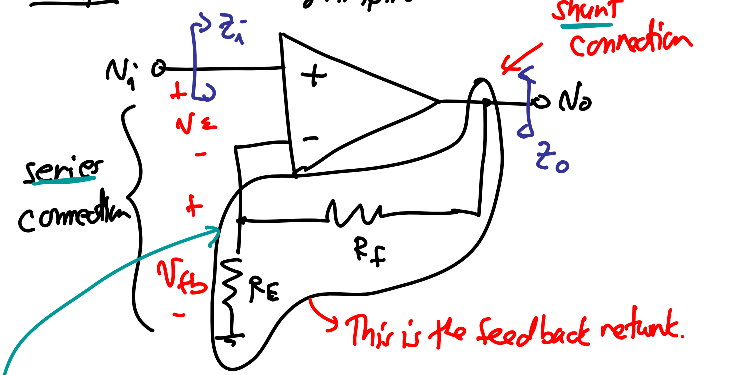
- **Announcements**:
  - HW#11 will be due Monday, 5/11, at 5 p.m., in the EE 140 box
  - Error in specification of problem 2 of HW#11. See email.
- **Today**:
  - Feedback loading (continued)
  - Example FB Analysis Procedure

Last Time -

Determine the FB Loading of an Amplifier

Example. Non-Inverting Amplifier

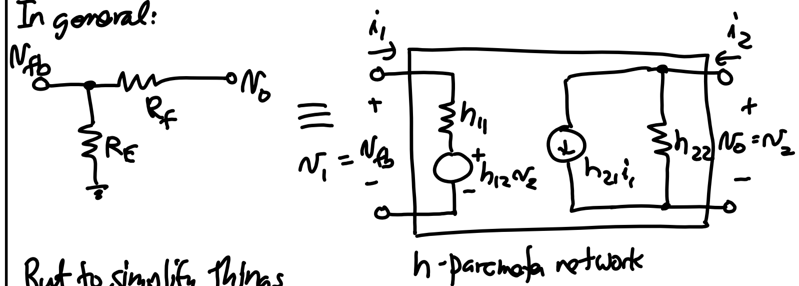


Objective: Use $A_o = \frac{a_v}{1+a_v f}$ to get A_o.

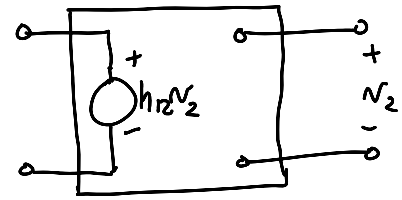
For FB loading @ output node, open this node.

In order to use this equation, we must know
(i) $a_v \triangleq$ gain of the amplifier
(ii) $f \triangleq$ gain of the feedback (also, called the feedback factor)

In general:

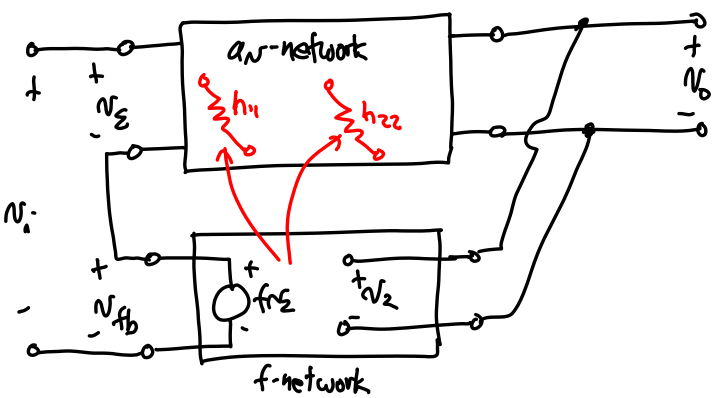


But to simplify things, we would like to be able to represent the feedback network by just:

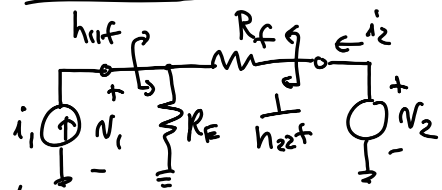


where: ① The small h_{21} is neglected.
② All impedances have been moved out of the f-network and moved to the a_v-network.

