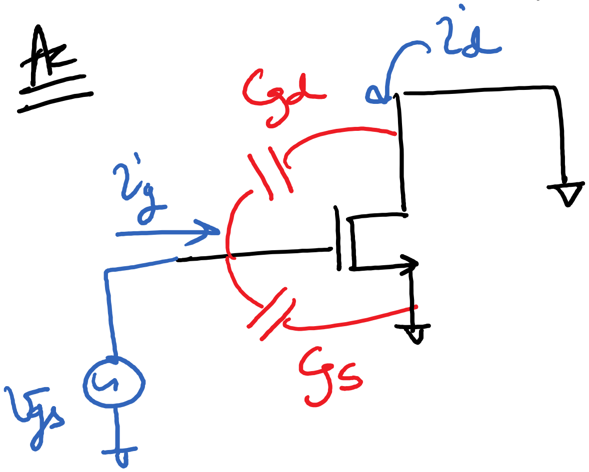
ECE 515 - Lecture 4

Tuesday, September 4, 2018 11:00 AM

Transition Frequency (f_T)

f_T



short circuit current gain

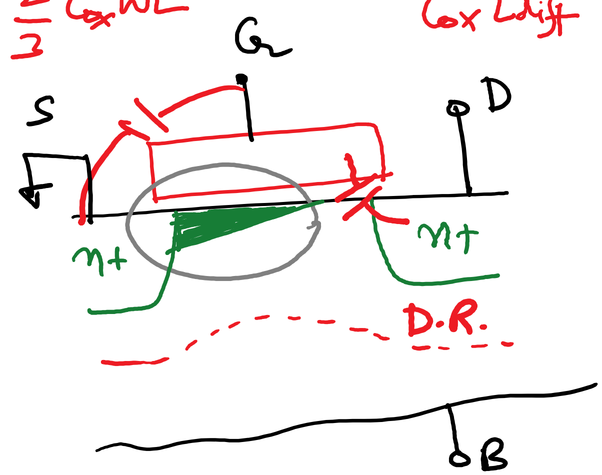
$$\left|\frac{i_d}{i_g}\right| = 1 \quad \text{at} \quad f = f_T$$

$C_{gd} = C_{GDO} \cdot W$

$\downarrow$

$C_{ox}' L_{diff}$

$C_{gs} \simeq \frac{2}{3} C_{ox}' W L$

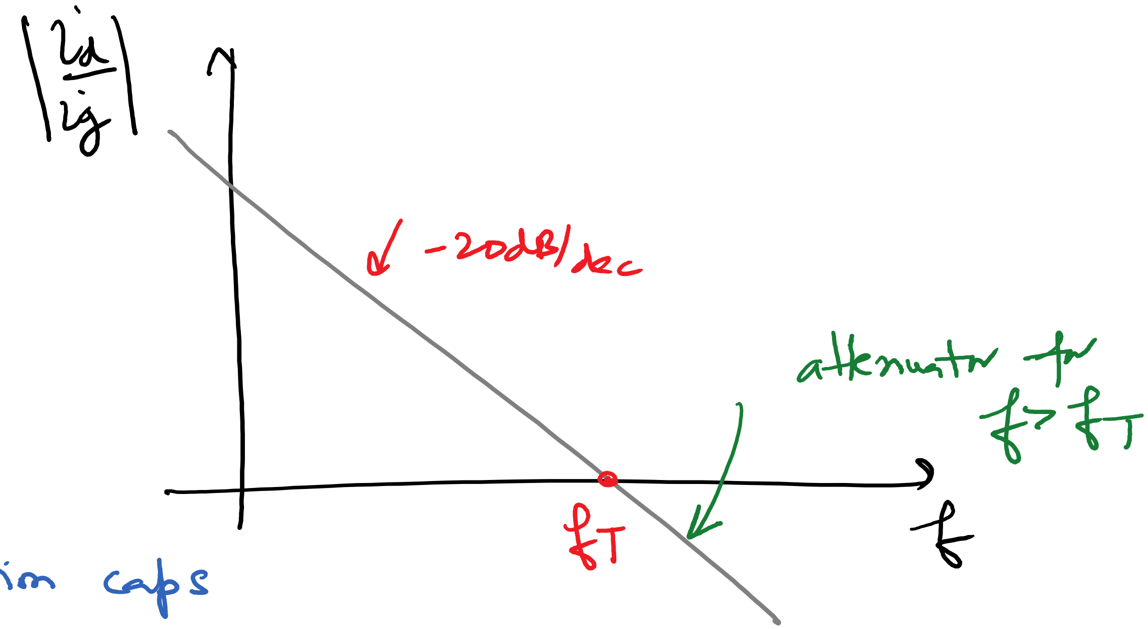


$$i_d = g_m v_{gs}$$

$$= g_m \cdot i_g \cdot \frac{1}{s(C_{gd}+C_{gs})}$$

$$\rightarrow \left|\frac{i_d}{i_g}\right| = \left|\frac{g_m}{2\pi f (C_{gd}+C_{gs})}\right| = 1$$

