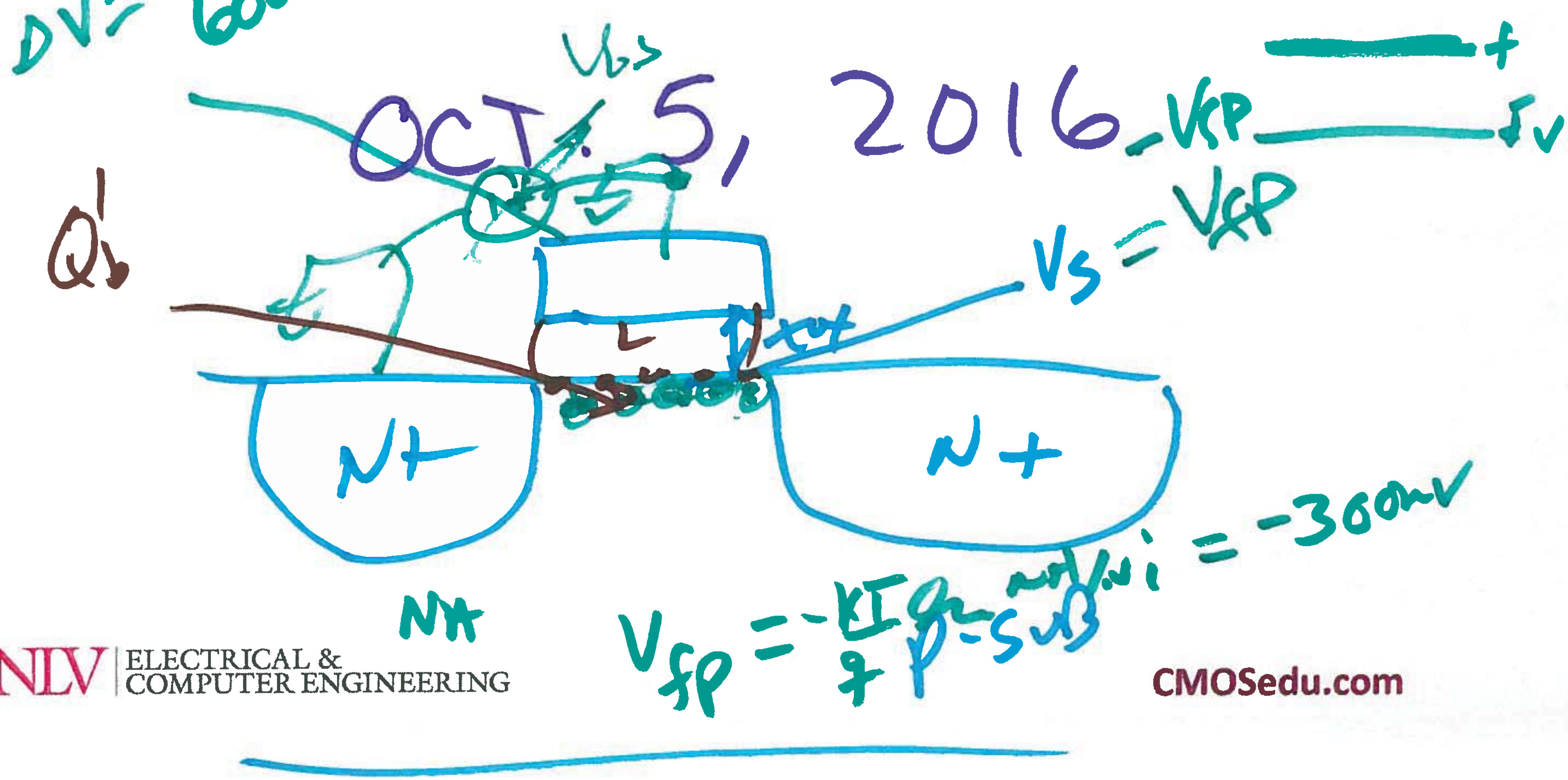
EE 421/ECG 621

Digital IC Design

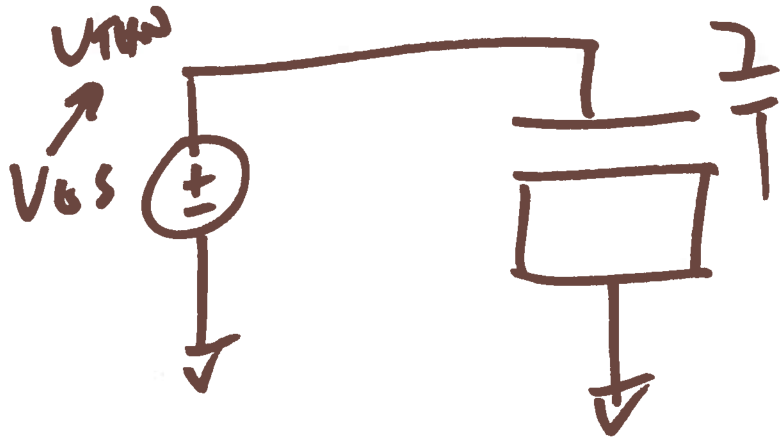
Lecture 11

Oct 5, 2016



Threshold Voltage

$V_{fp} = -\frac{KT}{q} \ln \frac{N_A}{N_i}$



$V_{THN} = 2|V_{fp}| + \frac{Q_b'}{C_{ox}'}$

$+ \ldots$

$Q_{ss}' =$ surface states

$CV = Q$

$= \frac{Q_b'}{C_{ox}'}$

$$V_{THN} = 2|V_{fp}| + \frac{Q_b' - Q_{ss}'}{C_{ox}'}$$

$+ \ldots$

N

P

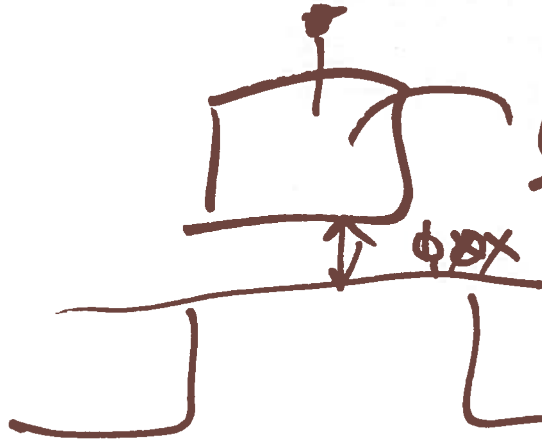
$$\phi_1 - \phi_4 = \phi_1 - \phi_2 + \phi_2 - \phi_3 + \phi_3 - \phi_4$$

$$\phi_1 = \frac{KT}{q} \ln \frac{N_D}{N_i}$$

$$\rightarrow -\frac{KT}{q} \ln \frac{N_A}{N_i}$$

$$V_{bi} = \phi_1 - \phi_2 = \frac{KT}{q} \ln \frac{N_D}{N_i} - \left(-\frac{KT}{q} \ln \frac{N_A}{N_i} \right)$$