Pictorially:

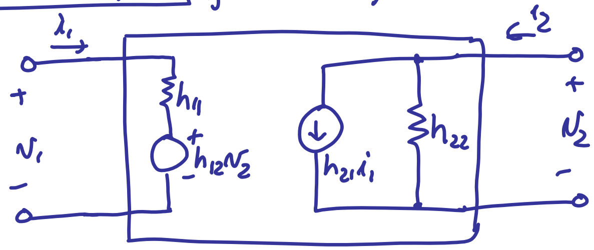


The FB Network: (find the h-parameter representation)



↳ we'll first get this, then we'll move its impedances to the a_v-network

h-parameter Network (just a reminder)



Port Equations:

$v_1 = h_{11}i_1 + h_{12}v_2$

$i_2 = h_{21}i_1 + h_{22}v_2$

Elements:

$h_{11} = \left.\frac{v_1}{i_1}\right|_{v_2=0}$ $h_{12} = \left.\frac{v_1}{v_2}\right|_{i_1=0}$

$h_{21} = \left.\frac{i_2}{i_1}\right|_{v_2=0}$ $h_{22} = \left.\frac{i_2}{v_2}\right|_{i_1=0}$

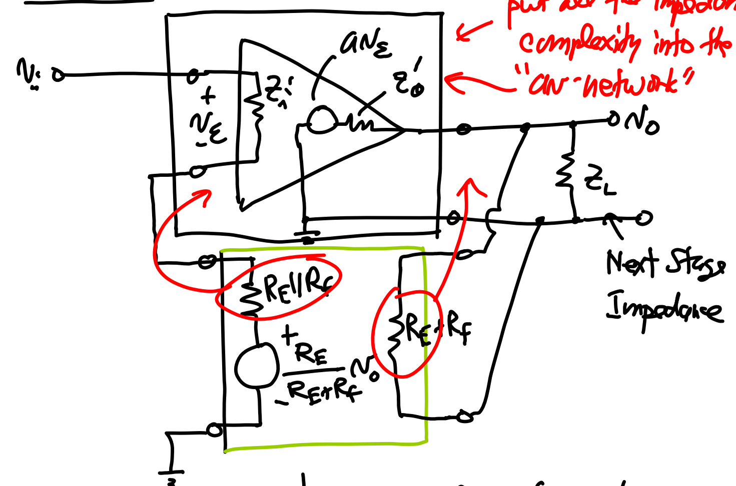
$h_{22f} = \left.\frac{i_2}{v_2}\right|_{i_1=0} = \frac{1}{R_E + R_F}$ (this is loading at port 2, i.e., the amplifier output port)

↑ This is a conductance.

$h_{12f} = \left.\frac{v_1}{v_2}\right|_{i_1=0} = \frac{R_E}{R_E + R_F} = f$ (feedback gain factor)

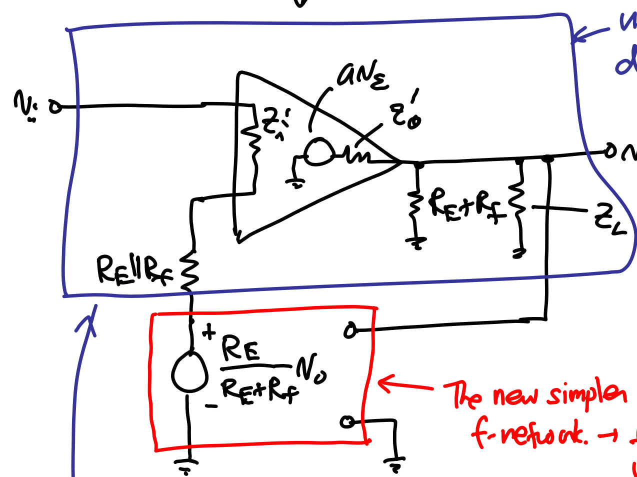
$h_{11f} = \left.\frac{v_1}{i_1}\right|_{v_2=0} = R_E \| R_F$ (this is loading at port 1, i.e., at the amplifier input port)

So we have:



put all the impedance complexity into the "a_v-network"

↓ Move the R's f/ the f-network

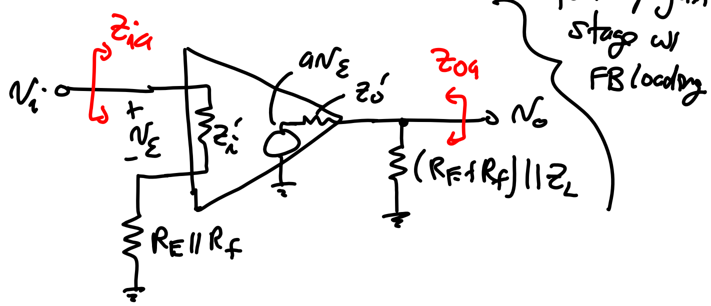


use this to determine a_v!

