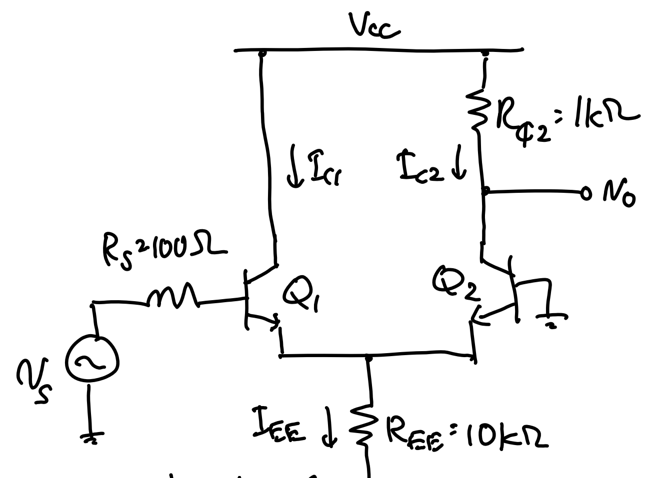
Lecture 5: MOS Inspection Analysis

- **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

↩ over

Inspection Analysis of a Multi-Transistor Ckt.



Assume Q_1 & Q_2 identical. V_{EE}

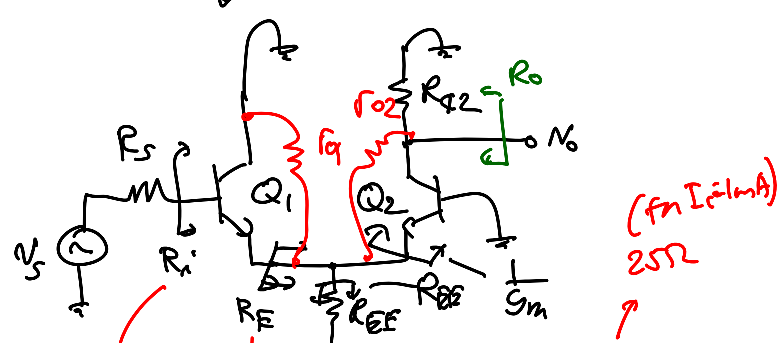
Want R_i, R_o, gain.

$I_{C1} = I_{C2} = \frac{I_{EE}}{2} \longrightarrow r_{\pi 1} = r_{\pi 2} = r_\pi$

$r_{o1} = r_{o2} = r_o$

$g_{m1} = g_{m2} = g_m$

S.S. Ckt. ⇓



$R_i = r_\pi + (\beta+1)(\,?\,) = r_\pi + (\beta+1)\left(\frac{1}{g_m} \| R_{EE}\right)$ *

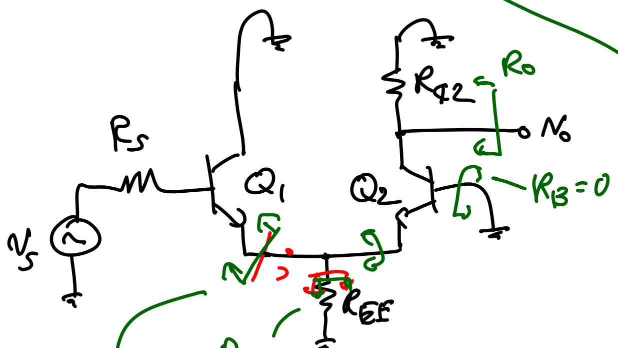
$R_i = r_\pi + (\beta+1)\left(\frac{1}{g_{m2}} \| r_{o2} \| R_{EE} \| r_{o1}\right)$

