ECE 511 - Lecture 4

Note Title 1/22/2015

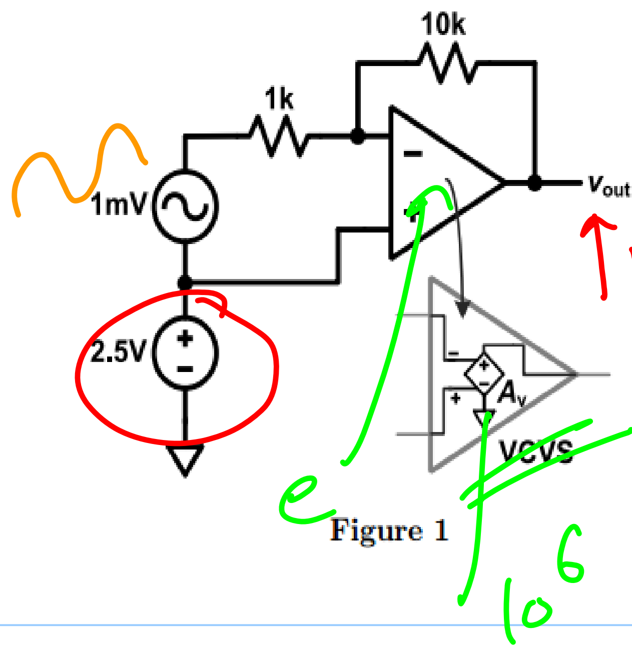


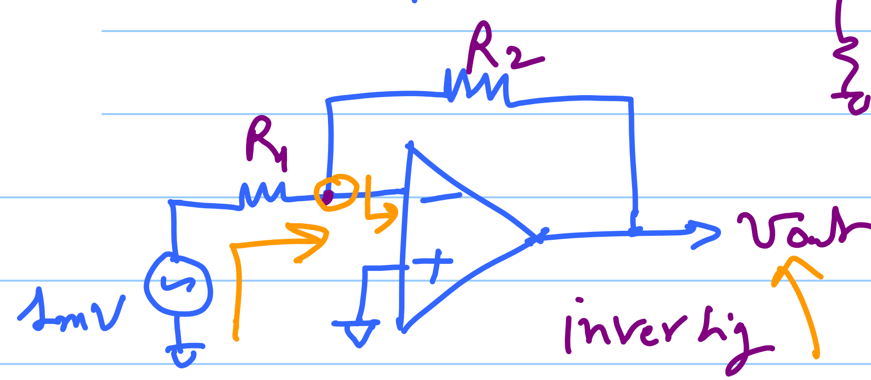
Figure 1

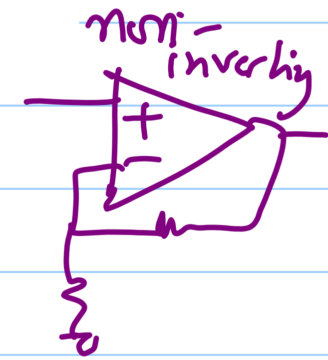
1. Calculate the DC and AC voltages in the circuit nodes. What is the AC gain of the amplifier?

2. What are the DC and AC currents (magnitude and direction) flowing across the resistors?

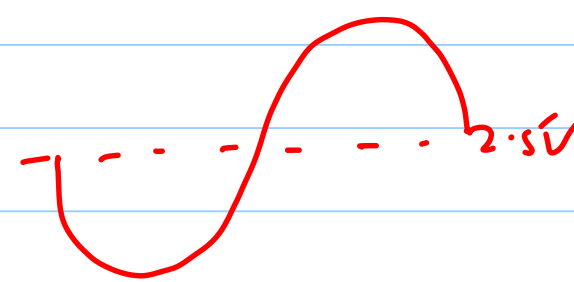
↑ well-defined DC level

AC picture





KCL: $\frac{V_{in}}{R_1} + \frac{V_{out}}{R_2} = 0$



* r_o change with "L" & "V_{ov}"

$$I_{D,sat} = \frac{K'_n}{2}\frac{W}{L}V_{ov}^2$$

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

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

Long-channel MOSFET

* for a fixed V_{GS} ⇒ fixed V_{ov}, $r_o \uparrow$ if $L \uparrow$ *
* for fixed L, $V_{ov} \downarrow$ ⇒ $I_D \downarrow$, $r_o \uparrow$ *

