MOS Model

$Sub\text{-}V_{th}$

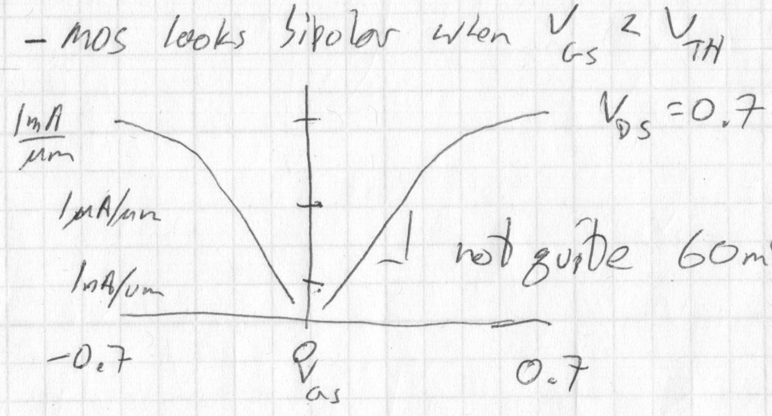
velocity saturation

regions of operation

Body effect

Last time

- MOS looks bipolar when $V_{GS} < V_{TH}$



6 orders of magnitude I_{on}/I_{off} ! Great!

What if you have 10 billion "off" transistors w/ $W = 100nm$

Razavi: sub-threshold is "slow"

$(1\mu m)(10 fF/\mu m) \doteq 10 fF = 10^{-14} F$

$I_D = 10^{-6} A$

$\frac{dV_o}{dt} = \frac{I}{C} = \frac{10^{-6}}{10^{-14}} = 10^8 \frac{V}{s}$

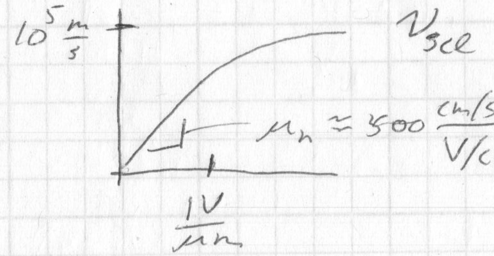
$g_m = \frac{I_C}{nV_T} = \frac{10^{-6}}{30mV} = 30\mu S$

$\omega_u = \frac{g_m}{C} = \frac{30\mu S}{10^{-14} F} = 30 \times 10^8 \frac{rad}{s} = 500 MHz$

Velocity saturation - when $V_{GS} - V_{TH} > 0$

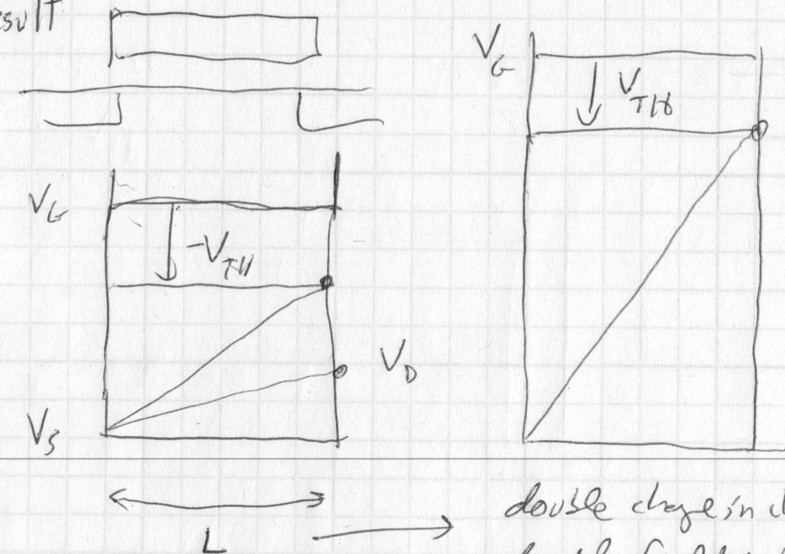
$I_D = [\text{avg charge per length}]\,[\text{velocity}]$

