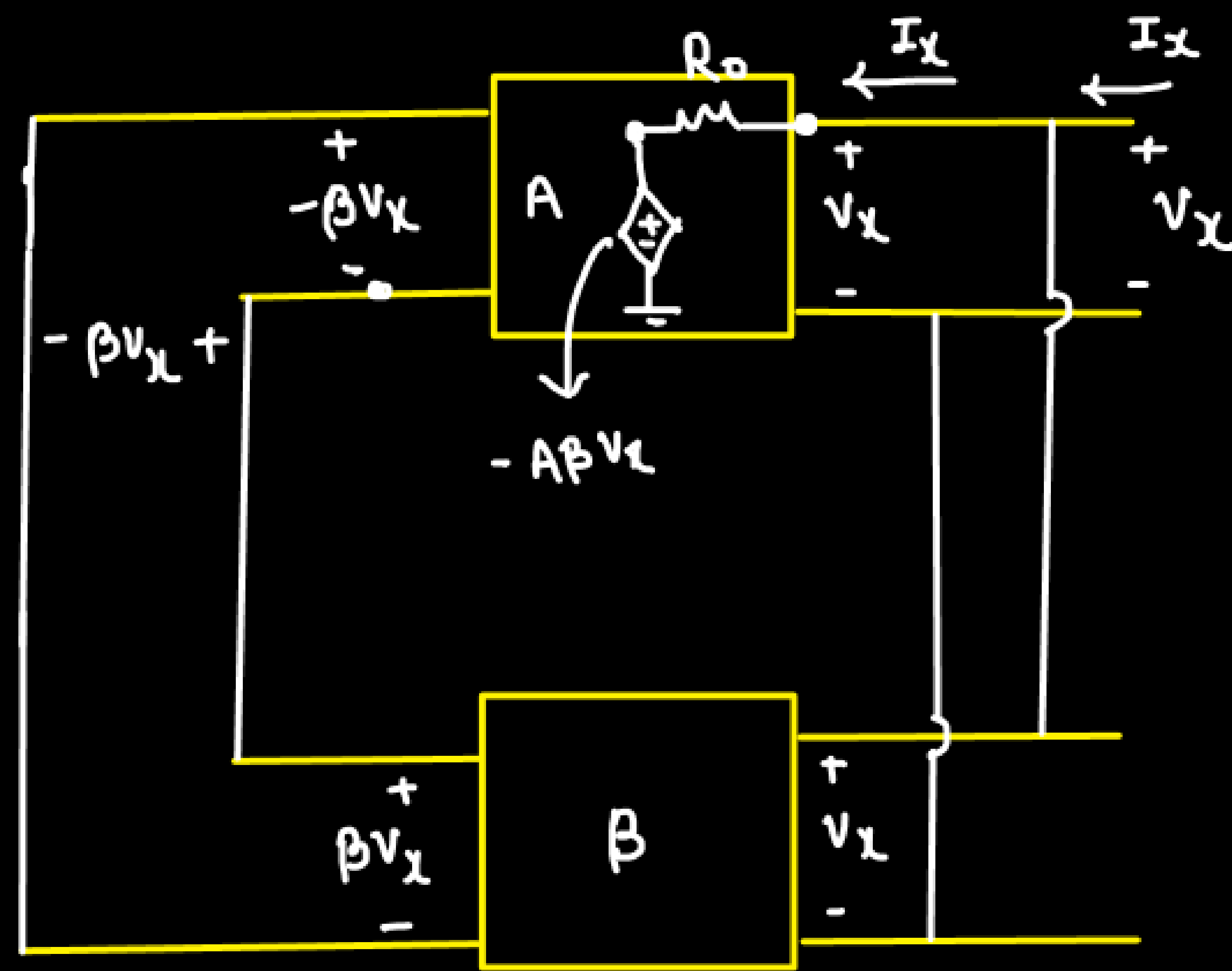


$$(R_{in})_f = \frac{V_{in}}{I_{in}}$$

$$V_{in} = I_{in}R_{in} + \alpha\beta\, I_{in}R_{in}$$

$$\boxed{\frac{V_{in}}{I_{in}} = (R_{in})_f = R_{in}(1+\alpha\beta)}$$

③ Closed-Loop Output Impedance :-



$$(R_o)_f = \frac{V_x}{I_x}$$

Assumption :-

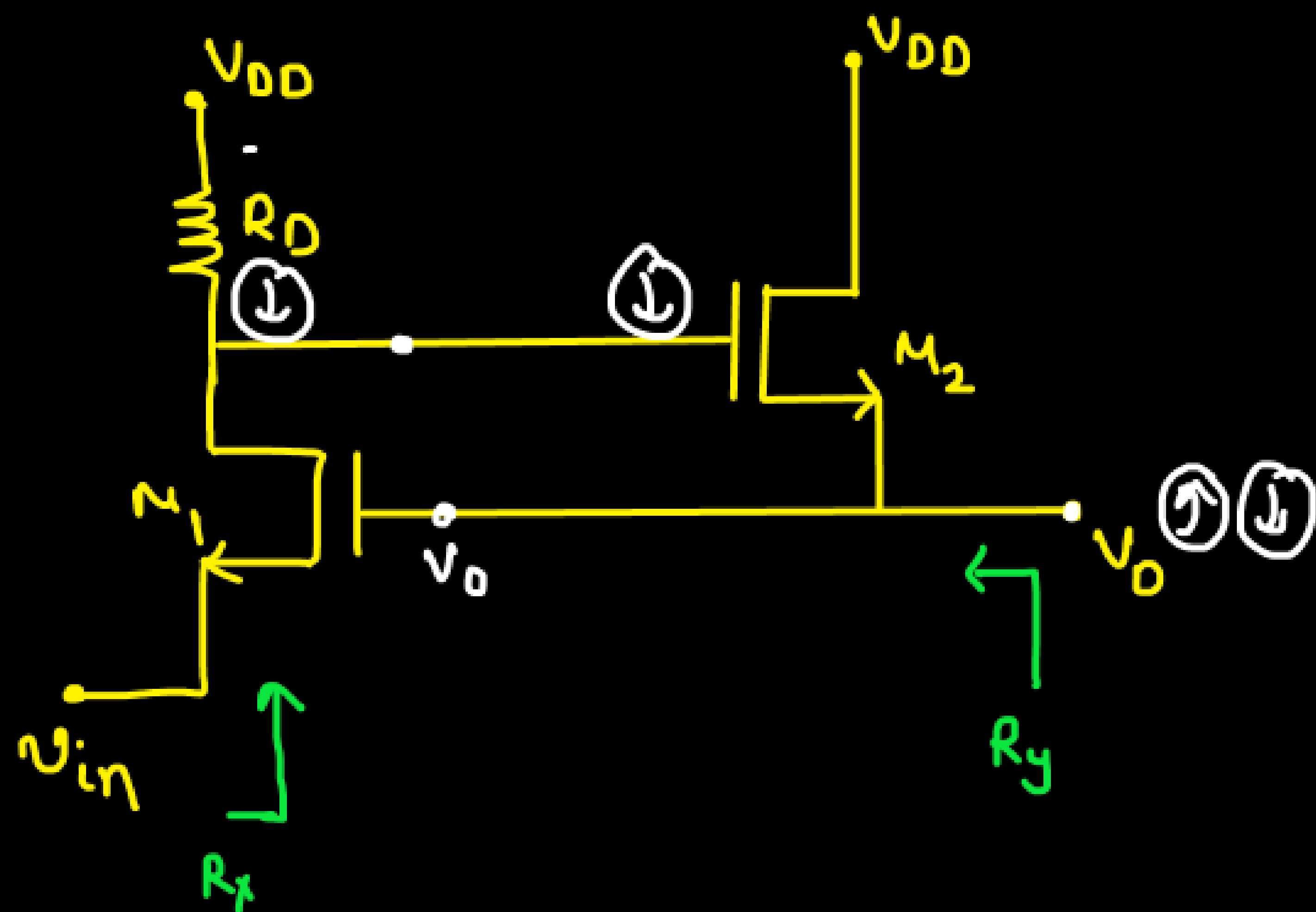
R_o is very small, so complete I_x will be flowing through R_o. (NOT in f/b path)

$$\frac{V_x - (-A\beta V_x)}{R_o} = I_x$$

$$\Rightarrow \boxed{(R_o)_f = \frac{V_x}{I_x} = \frac{R_o}{1+A\beta}}$$

Example:-

Q.



Take $\lambda = 0$

Find R_x, R_y and $\frac{v_0}{v_i} = ?$

$\Rightarrow$ Negative f/b

Topology $\rightarrow$ Voltage-voltage f/b

* Short-cut to find f/b Topology:-

① For sampling, always look at O/P voltage

if there is voltage sampling

$v_f = \beta v_o$, $I_f = G_m v_o$

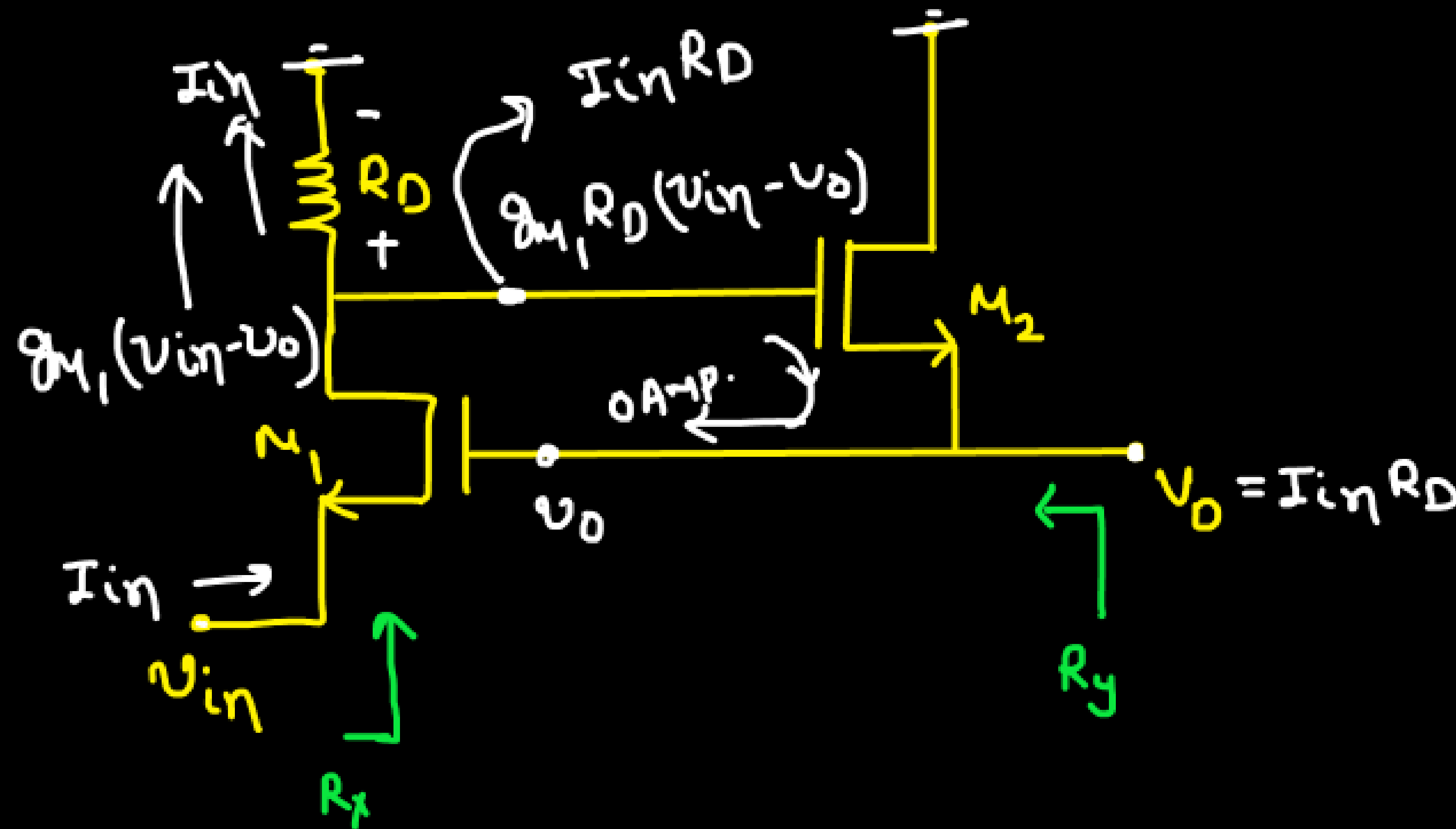
if we put $v_o = 0V$ ⇒ There should be no f/b that is coming towards the i/p side.

⇒ if that is so, that means there is voltage sampling

o/w current sampling

② For mixing, always check the i/p current. If current is mixed, then there is current mixing, o/w voltage mixing.

M-I w/o the concept of f/b topology:-



$$g_{m1}R_D(v_{in}-v_o) = v_o$$

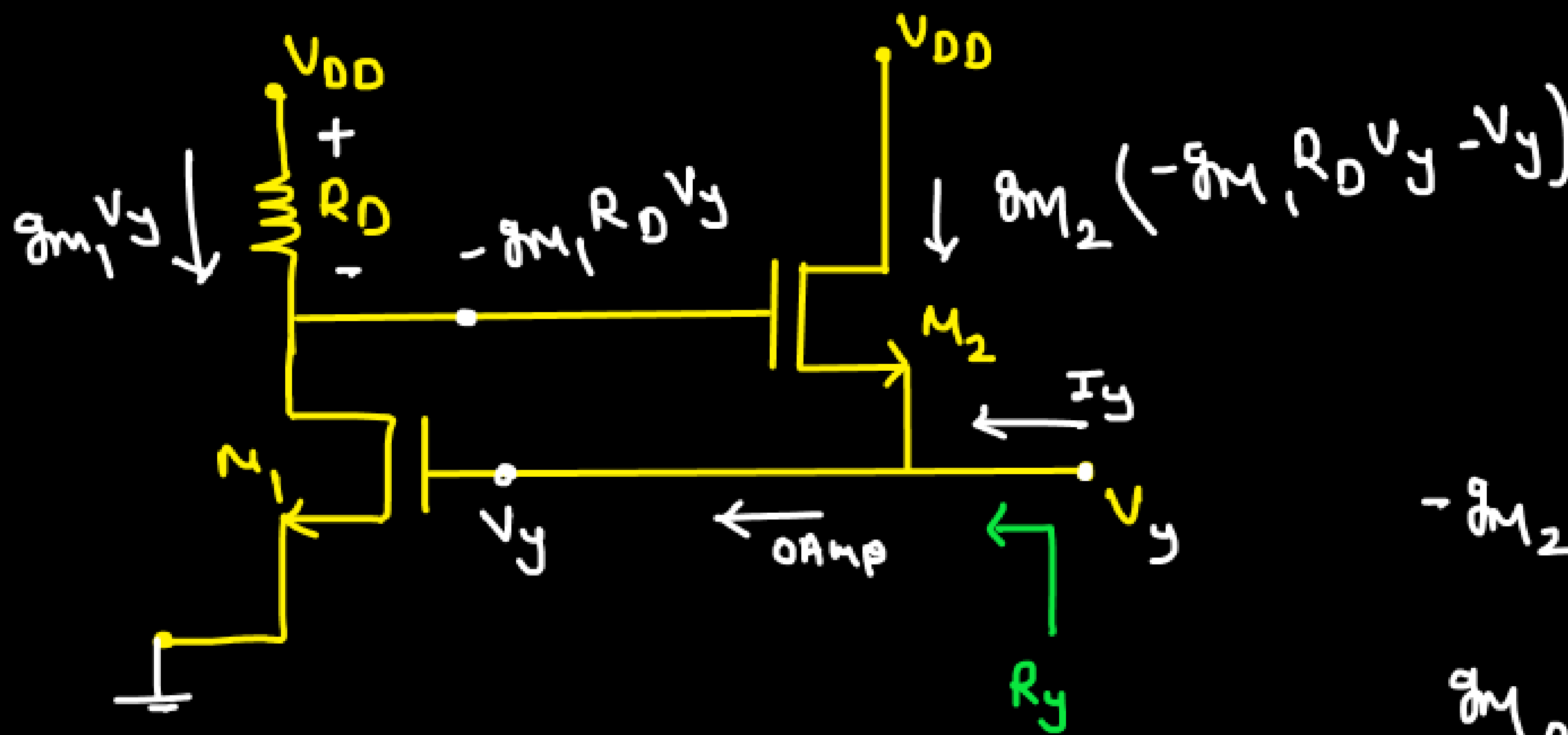
$$\boxed{\frac{v_o}{v_{in}} = \frac{g_m R_D}{1+g_m R_D}}$$

$$R_x = \frac{v_{in}}{I_{in}}$$

$$g_{m1}(v_{in} - I_{in}R_D) = I_{in}$$

$$g_{m1}v_{in} = (g_{m1}R_D + 1)I_{in}$$

$$\boxed{\frac{v_{in}}{I_{in}} = R_x = \frac{1}{g_{m1}}(1+g_{m1}R_D)}$$

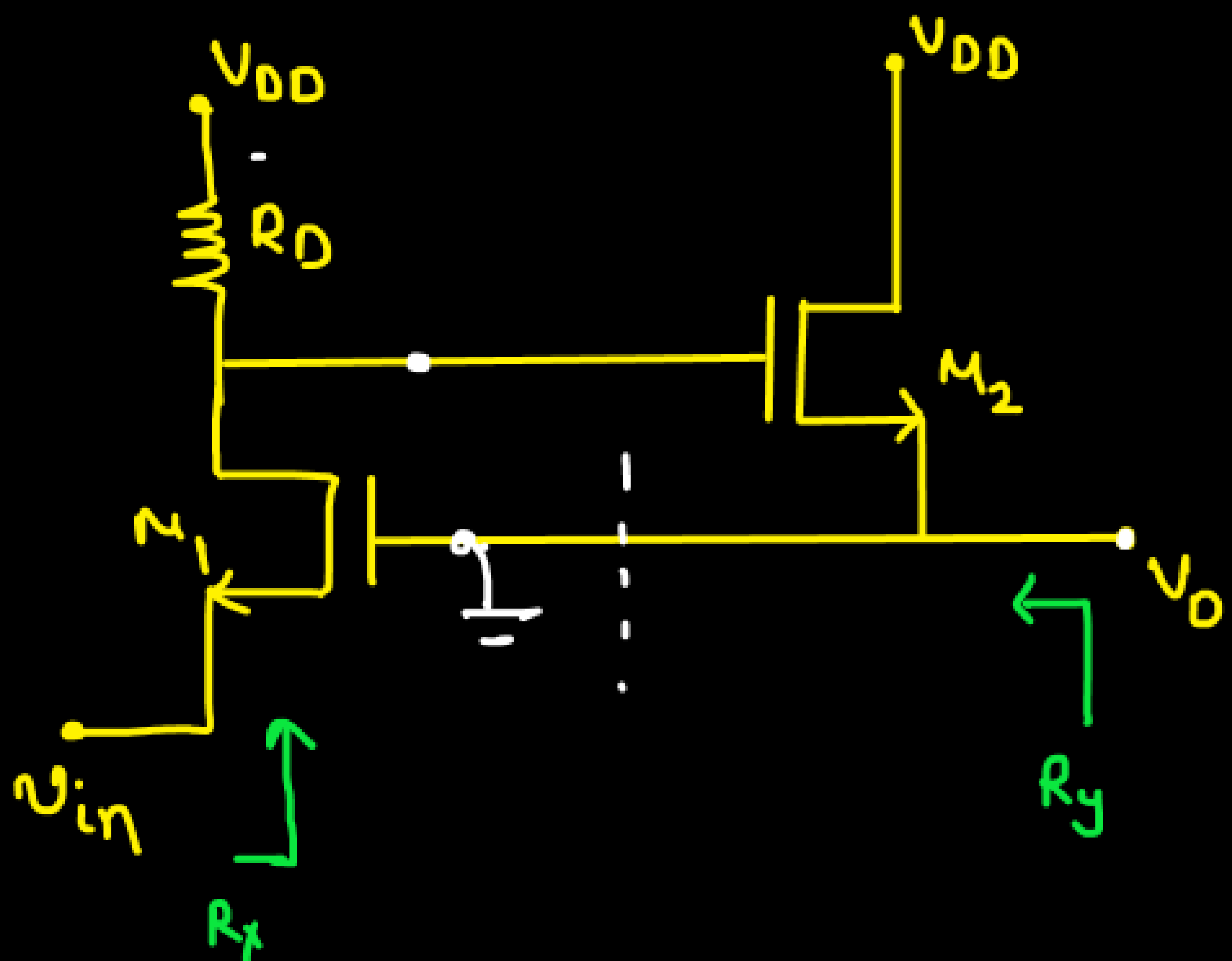


$$-g_{m2}\left(-g_{m1}R_D V_y - V_y\right) = I_y$$

$$g_{m2}\left(g_{m1}R_D + 1\right) V_y = I_y$$

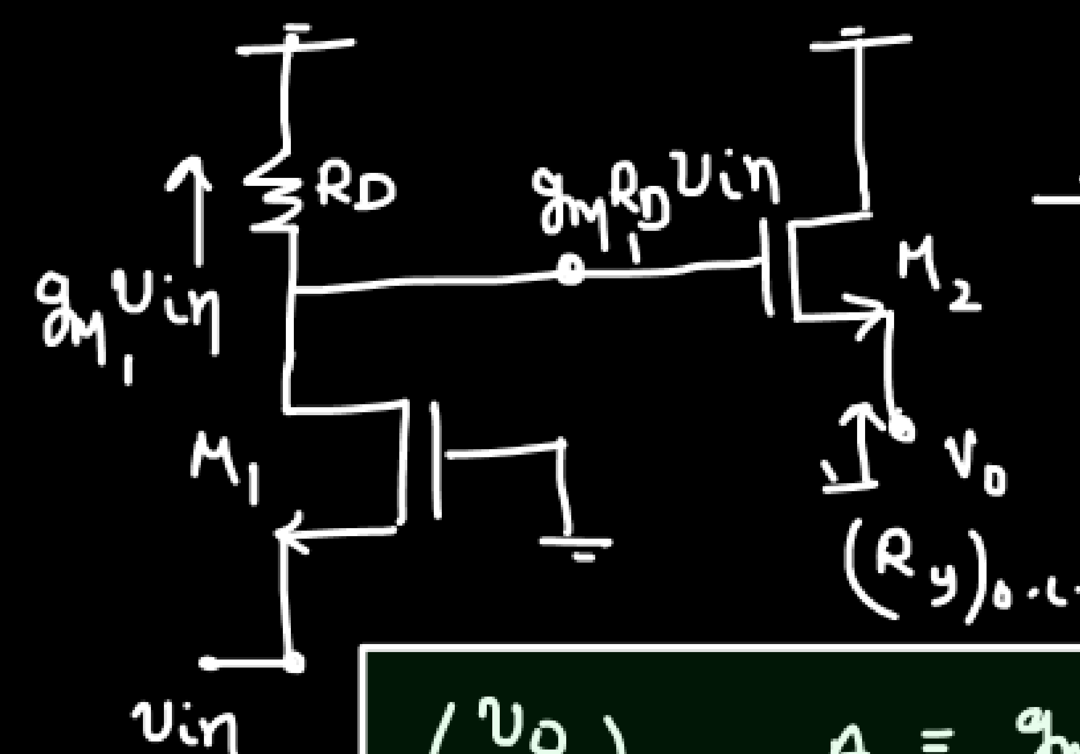
$$\boxed{R_y = \frac{V_y}{I_y} = \frac{1/g_{m2}}{1 + g_{m1}R_D}}$$

