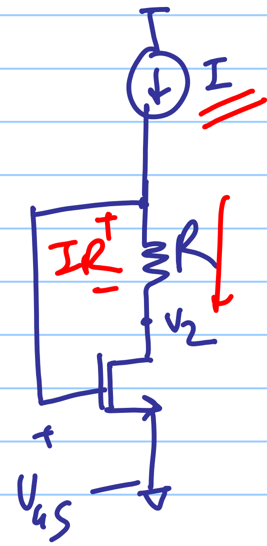
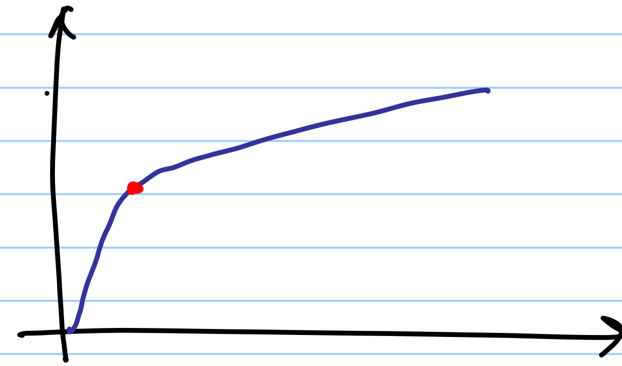
ECE 511 – Lecture 5

Note Title 2/4/2014

HW #2
Prob 3





$$V_2 = V_{GS} - V_{THN}$$

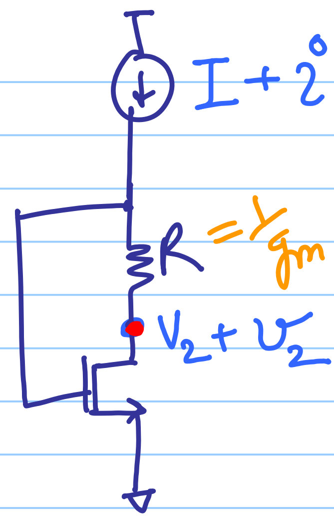
$$= V_{GS} - IR$$

$$\Rightarrow \quad IR = V_{THN}$$

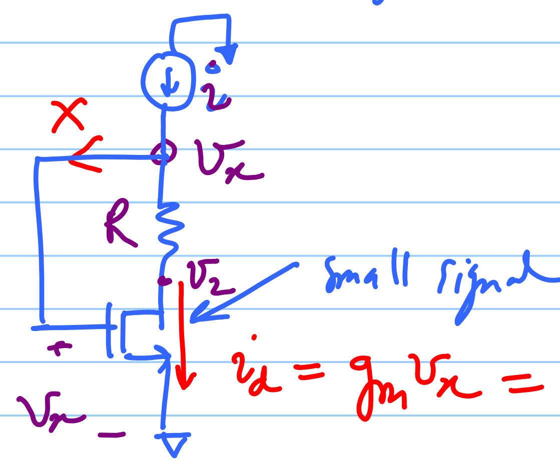
$$\boxed{I = V_{THN}/R}$$

(b)

