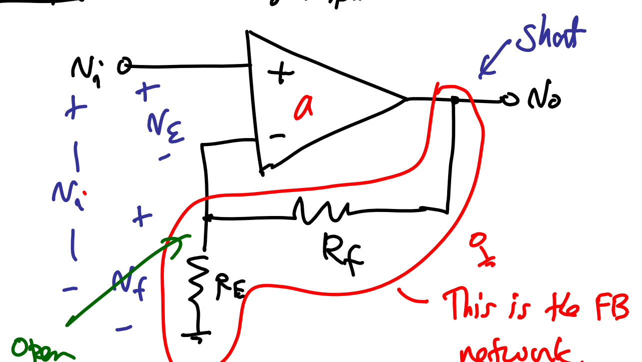
Lecture 27: Feedback By Inspection

- **Announcements**:
  - Lab#3 (your project) due on Friday, May 4, at 6 p.m., in the EE140 box
  - Passed out Feedback Inspection Handout (last time) but covered it today
  - Passed out Final Information Sheet and sample Final Exams (from 2009 & 2011)
- **Lecture Topics**:
  - Feedback Loading
  - Open-Loop Amp w/ Feedback Loading
  - Feedback By Inspection
  - Final Exam Info & Course Wrap Up
- -------------------------------------
- **Last Time**: Open-Loop Amp w/ Feedback Loading

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.

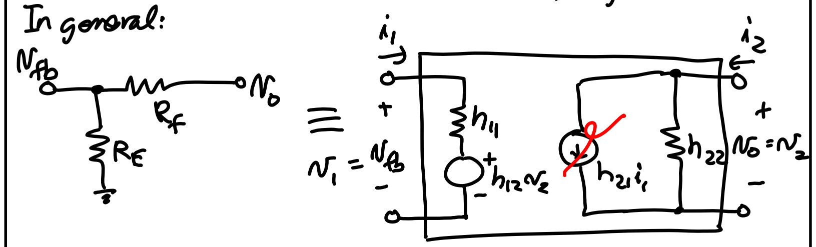
(closed loop gain; open-loop gain; feedback factor)

In order to use this equation, we must know

(i) $a_v \triangleq$ gain of the amplifier

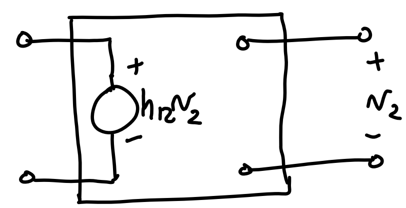
(ii) $f \triangleq$ gain of the feedback (also called the feedback factor)

In general:



h-parameter network

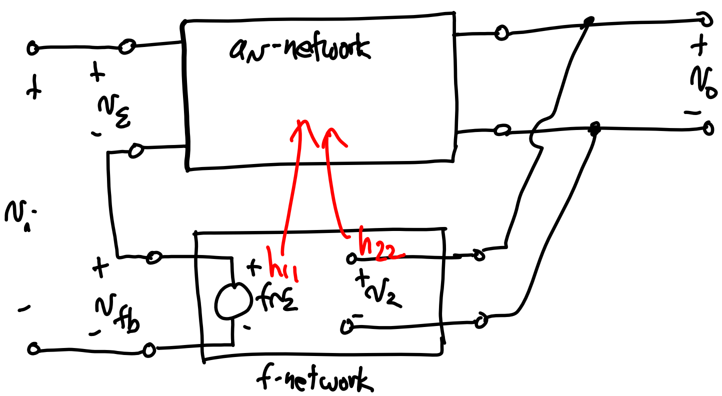
But to simplify things, we would like to be able to represent the feedback network by just:



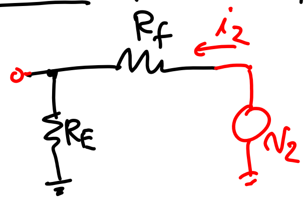
Where: ① The small h_{21} is neglected.

② All impedances have been moved out of the f-network and moved to the a_v-network.

