Announcements:

- HW#1 will be due at 6 p.m. today
  "Change in time from 5 p.m. to 6 p.m. to accommodate people with classes that go till 5 p.m."
- HW#2 is online and is due next Tuesday, at 6 p.m.
- Lab#1 is online
  "Labs start next week → go to your lab section"
- As indicated in your syllabus, next Tuesday is a travel day for me, so I will miss lecture that day
  "Make-up lecture TBA – shooting for Friday afternoon"
- Lecture Topics:
  "Multi-Tx Amplifier Examples"
  "MOS Inspection Analysis"

Last Time:
- Multi-Tx inspection analysis
- Continue with this

\[ I_{C1} = I_{C2} = \frac{I_{EE}}{2} \]
\[ r_{g1} = r_{g2} = r_f \]
\[ r_{o1} = r_{o2} = r_o \]
\[ g_m1 = g_m2 = 5m \]

\[ R_4 = r_{r1} + (\beta+1)(\frac{1}{2}r_{r1}) \]
\[ R_s = R_{m1} + (\beta h) \left( \frac{1}{g_m^2} \right) \left( \frac{1}{1 + (1/\gamma m)} \right) R_E \]

\[ R_i' = R_i + (\beta h) \frac{1}{\gamma m} \rightarrow R_{i'} = 2 R_i \]

\[ R_o = R_{o2} \left( 1 + \frac{g_m}{\gamma m \left( 1/g_{m1} \right)} \right) || R_{o2} \approx \frac{\text{large gain}}{\text{CMRR}} \]

\[ V_o = V_{o2} \cdot \frac{N_{o2}}{N_{o1}} = -g_{m2}R_E \]

\[ V_{o1} = V_{o2} \cdot \frac{R_E}{R_{E2}} = \frac{1}{g_{m2}} \cdot \frac{V_{o2}}{R_{E2}} \]

\[ V_{o2} = \frac{2 \gamma m}{R_{o2} + 2 \gamma m} \]

\[ V_o = \frac{2 \gamma m}{2 \gamma m + 2 R_E} \cdot \frac{1}{g_{m2}} \cdot R_E \]
Try to figure out whether or not there is a different beta and come up with an inspection formula for this case.

This will be discussed in discussion section, but try to come up with the solution on your own.
\[ \frac{V_{d}}{V_{g}} = -G_{m}R_{D}, \quad G_{m} = \frac{g_{m}}{1+g_{m}R_{f}} \]
\[ \frac{V_{d}}{V_{s}} = -G_{m}R_{D}, \quad G_{m} = -g_{m} \]
\[ \frac{V_{s}}{V_{g}} = \frac{g_{m}R_{f}}{1+g_{m}R_{f}}, \quad \frac{R_{f}}{g_{m}+R_{f}} \]

**MOS Inspection Analysis**

Ex. Common-Source Common-Drain Cascade

\[ \frac{V_{o}}{V_{s}} = \frac{A_{n}}{R_{s}} = \frac{V_{o}}{V_{o}} \cdot \frac{V_{o}}{V_{o}} \cdot \frac{V_{o}}{V_{o}} \]

\[ \frac{V_{o}}{V_{s}} = (1)(-g_{m}R_{D})(\frac{R_{s}}{R_{s}+R_{f}}) \]

Problems: Simulate in SPICE — the gain will be

From 80-90% of what we calculate using

the problem is that the gmb was neglected when determining the source/follower gain

one difference between

bipolar + MOS hybrid-IT

models

\[ V_{o} = \frac{A_{n}}{R_{s}} = \frac{V_{o}}{V_{o}} \cdot \frac{V_{o}}{V_{o}} \cdot \frac{V_{o}}{V_{o}} \]

Source Follower:

(uj substrate grounded)

\[ V_{o} = \frac{A_{n}}{R_{s}} = \frac{V_{o}}{V_{o}} \cdot \frac{V_{o}}{V_{o}} \cdot \frac{V_{o}}{V_{o}} \]

invert hybrid-IT model
For cost reasons, bulks are rarely tied to sources in circuits like followers or differential pairs. So you need to be able to deal with the $g_{mb}$'s when doing small-signal analysis. See the MOS inspection formulas at the end of this lecture.
**Effect of \( g_{mb} \)**

\[
R_s = \frac{1}{g_{m} + g_{mb} + g_{ds}}
\]

\[
R_s \approx \frac{1}{g_{m} + g_{mb}}
\]

**MOS Inspection Formulas at Substrate Grounded**

\[
R_g = \infty
\]

\[
R_s = \frac{1}{g_{m} + g_{mb}}
\]

\[
R_d = R_b \left[ 1 + (g_{m} + g_{mb}) R_b \right]
\]

\[
\frac{N_d}{N_g} = - G_m R_d \quad ; \quad G_m = \frac{g_m}{1 + (g_{m} + g_{mb}) R_b}
\]

\[
\frac{N_d}{N_s} = - G_m R_d \quad ; \quad G_m = -(g_m + g_{mb})
\]

\[
\frac{N_s}{N_b} = \frac{g_m R_s}{1 + (g_{m} + g_{mb}) R_b}
\]

Remark, when the substrate is tied to the source, \( g_{mb} = 0 \).