

Lecture 22: CMOS Op Amp Compensation

• Announcements:

- ↳ HW#9 due today
- ↳ HW#10 online
- ↳ To start your project, design for phase margin = 60°; then you can play with phase margin to try to optimize power consumption

• Lecture Topics:

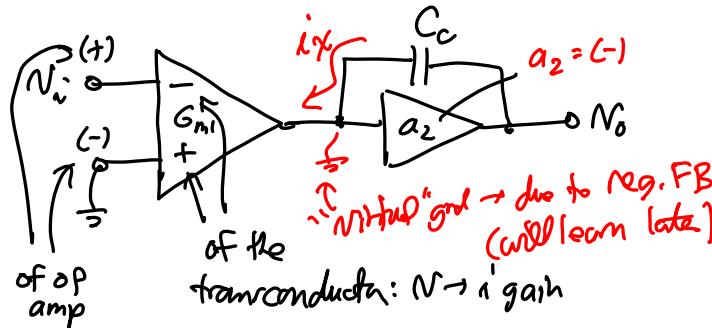
- ↳ Choosing  $C_c$  (cont.)
- ↳ CMOS 2-Stage Op Amp Poles & Zeros
- ↳ RHP Zero
- ↳ Nulling the RHP Zero

• Last Time:

Choosing  $C_c$  (assume no RHP zero  $\nmid |P_2| \gg |P_1|$ )

$\Rightarrow$  assume  $\frac{1}{sC_c} \ll$  (surrounding impedance) @

① Case: Two-Stage Amplifier, Miller Compensation <sup>high freq.</sup>



$$\left| \frac{V_o}{V_i(j\omega)} \right| = \frac{G_m 1}{\omega C_c} \Rightarrow \text{this should equal } A_o \text{ @ the freq } \omega \text{ corresponding to the target phase margin}$$

For  $PM = 45^\circ$ :

$$\omega_{ult} = \omega @ |T(j\omega)| = 1$$

↳ "unity loop transmission"

$$\text{For } PM = 45^\circ \rightarrow \omega_{ult} = \omega_2$$

$$\left| \frac{V_o}{V_i(j\omega_2)} \right| = A_o = \frac{G_m 1}{\omega_2 C_c}$$

freq. of the 2<sup>nd</sup> pole  
in the  $a(j\omega)$   
transfer fun.

$$C_c = \frac{G_m 1}{\omega_2 A_o}$$

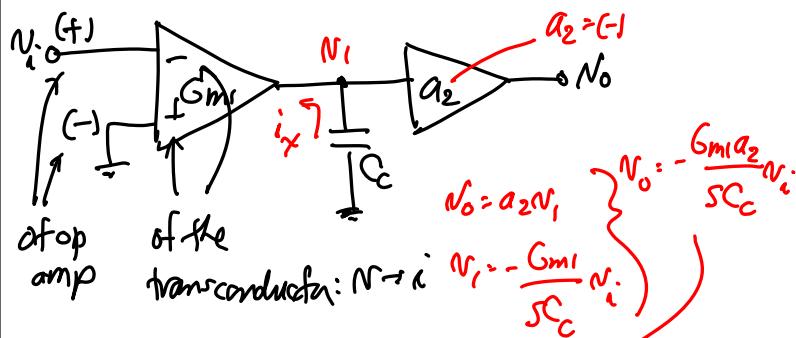
For  $PM = 45^\circ$  (provided high-order poles are far away, i.e.,  $|P_3| \gg |P_2|$ )  
closed-loop gain

$$\omega_{ult} = \frac{\omega_2}{1.73} \rightarrow \left| \frac{V_o}{V_i(j\frac{\omega_2}{1.73})} \right| = A_o = \frac{G_m 1}{(\frac{\omega_2}{1.73}) C_c}$$

$$C_c = \frac{1.73 G_m 1}{\omega_2 A_o}$$

for  $PM = 60^\circ$ .

