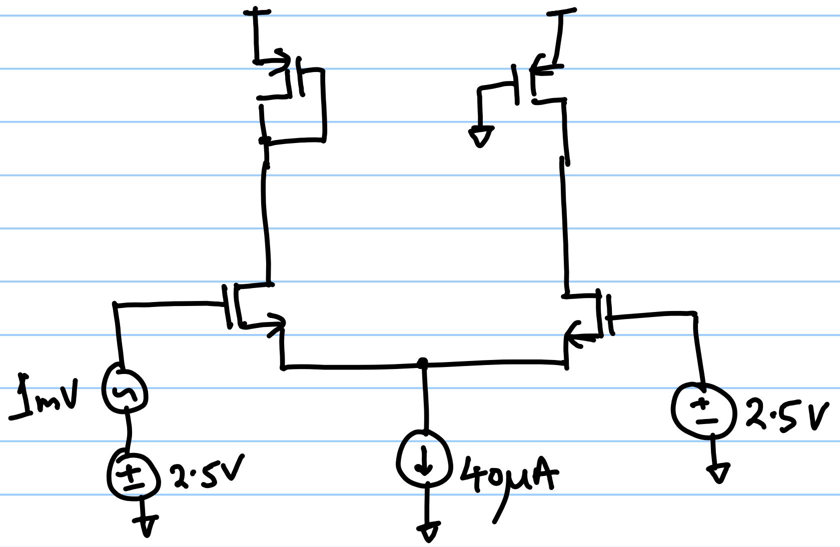
ECE 511 – Lecture 4

1μm CMOS

Note Title 1/30/2014

CMOS Book
Ex 9.5

* Find all the DC & AC voltages & currents



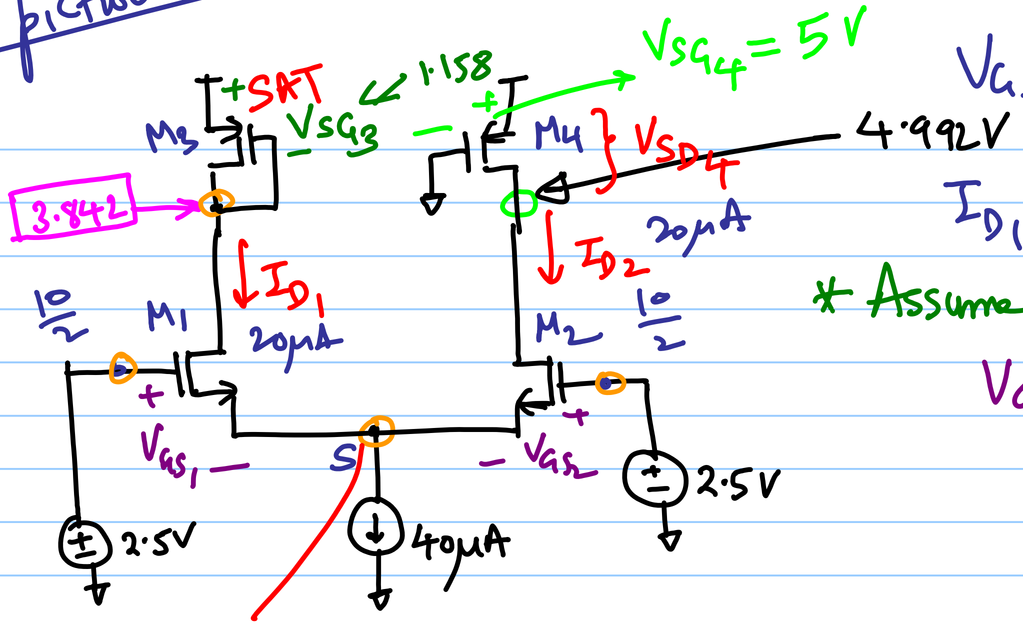
All NMOS 10/2
PMOS 30/2

$V_{THN} = 0.8V$ $V_{THP} = 0.9V$

$KP_n = 120\mu \frac{A}{V^2}$ $KP_p = 40 \frac{\mu A}{V^2}$

$V_{DD} = 5V$

DC picture



Assume No CLM

$\lambda = 0$

$V_{GS_1} = V_{GS_2} = V_{GS_{1/2}}$

$I_{D_1} = I_{D_2} = I_D = 20\mu A$

* Assume M_1 & M_2 are in Saturation

↑ verify later

$$V_{GS_{1/2}} = \sqrt{\frac{2 I_D}{KP_n \cdot \frac{W}{L}}} + V_{THN}$$

$$= \sqrt{\frac{2 \times 20\mu}{120\mu \cdot 5}} + 0.8$$

$$= \boxed{1.058V}$$

$$V_{S_{1/2}} = 2.5 - 1.058$$

$$= \boxed{1.442 V}$$

$M_3 \in SAT$ →

$$V_{SG_3} = \sqrt{\frac{2 I_D}{KP_p \left(\frac{W}{L}\right)_p}} + |V_{THP}| = 1.158V$$

$$V_{D_1} = V_{DD} - V_{SG_3} =$$

$$= 5 - 1.158 = \boxed{3.842}$$

Verify Regim for M_1 :

