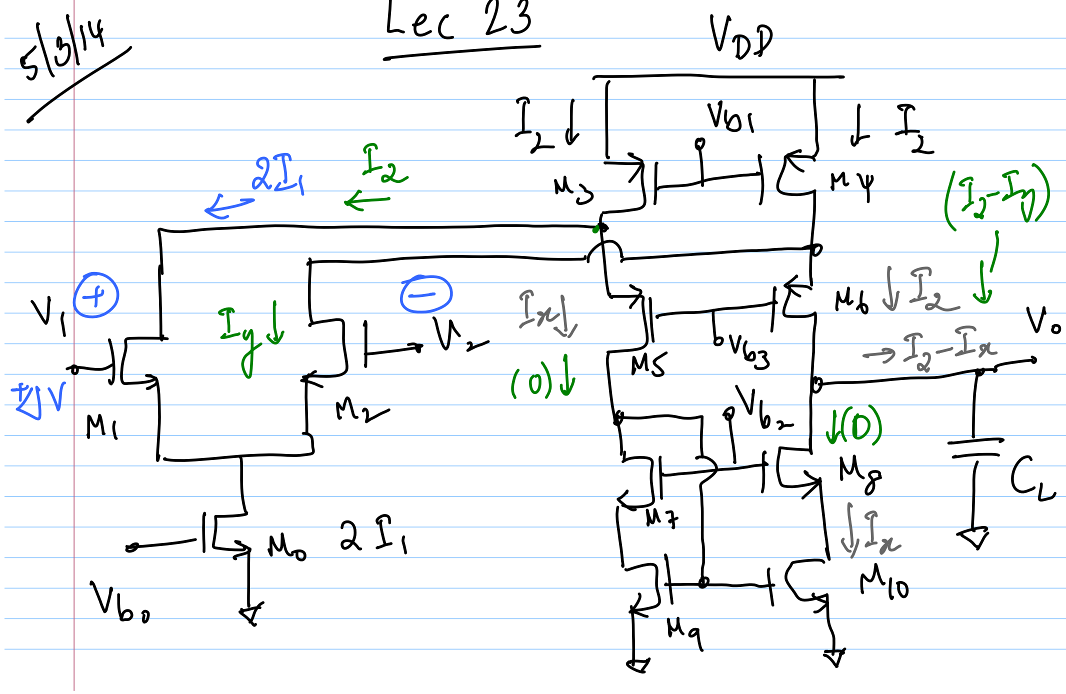
5/3/14

Lec 23



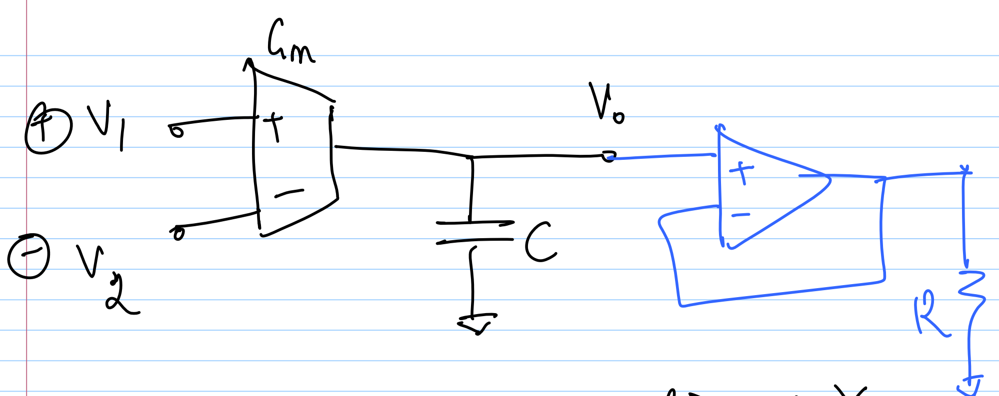
1) $I_2 - 2I_1 = I_x > 0$

$I_{out} = I_2 - I_x = 2I_1$

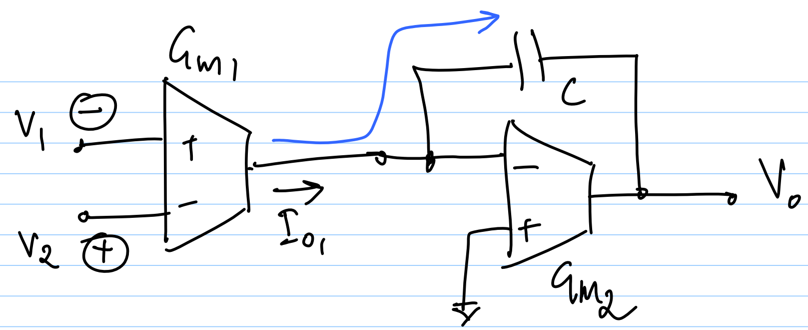
$SR = \dfrac{2I_1}{C_L}$

2) $I_2 - 2I_1 < 0$

$2I_1 - I_2 = I_y > 0$



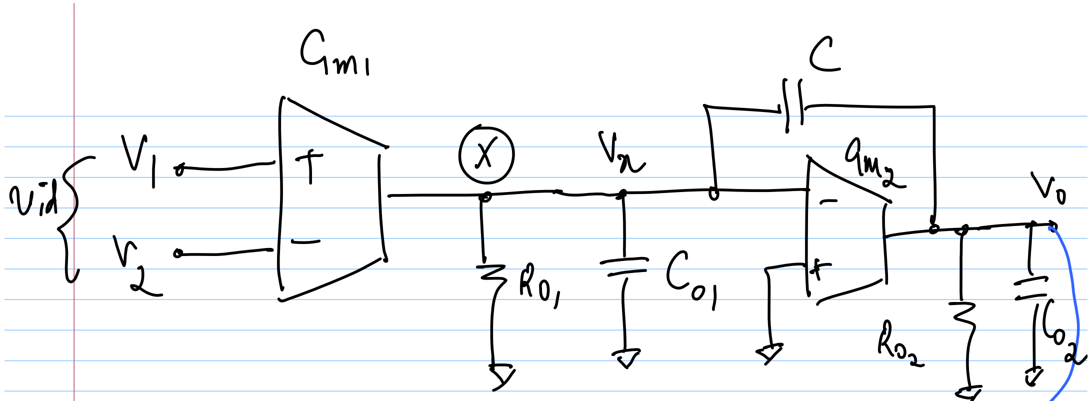
CD amp X



$I_{o1} = G_{m1}(V_1 - V_2)$ flows through C

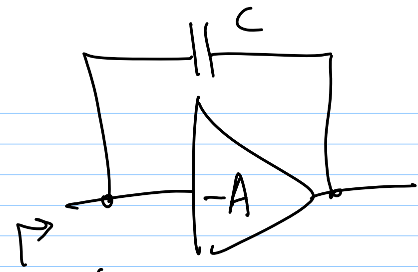
$V_o = -\dfrac{I_{o1}}{sC} = \dfrac{-G_{m1}}{sC}(V_1 - V_2)$

$\omega_u = \dfrac{G_{m1}}{C}$; terminal signs are reversed



Miller cap $\approx G_{m2} R_{o2} \cdot C$
@ X

$R_L << R_{o2}$ $\quad \frac{v_o}{v_{id}}(s)$



$C_{in} = (1+A)C \approx AC$

1) DC gain $= G_{m1} R_{o1} \cdot G_{m2} R_{o2}$

w/ R_L $= G_{m1} R_{o1} \cdot G_{m2} R_L$

1st stage provides DC gain

2) $\omega_u = G_{m1}/C$

3) ND poles & zeros

10/3/14

Lec 24

