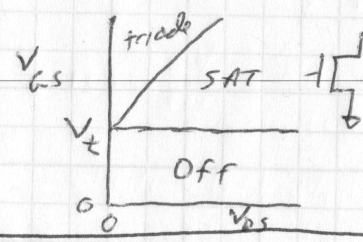
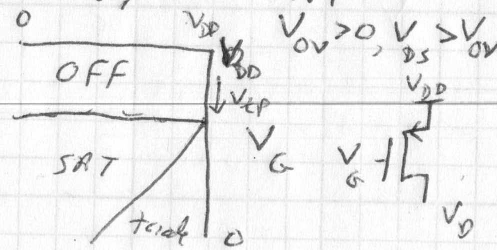
Regions of operation

Quadratic model

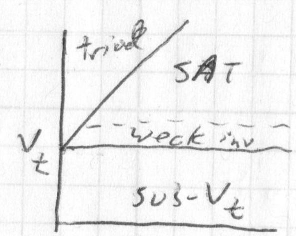
$$I_D = \begin{cases} 0 & V_{GS} \le V_t \quad (V_{ov} \le 0) & \text{OFF} \\ \mu_n C_{ox} \frac{W}{L}\left(V_{ov} - \frac{1}{2}V_{DS}\right)V_{DS}\left(1+\lambda V_{DS}\right) & \text{linear, triode} & V_{ov}>0,\ V_{DS}<V_{ov} \\ \frac{\mu_n C_{ox}}{2}\frac{W}{L}\left(V_{ov}\right)^2\left(1+\lambda V_{DS}\right) & \text{SAT} & V_{ov}>0,\ V_{DS}>V_{ov} \end{cases}$$

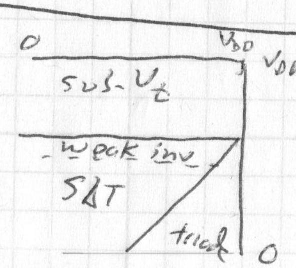




Quadratic

$$g_m = \frac{2 I_D}{V_{ov}} = \mu_n C_{ox}\frac{W}{L}\left(V_{ov}\right)\left(1+\lambda V_{DS}\right) \approx \sqrt{I_D\, 2\mu_n C_{ox}\frac{W}{L}}$$

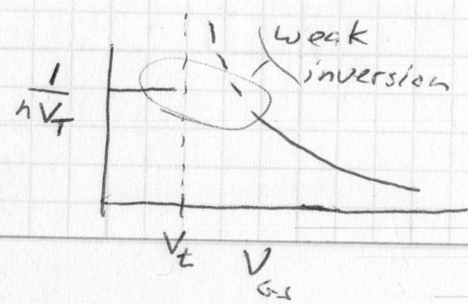




OFF is not really OFF

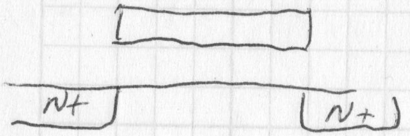
$$\left.\begin{aligned} I_D &= I_s\, e^{V_{GS}/(nV_T)}\left(1+\frac{V_{DS}}{V_A}\right) \\ g_m &= \frac{I_D}{nV_T} \end{aligned}\right\} \quad 0 < V_{GS} < V_t \quad \text{sub-threshold}$$

$$\frac{g_m}{I_D} = \begin{cases} \frac{2}{V_{ov}} & \text{quad} \\ \frac{1}{nV_T} & \text{sub-}V_t \end{cases}$$



140/240A 165P U3L1

Velocity saturation, scattering limited, short channel



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

$W C_{ox}\left(V_{GS} - V_t - \frac{1}{2}V_{DS}\right) \quad \mu_n \frac{V_{DS}}{L} \qquad \frac{V_{DS}}{L} < 10^6 \frac{V}{m}$

$W C_{ox}\left(\frac{V_{GS} - V_t}{2}\right) \quad v_{sel} \qquad \frac{V_{DS}}{L} > 10^7 \frac{V}{m}$

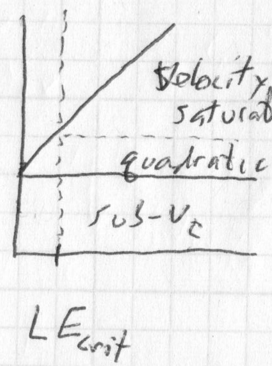
below $\frac{1V}{\mu m}$ quadratic model is fine

$\frac{V_{DS}}{L} < \frac{1V}{\mu m}$ $\qquad L = 0.18\mu m - 180mV$

$L = 14nm - 14mV$

$$V_{DSAT} = \begin{cases} V_{ov} & \frac{V_{DS}}{L} < 1\frac{V}{\mu m} \\ L E_{crit} & \frac{V_{DS}}{L} > E_{crit} \end{cases}$$

$\left(\frac{1}{V_{ov}} + \frac{1}{L E_{crit}}\right)^{-1}$ in between



E.g. $V_t = 0.5V \qquad V_{DD} = 1V \qquad L = 1\mu m$

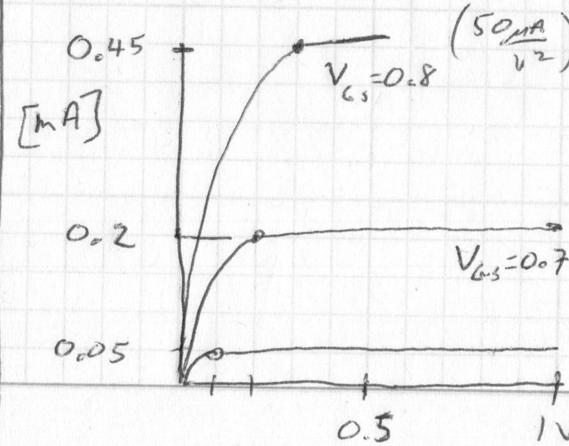
$\mu_n C_{ox} = 100\mu A/V^2 \qquad \lambda = 0.1\frac{1}{V} \qquad W = 100\mu m$

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

$\left(50\frac{\mu A}{V^2}\right)\left(\frac{100}{1}\right) = 5\frac{mA}{V^2}$

$V_{GS} = 0.6V$

$\left(V_{GS} - V_t\right)^2 = 0.01V^2$



$\mu_n C_{ox} = 200 \frac{\mu A}{V^2}$? $L = 14nm$ $W = 1.4\mu m$

$V_t = 0.5$ $\lambda = 1V^{-1}$

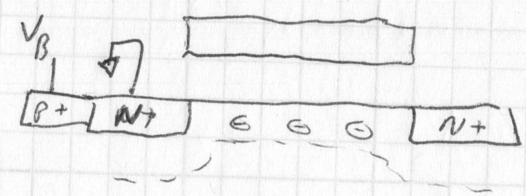
$WC_{ox} =$

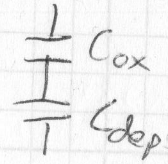
$V_{DD} = 1V$

$$I_D = \cancel{\mu_n} W C_{ox} (V_{gs} - V_t) v_{sat} (1 + \lambda V_{DS})$$

$-E_{sat} L$

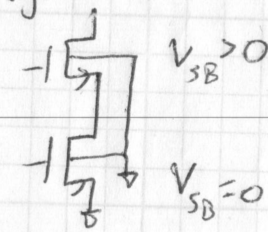
$$g_m = \frac{I_d}{V_{gs} - V_t} = WC_{ox}(v_{sat})(1 + \lambda V_{DS})$$





$V_{SB} > 0$

e.g.



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