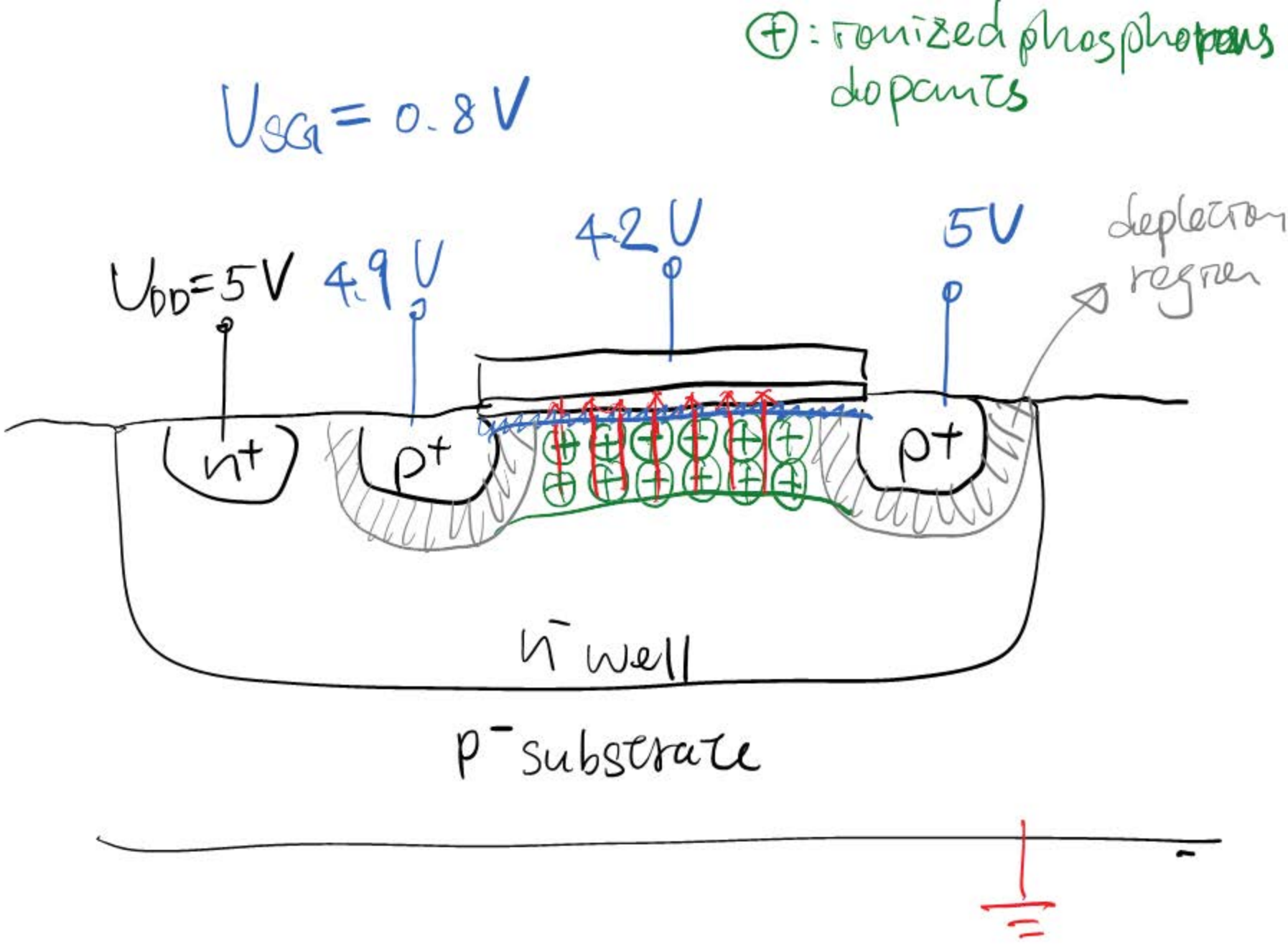
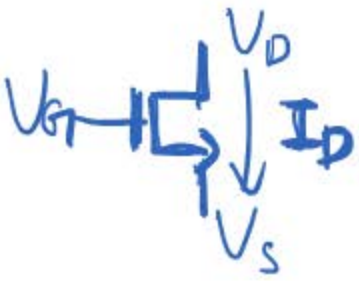

⊕: ionized phosphorus dopants
$V_{SG} = 0.8\,V$
$V_{DD} = 5V$
4.9 V
4.2 V
5V
depletion region
n+
p+
p+
n- well
p- substrate