$$\frac{v_o}{v_{id}}(s) = \frac{\frac{G_{m2} G_{m1}}{G_{o1} G_{o2}} \cdot \left[\frac{sC}{G_{m2}} - 1\right]}{s^2\left[C C_{o1} + C_{o1} C_{o2} + C_{o2} C\right] \cdot r_{o1} r_{o2} + s\left[C\left\{r_{o1}(1 + g_{m2} r_{o2}) + r_{o2}\right\} + C_{o2} r_{o2} + C_{o1} r_{o1}\right] + 1}$$

DC gain : $-G_{m1} G_{m2} / G_{o1} G_{o2}$

Zero $z_1 = +\frac{G_{m2}}{C}$ [RHP zero]

$ax^2 + bx + c = 0$ — x_1 & x_2 roots

if x_1 & x_2 — far apart $(x_1 << x_2)$

$x_1 \approx -\frac{c}{b}$; $x_2 = \frac{-b}{a}$

p_1 − dominant pole $(p_1 << p_2)$

p_2 − ND pole

$$p_1 \approx -\frac{c}{b}$$

$$= -\frac{G_{o1} G_{o2}}{\left\{ C\left[G_{m2} + G_{o1} + G_{o2}\right] + G_{o2} C_1 + G_{o1} C_2 \right\}}$$

$$\approx -\frac{G_{o1}}{C\left[\frac{G_{m2}}{G_{o2}} + 1 + \frac{G_{o1}}{G_{o2}}\right] + C_1 + \frac{G_{o1}}{G_{o2}} C_2}$$

$$p_1 \approx -\frac{G_{o1}}{C\left(\frac{G_{m2}}{G_{o2}}\right)}$$

$$p_2 \approx -\frac{b}{a}$$

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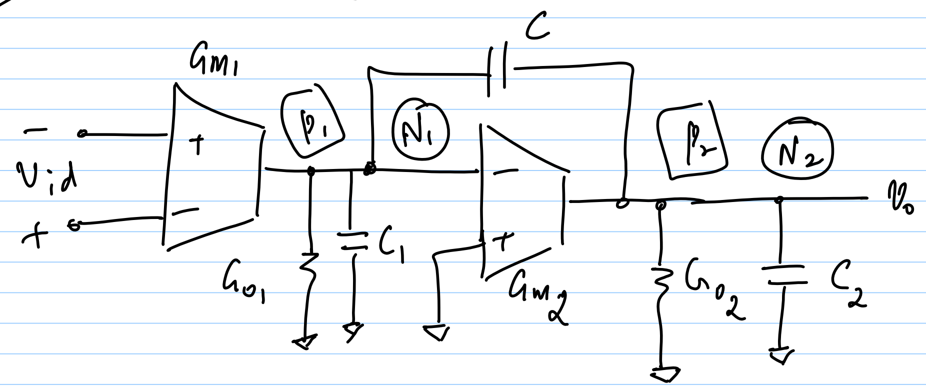
Lec 25



