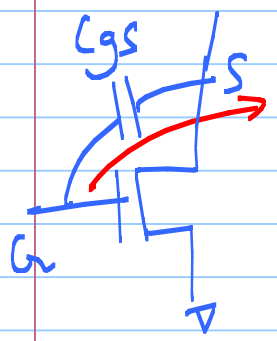
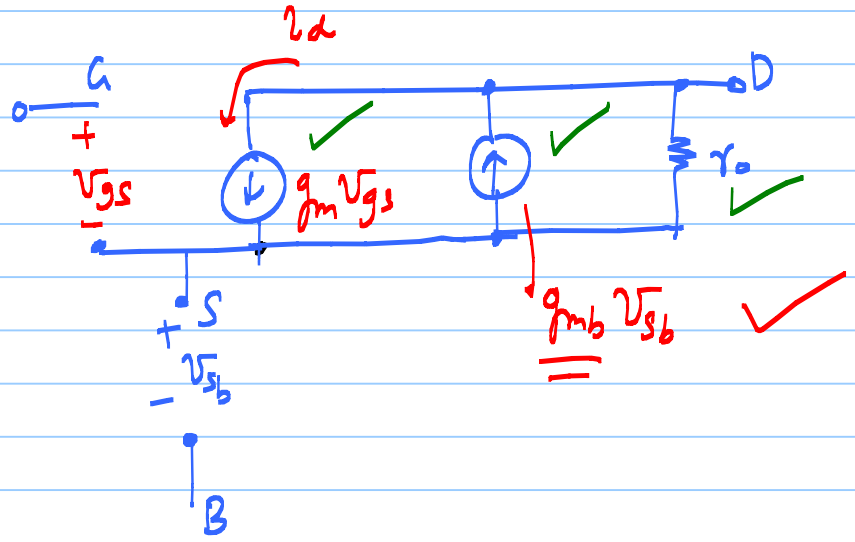
ECE 511 – Lecture 5

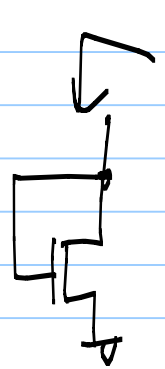
Note Title 2/1/2012

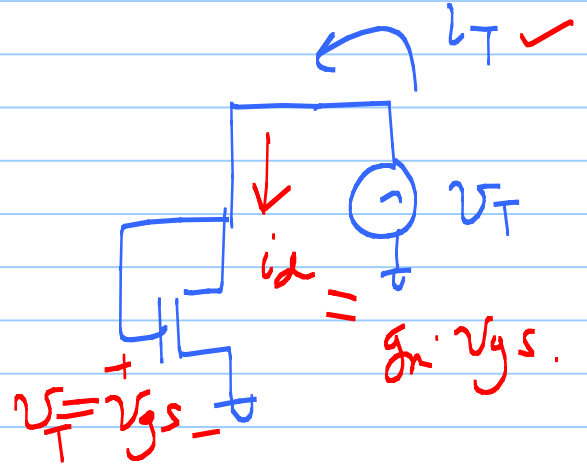




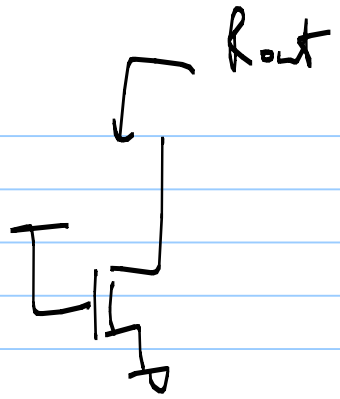
Small-signal equivalent circuit for NMOS (low frequency)

