Lecture 5: MOS Inspection Analysis

- **Announcements**:
- Make-up lecture: Saturday, 2/5, 3:30-5 p.m., in 213 Wheeler (this room) → no longer true! Watch email for update to time and place (if no email, then nothing over the weekend)
- Lab#1 is online (and hardcopies were handed out in class today)
- HW#2 has been online since Tuesday and is due next Tuesday, at 5 p.m.
- **Lecture Topics**:
  - Multi-Tx Amplifier Examples
  - MOS Inspection Analysis
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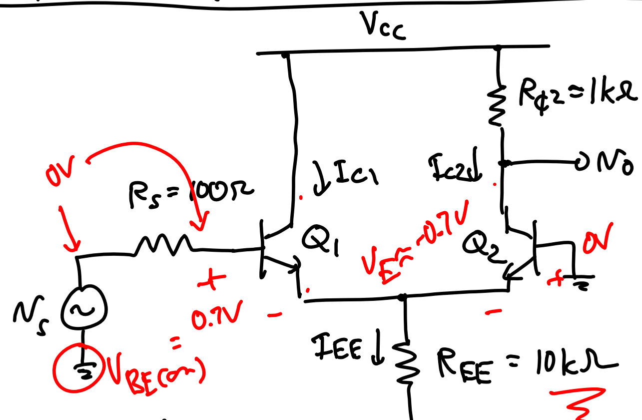
Inspection Analysis on a Multitransistor Ckt.



Assume: Q_1 & Q_2 identical

Do small-signal analysis to get: $R_i, R_o, A_v = \frac{v_o}{v_s}$

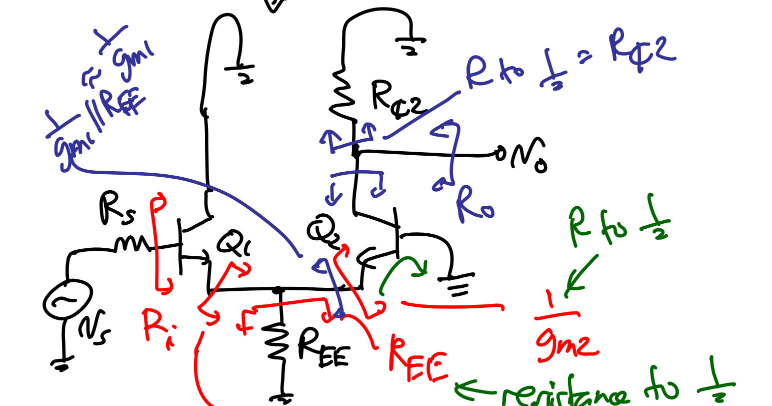
First: Get the DC operating pt.

$I_C = I_{C1} = I_{C2} = \frac{I_{EE}}{2}$ → determine S.S. parameters

$r_{\pi 1} = r_{\pi 2} = r_\pi = \frac{\beta}{g_m}$

$r_{o1} = r_{o2} = r_o = \frac{V_A}{I_C}$ $\quad g_{m1} = g_{m2} = g_m = \frac{I_C}{V_T}$

⇓ convert to AC ckt.



$R_i = r_{\pi 1} + (\beta+1)(?) = r_\pi + (\beta+1)\frac{1}{g_{m2}} = 2r_\pi = R_i$

