Lecture 5: MOS Inspection Analysis

- **Announcements**:
- HW#2 already online and due next week on Wednesday at 8 a.m.
- EE 240A lecture increased again to accommodate all who want in
- Need to equalize labs, so go to the lab that is available if you still must get into the class
- If you still cannot get into the class, go and see Lydia in 205 Cory
- Room Change Verdict: 19 for 521 Cory, 12 for 289 Cory … in the end, we need 521 Cory, since it can properly fit the class
- Class accounts passed out
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- **Lecture Topics**:
  - Procedure for Small Signal Analysis
  - Inspection Formulas
  - 1-Tx Amplifier Example
  - Multi-Tx Amplifier Examples
  - MOS Inspection Analysis
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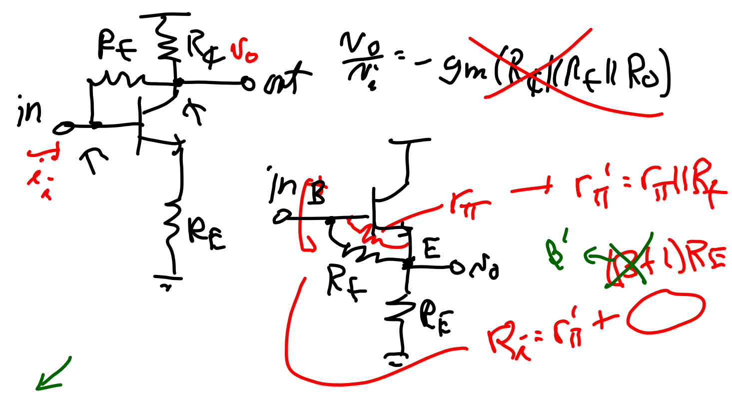
- **Last Time**:
- Small Signal Analysis procedure
- Continue with examples

over

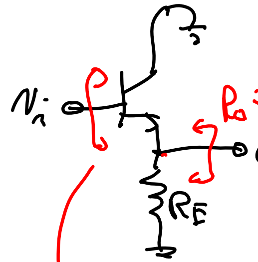
Procedure:

1. Find the DC operating point
   - Get all the voltages & currents at all nodes & branches, respectively
2. Determine S.S. parameters for devices in the *signal path* (e.g., g_m, r_π, r_o, …)
3. Convert the full circuit to the S.S. circuit
   - Zero out DC sources
   - Short out large capacitors (e.g., with values greater than nF's)
4. (a) If needed, replace transistor with its S.S. model (e.g., hybrid-π, T-model, …)
   - This should NOT be needed often!
   - When is it needed? → generally in cases where there is feedback



4. (b) Analyze by inspection based on prior S.S. analysis experience! (This should be 99% of the time.)

Ex. Common-Collector



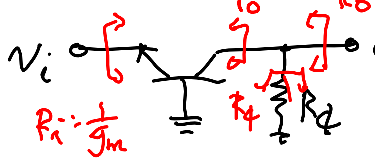
$R_o = \frac{1}{g_m} \| (r_o \| R_E) \approx \frac{1}{g_m} \| R_E$

$\frac{v_o}{v_i} = \frac{R_E}{r_e + R_E} = \frac{(\beta+1)R_E}{r_\pi + (\beta+1)R_E}$

$r_e = \frac{1}{g_m}$, $\quad r_\pi = \frac{\beta}{g_m}$

$R_i = r_\pi + (\beta+1)R_E$

Ex. Common-Base



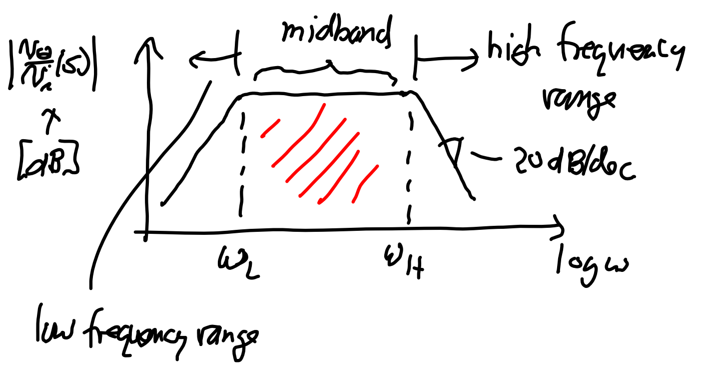
$R_o = r_o \| R_\ell \approx R_\ell$ $[r_o >> R_\ell]$