* with the concept of feedback Topology:-

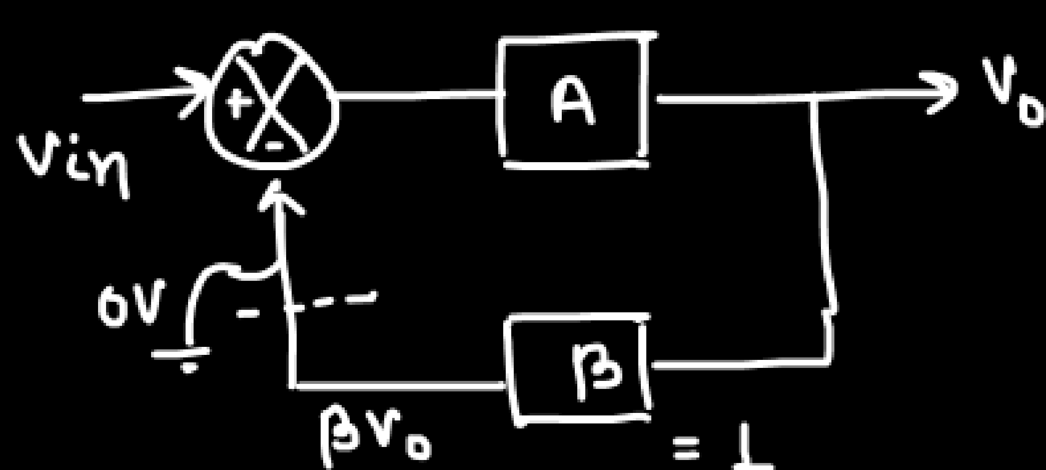


⇒ Voltage-Voltage f/b

* open loop gain = ? = A



→ open loop



$$\boxed{(R_x)_{o.l.} = \frac{1}{g_{m_1}}}$$

$$\boxed{\left(\frac{v_o}{v_i}\right)_{o.l.} = A = g_{m_1} R_D}$$

$$\boxed{\beta = 1}$$

$$\boxed{(R_y)_{o.l.} = 1/g_{m_2}}$$

For voltage - voltage f/b Topology :-

(in case of Neg. f/b)

① Close loop gain $\boxed{(A_v)_f = \frac{A}{1+A\beta} = \frac{g_{m_1} R_D}{1+g_{m_1} R_D}}$

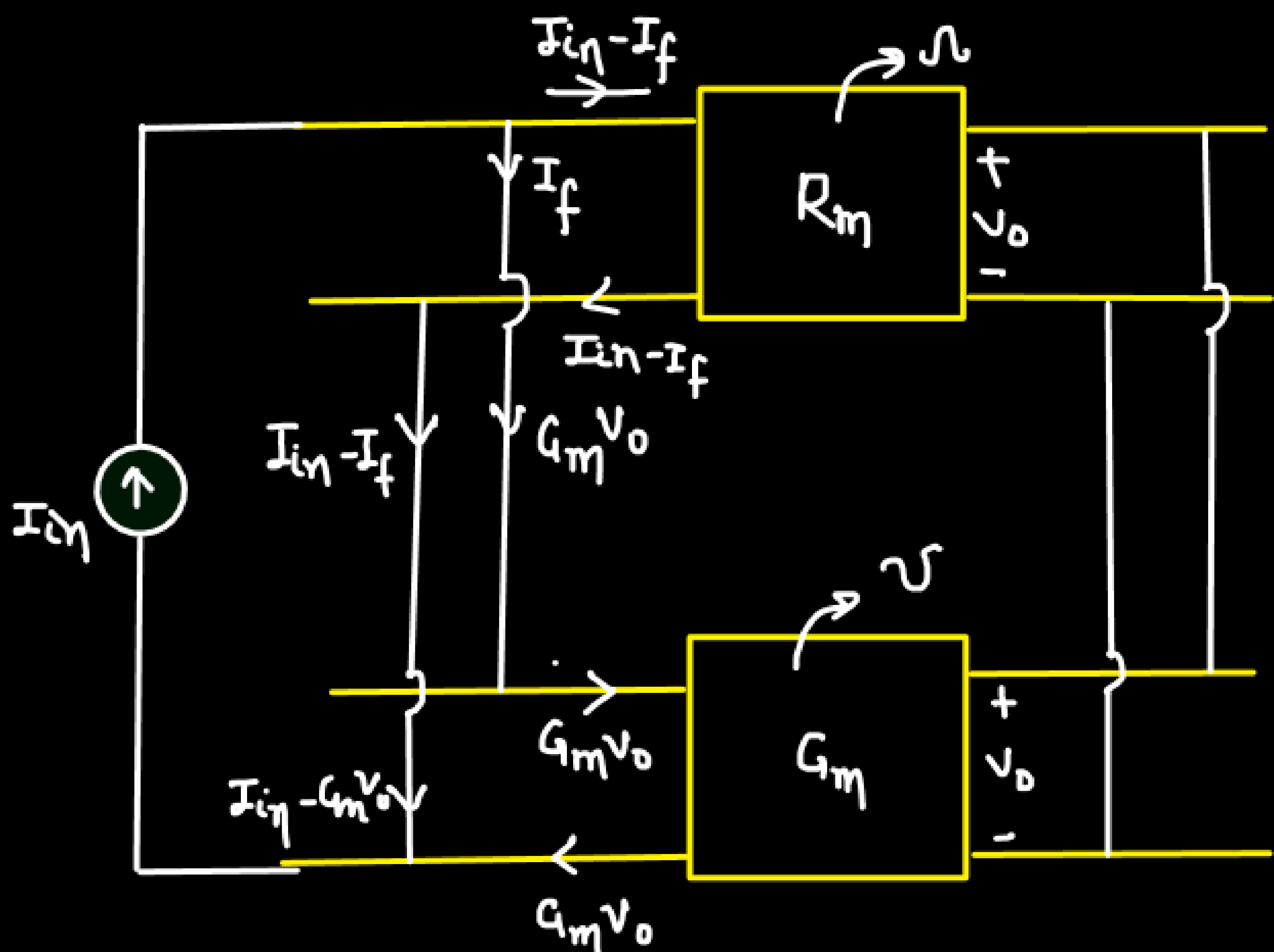
② Close loop input impedance $R_x = (R_x)_{o.L.}(1+A\beta)$

$$\boxed{R_x = \frac{1}{g_{m_1}}(1+g_{m_1} R_D)}$$

③ Closed loop o/p impedance $\boxed{R_Y = \frac{(R_Y)_{o.L.}}{1+A\beta} = \frac{1/g_{m_2}}{1+g_{m_1} R_D}}$

★ Voltage - Current f/b :-

(Shunt - Shunt)

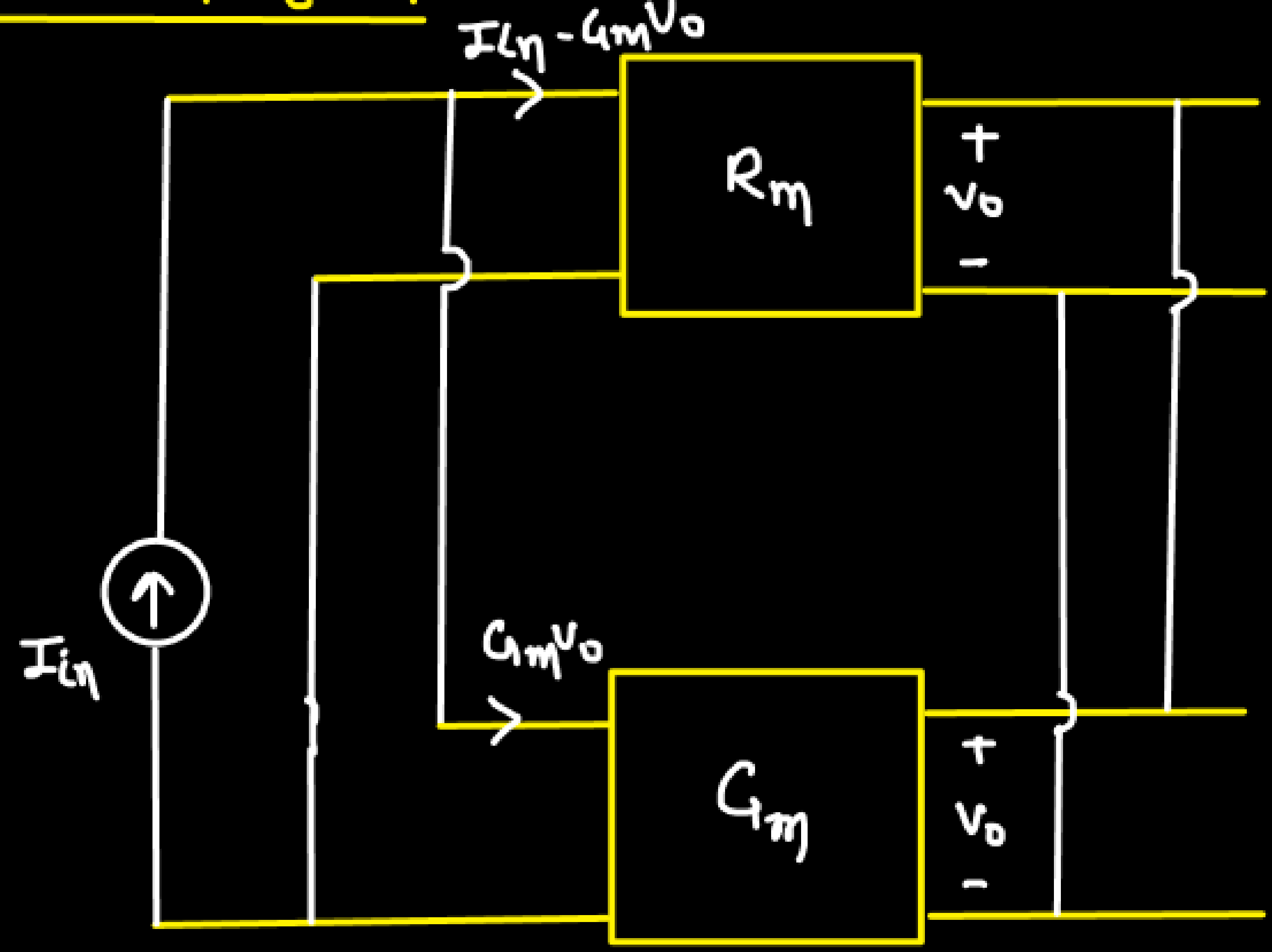


Open loop gain → R_m (Ω)

Open loop input impedance → R_{in}

Open loop output impedane → R_o

① **Closed loop gain:**



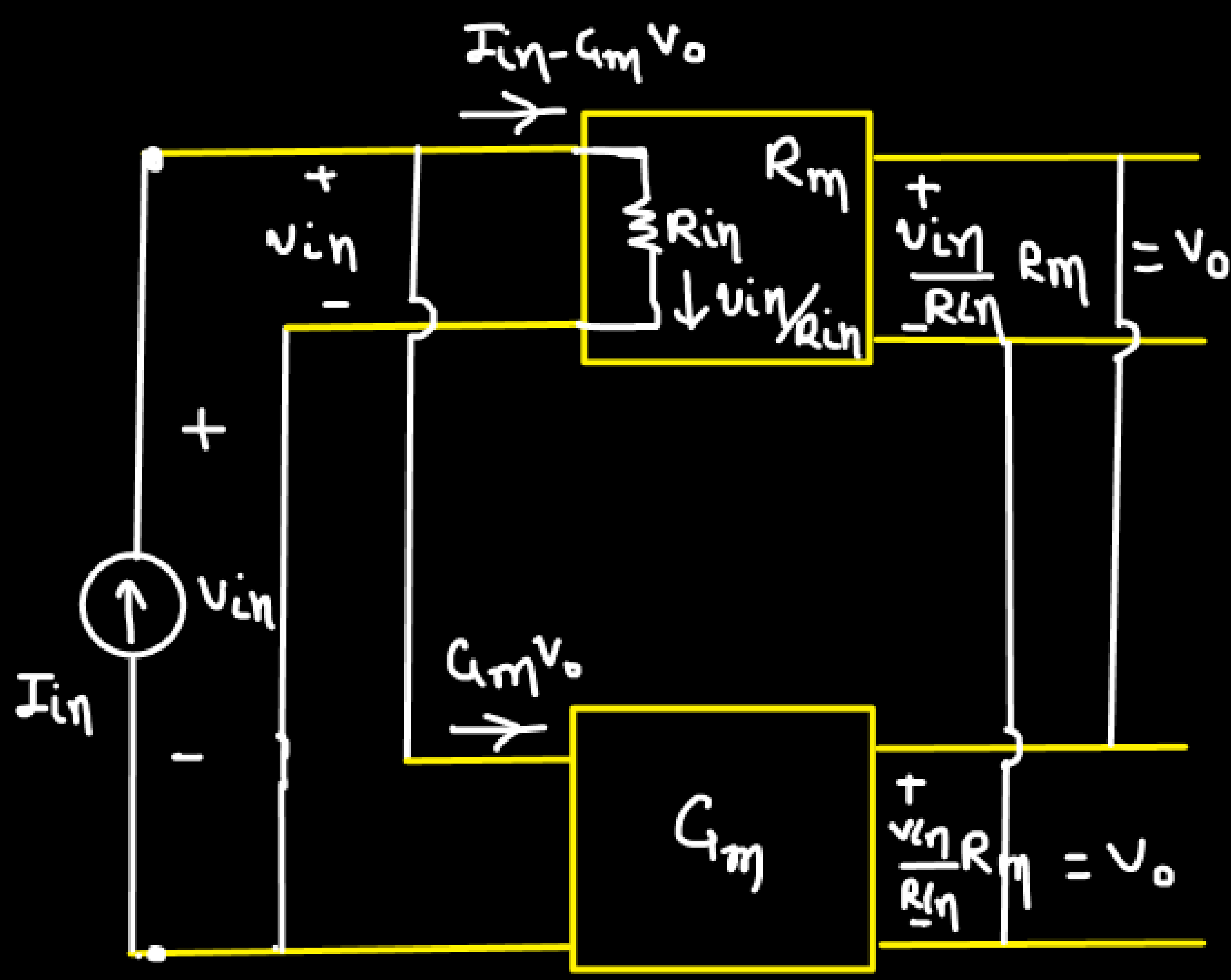
closed loop gain

$$\boxed{(A_R)_f = \frac{V_o}{I_{in}}}$$

$$(I_{in} - G_m V_o) R_m = V_o$$

$$\boxed{\frac{V_o}{I_{in}} = (A_R)_f = \frac{R_m}{1 + G_m R_m}}$$

② Closed loop input Resistance:-



$$(R_{in})_f = \frac{v_{in}}{I_{in}}$$

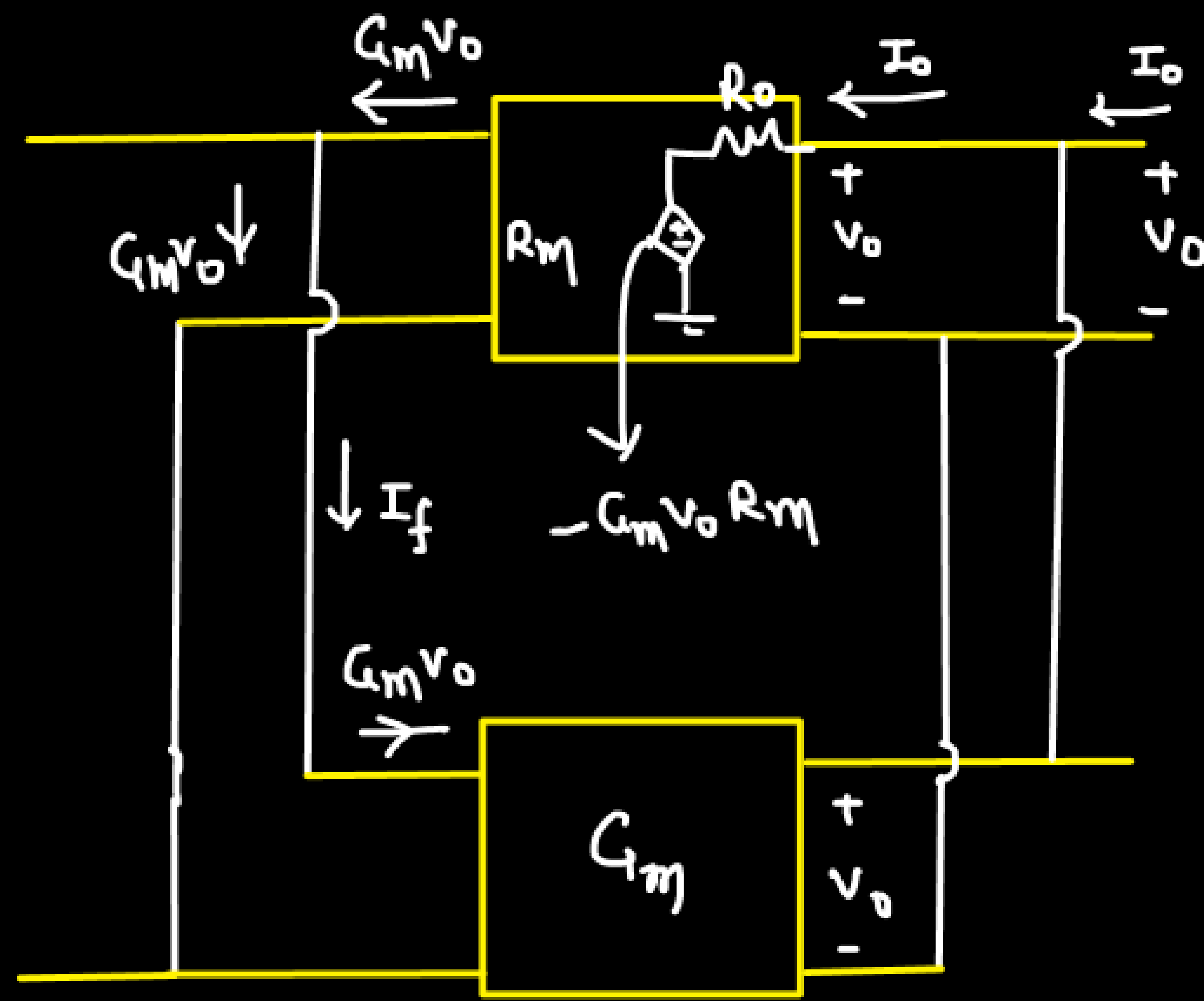
$$\frac{v_{in}}{R_{in}} = I_{in} - G_m V_o$$