$\boxed{\lambda = 0}$



$v_2 = f(i)$



$i_d = g_m v_x = i$

$i = g_m v_x \longrightarrow (1)$

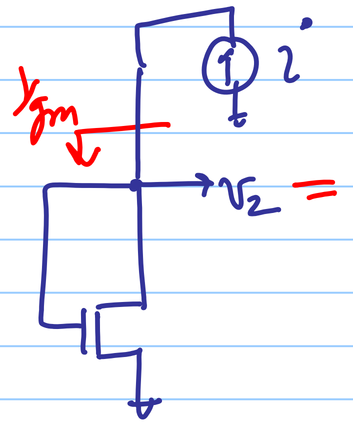
$v_2 = v_x - iR \longrightarrow (2)$

$$v_2 = \frac{i}{g_m} - iR$$

$$v_2 = i\left(\frac{1}{g_m} - R\right)$$

$$v_2 = 0$$

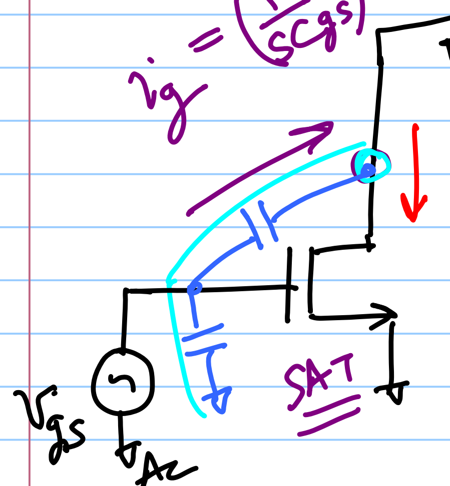
$$\boxed{R = \frac{1}{g_m}}$$



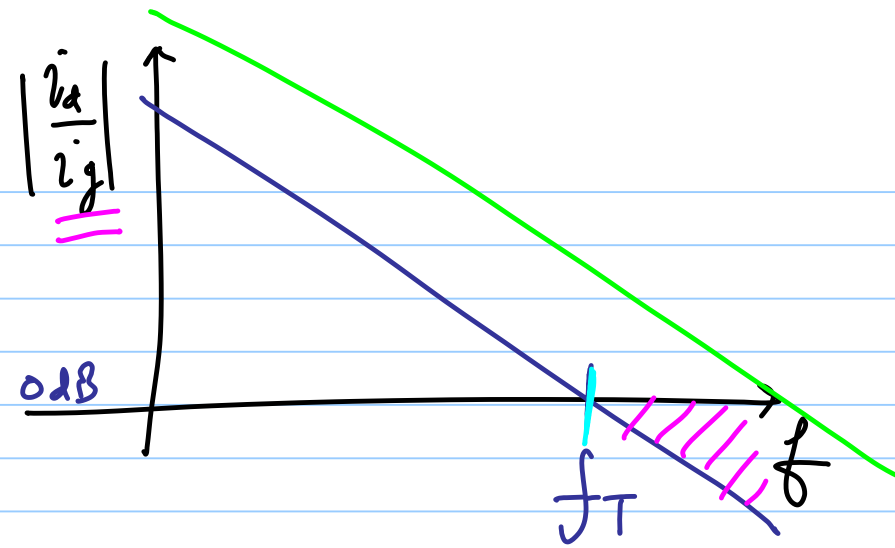
$$v_2 = \frac{1}{g_m} \cdot i$$

f_T

$$i_g = \frac{v_{gs}}{\frac{1}{sC_{gs}}} = sC_{gs}v_{gs}$$



$$i_d = g_m v_{gs}$$



$$@\ f = f_T,\quad \left|\frac{i_d}{i_g}\right| = 1$$

AZ

$$f_T = \frac{g_m}{2\pi C_{gs}}$$

$$= \frac{\mu_n \cancel{C_{ox}} \left(\frac{\cancel{W}}{L}\right)(V_{GS}-V_{THN})}{2\pi \cdot \frac{2}{3}\cancel{C_{ox}}\, \cancel{W} L}$$

Using Long-L equations

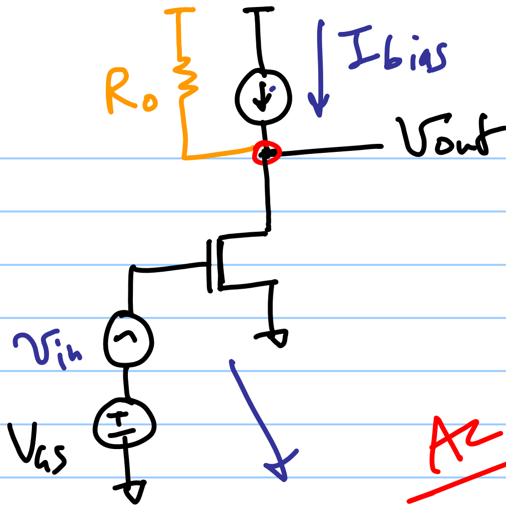
$$= \frac{3\mu_n}{4\pi} \cdot \frac{V_{ov}}{L^2}$$