NMOS vs PMOS

NMOS



triode: $I_D = \mu_n C_{ox} \left(\frac{W}{L_{eff}}\right)\left[(V_{GS} - V_{THN})V_{DS} - \frac{1}{2}V_{DS}^2\right]$

sat: $I_D = \frac{1}{2}\mu_n C_{ox} \left(\frac{W}{L_{eff}}\right)(V_{GS} - V_{THN})^2 (1 + \lambda V_{DS})$

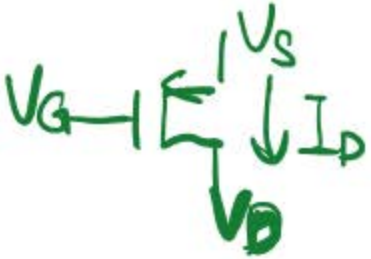
$V_{GS} \rightarrow V_{SG}$

$V_{THN} \rightarrow |V_{THP}|$

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

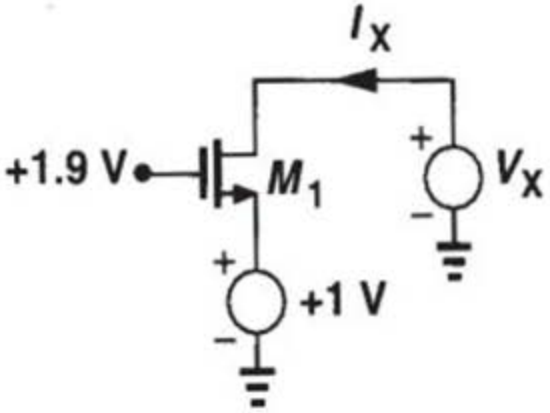
$\mu_n \rightarrow \mu_p$

PMOS

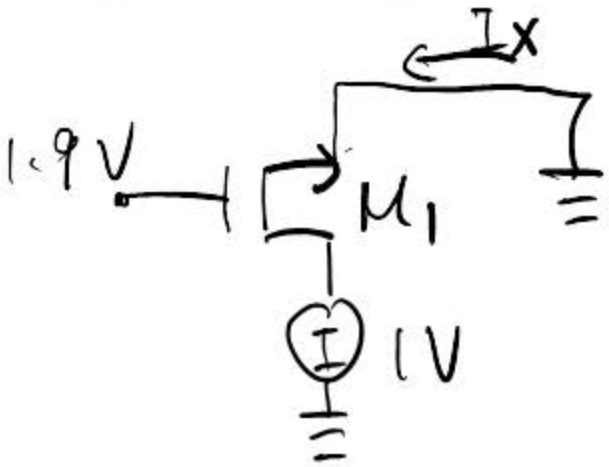


triode: $I_D = \mu_p C_{ox} \left(\frac{W}{L_{eff}}\right)\left[(V_{SG} - |V_{THP}|)V_{SD} - \frac{1}{2}V_{SD}^2\right]$

sat: $I_D = \frac{1}{2}\mu_p C_{ox} \left(\frac{W}{L_{eff}}\right)(V_{SG} - |V_{THP}|)^2 (1 + \lambda V_{SD})$



When $V_X = 0$



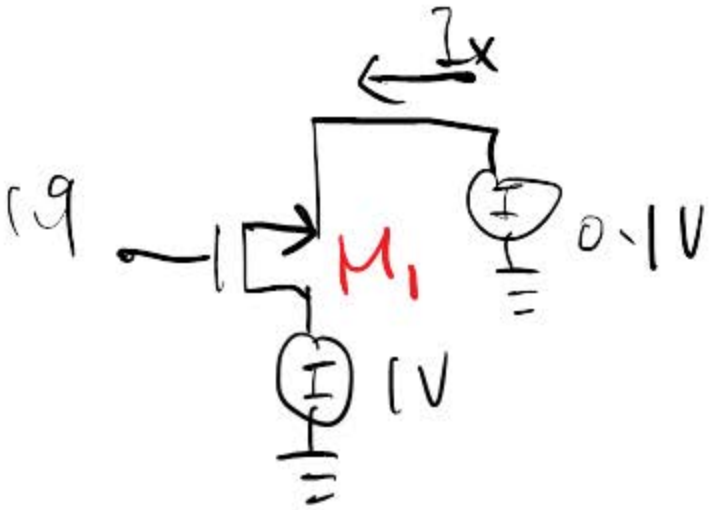
$V_{DS} = 1\ V$

$V_{GS} = 1.9\ V$

$V_{DS} < V_{GS} - 0.7$

(triode)