$$= \frac{KT}{q} \ln \frac{N_D N_A}{N_i^2}$$



$$\frac{kT}{q}\ln\frac{N_{D,poly}}{N_i}$$

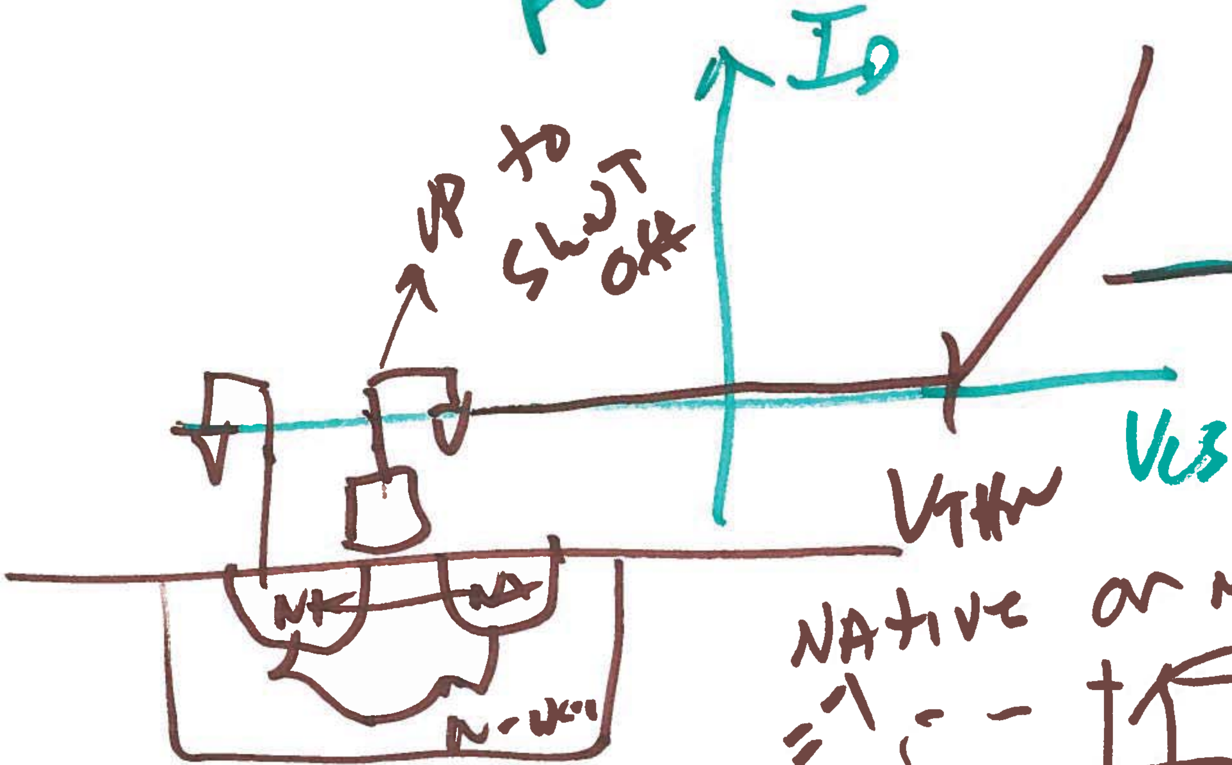
$$-\frac{kT}{q}\ln\frac{N_A}{N_i}$$

$$V_{ms} = \phi_{ms} = \frac{kT}{q}\ln\frac{N_{D,poly}}{N_i} - \left(-\frac{kT}{q}\ln\frac{N_A}{N_i}\right)$$

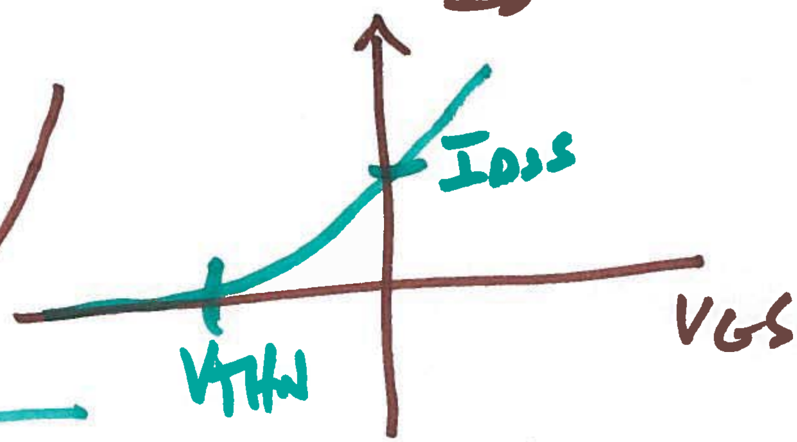
$$= \frac{kT}{q}\ln\frac{N_{D,poly}\cdot N_A}{N_i^2}$$

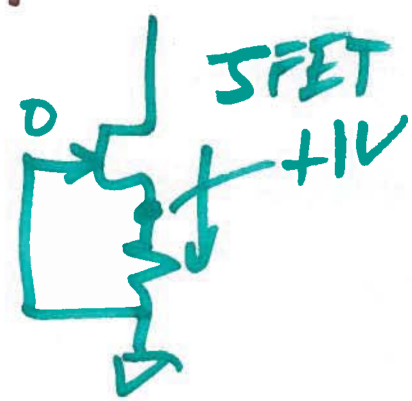
$$V_{THN0} = -V_{ms} + 2|V_{fp}| + \frac{Q'_{b0} - Q'_{ss}}{C'_{ox}}$$