(Long-channel)
$V_{DS,sat} = V_{GS} - V_{THN}$

$$V_{DS_1} > \overbrace{V_{GS_1} - V_{THN}}^{V_{DS,sat}}$$

$$V_{D_1} - \cancel{V_{S_{1,2}}} > V_{G_1} - \cancel{V_{S_{1,2}}} - V_{THN}$$

$$\Rightarrow \quad V_{D_1} > V_{G_1} - V_{THN}$$

$$3.842 > \underbrace{2.5 - 0.8}_{1.7\,V}$$

yes, M_1 is in Saturation

Assume $M_4 \leftarrow$ Triode : $V_{SD_4} = ?$

$$I_D = KP_p \frac{W}{L}\left[\underbrace{(V_{SG_4} - V_{THP})}_{5-0.9}\underbrace{V_{SD_4}}_{x} - \frac{V_{SD_4}^2}{2}\right] \longleftarrow$$

Current
Triode Equation

TI-89
fsolve( )

$$20\mu = 40\mu \cdot \frac{30}{2}\left[4.1x - \frac{x^2}{2}\right]$$

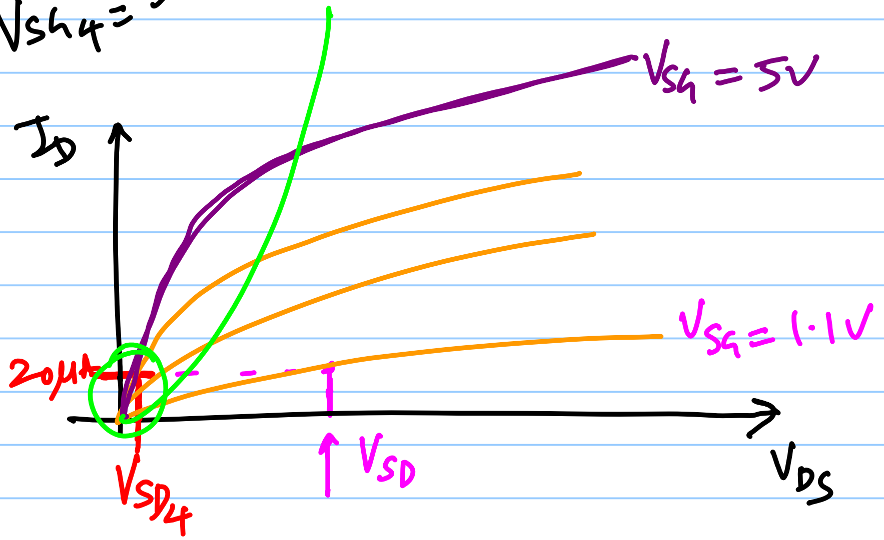
solve for $x \Leftarrow 8.13$ mV

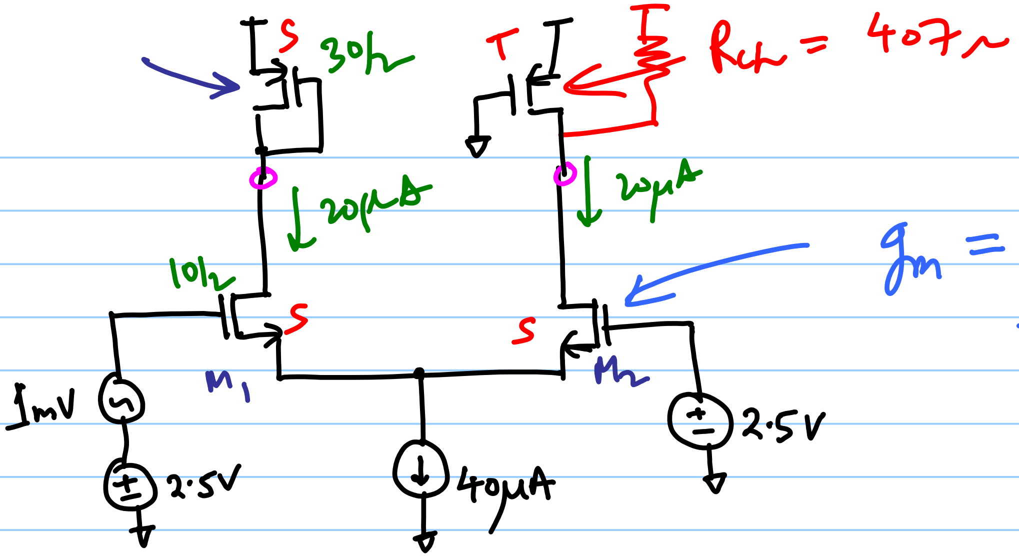
$I_D = 20\mu A$

$V_{SG4} = 5V$

$$V_{D4} = 5V - V_{SD4} = 5 - 0.00813$$

$$= \boxed{4.992V}$$





$$g_m = \sqrt{2\,\beta\, I_D} = 150\,\frac{\mu A}{V}$$