Diode Connected load :





$$R_{out} = \frac{v_T}{i_T} = \frac{v_{gs}}{i_d} = \frac{1}{g_m}$$



$$R_{out} = R_{ch} = \frac{1}{K P_n \frac{W}{L} (V_{GS} - V_{THN})}$$

$$\simeq \frac{1}{g_m}$$

γ_o

$\gamma_o = \frac{1}{\lambda I_{DSat}}$

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

$I_{DSat} = \frac{KP_n}{2} \frac{W}{L} V_{DS,sat}^2$

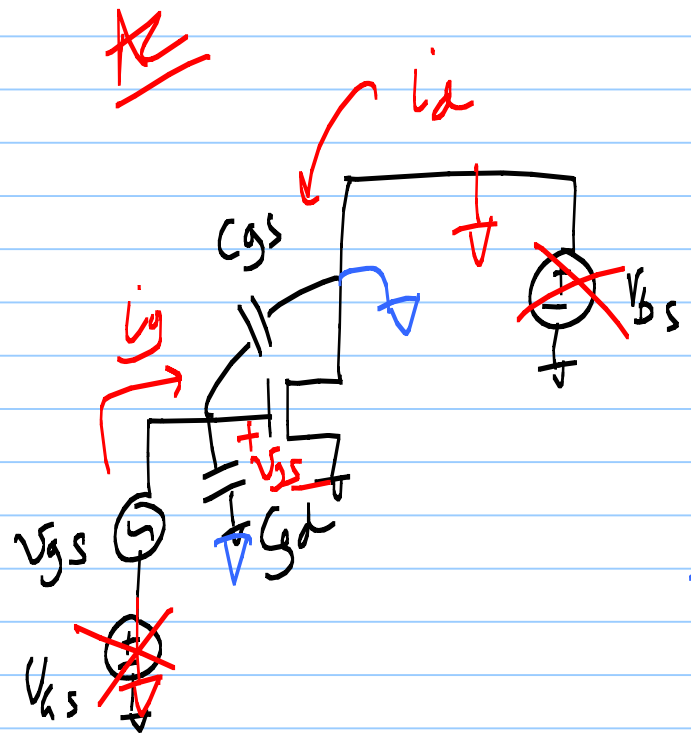
$\gamma_o \propto \frac{L^2}{V_{DS,sat}^2}$

$\propto \frac{V_{DS,sat}^2}{L}$

$L \uparrow \Rightarrow \gamma_o \uparrow$

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

MOSFET Transition frequency, f_T



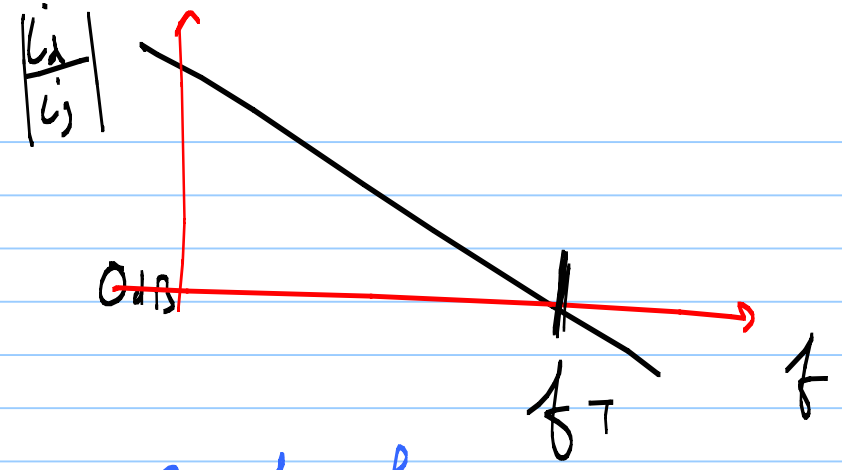
@ $f = f_T$ $\quad \left|\frac{i_d}{i_g}\right| = 1$

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

$$i_d = g_m V_{gs}$$

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

$$\Rightarrow \left|\frac{i_d}{i_g}\right| = \left|\frac{g_m}{s(C_{gs}+C_{gd})}\right| = 1$$



