HW2 - piazza - great!

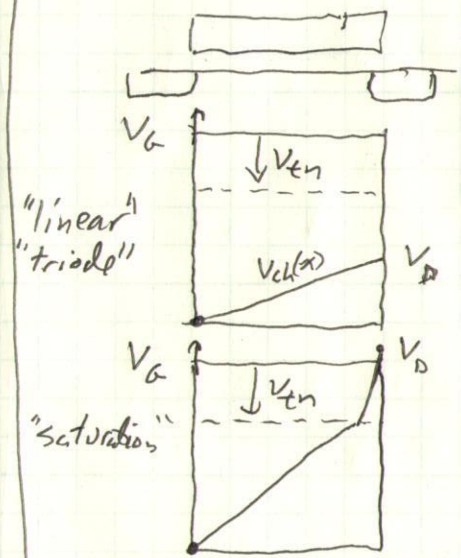
regions of operation

scattering limited

SUS - V_t

Last time

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



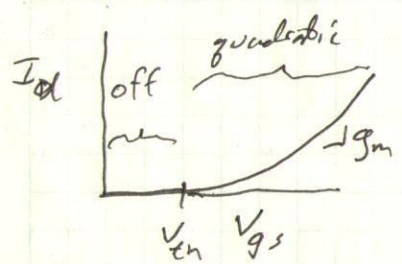
charge: $W C_{ox}\left(V_{gs} - V_{tn} - \frac{1}{2}V_{ds}\right)$

vel: $\mu_n \frac{V_{ds}}{L}$

charge: $W C_{ox} \frac{1}{2}\left(V_{gs} - V_{tn}\right)$

vel $= \mu_n \frac{V_{gs} - V_{tn}}{L - \Delta L}$ ← V_{ds} dep.

Choose V_{ds} "large enough" (say V_{DD})



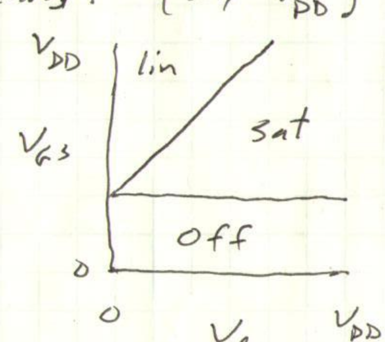
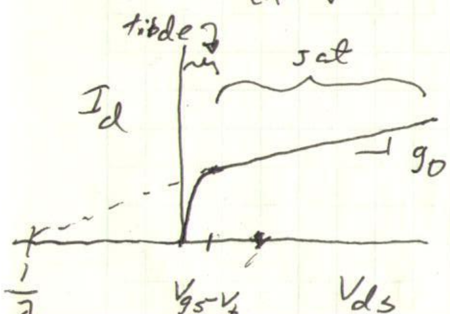


fig 2.18



like V_A

In saturation

$r_O = \frac{1 + \lambda V_{ds}}{\lambda I_d}$

$g_m = \mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_{tn}\right)(1 + \lambda V_{ds})$

$= \frac{2 I_D}{V_{GS} - V_{tn}}$

what if vel $\neq \mu E$ 3.d rather

vel $= v_{scl}$ when $E > 1\,mV/nm$

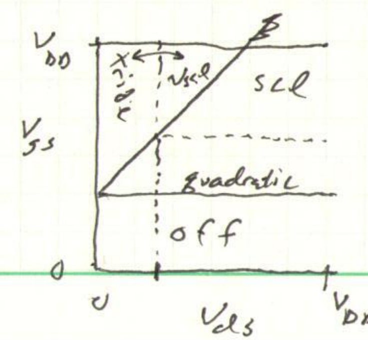
$= E_{scl}$

$I_d = \left(\text{charge per length}\right) v_{scl}$

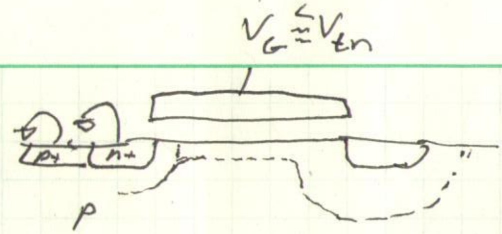
in triode $E = V_{ds}/L$

in saturation $E = \frac{V_{gs} - V_t}{L - \Delta L}$

$V_{ds,scl} = E_{scl} L$



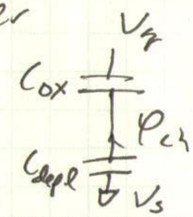
Let's revisit "off"



