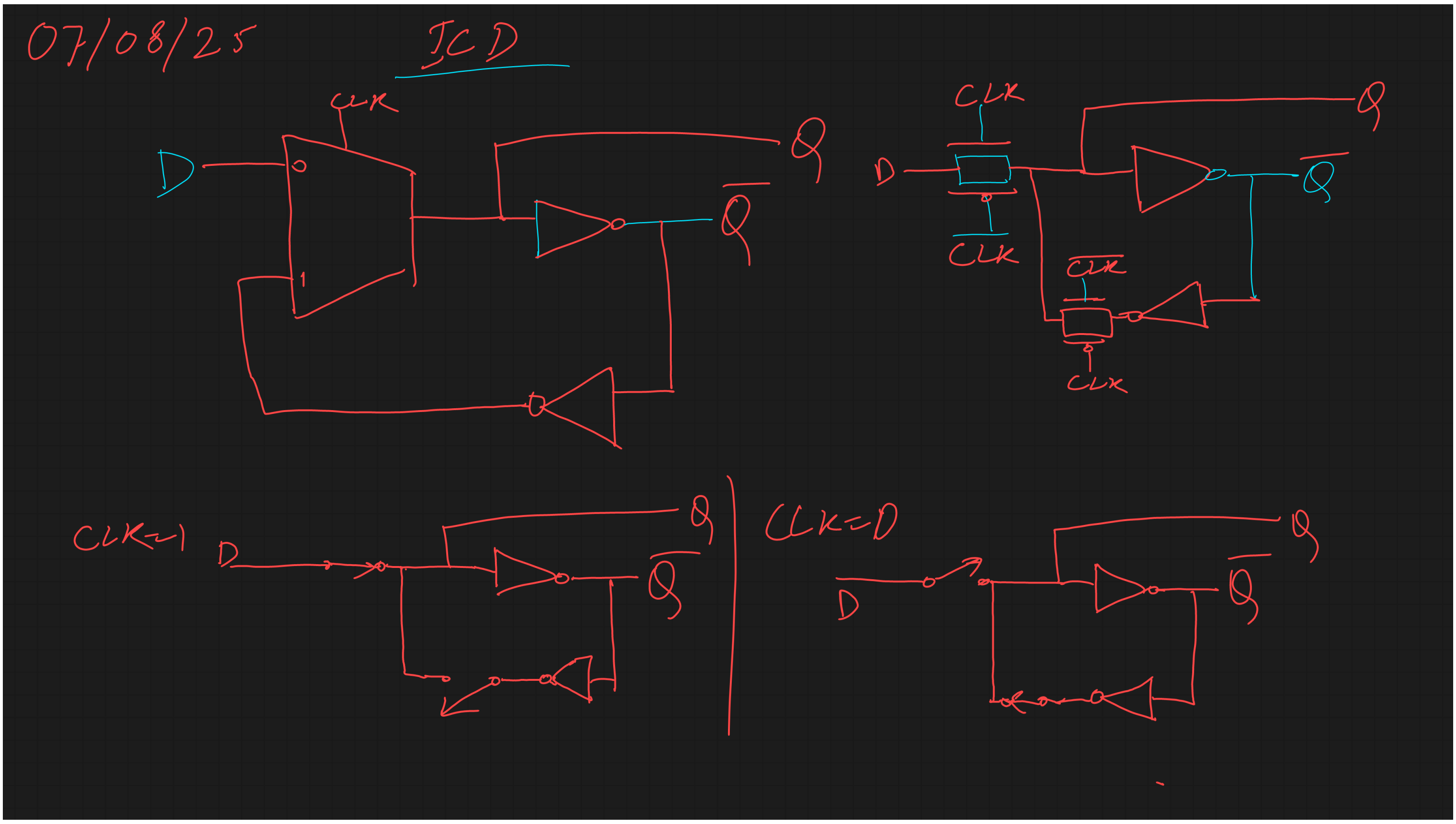
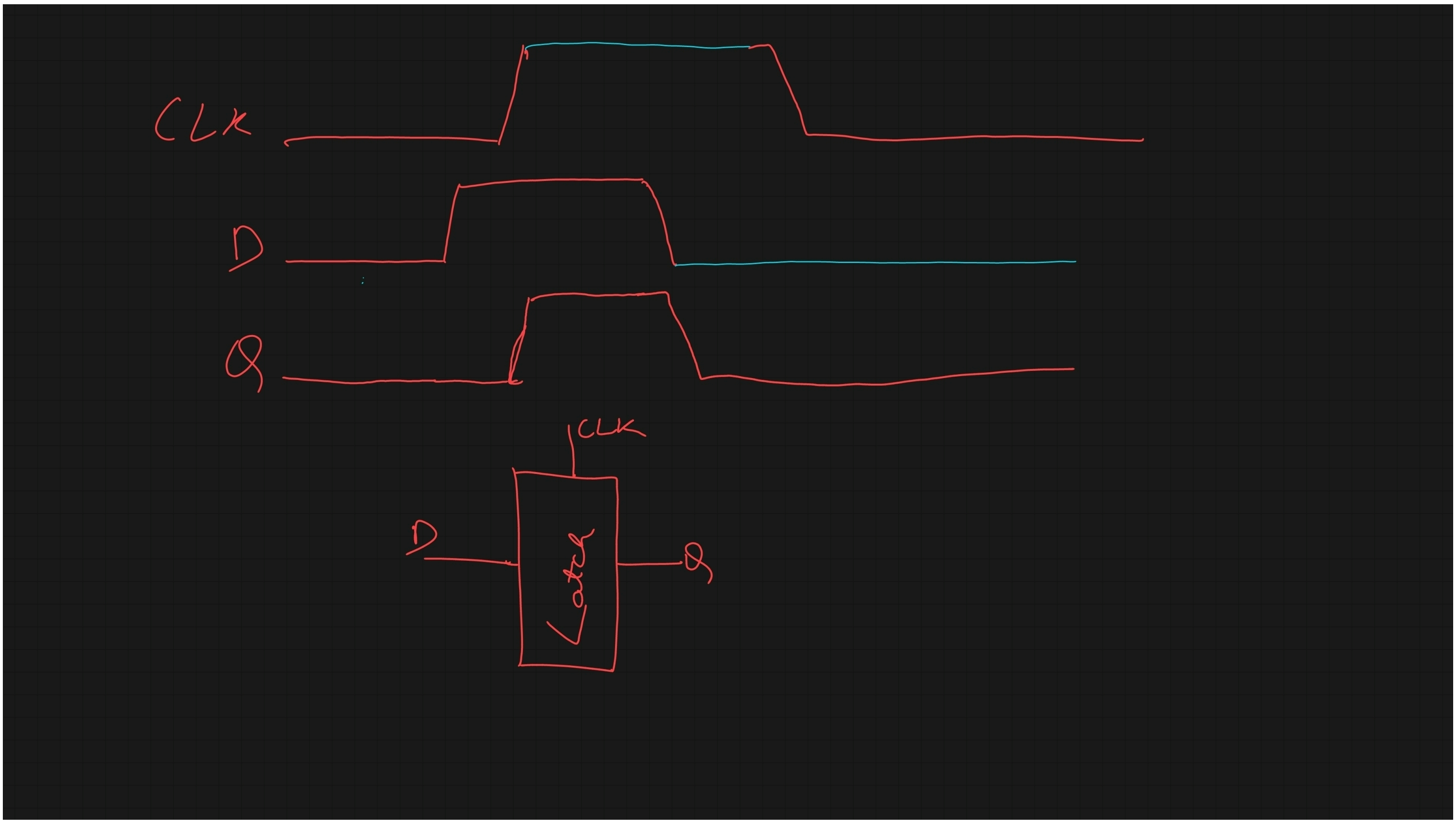
