Lab 3
Lab 2
HW 4
midterm in class friday! 1 page, 2 sides notes

CS amplifier design example

Cascode

potato model for G_m, R_o

CS design example - HW3/4 specs

$\mu_n C_{ox} = 200 \frac{\mu A}{V^2}$ $\mu_p C_{ox} = 100 \frac{\mu A}{V^2}$

$\lambda = \frac{1}{10V}\left(\frac{0.5\mu m}{L}\right)$ $L_{min} = 0.5\mu m$

$C_{ox} = 5 \frac{fF}{\mu m^2}$, $C_{ol}' = 0.5 \frac{fF}{\mu m}$

Design an amp w/ low freq gain ≈ 50 (mag)

gain of 2 at $1 G \frac{rad}{sec}$ driving 100fF

input cap less than 1pF

$|A_{v_0}| = g_m(r_{on} \| r_{op})$ ~~choose~~ pick $L_n = L_p$

$\Rightarrow r_{on} = r_{op}$ $r_{on} \| r_{op} = \frac{1}{2\lambda I_D}$

$A_v = \frac{2I_D}{V_{ov}} \frac{1}{2\lambda I_D} = \frac{1}{\lambda V_{ov}}$

$A_v \approx 50 = \frac{10V}{V_{ov}} \frac{L}{0.5}$ pick $\boxed{L_n = L_p = 0.5\mu m}$

$\Rightarrow \boxed{V_{ov} = 0.2V}$

$g_m = \omega_u C_o = \underbrace{(2)\left(10^9 \frac{rad}{s}\right)}_{\omega_u}\left(10^{-13} F\right) = 200 \frac{\mu A}{V}$

$g_m = \mu_n C_{ox}\left(\frac{W}{L}\right)_n V_{ov} = 200 \frac{\mu A}{V^2}\left(\frac{W}{L}\right)_n (0.2V)$

$\Rightarrow \left(\frac{W}{L}\right)_n = 5$ $W_n = 2.5\mu m$

$C_{in} = C_{gsn} + (1-A)C_{gdn} = \frac{2}{3}\left(5\frac{fF}{\mu m^2}\right)(1.25\mu m^2) + 51(1.25\mu m)$

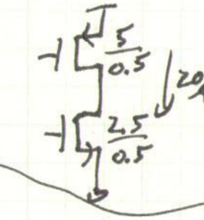
$\approx 60fF$

pick $V_{ovp} = V_{ovn} = 0.2 \Rightarrow W_p = 2W_n = 5\mu m$

output parasitic cap: $C_{gdp} + C_{gdn} = 4fF \ll 100fF$

~~What~~ $I_d = \left(100 \frac{\mu A}{V^2}\right) 5 (0.2V)^2$

$= 20\mu A$



what if A_v spec were 500?

$A_v = 500 = \frac{10V}{V_{ov}} \frac{L}{0.5}$ pick $V_{ov} = 100mV$ (minimum allowed)

$\Rightarrow L_n = L_p = 2.5\mu m$

$g_m = 200\mu A/V = 200 \frac{\mu A}{V^2}\left(\frac{W}{L}\right)_n (0.1V) \Rightarrow \left(\frac{W}{L}\right)_n = 10$

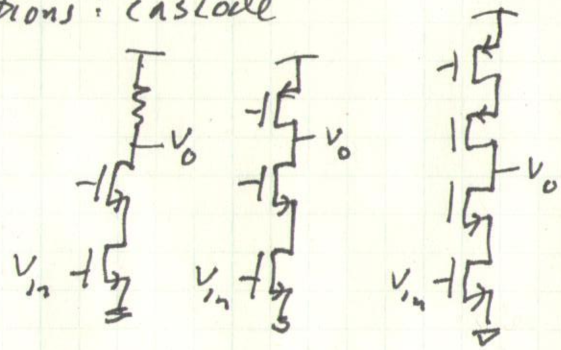
$\Rightarrow L_n = 25\mu m \Rightarrow C_{gdn} = 12.5fF \Rightarrow C_{in} \approx 6pF!$