BIS! ~ 200kΩ; 25Ω

$R_i = r_\pi + (\beta+1)\frac{1}{g_m} \Rightarrow R_i = 2r_\pi$

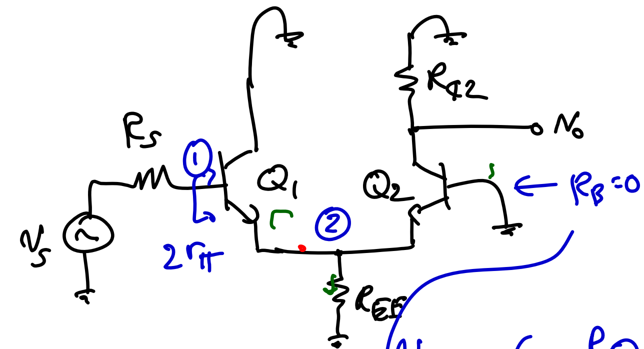
$R_{EE} \to$ usually large for good CMRR

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



$\frac{r_\pi + R_s}{\beta+1} = \frac{1}{g_{m1}} + \frac{R_s}{\beta+1}$; R_s = small $\to \sim \frac{1}{g_{m1}}$

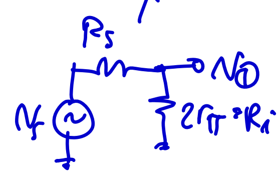
$(2r_{o2}) \| R_{C2} \approx R_{C2}$



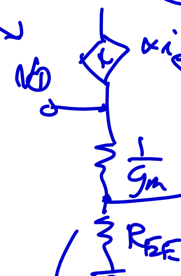
$\frac{v_o}{v_s} = \frac{v_1}{v_s} \cdot \frac{v_2}{v_1} \cdot \frac{v_o}{v_2}$

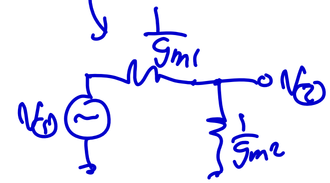
$\frac{v_o}{v_2} = -G_{m2} R_C = -(-g_{m2}) R_{C2}$

$\frac{v_o}{v_2} = g_{m2} R_{C2}$



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

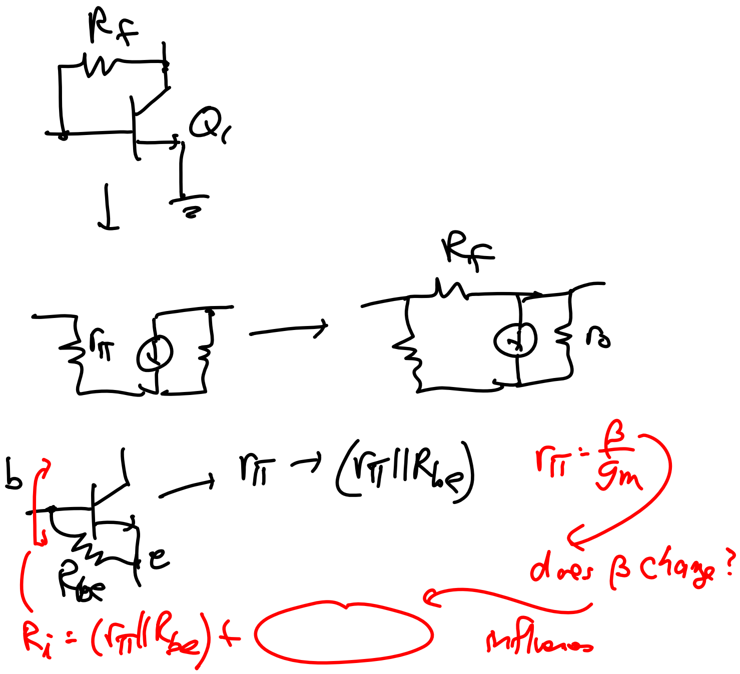




$\frac{v_2}{v_1} = \frac{1/g_{m2}}{\frac{1}{g_{m2}} + \frac{1}{g_{m1}}} = \frac{1}{2}$

$\frac{v_o}{v_s} = \frac{2r_\pi}{R_s + 2r_\pi} \cdot \frac{1}{2} \cdot g_{m2} R_C$

Inspection analysis might not work when you have feedback!