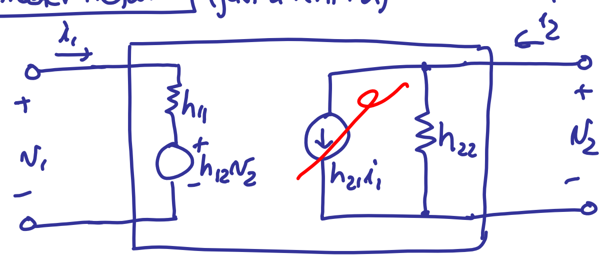
Pictorially:



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



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:

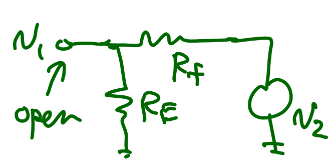
$h_{11} = \frac{v_1}{i_1}\Big|_{v_2=0}$ $\quad h_{12} = \frac{v_1}{v_2}\Big|_{i_1=0}$

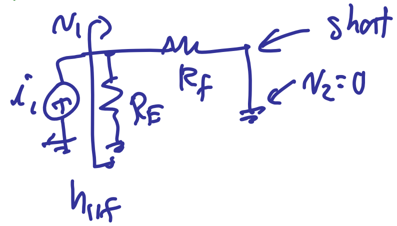
$h_{21} = \frac{i_2}{i_1}\Big|_{v_2=0}$ $\quad h_{22} = \frac{i_2}{v_2}\Big|_{i_1=0}$

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

↑ This is a conductance.

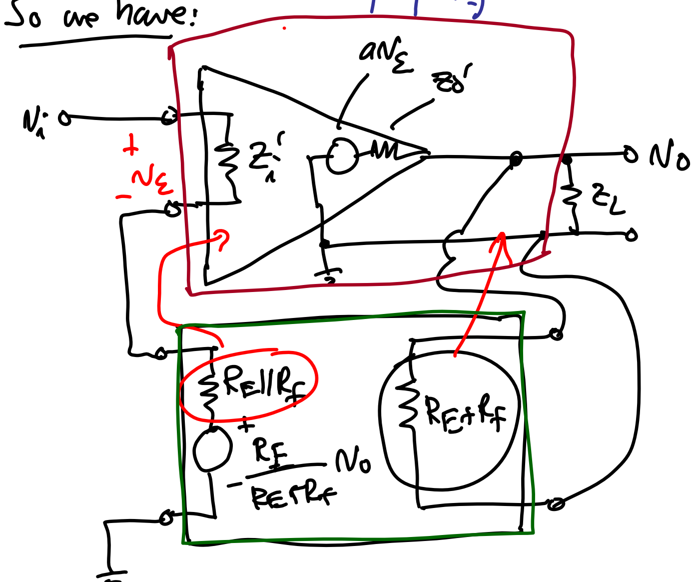
$h_{12f} = \frac{v_1}{v_2}\Big|_{i_1=0} = \frac{R_E}{R_E+R_F} = f$ (feedback gain factor)

