140/240A 19FA W3L1

Midterm 2 weeks ~~friday~~ friday in class, 1 page, 2 sides

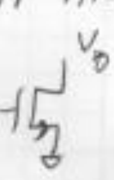
OH W3-4 ~~F2-3~~ Th 1-2

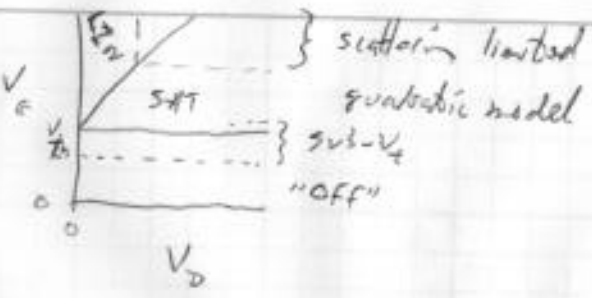
NMOS examples

scaling

PMOS

Last time





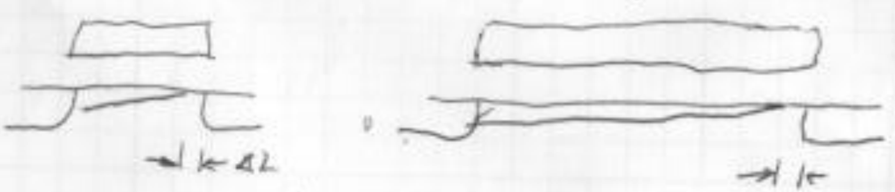
for this semester: mostly saturation w/ quadratic model

$$I_d = \underbrace{\frac{\mu_n C_{ox}}{2}}_{\text{process}} \underbrace{\left(\frac{W}{L}\right)}_{\text{design}} \left(V_{gs}-V_{tn}\right)^2 (1+\lambda V_{ds})$$

process & design

EX: $V_{DD} = 2V$ $V_{tn} = 0.5V$ $\mu_n C_{ox} = 200 \frac{\mu A}{V^2}$

$L_{min} = 0.1\mu$ $\lambda = \frac{1}{20V}\underbrace{\left(\frac{1\mu m}{L}\right)}_{\text{why?}}$



$I_D = \left(\frac{\text{charge}}{\text{length}}\right)(\text{velocity})$

Bigger V_{DS}, shorter channel more field, faster electrons more current

$\mu\left(\frac{V_{gs}-V_{tn}}{L-\Delta L}\right) \sim 1 + \frac{\Delta L}{L} \Rightarrow (1+\lambda V_{DS})$

longer channel: less effect

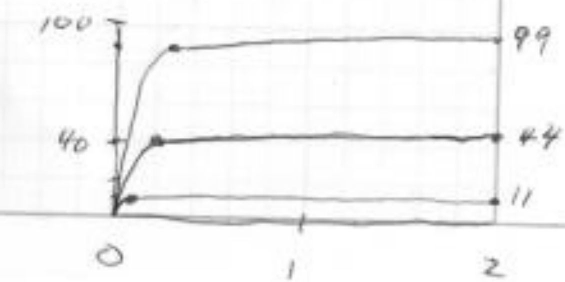
$\Delta L \approx V_{DS}/E_{RD}$

w/ $W = 10\mu m$, $L = 1\mu m$ plot I_D vs. V_{DS} for $V_{GS} = 0.5, 0.6, 0.7, 0.8$

$$I_D = \underbrace{\underbrace{\frac{\mu_n C_{ox}}{2}\frac{W}{L}}_{\left(\frac{100\mu A}{V^2}\right)(10)}(V_{GS}-V_{tn})^2}_{I_{DO}}(1+\lambda V_{DS})$$

$\frac{5\%}{V}$ or $\frac{1}{V_A}$ equiv.

