ECE5411 - Lecture 4.

Note Title 1/31/2011

$$I_{Dsat} = \frac{k'_n}{2}\frac{W}{\boxed{L}}\boxed{V_{DS,sat}^2}$$

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

$$r_o = \frac{1}{\lambda I_{Dsat}} \propto \frac{L^2}{V_{DS,sat}^2}$$

* for a fixed $V_{GS} \Rightarrow V_{DS,sat}$ is fixed

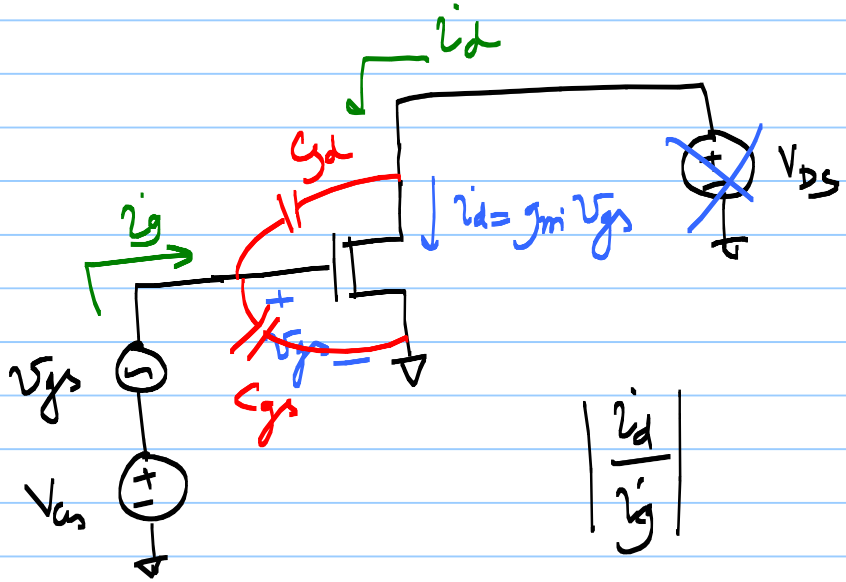
$L\uparrow \Rightarrow r_o \uparrow$

* for fixed L,

$V_{DS,sat}\downarrow \Rightarrow r_o \uparrow$

* why not use large 'L' devices and get high r_o?

MOSFET Transition frequency (f_T):



* Drain & Source terminals at AC ground

* C_{gd} & C_{gs} are in $\|^{el}$

$$\left| \frac{i_d}{i_g} \right|$$

$$v_{gs} = \frac{i_g}{s(C_{gd}+C_{gs})} \longrightarrow ①$$

$$i_d = g_m v_{gs} \longrightarrow ②$$

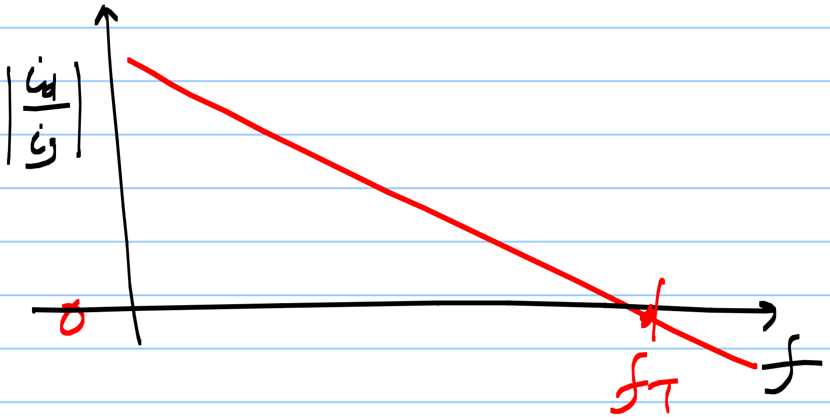
current gain ⇒ $$\frac{i_d}{i_g} = \frac{g_m}{s(C_{gs}+C_{gd})}$$

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

$$\boxed{f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})}}$$

f_T ⇒ frequency where the Ai current gain becomes 1.

