Lecture 33: MOS Inspection Analysis

- **Announcements**:
- HW#10 online and due Friday Nov. 16
- Midterm Friday this week, Nov. 9, @ 5 p.m., in 277 Cory (just like last time)
  - We will have 2 hours for this exam
  - Midterm Info Sheet online
- Lab 6 online and due 5 p.m., Friday, Dec. 7
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- Lecture Topics:
  - Multi-Transistor Example (Inspection Analysis)
    - —Input/Output Resistances
    - —Gain
    - —High Frequency
  - MOS Inspection Analysis
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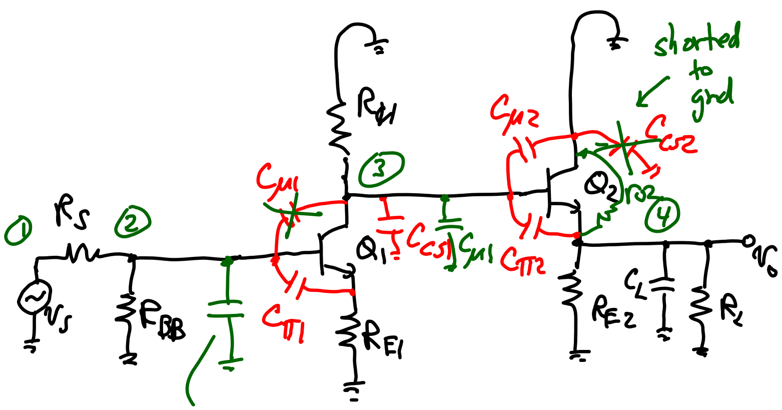
- **Last Time**:
- Practically finished high frequency cut-off
- Finish it off, then move to MOS inspection analysis



$C_{\mu 1}(1-a_{v1}) : C_{\mu 1}(1+G_{m1}R_{③})$

Using OCTC Analysis:

$$\omega_H = \frac{1}{C_{②}R_{②} + C_{③}R_{③} + C_{④}R_{④} + C_{\pi 1}R_{\pi 1} + C_{\pi 2}R_{\pi 2}}$$

total shunt C @ node ②

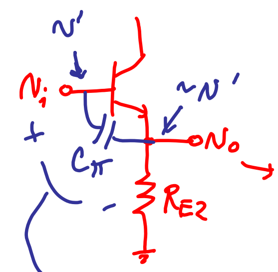
total shunt R @ node ②

C's in FB ∴ determined their driving pt. $R_{\pi o}$'s via hybrid-π model

Incorporating Results f/ Last Time

$$\omega_H = \frac{1}{\left\{ \begin{array}{l} C_{\mu 1}\left(1+\frac{g_{m1}R_{c1}}{1+g_{m1}R_{E1}}\right)(R_S\|R_B) + (C_{cs1}+C_{\mu 1}+C_{\mu 2})R_{c1} \\ + C_L\left(R_{E2}\|R_L\|\frac{r_{\pi 2}+R_{c1}}{\beta_2+1}\right) + C_{\pi 1}\left(r_{\pi 1}\|\left(\frac{R_B\|R_S+R_{E1}}{1+g_{m1}R_{E1}}\right)\right) \\ + C_{\pi 2}\left(r_{\pi 2}\|\left(\frac{R_c+R_{E2}}{1+g_{m2}R_{E2}}\right)\right) \end{array} \right\}}$$

✓ = include
X = maybe neglect
x = neglect



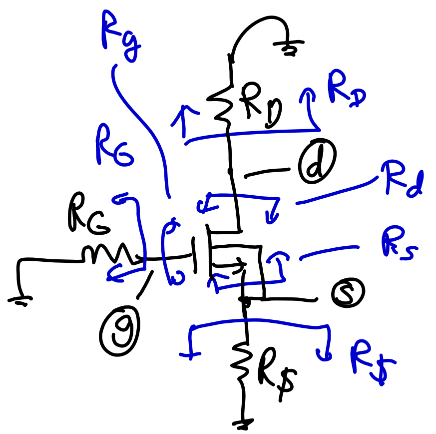
$$\frac{v_o}{v_i} = \frac{R_{E2}}{\frac{1}{g_{m2}} + R_{E2}} \cong 1 \text{ when } R_{E2} \gg \frac{1}{g_{m2}}$$

$\Delta v = v' - v' = 0 \rightarrow$ No voltage across C_π ∴ no C_π

MOS Xsistor Ckts.