@ $f = f_T$

$$\Rightarrow \frac{g_m}{2\pi f_T (C_{gs}+C_{gd})} = 1$$

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

C_{gs} $\quad$ ~~C_{gd}~~

$\frac{2}{3} C_{ox}' WL \gg C_{GDO} \cdot W$

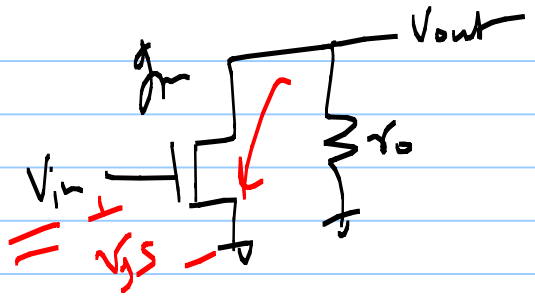
(Long-L MOSFET)

$$f_T = \frac{g_m}{2\pi C_{gs}} = \frac{3\mu_n}{4\pi} \frac{V_{DS,sat}}{L^2}$$

$L = L_{min}$ for maximum speed

$$f_T \propto \mu_n$$

$$\frac{f_{T_N}}{f_{T_P}} = \frac{\mu_n}{\mu_p} < 1$$



$A_0 =$

$r_o \uparrow$

$A_0 = g_m r_o \uparrow$ $\quad L \uparrow$

$f_T \downarrow$

$V_{out} = -i_d r_o$

$= -g_m V_{gs} \cdot r_o$

$= -(g_m r_o) V_{in}$

$$\frac{V_{out}}{V_{in}} = -\boxed{g_m r_o}$$ ← open-loop gain of the MOSFET.

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

$$GFT = \text{Constant}.$$

$\Rightarrow L = 2$ to 5 times L_{min}

$$V_{OV} = V_{OS,sat} = \begin{cases} 5\% \text{ of } V_{DD} \Rightarrow \text{fast design} \\ 1\% \text{ of } V_{DD} \Rightarrow \text{low-power} \end{cases}$$

Temperature Effects:

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

$$I_{D,sat} = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{THN})^2$$

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

$$\frac{\partial V_{THN}}{\partial T} = -\frac{k}{q} \ln\left(\frac{N_{D,poly}}{N_A}\right) \simeq -1\,mV/^\circ C$$