surface potential of channel in "depletion" before "inversion"

- with no gate: $-\varphi_0$
- with gate: capacitive divider

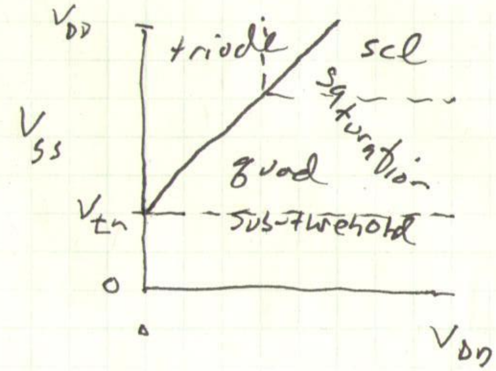
$$\varphi_{ch} = V_{gs} \frac{C_{ox}}{C_{ox}+C_{depl}} = \frac{1}{n} V_{gs}$$



forward bias source — channel diode

$$I_d = I_s e^{\varphi_{ch}/V_{th}} = I_s e^{V_{gs}/nV_{TH}}$$

"sub-threshold" or "weak inversion"



$n = 1.1 - 2+$ (↑ finFET, ↑ old tech.)

Exact same device can have

$$I_d = \frac{\mu_n C_{ox}}{2} \frac{W}{L}(V_{gs} - V_{tn})(1+\lambda V_{ds})$$

$$g_m = \frac{2 I_D}{V_{GS} - V_{tn}}$$

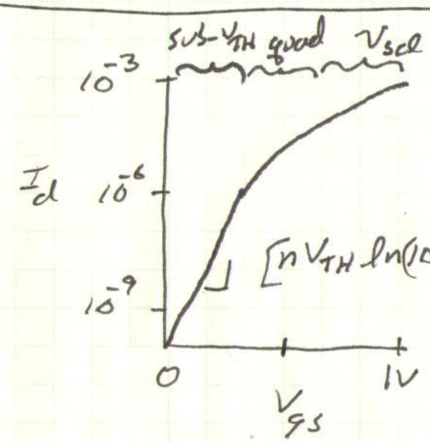
$$I_d = \frac{C_{ox} W (V_{gs} - V_{tn})}{2} v_{scl}$$