$$\boxed{f_T \propto \frac{V_{ov}}{L^2}}$$

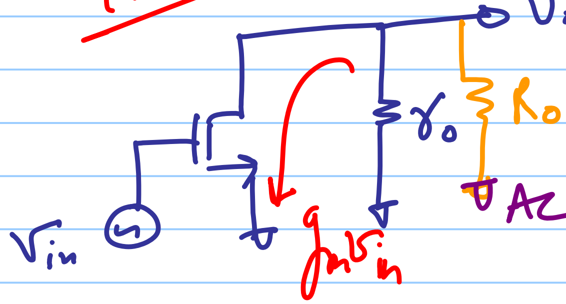
for large $f_T \Rightarrow V_{ov} \uparrow$

$L = L_{min}$

maximum gain of the transistor



AC picture



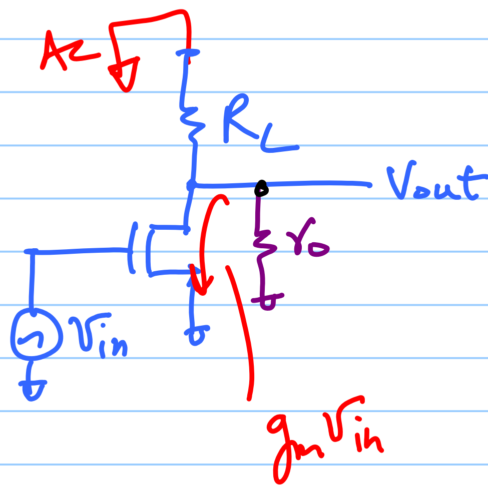
$$V_{out} = -g_m v_{in} r_o$$

$$= -(g_m r_o)\, v_{in}$$

max open-loop gain of the transistor $\boxed{A_v = -g_m r_o}$

$A_v =$

Example



$\lambda > 0$

$$V_{out} = -g_m (R_L \| r_o) V_{in}$$

$$A_v = -g_m (r_o \| R_L) \longrightarrow -g_m r_o$$

for $R_L \to \infty$

$$|A_v| = g_m r_o$$

open-loop gain of a transistor

$$|A_v| = g_m r_o \qquad \lambda \propto \frac{1}{L} =$$

$$= KP_n \cdot \frac{W}{L} \cdot V_{ov} \cdot \frac{1}{\lambda \cdot I_{Dsat}}$$

$$= \frac{\cancel{KP_n} \cancel{\left(\frac{W}{L}\right)} \cancel{V_{ov}}}{\cancel{KP_n} \cancel{\frac{W}{L}} V_{ov}^{\cancel{2}}} \cdot \frac{1}{\frac{1}{L} \cdot \alpha}$$

$$\boxed{g_m r_o \propto \frac{L}{V_{ov}}}$$

$$f_T \propto \frac{V_{ov}}{L^2}$$

$$g_m r_o \propto \frac{L}{V_{ov}}$$

gain x BW product

$$g_m r_o \cdot f_T = \frac{g_m^2}{2\pi C_{gs}} \cdot \frac{1}{\lambda I_D} = \frac{3\mu_n}{2\pi L^2 \lambda} \propto \frac{\mu_n}{L}$$

for a fixed length L

$$(g_m r_o) f_T = \text{constant}$$

$V_{ov} \uparrow \Rightarrow f_T \uparrow$ but $g_m r_o \downarrow$

Tradeoff b/w gain and speed.

