Lecture 32: MOS Inspection Analysis

- **Announcements:**
- HW#10 online and due Friday Nov. 22
- Lab 6 online and due 5 p.m., Friday, Dec. 13
- Midterm 2 today @ 7 p.m., in 160 Kroeber Hall
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- Lecture Topics:
  - Multi-Transistor Example (Inspection Analysis)
    - —Input/Output Resistances
    - —Gain
    - —High Frequency
  - MOS Inspection Analysis
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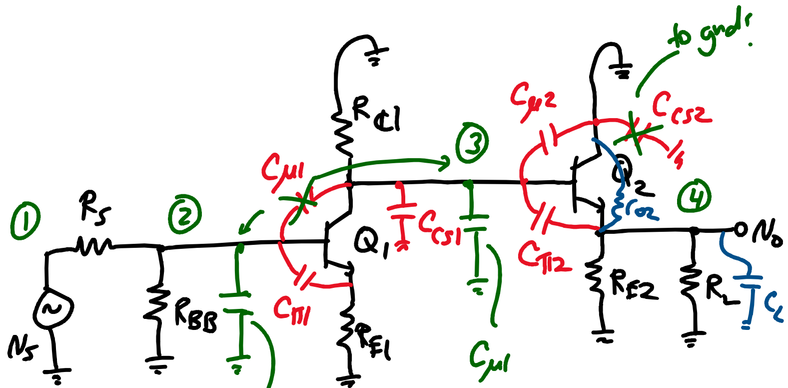
- **Last Time:**
- Practically finished high frequency cut-off
- Finish it off, then move to MOS inspection analysis



$C_{M1} = C_{\mu 1}(1 - A_{v1}) = C_{\mu 1}(1 + G_{m1} R_{③})$

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

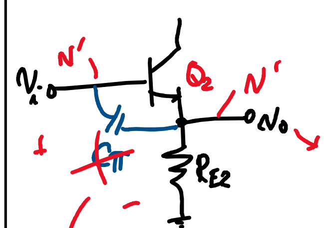
Incorporating Results f/ Last Time

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

R_{E1} is not large

R_{E2} = large!

✓ = include
✗ = maybe neglect
X = neglect

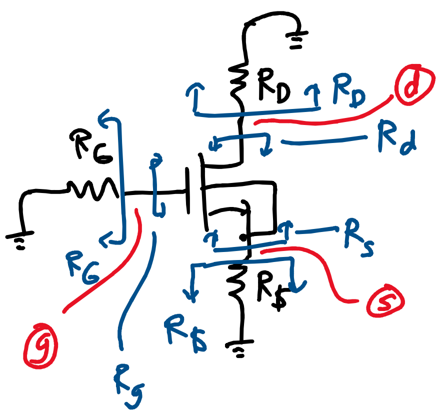


$$\frac{v_o}{v_i} = \frac{R_{E2}}{\frac{1}{g_{m2}} + R_{E2}} \cong 1 \text{ when } R_{E2} \gg \frac{1}{g_{m2}}$$

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

MOS Xsistor Ckt.

$\Rightarrow$ for now, ignore Body effect (i.e., ignore g_{mb}) (short bulk to source)
use the same inspection formulas as bipolar, but $\beta \to \infty$, $r_\pi = \frac{\beta}{g_m} \to \infty$



$\Rightarrow$ refer to the bipolar "Inspection Formula Sheet":

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

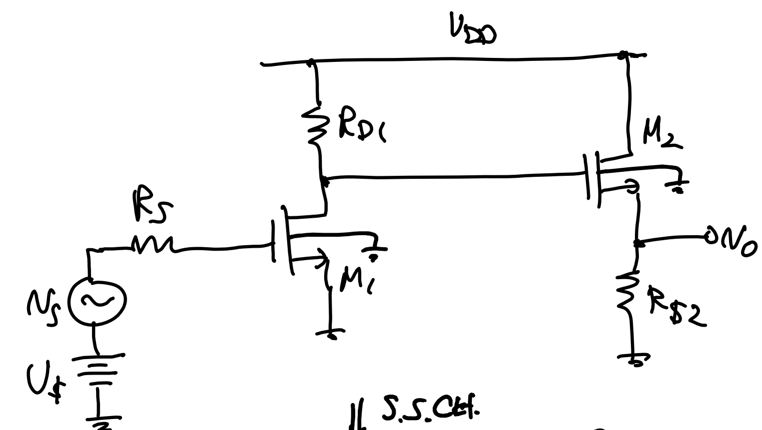
$$\frac{v_d}{v_g} = -G_m R_{d}, \quad G_m = \frac{g_m}{1 + g_m R_S}$$

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

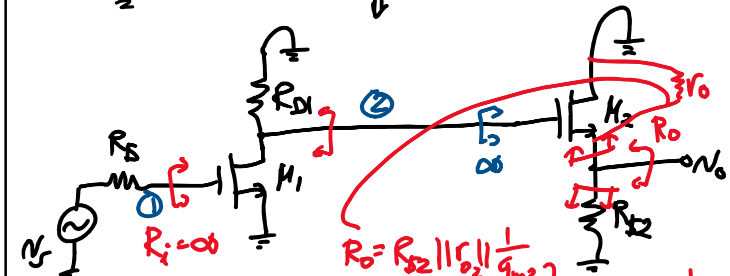
$$\frac{v_s}{v_g} = \frac{g_m R_S}{1 + g_m R_S} = \frac{R_S}{\frac{1}{g_m} + R_S}$$

MOS Inspection Analysis

Ex. Common-Source Common-Drain Cascade



$\Downarrow$ S.S. Ckt.