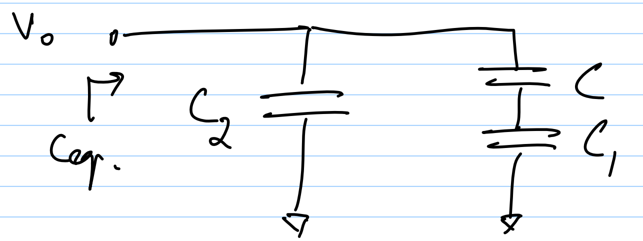
$$p_1 = \frac{G_{o1}}{C \cdot \left(\frac{G_{m2}}{G_{o2}}\right)}$$

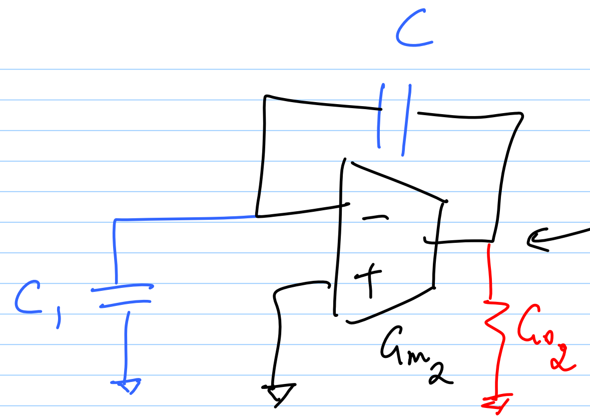
$$p_2 = \frac{-b}{a} = -\frac{C(G_{m2} + G_{o1} + G_{o2}) + C_1 G_{o2} + C_2 G_{o1}}{C_1 C + C_2 C + C_1 C_2}$$

Divide Nr & Dr by $(C + C_1)$

$$p_2 = -\frac{\frac{C}{C+C_1} G_{m2} + G_{o2} + G_{o1} \cdot \frac{C + C_2}{C + C_1}}{C_2 + \frac{C C_1}{C + C_1}}$$

$$p_2 = \frac{G_{eq}\,(N_2)}{C_{eq.}\ (\text{seen from o/p } N_2)} \quad \left\{ \frac{g_x}{c_x} \right\}$$

