ECE 5411 – Lecture 5

Note Title 2/2/2011

$\frac{f_{T_p}}{f_{T_n}} < 1$ $\mu_p < \mu_n$

$v_{sat_p} < v_{sat_n}$

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

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

→ using square-law equations

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

$\frac{g_m}{I_D}$ method

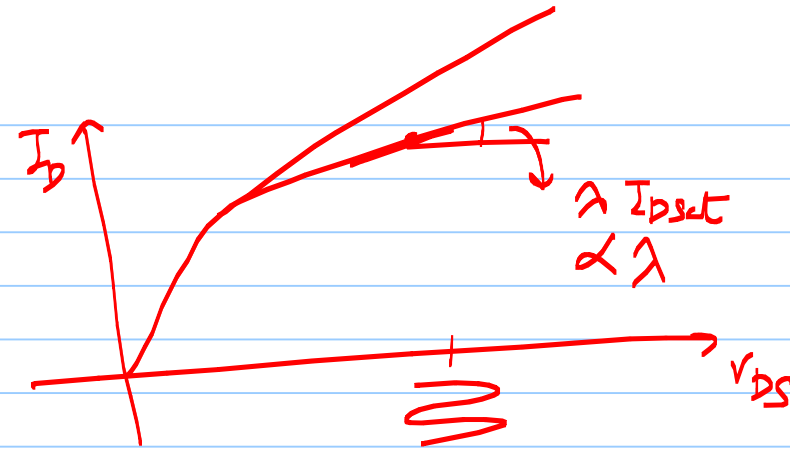
$$\frac{g_m}{I_D} = \frac{2}{\boxed{V_{ov}}} \rightarrow 50\% \text{ of } V_{DD}$$

Fixed overdrive method

$\boxed{\text{tsmc\_02d}}$

180n

$$\lambda = \frac{1}{L}\cdot\left(\frac{dX_{d}}{dV_{ds}}\right)$$



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

$$V_{DS}\uparrow \Rightarrow I_D \uparrow$$

Temperature behavior of MOSFETs

$$I_D = \frac{\mu_n C_{ox}'}{2}\frac{W}{L}\left(V_{GS} - V_{THN}\right)^2$$

$T \uparrow$

V_{THN}

$\mu_n \rightarrow KP_n$

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

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

$$V_{THN}(T) = V_{THN}(T_0)\left[1 + \underline{TC_{V_{THN}}}\,(T - T_0)\right]$$

$$TC_{V_{THN}} = \frac{1}{V_{THN}(T_0)}\frac{\partial V_{THN}}{\partial T}$$

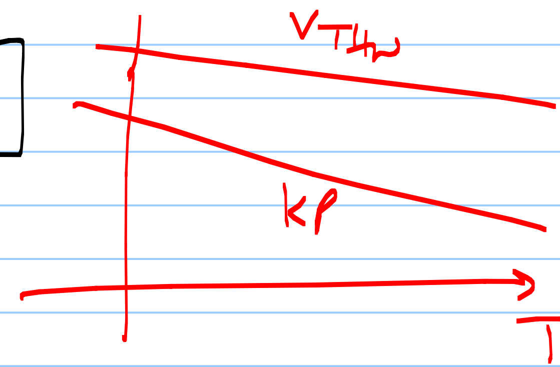
$T\uparrow \Rightarrow \mu_n \downarrow$

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

$KP = \mu C_{ox}'$

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

$$KP(T) = KP(T_0)\left[1 - 1.5\,\frac{T-T_0}{T}\right]$$



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

$$\frac{\partial I_D}{\partial T} = \frac{\partial KP_n}{\partial T}\left(\frac{1}{2}\frac{W}{L}(V_{GS}-V_{THN})^2\right) - \left(\frac{KP_n}{2}\frac{W}{L}2(V_{GS}-V_{THN})\right)\frac{\partial V_{THN}}{\partial T}$$

$$= \frac{W}{L}(V_{GS}-V_{THN})\left[\frac{1}{2}(V_{GS}-V_{THN})\frac{\partial KP_n}{\partial T} - KP_n\frac{\partial V_{THN}}{\partial T}\right]$$

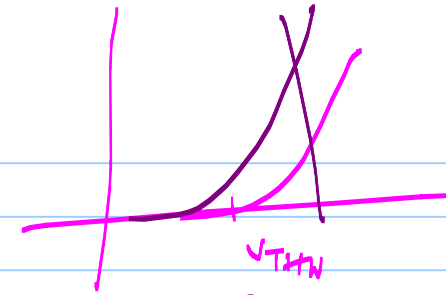
$$\boxed{\frac{\partial I_D}{\partial T}} \propto \underbrace{\frac{(V_{GS}-V_{THN})}{2}\boxed{\frac{\partial KP_n}{\partial T}}}_{1^{st}} = \underbrace{KP_n\Big|_{T_0}\boxed{\frac{\partial V_{THN}}{\partial T}}}_{2^{nd}}$$

