

Lecture X: RHP Zero

- Announcements:
- Yep, I'm a substitute teacher
- Lecture Topics:
  - Nulling the RHP Zero
- ------------------------------------
- Not sure, but I'm told that you've already derived the poles and zero of a two-stage CMOS amp
- And you understand how to compensate by

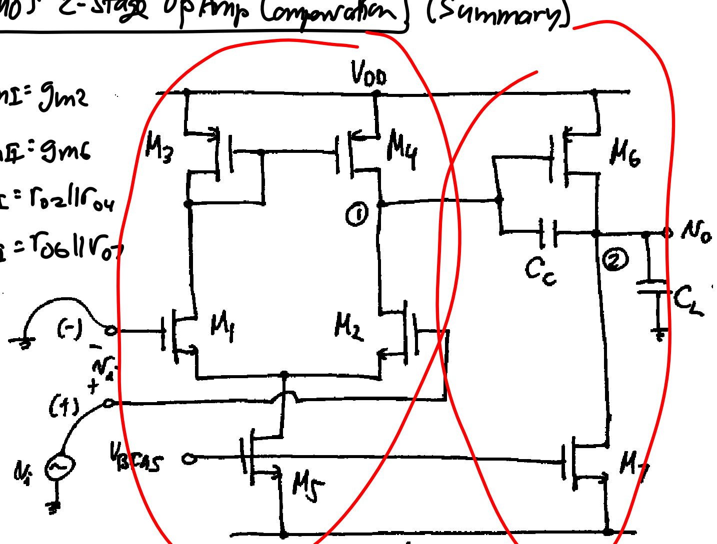
$\boxed{\text{CMOS 2-Stage Op Amp Compensation}}$ (Summary)

$g_{mI} = g_{m2}$

$g_{mII} = g_{m6}$

$R_I = r_{o2} \| r_{o4}$

$R_{II} = r_{o6} \| r_{o7}$



From our previous analysis:

$$p_1 = -\frac{1}{g_{mII} R_I R_{II} C_c}$$

$[C_c \gg C_I \text{ or } C_{II}]$ $[C_L \gg C_I]$

$$p_2 = -\frac{g_{mII} C_c}{C_I C_{II} + C_c (C_I + C_{II})} \approx -\frac{g_{mII}}{C_I + C_{II}} \approx -\frac{g_{m6}}{C_L}$$

$$z = +\frac{g_{mII}}{C_c}$$ ← RHP zero (this will cause problems)

Remarks:

① Note that as $C_c \uparrow \rightarrow |p_1| \downarrow$

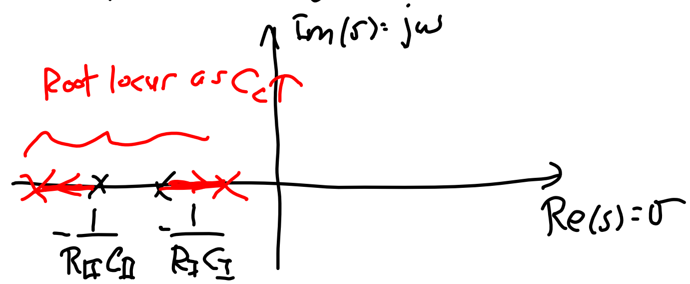
② As $C_c \uparrow \rightarrow |p_2| \uparrow \rightarrow |p_2| = \frac{g_{mII}}{C_I + C_{II}}$

$\Big\}$ pole-splitting

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

$$p_1 = -\frac{1}{R_I C_I}, \quad p_2 = -\frac{1}{R_{II} C_{II}}$$

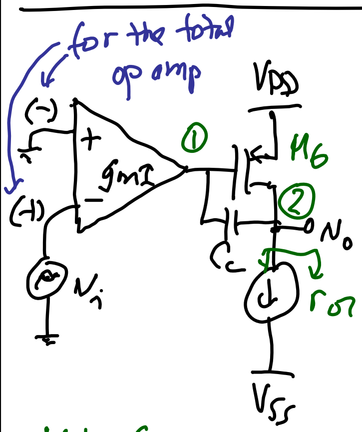
④ On a pole/zero diagram:

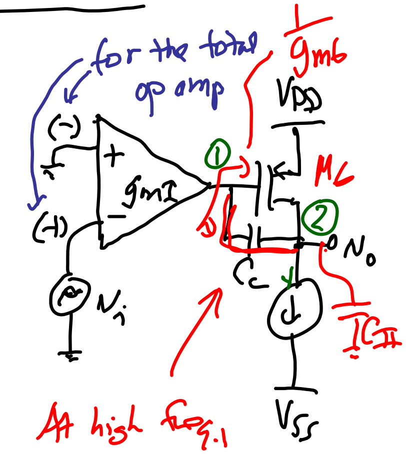


Great! → But what about the RHP zero!

- Now, go through the handouts:
  - Review of Pole/Zero Plots
  - RHP Zero
- These give a general picture of how a RHP zero can hurt stability (but a LHP plane zero can really help)

Where Does the RHP Zero Come from?





At low freq.:

$$\frac{v_②}{v_①} = -g_{m6}(r_{o6} \| r_{o7})$$

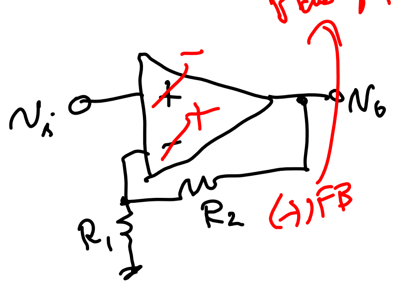
total gain $= \frac{v_①}{v_i} \cdot \frac{v_②}{v_①} = (+)$

(−) (−)

At high freq., this shorts → get a feed-forward path

$$\frac{v_o}{v_i} = -\frac{g_{m1}}{g_{m6}} = (-)$$

Blows up!