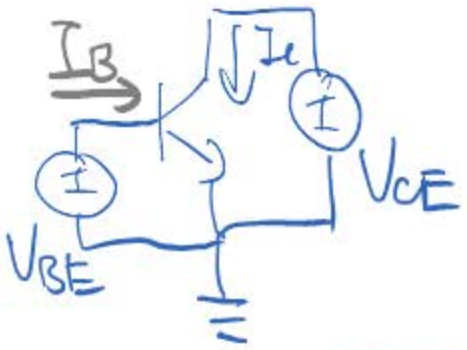
When $V_X = 0.1$



$V_{DS} = 0.9\ V$

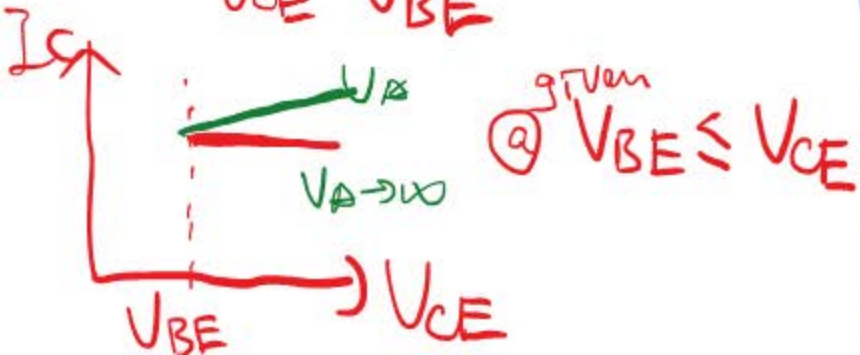
$V_{GS} = 1.8\ V$

npn BJT

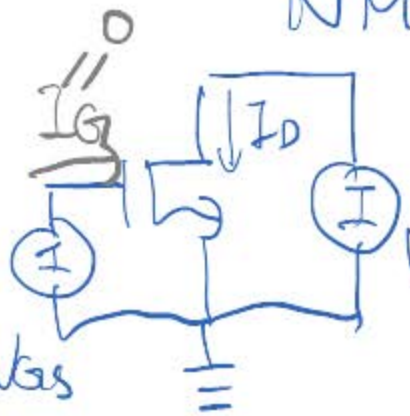


For $V_{CE} \geq V_{BE}$ in forward-active

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$



NMOS

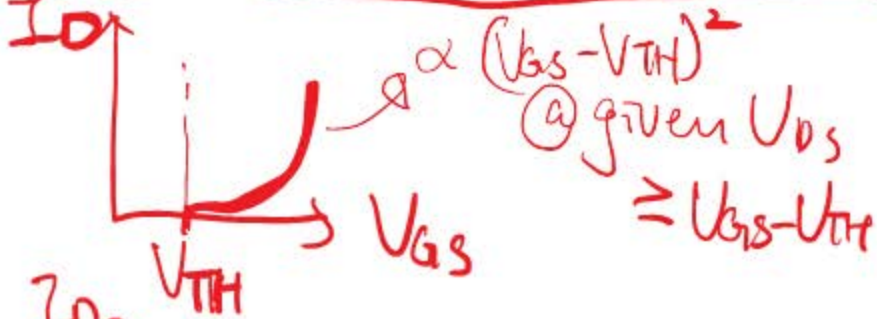


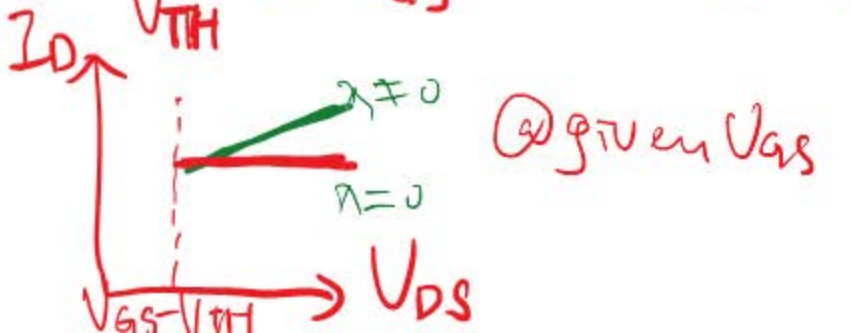
$V_{GS} > V_{TH}$

For $V_{DS} \geq V_{GS} - V_{TH}$ in sat.