Short-channel

$$f_T = \frac{g_m}{2\pi C_{gs}} \propto \boxed{\frac{V_{ov}}{L}}$$

$\cancel{\mu_n}$

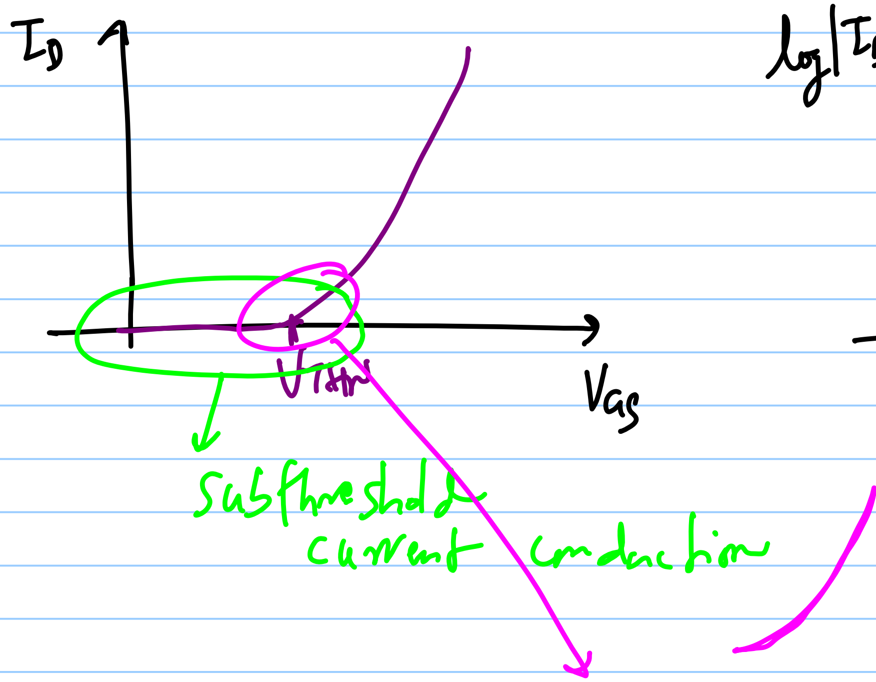
v_{sat}

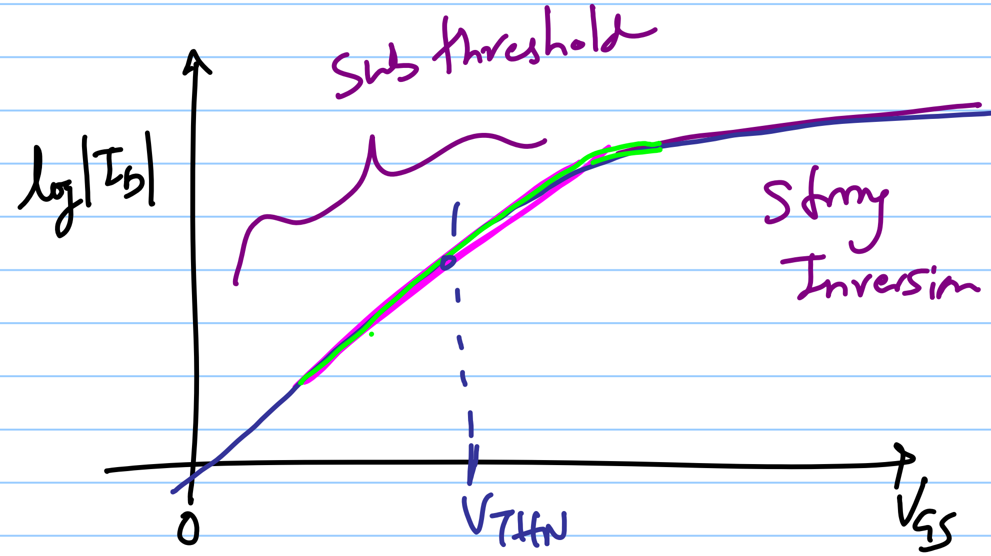
$$g_m r_o \propto \frac{L}{V_{ov}}$$

$$I_D \propto v_{sat}(V_{GS} - V_{THN})$$

$g_m r_o f_T \simeq$ constant in short channel technologies.