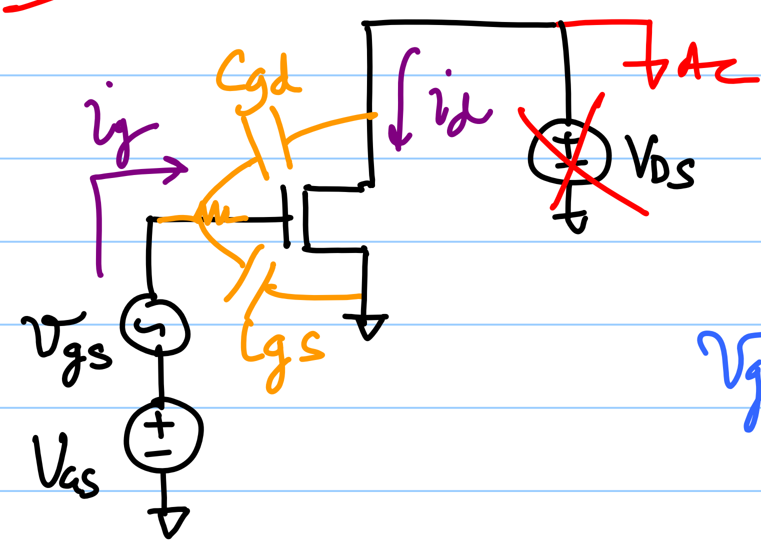
$$\text{Gain} \triangleq g_m r_o = \frac{\cancel{\beta} \cancel{V_{ov}}}{\lambda \cdot \frac{\cancel{\beta}}{2} V_{ov}^{\cancel{2}}} \propto \frac{L}{V_{ov}}$$

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

MOSFET Transition Frequency (f_T):

$\boxed{\begin{array}{l} f_{max} \\ RFIC \end{array}}$

Ac picture



@ $f = f_T$

$$\left|\frac{i_d}{i_g}\right| = 1 \quad \text{or} \quad 0\,dB$$

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

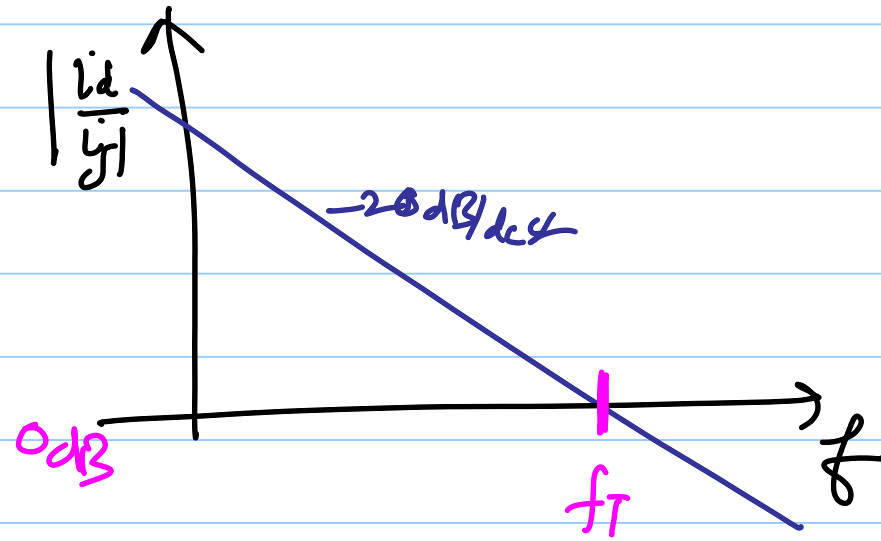
$$i_d = g_m v_{gs} \longrightarrow (2)$$

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

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

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

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



In sat

$C_{gs} \gg C_{gd}$

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

$g_m \propto V_{ov}$

$\left\{ \begin{matrix} W/L \\ V_{ov} \end{matrix} \right\}$

$C_{gs} \uparrow$ with WL

f_T ignores the junction caps and is defined such that r_o is excluded.

$$f_T = \frac{g_m}{2\pi C_{gs}} = \frac{\frac{KP_n}{2\pi}\frac{W}{L} V_{ov}}{\frac{2}{3} C_{ox}' WL}$$

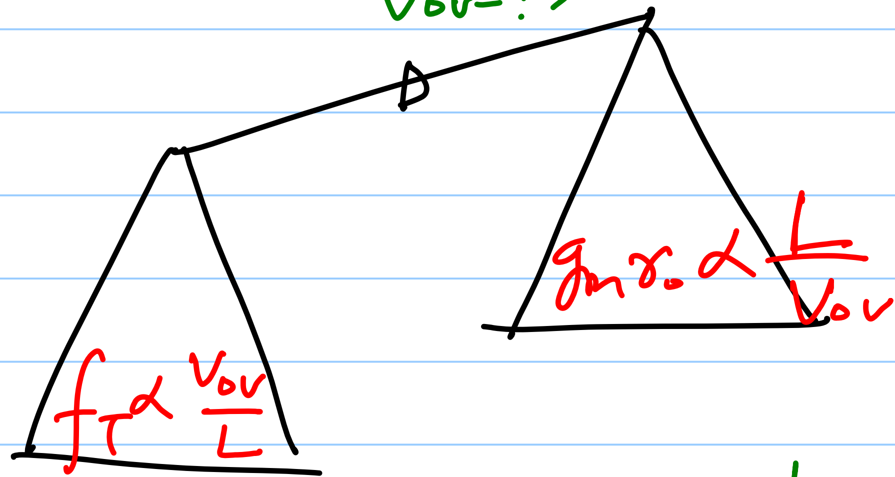
$$\simeq \frac{3\mu_n}{4\pi} \cdot \frac{V_{ov}}{L^2}$$