$$f_T = \frac{g_m}{2\pi\,(\underbrace{C_{gd}}+\underbrace{C_{gs}})} \simeq \frac{g_m}{2\pi C_{gs}}, \quad \because C_{gs} \gg C_{gd}$$



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

→ ignores junction caps and is defined such that r_o is excluded

$$C_{gs} = \frac{2}{3} C_{ox}' WL$$

$$f_T = \frac{g_m}{2\pi C_{gs}} = \frac{\mu_n \cancel{C_{ox}} \frac{\cancel{W}}{L} \overbrace{(V_{GS} - V_{THN})}^{V_{OV}}}{2\pi \cdot \frac{2}{3} \cdot \cancel{C_{ox}} \cdot \cancel{W} L} = \frac{3\mu_n}{4\pi} \cdot \frac{V_{OV}}{L^2}$$

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

for high-speed use minimum channel length

Use large overdrive voltage

Tuesday, September 4, 2018   11:15 AM

maximum gain that can be extracted from a transistor

$$A_{vo} = g_m r_o$$

$$= \sqrt{2\beta I_D} \cdot \frac{1}{\lambda I_D} = \frac{\sqrt{2 k'_n W/L}}{\lambda} \cdot \frac{1}{\sqrt{I_D}}$$

$I_D \uparrow \Rightarrow A_{vo} \downarrow$

$\lambda \propto \frac{1}{L}$

$$\Rightarrow g_m r_o = \frac{\cancel{k'_n \frac{W}{L}} \cdot \cancel{V_{ov}}}{\lambda \cdot \cancel{\frac{k'_n}{2} \cdot \frac{W}{L}} \cdot V_{ov}^2} = \frac{2}{\lambda \cdot V_{ov}} \propto \frac{L}{V_{ov}}$$

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

open circuit gain $\downarrow$

$L \downarrow$ or $V_{ov} \uparrow$

Tuesday, September 4, 2018 11:20 AM

CMOS

g_m short-channel process

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

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

$\because$ Devices are not square law in short channel CMOS

$$GFT = g_m r_o \cdot f_T \propto \frac{V_{ov}}{L} \cdot \frac{L}{V_{ov}} \simeq \text{const.}$$

Trade off between $g_m r_o$ & f_T

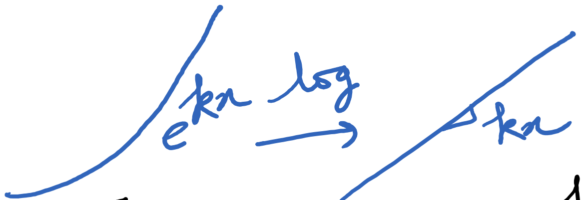
$$V_{ov} \uparrow \Rightarrow f_T \uparrow \; + \; g_m r_o \downarrow$$