Subthreshold g_m





Sub-V_T Current is due to diffusion

g_m subthreshold.

$$\boxed{i_D = I_{D_0} \cdot \frac{W}{L} e^{\frac{v_{GS} - V_{THN}}{n V_T}}}$$

only true in the subthreshold region

$$i_D \propto e^{v_{GS} - V_{THN}}$$

What is the g_m?

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS} = V_{GS}}$$

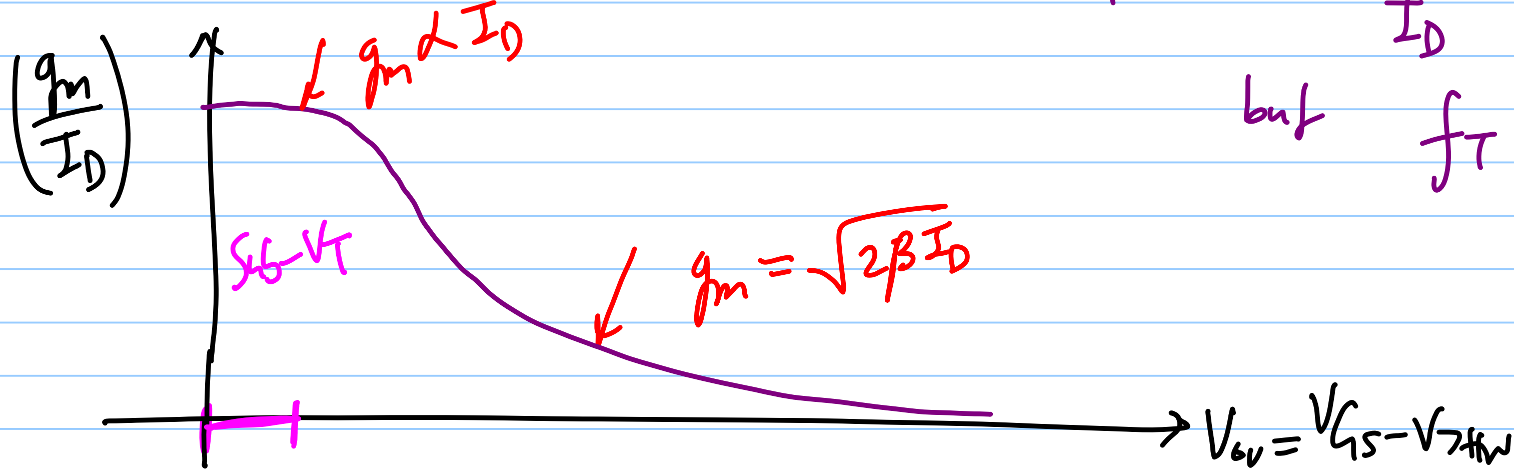
$$g_m = I_{D0} \cdot \frac{W}{L} \cdot \frac{1}{nV_T} e^{\frac{V_{GS} - V_{THN}}{nV_T}}$$