$= [W C_{ox}(V_{GS} - V_T)]\,[\ ?\ ]$



$\mu_n \approx 500 \frac{cm/s}{V/cm} = 5 \times 10^4 \frac{m/s}{V/\mu m}$

Result

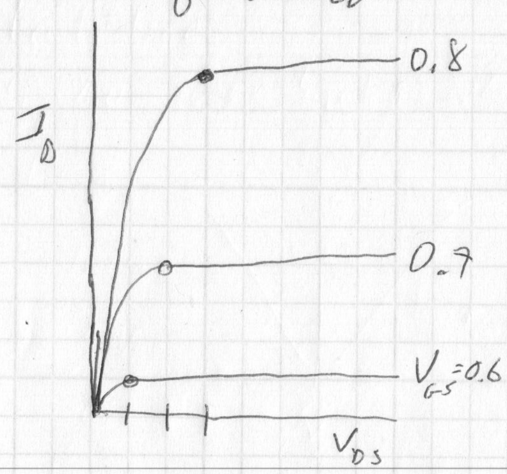


double $V_{GS}-V_{TH}$ → double charge in channel

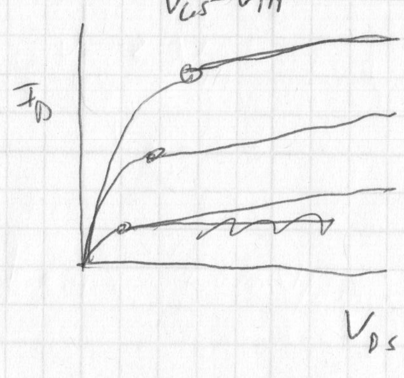
double field in channel

$\Rightarrow I_D$ quadratic

quadratic



linear in $V_{GS}-V_{TH}$



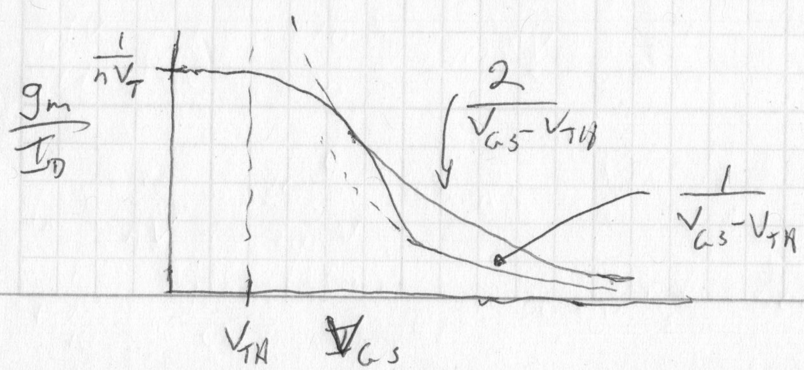
Say $V_{TH} = 0.5\,V$

$$\frac{V_{GS}-V_{TH}}{L} < \frac{1V}{\mu m}$$

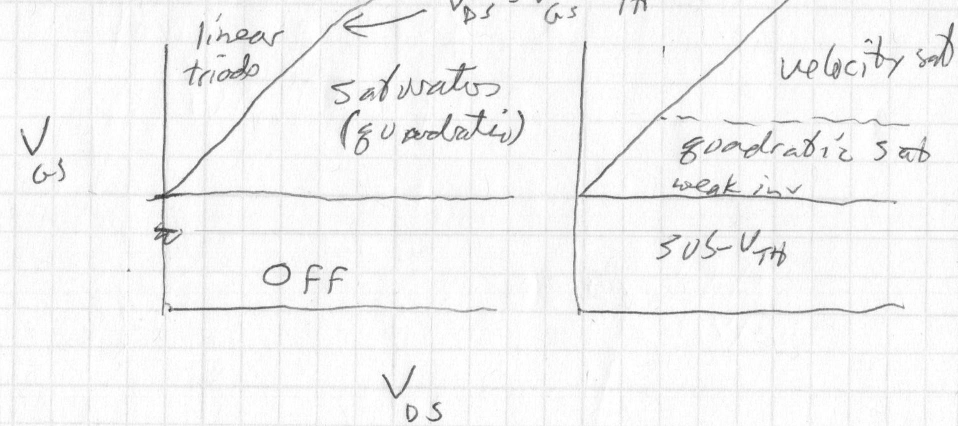
$$I_D = W C_{ox}(V_{GS}-V_{TH}) v_{sat}$$

$$g_m = W C_{ox} v_{sat} = \frac{I_D}{V_{GS}-V_{TH}}$$

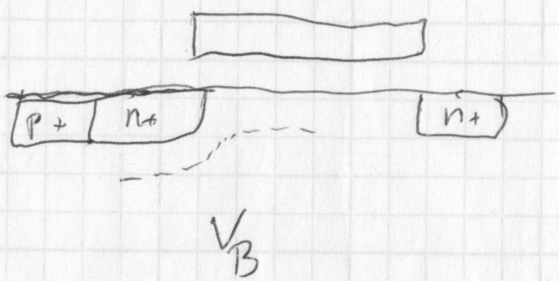
$$g_m = \begin{cases} \dfrac{2 I_D}{V_{GS}-V_{TH}} & \text{quadratic} \\ \dfrac{I_D}{n V_{TH}} & \text{sub-threshold} \\ \dfrac{I_D}{V_{GS}-V_{TH}} & \text{velocity saturated} \end{cases}$$



Regions of Operation

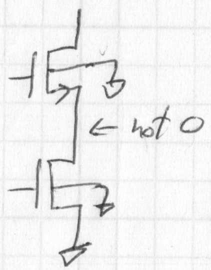


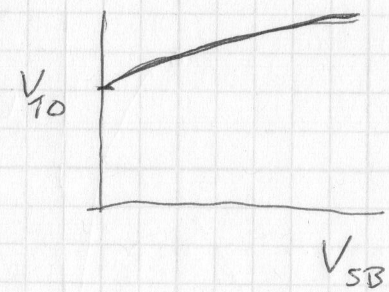
what if $V_B \neq V_s$



now V_B influences threshold!

cascode





$$V_t = V_{t0} + \frac{C_{dep}}{C_{ox}} V_{SB}$$

$$\frac{\partial I_D}{\partial V_{SB}} = g_{mb} = \chi g_m$$