→ Enhancement positive threshold

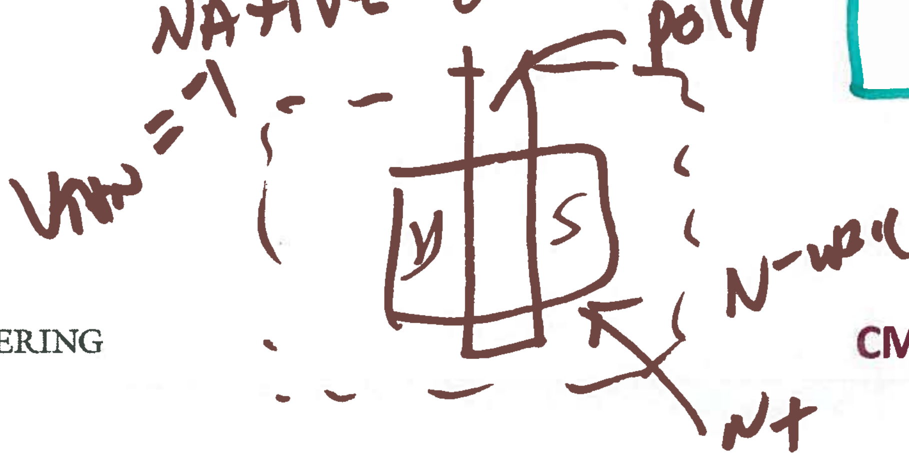


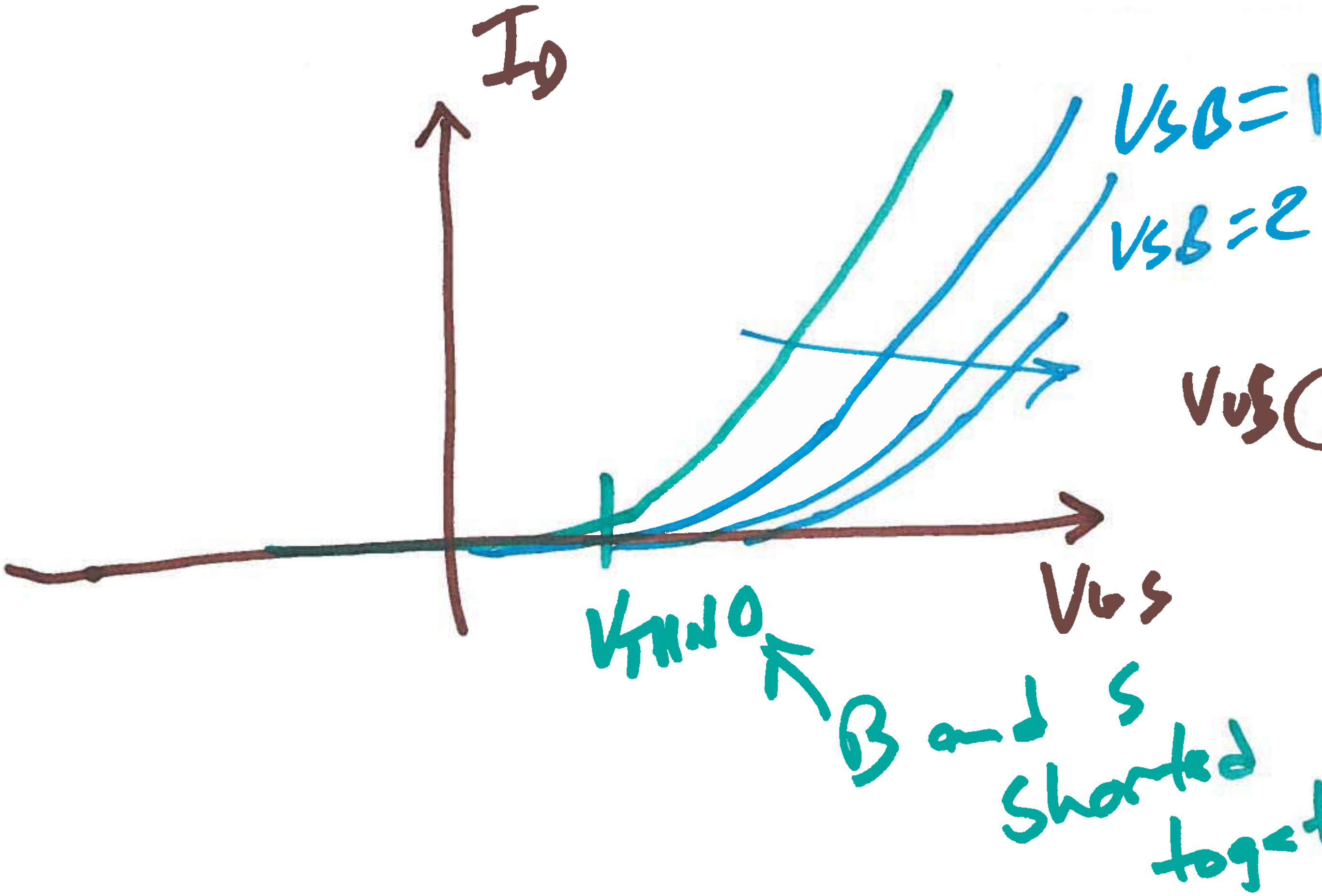
Depletion (neg. threshold)