$\frac{1}{g_{m2}} \| R_{EE} \approx \frac{1}{g_{m2}}$ $\quad r_{\pi 2}$

$R_{EE} \gg \frac{1}{g_{m2}}$

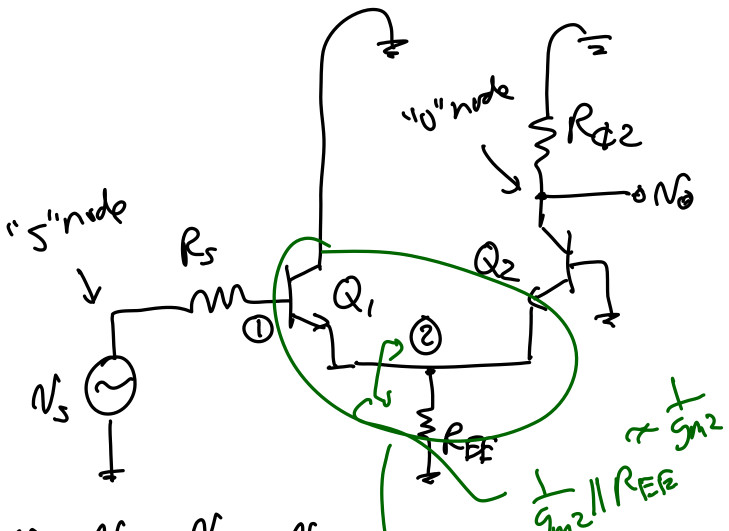
$\frac{1}{g_{m1}} + \frac{R_S}{(\beta+1)} \approx \frac{1}{g_{m1}}$

$R_o = R_{C2} \| r_{o2}\left(1 + \frac{g_{m2}\left(\frac{1}{g_{m1}}\right)}{1+0}\right) = (2r_{o2}) \| R_{C2}$

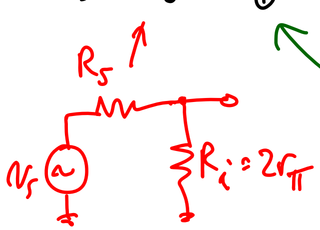
$R_B = 0$

$[r_{o2} \gg R_{C2}]$

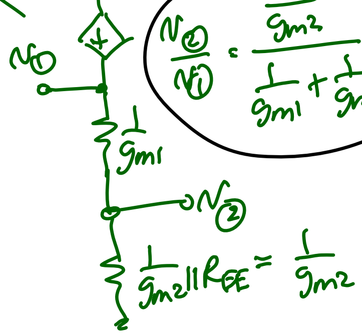
$\approx R_{C2}$



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



$$\frac{v_1}{v_s} = \frac{2r_\pi}{R_s + 2r_\pi}$$



$$\frac{v_2}{v_1} = \frac{\frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} = \frac{1}{2}$$

$$\frac{v_o}{v_2} = g_{m2}(2r_{o2} \| R_{L2}) \approx g_{m2} R_{L2}$$

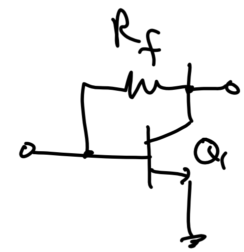
$[2r_{o2} \gg R_{L2}]$

$v_2 \rightarrow$ C.B.

$$A_v = \frac{v_o}{v_s} = \left(\frac{2r_\pi}{2r_\pi + R_s}\right)\left(\frac{1}{2}\right) g_{m2} R_{L2}$$

Inspection analysis <u>doesn't</u> always work!

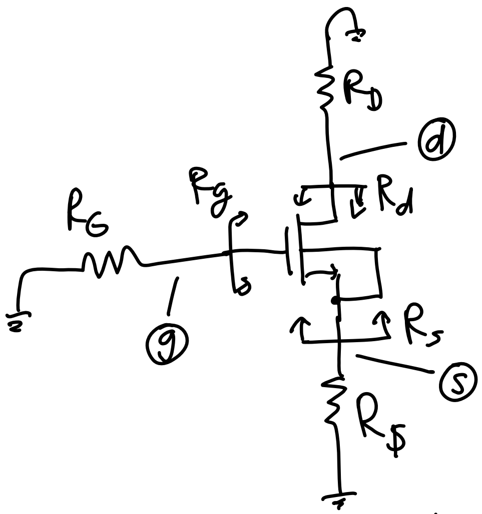
→ Ex. Feedback, e.g.,



$\boxed{\text{MOS Xsistor Ckt.}}$

⇒ for now, ignore Body effect (i.e., ignore g_{mb}) — achieved when source tied to bulk

→ use same inspection formulas as bipolar, but use $\beta \rightarrow \infty$, $r_\pi = \frac{\beta}{g_m} \rightarrow \infty$



⇒ referring to the "inspection formula sheet:"