$T\uparrow$

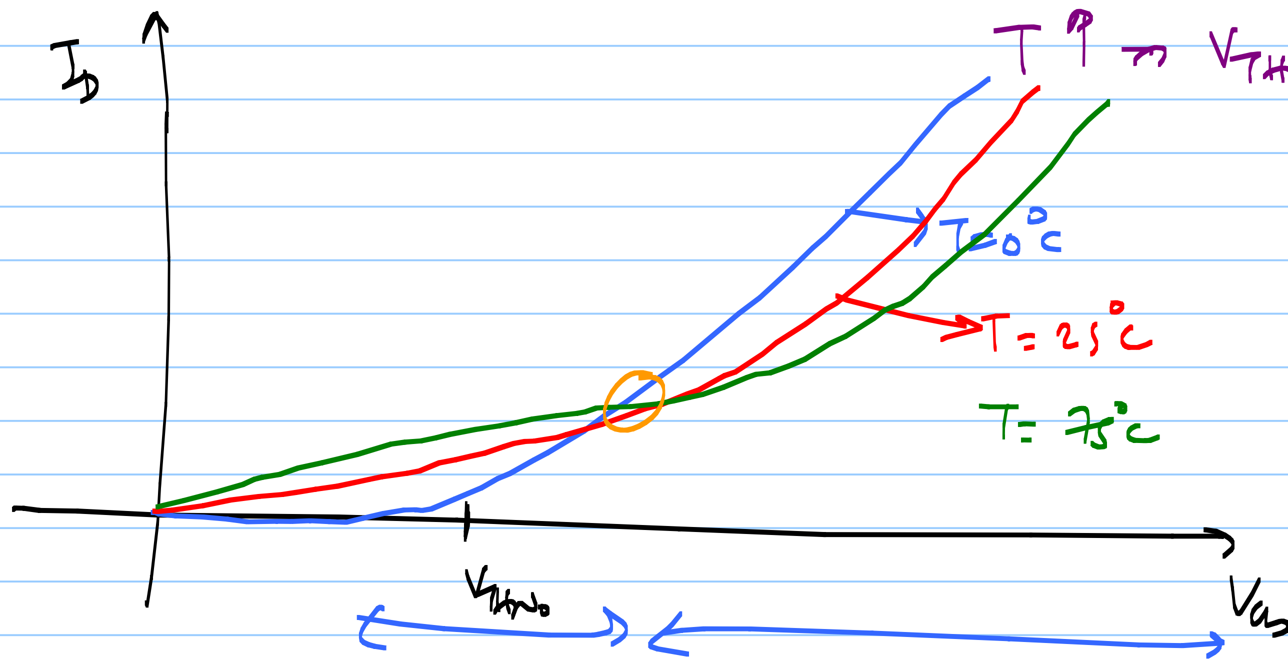
depends upon V_{GS}

At low V_{GS} ⇒ V_{THN} effect dominates

@ Large V_{GS} ⇒ KP_n effect dominates



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



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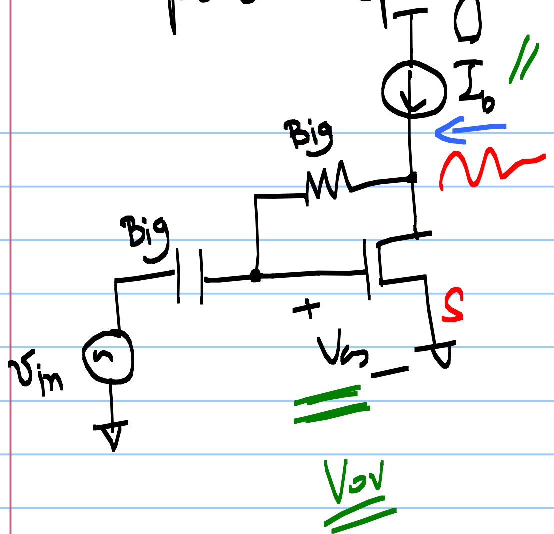
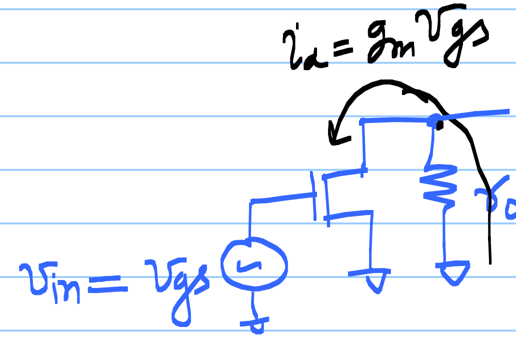
Open-Loop Gain of the MOSFET