$R_i = \frac{1}{g_m}$

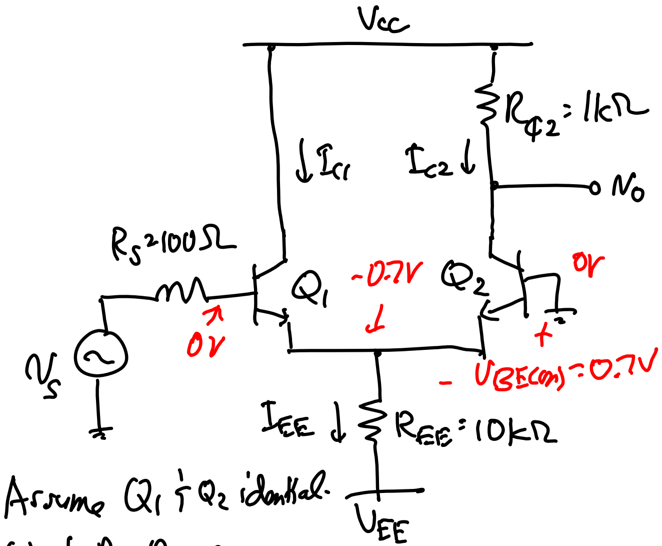
$\frac{v_o}{v_i} = g_m (r_o \| R_\ell) \approx g_m R_\ell$

⇒ so far, we've been focused on "midband" analysis

⇒ Bode plot: (for the discrete amp f/ last time)



Inspection Analysis of a Multi-Transistor Ckt.



Assume Q_1 & Q_2 identical.

Want R_i, R_o, gain.

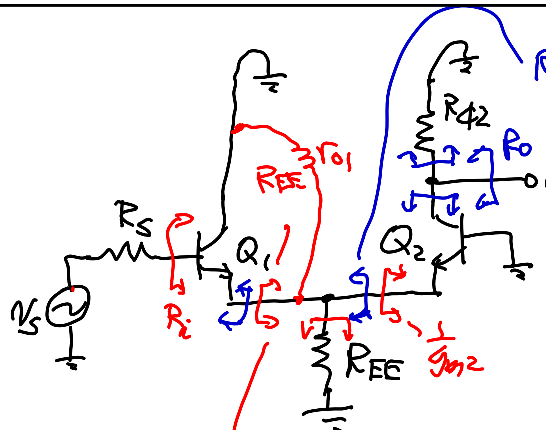
First, get the DC operating point.

$V_{BE1} = V_{BE2} \rightarrow V_{E1} = V_{E2} = -V_{BE(on)} = -0.7V$

$I_{EE} = \frac{-V_{BE(on)} - V_{EE}}{R_{EE}} \rightarrow I_{C1} = I_{C2} = \frac{I_{EE}}{2}$

$r_{\pi 1} = r_{\pi 2}$, $r_{o1} = r_{o2}$, $g_{m1} = g_{m2}$

⇓ S.S. AC Ckt.



$$R_{EE} \,\|\, \left(\frac{1}{g_{m1}} + \cancel{\frac{R_s}{(\beta+1)}}\right) \approx \frac{1}{g_{m1}}$$

neg.

$[\beta+1 \gg R_s]$

$$R_i = r_{\pi 1} + (\beta+1)\left(\frac{1}{g_{m2}} \,\|\, R_{EE} \,\|\, r_{o1}\right) = r_{\pi 1} + (\beta+1)\frac{1}{g_{m2}}$$

large $\gg \frac{1}{g_m}$

$[R_{EE} \gg \frac{1}{g_{m1}}]$

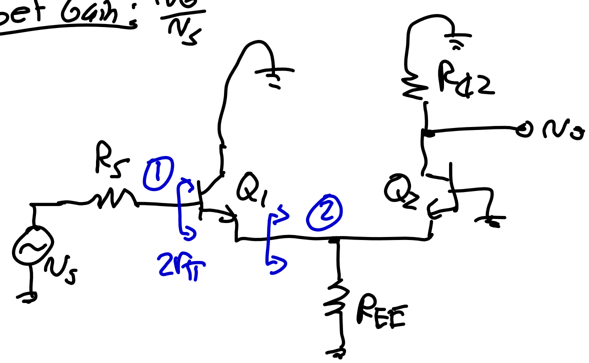
$$\boxed{R_i = r_{\pi 1} + r_{\pi 2} = 2r_\pi}$$

$$R_o = R_{c2} \,\|\, r_{o2}\left(\frac{1 + g_{m2}\left(\frac{1}{g_{m1}}\right)}{1 + 0}\right) = R_{c2} \,\|\, (2r_o)$$