$$= \sqrt{2\times KP_n \frac{W}{L}\times 20\mu}$$

$$g_{m_{1,2}} = 150\,\frac{\mu A}{V}$$

$$g_{m_3} = \sqrt{2\times 40\frac{\mu A}{V^2}\times\frac{30}{2}\times 20\mu} = \boxed{150\,\frac{\mu A}{V}}$$

$$R_{ch_4} = \frac{1}{KP_p\frac{W}{L}\left(V_{SG}-V_{THP}\right)} = \boxed{407\,\Omega}$$

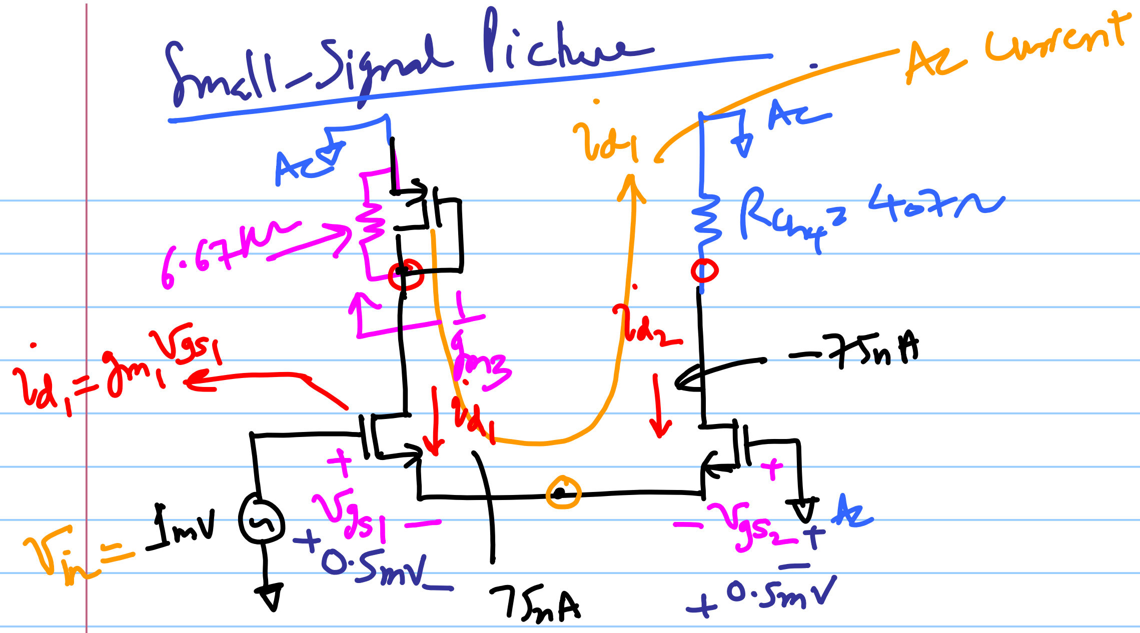
g_{ds}^{-1}

$$* \; r_o = \frac{1}{\lambda .\, I_{D,sat}}$$

~ find from the $I_D - V_{DS}$

$$* \quad g_{mb} = (\eta)\, g_m$$

Small-Signal Picture



$$v_{in} = \boxed{1mv = v_{gs_1} - v_{gs_2}} \rightarrow ①$$

$$i_{d_1} + i_{d_2} = 0$$

$$\boxed{i_{d_2} = - i_{d_1}} \rightarrow ②$$

$$\cancel{g_{m_2}} \cdot v_{gs_2} = - \cancel{g_{m_1}} v_{gs_1}$$

$$\boxed{v_{gs_2} = - v_{gs_1}} \rightarrow ③$$

Plug ③ into ①

$$v_{gs_1} - (- v_{gs_1}) = 1mV$$

$$\boxed{\begin{array}{l} v_{gs_1} = 0.5 \, mV \\ v_{gs_2} = -0.5mv \end{array}}$$