② Case: Two-Stage Amplifier, Shunt  $C_c$  Compensation



$\therefore \frac{N_0}{N_i}(s) = -\frac{Gm_1 a_2}{SC_C}$  } Closed loop gain  $A_{OL}$  must again intersect this curve @ the right  $\omega_{ult}$  for a given PM

Xtra fns for open loops

For PM = 45°,

$$\left| \frac{N_0}{N_i}(j\omega_{ult}) \right| = A_0 = \frac{Gm_1 a_2}{\omega_{ult} C_C}$$

For PM = 45°:  $\omega_{ult} = \omega_2 \Rightarrow$

$$|TC(j\omega)| = 1$$

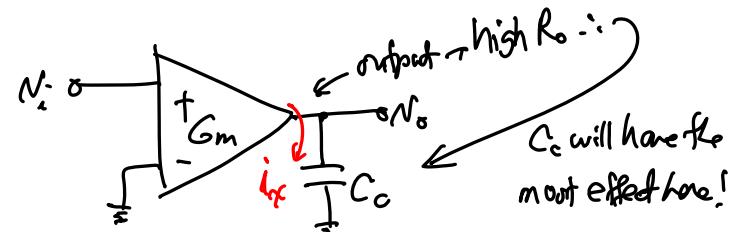
$$C_C = \frac{Gm_1 a_2}{\omega_2 A_0} \quad \text{PM} = 45^\circ$$

For PM = 60°:

$$C_C = \frac{1.736 Gm_1 a_2}{\omega_2 A_0}$$

Case ③: Single-Stage Amplifier, Shunt  $C_c$  compensation  
e.g., telescopic op-amp — i.e., cascode

case



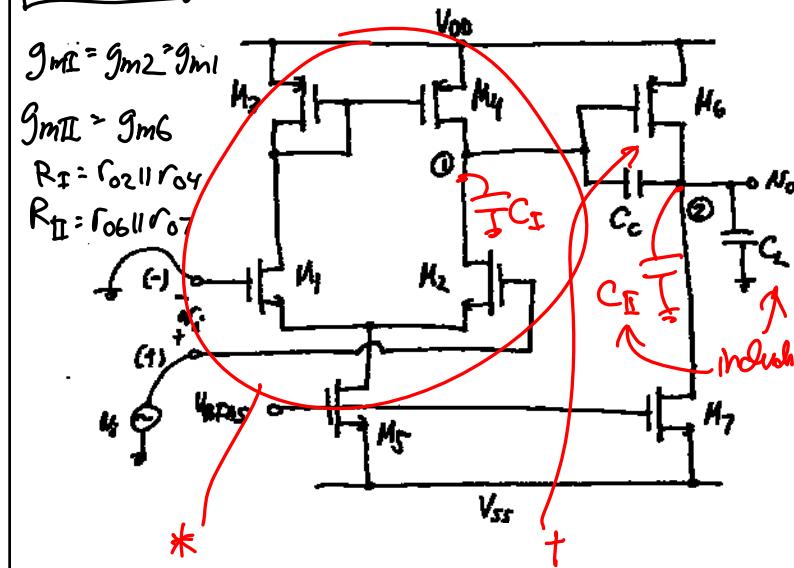
$$\left. \begin{aligned} N_o &= \frac{i_X}{SC_C} \\ i_X &= Gm N_i \end{aligned} \right\} \frac{N_o}{N_i}(s) = \frac{Gm}{SC_C} \quad \text{same as Case ①!}$$