$$\frac{v_{in}}{R_{in}} = I_{in} - \frac{G_m v_{in}}{R_{in}} R_m$$

$$v_{in}[1 + G_m R_m] = R_{in} I_{in}$$

$$\boxed{(R_{in})_f = \frac{R_{in}}{1 + G_m R_m}}$$

③ Closed loop Output Impedance:-



$$(R_o)_f = \frac{v_o}{I_o}$$

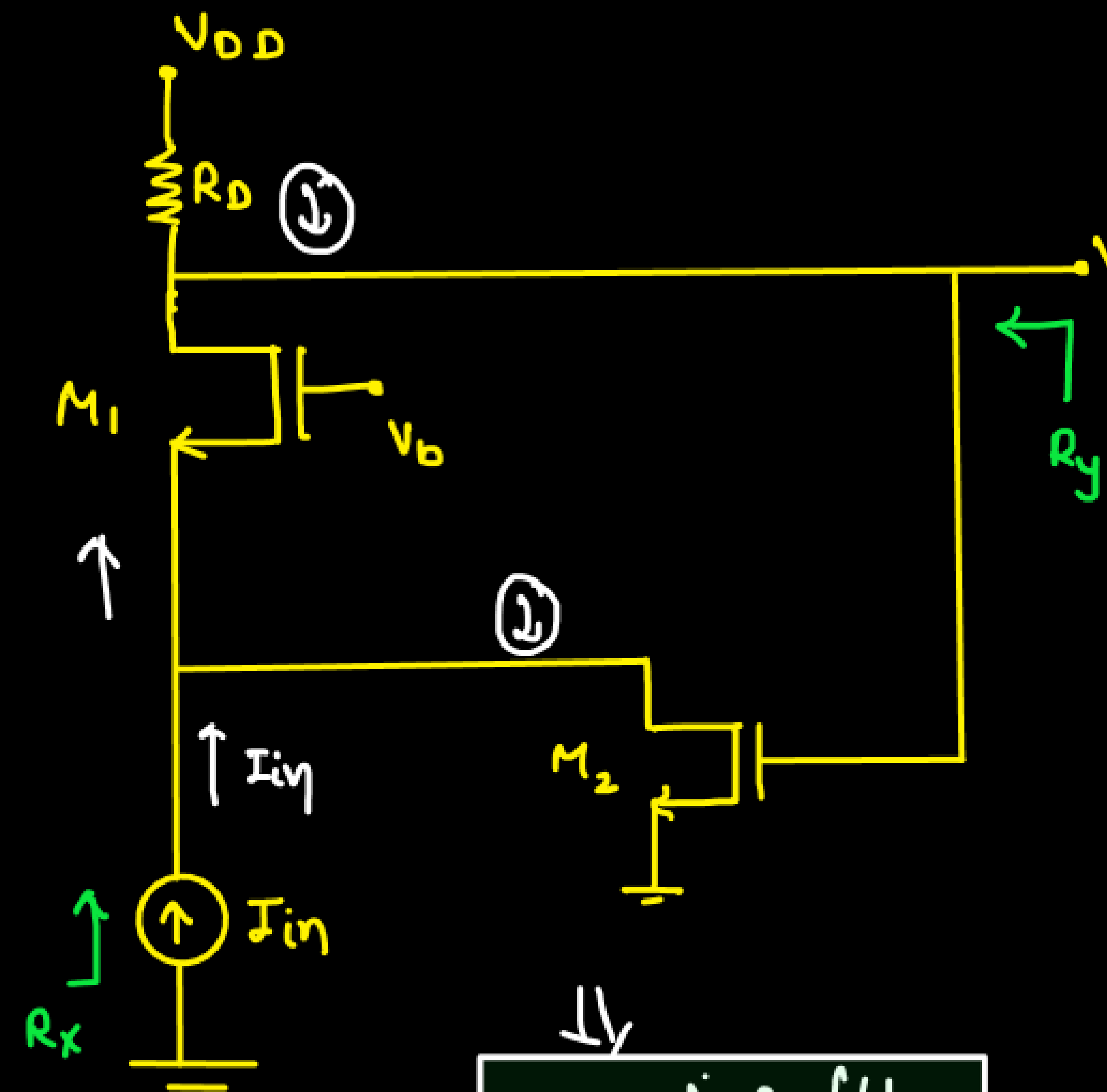
Assumption:-

Complete I_o is flowing through R_o.

$$\frac{v_o + G_m v_o R_m}{R_o} = I_o$$

$$\boxed{\frac{v_o}{I_o} = (R_o)_f = \frac{R_o}{1 + G_m R_m}}$$

Eg:.



Negative f/b

Take $\lambda = 0$

1. Find $\frac{v_o}{I_{in}}$?

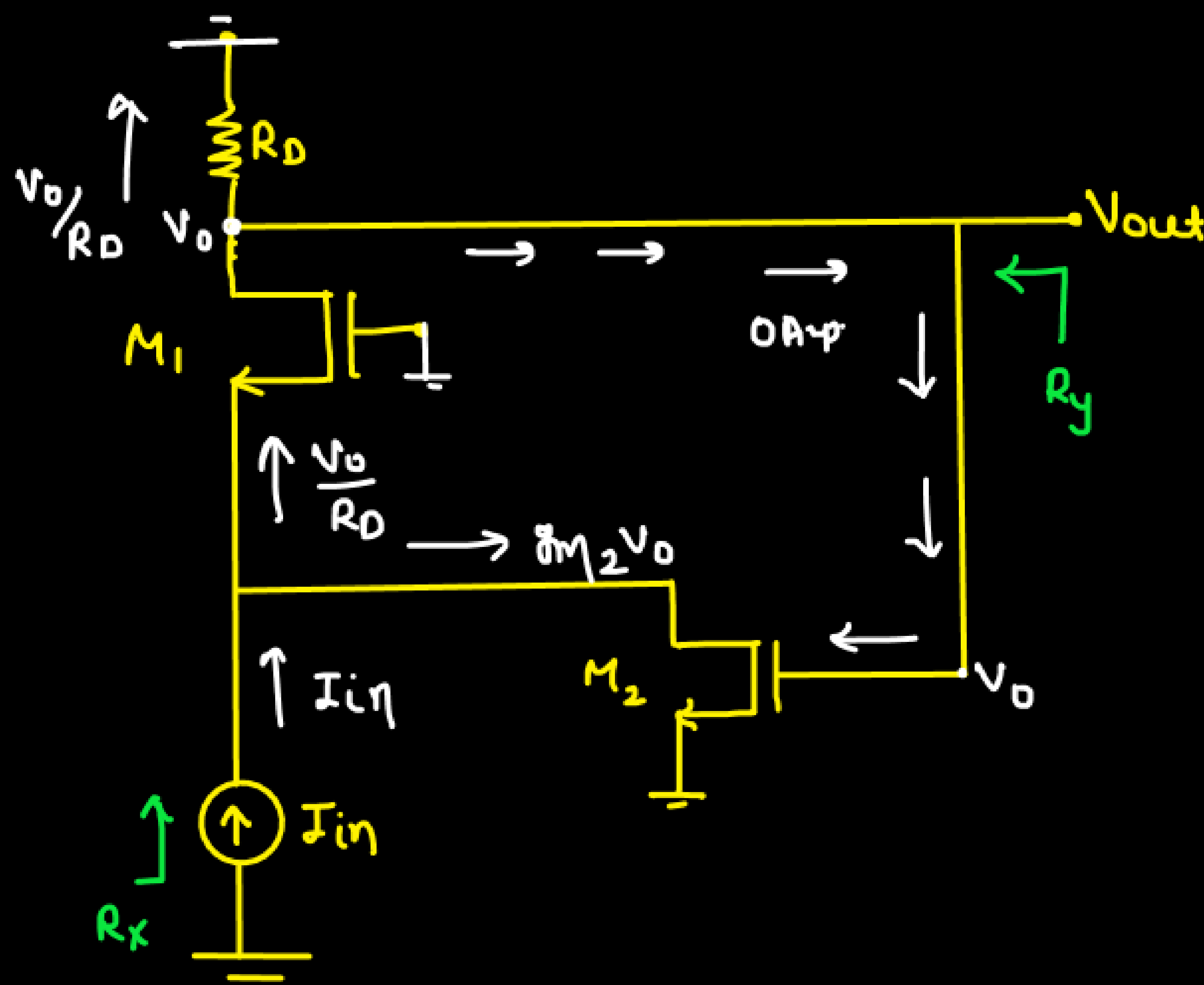
2. Find R_x and R_y.

current mixing

voltage sampling

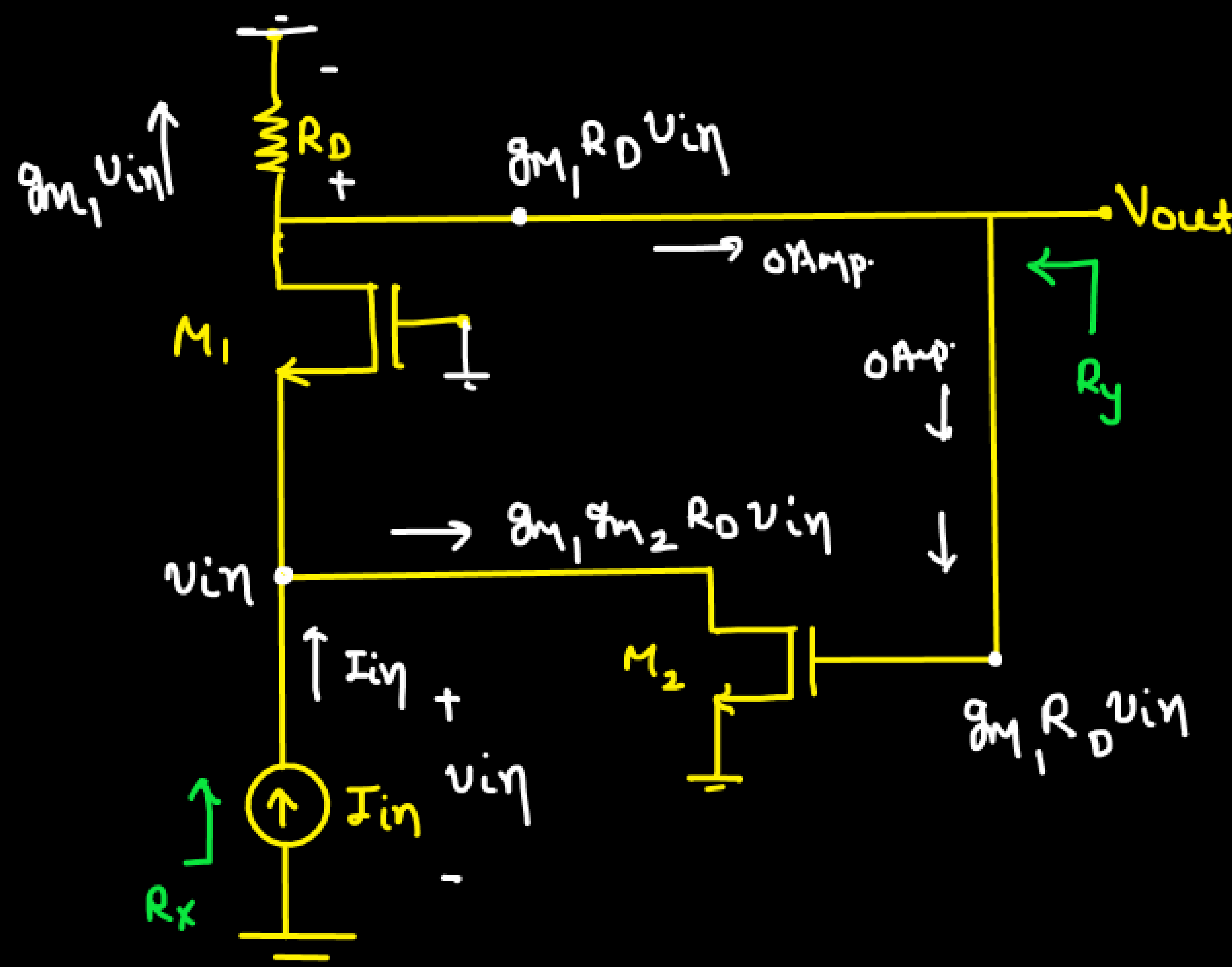
$\Rightarrow$ Voltage current f/b

M-I w/o using the concept of f/b



① $I_{in} = g_{m_2}V_0 + \frac{V_0}{R_D}$

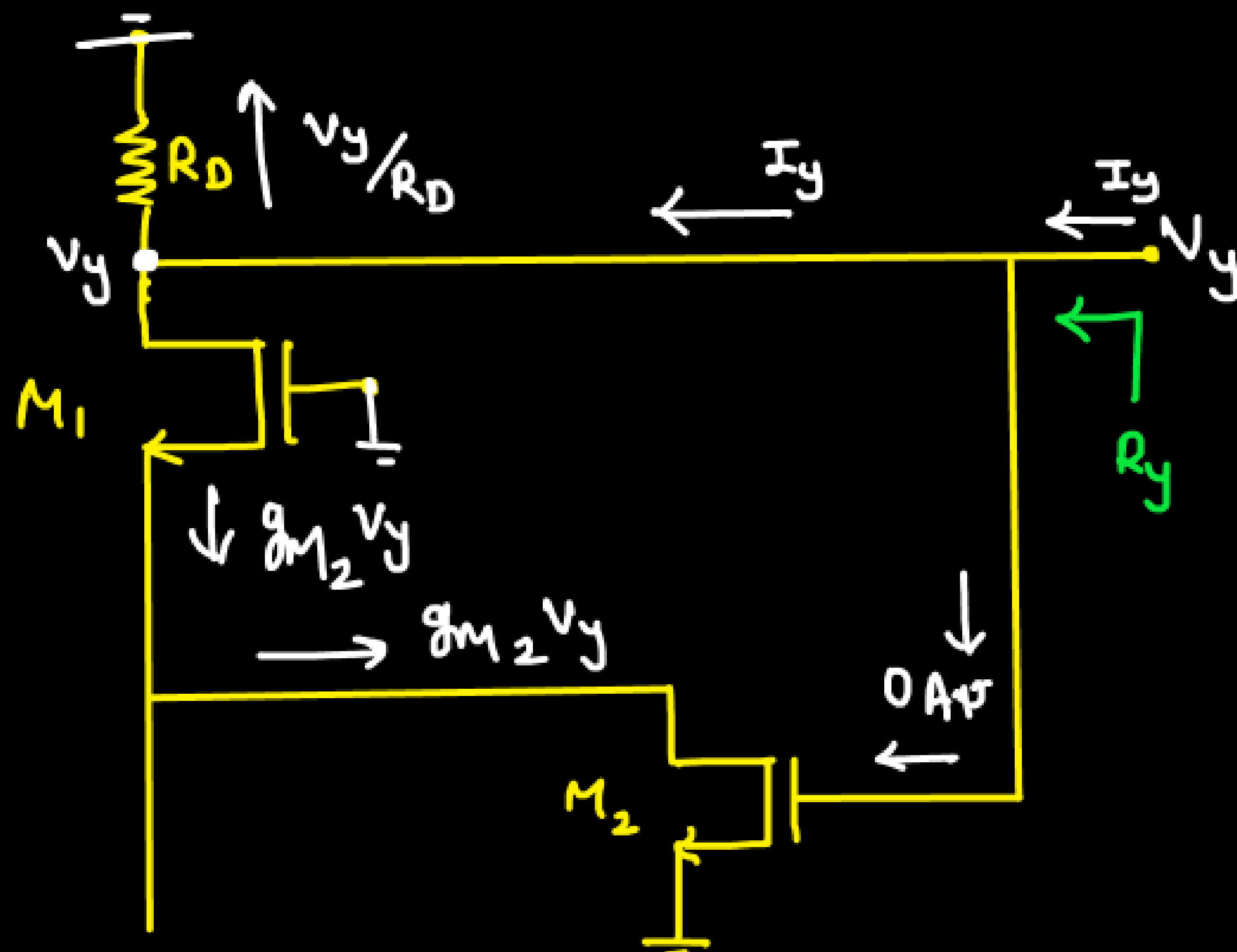
$$\boxed{\frac{V_0}{I_{in}} = \frac{R_D}{g_{m_2}R_D+1}}$$