With CMOS Scaling $\Rightarrow$ $L_{min} \downarrow$ in every generation

$f_T \uparrow$ but $g_m r_o \downarrow$

Tuesday, September 4, 2018 11:24 AM

Subthreshold g_m



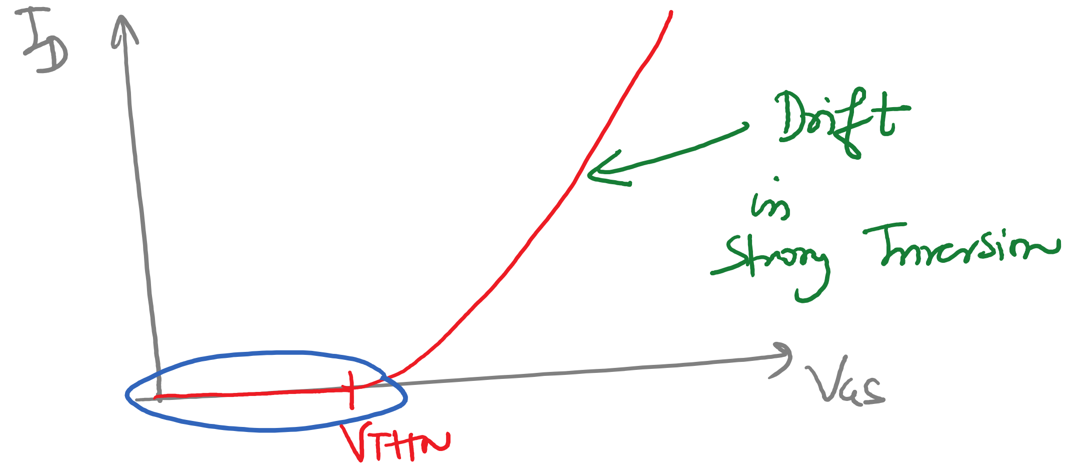
g_m Sub-V_T

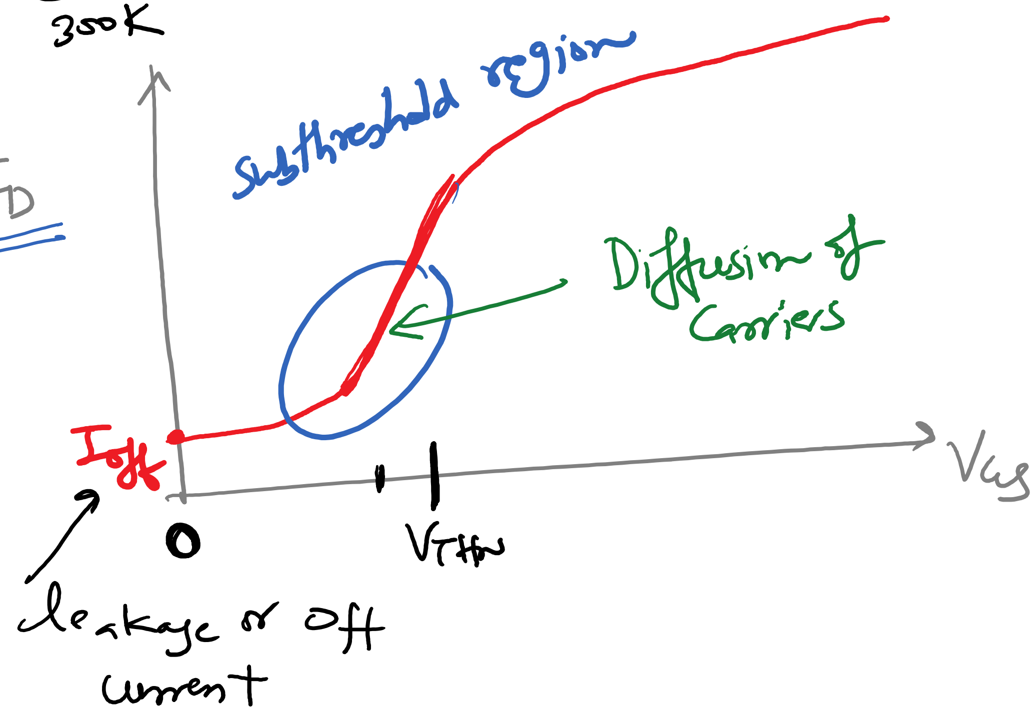
$$I_D = I_{D_0} \cdot \frac{W}{L} \, e^{\frac{V_{GS} - V_{THN}}{n V_T}}$$