$$i_{d_1} = g_{m_1} v_{gs_1} = 150\frac{\mu A}{V} \times 0.5mV = \boxed{75nA}$$

$$i_{d_2} = -i_{d_1} = -\boxed{75nA}$$

$$v_{d_1} = -i_{d_1} \times \frac{1}{g_{m_3}} = \boxed{-0.5mV}$$

$$v_{d_2} = -\underset{\substack{\uparrow \\ -75nA}}{i_{d_2}} \times R_{ch_4} = \boxed{0.03\ mV}$$

Total

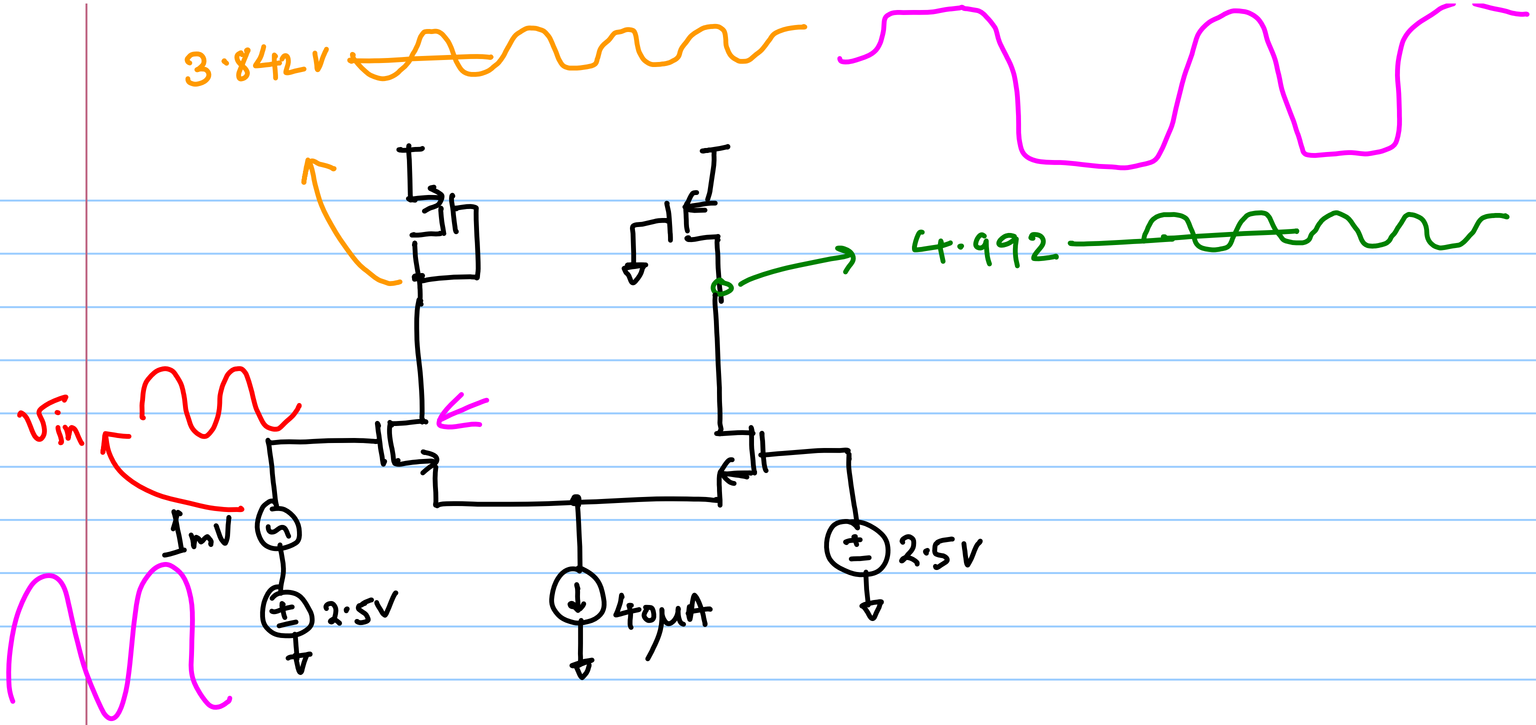
$$\underline{i_{D_1}} = \overset{DC}{I_{D_1}} + \overset{AC}{\boxed{i_{d_1}}}$$