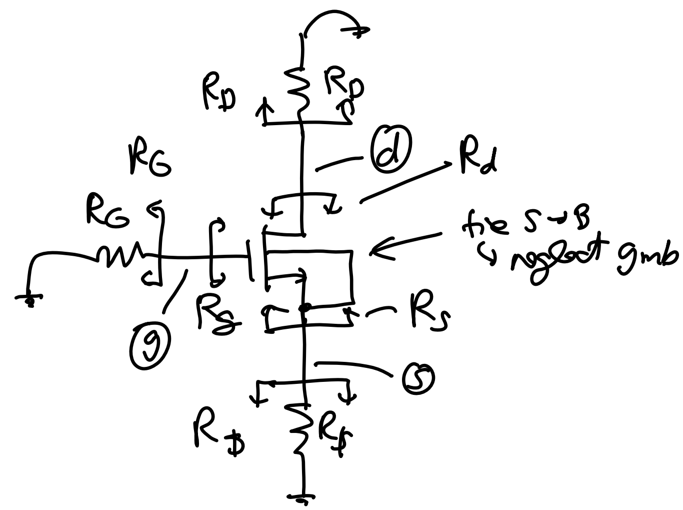


- Try to figure out whether or not there is a different beta and come up with an inspection formula for this case
- This will be discussed in discussion section, but try to come up with the solution on your own

MOS Xsistor Ckt.

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

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



⇒ refer to the "Inspection Formula Sheet" for bipolar:

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

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

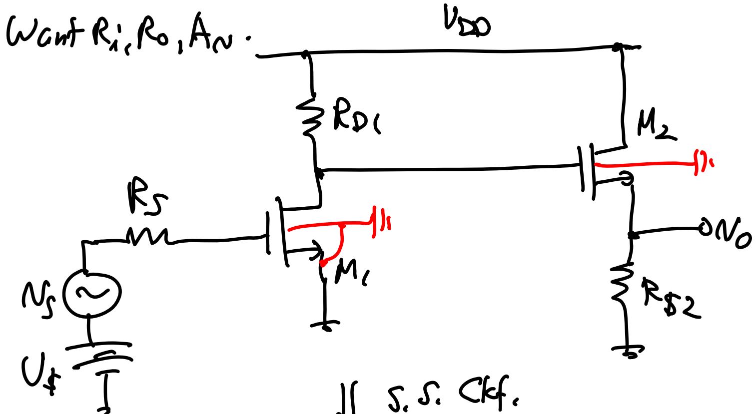
$$\frac{v_d}{v_s} = -G_m R_{d},\quad G_m = -g_m$$

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

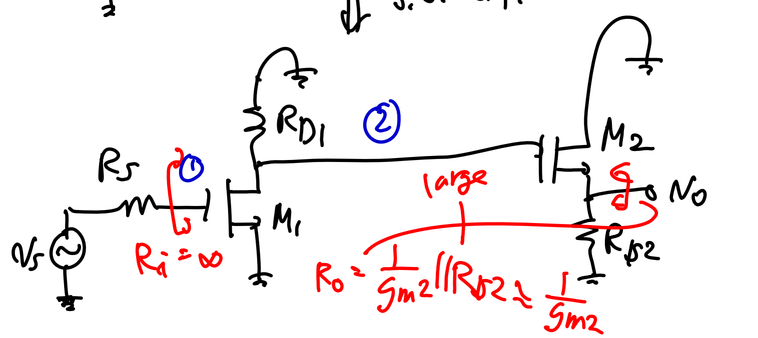
MOS Inspection Analysis

Ex. Common-Source Common-Drain Cascade

Want R_i, R_o, A_v.



⇓ S.S. Ckt.