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

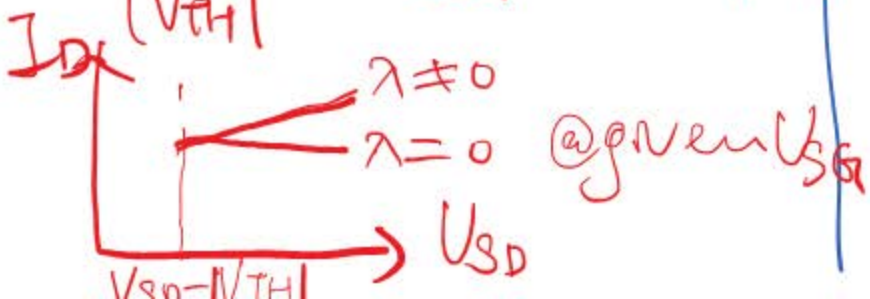
$$= \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L_{eff}}\right)(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$





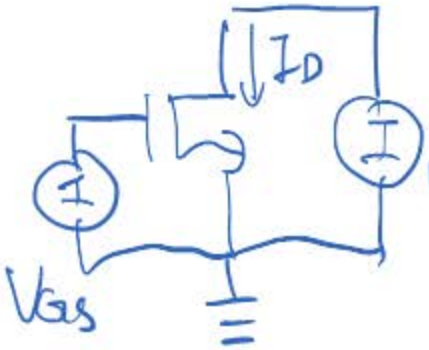
PMOS

$$I_D = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L_{eff}}\right)(V_{SG}-|V_{TH}|)^2(1+\lambda V_{SD})$$



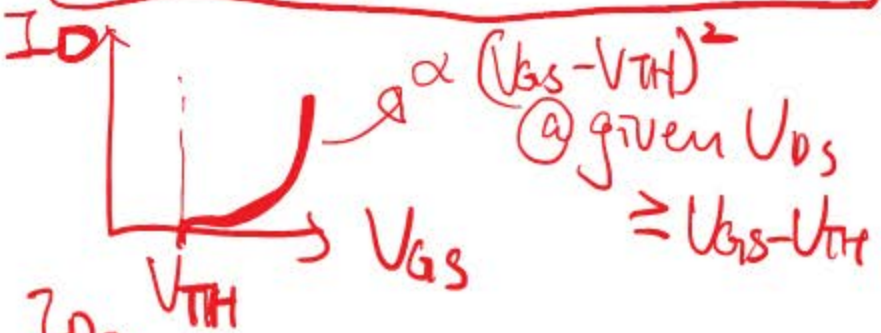
NMOS

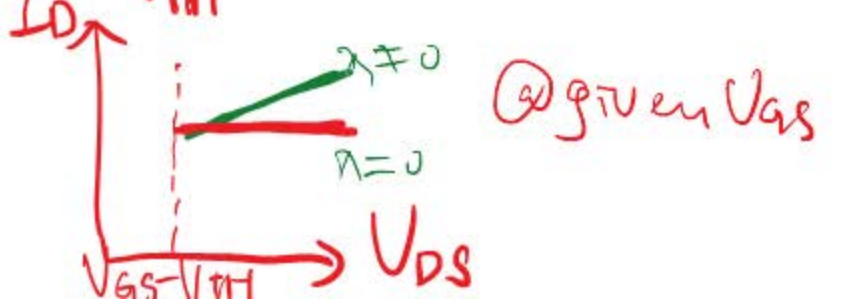
$V_{GS} > V_{TH}$
For $V_{DS} \geq V_{GS}-V_{TH}$



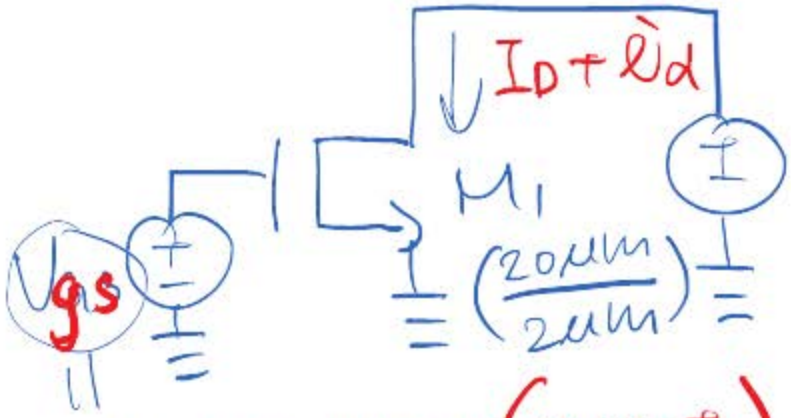
$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_{TH})^2$$