V_{GS}	I_{DO}
0.5	0
0.6	10μ
0.7	40μA
0.8	90μA



g_m @ $V_{GS} = 0.7$ $\quad V_{DS} = 2V$ $\quad$ graphically

r_o @ $V_{GS} = 0.7$ $\quad$ formulas

$$g_m = \frac{\partial I_d}{\partial V_{GS}} = \frac{\Delta I_D}{\Delta V_{GS}} = \underbrace{\frac{33\mu A}{0.1V} \text{ or } \frac{55\mu A}{0.1V}}_{\text{average? } 440\frac{\mu A}{V}}$$

$$r_o = \left(\frac{44-40\mu A}{2V}\right)^{-1} = \frac{2\mu A}{V} = 500K\Omega$$

$$g_m = \frac{2 I_D}{V_{GS}-V_{th}} = \frac{88\mu A}{0.2V} = 440\frac{\mu A}{V}$$

$$r_o = \frac{1+\lambda V_{DS}}{\lambda I_D} \approx \frac{1}{\lambda I_{D0}} = \frac{1}{\frac{1}{20V} 40\mu A} = \frac{1}{2}\frac{V}{\mu A} = 500K$$

check field in channel;

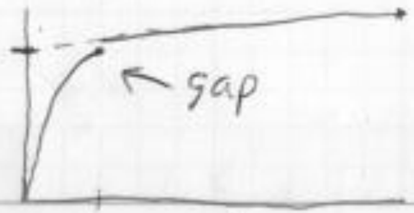
$$\frac{V_{GS}-V_{th}}{1\mu m} = 0.3\frac{V}{\mu m} \qquad v = \mu E \text{ good approx}$$

intrinsic gain: $-g_m r_o = \left(440\frac{\mu A}{V}\right)\left(\frac{1}{2}\frac{V}{\mu A}\right) = 220$

An aside on linear model:

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

when $\underbrace{V_{DS} = V_{GS}}_{\text{edge of sat.}} \Rightarrow I_D = \underbrace{\mu_n C_{ox} \frac{W}{L}\left(\frac{V_{GS}-V_{th}}{2}\right)^2}_{I_{D0}}$



so add "$(1+\lambda V_{DS})$" to linear model to avoid discontinuity

now: same process, $W = 1\mu m$, $L = 0.1\mu m$

now $\frac{V_{GS}-V_{th}}{L} = \frac{0.1V}{0.1\mu m} = \frac{1V}{\mu m} \quad \frac{2V}{\mu m} \quad \frac{3V}{\mu m}$

about 30% less than quadratic

$I_{D0} \approx 7\mu A$

C_{ox}

$I_D = v_{sat} W (V_{GS} - V_{th})(1+\lambda V_{DS})$

say $v_{sat} C_{ox} = 10^{-10} \left(\frac{m}{s}\right)\left(\frac{F}{\mu m^2}\right)$

$I_{D0} = 30\mu A$

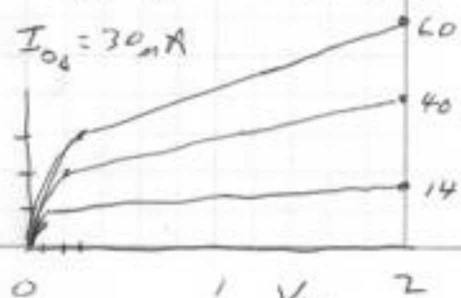
$\lambda = \frac{1}{20V} \frac{1\mu m}{0.1\mu m}$

$= \frac{1}{2V} = 50\%/V$

r_o 10x smaller

g_m smaller

A_v smaller



W/L	10/1	1/0.1
r_o	500K	66KΩ
g_m	440 $\frac{\mu A}{V}$	200 $\frac{\mu A}{V}$
A_{vo}	220	13
C_{gs}	10fF	1fF
ω_u	44G $\frac{rad}{s}$	200G $\frac{rad}{s}$

$C_{gs} = \left(1 \frac{fF}{\mu m^2}\right)(10\mu m^2) = 10fF$

$\omega_u = \frac{g_m}{C_{gs}} = \frac{440\mu A/V}{10^{-14} C/V} = 4.4 \times 10^{-4+14} \frac{A}{C}$