⇒ for now, ignore Body effect (i.e., ignore g_{mb})

↳ use the same inspection formulas as bipolar, but use $\beta \to \infty$, $r_\pi = \frac{\beta}{g_m} \to \infty$



⇒ referring to the bipolar "Inspection Formula Sheet":

Bipolar		MOS
$R_b = \left(\frac{1}{g_m} + R_E\right)(\beta+1)$	$\xrightarrow{\beta\to\infty}$	$R_g = \infty$
$R_e = \frac{1}{g_m} + \frac{R_B}{\beta+1}$	$\xrightarrow{\beta\to\infty}$	$R_s = \frac{1}{g_m}$
$R_c = r_o\left[1 + \frac{g_m R_E}{1 + R_B/r_\pi}\right]$ ($r_\pi \to \infty$)	$\xrightarrow{\beta\to\infty}$	$R_d = r_o(1 + g_m R_S)$

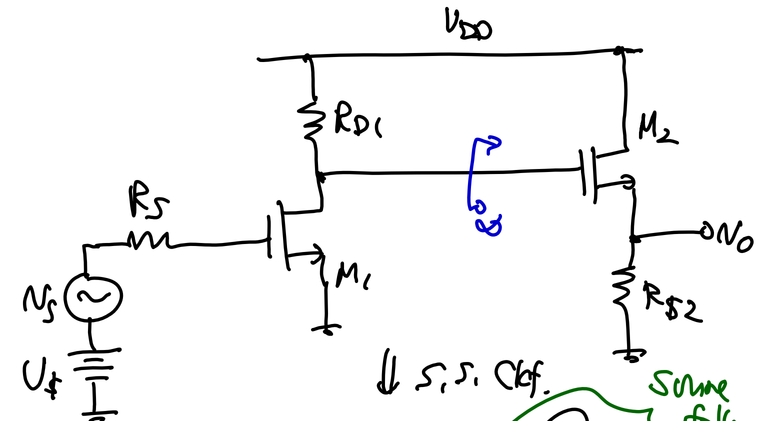
$$\frac{v_d}{v_g} = -G_m R_d, \quad G_m = \frac{g_m}{1 + g_m R_S}$$

$$\frac{v_d}{v_s} = -G_m R_d, \quad G_m = -g_m$$

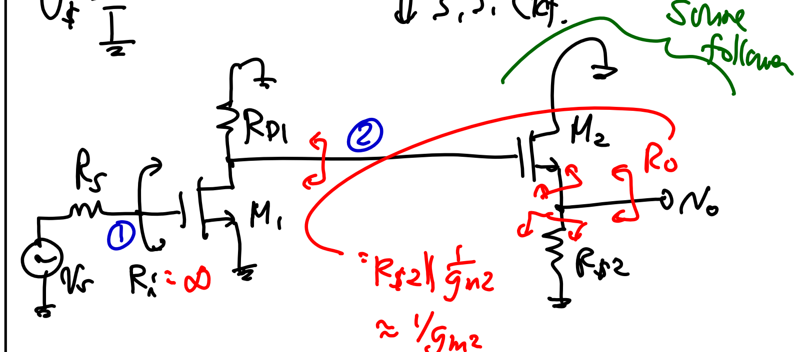
$$\frac{v_s}{v_g} = \frac{g_m R_S}{1 + g_m R_S} = \frac{R_S}{\frac{1}{g_m} + R_S}$$

MOS Inspection Analysis

Ex. Common-Source Common-Drain Cascade



⇓ s.s. Ckt.



$$\frac{v_o}{v_s}=\frac{v_1}{v_s}\cdot\frac{v_2}{v_1}\cdot\frac{v_o}{v_2}$$

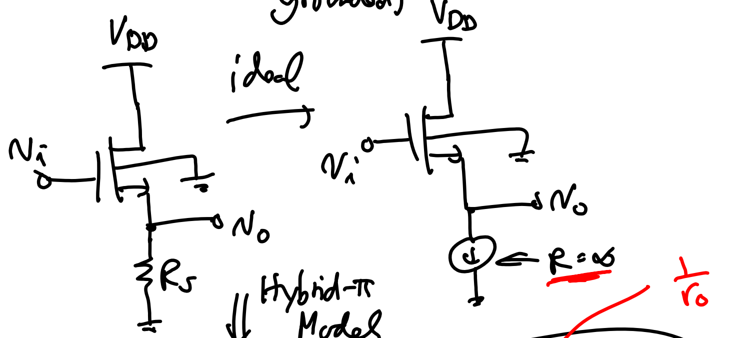
$$\boxed{=(1)(-g_{m1}R_{D1})\left(\frac{R_{S2}}{\frac{1}{g_{m2}}+R_{S2}}\right)=\frac{v_o}{v_s}}$$