The new simpler f-network. → $f = \frac{R_E}{R_E + R_F}$

The new a_v-network → use this to determine a_v in $A_0 = \frac{a_v}{1 + a_v f}$

Determine the "a_v" gain:



$$v_o = a v_\varepsilon \left\{\frac{(R_E+R_F)\|Z_L}{(R_E+R_F)\|Z_L + z_o'}\right\} \; ; \; v_\varepsilon = v_i\left(\frac{z_i'}{z_i'+R_E\|R_F}\right)$$

$$\therefore \left.\frac{v_o}{v_i}\right|_{FB\ loading} = \left(\frac{z_i'}{z_i'+R_E\|R_F}\right) a \left(\frac{(R_E+R_F)\|Z_L}{(R_E+R_F)\|Z_L+z_o'}\right) = a_v$$

We know f: $f = \frac{R_E}{R_E+R_F}$

Get closed loop gain, A_o:

$$A_o = \frac{v_o}{v_i} = \frac{a_v}{1+a_v f} \simeq \frac{1}{f} = 1+\frac{R_F}{R_E}$$

(for a_v = large)

Must use this if a_v is not large.

What about R_i & R_o?

→ for the open-loop amplifier w/ FB loading:

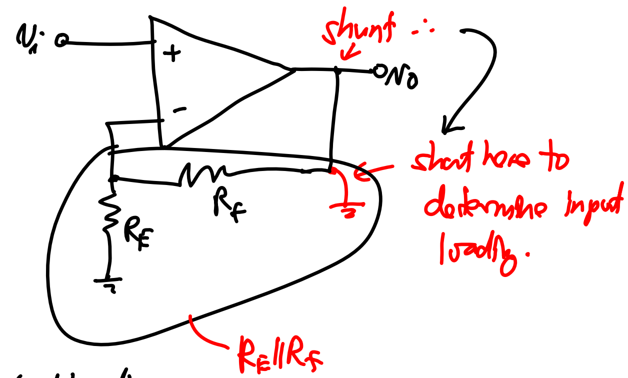
$Z_{ia} = z_i' + R_E\|R_F$ → $Z_i = (z_i'+R_E\|R_F)(1+a_v f)$

$Z_{oa} = z_o'\|(R_E+R_F)\|Z_L$ → $Z_o = \frac{z_o'\|(R_E+R_F)\|Z_L}{1+a_v f}$

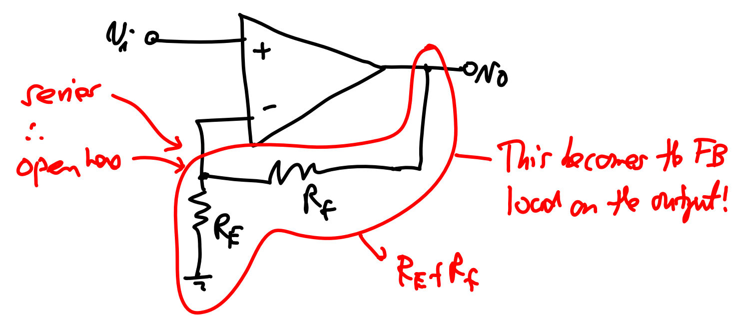
$$\omega_{-3dB}\big|_{closed\ loop} = \left[\omega_{-3dB}\big|_{open\text{-}loop\ w/\ FB\ loading}\right] \times (1+a_v f)$$

To determine loading by FB:

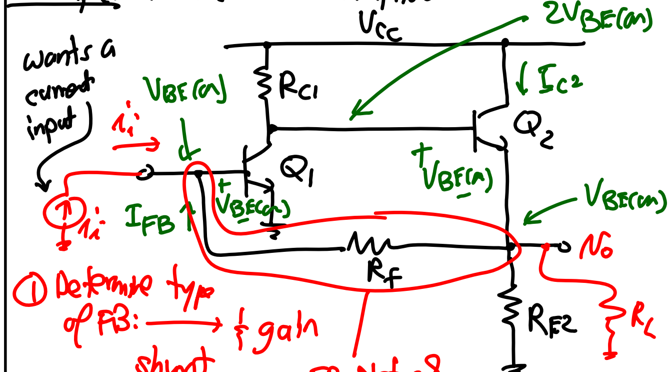
Input loading



Output loading:



Example: Transresistance Amplifier



① Determine type of FB: → ↑ gain
shunt
FB Network
shunt

② Biasing:

$I_{FB} = I_{B1}$ ← tiny ≈ 0 ← Note: Shouldn't do this if R_f is very large.