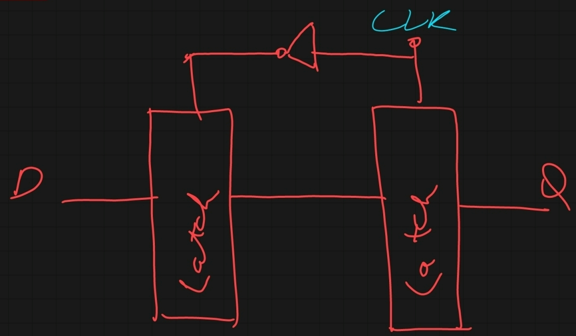
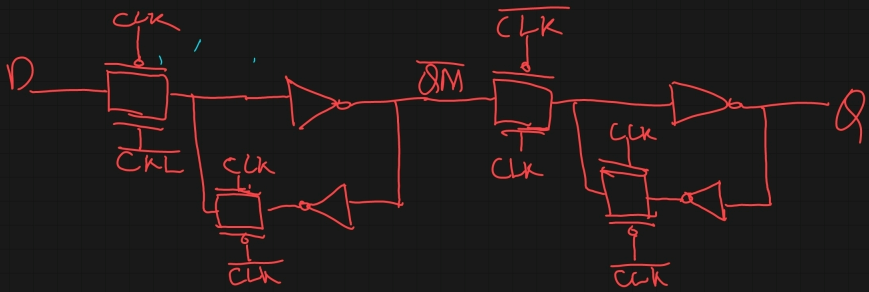