efficiency metric

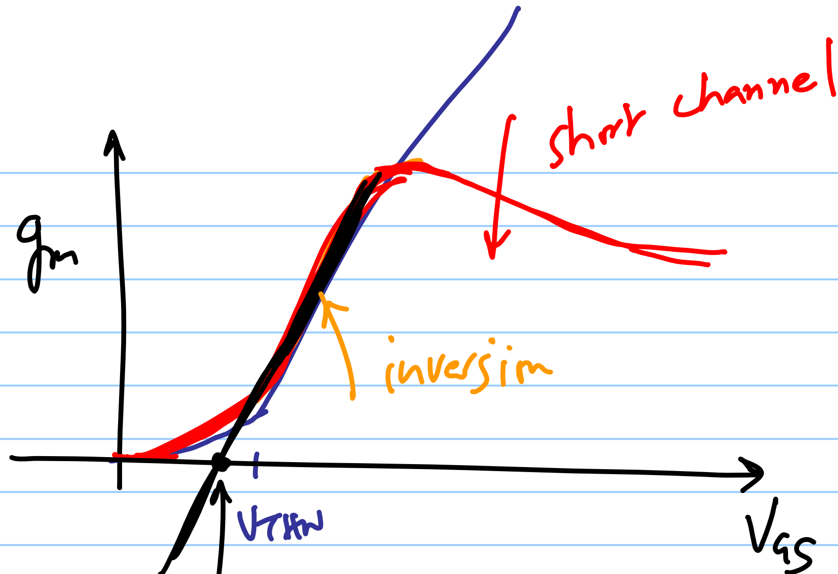
$$\boxed{g_m = \frac{I_D}{nV_T}}$$

Sub-V_T $\Rightarrow$ $\frac{g_m}{I_D}$ efficiency

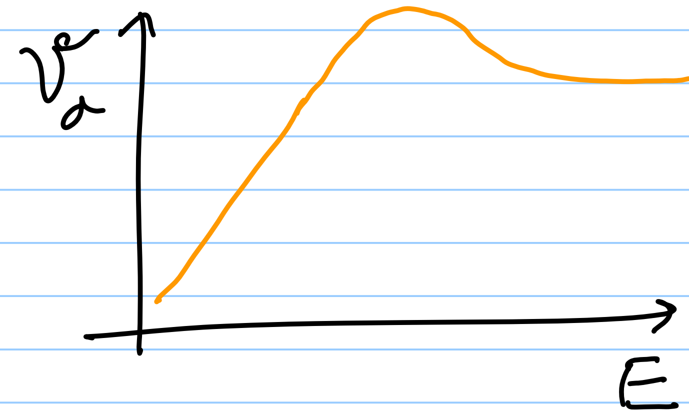
but f_T are low

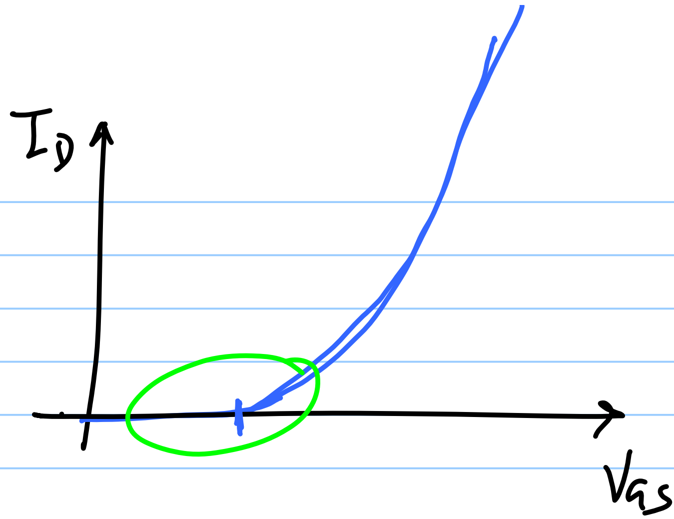


$$g_m = \beta(V_{GS} - V_{THN})$$

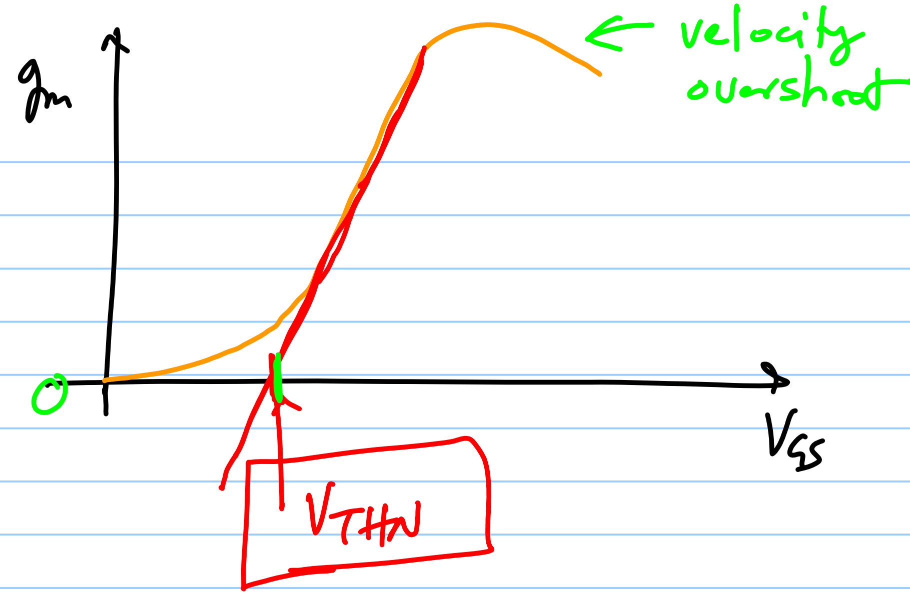


where $V_{GS} = V_{THN}$ for circuit design purpose





I_D
V_{GS}



g_m
velocity overshoot
0
V_{THN}
V_{GS}

from square law Equations.

$$\boxed{\boxed{\frac{g_m}{I_D}} \Rightarrow \frac{2}{\boxed{V_{ov}}}}$$

$$g_m = \frac{2I_D}{V_{ov}}$$

$$\Rightarrow \quad V_{ov} = \frac{2I_D}{g_m}$$

$\left(\frac{g_m}{I_D}\right) \Leftrightarrow$ fixing V_{ov} overdrive voltage

$$\Rightarrow \quad \frac{g_m}{I_D} = \frac{2}{V_{ov}} \leftarrow \text{only true}$$

$$g_m r_o \propto \frac{L}{V_{ov}}$$