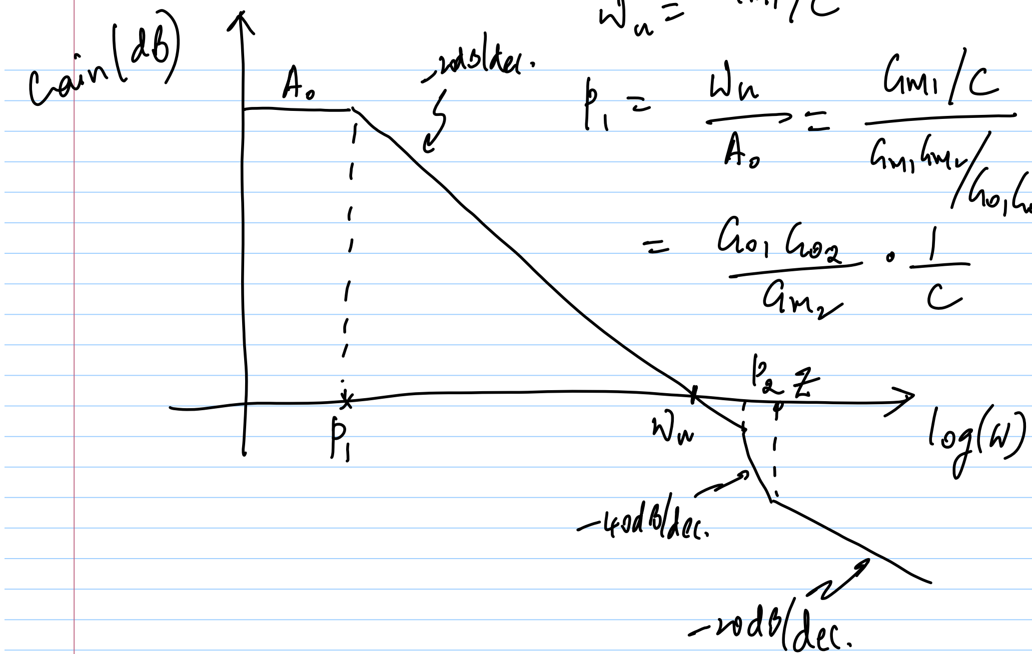




$$G_o = \frac{G_{m_2} \cdot C}{C + C_1} + G_{o_2}$$

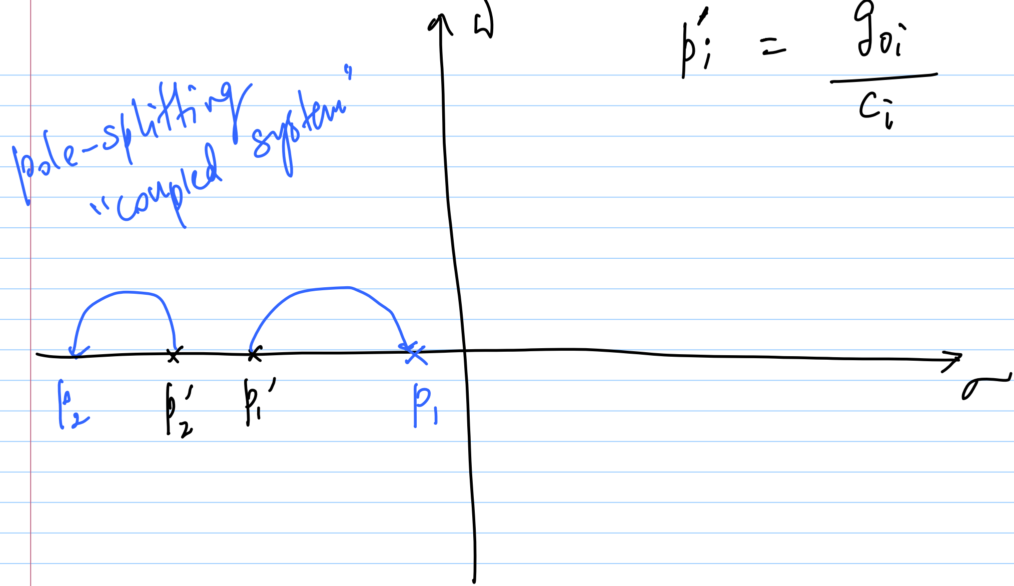
$$\omega_u = G_{m1}/C$$

$$p_1 = \frac{\omega_u}{A_o} = \frac{G_{m1}/C}{G_{m1}G_{m2}/G_{o1}G_{o2}} = \frac{G_{o1}G_{o2}}{G_{m2}} \cdot \frac{1}{C}$$



$$p_i' = \frac{g_{oi}}{C_i}$$

pole-splitting
"coupled system"



Conditions for Stability

$$\phi_{UGF} = -90^\circ - \tan^{-1}\left(\frac{\omega_u}{p_2}\right) - \tan^{-1}\left(\frac{\omega_u}{z}\right)$$

(p_1)

1) $\underline{z}$: $\phi_z = -\tan^{-1}\left(\frac{\omega_u}{z}\right) = -\tan^{-1}\left(\frac{G_{m1}}{G_{m2}}\right)$

$$\boxed{G_{m2} \gg G_{m1}}$$

2) $\underline{p_2}$: $\phi_{p_2} = -\tan^{-1}\left(\frac{\omega_u}{p_2}\right)$

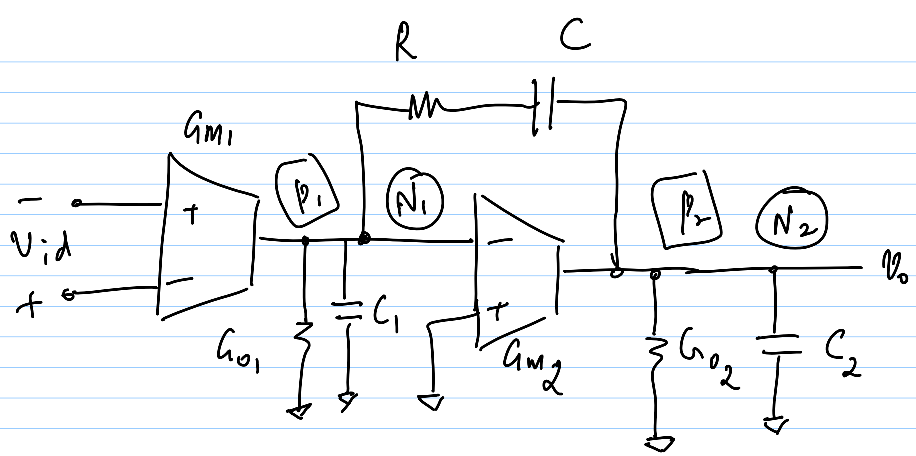
$p_2 \gg \omega_u$

$$\frac{G_{m2}\cdot\frac{C}{C+C_1}}{C_2 + \frac{C\,C_1}{C+C_1}} \gg \frac{G_{m1}}{C}$$