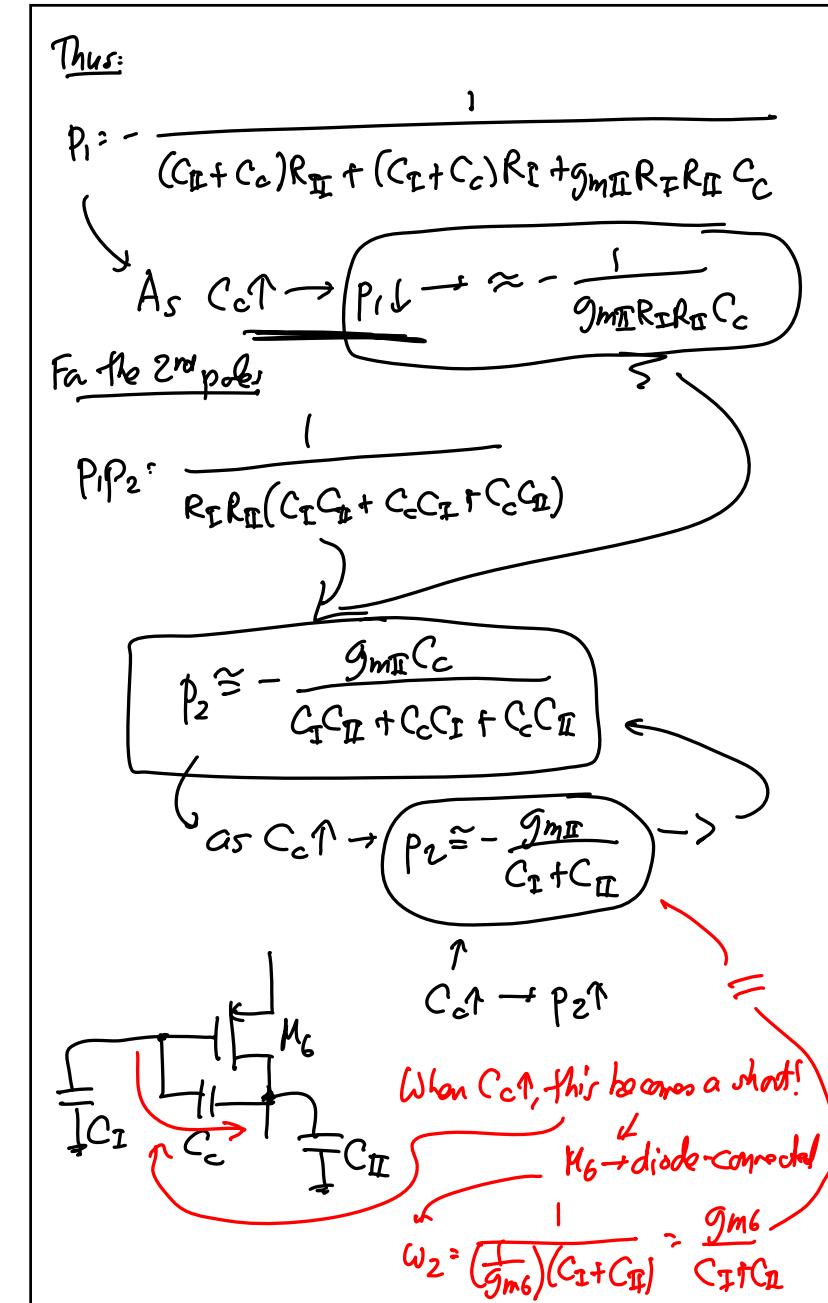
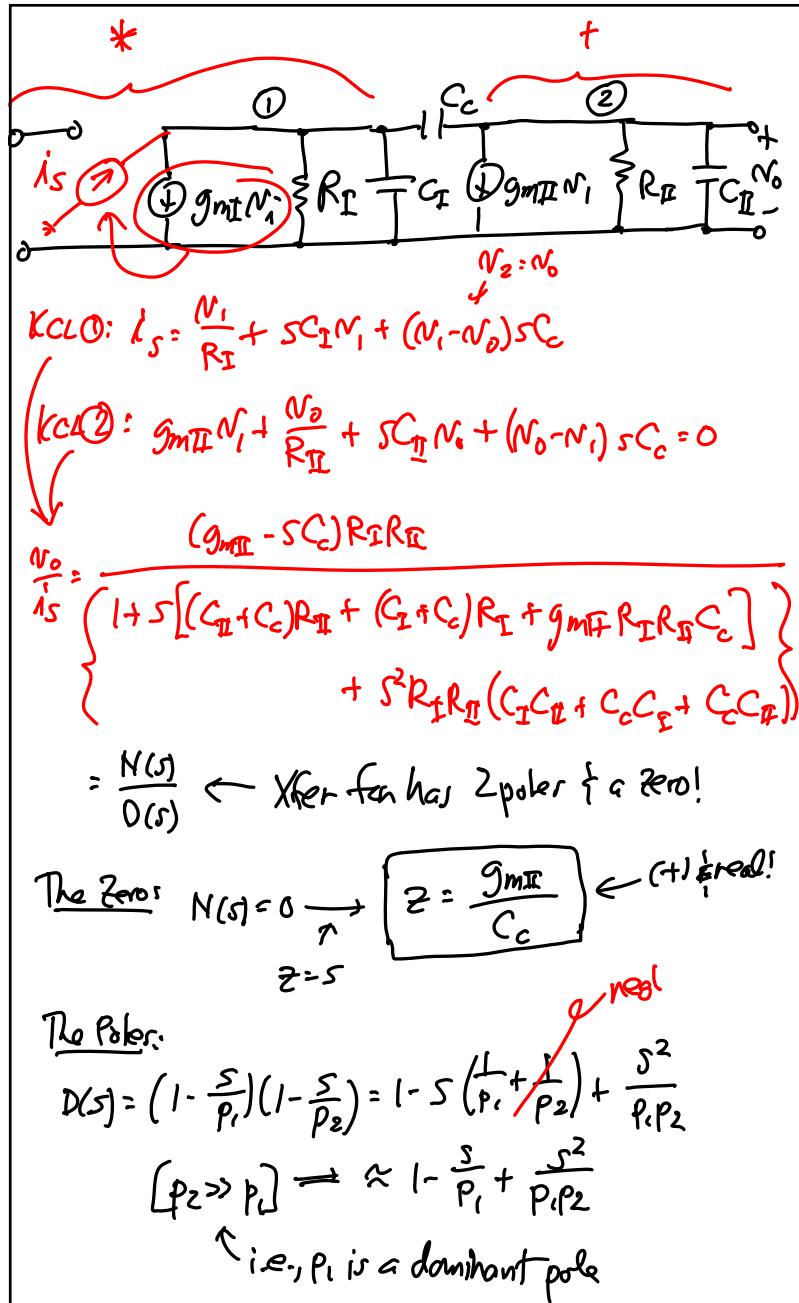
→ use same  $C_c$  equations:

$$C_C = \frac{Gm_1}{\omega_2 A_0} \quad \text{PM} > 45^\circ$$

$$C_C = \frac{1.736 Gm_1}{\omega_2 A_0} \quad \text{PM} = 60^\circ$$

CMOS 2-Stage Op Amp Compensation





Remarks:

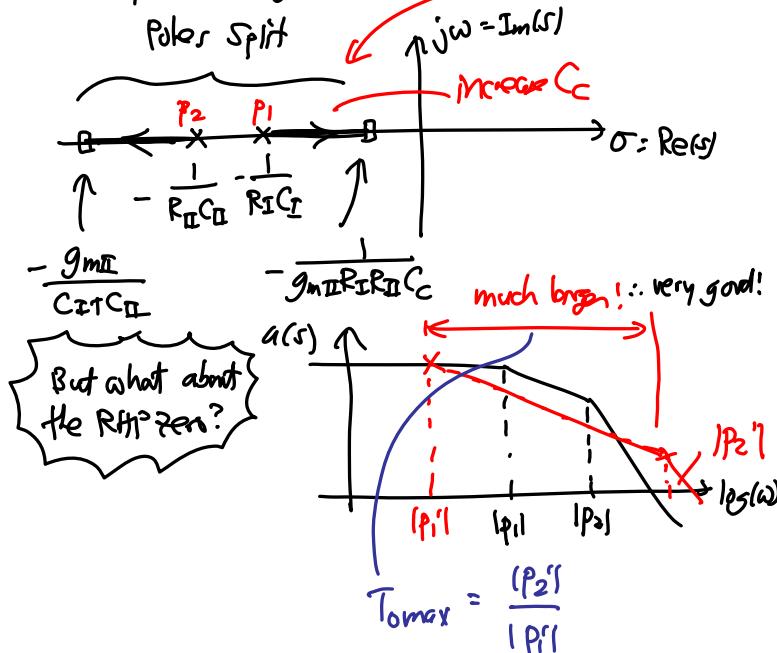
① Note that as  $C_c \uparrow \rightarrow P_1 \downarrow \rightarrow 0$

② As  $C_c \uparrow \rightarrow P_2 \uparrow \rightarrow P_2 = \frac{g_{mII}}{C_I + C_{II}}$

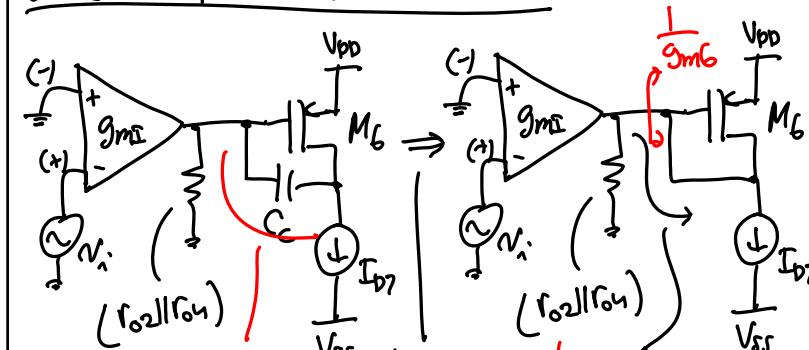
③ With  $C_c = 0$  (i.e., before compensation)

$$P_1 = -\frac{1}{R_I C_I}, \quad P_2 = -\frac{1}{R_{II} C_{II}}$$

④ On a pole zero diagram:



Where does the RHP zero come from?



high freq.  
current can just feed forward @ high freq.

$$\frac{V_o}{V_i} = -\frac{g_{m2}}{g_{m6}}$$

Negative! Should be (+).  
Thus  $\rightarrow$  instability!