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

long-L mosfets

for short-channel $\boxed{f_T \propto \frac{V_{ov}}{L}}$

$L = ?$
$V_{ov} = ?$ } Technology



for fast design → $L = L_{min}$

$V_{ov} \simeq 3\text{-}5\% \, V_{DD}$

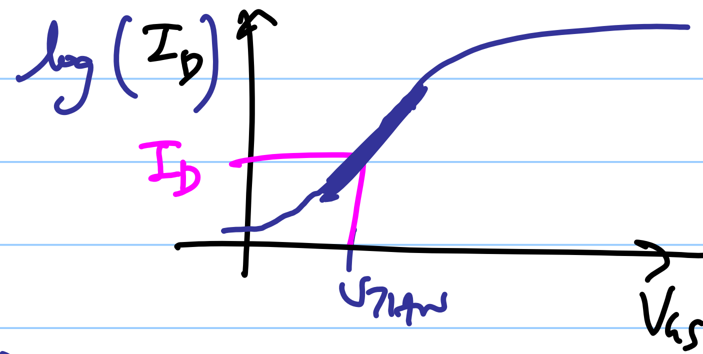
moderate/slow speed → $3\text{-}5 \, L_{min}$

V_{ov} $1\text{-}2\% \, V_{DD}$

Subthreshold

$$V_T = \frac{kT}{q}$$

$$V_{GS} \simeq V_{THN}$$



$$i_D = I_{D0} \cdot \frac{W}{L} e^{\frac{V_{GS} - V_{THN}}{n V_T}}$$

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

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

$g_m \propto I_D \longrightarrow$ Sub V_T

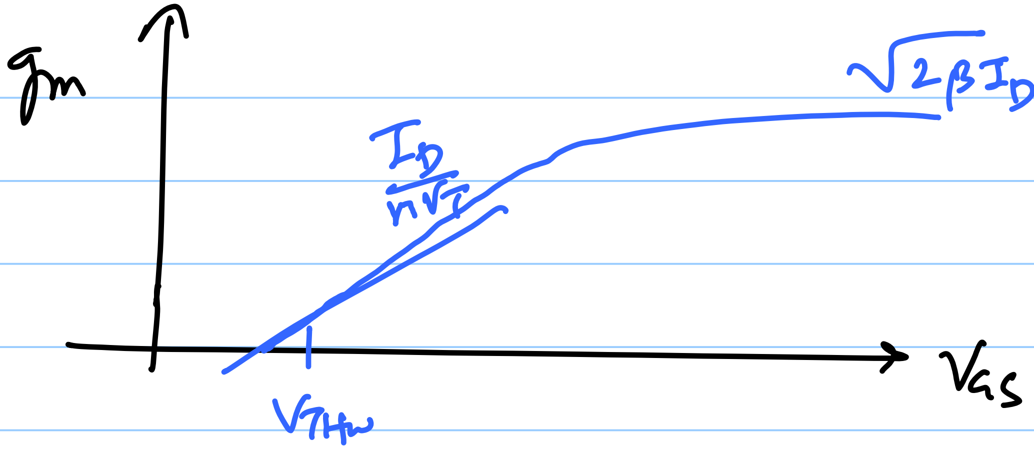
$g_m \propto \sqrt{I_D}$ inversion

$\frac{g_m}{I_D}$ ratio

$V_{OV} \Rightarrow 1\,mV$

$\hookrightarrow V_{GS} - \underbrace{V_{THN}}_{\text{variations due process}}$

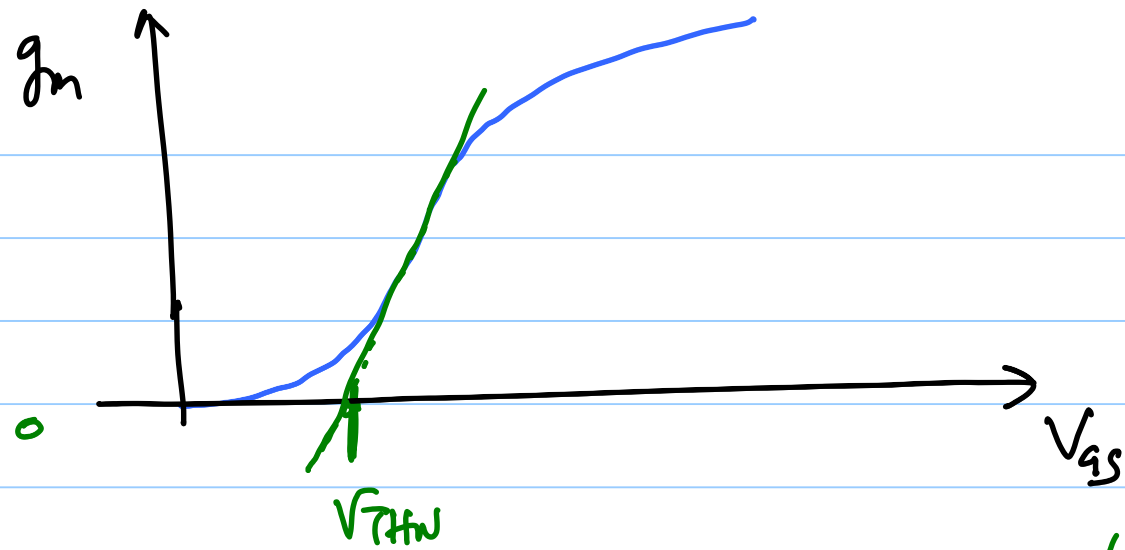
$$\sigma_{\Delta V_{THN}} \propto \frac{1}{\sqrt{WL}}$$



$$\left(\frac{g_m}{I_D}\right)$$