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

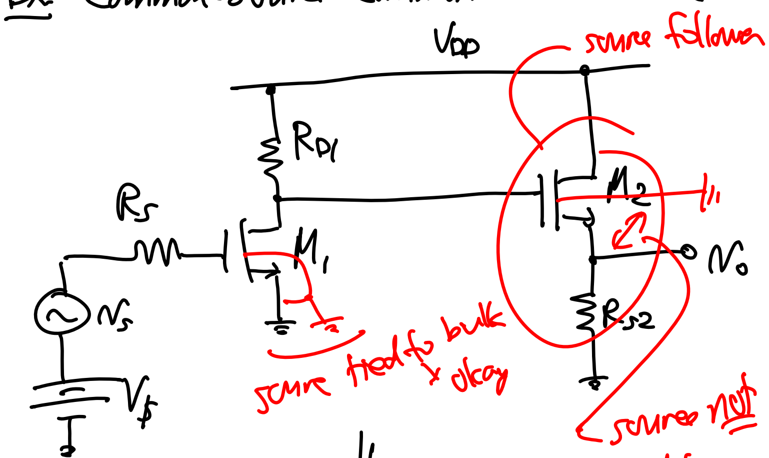
$$\frac{v_d}{v_g} = -G_mR_d\,,\quad G_m=\frac{g_m}{1+g_mR_S}$$

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

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

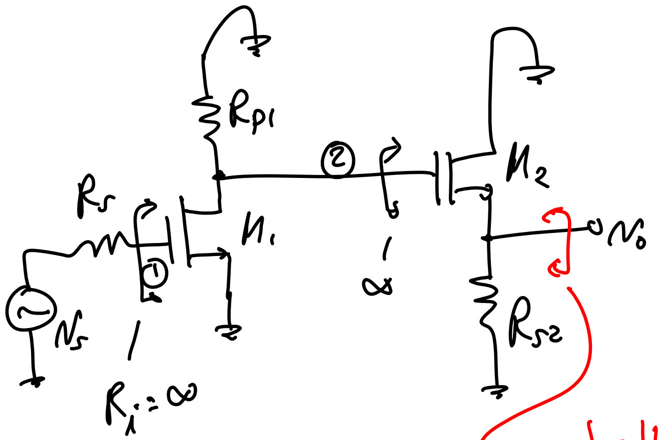
MOS Inspection Analysis

Ex. Common-Source Common-Drain Cascade



Want $R_i, R_o, A_v = \frac{v_o}{v_s}$ ⇓ S.S. Ckt.

can't use the inspect eqns!



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

$\approx \frac{1}{g_{m2}}$

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

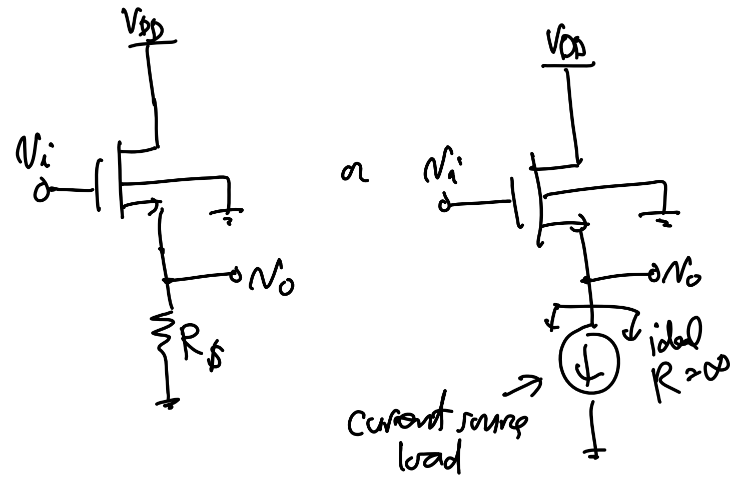
$$\frac{v_o}{v_s} = (1)(-g_{m1}R_{D1})\left(\frac{R_{S2}}{\frac{1}{g_{m2}} + R_{S2}}\right)$$

Problem: Simulate in SPICE → the gain will be from 80–90% of what this eqn. gives.