$$\boxed{G_{m2} \gg G_{m1}}$$

$\uparrow \left(\frac{W}{L}\right)_2 \Rightarrow C_1 \;\&\; C_2 \uparrow$

$\uparrow I_2 \Rightarrow (V_{GS} - V_T)\uparrow$ swing limits $\downarrow$



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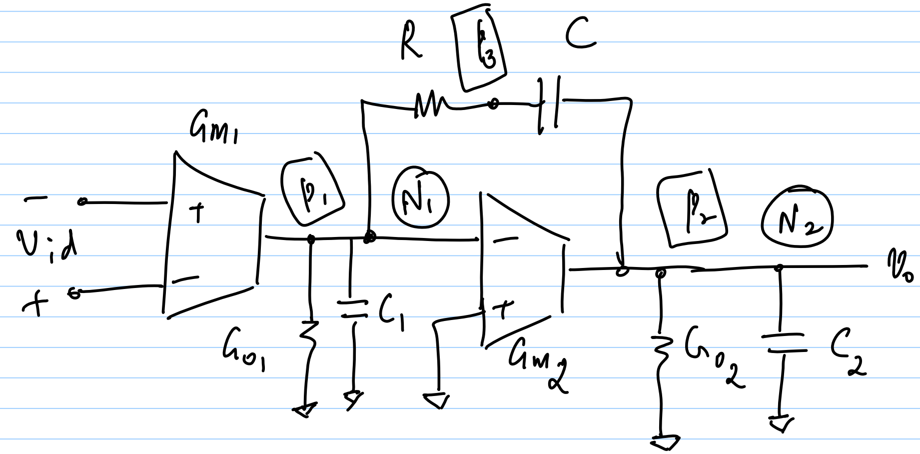


$$p_1 \approx \text{same as before} \approx \frac{G_{o1}}{C \cdot \frac{G_{m2}}{G_{o2}}}$$

$$p_2 \approx \text{same as before} \approx \frac{G_{m2} \cdot \frac{C}{C+C_1}}{C_2 + \frac{CC_1}{C+C_1}}$$

$$z \approx \frac{-G_{m2}}{C\left(G_{m2}R - 1\right)} \quad \text{(LHP zero)}$$

$$p_3 \approx \frac{-1}{R} \cdot \left[\frac{1}{C} + \frac{1}{C_1} + \frac{1}{C_2}\right]$$

1) Move z to ∞

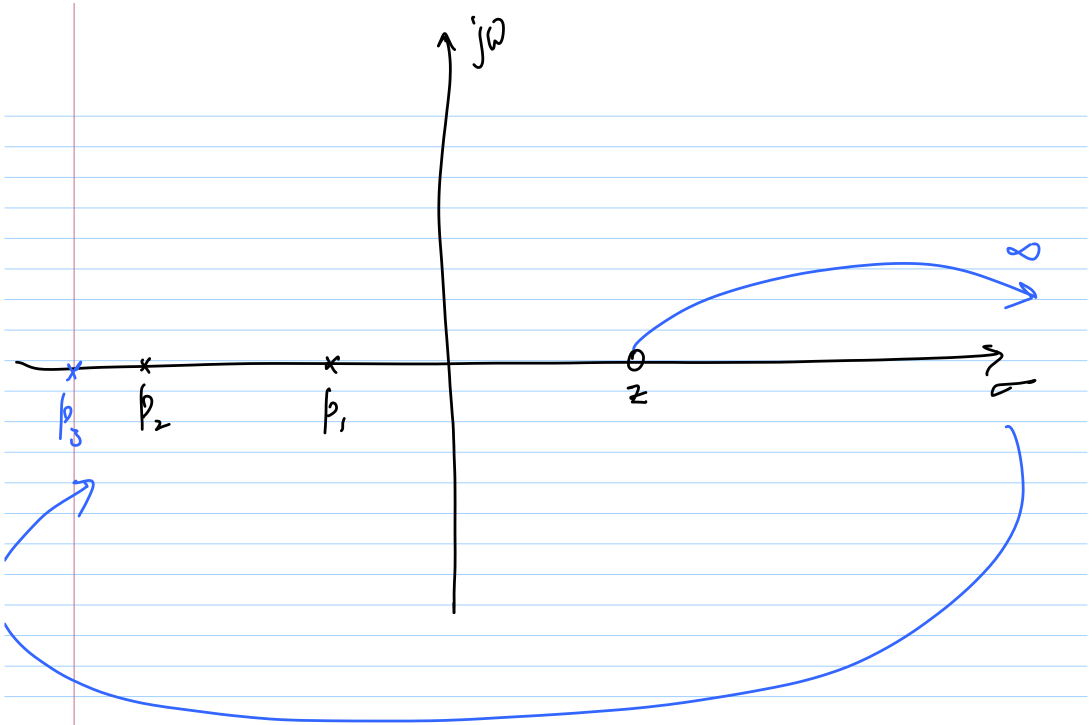
$\Rightarrow \boxed{G_{m2}R = 1}$ $\qquad \boxed{R = \frac{1}{G_{m2}}}$