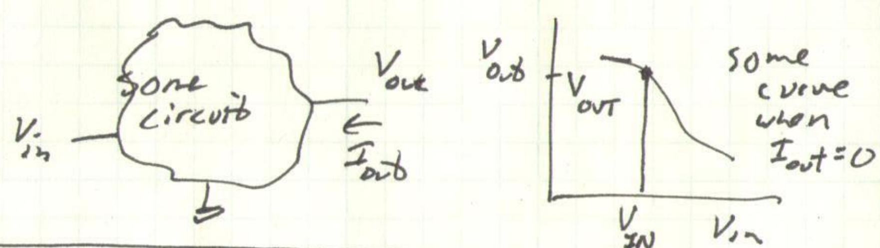
problem!

One of many solutions: cascode

what is G_m? R_o?

what are $\int$?





for most real circuits $I_{out}(V_{in}, V_{out})$ is a continuous function in some neighborhood.

So we use Taylor at a point on the input/output curve

$$I_{out}(V_{IN}+v_i, V_{OUT}+v_o) = \cancel{I_{out}(V_{IN}, V_{OUT})} + \left.\frac{\partial I_{out}}{\partial V_{in}}\right|_{V_{IN},V_{OUT}} v_i + \left.\frac{\partial I_{out}}{\partial V_{out}}\right|_{V_{IN},V_{OUT}} v_o + \text{h.o.t.}$$

If nothing is connected at the output, then $I_{out}=0$

and $G_m v_i + G_o v_o = 0$

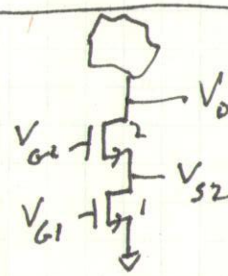
<u>So</u> to find R_o, we draw small signal model, set $v_i=0$

wiggle v_o, and measure i_o

that's $\left.\frac{\partial I_{out}}{\partial V_{out}}\right|_{V_{IN},V_{OUT}} = G_o = R_o^{-1}$

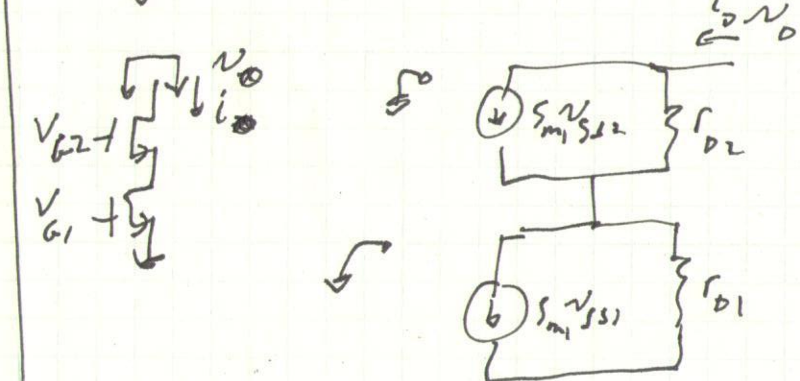
to find G_m, set $\underline{\underline{v_o=0}}$, wiggle v_i, measure i_o

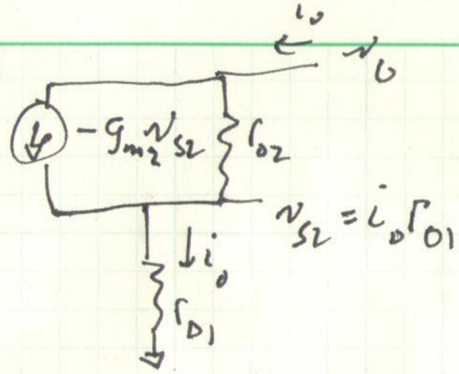
Sometimes people freak out when e.g. with ideal current source, is $G_m=0$? <u>NO</u>



4 G_m, R_o pairs (2 inputs, 2 outputs)

need to know all of them.