07/08/25
ICD
CLK
D
Q
$\overline{Q}$
0
1
CLK
D
Q
$\overline{Q}$
$\overline{CLK}$
CLK
$\overline{CLK}$
CLK
CLK=1
D
Q
$\overline{Q}$
CLK=0
D
Q
$\overline{Q}$

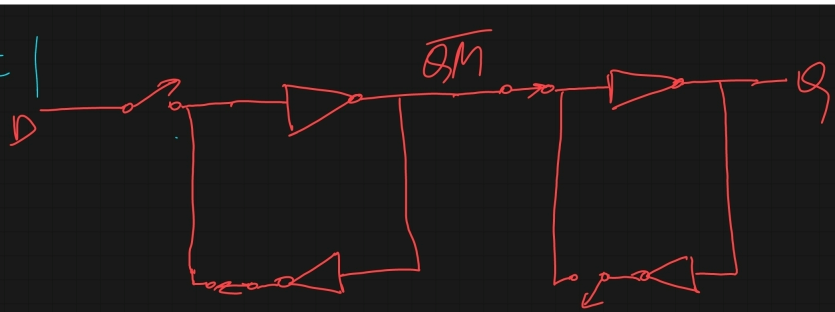

CLK
D
Q
CLK
D
Latch
Q

Flip-Flop :-

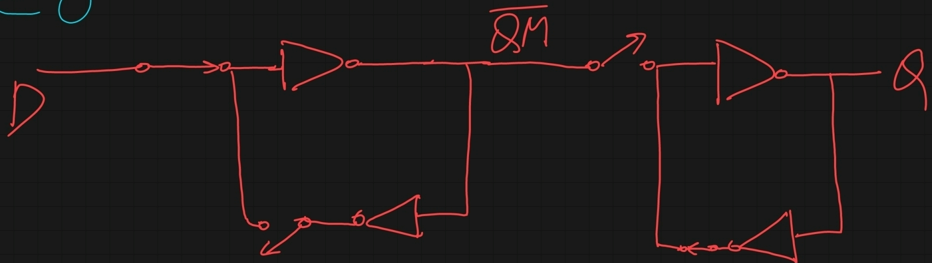


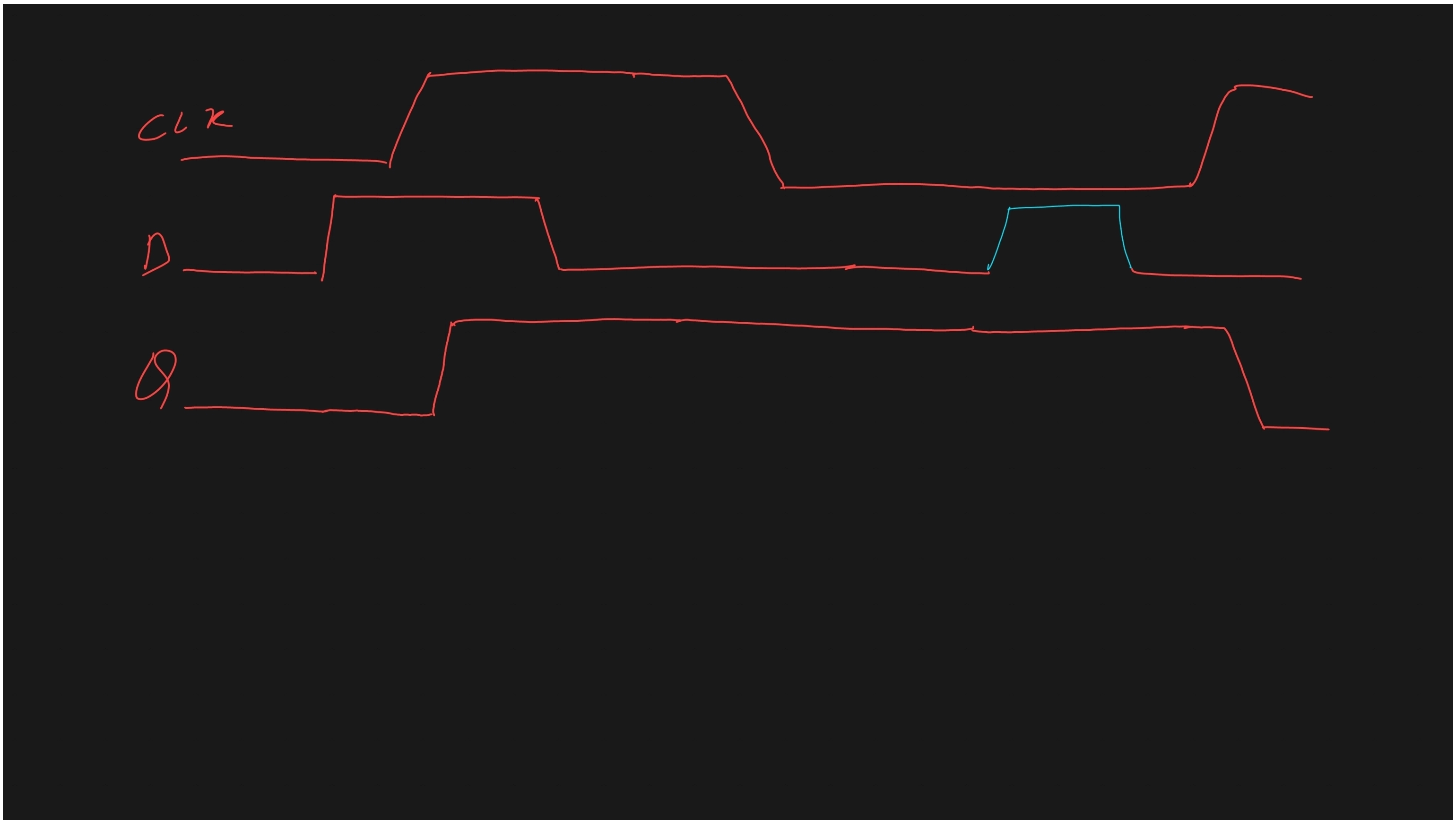


CLK = 1

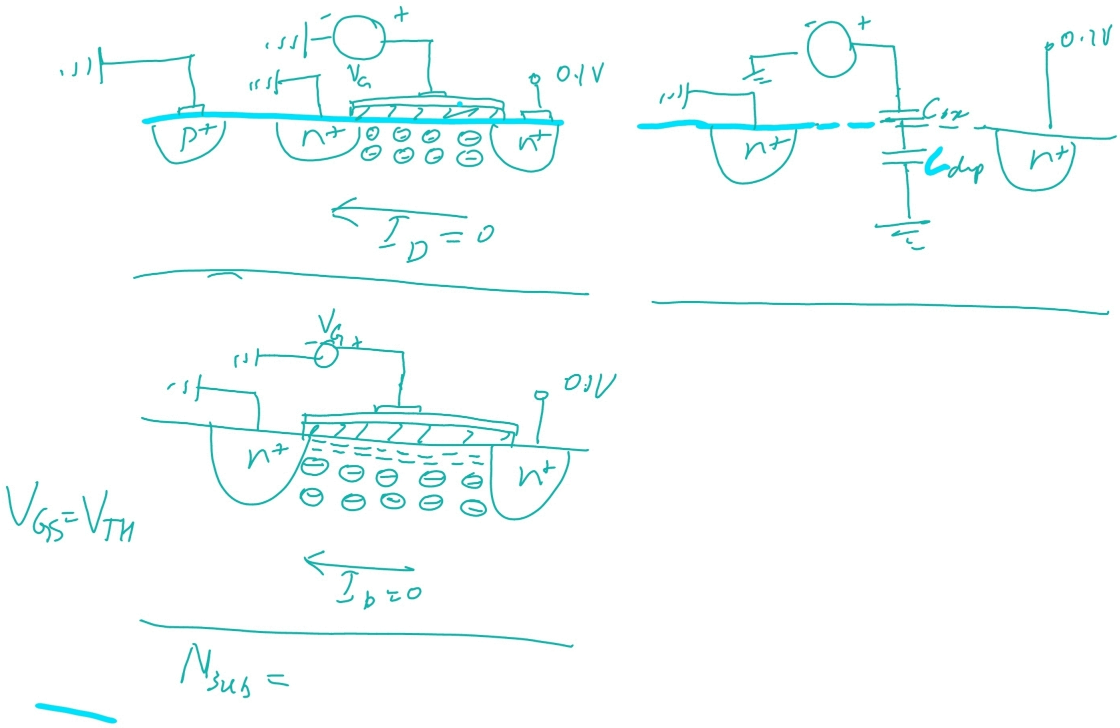


CLK = 0





20/08/25

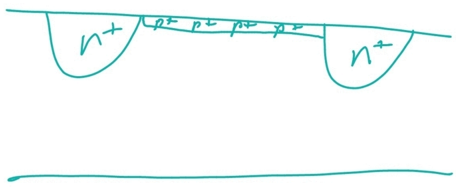