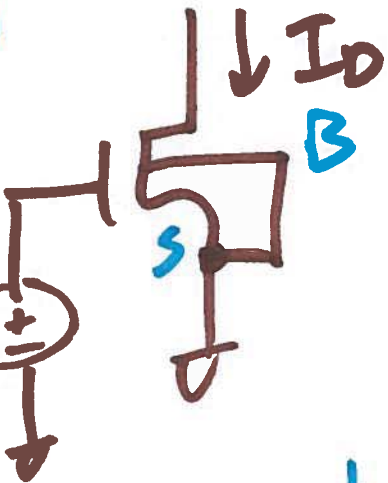


Native or natural

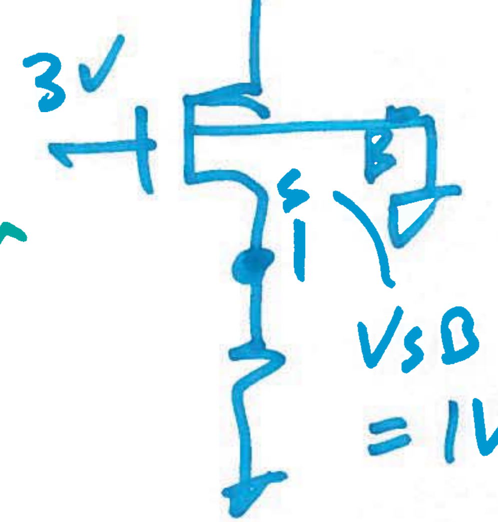




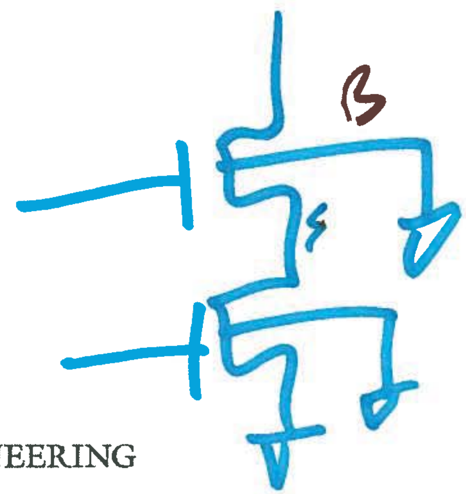
I_D
VSB=1
VSB=2
VGS
VTHN0
B and S shorted together