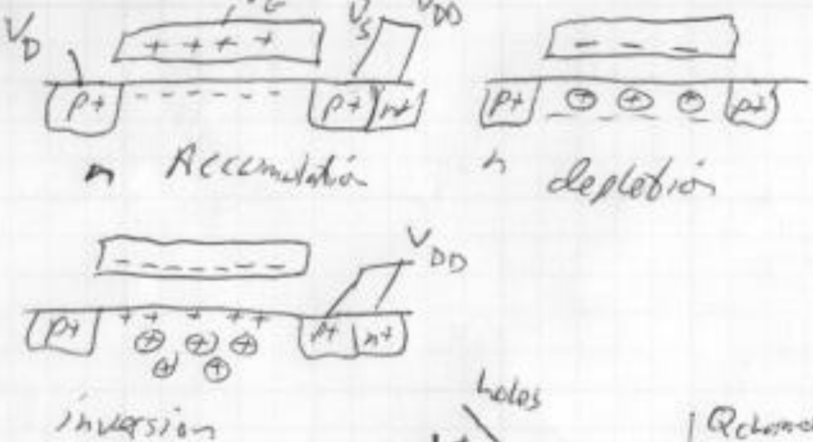
10/1 $= 44 G\ rad/s$

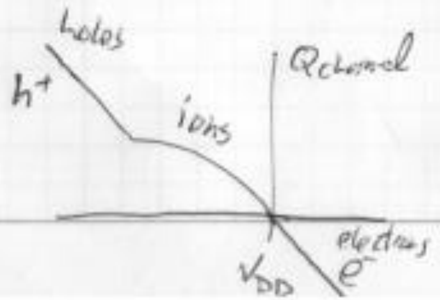
$= 7 GHz$

1/0.1 $\omega_u = \frac{200\mu A/V}{10^{-15}} = 200 G\ rad/s$

$= 30 GHz$

PMOS "All the same, w/ switched signs" ha!

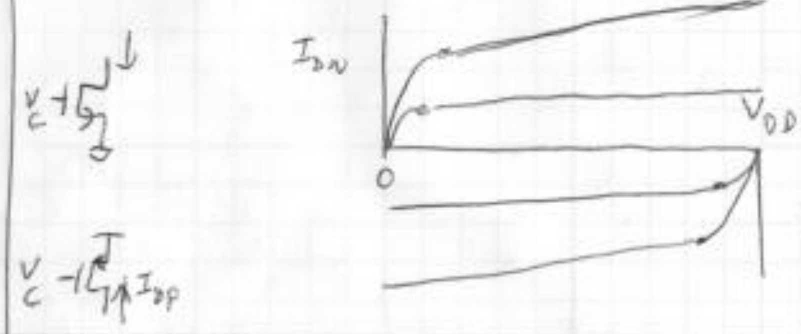




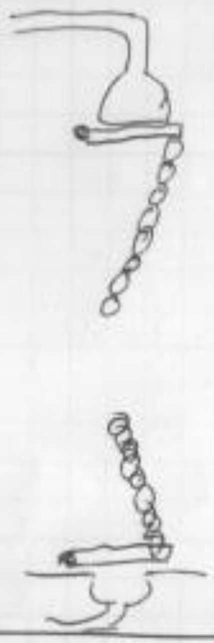
$I_D = (\text{avg charge/length})(\text{velocity})$

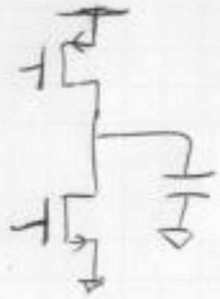
$= C_{ox} W \left(\frac{V_{GS}-V_{tp}}{2}\right) \left(\mu_p \frac{V_{GS}-V_{tp}}{L-\Delta L}\right)$