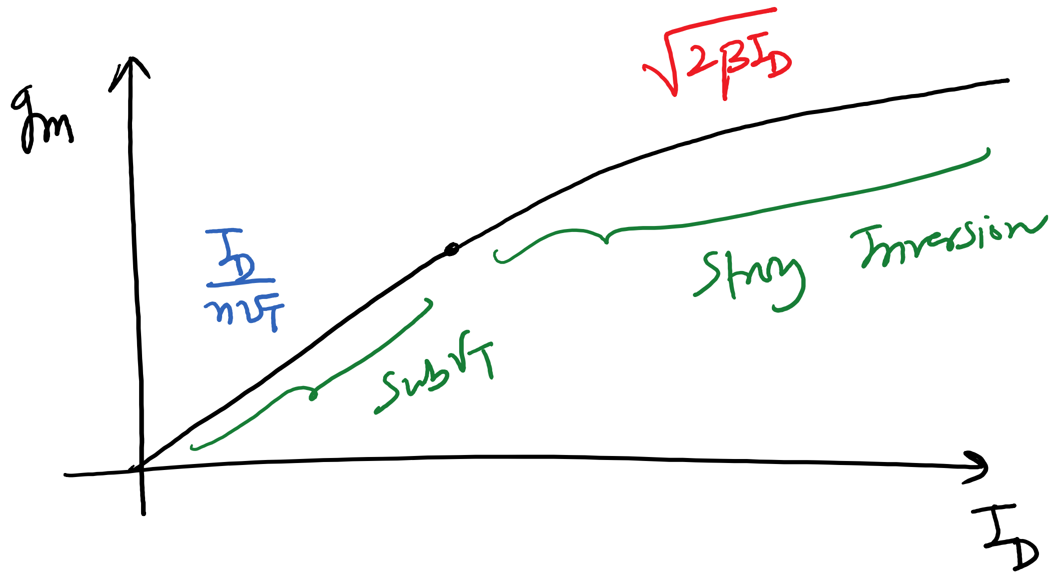
$$\frac{kT}{q} = 26\,mV \text{ @ } RT \; (300K)$$

$$g_m = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{GS}} = I_{D_0} \cdot \frac{W}{L} \cdot e^{\frac{V_{GS} - V_{THN}}{V_T}} \cdot \frac{1}{n V_T}$$

