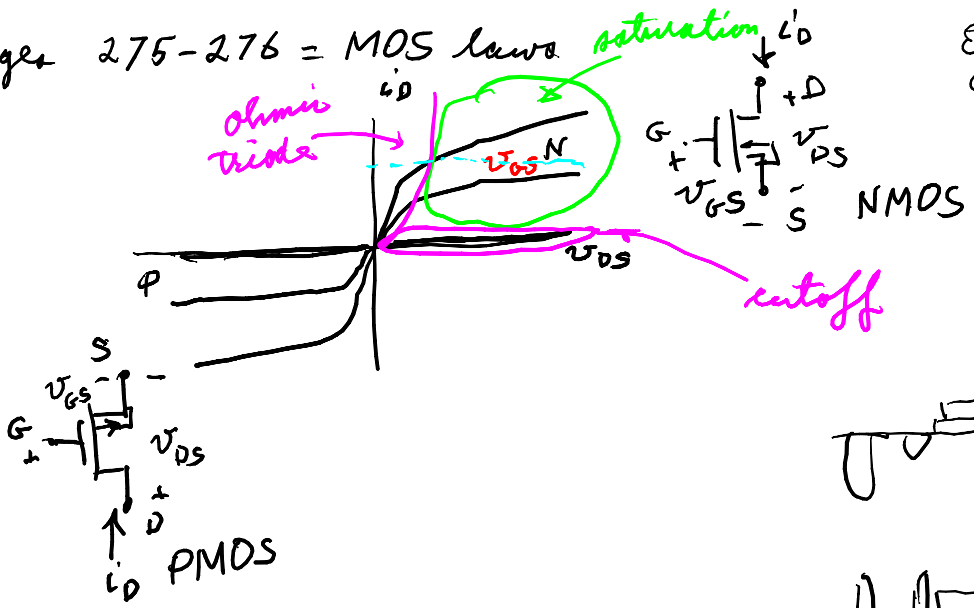
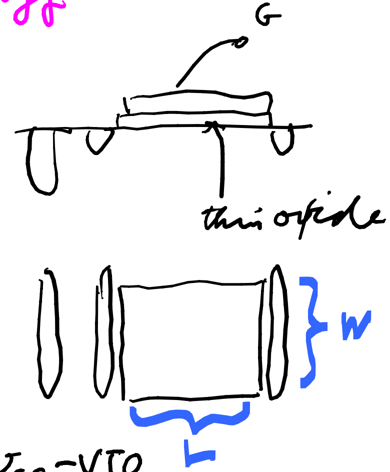
pages 275-276 = MOS laws

EE 303H
02/10/09





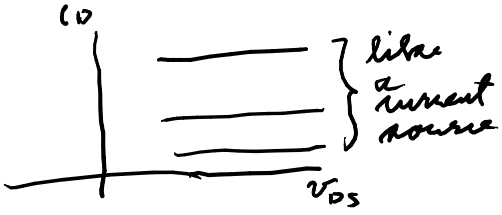
$$i_D = \frac{KP}{2}\frac{W}{L}\begin{cases} 0 & \text{cutoff; } v_{GS} < VTO \\ (v_{GS}-VTO)^2(1+\lambda v_{DS}) & \text{saturation; } v_{DS} \geq v_{GS}-VTO \\ \{2(v_{GS}-VTO)v_{DS}-v_{DS}^2\}(1+\lambda v_{DS}) & \text{ohmic: } v_{DS} \leq v_{GS}-VTO \end{cases}$$

note if v_{DS} is very small $i_D = \{KP\frac{W}{L}(v_{GS}-VTO)\}\cdot v_{DS}$

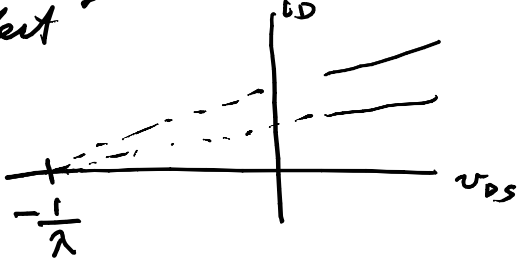
$(KP\frac{W}{L})\ R = \frac{1}{v_{GS}-VTO}$

in saturation region

$i_D = (\frac{KP}{2}\cdot\frac{W}{L})(v_{GS}-VTO)^2$ independent of v_{DS}

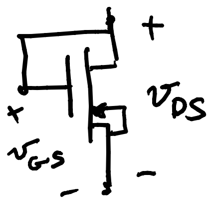


actually has an Early effect



λ = LAMBDA

For



here $v_{DS} = v_{GS} > 0$ so

$$\begin{array}{c} v_{DS} \\ \shortparallel \\ v_{GS} \end{array} > v_{GS} - VTO$$