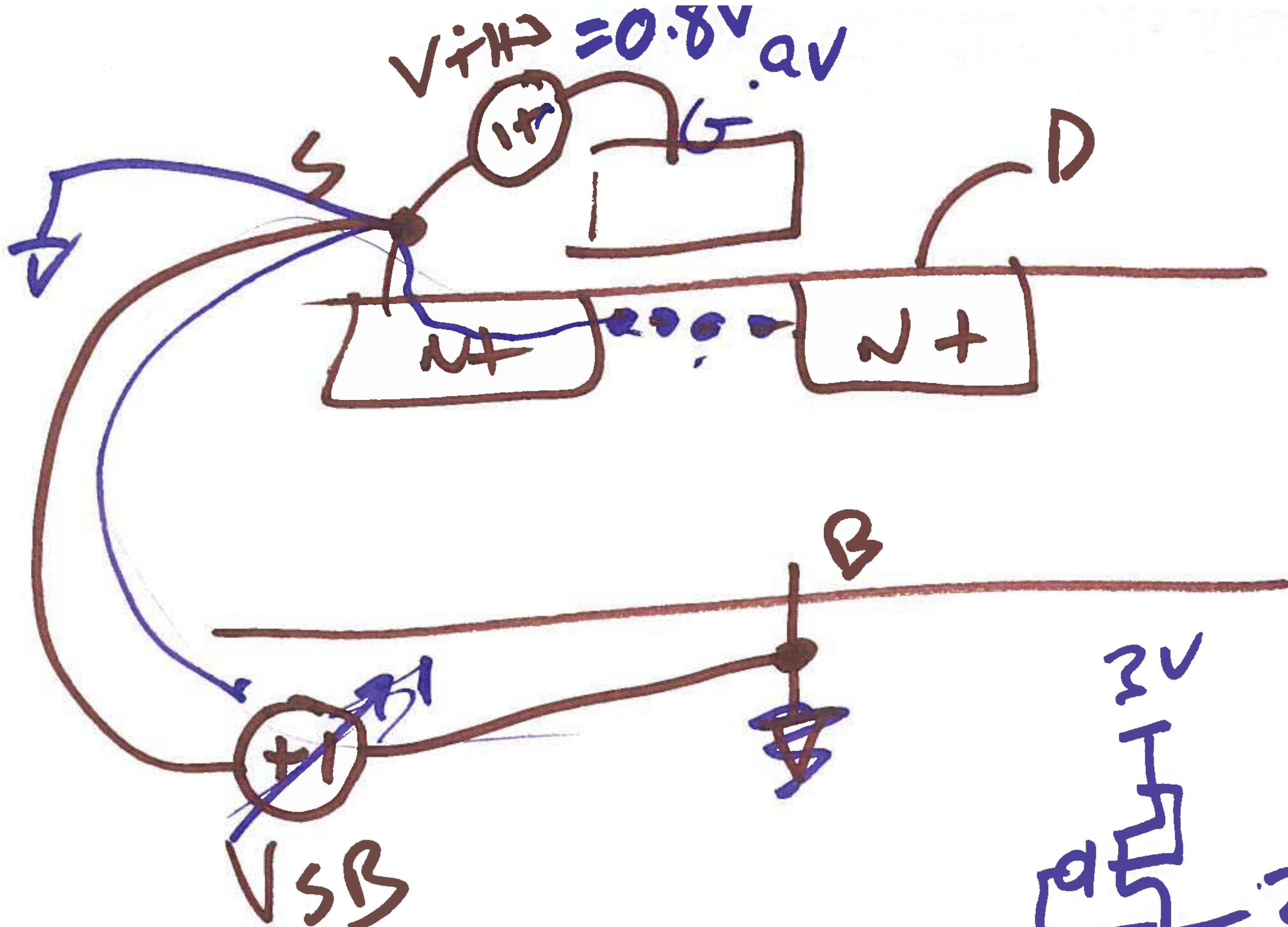
I_D
B
S
VGS

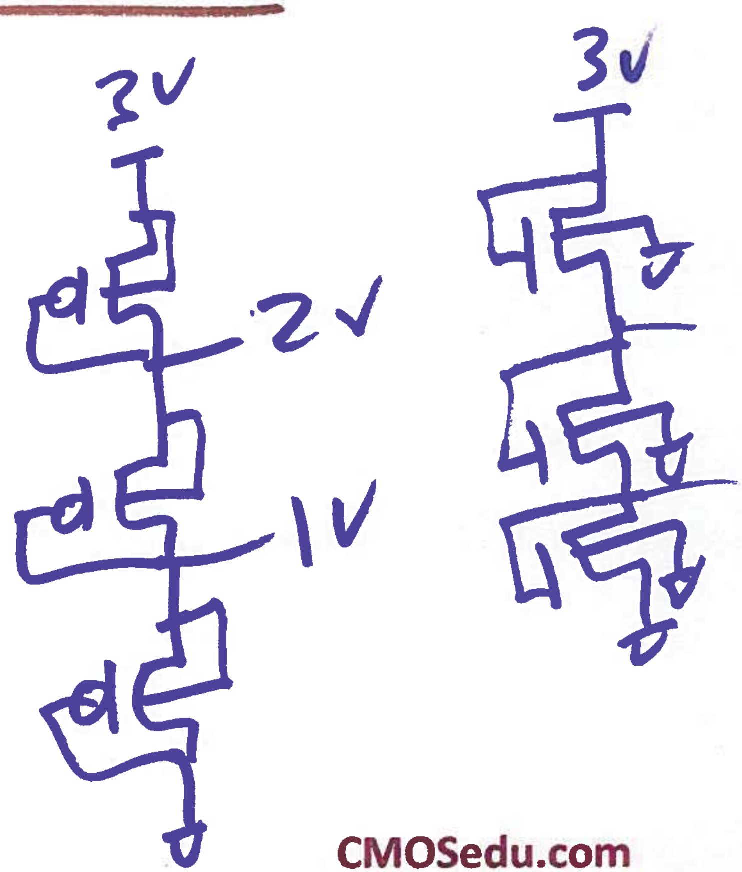