$$R_x = \frac{v_{in}}{I_{in}}$$

$$I_{in} = g_{m1} v_{in} + g_{m1} g_{m2} R_D v_{in}$$

$$\boxed{\frac{v_{in}}{I_{in}} = \frac{1/g_{m1}}{1 + g_{m2} R_D}}$$

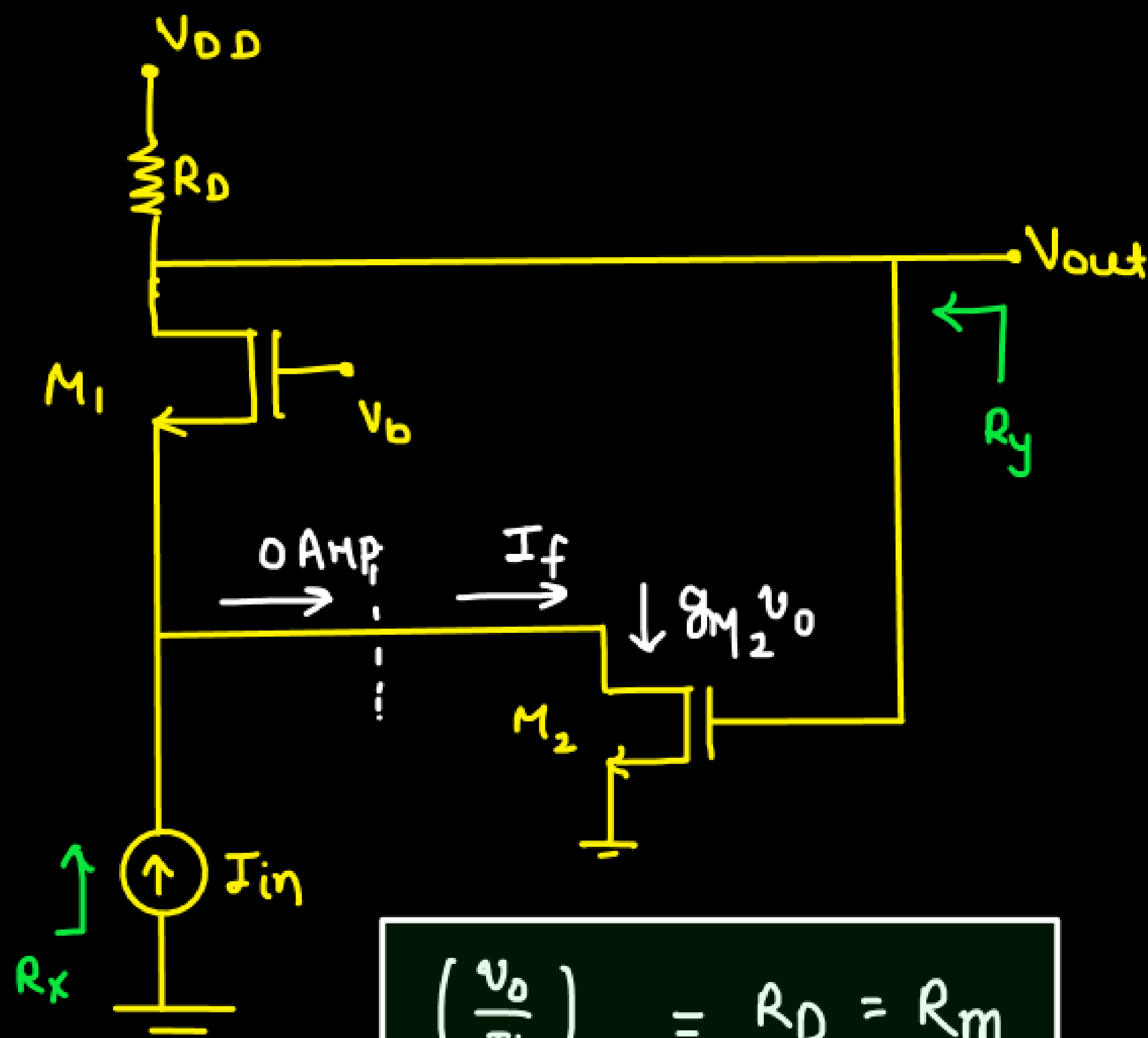


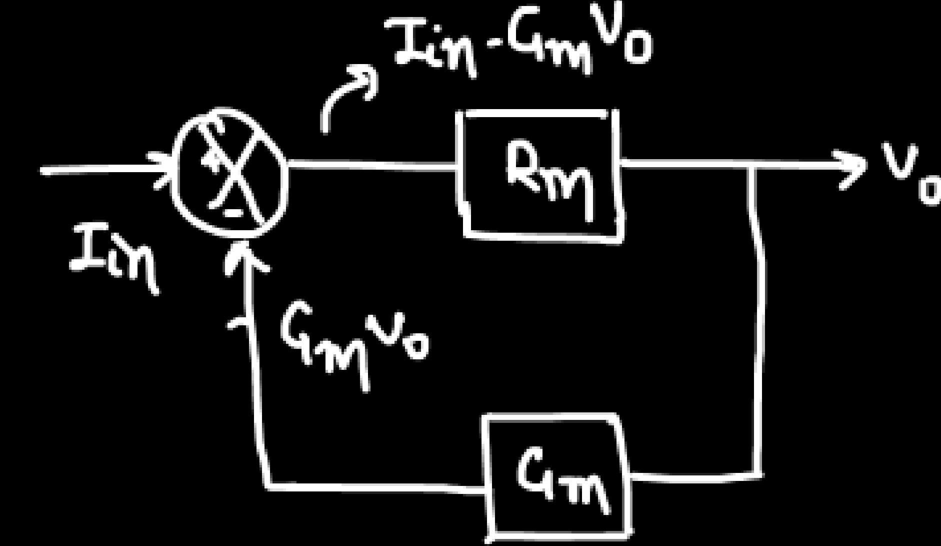
$$I_y = \frac{V_y}{R_D} + g_{m_2} V_y$$

$$\boxed{R_y = R_D \parallel \frac{1}{g_{m_2}}}$$

$$\boxed{R_y = \frac{R_D}{1 + g_{m_2} R_D}}$$

M-II with the concept of f/b topology:-

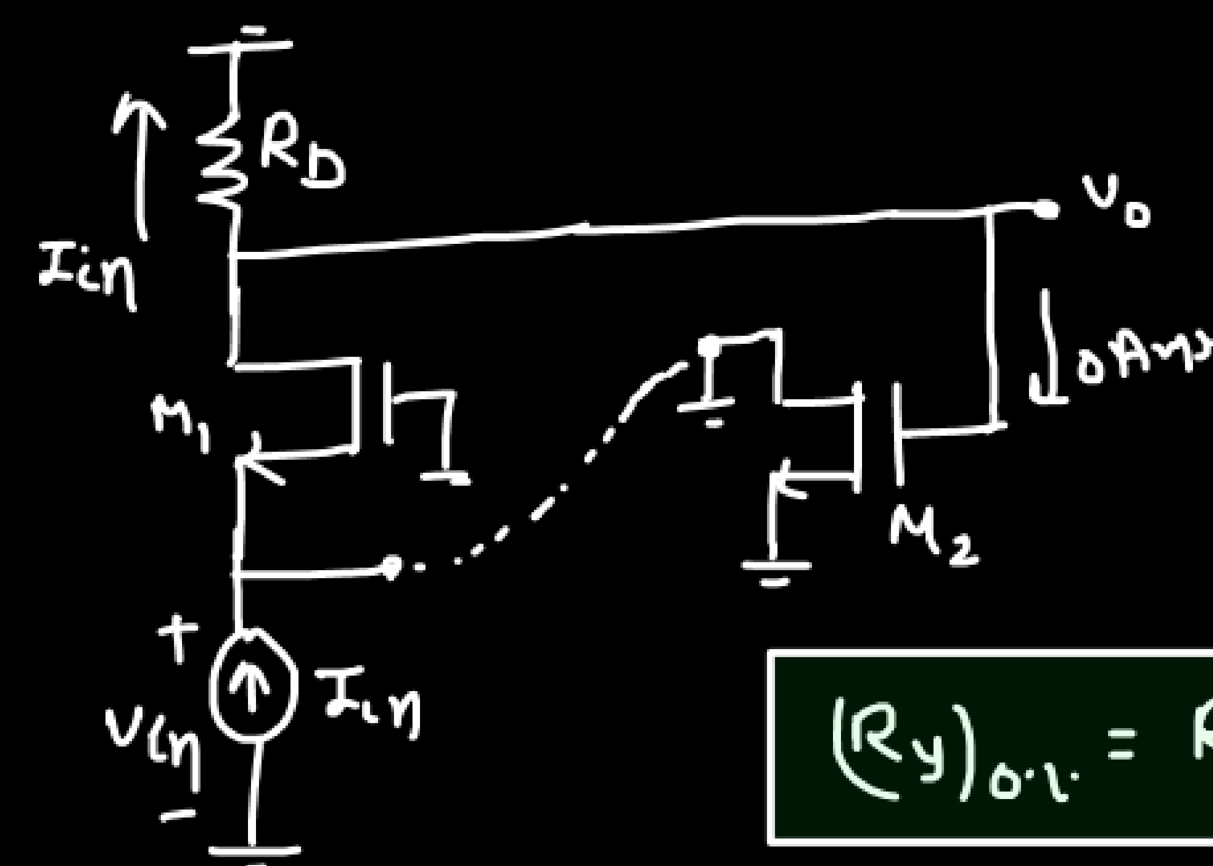




$$\boxed{\left(\frac{V_o}{I_{in}}\right)_{o.l.} = R_D = R_m}$$

$$\boxed{(R_x)_{o.l.} = 1/g_{m_1}}$$

open-loop →



$$\boxed{(R_y)_{o.l.} = R_D}$$

$$I_f = g_{m_2} v_o$$

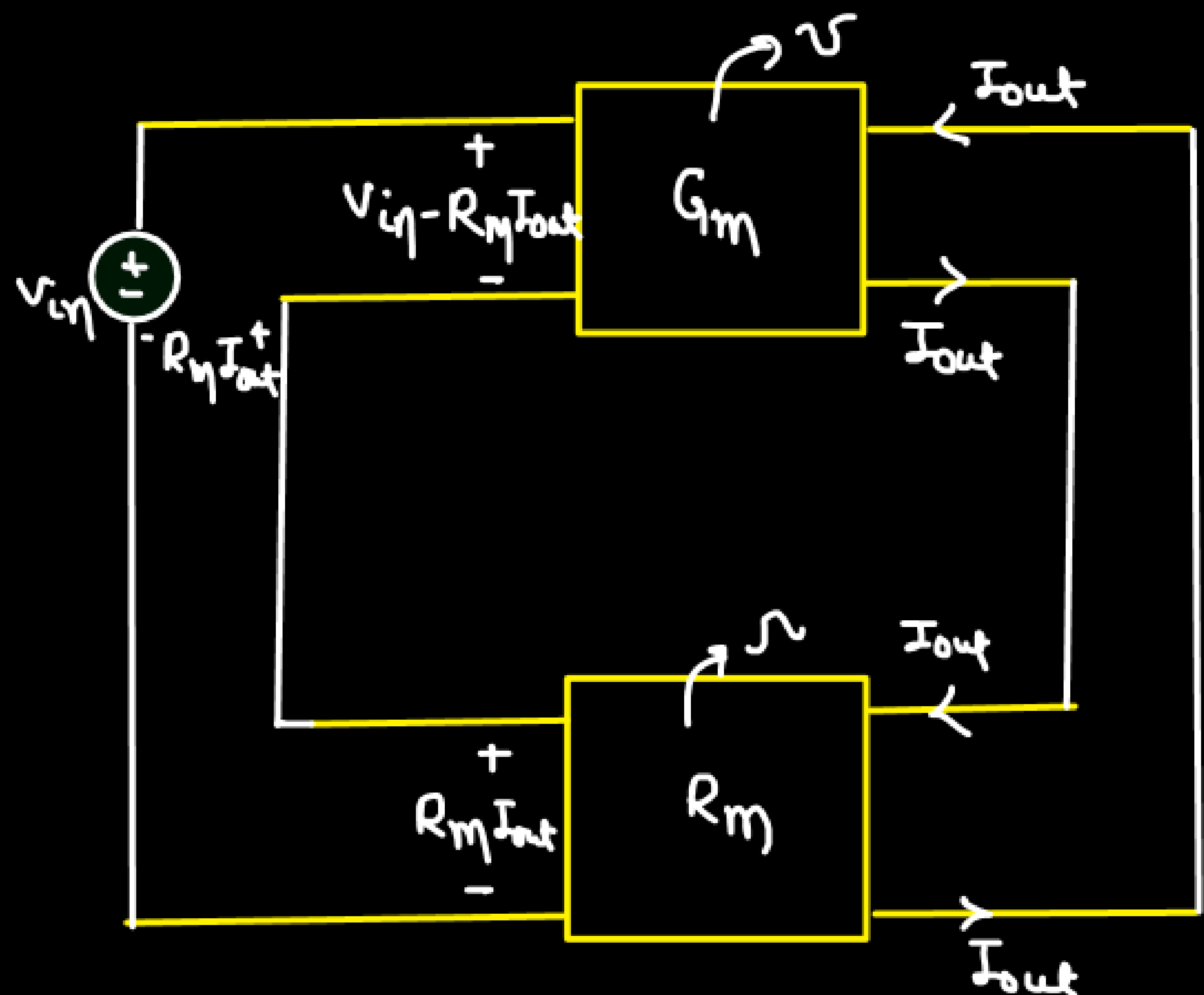
$$\boxed{\frac{I_f}{v_o} = G_m = g_{m_2}}$$

① $$\boxed{\text{Closed loop gain} = \frac{R_m}{1+G_m R_m} = \frac{R_D}{1+g_{m_2} R_D}}$$

② closed loop input impedance $$\boxed{(R_{in})_f = \frac{1/g_{m_1}}{1+g_{m_2} R_D}}$$

③ $$\boxed{(R_o)_f = \frac{R_D}{1+g_{m_2} R_D}}$$

* Current - Voltage feedback :- (series - Series)



open loop gain = G_m

open loop i/p impedance = R_{in}

open loop o/p impedance = R_o

① $\boxed{\text{Closed loop gain} = \dfrac{G_m}{1 + G_m R_m}}$

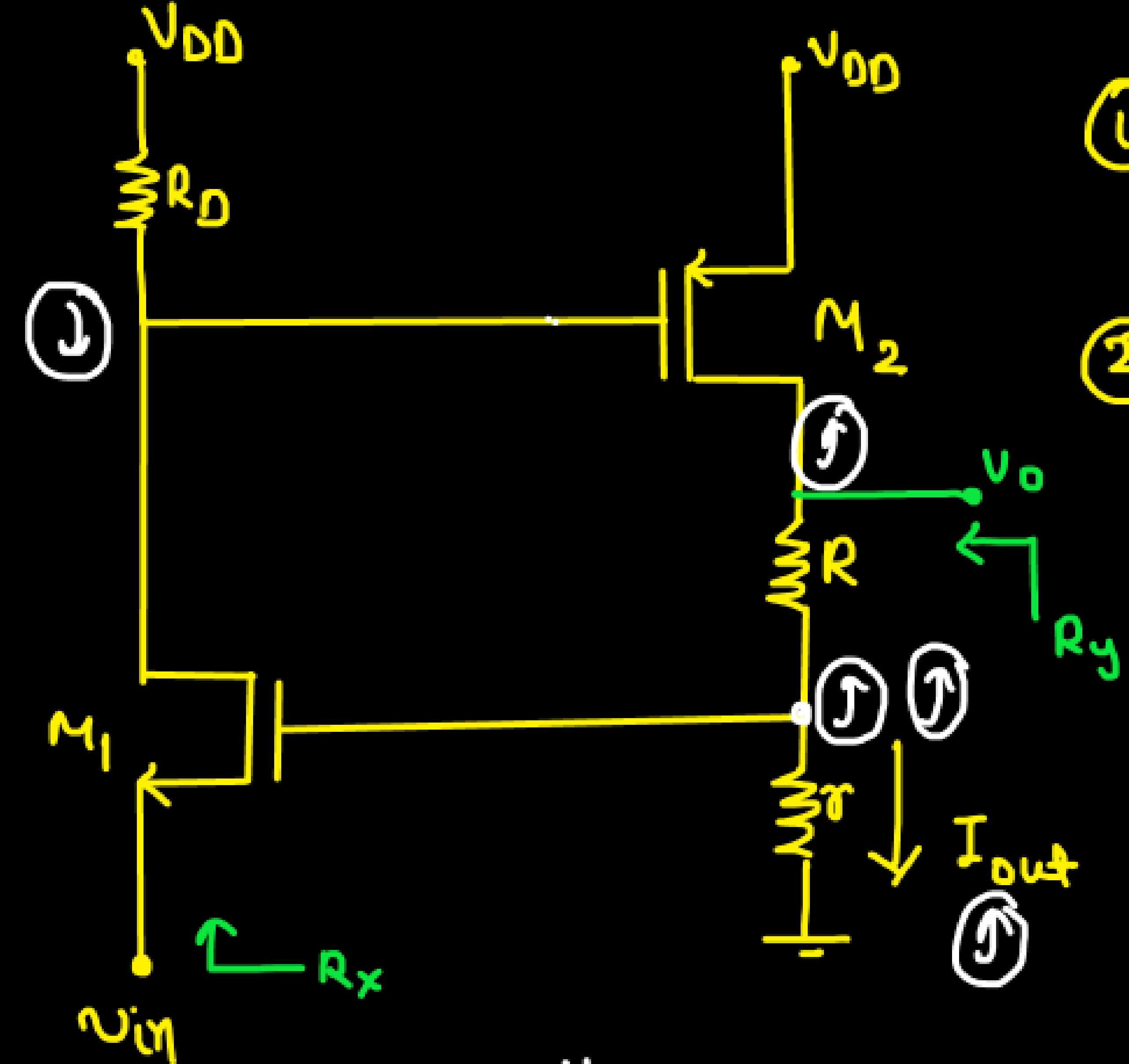
② Closed loop input impedance

$$\boxed{(R_i)_f = R_{in}(1 + G_m R_m)}$$

③ closed loop o/p impedance :-

$$\boxed{(R_o)_f = R_o(1 + G_m R_m)}$$

Eg. →



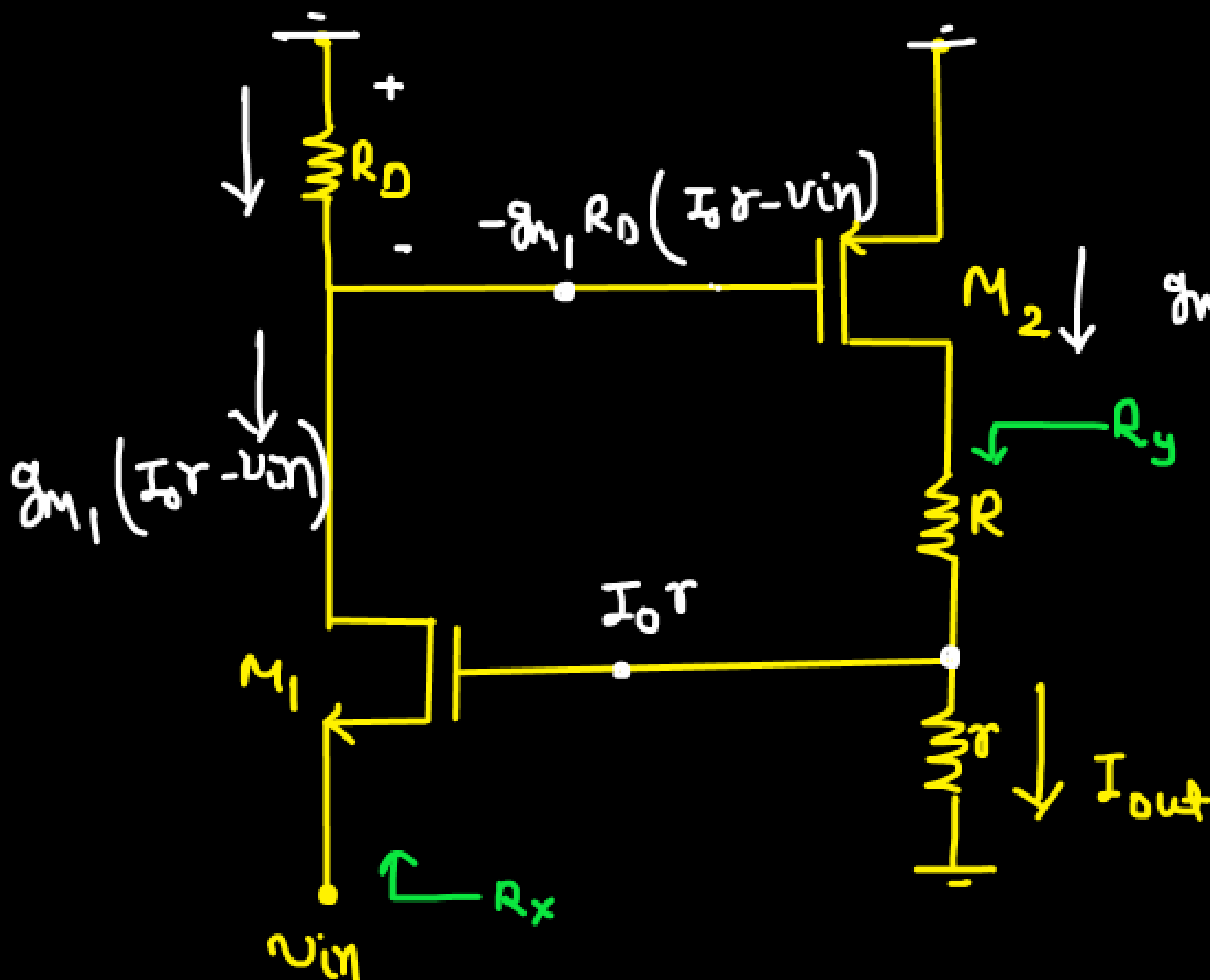
① Find $\frac{I_{out}}{v_{in}}$.

② Find R_x and R_y.