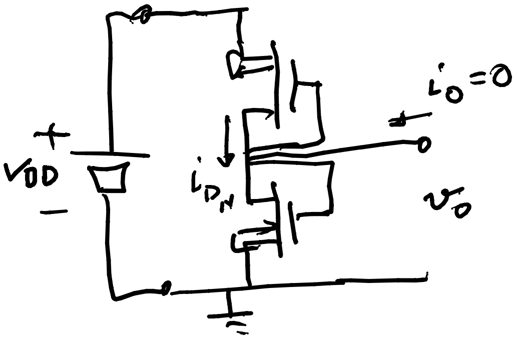
if $VTO > 0$

(true enhancement mode NMOS)

$$i_D = \frac{KP}{2}\cdot\frac{W}{L}\cdot(v_{DS}-VTO)^2 \text{ if } \underset{\underset{v_{GS}}{\shortparallel}}{v_{DS}} > VTO$$

$\Rightarrow$

Example of use:



$$i_{D_n} = \left(\frac{KP}{2}\frac{W}{L}\right)_n (v_O - VTO_n)^2$$

$$= -i_{D_p}$$

$$= \left(\frac{KP}{2}\frac{W}{L}\right)_p (\underbrace{V_{DD}-v_O}_{V_{SD}} + VTO_p)^2$$

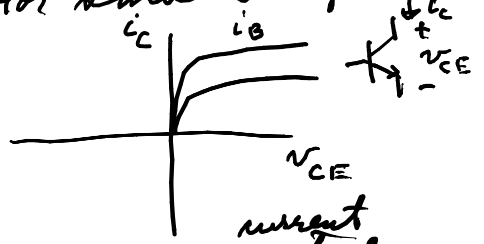
solve for $v_O \Rightarrow$ $v_O - VTO_n = \sqrt{\frac{(KPW/L)_p}{(KPW/L)_n}}\,(V_{DD} - v_O + VTO_p)$

$$\left(1+\sqrt{\left(\frac{KP_p}{KP_n}\right)\left(\frac{(W/L)_p}{(W/L)_n}\right)}\right) v_O = VTO_n + \sqrt{\left(\frac{KP_p}{KP_n}\right)\left(\frac{(W/L)_p}{(W/L)_n}\right)}\,(V_{DD}+VTO_p)$$

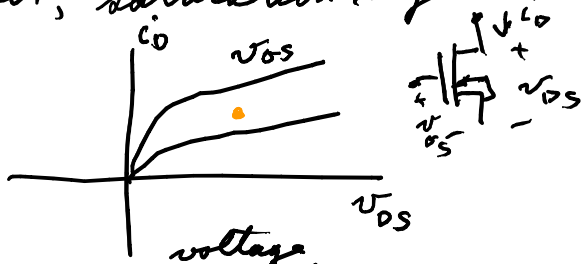
or if know v_O desired

$$\frac{(W/L)_n}{(W/L)_p} = \frac{(V_{DD}-v_O+VTO_p)^2}{(v_O-VTO_n)^2}$$

For small signal behavior; saturation region:



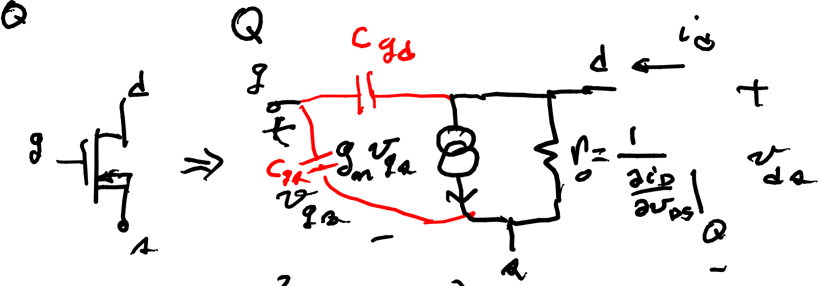
current control



voltage control

$$i_D = I_D + \frac{\partial i_D}{\partial v_{GS}}\Big|_Q (v_{GS}-V_{GS}) + \frac{\partial i_D}{\partial v_{DS}}\Big|_Q (v_{DS}-V_{DS}) + \cdots$$

$$(i_D - I_D) = i_d = \frac{\partial i_D}{\partial v_{GS}}\Big|_Q v_{gs} + \frac{\partial i_D}{\partial v_{DS}}\Big|_Q v_{ds} = g_m v_{gs} + g_o v_{ds}$$