$$V_{TH} = \Phi_{MS} + 2\Phi_F + \frac{Q_{dep}}{C_{ox}}$$

where, $\Phi_F = (kT/q)\ln(N_{sub}/n_i)$

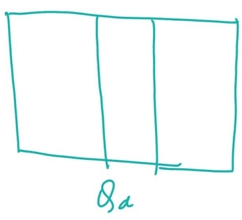
$$Q_{dep} = \sqrt{4q\epsilon_{si}|\Phi_F|N_{sub}}$$

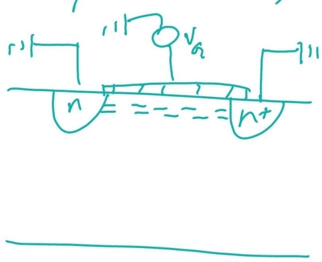
$C_{ox} = 6.9\ fF/\mu m^2$ for $t_{ox} = 50\ \text{Å}$.

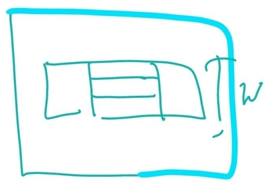


$$I_d = Q_d\, v$$

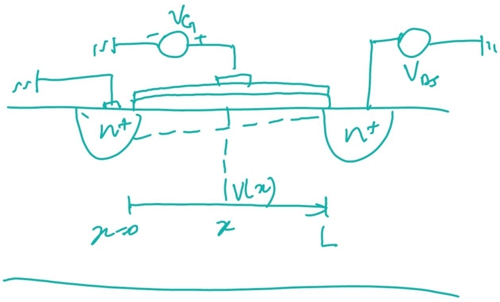
where, Q_d (coulombs per meter)