⇓

$\boxed{\text{positive f/b}}$

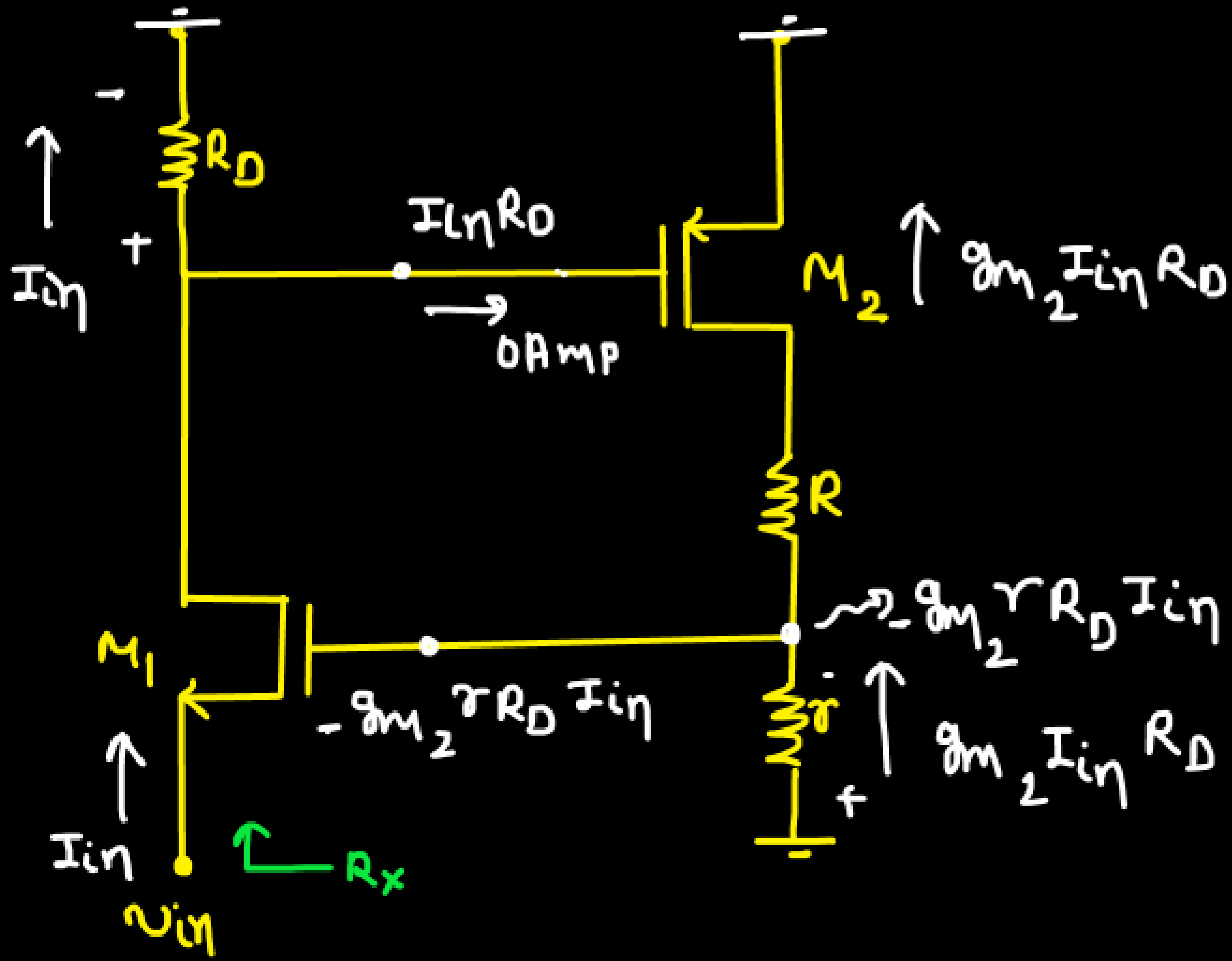
M·I w/o the concept of feedback:-



$$g_{m_2} g_{m_1} R_D (I_o r - v_{in}) = I_o$$

$$g_{m_2} g_{m_1} R_D r I_o - I_o = g_{m_1} g_{m_2} R_D v_{in}$$

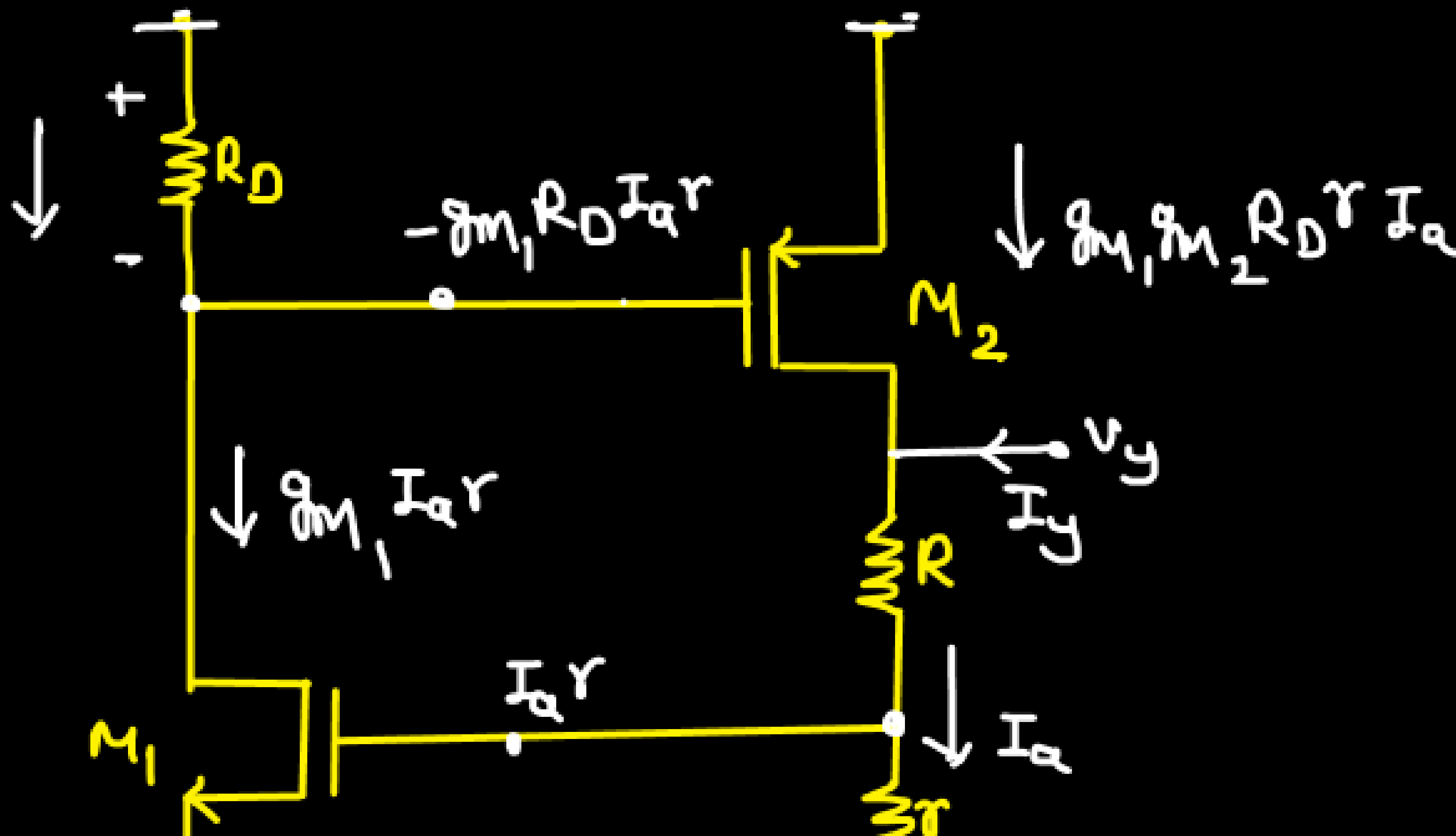
$$\boxed{\frac{I_o}{v_{in}} = \frac{-g_{m_1} g_{m_2} R_D}{1 - g_{m_1} g_{m_2} R_0 r}}$$



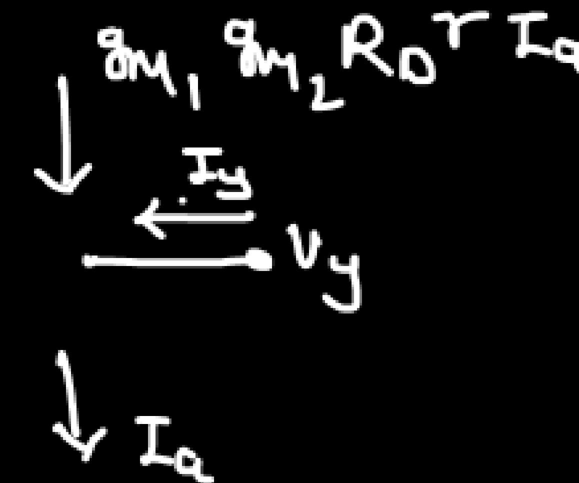
$$g_{m_1}\left(v_{in} + g_{m_2} r R_D I_{in}\right) = I_{in}$$

$$g_{m_1} v_{in} = I_{in}\left[1 - g_{m_1} g_{m_2} r R_D\right]$$

$$\boxed{\frac{v_{in}}{I_{in}} = \left[1 - g_{m_1} g_{m_2} r R_D\right] \frac{1}{g_{m_1}}}$$



$$\boxed{R_y = \frac{v_y}{I_y}}$$



$$\boxed{I_a = \frac{v_y}{r+R}}$$

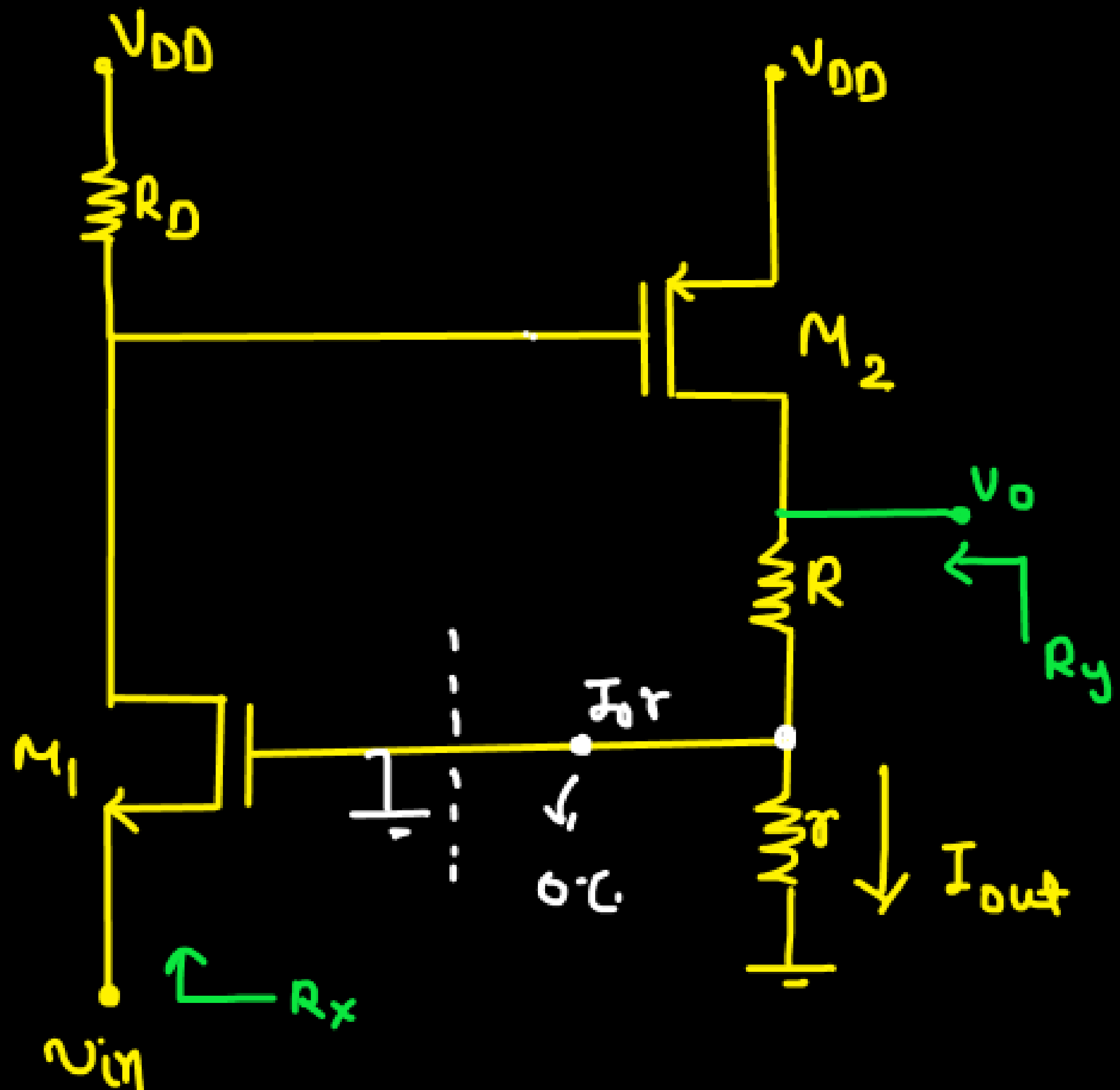
$$I_y + \frac{g_{m1}g_{m2}R_D r v_y}{r+R} = \frac{v_y}{r+R}$$

$$I_y = \left(\frac{1 - g_{m1}g_{m2}R_D r}{r+R}\right) v_y$$

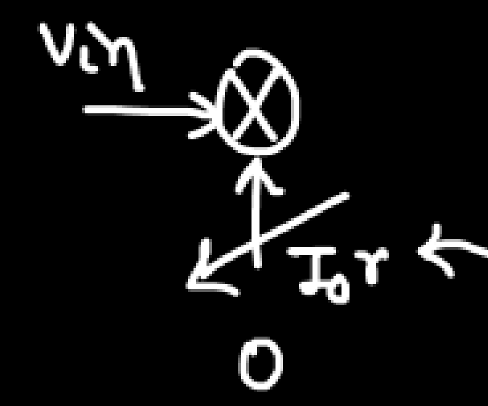
★★

$$\boxed{\frac{v_y}{I_y} = R_y = \frac{r+R}{1 - g_{m1}g_{m2}R_D r}}$$

M-I with the concept of f/b Topology:-

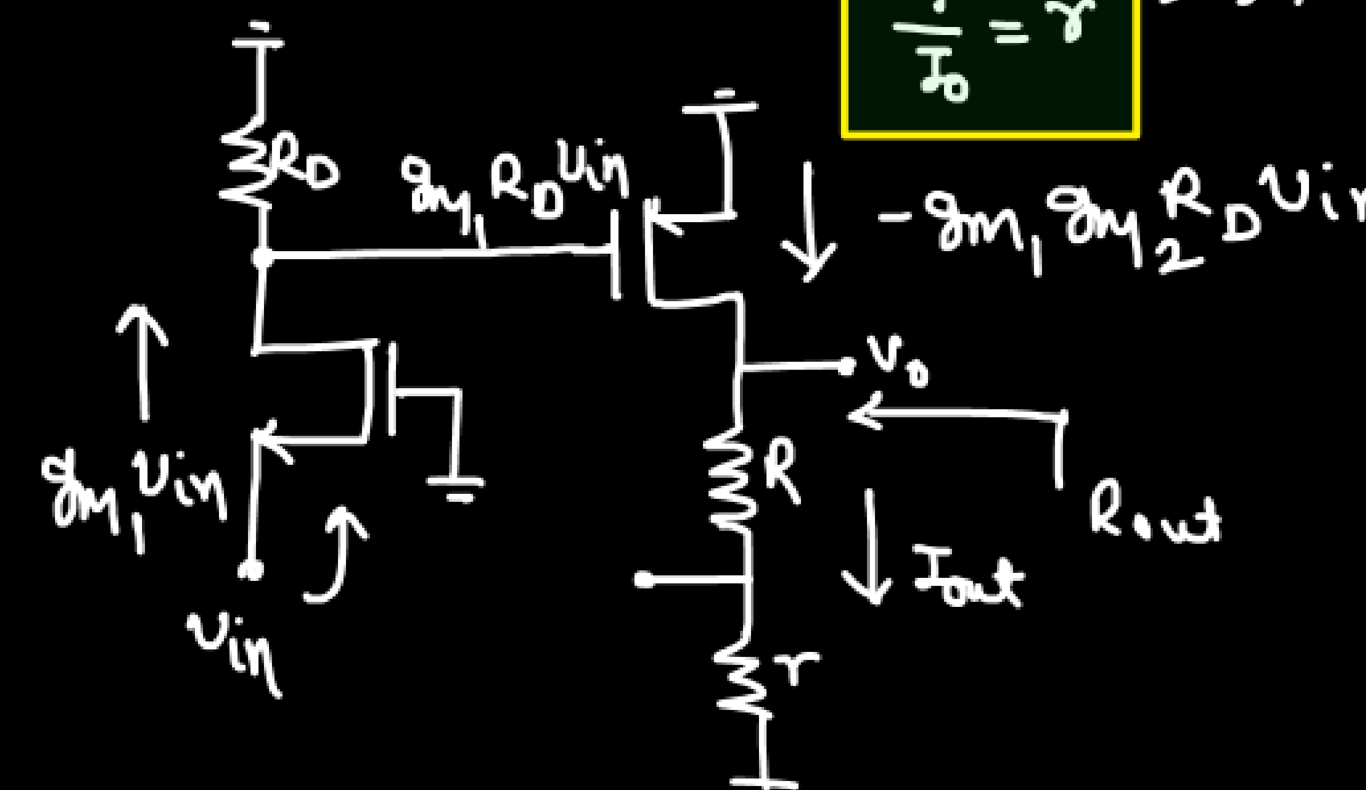


$\Rightarrow$



$$V_f = I_o r$$

$$\boxed{\frac{V_f}{I_o} = r} \rightarrow \text{f/b factor}$$



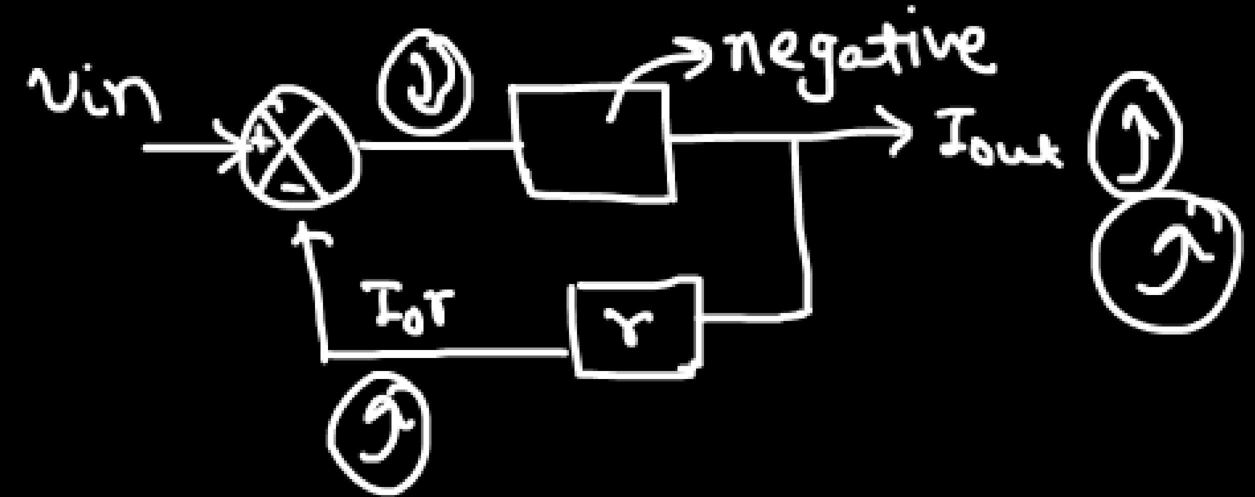
current-voltage f/b

Voltage mixing, current sampling

$$\boxed{\left(\frac{I_{out}}{v_{in}}\right)_{o.L.} = -g_{m_1} g_{m_2} R_D}$$

$$(R_{in})_{O.L.} = \frac{1}{g_{m_1}}$$

$$(R_o)_{O.L.} = R + r$$

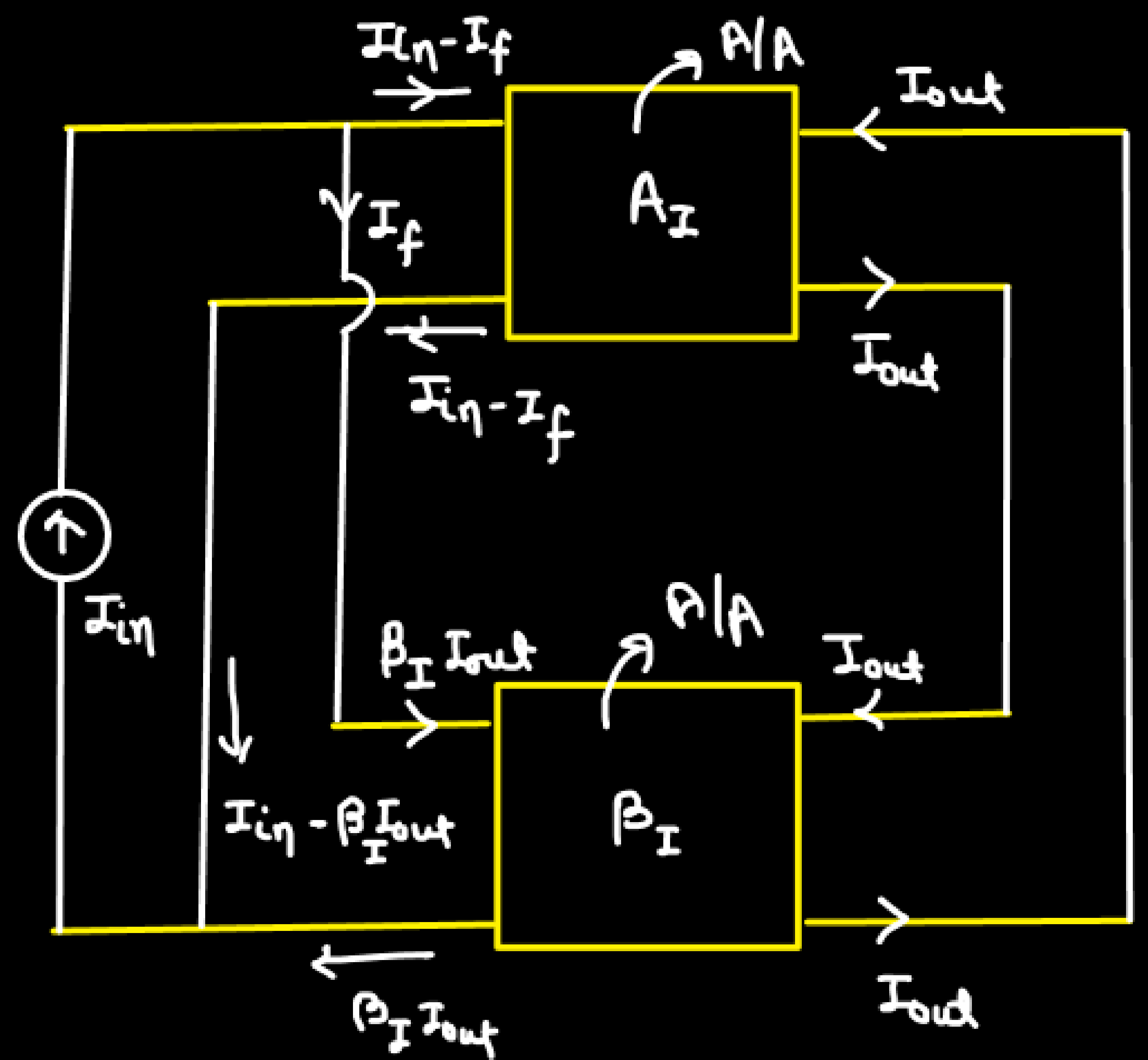


☆ $$\text{closed loop gain} = \frac{-g_{m_1} g_{m_2} R_D}{1 - g_{m_1} g_{m_2} R_D r}$$