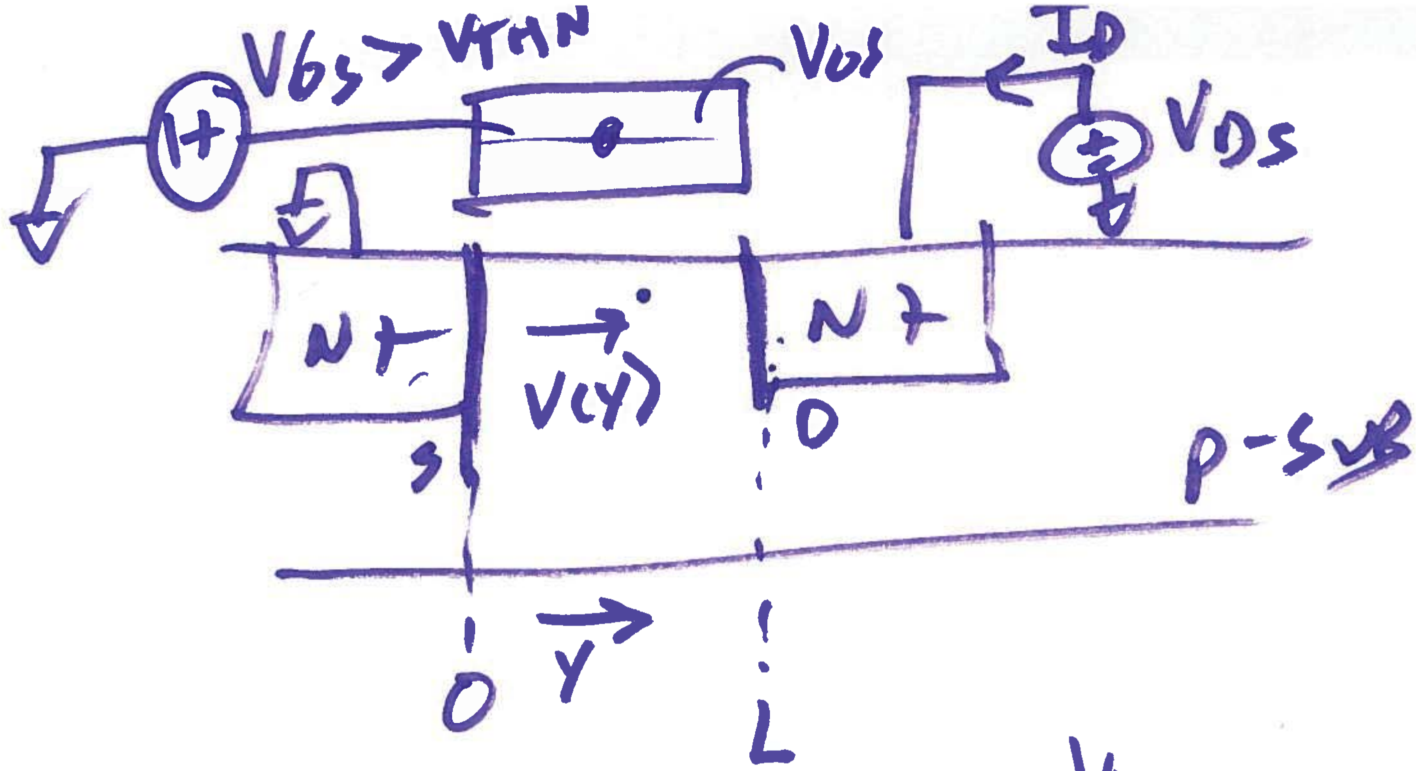
3V
B
S
VSB
=1V



B
S


S
G
D
N+
N+
B
VSB


3V
2V
1V
3V