$$Q_d = W C_{ox}(V_{GS} - V_{TH})$$



$$Q_d = WC_{ox}(V_{GS} - V(x) - V_{TH})$$

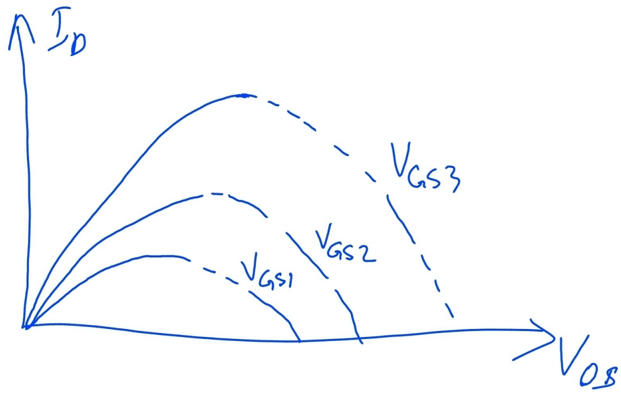
$$I_d = -WC_{ox}(V_{GS} - V(x) - V_{TH})v$$

$$I_d = WC_{ox}(V_{GS} - V(x) - V_{TH})\mu_n \frac{dV(x)}{dx}$$

$$\int_{x=0}^{x=L} I_d\,dx = \int_{V_D=0}^{V_{DS}} WC_{ox}(V_{GS} - V(x) - V_{TH})\mu_n\, d(V(x))$$

$$v = \mu E = -\mu \frac{dV(x)}{dx}$$

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

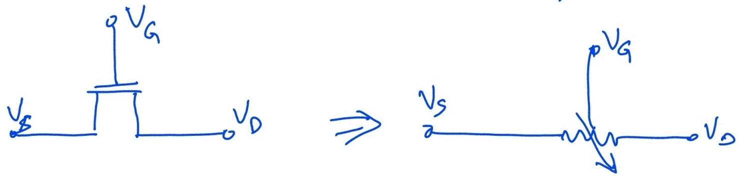


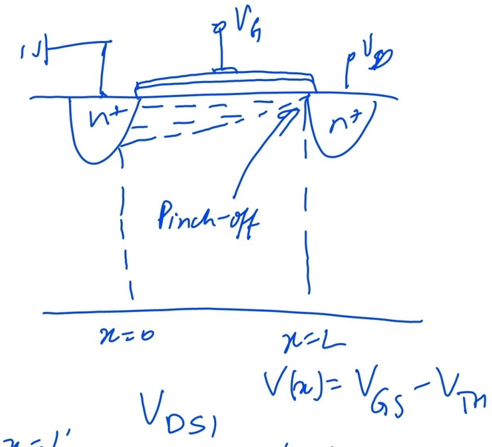
$V_{GS} - V_{TH} =$

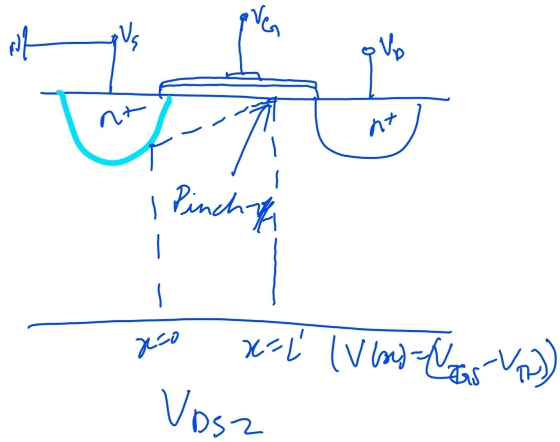
For $V_{DS} << V_{GS} - V_{TH}$

$$I_d = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{TH})V_{DS}\right]$$

$$R_o = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})}$$

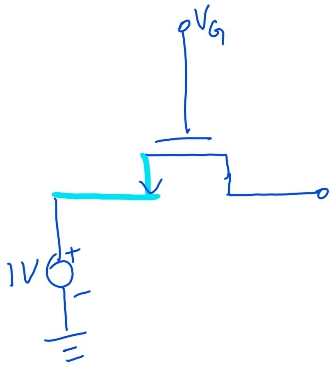






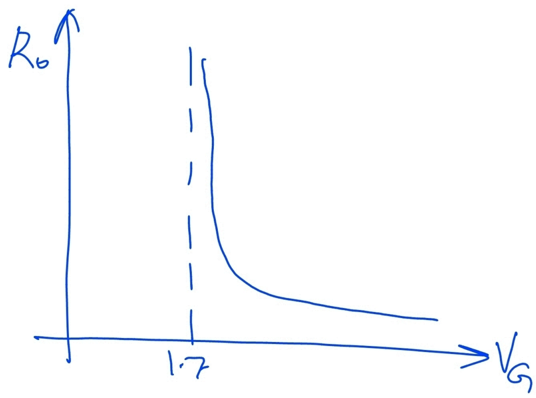
$$\int_{x=0}^{x=L'} I_d\,dx = \int_0^{V_{GS}-V_{TH}} \mu_n C_{ox} \frac{W}{L} \left[V_{GS} - V(x) - V_{TH} \right]$$

$$I_d = \frac{\mu_n C_{ox}}{2} \frac{W}{L'} \left[V_{GS} - V_{TH} \right]^2 \qquad L \approx L'$$



$$R_o = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})}$$

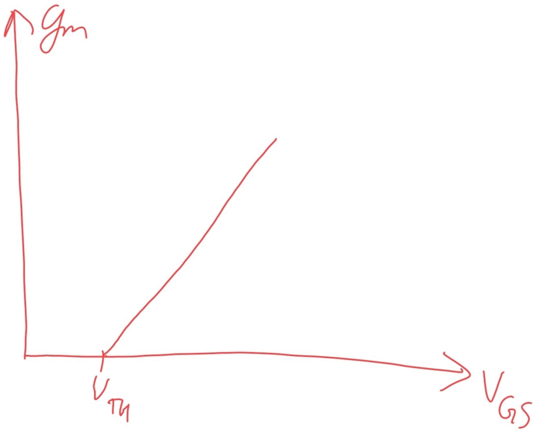
$$R_o = \frac{1}{50 \times 10^{-6} \times 10 (V_G - 1 - 0.7)} = R_o = \frac{1}{5 \times 10^{-4} \times (V_G - 1.7)}$$