☆ $$R_x = \frac{1}{g_{m_1}}\left[1 - g_{m_1} g_{m_2} R_D r\right]$$

★ $$R_y = (R + r)\left[1 - g_{m_1} g_{m_2} R_D r\right]$$

* Current - Current feedback :- (shunt - series)



open loop gain = A_I

open loop i/p impedance = R_{in}

open loop o/p impedance = R_o

① Closed loop gain = $\dfrac{A_I}{1 + A_I \beta_I}$

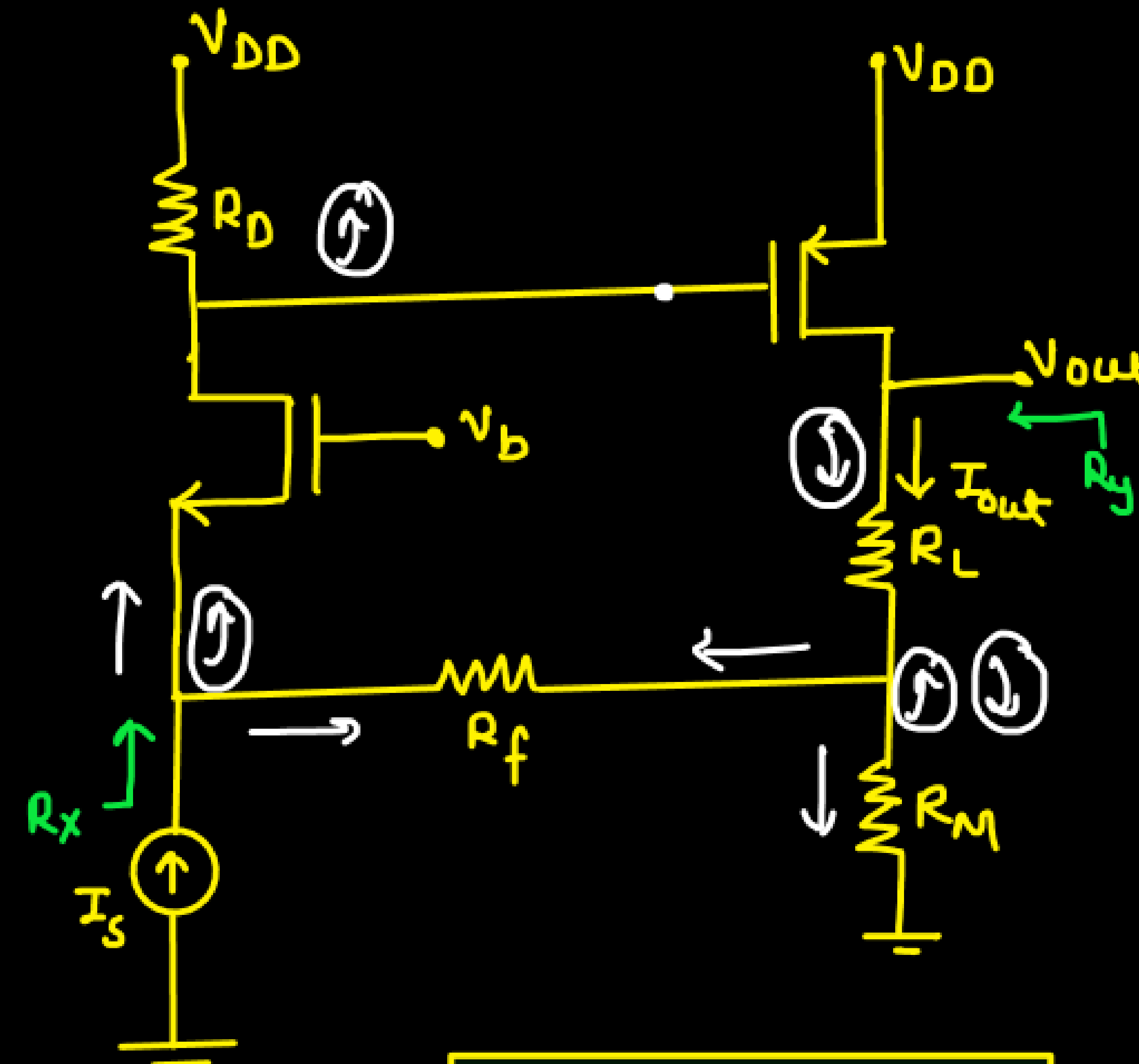
② Closed loop I/P impedance

$$= R_{in} / 1 + A_I B_I$$

③ Closed loop o/p impedance

$$= R_o [1 + A_I B_I]$$

Eg. →



[Make Proper Assumption.]

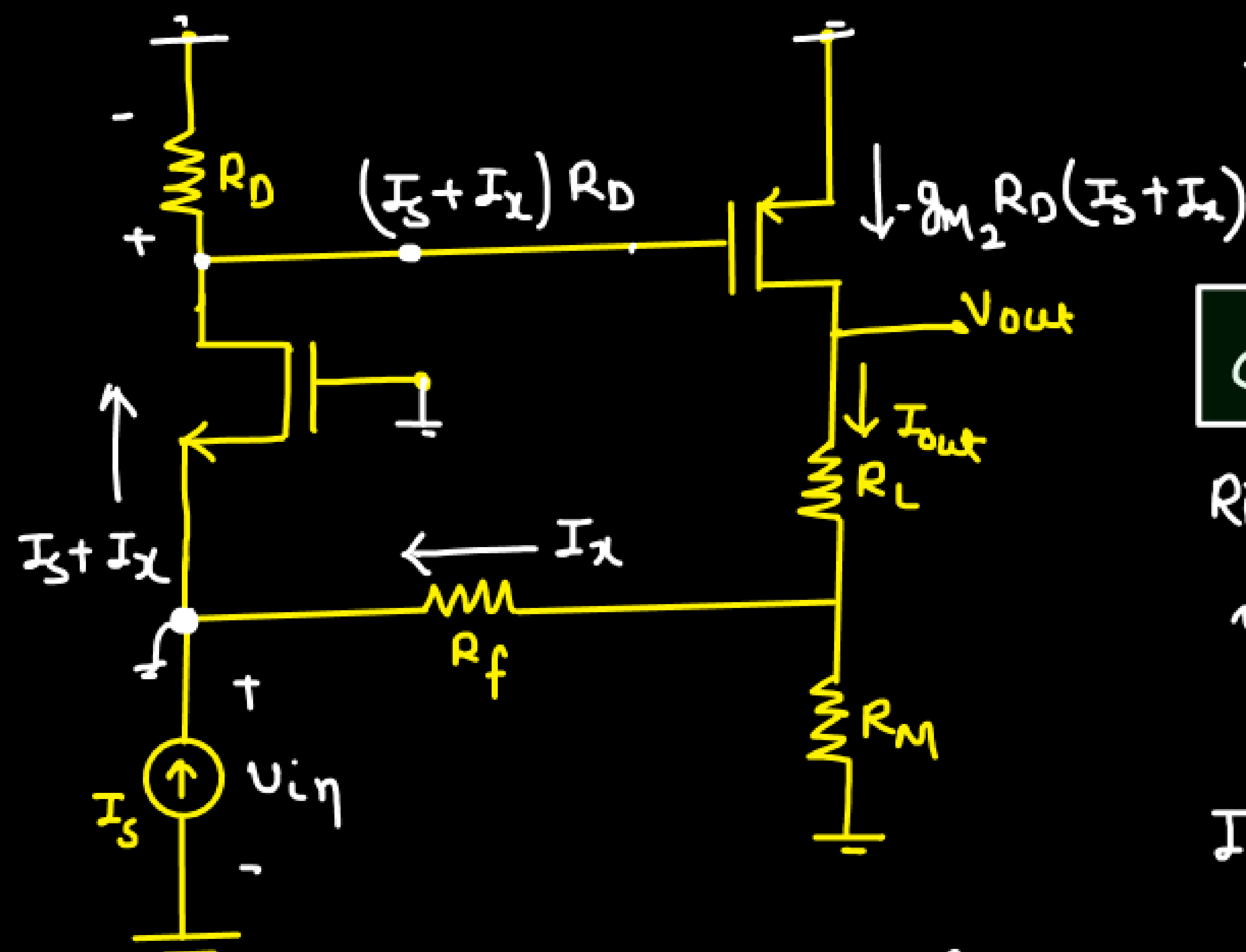
① Find $\frac{I_{out}}{I_s}$.

② Find R_x & R_y.

$\boxed{\Rightarrow \text{Negative f/b}}$

current mixing, current-sampling ⇒ $\boxed{\text{Current - Current f/b Topology}}$

M-I   w/o the concept of f/b Topology :-



$$\frac{I_{out}}{I_S} = ?$$

$\boxed{\text{CURRENT - CURRENT f/b}}$

$R_{in} \rightarrow$ very low

$\frac{v_{in}}{I_S} \rightarrow$ very low

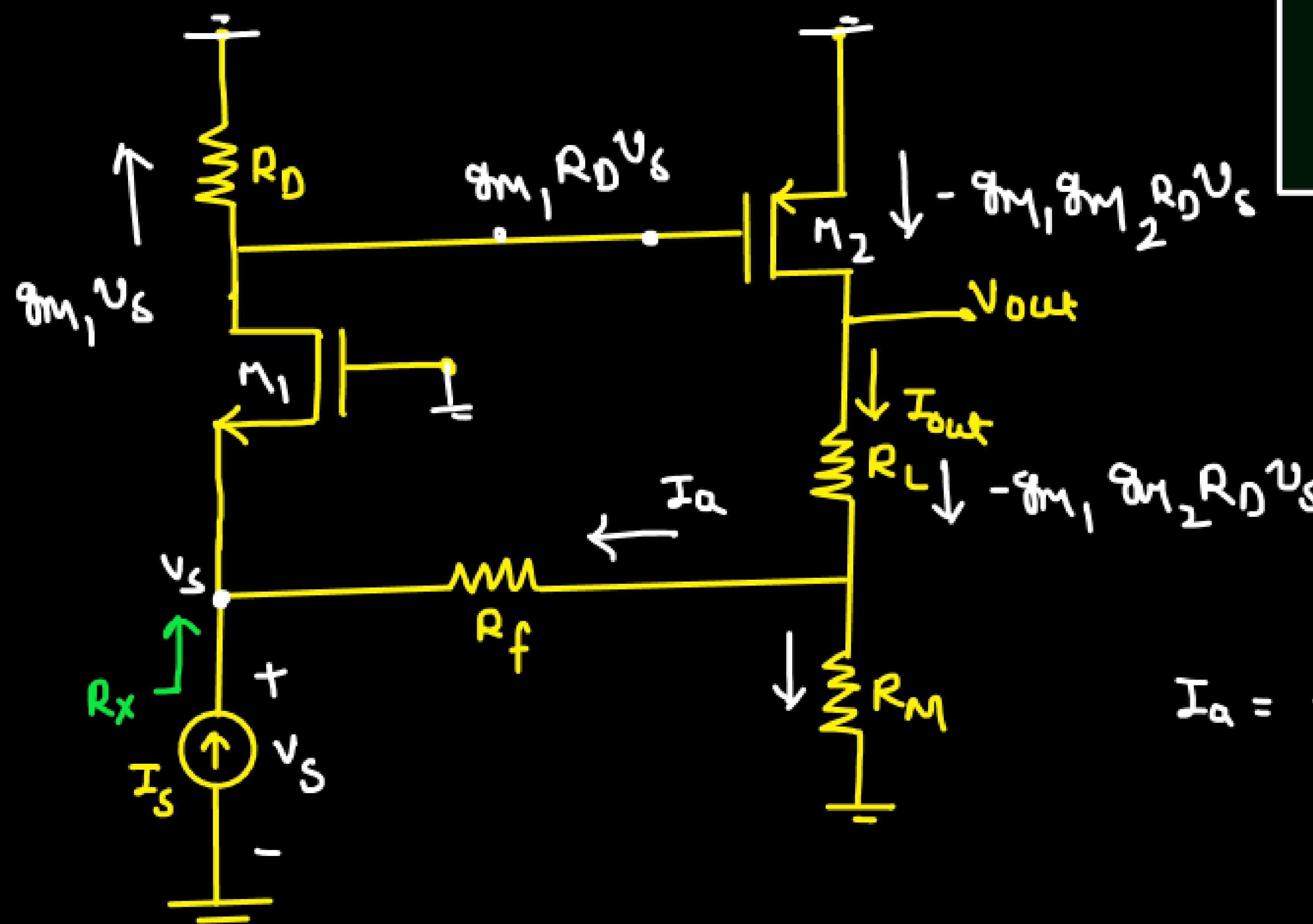
I can take, $v_{in} \rightarrow 0$

$$I_x = \frac{R_M}{R_M + R_f} I_{out}$$

$$-g_{m_2}R_D\left(I_S+\frac{R_M}{R_M+R_f}I_{out}\right)=I_{out}$$

$$-g_{m_2}R_D I_S = I_{out}\left[1+\frac{g_{m_2}R_D R_M}{R_M+R_f}\right]$$

$$\boxed{\frac{I_{out}}{I_S}=\frac{-g_{m_2}R_D}{1+g_{m_2}R_D\left(\frac{R_M}{R_M+R_f}\right)}}$$



$$\boxed{R_x = \frac{V_s}{I_s}}$$

$$I_a = -g_{m1} g_{m2} R_D v_s \times \frac{R_M}{R_M + R_f} \longrightarrow (1)$$

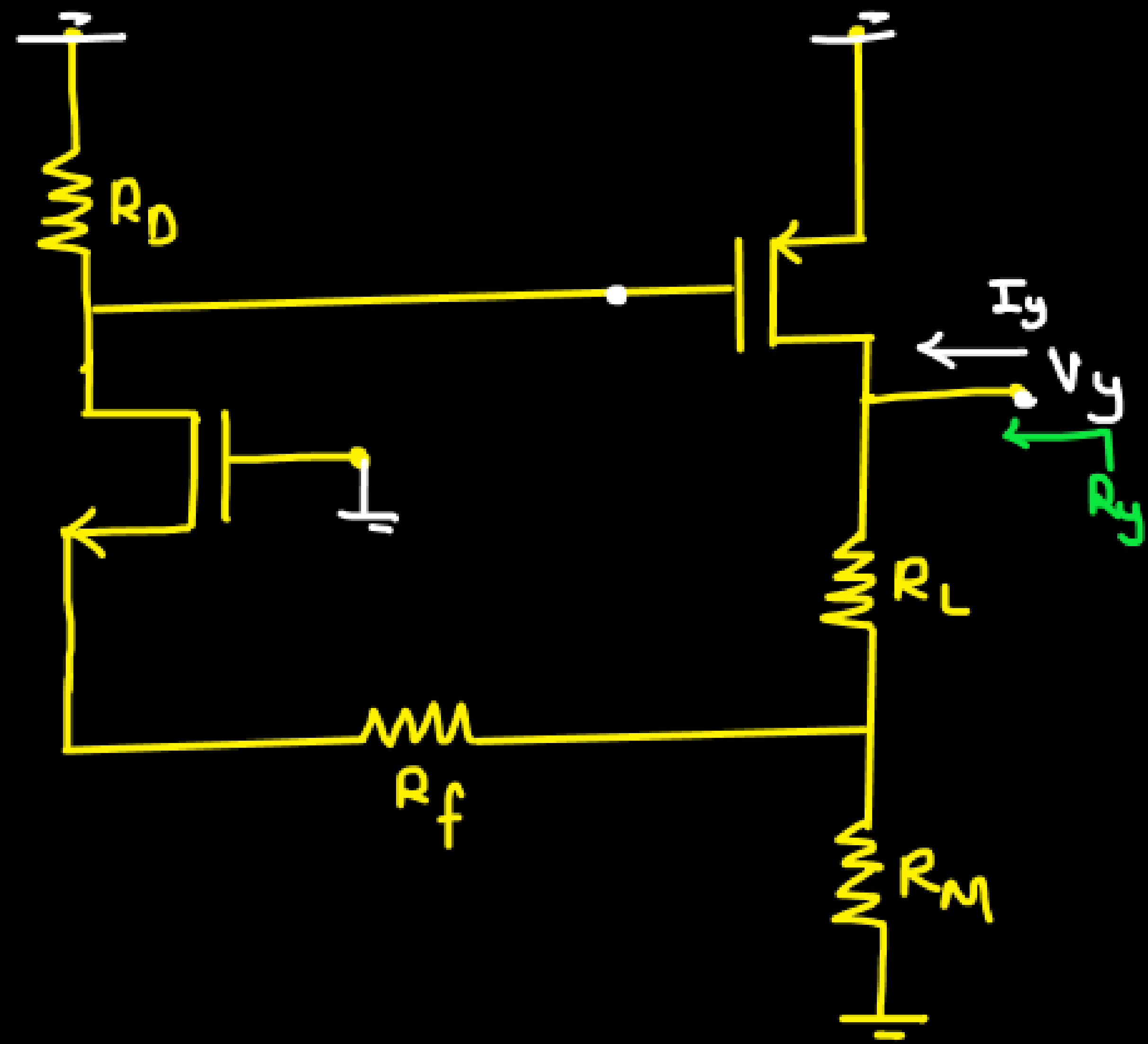
$\{ v_s \to \text{very small} \}$

$$I_s + I_a = g_{m1} v_s$$

$$I_s - g_{m1} g_{m2} R_D \left(\frac{R_M}{R_M + R_f} \right) v_s = g_{m1} v_s$$

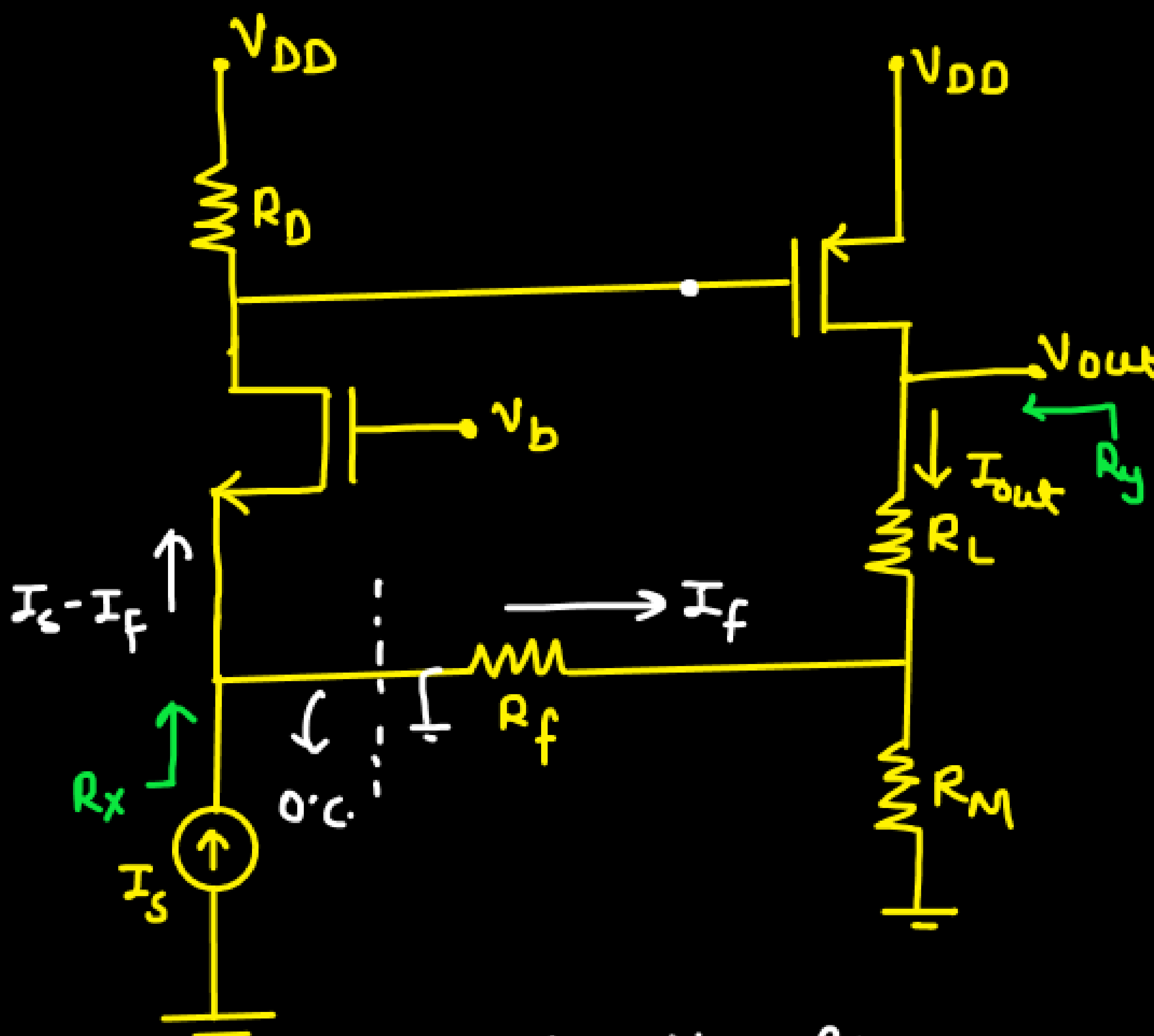
$$I_s = \left[g_{m_1} + g_{m_1} g_{m_2} R_D \left(\frac{R_M}{R_M + R_f} \right) \right] V_s$$

$$\boxed{R_x = \frac{V_s}{I_s} = \frac{1/g_{m_1}}{1 + g_{m_2} R_D \left(\frac{R_M}{R_M + R_f} \right)}}$$