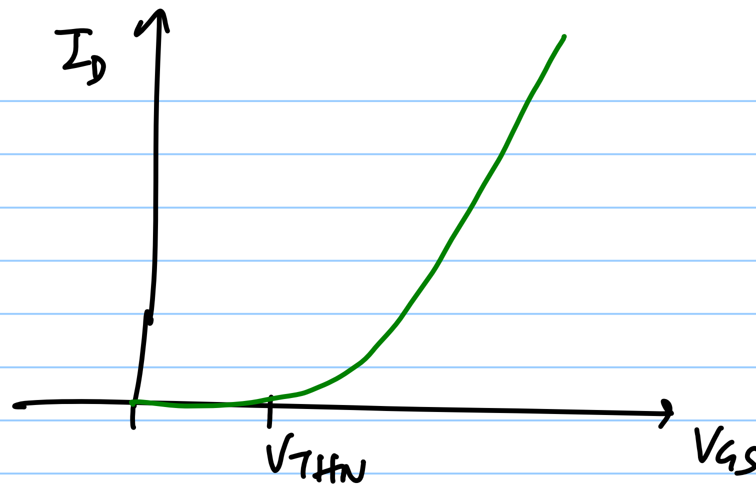
$$f_T \propto \frac{V_{ov}}{L}$$

$$\left(\frac{g_m}{I_D}\right) \propto \frac{L}{V_{ov}}$$

Temperature :

μ_n V_{THN}

$$I_D = KP_n \cdot \frac{W}{L}\left(V_{GS} - V_{THN}\right)^2$$



T ↑

① $\mu(T) \propto \left(\frac{T}{T_0}\right)^{-3/2}$

Scattering ⇐ more collisions with the lattice

$$\mu(T) = \mu(T_0)\left(\frac{T}{T_0}\right)^{-3/2}$$

$T \uparrow \Rightarrow \mu \downarrow$

$$KP(T) = KP(T_0) \cdot \left(\frac{T}{T_0}\right)^{-3/2}$$

② $$V_{THN} = -V_{ms} - 2V_{fp} + \frac{Q_{bo}' - Q_{ss}'}{C_{ox}'}$$

$T \uparrow \Rightarrow V_{THN} \downarrow$

$$\frac{\partial V_{THN}}{\partial T} \simeq -\frac{k}{q} \ln\left(\frac{N_{D,poly}}{N_A}\right)$$

$$\Rightarrow \frac{\partial V_{THN}}{\partial T} \simeq -1\, mV/^{\circ}C \quad \text{for} \quad N_{D,poly} = 10^{20}, \; N_A = 10^{15}$$