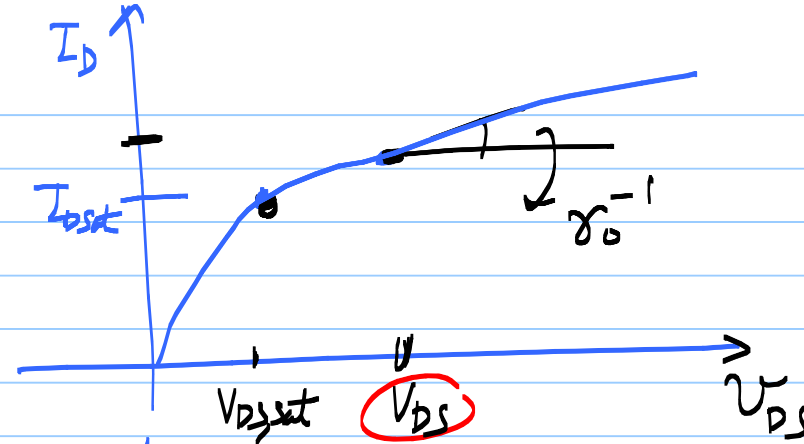
$$\frac{V_{out}}{v_{in}} = -g_m r_o$$

$$\left|\frac{V_{out}}{V_{in}}\right| = A_{V_0} = g_m r_o$$

open loop gain

inherent gain of the MOSFET

$$A_o = \underline{g_m r_o} = \sqrt{2\beta I_{Dsat}} \cdot \frac{1}{\lambda I_{Dsat}}$$

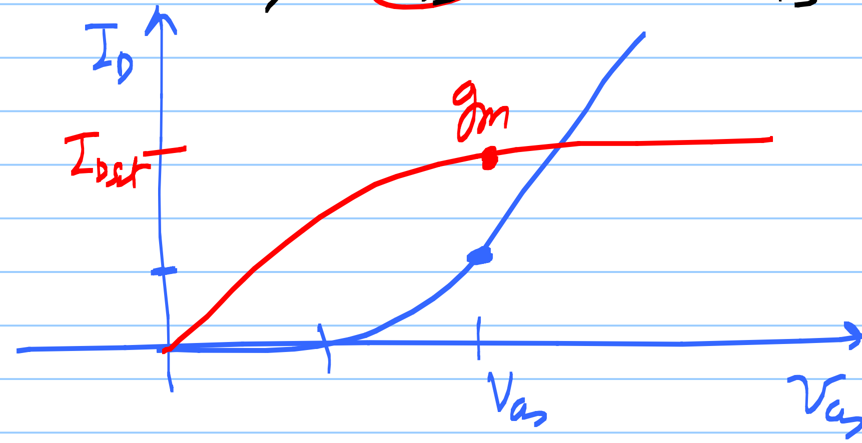


$$= \frac{\sqrt{2 k'_n W/L}}{\lambda} \cdot \frac{1}{\sqrt{I_D}}$$

$$A_{vo} \propto \frac{1}{\sqrt{I_D}}$$

$$g_m r_o = \frac{\cancel{k'_n \frac{W}{L}}\ \cancel{(V_{GS} - V_{THN})}}{\lambda \cdot \frac{k'_n}{\cancel{2}} \cancel{\frac{W}{L}}\ (V_{GS} - V_{THN})^{\cancel{2}}} = \frac{2}{\lambda (V_{GS} - V_{THN})}$$

$$\propto \frac{L}{V_{OV}}$$



LC

$A_o = \boxed{g_m r_o \propto \frac{L}{V_{ov}}}$ $\boxed{f_T \propto \frac{V_{ov}}{L^2}}$

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

$L \uparrow \Rightarrow g_m r_o \uparrow$ $f_T \downarrow$

$GFT = \text{gain} \times f_T$ figure of merit for a technology

For Long-channel devices

$GFT = g_m r_o \cdot f_T$

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

$\lambda L =$ const.

$GFT \neq f(V_{ov})$ ✗

$GFT = f(L)$ ✓

$\mu_n =$ const.

for a fixed 'L' $\Rightarrow$ $GFT =$ const.

$(g_m r_o) \cdot (f_T) =$ const.

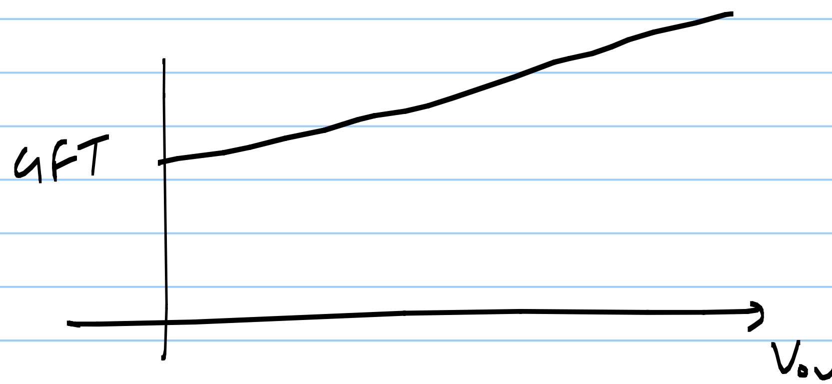
$V_o \uparrow$ $\quad\downarrow\quad\uparrow$

fundamental trade-off b/w gain and speed of the MOSFET!

<u>for short channel:</u>

$V_{ov} \Rightarrow \underline{\underline{\mu_n}}$

$\frac{\mu_n}{L}$



Variance

$\sigma_{\Delta L}$

$L + \Delta L$

$2L + \Delta L$

'mismatch'

$\frac{g_m}{I_D}$