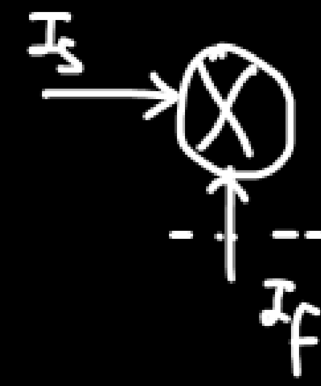


$$\boxed{R_y = \frac{V_y}{I_y}} \rightarrow \text{complex expression}$$

With the concept of f/b Topology:-

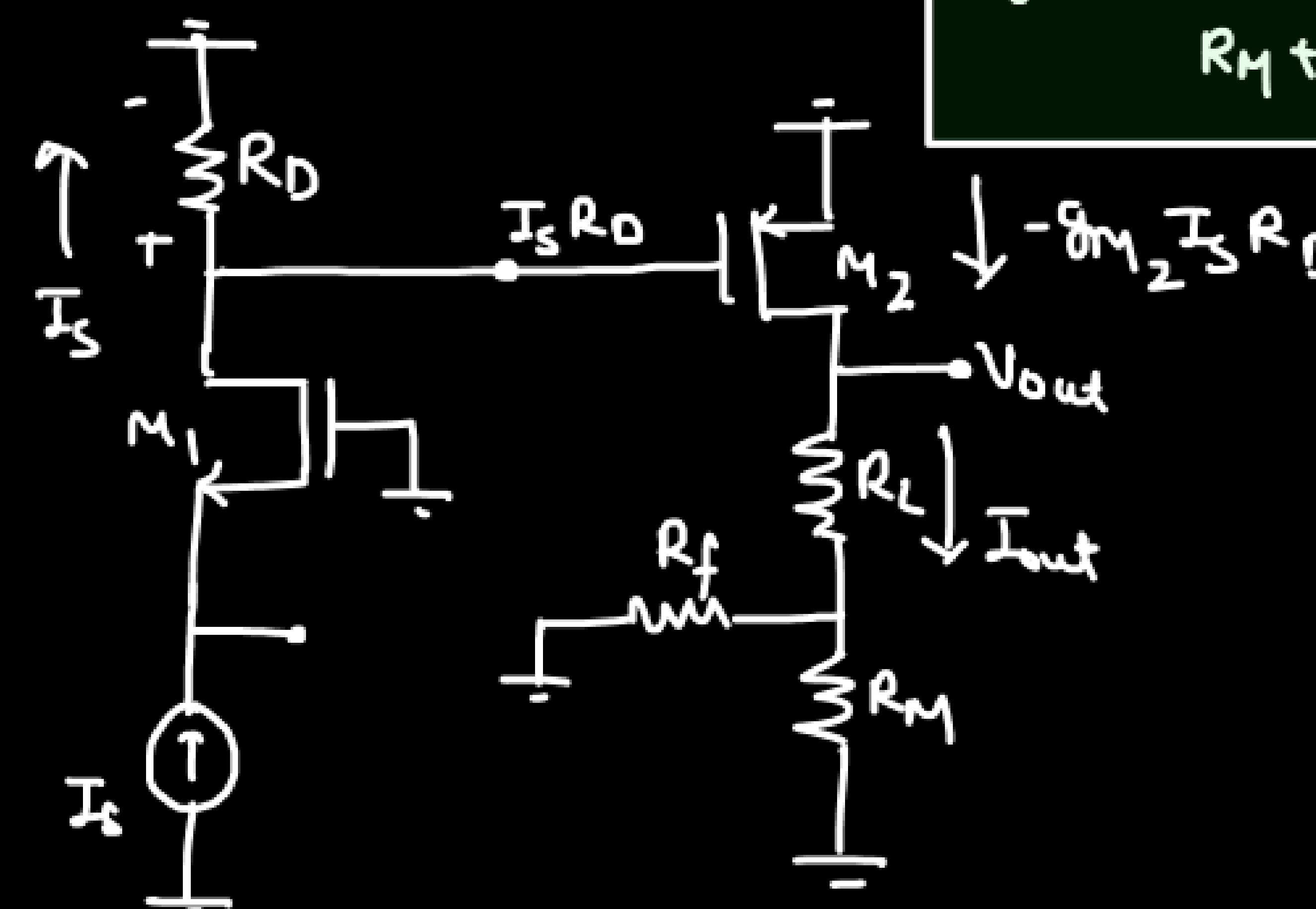


Negative f/b



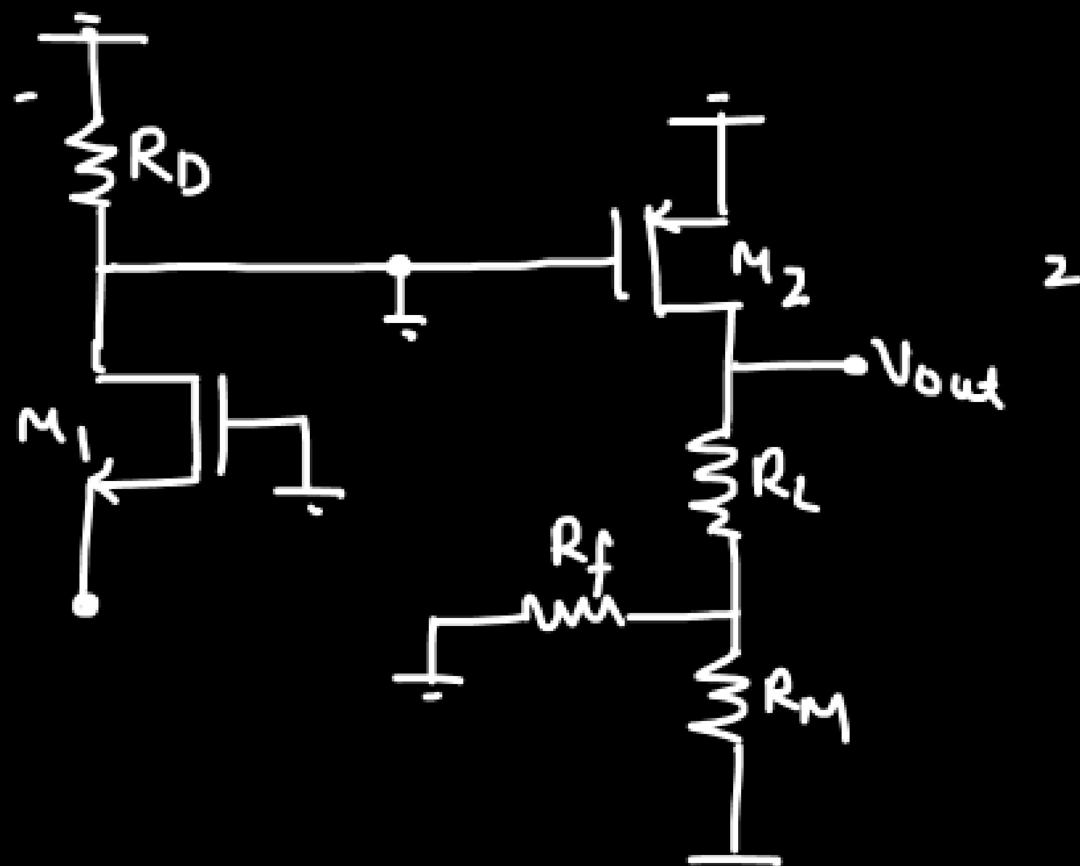
$$I_f = \frac{-R_M}{R_M+R_f} I_{out}$$

$$\boxed{B_I = -\frac{R_M}{R_M+R_f}}$$



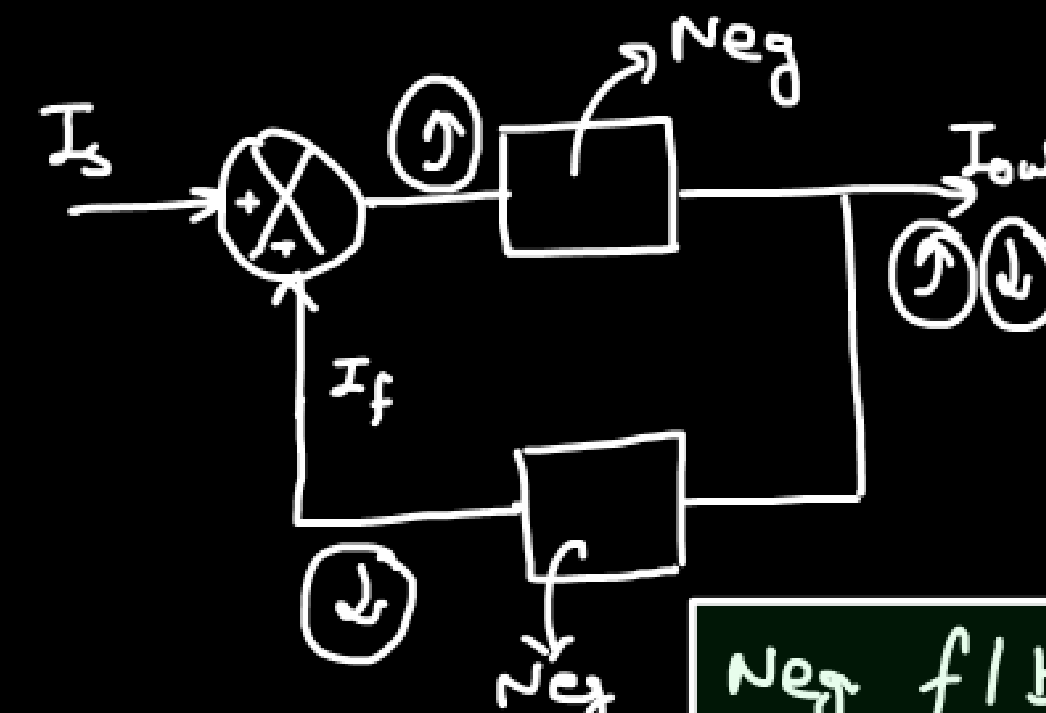
$$I_{out} = -g_{M_2} I_s R_D$$

$$\boxed{\left(\frac{I_{out}}{I_s}\right)_{O.L.} = -g_{M_2} R_D}$$



$$\boxed{(R_i)_{o.L.} = \frac{1}{g_{m_1}}}$$

$$\boxed{(R_o)_{o.L.} = \left(R_L + R_M \| R_f\right)}$$



① $$\boxed{\text{Closed loop gain} = \frac{-g_{m_2}R_D}{1 + g_{m_2}R_D\left(\frac{R_M}{R_M+R_f}\right)}}$$

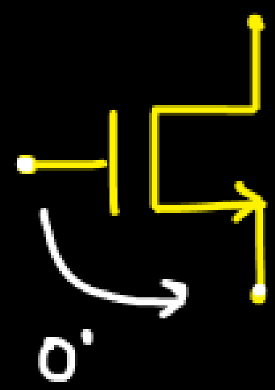
Neg f/b

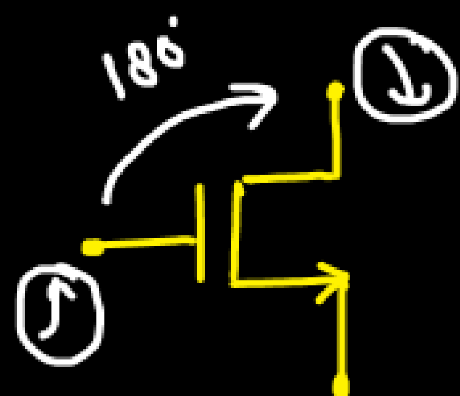
② $$\boxed{R_x = \frac{1/g_{m_1}}{1+g_{m_2}R_D\left(R_M/R_M+R_f\right)}}$$

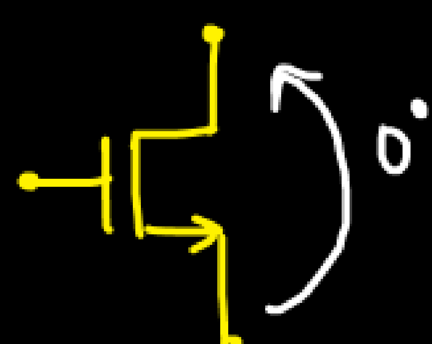
③ $$\boxed{R_y = \left(R_L + R_M \| R_f\right)\left(1 + g_{m_2}R_D\left\{\frac{R_M}{R_M+R_f}\right\}\right)}$$

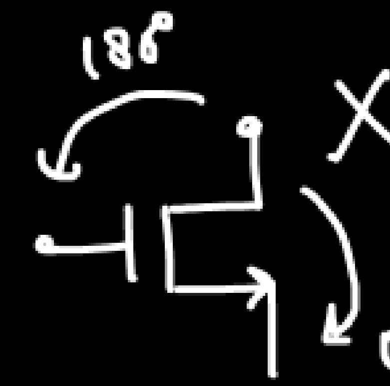
★★★★

Type of feedback Topology	Forward Gain (open loop)	Feedback Factor (β)	Closed loop Gain	Closed loop Input impedance	Closed loop o/p impedance
1. Voltage - voltage	A_V	β_V	$\frac{A_V}{1+A_V\beta_V}$	$R_{in}(1+A_V\beta_V)$	$R_o/1+A_I\beta_I$
2. Voltage - Current	R_m	G_m	$\frac{R_M}{1+G_mR_M}$	$\frac{R_{in}}{1+G_mR_m}$	$\frac{R_o}{1+G_mR_M}$
3. Current - Voltage	G_m	R_m	$\frac{G_m}{1+R_mG_m}$	$R_{in}(1+G_mR_m)$	$R_o(1+G_mR_m)$
4. Current - Current	A_I	β_I	$\frac{A_I}{1+A_I\beta_I}$	$\frac{R_{in}}{1+A_I\beta_I}$	$R_o(1+A_I\beta_I)$



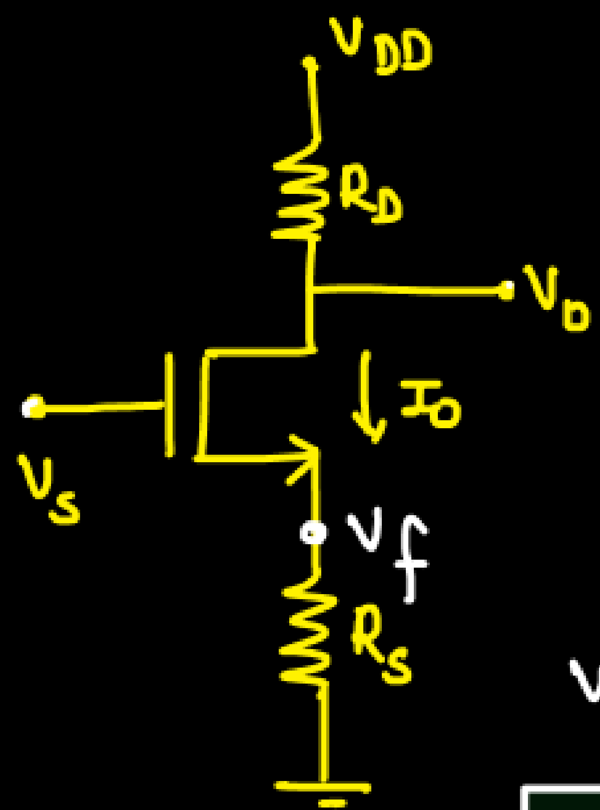






@ drain, you never apply i/p.

Q. Determine the type of feedback and feedback factor.



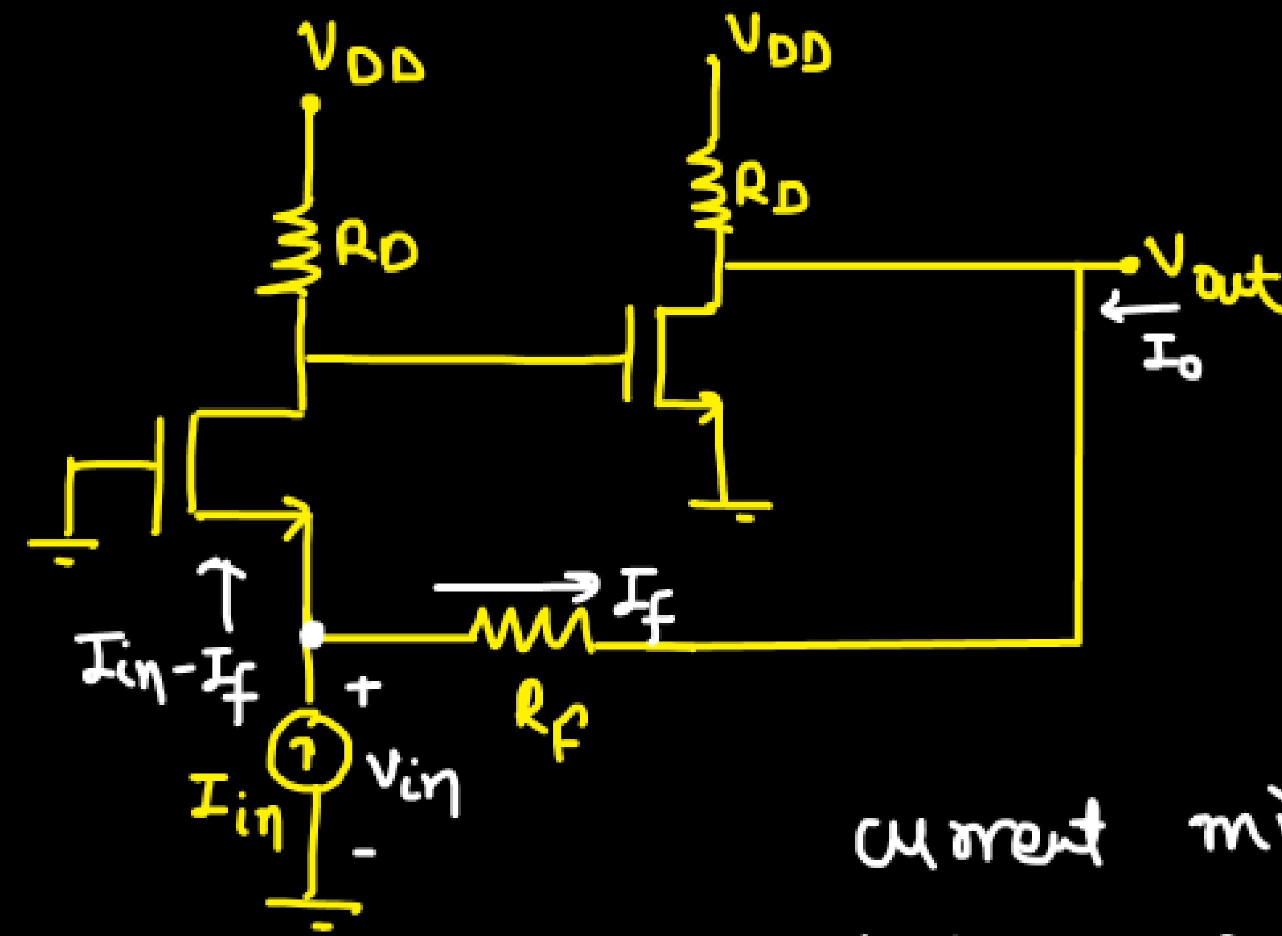
$V_f = I_o R_s$

$$\boxed{R_m = \frac{V_f}{I_o} = R_s}$$

(a)

current sampled
voltage mixing

Current - Voltage



(b)