Saturation Mode $(V_{DS} > V_{GS} - V_{TH})$

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

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



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

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

$$\Rightarrow g_m = \sqrt{\left(\frac{2}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})\right)^2}$$

$$\Rightarrow g_m = \sqrt{2\left(\mu_n C_{ox} \frac{W}{L}\right)\left(\frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2\right)}$$

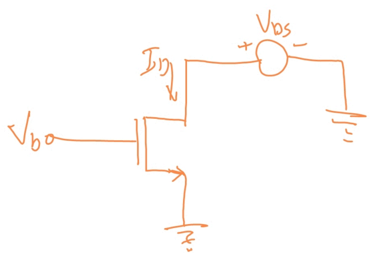
$$\Rightarrow \boxed{g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D}}$$

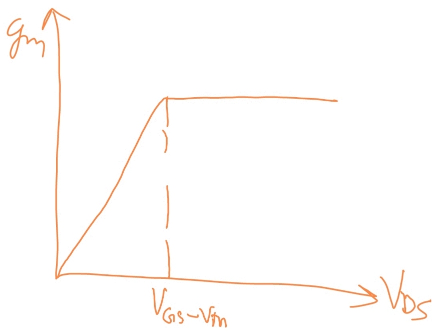
$$g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS}-V_{TH})$$

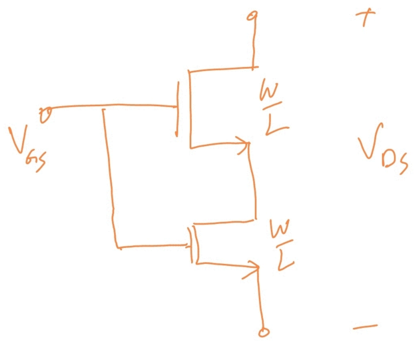
$$\Rightarrow g_m = \frac{2}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH}) \times \frac{(V_{GS}-V_{TH})}{(V_{GS}-V_{TH})}$$

$$\Rightarrow \boxed{g_m = \frac{2 I_D}{(V_{GS}-V_{TH})}}$$

S $\rightarrow$







$$\boxed{V_{TH} = \phi_{MS} + 2\phi_F + \frac{Q_{dep}}{C_{ox}}}$$

$$\boxed{\epsilon_{Si} = 11.7 \times 8.85 \times 10^{-14}}$$

$$L' = L - \Delta L = L\left(1 - \frac{\Delta L}{L}\right)$$

$$\Rightarrow \frac{1}{L'} = \frac{1}{L} \cdot \frac{1}{(1 - \Delta L/L)} = \frac{1}{L}(1 - \Delta L/L)^{-1}$$

$$\Rightarrow \frac{1}{L'} = \frac{1}{L}\left(1 + \frac{\Delta L}{L}\right) \quad \text{———} \quad (1)$$

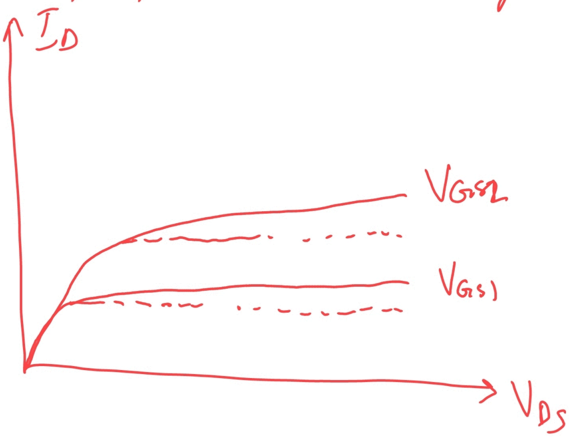
$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L'}(V_{GS} - V_{TH})^2$$

$$\Rightarrow I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2\left(1 + \frac{\Delta L}{L}\right)$$

$$\because \frac{\Delta L}{L} \propto V_{DS}$$

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

where, λ = channel length coefficient.