$V(0) = 0 \quad V(L) = V_{DS}$

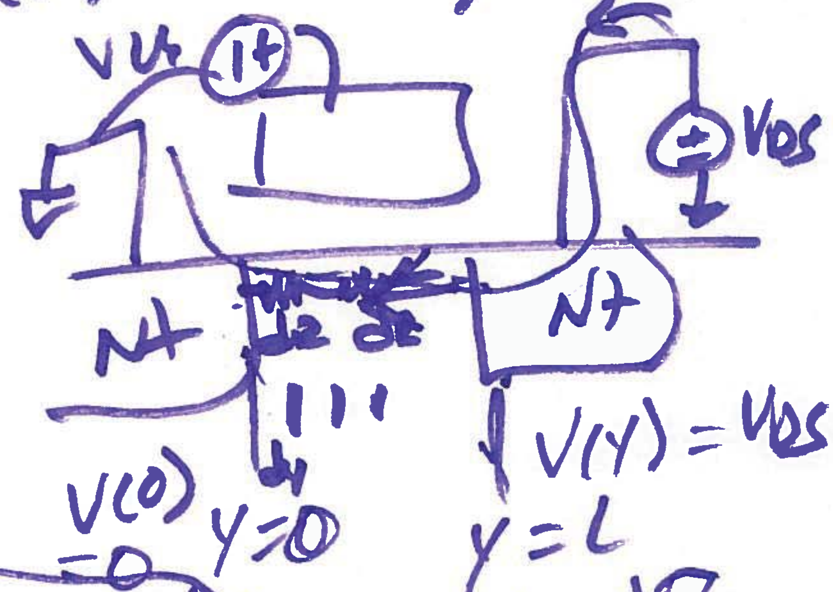
$Q'_{CH} = C'_{ox}\left[V_{GS} - V(y)\right]$