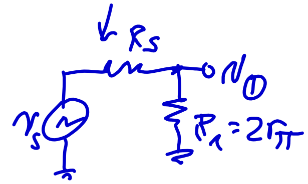
$[r_o \gg R_{c2}]$

$$R_o = R_{c2}$$

Get Gain: $\frac{v_o}{v_s}$

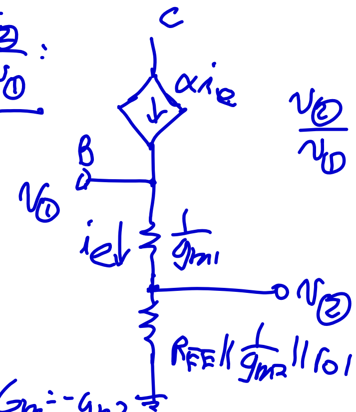


$$\frac{v_o}{v_s} = \frac{v_1}{v_s}\cdot\frac{v_2}{v_1}\cdot\frac{v_o}{v_2} = \boxed{\left(\frac{2r_\pi}{2r_\pi + R_s}\right)\left(\frac{1}{2}\right)\left(g_{m2}R_{c2}\right) = \frac{v_o}{v_s}}$$



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

$\frac{v_2}{v_1}$:



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

$[g_{m1} = g_{m2}]$

$$R_{EE} \,\|\, \frac{1}{g_{m2}} \,\|\, r_{o1} \approx \frac{1}{g_{m2}}$$

$$G_m = -g_{m2}$$

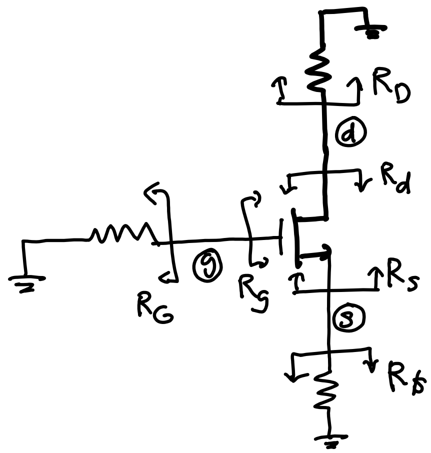
$[r_o \gg R_{c2}]$

$$\frac{v_o}{v_2} = -G_m R_o = +g_{m2}(2r_{o2} \,\|\, R_{c2}) \approx g_{m2}R_{c2}$$

MOS Xsistor Ckts

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

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



⇒ referring to the bipolar "inspection formula sheet":

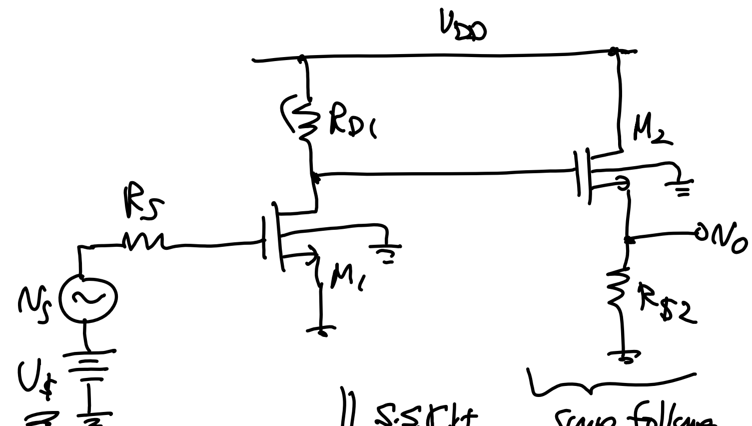
Bipolar		MOS
$R_b = \left(\frac{1}{g_m} + R_E\right)(\beta+1)$	$\xrightarrow{\beta\to\infty}$	$R_g = \infty$
$R_e = \frac{1}{g_m} + \frac{R_B}{\beta+1}$	$\xrightarrow{\beta\to\infty}$	$R_s = \frac{1}{g_m}$
$R_c = r_o\left[1 + \frac{g_m R_E}{1 + R_B/r_\pi}\right]$	$\xrightarrow[r_\pi\to\infty]{\beta\to\infty}$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