$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})(1 + \lambda V_{DS})$$

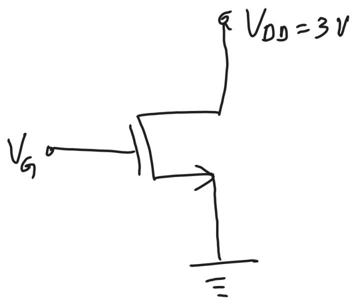
$$\lambda \propto \frac{1}{L}$$

$$r_o = \frac{1}{\lambda I_D}$$

Q→ Given: $W/L = 50/0.5$

$|V_{GS}| \Rightarrow (0, 3V)$

$V_{DS} = 3V$



NFET:-

For $V_{GS} < V_{TH}$

$I_D = 0$

For $V_{GS} > V_{TH}$

Since, $V_{DS} = 3V$ and $V_{GS} > V_{TH}$

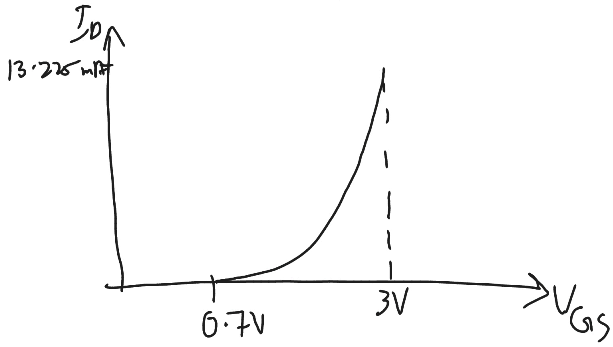
$\Rightarrow V_{DS} > V_{GS} - V_{TH}$ for all values of $V_{TH} < V_{GS} < 3V$

Therefore, the transistor is in saturation region. Hence,

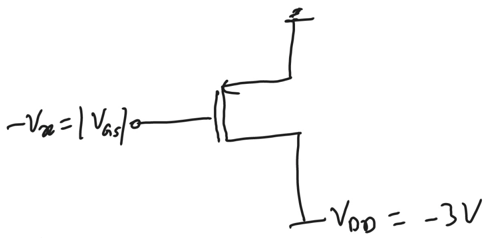
$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2$$

$$= \frac{1}{2}\times 50\left(\frac{\mu A}{V^2}\right)\cdot\frac{50}{0.5}(V_{GS}-V_{TH})^2$$

$$= 2.5\left(\frac{mA}{V^2}\right)(V_G-0.7)^2$$



PFET:

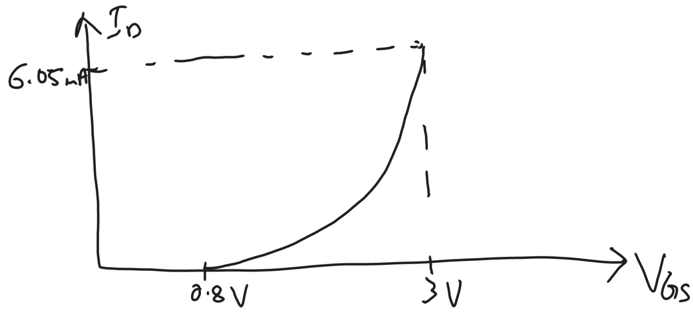


For $|V_{GS}| < V_{TH}$; $I_D = 0$

For $|V_{GS}| > V_{TH}$;

$$I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_x - V_{TH})^2 = \frac{1}{2}\left(25\left(\frac{\mu A}{V^2}\right)\right)\left(\frac{50}{0.5}\right)(V_x-0.8)^2$$

$$\Rightarrow 1.25(V_x-0.8)^2 \ (mA)$$



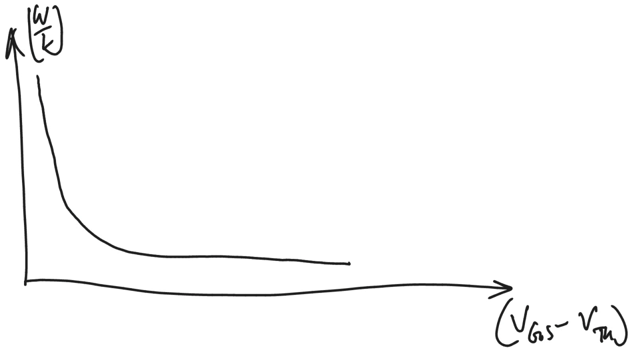
Q: Given: NMOS is in saturation mode.
Plot $\frac{W}{L}$ vs $(V_{GS}-V_{TH})$

a) I_D is constant:

In saturation,

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

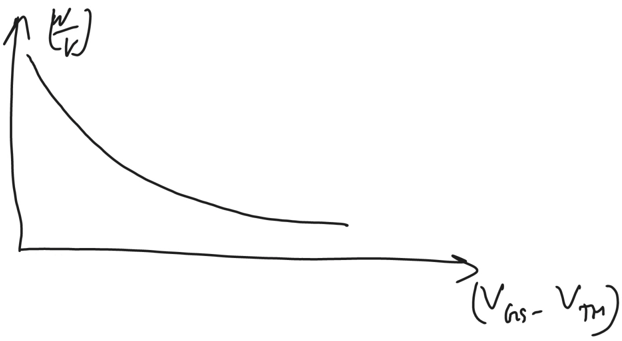
$$\Rightarrow \left(\frac{W}{L}\right) = \frac{2I_D}{\mu_n C_{ox}(V_{GS}-V_{TH})^2}$$