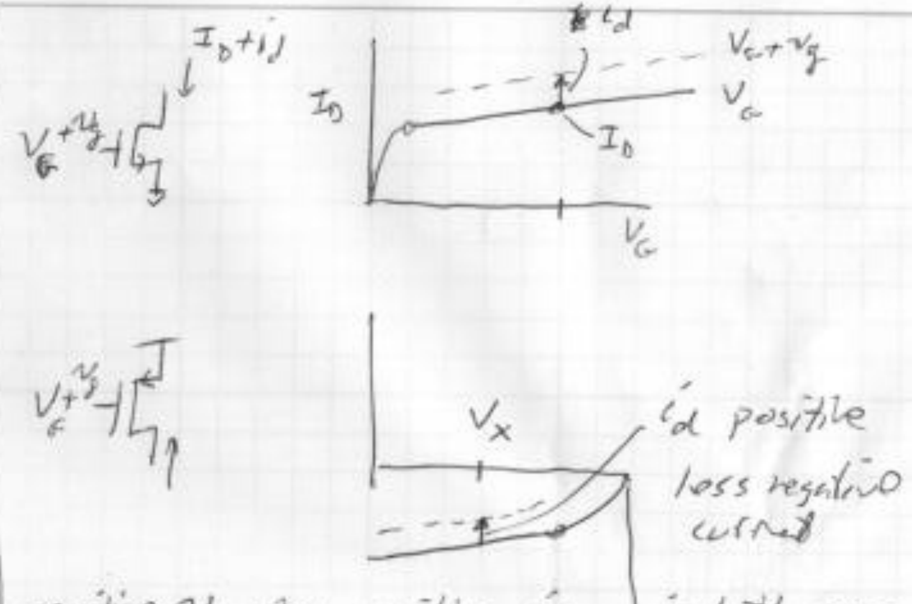
$= -\frac{\mu_p C_{ox}}{2} \frac{W}{L} (V_{GS}-V_{tp})^2 (1+\lambda_p V_{DS})$



Shower head and tub drain analogy

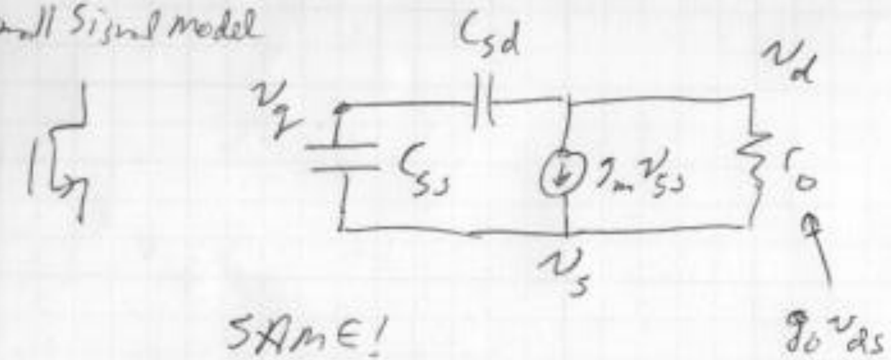




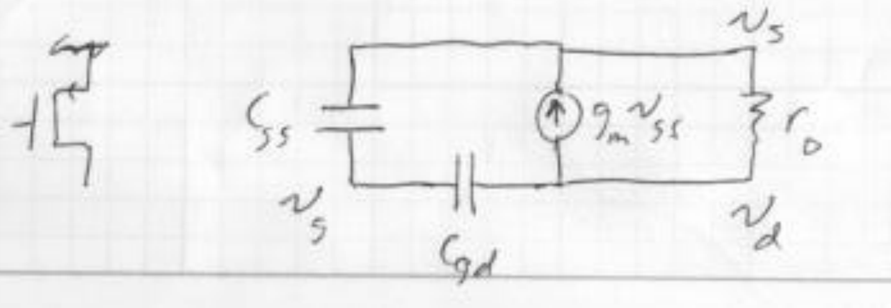


positive v_g gives positive i_d in both cases

Small Signal Model



SAME!



Bias point & linearization (SSM)