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





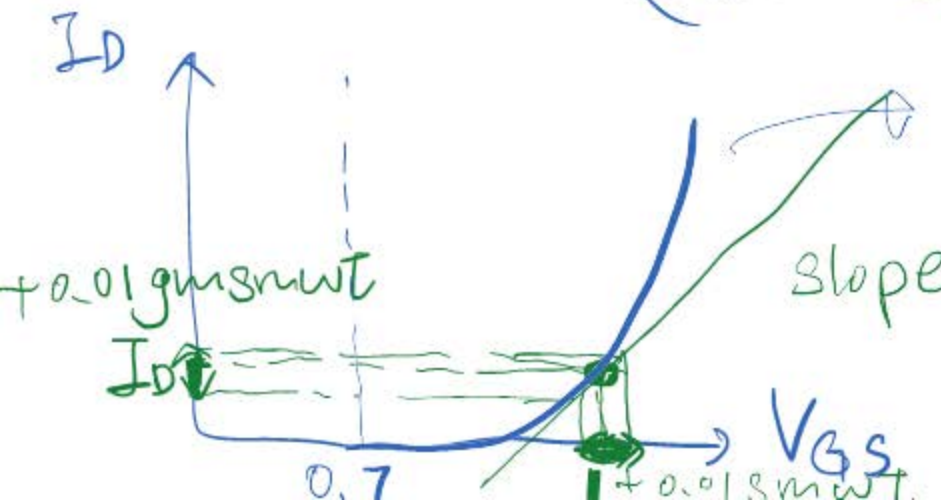
$I_D = ?$ $\hat{v}_d = ?$



$V_{DS} = 1V$

$V_{DS} = 1V$
$> V_{GS} - V_{TH} = 0.3V$
$\Rightarrow M_1$ in sat.

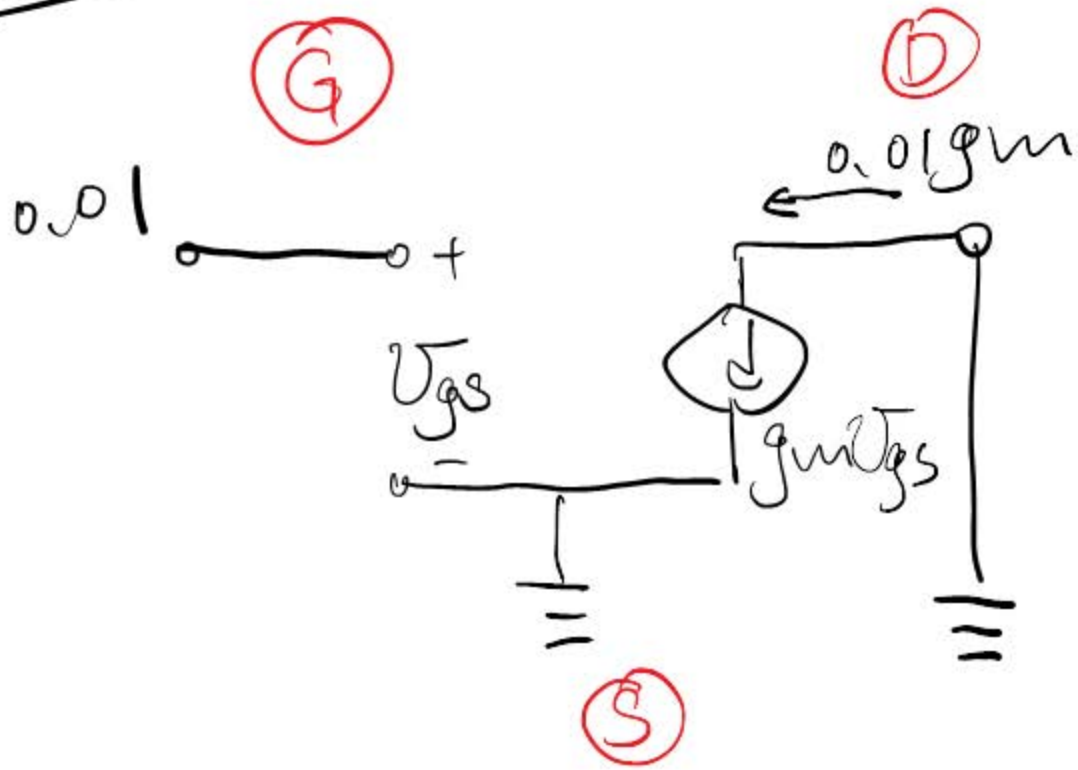
$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{20\times10^{-6}}{2\times10^{-6} - 2L_D}\right)(1-0.7)^2(1+\lambda\cdot 1)$$