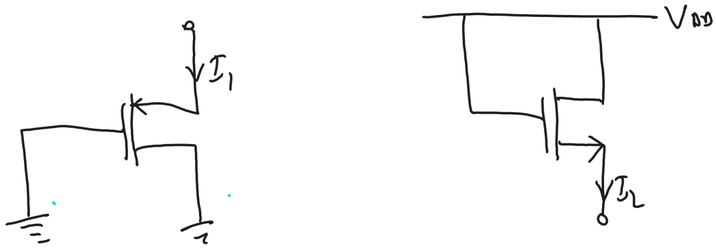
b) g_m is constant:

For saturation mode, $g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})$

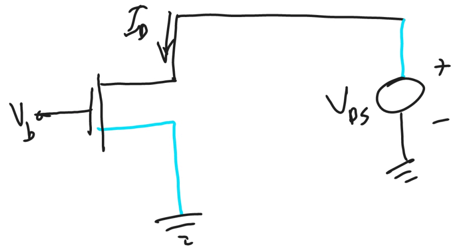
$$\left(\frac{W}{L}\right) = \frac{g_m}{\mu_n C_{ox}(V_{GS}-V_{TH})}$$



Q:- Explain why the structures shown in the figure below cannot operate as current source even the transistors are in saturation.



Q:

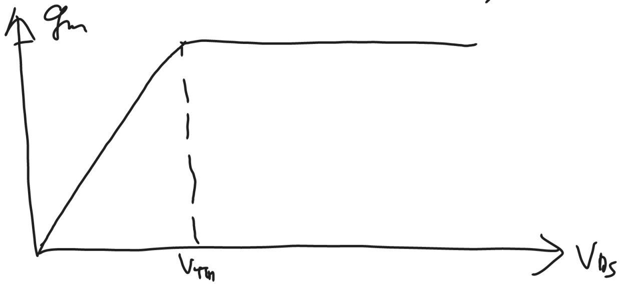


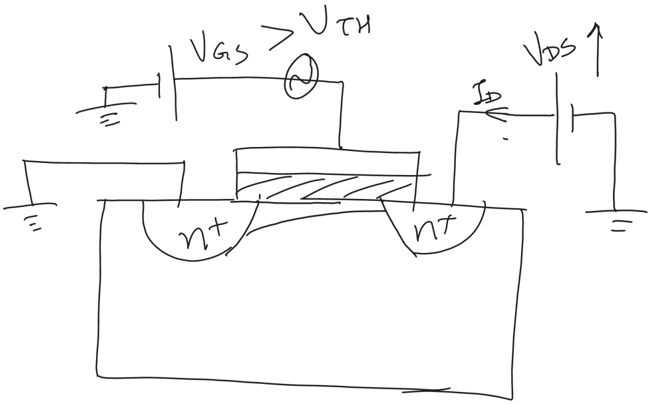
As, $V_{DS} \geq V_b - V_{TH}$, the transistor is in saturation mode.

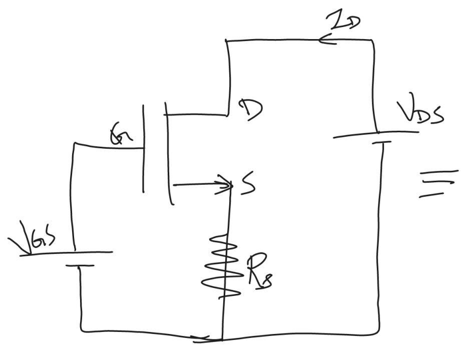
for, $V_{DS} < V_b - V_{TH}$, the transistor is working in triode region.

$$g_m = \frac{\partial}{\partial V_{GS}}\left\{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2(V_{GS}-V_{TH})V_{DS} - V_{DS}^2\right]\right\}$$

$$= \mu_n C_{ox}\frac{W}{L}V_{DS}$$







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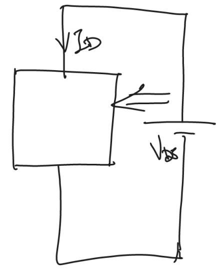

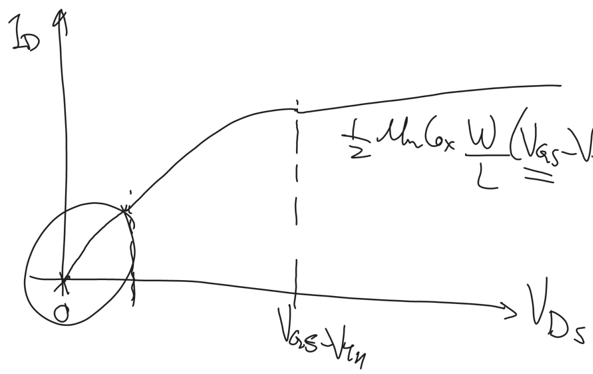

$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{DS})$$

$I_D \propto f(V_{DS})$

$$r_o = \frac{dV_{DS}}{dI_D} = \frac{1}{dI_D/dV_{DS}}$$

$$r_o = \frac{1}{\left\{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2\right\}\lambda}$$

$$r_o \approx \frac{1}{\lambda I_D}$$

Small Signal Model

- SSM represents time varying quantities
- All constant sources should be made zero