⇒



RF circuits $\quad f_{max} > f_T \quad$ TH Lee Pg. 178

$C_{gs} >> C_{gd}$ (Saturation)

$$f_T \simeq \frac{g_m}{2\pi C_{gs}} = \frac{\overset{\mu_n \cancel{C_{ox}'}}{KP_n}\,\cancel{W}\,(V_{GS}-V_{THN})}{2\pi \cdot L\,\frac{2}{3}\cdot \cancel{C_{ox}'}\,\cancel{W}L} = \frac{3\mu_n(V_{GS}-V_{THN})}{4\pi L^2}$$

$$\boxed{f_T = \frac{3\mu_n}{4\pi}\cdot\frac{V_{DS,sat}}{L^2}}$$

$L\downarrow$, $f_T\uparrow$

$V_{DS,sat}\uparrow$, $f_T\uparrow$

for max speed ⇒ $L = L_{min}$

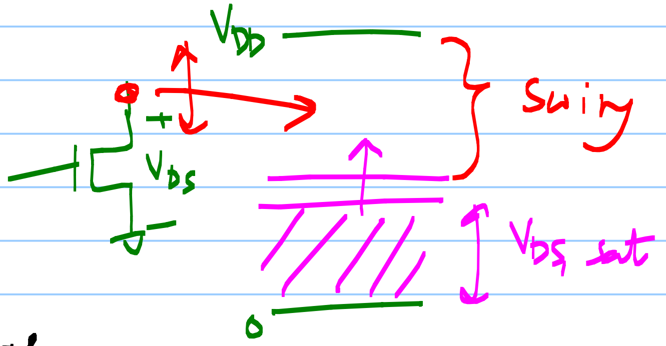
⇒ large overdrive ⇒ $V_{DS,sat} = \underline{\underline{V_{GS}}} - V_{THN}$

* Trade-offs :

↳ min L ⇒ $r_o \downarrow$ ⇒ lower gain

⇒ gain × speed trade-off

↳ large $V_{DS,sat}$ ⇒ $r_o \downarrow$



⇒ MOSFETs triode early

↳ reduced output swings

(amplifier or mirrors)

$f_T \propto \mu_n$

Same $\frac{W}{L}$ $$\frac{f_{T_p}}{f_{T_n}} = \frac{\mu_p}{\mu_n} < 1$$

* PMOS devices are slower than NMOS for the same size.

* short-channel devices :

* μ_n is no longer constant, starts to decrease with decreasing Length

$\mathcal{E}\uparrow \Rightarrow$

$$\mu_n = \frac{\partial v_d}{\partial \mathcal{E}} \Rightarrow \downarrow$$

$\Rightarrow \left(\frac{\mu_n}{L}\right)$ is relatively constant

$$f_T \propto \cancel{\left(\frac{\mu_n}{L}\right)} \frac{V_{DS,sat}}{L} \propto \boxed{\frac{V_{DS,sat}}{L}}$$

no longer L^2

With CMOS Technology Scaling

$L \downarrow$

(+) $f_T \uparrow$, $WL \downarrow$

(−) $r_o \downarrow \rightarrow g_m r_o \downarrow$

(−) lower swing

(+/−) $V_{DD} \downarrow$ $(CV^2f \downarrow)$

$\underline{\underline{V_{THN/P}}} \leftrightarrow$

"Digital Assisted Analog Design"

Device Sizes for Analog Design

Use $L \Rightarrow 2 \rightarrow 5 \times L_{min}$

High-speed Design $\Rightarrow$ $V_{ov} = 5\%$ of V_{DD}

$V_{ov} \neq V_{DS,sat}$ in Short-channel

See Table 9.1 Pg (292)

$$g_m = \sqrt{2\beta_n I_D} = \underline{\underline{\frac{2I_D}{V_{ov}}}} = \beta_n (V_{ov})$$

$$g_m = \frac{2I_D}{V_{ov}} \qquad V_{ov} \Rightarrow 5\% \; V_{DD}$$

$$\rightarrow \left(\frac{g_m}{I_D}\right) = \frac{2}{V_{ov}}$$

↳ g_m/I_D design methodology

$\frac{g_m}{I_D}$ is a key metric for devices

MOSFET

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

BJT

$$\underline{\underline{g_m}} = \frac{I_c \nearrow}{V_T} \sim 26\,mV$$

$\frac{g_m}{I_D}$ large = 15-20

Subthreshold g_m

$$i_D = I_{D0} \frac{W}{L} e^{\frac{v_{GS} - V_{THN}}{nV_T}}$$

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS} = cnt} = \overbrace{I_{D0} \frac{W}{L} e^{\frac{v_{GS} - V_{THN}}{V_T}}}^{I_D} \cdot \frac{1}{nV_T}$$