$$\boxed{g_m = \frac{I_D}{n V_T}}$$







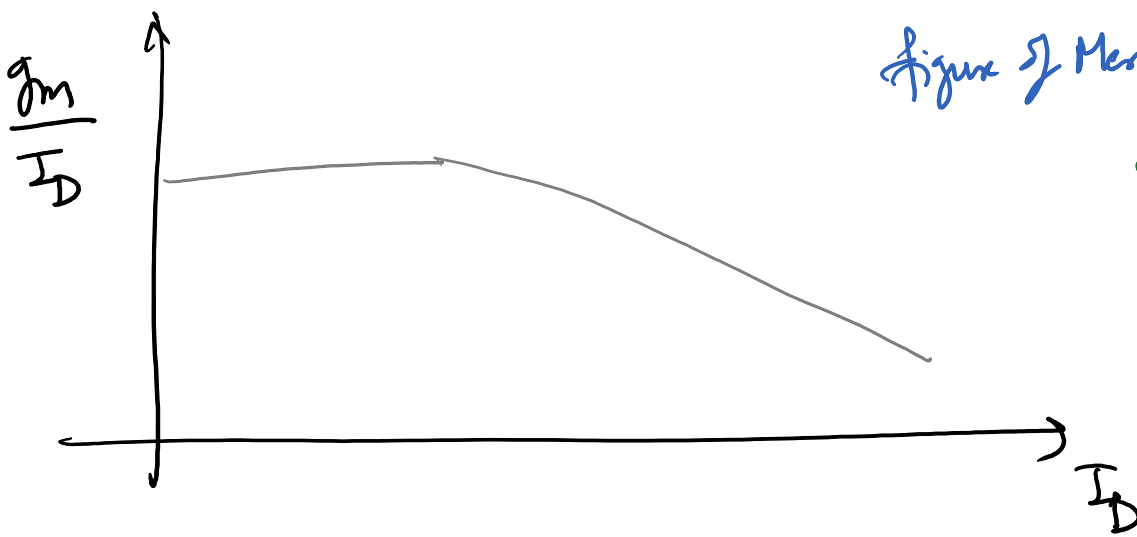


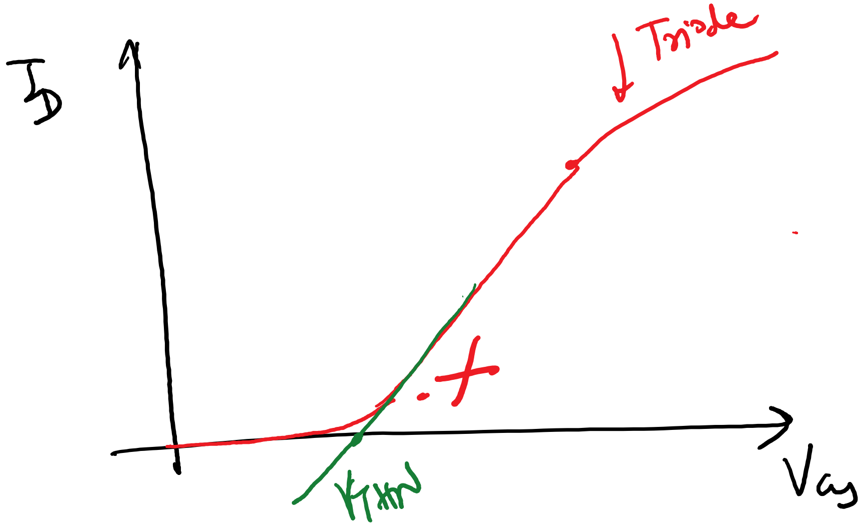
figure of Merit = $\frac{g_m}{I_D}$

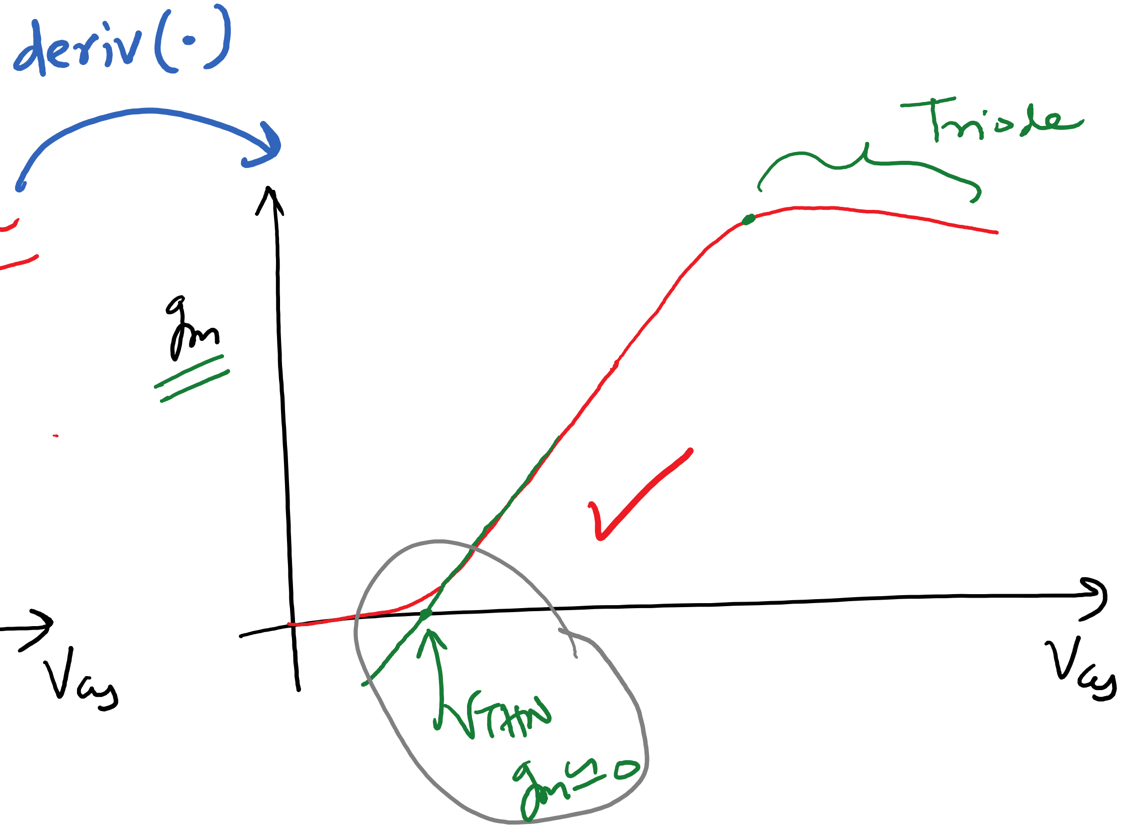
In subV_T ⇒ we get higher $\frac{g_m}{I_D}$ but

f_T will be small

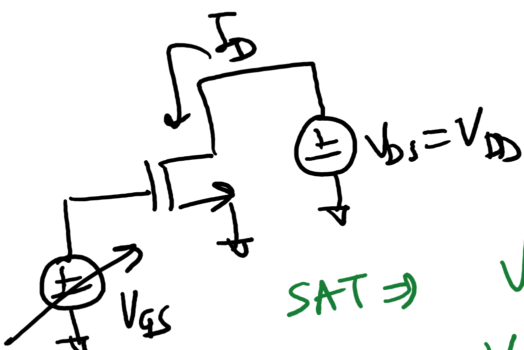
$f_T <$ MHz

Tuesday, September 4, 2018 11:41 AM





$V_{GS} = V_{THN}$ where $g_m = 0$.