* $p_3 = f(\alpha)$

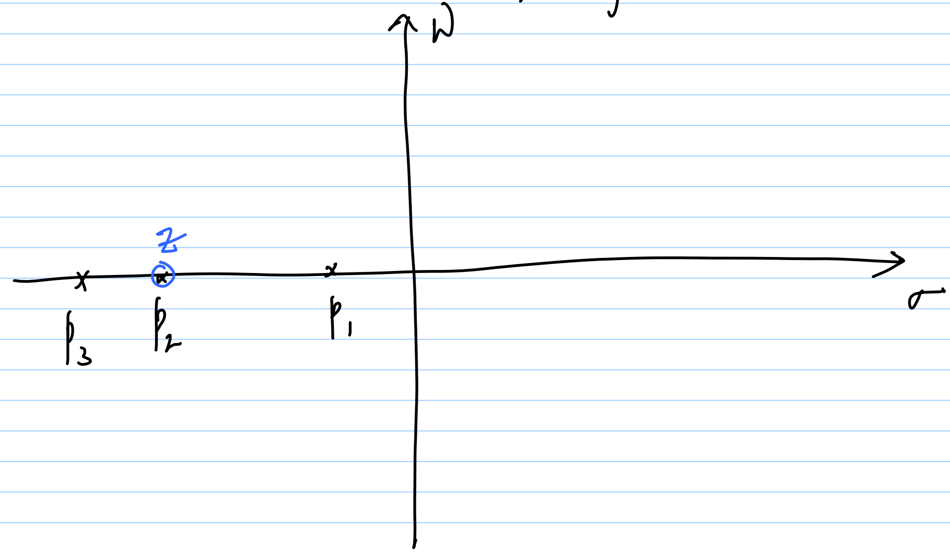
but $p_3 >$ original z

* We can only ensure $R \approx \frac{1}{G_{m2}}$

↳ still better than original zero



2) Move z on top of p_2



* $z = p_2$

$$\frac{-G_{m_2}}{C(G_{m_2}R-1)} = \frac{-G_{m_2}\cdot\frac{C}{C+C_1}}{C_2+\frac{C\,C_1}{C+C_1}}$$

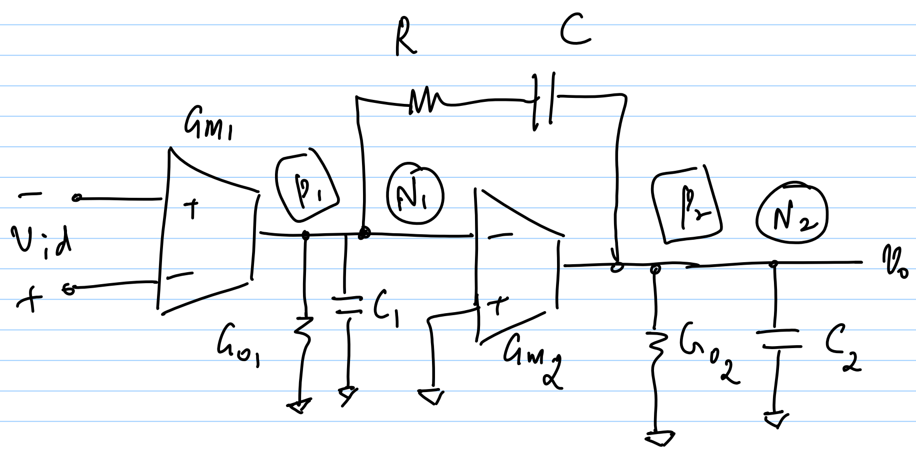
$$C_2 + \frac{C\,C_1}{C+C_1} = \frac{C}{C+C_1}\cdot C(G_{m_2}R-1)$$

$R = f(G_{m_2})$

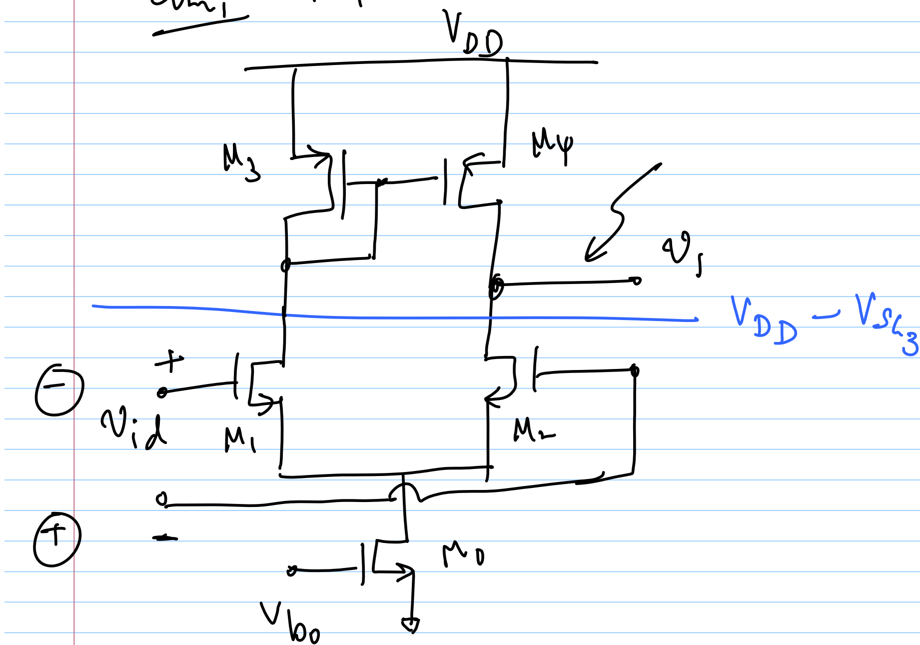
* z not exactly $= p_2$

$\Rightarrow$ pole-zero doublet

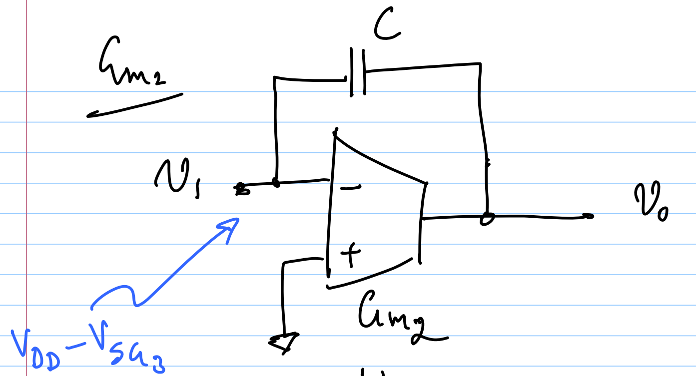
$\Rightarrow$ problems w/ time domain response