$$g_m = \frac{C_{ox} W v_{scl}}{2} = \frac{I_D}{(V_{GS} - V_{tn})}$$

$$I_d = I_s e^{V_{gs}/nV_{TH}}$$

$$g_m = \frac{I_D}{n V_{TH}}$$

} V_{ds} dependence? r_0? complex



e.g. $[100\,mV/decade]^{-1}$

⇑

$n = \frac{100}{60} = 1.67$

big problem for turning transistors off

$$\frac{V_{tn}}{n V_{TH} \ln(10)} \cong \#\text{decades on/off ratio}$$

Consider a process w/ $V_{th} = 0.5$ $V_{DD} = 2V$

$L_{min} = 0.1 \mu m$ $\mu_n C_{ox} = 200 \frac{\mu A}{V^2}$

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

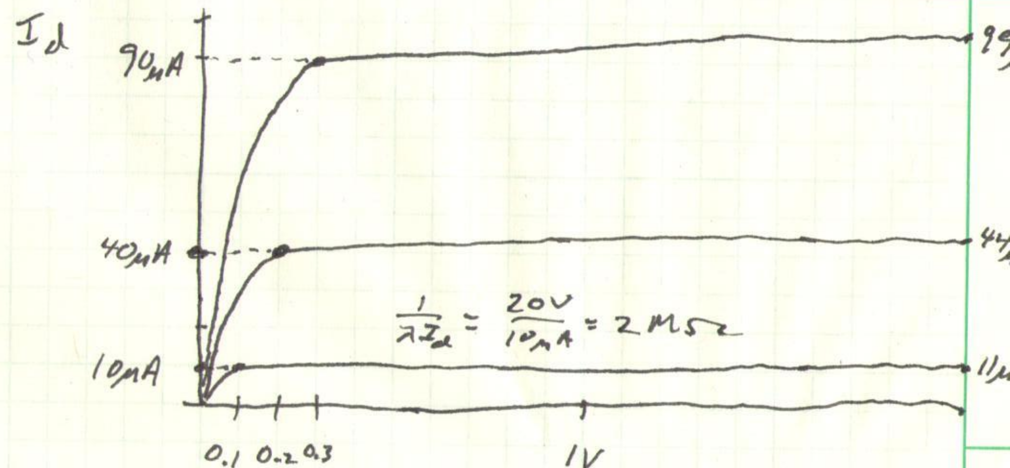
Device w/ $W = 10 \mu m$, $L = 1 \mu m$, $V_{GS} = V_t + \{0, 0.1, 0.2, 0.3\}$

plot I_d vs. V_{ds} $\Rightarrow \lambda = \frac{1}{20V}$ $\frac{V_{DD}}{\lambda} = 10\%$

$\frac{\mu_n C_{ox}}{2} \frac{W}{L} = 1 \frac{mA}{V^2}$

$(V_{gs} - V_t) = 0, 0.1, 0.2, 0.3$

$\frac{\mu_n C_{ox}}{2} \frac{W}{L} (0.1V)^2 = 10 \mu A$ $40 \mu A$ $90 \mu A$



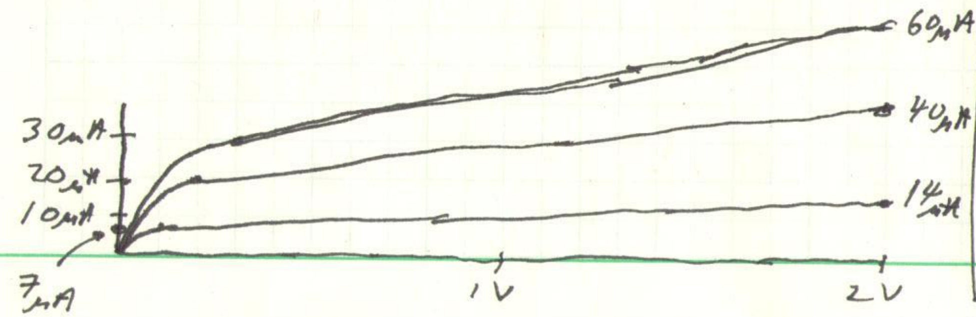
$\frac{1}{\lambda I_d} = \frac{20V}{10 \mu A} = 2 M\Omega$

$E_{max} = \frac{0.3V}{1 \mu m} = 0.3 \frac{V}{\mu m} \Rightarrow v = \mu E$ is fine

Same process, $W = 1 \mu m$, $L = 0.1 \mu m \Rightarrow \lambda = \frac{1}{2V}$ $\frac{V_{DD}}{\lambda} = 100\%$

$E_{max} = \frac{V_{gs} - V_t}{L} = \frac{\{0.1, 0.2, 0.3\} V}{0.1 \mu m} = \{1, 2, 3\} \frac{V}{\mu m}$

already losing velocity 30%



Same $\frac{W}{L}$ but much less current

much less g_m

much less r_o

Why would anybody do that?

$C_{gs} \sim 100\times$ lower   (speed)

Area $\sim 100\times$ lower   (cost)