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

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

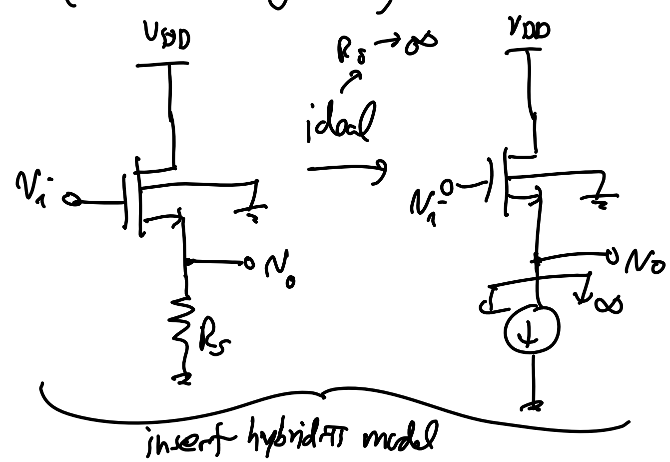
Problem: Simulate in SPICE → the gain will be from 80–90% of what we calculate using ↑

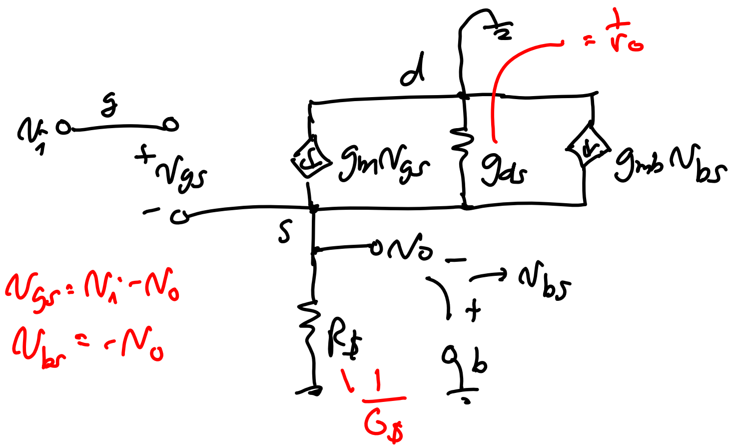
↳ the problem is that the g_{mb} was neglected when determining the source/follower gain

one difference between bipolar & MOS hybrid-π models

Source Follower:

(w/ substrate grounded)





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

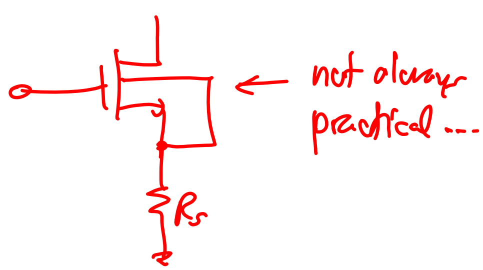
$\Rightarrow A_v = \frac{v_o}{v_i} = \frac{g_m}{g_m + g_{mb} + g_{ds} + G_s}$