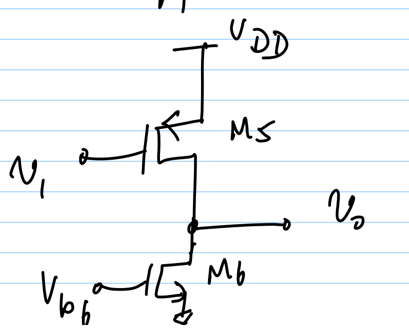
$G_{m_1} = g_{m_1}$



G_{m2}



$\parallel$



(I) $R = f(g_{m5})$

(II) $g_{m5} = f(R)$

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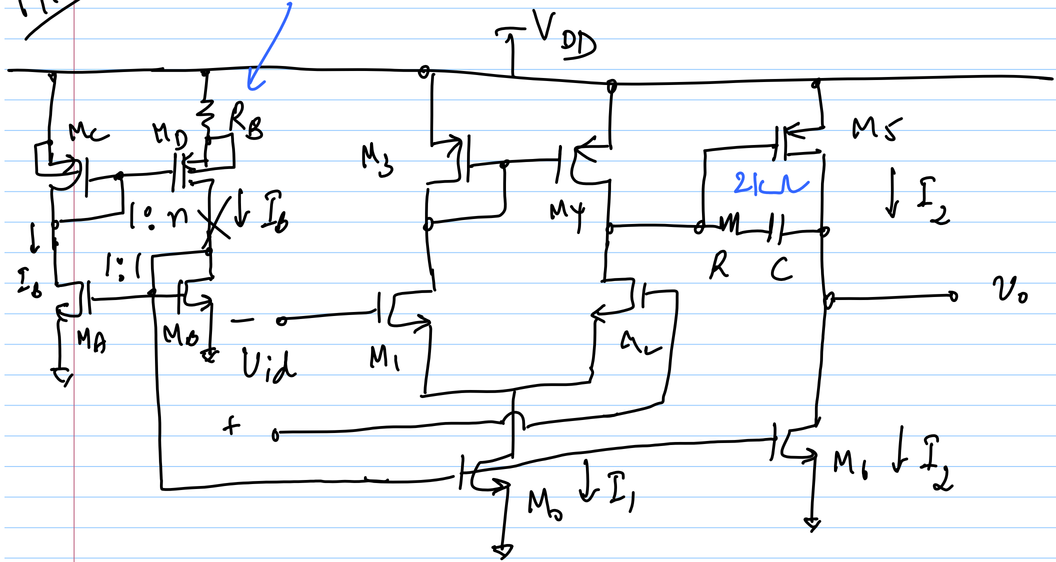


$$V_{SG_C} = V_{SG_D} + I_B R_B \quad \text{—— (1)}$$

$$\left(\frac{W}{L}\right)_D = n\left(\frac{W}{L}\right)_C \Rightarrow V_{ov_D} = \frac{V_{ov_C}}{\sqrt{n}}$$

$$V_{ov_C} = \frac{V_{ov_C}}{\sqrt{n}} + I_B \cdot R_B$$

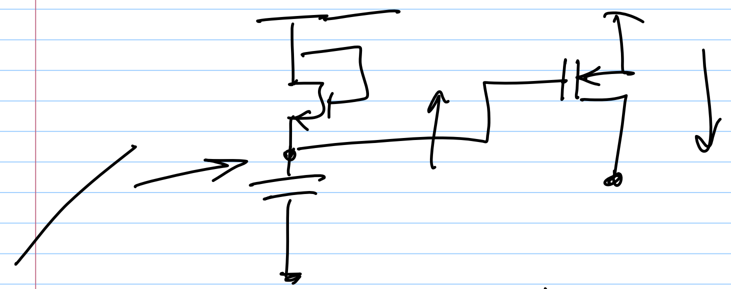
$$g_m = \frac{2I_D}{V_{ov}}$$

$$\frac{2I_B}{g_{mC}} = \frac{2I_B}{\sqrt{n} \cdot g_{mC}} + I_B R_B$$

assuming $I_B \neq 0$,

$$\boxed{g_{m_C} = \frac{2\left(1 - \frac{1}{\sqrt{n}}\right)}{R_B}}$$

$$I_B \propto \frac{1}{R_B^2}$$



$\therefore$ R_B & R = same type of res.