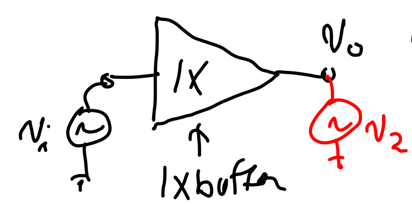


Observation:

Miller effect compensation requires FB path.

↳ BUT: The feedforward path (that creates the zero) is not needed!

Solution: ① Kill the feedforward path.
② keep the feedback path.



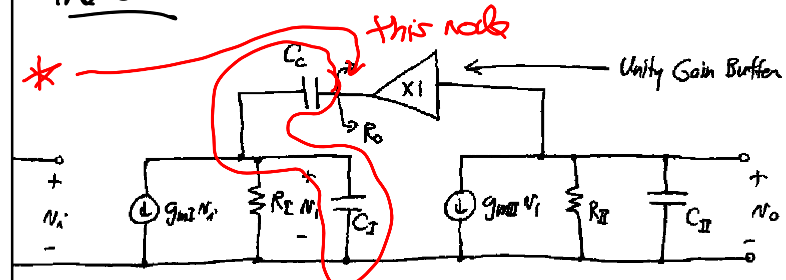
$\frac{v_o}{v_i} = 1$

$\frac{v_i}{v_2} \ll 1$

∴ buffer is directional

Solution: Put a 1X buffer in series w/ C_c to prevent the feed-forward path, but allow FB!

The Ckt.



Apply KCL:

$$p_1 \cong -\frac{1}{g_{mII} R_I R_{II} C_c} \quad \text{(same as before)}$$

$$p_2 \cong \frac{-g_{mII} C_c}{C_{II}(C_I + C_c)} \underset{\uparrow}{\simeq} -\frac{g_{mII}}{C_{II}}$$

$[C_c >> C_I]$

comes from

$$p_3 \cong -\frac{1}{R_o \underbrace{(C_I C_c/(C_I + C_c))}_{\text{series comb. of } C_I \,\&\, C_c}} \cong -\frac{1}{R_o C_I}$$

$$z \cong -\frac{1}{R_o C_c} \leftarrow \text{LHP zero!}$$

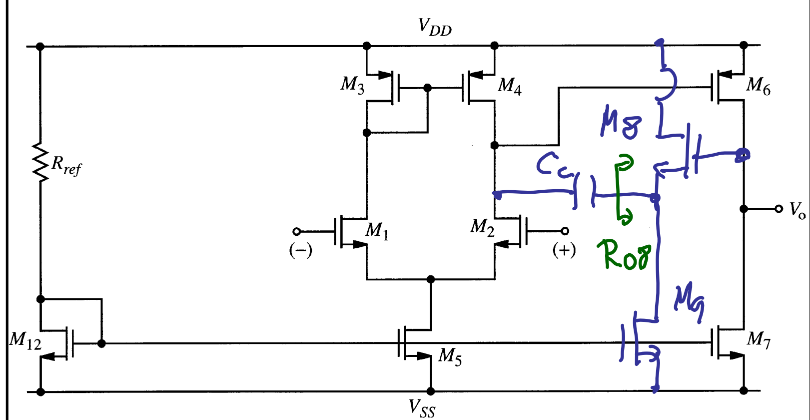
Great!

Remarks:

① An additional pole $p_3 = -\frac{1}{R_o C_I}$ has been created! But since R_o: small (for a buffer) and C_I: small, p_3 is at a very high freq. → contributes very little phase @ ω_{ulg}, where $|T(j\omega)| = 1$.

② A LHP zero now emerges $z_1 = -\frac{1}{R_o C_c}$.
This helps stability as discussed before.
(by contributing (+) phase shift → PM↑)

Actual Implementation of Buffer-Based Zero Cancellation



$$R_{o8} = \frac{1}{g_{m8}} = \frac{1}{\sqrt{2\mu_n C_{ox} (W/L)_8 I_{D8}}}$$ → Want this sufficiently small to drive $|p_3|$↑

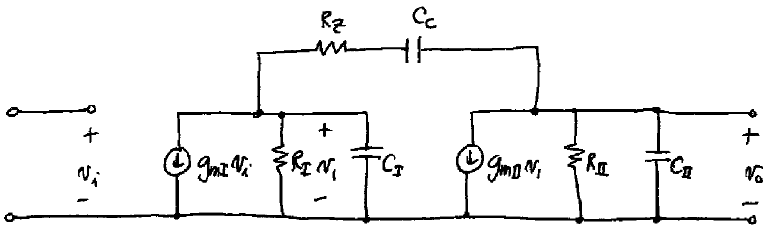
increase I_{D8} or increase $(W/L)_8$

Problems: ↓ more power ✗ ↘ more area ✗ ↘ cost!

Solution: Better technique!

↓ over

Nulling Resistor in Series w/ C_c



Doing KCL:

$$p_1 = -\frac{1}{g_{mII} R_I R_{II} C_c}$$

$$p_2 = \frac{-g_{mII} C_c}{C_I C_{II} + C_c(C_I + C_{II})} \simeq -\frac{g_{mII}}{C_{II}}$$

same as before

$$p_3 = -\frac{1}{R_Z C_I} \leftarrow \text{pole due to } R_Z$$

$$z_1 = \frac{1}{C_c\left(\frac{1}{g_{mII}} - R_Z\right)} \leftarrow \text{relocated zero (function of } R_Z)$$