$R_o = R_{S2} \| r_{o2} \| \frac{1}{g_{m2}} \approx R_{S2} \| \frac{1}{g_{m2}}$

$$\frac{v_o}{v_s} = \frac{v_{①}}{v_s}\cdot\frac{v_{②}}{v_{①}}\cdot\frac{v_o}{v_{②}}$$

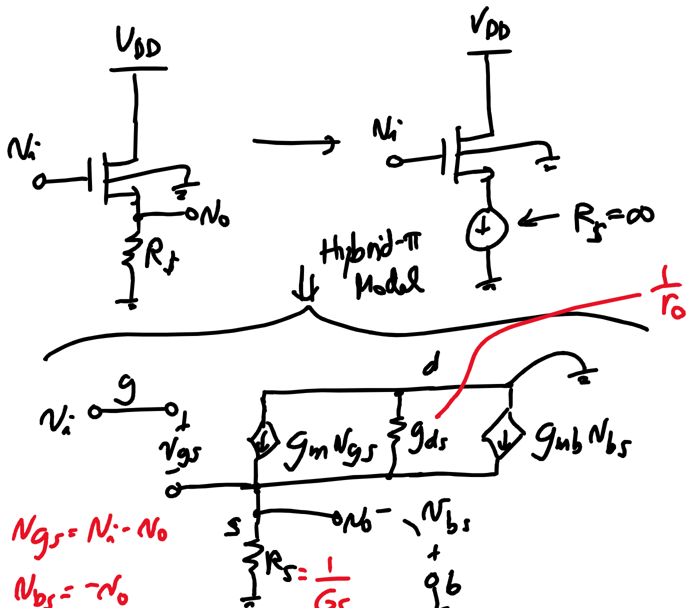
$$= \boxed{(1)(-g_{m1}R_{D1})\left(\frac{R_{S2}}{\frac{1}{g_{m2}}+R_{S2}}\right) = \frac{v_o}{v_s}}$$

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

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

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

Source Follower:



$v_{gs} = v_i - v_o$

$v_{bs} = -v_o$

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

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

$R_S\to\infty \to G_S\to 0$

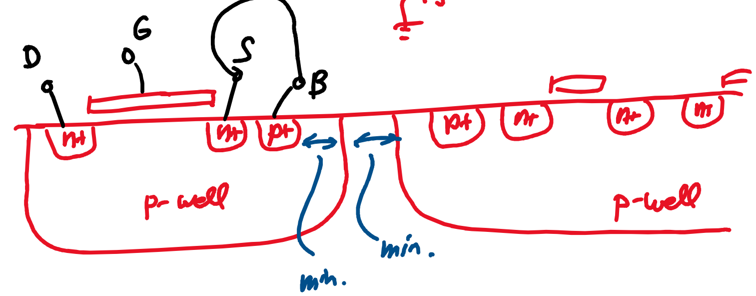
$g_{ds} \ll g_m + g_{mb}$

Body factor

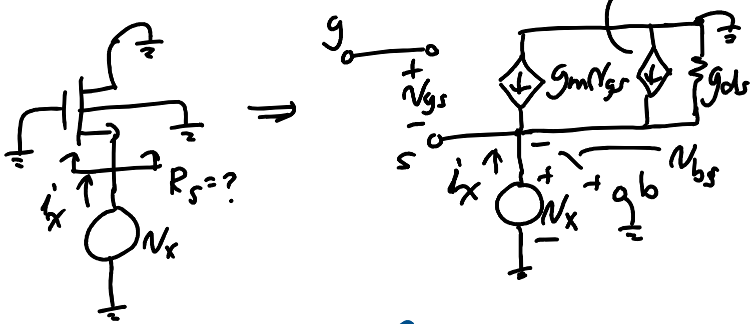
$$\boxed{A_v \simeq \frac{g_m}{g_m+g_{mb}} = \frac{1}{\underbrace{1+\eta}_{\neq 1}}\,,\quad \eta = \frac{\gamma}{2\sqrt{V_{SB}+2\phi_F}}}$$

To make it '1' do this:

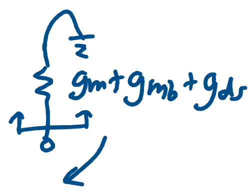
⇒ not always practical!



Effect of g_{mb} on Impedance



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



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

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

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

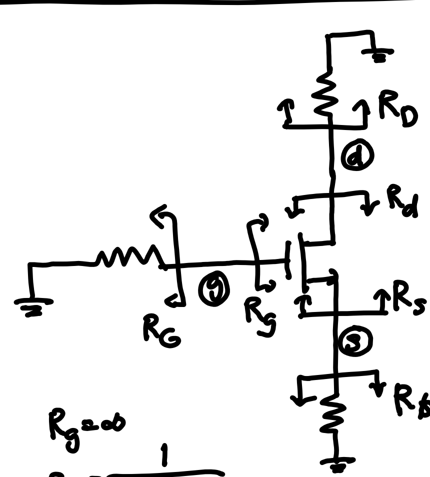
⇒ end up w/ the following: over

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!



$R_g = \infty$

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

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

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

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

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

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