SAT $\Rightarrow$ $V_{DS} > V_{GS} - V_{THN}$

$V_{GS} < V_{DS} + V_{THN}$

MOSFET Temperature Effects

Tuesday, September 4, 2018 11:49 AM

How does I_D change with T.

$$I_D = \frac{\overbrace{K'_n}^{\mu_n C'_{ox}}}{2} \frac{W}{L}\left(V_{GS} - V_{THN}\right)^2$$

$\mu_n = \mu_n(T)$

$V_{THN} = V_{THN}(T)$

$$V_{THN} = -V_{ms} - 2V_{fp} + \frac{Q'_{bo} - Q'_{ss}}{C'_{ox}}$$

$$V_{ms} \rightarrow \frac{kT}{q} \ln \frac{N_{D,poly}}{N_A}$$

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

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

$$\boxed{\frac{\partial V_{THN}}{\partial T} \simeq -1\,mV/^{\circ}C}$$

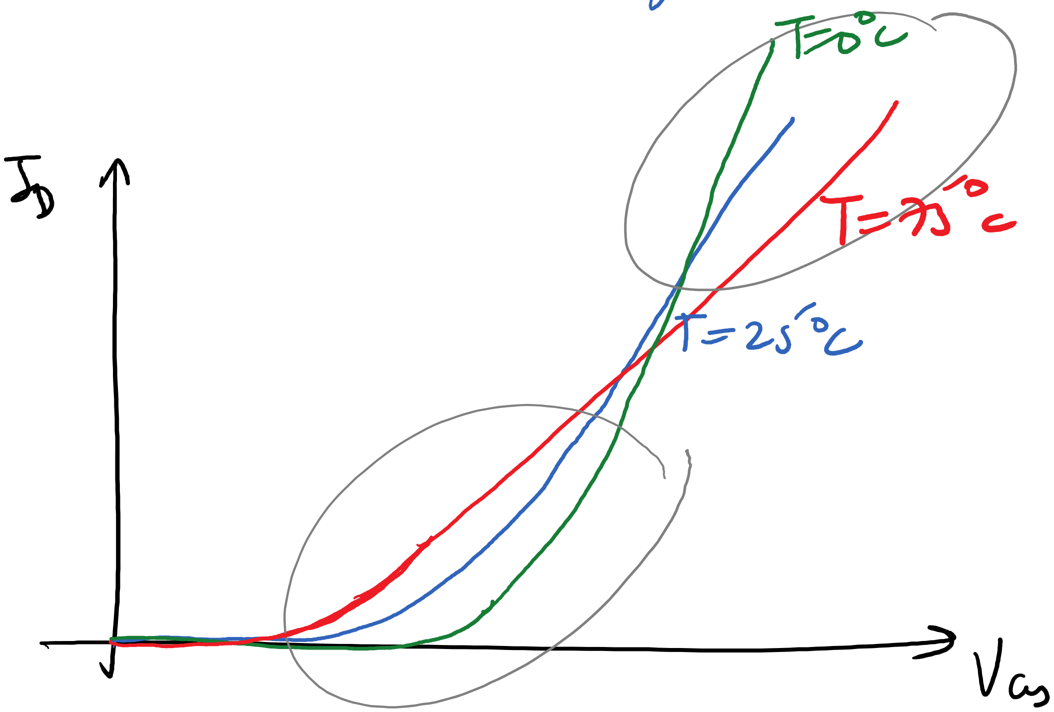
$k'_n = \mu_n C_{ox}$

μ_n → mobility

$T \uparrow$ scattering

$v_d \downarrow \Rightarrow \mu_n \downarrow$

$\mu(T) \propto T^{-3/2}$



$T = 75°C$

$T = 0°C$

$I_D \uparrow$ for small V_{ov}

but $I_D \downarrow$ for larger

$V_{GS} = V_{DD}$

Really depends upon the application.

$$\frac{\partial I_D}{\partial T} \propto \frac{(V_{GS}-V_{THN})}{2}\frac{\partial KP_n}{\partial T} - KP_n \cdot \frac{\partial V_{THN}}{\partial T}$$

term dominates at higher V_{OV}.