KCL @ v_0 $\quad i_0 = -g_{m2} i_0 r_{01} + \frac{1}{r_{02}}\left(v_0 - i_0 r_{01}\right)$

$$i_0\left(1 + g_{m2}r_{01} + \frac{r_{01}}{r_{02}}\right) = \frac{1}{r_{02}} v_0$$

$$R_0 = \frac{v_0}{i_0} = r_{02}\left(1 + g_{m2} r_{01}\left(1 + \frac{1}{g_{m2} r_{02}}\right)\right) \approx \underbrace{g_{m2} r_{02}}_{\text{int gain}} r_{01}$$

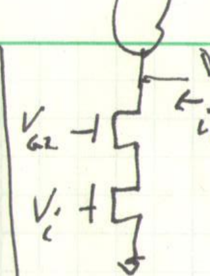
KCL @ v_{s2} $\quad i_0 = g_{m1} v_i + \frac{1}{r_{01}} v_{s2}$

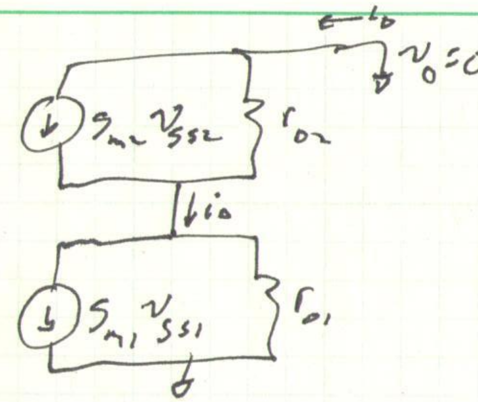
$$= g_{m1} v_i - \frac{1}{r_0} \frac{i_0}{g_{m2}\left(1 + \frac{1}{g_{m2} r_{02}}\right)}$$

$$g_{m1} v_i = i_0\left[1 + \frac{1}{g_{m2} r_{01}\left(1 + \frac{1}{g_{m2} r_{02}}\right)}\right]$$

$$G_m = \frac{i_0}{v_i} \approx g_{m1}$$

$$A_v = -G_m R_0 = -g_{m1}\left(r_{01} g_{m2} r_{02} \,\|\, R_{UP}\right)$$





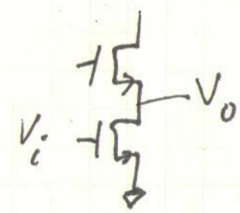
v_i 0

$$i_0 = -g_{m2} v_{s2} - \frac{1}{r_{02}} v_{s2}$$

$$\frac{1}{g_{m2}}\left(1 + \frac{1}{g_{m2} r_{02}}\right)$$

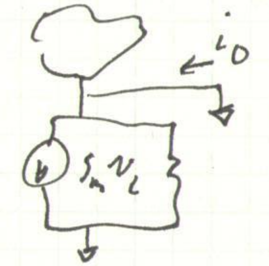
$$(0 - v_{s2})\, g_{m2}\left(1 + \frac{1}{g_{m2} r_{02}}\right) = i_0$$

For C_{in}, need gain to V_{s2} (miller)



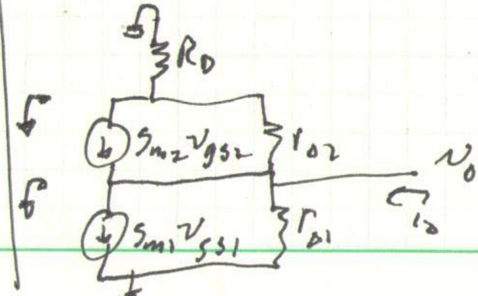
G_m easy:

v_i 0



$G_m = g_{m1}$ exact

R_0 harder: depends on R_{UP} or R_D



$r_{01} \,\|\, R_{UP}$