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

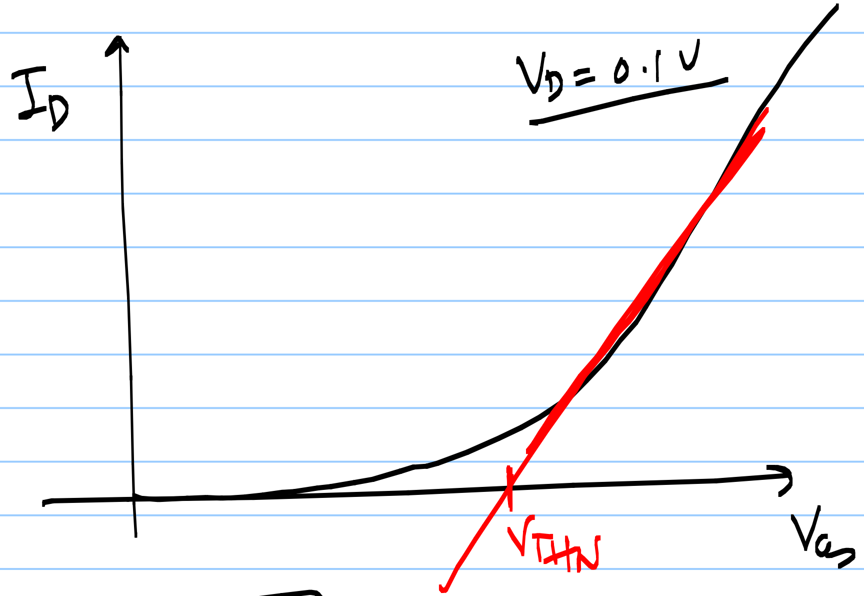
WEAK INVERSION

$$g_m = \sqrt{2\beta I_D}$$

SATURATION

f_T is very small

V_{THN}



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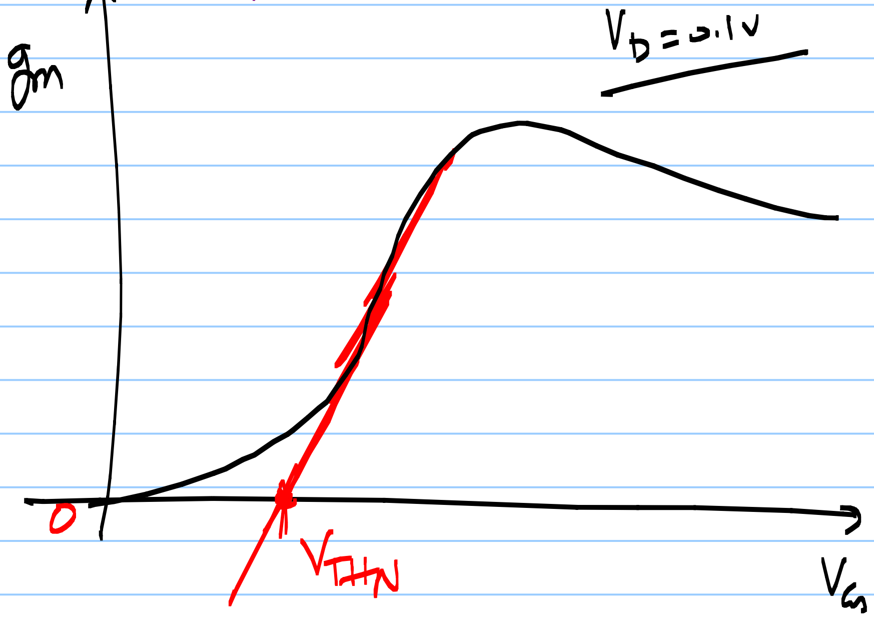
Better for Analog



$$g_m = \beta_n\,(\underline{\underline{V_{GS}}} - V_{THN})$$

Temperature Effects

$\boxed{\mu_n} C_{ox}'$

$$I_{D,sat} = \frac{KP_n}{2}\left(V_{GS} - \boxed{V_{THN}}\right)^2$$

$\boxed{V_{THN}}$

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

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

$$\frac{k}{q} = \frac{\partial V_T}{\partial T} = 0.085\ mV/^\circ C$$

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

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

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

$T \uparrow$

$V_{THN} \downarrow$

$\mu_n \downarrow$