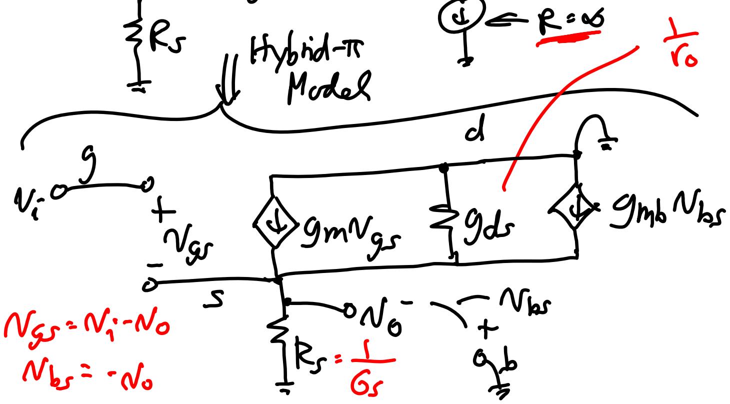
Problem: Simulate via SPICE → the gain will be 80-90% of what is calculated using

the problem is w/ g_{mb} in the source follower

this is the difference between bipolar & MOS hybrid-π models!

Source Follower: (w/ substrate grounded)





$v_{gs}=v_i-v_o$
$v_{bs}=-v_o$

$$g_m(v_i-v_o)=v_o(g_{ds}+G_s+g_{mb})$$

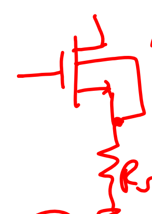
$$\Rightarrow A_v=\frac{v_o}{v_i}=\frac{g_m}{g_m+g_{mb}+g_{ds}+G_s}$$

$R_s\to\infty \to G_s=0$
$g_{ds}\ll g_m+g_{mb}$

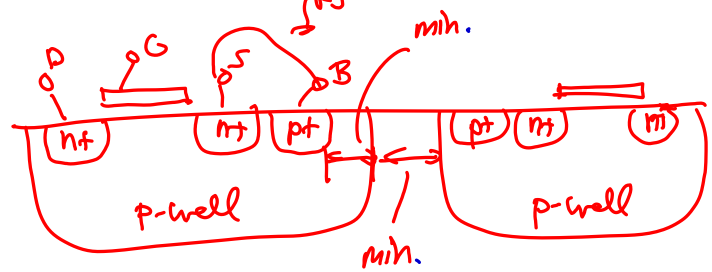
Body factor

$$\boxed{A_v\simeq\frac{g_m}{g_m+g_{mb}}=\underbrace{\frac{1}{1+\eta}}_{\neq 1},\quad \eta=\frac{\gamma}{2\sqrt{V_{SB}+2\phi_F}}}$$

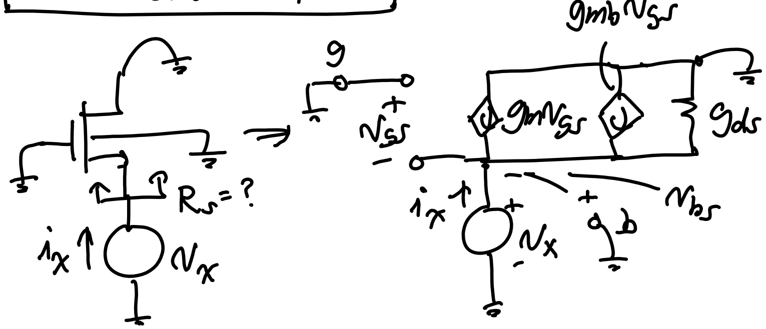
To make it '1', do this:



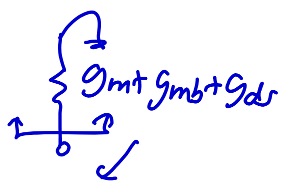
⇒ not always practical!