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

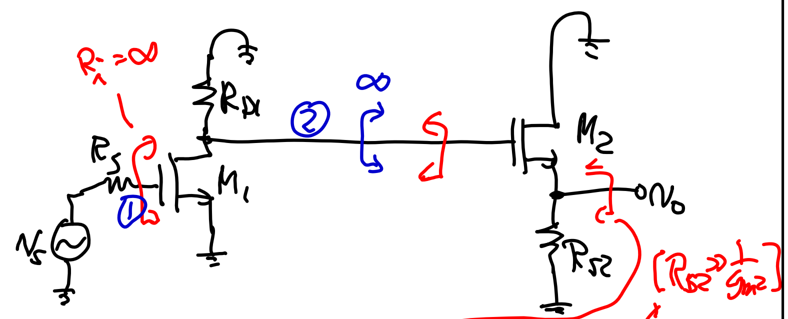
$$\frac{v_d}{v_s} = -G_m R_{ⓓ}, \quad G_m = -g_m$$

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

MOS Inspection Analysis



⇓ S.S. Ckt. source follower



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

$$\frac{v_o}{v_s} = \frac{v_{o1}}{v_s}\cdot\frac{v_{o2}}{v_{o1}}\cdot\frac{v_o}{v_{o2}}$$

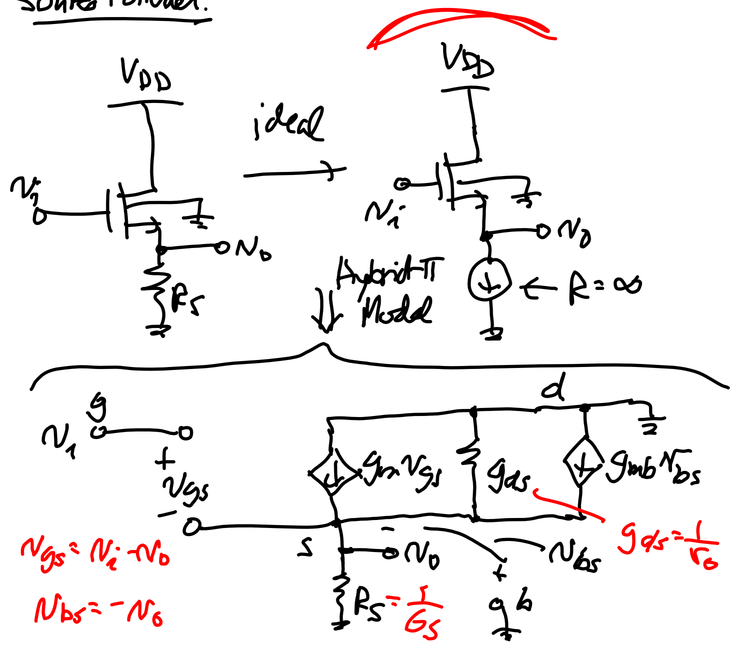
$$\boxed{= (1)(-g_{m1}R_{D1})\left(\frac{R_{S2}}{R_{S2}+\frac{1}{g_{m2}}}\right) = \frac{v_o}{v_s}}$$

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

the problem is we ignored g_{mb} (shouldn't do this for a source follower)

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

Source Follower:



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

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

$R_s = \infty \to G_s = 0$

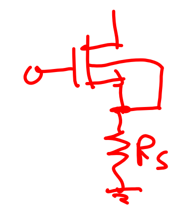
$g_{ds} \ll g_m + g_{mb}$

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

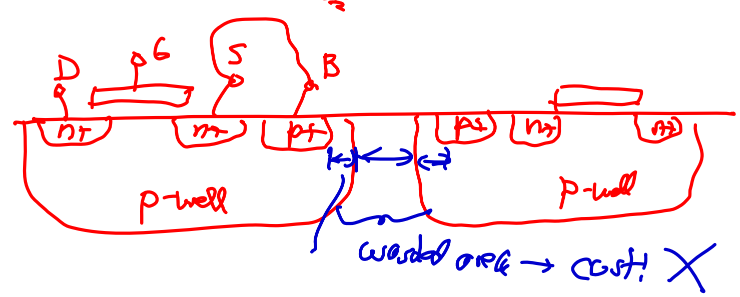
← Body factor

$\neq 1$

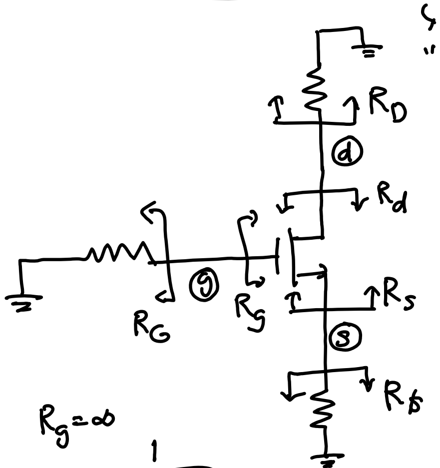
To make it '1', can do this:



⇒ not usually practical



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!

$R_g = \infty$

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

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

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

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

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

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