Design example – dominant pole compensation

Specs

$A_0 \geq 80\,dB$; $f_u \geq 5\,MHz$; $V_{o_{p\text{-}p}} = 4V$

$SR \geq 10\,V/\mu s$; $PM = 60°$; $I_{ref} = 100\,\mu A$

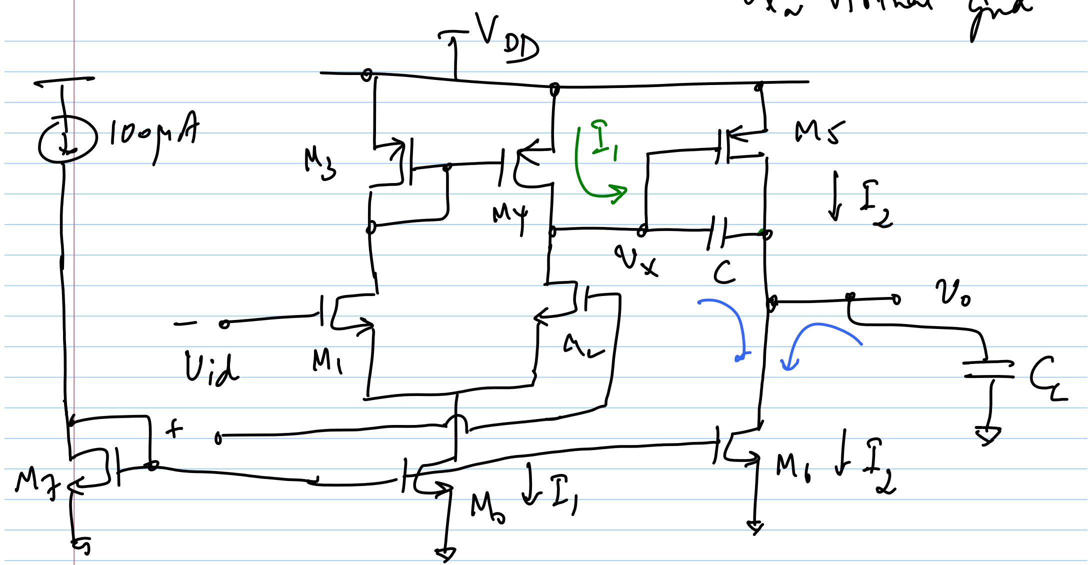
Design parameters

$V_{DD} = 5V$; $C_L = 10\,pF$; $\mu_n C_{ox} = 50\,\mu A/V^2$

$\mu_p C_{ox} = 25\,\mu A/V^2$; $V_{Tn} = |V_{Tp}| = 1V$; $(\lambda L)_n = 0.04\,\mu m/V$

$L_{min} = 2\,\mu m$; $C_{ox} = 1.5\,fF/\mu m^2$; $(\lambda L)_p = 0.1\,\mu m/V$

$v_x \approx$ virtual gnd



SR (o/p limited) $\approx \dfrac{I_2}{C + C_L}$

SR (i/p limited) $\approx \dfrac{I_1}{C}$

1) <u>60° PM</u> : assume only p_2 effects

PM

$$w_z = \frac{g_{m5}}{C} \; ; \quad w_u = \frac{g_{m1}}{C}$$

a) $w_z \geq 10 w_u \Rightarrow g_{m5} = 10\, g_{m1}$

<u>1st ND pole</u> $\Rightarrow$ sets PM

$$\underline{PM > 60°} \quad C \approx 2.2 \left(\frac{g_{m1}}{g_{m5}}\right) \cdot C_L$$

set $\boxed{C = 0.25 C_L} = 2.5pF$

2) <u>Slew Rate</u>

(i/p) $\dfrac{I_1}{C} \geq 10V/\mu s \Rightarrow I_1 \geq 25\mu A$

(o/p) $\dfrac{I_2}{C + C_L} \geq 10 V/\mu s \Rightarrow I_2 \geq 125\mu A$

3) <u>o/p swing</u>

$V_o \geq 4V_{p-p} \Rightarrow V_{DSAT_5} = V_{DSAT_6} = 0.5V$

$$\Rightarrow \left(\frac{W}{L}\right)_5 = 40 \qquad \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 4$$

$$\left(\frac{W}{L}\right)_6 = 20$$

$$\left(\frac{W}{L}\right)_0 = 4$$

$$(W/L)_7 = 16$$

4) $\underline{f_u}$

$$w_u = \frac{g_{m1}}{C} \geq 2\pi \cdot 5MHz$$

$$g_{m1} \geq 78.5\,\mu S$$

$$\boxed{\left(\frac{W}{L}\right)_{1,2} = 5}$$

5) <u>DC gain</u> $\quad A_o \geq 80dB$

$\rightarrow \lambda_{1-4} , \lambda_{5-6}$

Assume λ's are equal

$\lambda \approx 2.5 \times 10^{-2}\ V^{-1}$

$\left.\begin{array}{l}\lambda_n L_n \quad \& \quad \lambda_p L_p\end{array}\right)$ $L_n = 2\mu m$

$L_p = 4\mu m$

Check

1) $g_{m5} = 10 g_{m1}$

2) other poles/zeros $\geq 10 \omega_u$

3) V_{iCM}