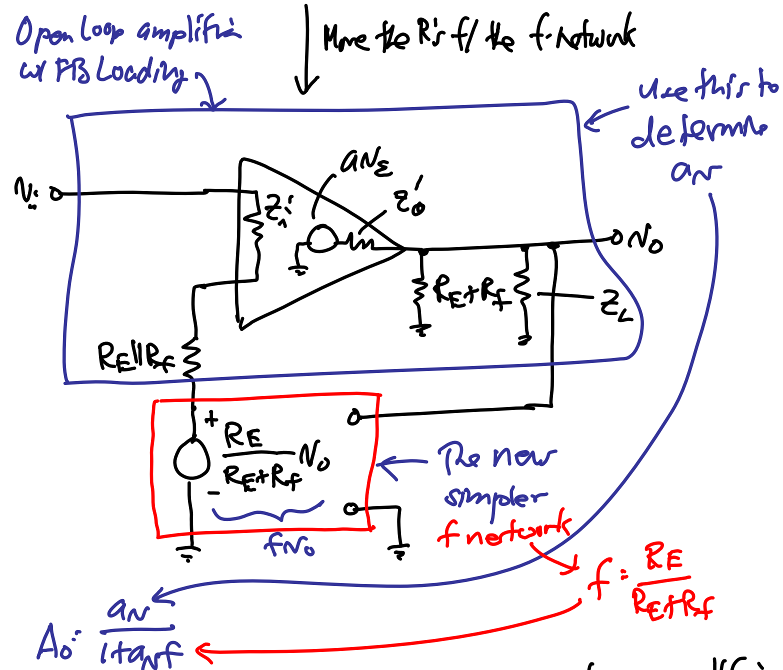




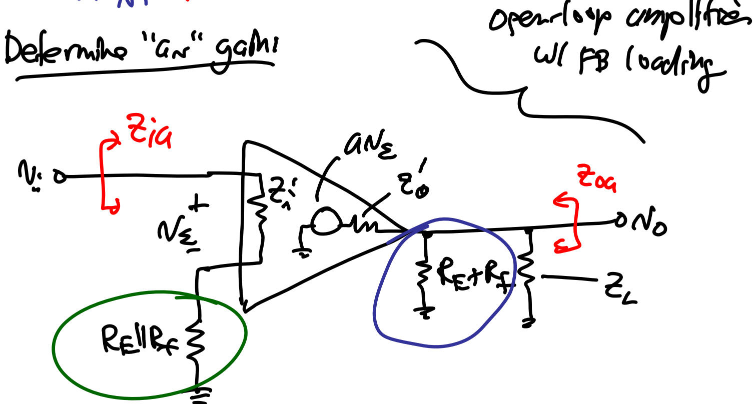
$h_{11f} = \frac{v_1}{i_1}\Big|_{v_2=0} = R_E \| R_F$ (This is the loading at port 1, i.e., at the amplifier's input port)

So we have:





Determine "a_v" gain:



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

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

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

Get closed-loop gain, A_o: (for a_v = large)

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

Must use this ($\frac{a_v}{1+a_v f}$) if a_v not large.

What about R_i & R_o?

⇒ For the open-loop amp w/ FB loading:

$z_{ia} = z_i' + R_E\|R_F$ —series→ $z_i = (z_i' + R_E\|R_F)(1+a_v f)$

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

What about ω_{-3dB}?

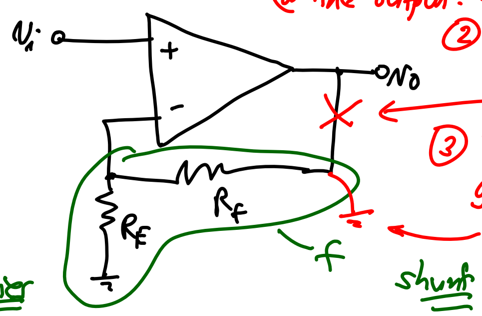
$$\omega_{-3dB}\big|_{closed\text{-}loop} = \left[\omega_{-3dB}\big|_{open\,loop\,amp\,w/\,FB\,loading}\right] \times (1+a_v f)$$

- Go through the "Inspection Analysis of Feedback Circuits" handout
- In the end, if one can determine the open loop gain with FB loading and feedback factor, then the rest of the problem becomes simple
- Study the table in the handout

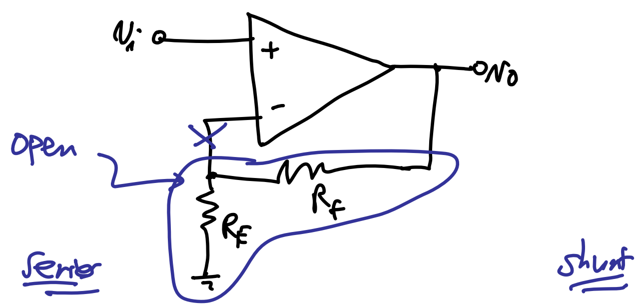
To determine loading by FB:

Input loading:

① Determine the feedback type @ the output. (Here, it's shunt.)
② Break the loop @ the output.
③ For shunt, ground the loose end. (If series, open it.)

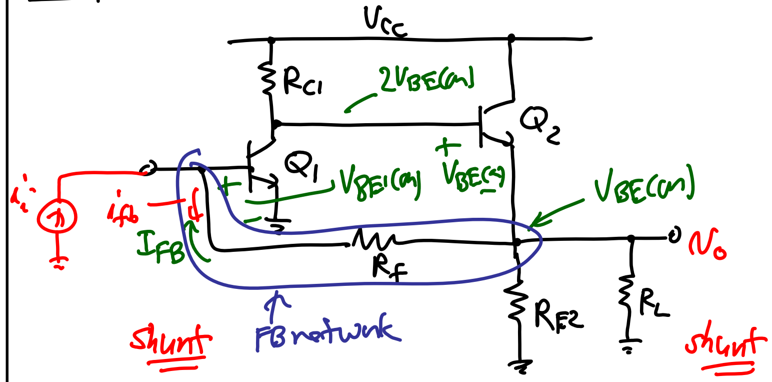


Output loading:



① Determine the feedback type @ the input. (Here, it's series.)
② Break the loop @ the input.
③ For series, open the loose end. (If shunt, short it.)