$I_{C2} \approx I_{E2} = \frac{V_{BE(on)}}{R_{E2}}$ $I_{C1} = \frac{V_{CC} - 2V_{BE(on)}}{R_{C1}}$

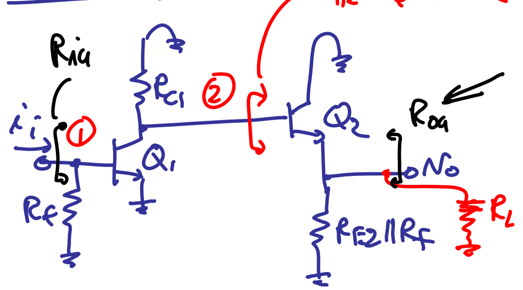
③ What kind of gain?

shunt-shunt FB → $i \to v$ gain

∴ we're looking for $R_m = \frac{v_o}{i_i} = \frac{r_m}{1 + r_m f}$
↑ Ω

④ Determine r_m:

$r_{\pi 2} + (\beta+1)(R_{E2} \| R_f \| R_L)$



Get Gain: $\frac{v_o}{i_i} = \frac{v_①}{i_i} \cdot \frac{v_②}{v_①} \cdot \frac{v_o}{v_②} = \frac{v_o}{i_i}\Big|_{OL\ w/FB\ loading} = r_m$

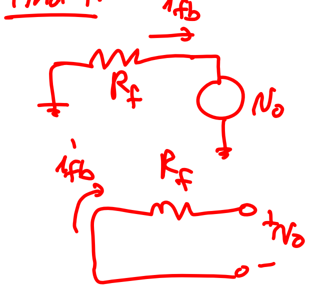
$v_① = i_i (r_{\pi 1} \| R_f) \rightarrow \frac{v_①}{i_i} = r_{\pi 1} \| R_f$

$\frac{v_②}{v_①} = -g_{m1}\left(R_{C1} \| [r_{\pi 2} + (\beta+1)(R_{E2} \| R_f \| R_L)]\right)$

$\frac{v_o}{v_②} \approx 1$

$r_m = \frac{v_o}{i_i}\Big|_{OL\ w/FB\ loading} = -g_m (r_{\pi 1} \| R_f)[R_{C1} \| (\quad)] = r_m$

Find f:



$f = \frac{i_{fb}}{v_o} = -\frac{1}{R_f}$

Thus: $T = r_m f = (-g_{m1}(r_\pi \| R_f)[R_C \| (\quad)])\left(-\frac{1}{R_f}\right)$ ← large

$T \approx g_{m1} R_{C1} \left(\frac{r_\pi \| R_f}{R_f}\right)$

⑤ Finally, get all parameters:

$R_m = \frac{r_m}{1 + r_m f} \approx \frac{1}{f} = -R_f \Rightarrow \boxed{R_m = -R_f}$

↑ if $r_m f$ = large

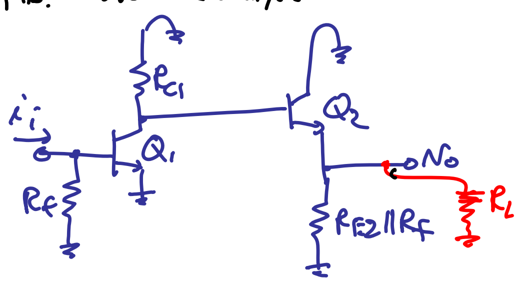
$$R_i = \frac{R_{ia}|_{w/FB\ loading}}{1 + r_m f} = \frac{r_\pi \| R_f}{1 + g_{m1} R_{C1} \frac{(r_\pi \| R_f)}{R_f}} \approx R_i$$

large ∴ this ≈ tiny

$$R_o = \frac{R_{oa}|_{w/FB\ loading}}{1 + r_m f} = \frac{\frac{r_{\pi 2} + R_{C1}}{\beta + 1} \| R_{E2} \| R_f \| R_L}{1 + g_{m1} R_{C1} \frac{(r_\pi \| R_f)}{R_f}} \approx R_o$$

Find ω_{-3dB}:

① Find the ω_{-3dB} of the open-loop amplifier w/ FB loading, i.e., of this: → use OCTC analysis



② Multiply by $(1+T)$:

$$\omega_{-3dB}|_{closed\text{-}loop} = (1+T) \times \omega_{-3dB}|_{OL\ w/\ FB\ loading}$$