$N_{D,poly} \sim 10^{20}$

$N_A \sim 10^{15}$

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

$T \uparrow \Rightarrow \mu_n \downarrow$

$\Rightarrow V_{THN} \downarrow$

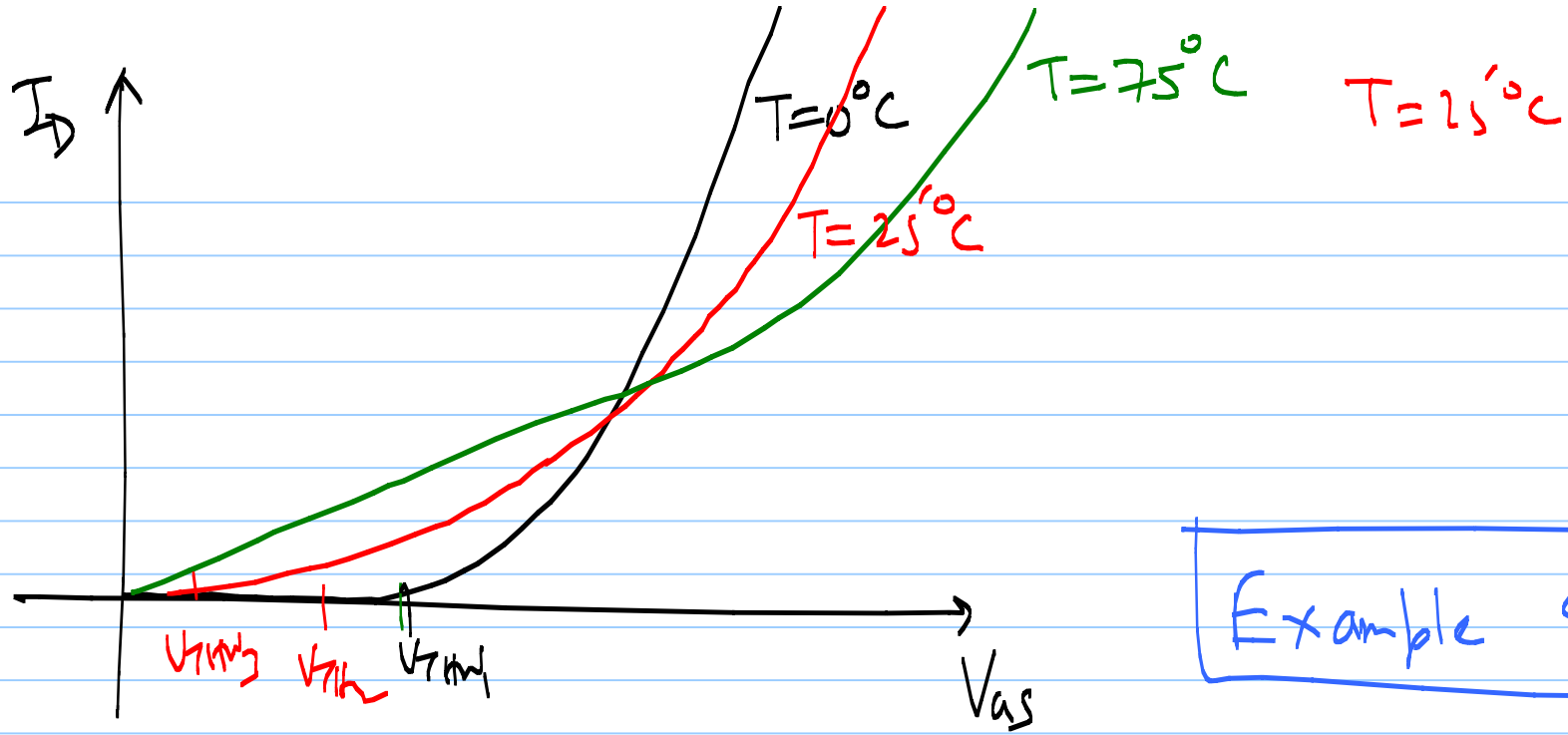
$$I_D = \overbrace{\frac{\mu_n C_{ox}}{2}}^{K_{Pn}} \frac{W}{L}\left(V_{GS} - V_{THN}\right)^2$$

$$\frac{\partial I_D}{\partial T} = \frac{\partial K_{Pn}}{\partial T}\left[\frac{1}{2}\frac{W}{L}\left(V_{GS} - V_{THN}\right)^2\right] - \left[\frac{K_{Pn}}{2}\cdot\frac{W}{L}\cdot 2\left(V_{GS} - V_{THN}\right)\right]\cdot\frac{\partial V_{THN}}{\partial T}$$

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

@ low V_{GS} ⇒ $\frac{\partial V_{THN}}{\partial T}$ dominates

@ large V_{GS} ⇒ $\frac{\partial KP_n}{\partial T}$ dominates



Example 9.3

GFT:

Sechim 9.2.2

$GFT = g_m r_o \cdot f_T$

Long-L process

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

$$\boxed{GFT \propto \frac{\mu_n}{L}} \leftarrow \text{Long-L CMOS}$$

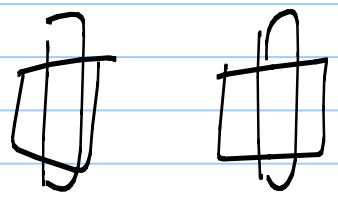
for a device with fixed L $\Rightarrow$ f_T = constant

g_m ↑ ↓ $\Rightarrow$ f_T ↓ ↑

for short channel CMOS ⇒

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

$GFT \uparrow \quad V_{ov} \uparrow$



Short-channel CMOS

* Lower $g_m r_o$ $L = L_{min}$
* higher mismatch
* Voltage headroom shrinks

$\frac{g_m}{I_D}$ methodology

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

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