total channel charge

$Q'_b = C'_{ox} \cdot V_{THN}$

$Q' = Q'_{..} - Q'_{.}$

$$Q'_I(y) = C'_{ox}\left(V_{GS} - V(y) - V_{THN}\right)$$



$$dR = \frac{1}{\mu_n Q'_I} \cdot \frac{dy}{W}$$

eff. sheet resistance

$$dR = \frac{1}{\mu_n C'_{ox}\left(V_{GS} - V(y) - V_{THN}\right)} \cdot \frac{dy}{W}$$

$$dV(y) = I_D \cdot dR$$

$$\mu = \frac{v}{\mathcal{E}} \quad \frac{\text{cm/s}}{\text{V/cm}}$$

$$\mu \quad \frac{\text{cm}^2}{\text{V} \cdot \text{s}}$$

a)

$$\int_0^L I_D \cdot dy = \int_0^{V_{DS}} W \cdot \mu_n C'_{ox} (V_{GS} - V(y) - V_{THN}) \cdot dV(y)$$

$V_{DS} @ V(y) = L$

$$I_D \cdot L = W \mu_N C'_{ox} \left[\int_0^{V_{DS}} V_{GS} \cdot dV(y) - \int_0^{V_{DS}} V(y)\, dV(y) - \int_0^{V_{DS}} V_{THN} \cdot dV(y) \right]$$

$V_{GS} \cdot V_{DS}$ $\quad \frac{1}{2} V_{DS}^2$ $\quad V_{THN} \cdot V_{DS}$

$\beta_N = KP_N \cdot \frac{W}{L}$

$$I_D = \underbrace{\mu_n C'_{ox}}_{KP_N} \cdot \frac{W}{L} \left((V_{GS} - V_{THN}) V_{DS} - \frac{1}{2} V_{DS}^2 \right)$$

($\mu_n C'_{ox} \cdot \frac{W}{L} = \beta_N$)

$V_{GS} > V_{THN}$

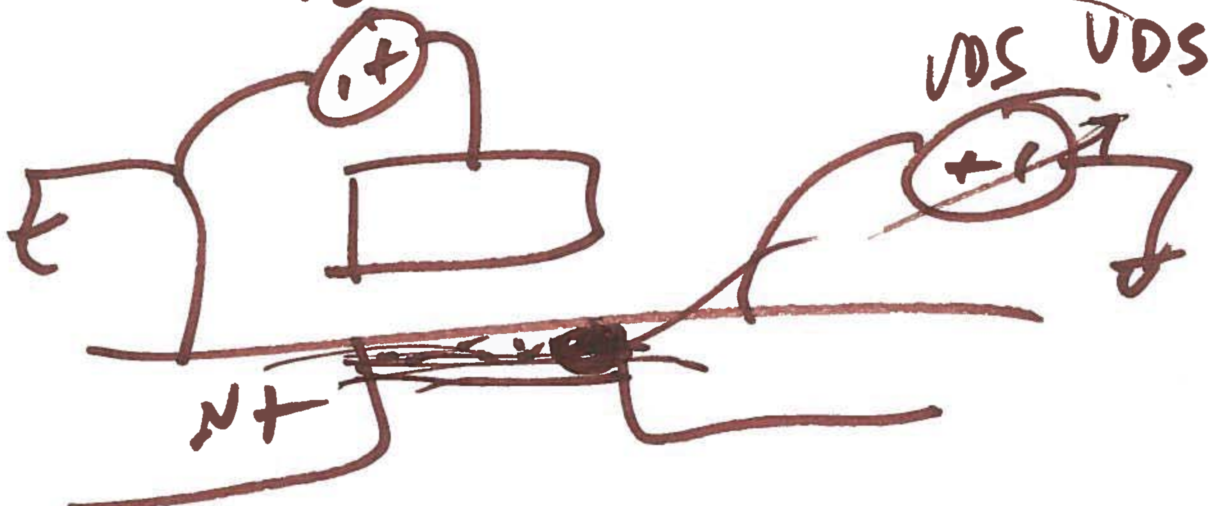
triode

$$I_D = \mu_n \cdot C'_{ox} \cdot \frac{W}{L}\left((V_{GS} - V_{THN}) V_{DS} - \frac{V_{DS}^2}{2}\right)$$

$V_{GS} > V_{THN}$ triode

$V_{GS} \geq V_{THN}$

$V_{DS} \leq V_{GS} - V_{THN}$



SATUration

$V_{GS} > V_{THN}$

$V_{DS} \geq V_{GS} - V_{THN}$

$$I_D = \mu_n C'_{ox} \cdot \frac{W}{L}\left((V_{GS} - V_{THN})(V_{GS} - V_{THN}) - \frac{(V_{GS} - V_{THN})^2}{2}\right)$$

$$= \frac{\mu_n C'_{ox}}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_{THN})^2$$