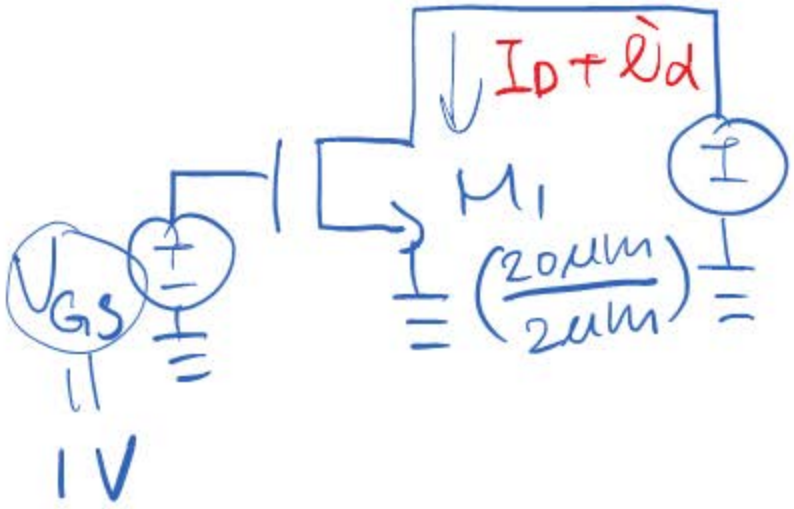
$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L_{eff}}(V_{GS}-0.7)^2((+\lambda\cdot 1)$$

$$\text{Slope} = g_m = \frac{dI_D}{dV_{GS}}\Big|_{@\ V_{GS}=1V}$$

small-signal



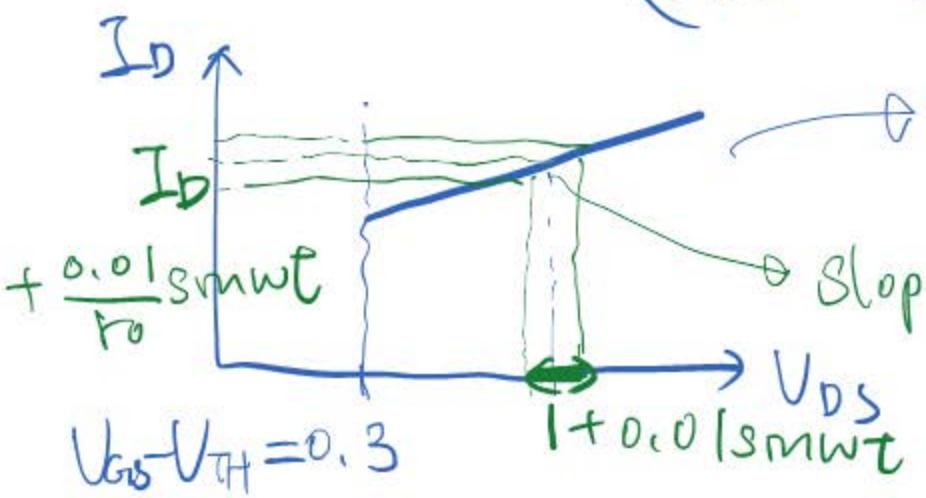
$I_D = ?$ $\hat{v}_d = ?$



$V_{ds} = 1V + 0.01 \sin \omega t$

$V_{DS} = 1V$
$> V_{GS} - V_{TH} = 0.3V$
$\Rightarrow M_1$ in sat.

$$I_D = \frac{1}{2} \mu_n C_{ox} \left(\frac{20 \times 10^{-6}}{2 \times 10^{-6} - 2LD} \right) (1 - 0.7)^2 (1 + \lambda \cdot 1)$$



$\rightarrow \frac{1}{2} \mu_n C_{ox} \frac{W}{L_{eff}} (\quad - 0.7)^2 (1 + \lambda \cdot V_{DS})$

$\text{Slope} = \frac{1}{r_o} = \left. \frac{d I_D}{d V_{DS}} \right|_{@ V_{DS} = 1V}$

small-signal