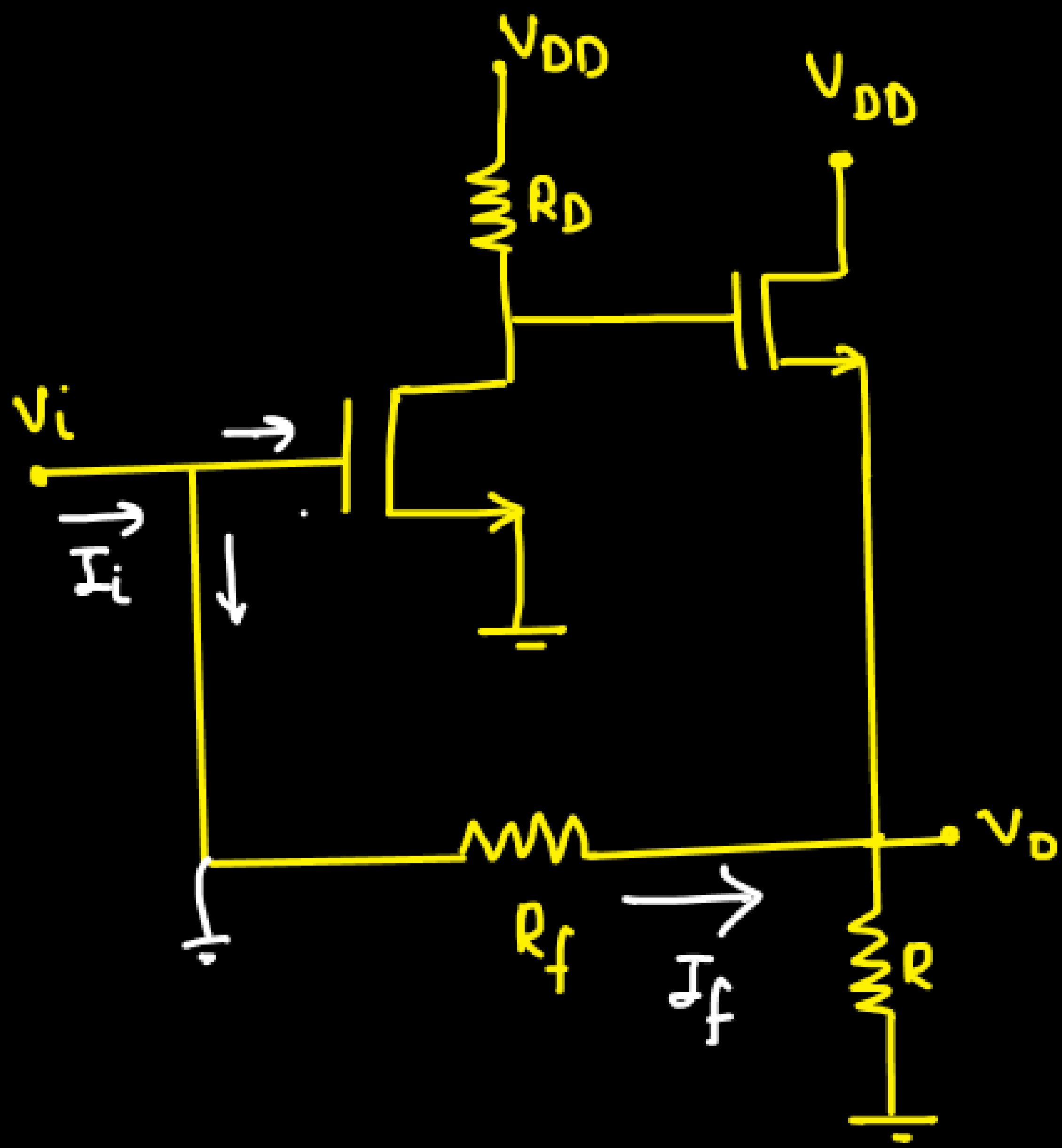
$$\frac{V_o}{R_f} = -I_f$$

$$\boxed{\frac{I_f}{V_o} = -\frac{1}{R_f}}$$

current mixing
Voltage sampling

⇒ **Voltage - Current**

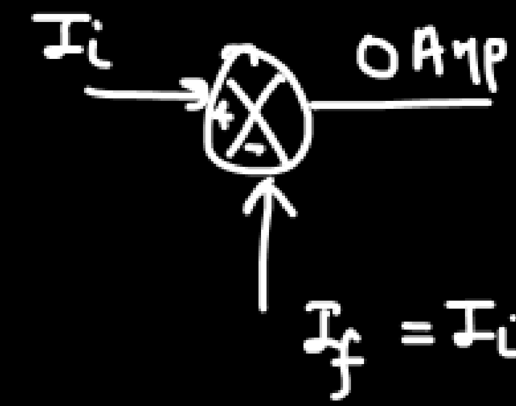
⇐ $(R_{in})_f \to$ low ⇒ $v_{in} \to 0$



(c)

current mixing

voltage sampling



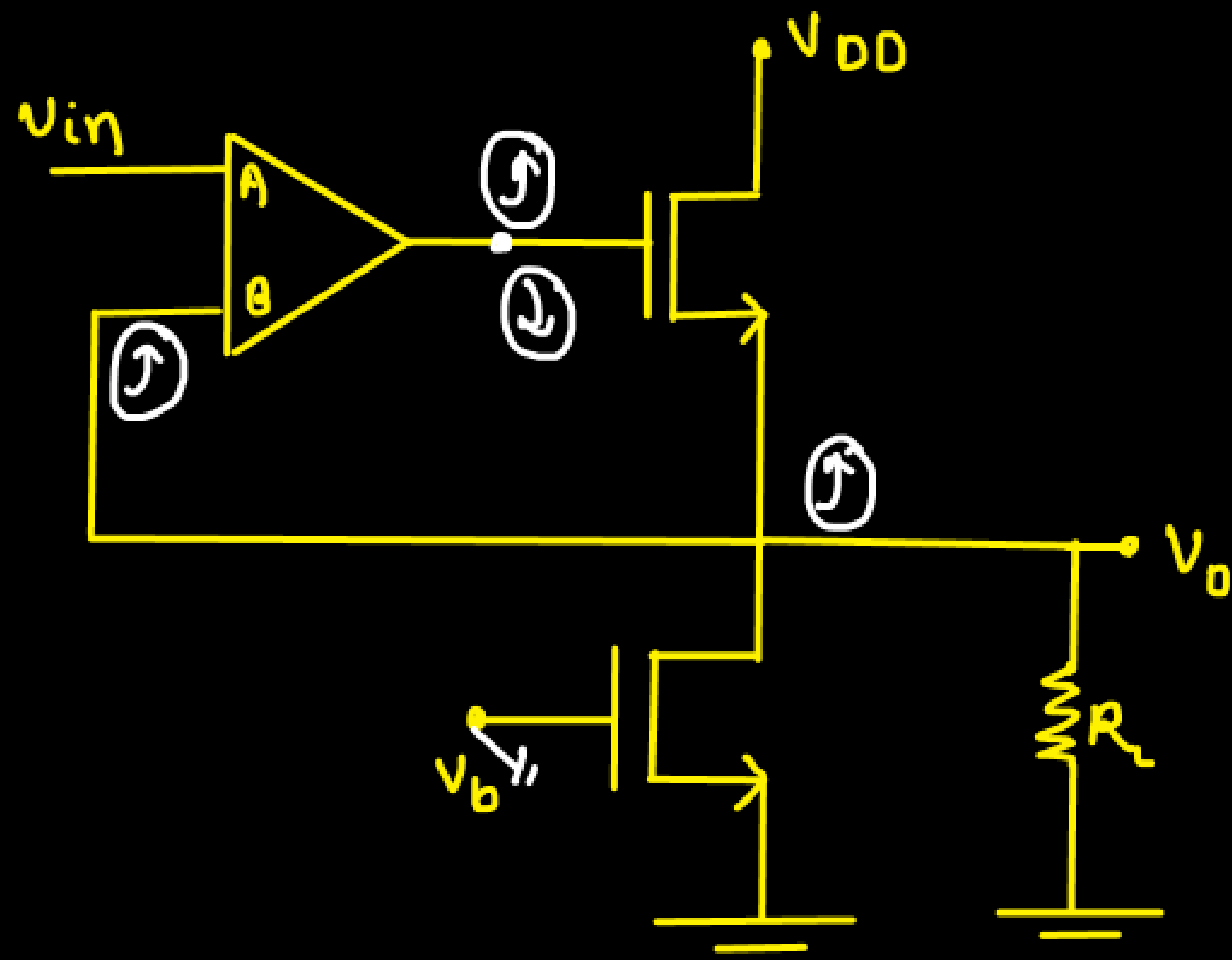
$$I_f = \frac{-V_o}{R_f}$$

$$\boxed{\frac{I_f}{V_o} = -\frac{1}{R_f}}$$

** $\boxed{\text{Voltage - Current}}$

$R_{in} \rightarrow$ low $\Rightarrow V_{in} \rightarrow$ low

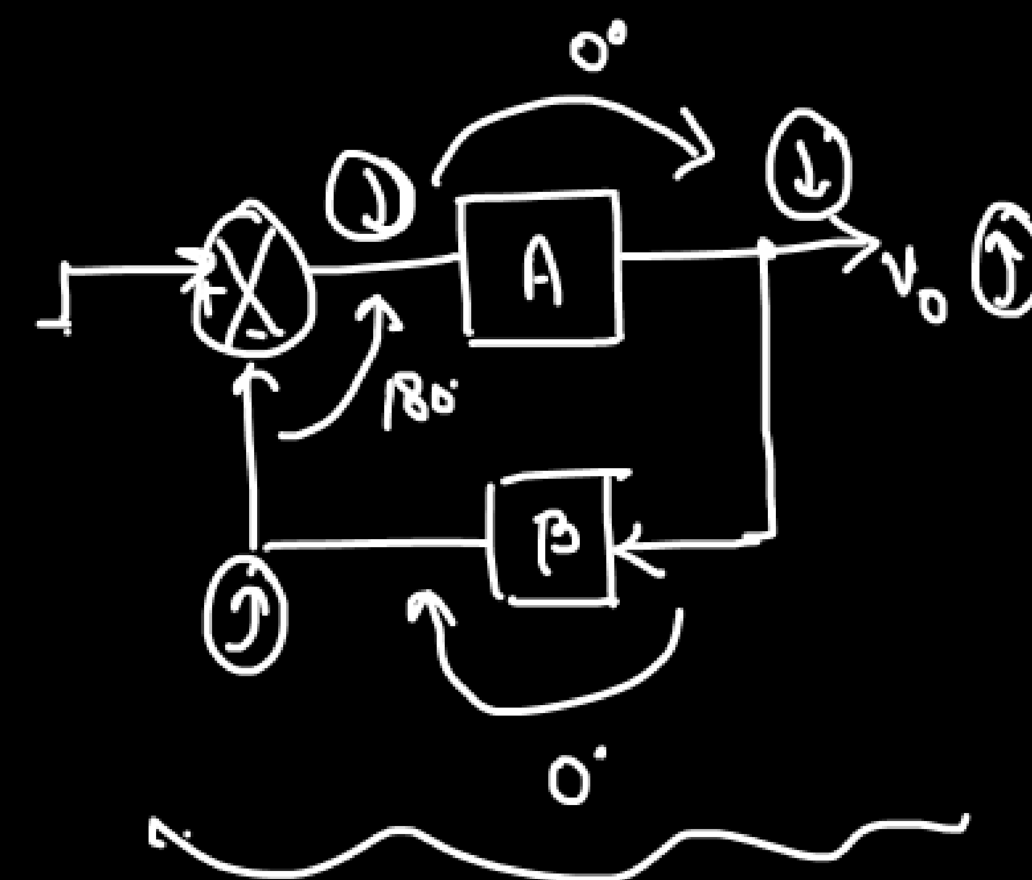
Q. Determine the sign of A and B for Negative f/b.



(a)

$B \rightarrow -ve$

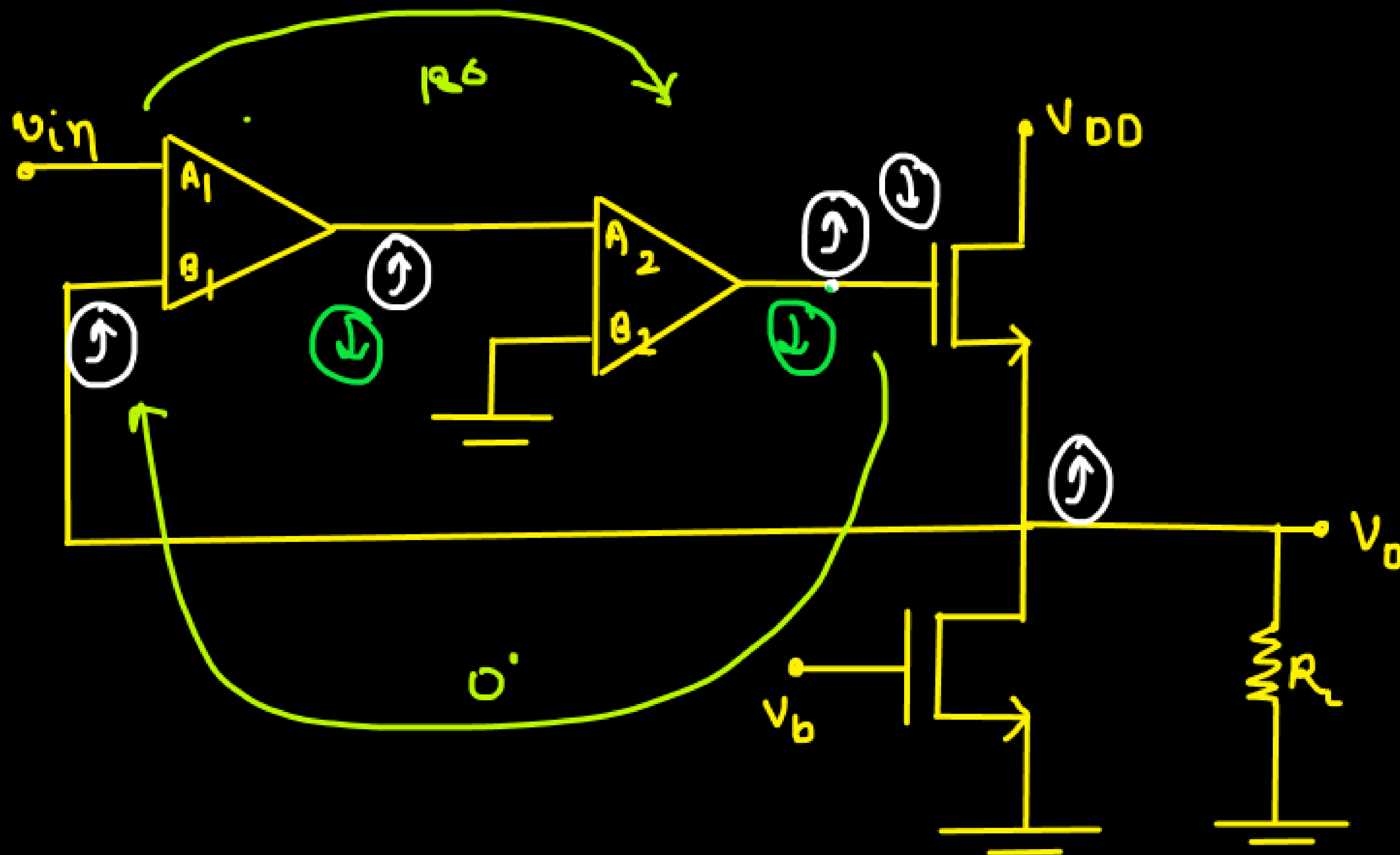
$A \rightarrow +ve$



Neg f/b → 180°, 540° ... $(2n+1)180°$

Pos f/b → 0°, 360° ... $360°n$

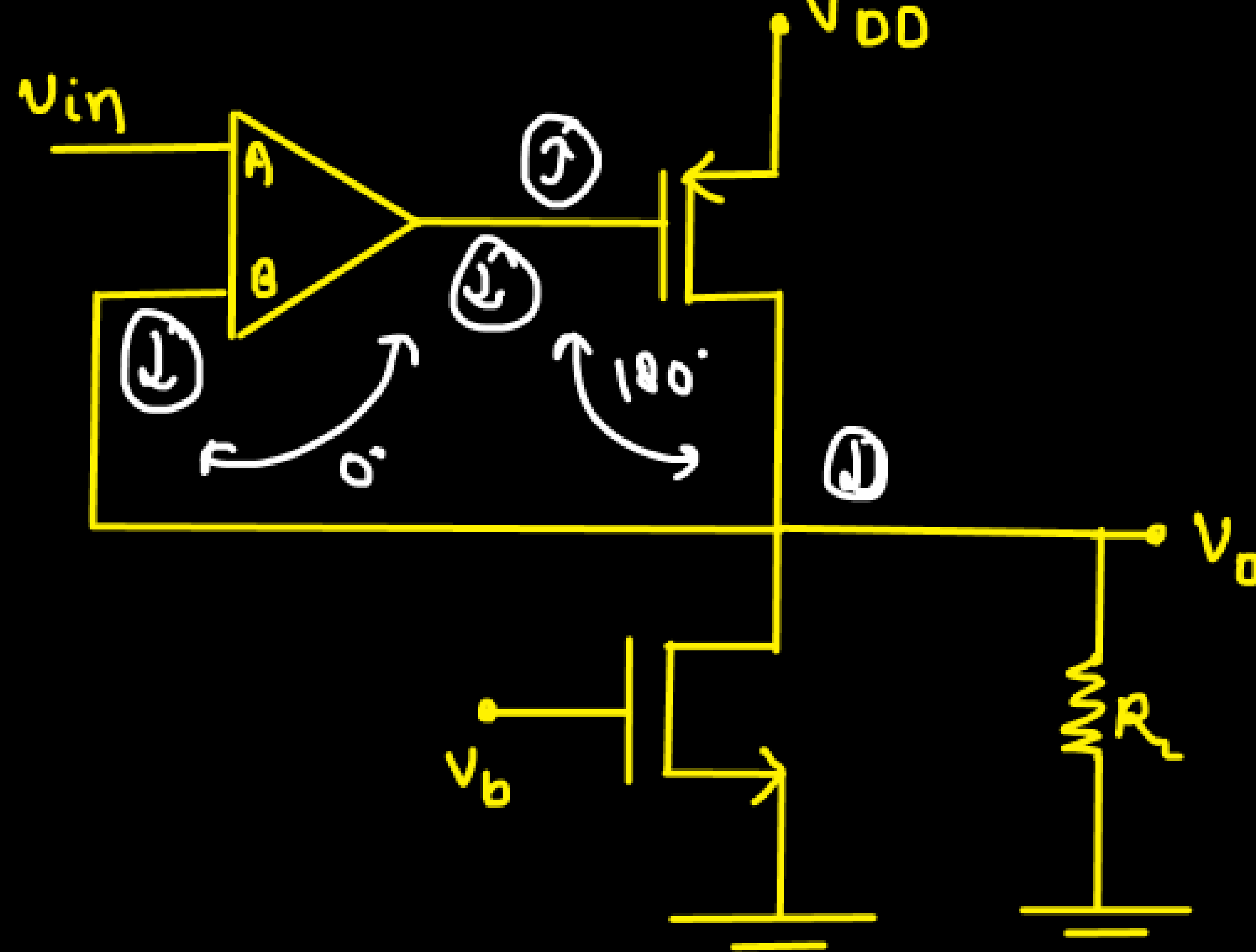
$\Rightarrow \underline{\underline{180°}}$



(b)

① if $A_1 = -ve$, $B_1 = +ve$ $\Rightarrow$ $A_2 = -ve$, $B_2 = +ve$

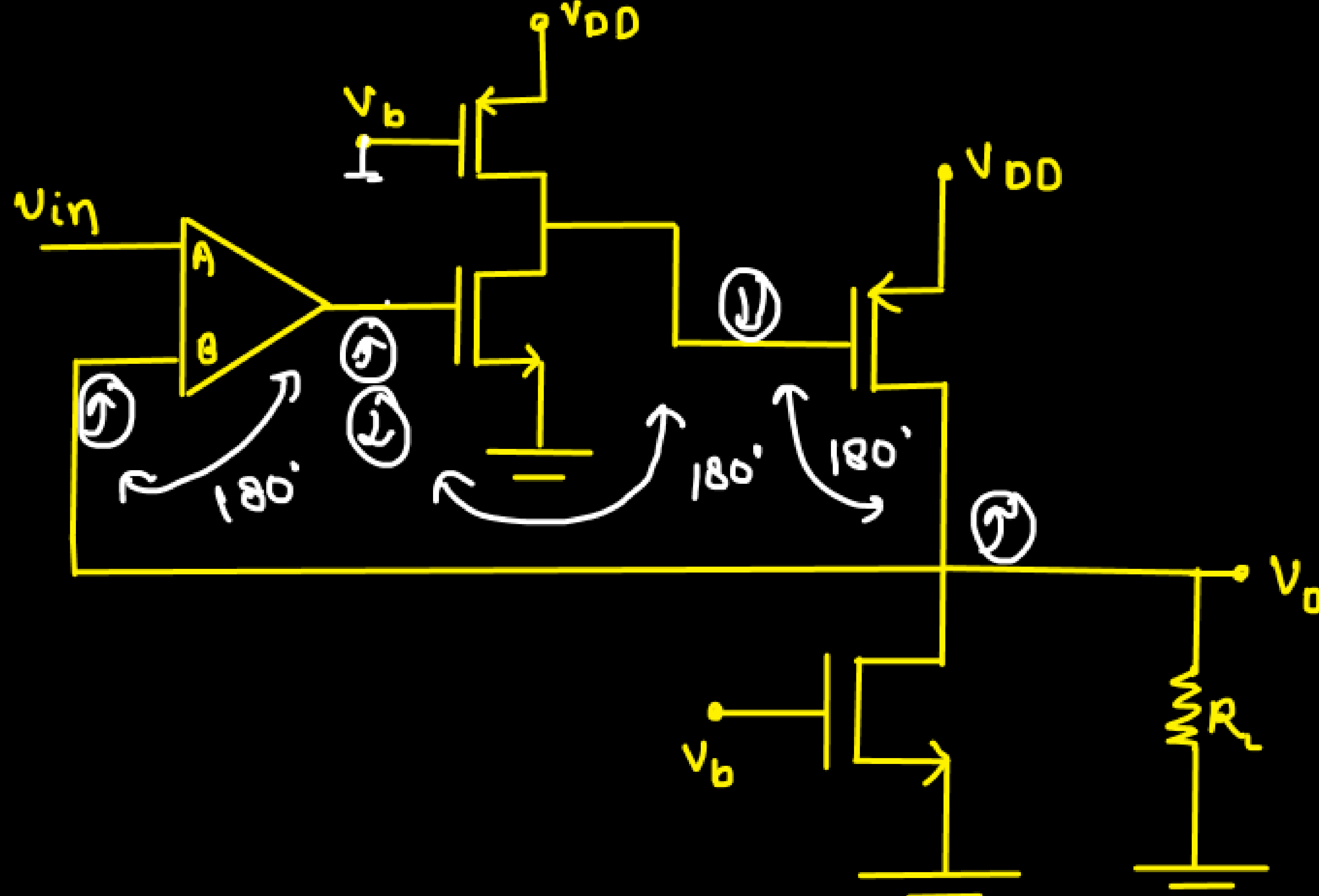
② if $A_1 = +ve$, $B_1 = -ve$ $\Rightarrow$ $A_2 = +ve$, $B_2 = -ve$



(c)

B = +ve

A = -ve



(d)

B = -ve

A = +ve