$$= 20\mu A + (75nA)\sin(\omega_{in}t)$$

$$i_{D_2} = 20\mu A - (75nA)\sin(\omega_{in}t)$$

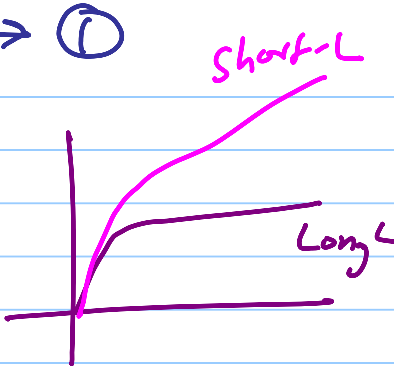
$$v_{D_{1/3}} = \underbrace{3.842}_{DC} \boxed{-} \underbrace{0.5\times10^{-3}\sin(\omega_{in}t)}_{AC}$$

$$v_{D_{2/4}} = 4.992 + 0.03\times10^{-3}\sin(\omega_{in}t)$$


3·842V
4·992
Vin
1mV
2·5V
40μA
2·5V

$$I_{D,sat} = \frac{K'_n}{2}\,\frac{W}{L}\,(\underbrace{V_{GS}-V_{THN}}_{V_{ov}})^2 \longrightarrow ①$$

$$\lambda \propto \frac{1}{L} \longrightarrow ②$$



$$r_o = \frac{1}{\lambda I_{D,sat}} = \frac{1}{\lambda}\cdot\frac{L}{K'_n\, W\, V_{ov}^2}$$

from ①&②

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

Long-channel MOSFET

* for fixed Length

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

* for fixed Vov

$L\downarrow \Rightarrow r_o\downarrow$

for fixed L, $V_{ov} \downarrow \Rightarrow r_o \uparrow$

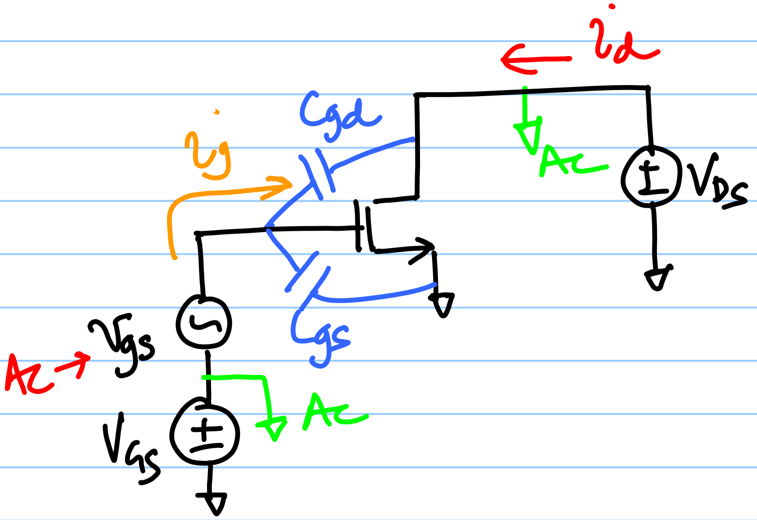
But $\Rightarrow I_D \downarrow$

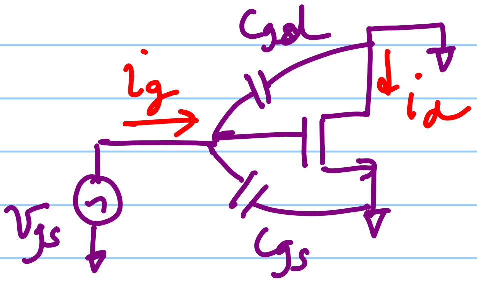
ITRS Roadmap

Transition frequency (f_T)

f_T is the frequency where the AC current gain

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





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

&

$$i_d = g_m v_{gs}$$

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

Current gain in the MOSFET

$$\frac{\dot{i}_d}{\dot{i}_g} = \frac{g_m}{s(C_{gd}+C_{gs})} \quad \checkmark$$

$s = j\omega$

$$\left|\frac{\dot{i}_d}{\dot{i}_g}(j\omega)\right| = \left|\frac{g_m}{j\omega(C_{gd}+C_{gs})}\right|$$

$$\left|\frac{\dot{i}_d}{\dot{i}_g}\right| = \frac{g_m}{\omega(C_{gd}+C_{gs})} \quad \checkmark \quad \triangleq 1$$

f_T

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

In saturation

$$f_T = \frac{g_m}{2\pi(\underset{\uparrow\ CGDO\cdot L}{\cancel{C_{gd}}} + \underbrace{C_{gs}}_{\longrightarrow\ \frac{2}{3}C_{ox}'WL})}$$

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

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