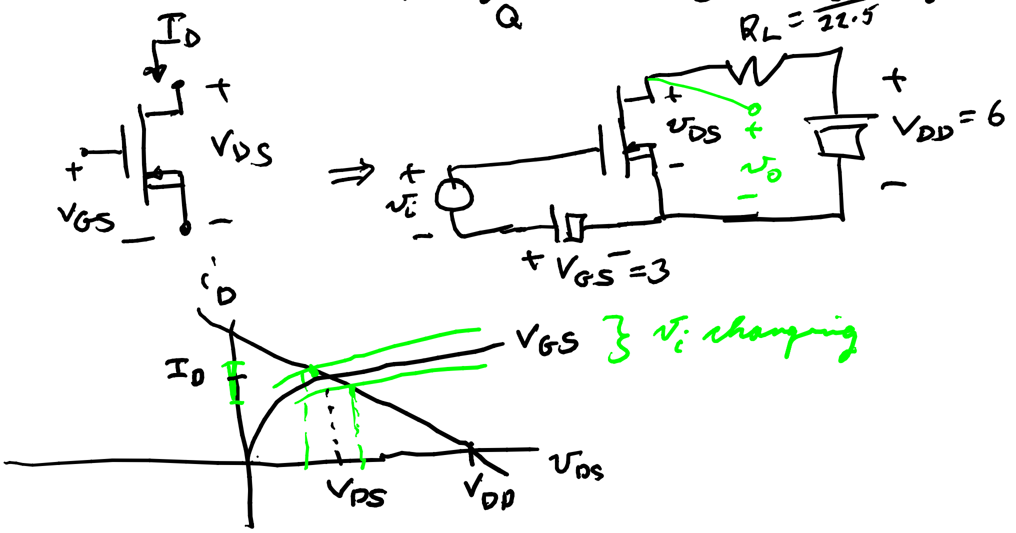
here $$\frac{\partial i_D}{\partial v_{GS}} = \frac{\partial}{\partial v_{GS}}\left(\frac{KP}{2}\frac{W}{L}(v_{GS}-VTO)^2(1+\lambda v_{DS})\right)$$

$$= \frac{2\, i_D}{(v_{GS}-VTO)}\Big|_Q = \frac{2 I_D}{V_{GS}-VTO} = g_m$$

$$g_o = \frac{1}{r_o} = \frac{\partial i_D}{\partial v_{DS}}\Big|_Q = \frac{\partial}{\partial v_{DS}}\left(\frac{KP}{2}\frac{W}{L}(v_{GS}-VTO)^2(1+\lambda v_{DS})\right)$$

$$= \lambda \frac{i_D}{1+\lambda v_{DS}}\Big|_Q = \lambda \frac{I_D}{1+\lambda V_{DS}} \approx \lambda I_D$$

To bias



assume: $V_{GS} = 3V$, $VTO = 1.5V$, $KP = 20 \times 10^{-6}$ A/V^2

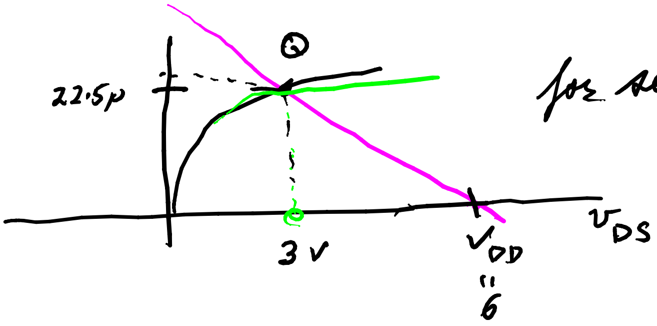
$\lambda = 10m$/V $W = 100\mu$, $L = 10\mu$ $V_{DD} = 6$

$$I_O \approx \frac{KP}{2}\frac{W}{L}(V_{GS}-VTO)^2$$ if in saturation

$$= \frac{20\times10^{-6}}{2}\cdot\frac{100\times10^{-6}}{10\times10^{-6}}(3-1.5)^2 = 10\times10^{-6}\times10\times2.25\ \text{A}$$

$$= 10^{-4}\times2.25 = 0.0225\ \text{mA} = 22.5\,\mu\text{A}$$

$$\begin{array}{r} 1.5 \\ \times 1.5 \\ \hline 75 \\ 15 \end{array}$$



for saturation need $V_{DS} > \underbrace{V_{GS}-VTO}_{3-1.5}$

$= 1.5$

$$G_L = \frac{22.5\times10^{-6}}{6-3} = -\text{slope load line}$$

$$= \frac{22.5}{3}\times10^{-6} \Rightarrow R_L = \frac{3}{22.5}\ \text{Meg}\Omega$$