low - f_T in subVT.

In subVT $\Rightarrow$ NMOS look like BJT.



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

$g_m \triangleq 0$ when $V_{GS} = V_{THN}$

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

$$\frac{\partial I_D}{\partial T}$$

$T \uparrow$

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

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

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

$$\simeq -1\ mV/^\circ C$$

$V_{THN} \downarrow \Rightarrow I_D \uparrow$ ← dominates for $V_{GS} \simeq V_{THN}$

$\mu_n \downarrow \Rightarrow I_D \downarrow$ ← dominates at large currents

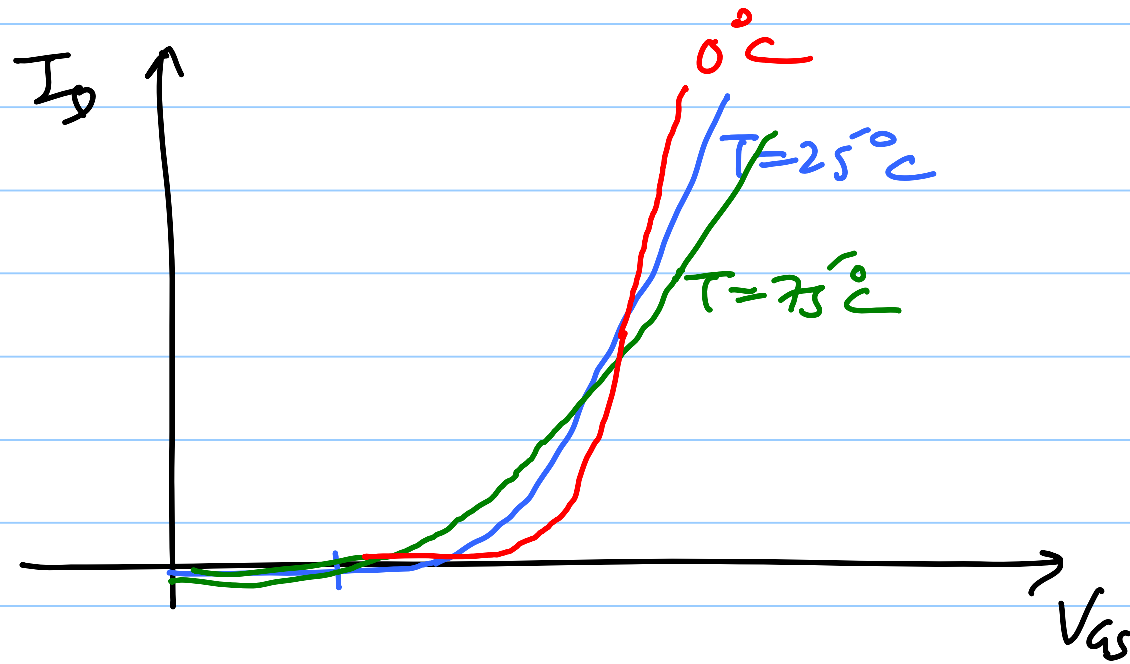


Figure-of-merit:

$$GFT \Rightarrow (g_m r_o) \cdot f_T$$

Long-channel process:

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

$g_m r_o f_T$ is constant for a device with
with fixed L
independent of the current level

"L"

$$(g_m r_o)\,(f_T)$$

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