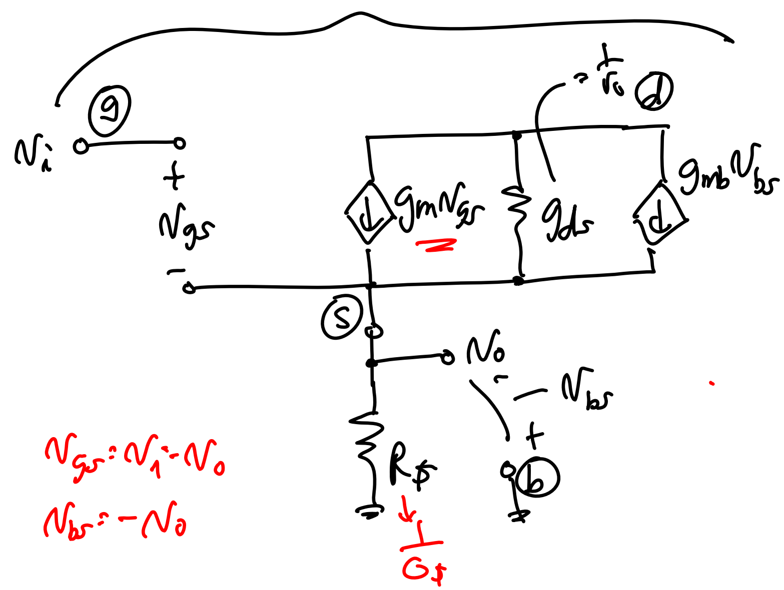
→ the problem is w/ g_{mb} in the source follower

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

Source Follower: (w/ substrate grounded)



⇓ Hybrid-π Model



$v_{gs} = v_i - v_o$

$v_{bs} = -v_o$

Apply KCL:

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

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

$R_s \to \infty \to G_s \to 0$

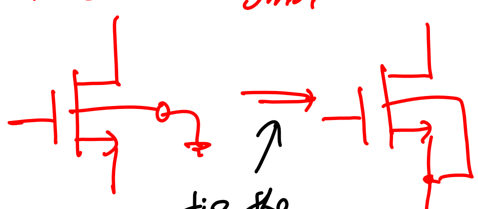
$g_{ds} \ll g_m + g_{mb}$

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

Body fact

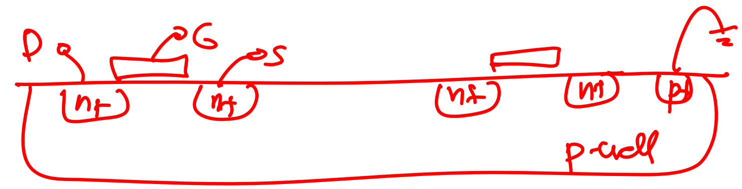
$\neq 1$ even when $R_s = \infty$.

To eliminate g_{mb}, do this!



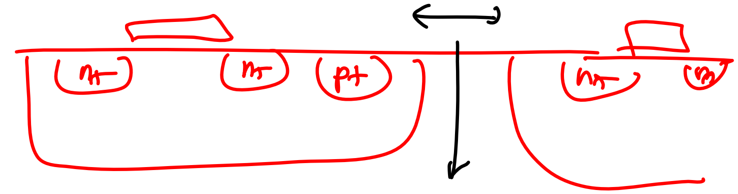
tie the bulk to the source → Unfortunately, can't do this all the time:

→ usually, have many MOS devices sharing a single well:



→ to tie bulk to source for a given device, the device would require its own well:

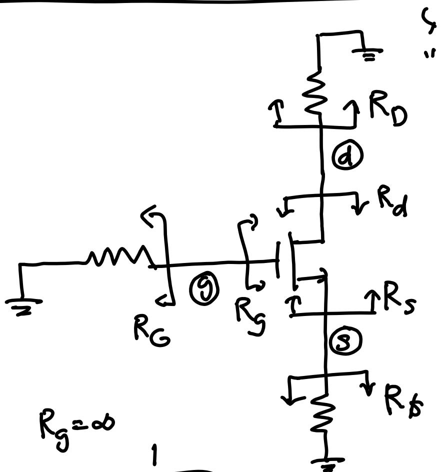
Must maintain a certain distance



Lot more area!

(and this is not good for cost!)

$\boxed{\text{MOS Inspection Formulas w/ Substrate Grounded}}$



"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 over 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, $g_{mb} = 0$.