Effect of g_{mb} on Impedance



$$\begin{bmatrix} v_{gs} = -v_x = v_{bs} \\ v_{ds} = -v_x \end{bmatrix}$$



$$R_s = \frac{1}{g_m + g_{mb} + g_{ds}} = \frac{1}{g_m} \| \frac{1}{g_{mb}} \| r_o$$

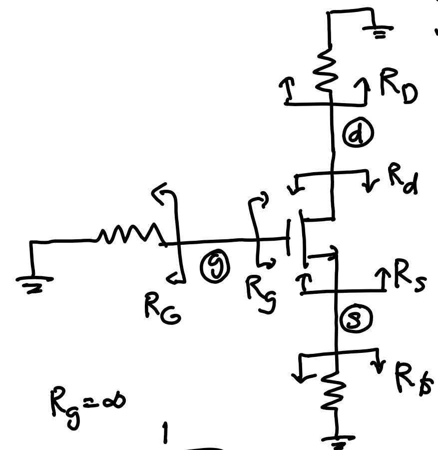
$$\boxed{R_s \approx \frac{1}{g_m + g_{mb}}}$$

⇒ more extensive analysis shows that other inspection formulas change to accommodate a grounded body by replacing "g_m" in the numerators w/ "$g_m + g_{mb}$"

⇒ end up w/ the following:

over

MOS Inspection Formulas w/ Substrate Grounded



↳ only difference from "substrate tied to source" case is that g_m is replaced by $g_m + g_{mb}$ in some of the formulas

particularly ones where the source is involved!

$R_g = \infty$

$$R_s = \frac{1}{g_m + g_{mb}}$$

$$R_d = r_o\left[1 + (g_m + g_{mb})R_{\$}\right]$$

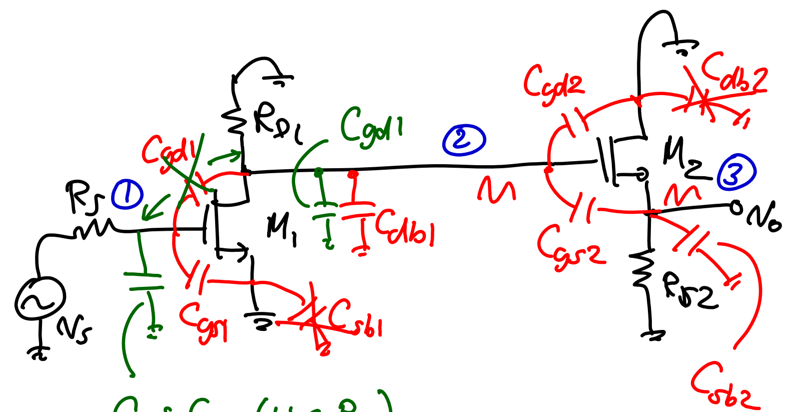
$$\frac{v_d}{v_g} = -G_m R_{(d)}, \quad G_m = \frac{g_m}{1 + (g_m + g_{mb})R_{\$}}$$

$$\frac{v_d}{v_s} = -G_m R_{(d)}, \quad G_m = -(g_m + g_{mb})$$

$$\frac{v_s}{v_g} = \frac{g_m R_{\$}}{1 + (g_m + g_{mb})R_{\$}}$$

Remark: When the substrate is tied to the source, $g_{mb} = 0$.

MOS High Frequency Inspection Analysis



$$C_M = C_{gd1}(1+g_{m1}R_{D1})$$

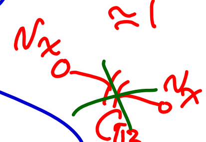
$$\tau_{①} = [C_{gs1} + C_{gd1}(1+g_{m1}R_{D1})]R_S$$

$$\tau_{②} = [C_{gd1} + C_{db1} + C_{gd2}](\cancel{r_{o1}} \| R_{D1})$$

$$\tau_{③} = C_{sb2}\left(\frac{1}{g_{m2}+g_{mb2}} \| R_{S2}\right)$$

$$\cancel{\tau_{gs2} = C_{gs2}\left(\frac{R_{D1}+R_{S2}}{1+(g_{m2}+g_{mb2})R_{S2}}\right)}$$

because no signal across $C_{\pi 2}$ cuz 2nd stage gain ≈ 1



$$\omega_H = \frac{1}{\tau_{①} + \tau_{②} + \tau_{③} + \tau_{gs2}}$$