Example. Transresistance Amplifier



① Determine type of FB: → determines type of gain

② Biasing:

$I_{FB} = I_{B1}$ ← for $v_{in} \approx 0$ ← Note: Don't do this if R_f = large

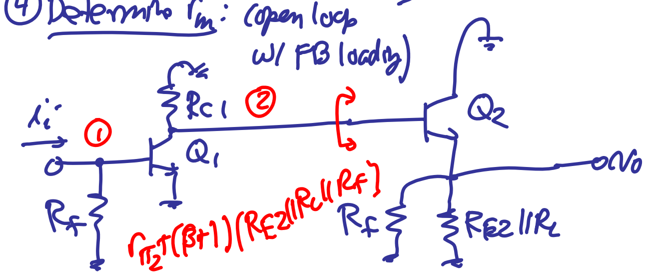
$I_{C2} \approx I_{E2} = \frac{V_{BE(on)}}{R_{E2}||R_L}$; $I_{C1} = \frac{V_{CC} - 2V_{BE(on)}}{R_{C1}}$

③ What kind of gain?

shunt-shunt FB → i→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: (open loop w/ FB loading)



Get Gain:

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

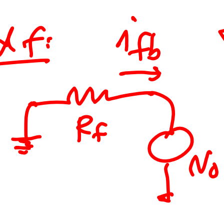
$$v_1 = i_i(r_\pi \| R_f) \rightarrow \frac{v_1}{i_i} = r_\pi \| R_f$$

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

$$\frac{v_o}{v_2} \approx 1$$

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

Find f:



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

Thus:

$$T = r_m f = \left(-g_{m1}(r_\pi \| R_f)\left[R_{C1} \| (\ \overset{\text{large}}{\downarrow}\ )\right]\right)\left(-\frac{1}{R_f}\right)$$

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

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 $r_m f \gg 1$]

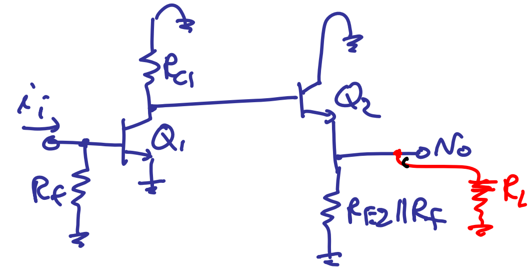
$$R_i = \frac{R_{ia}|_{w/\ FB\ loading}}{1 + r_m f} = \frac{r_\pi \| R_f}{1 + g_{m1} R_{C1}\frac{(r_\pi \| R_f)}{R_f}} = R_i$$

large ∴ this = tiny

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

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):

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

- What's next?
- EE 240: Advanced Analog Integrated Circuits
- Analysis and optimized design of integrated analog systems and building blocks. Specific topics include operational and wide-band amplifiers, gain-bandwidth and power considerations, analysis of noise in integrated circuits, low noise design, feedback, precision passive elements, analog switches, comparators, CMOS voltage references, non-idealities such as matching and supply/IO/substrate coupling. The course will include a significant design project applying the techniques taught in class to implement the analog front-end of a high-speed serial link.
- EE 142: Integrated Circuits for Communication
- Analysis and design of electronic circuits for communication systems, with an emphasis on integrated circuits for wireless communication systems. Analysis of noise and distortion in amplifiers with application to radio receiver design. Power amplifier design with application to wireless radio transmitters. Radio-frequency mixers, oscillators, phase-locked loops, modulators, and demodulators.
- EE C245: Introduction to MEMS
- Physics, fabrication, and design of micro-electromechanical systems (MEMS). Micro and nanofabrication processes, including silicon surface and bulk micromachining and non-silicon micromachining. Integration strategies and assembly processes. Transduction strategies and mechanical circuits. Electronic position-sensing circuits and electrical and mechanical noise. CAD for MEMS. Design project is required.