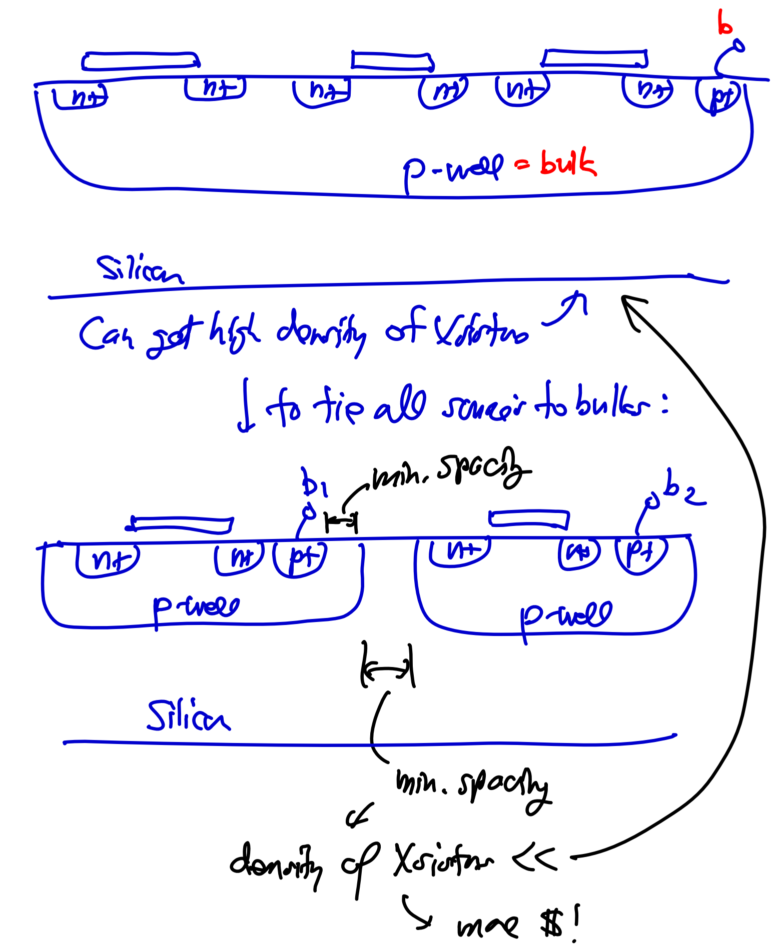
$R_s \to \infty \rightarrow G_s = 0$

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

$A_v \cong \frac{g_m}{g_m + g_{mb}} = \frac{1}{1+\eta}$, $\eta = \frac{\gamma}{2\sqrt{V_{SB} + 2\phi_F}}$ (Body factor)

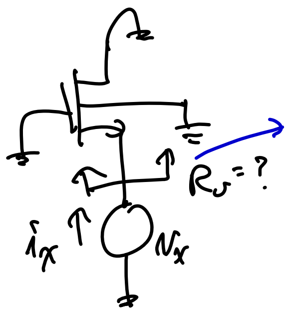
To make this = '1', do this:

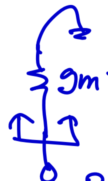




- For cost reasons, bulks are rarely tied to sources in circuits like followers or differential pairs
- So you need to be able to deal with the g_{mb}'s when doing small-signal analysis
- See the MOS inspection formulas at the end of this lecture

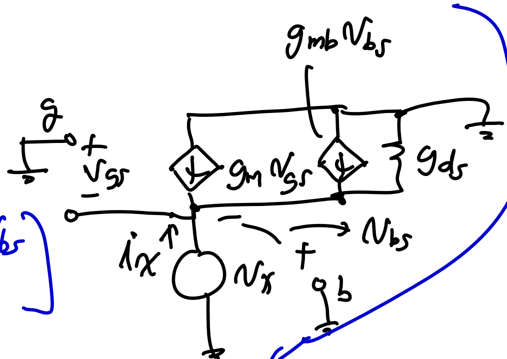
Effect of g_{mb}





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

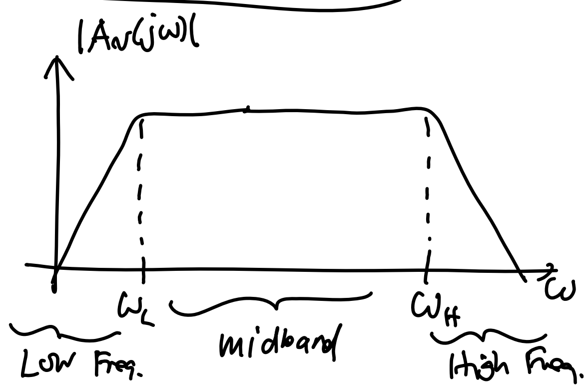
hybrid-π



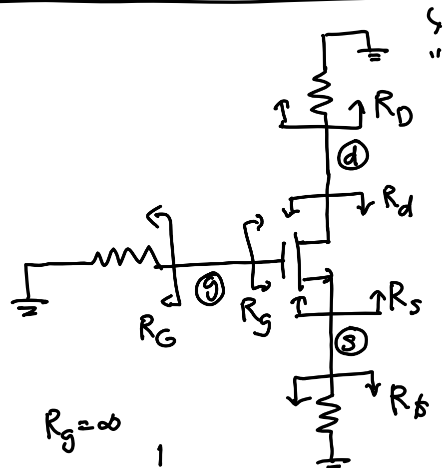
$$\begin{bmatrix} v_{gs} = -v_x = v_{bs} \\ v_{ds} = -v_x \end{bmatrix}$$

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

So far → focus on "midband":



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, $g_{mb} = 0$.