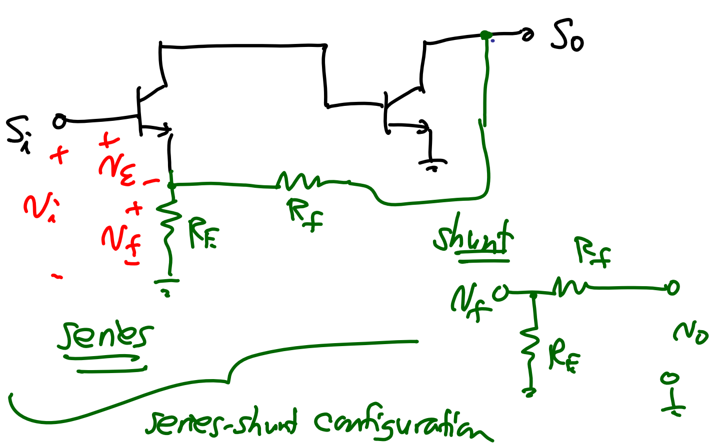
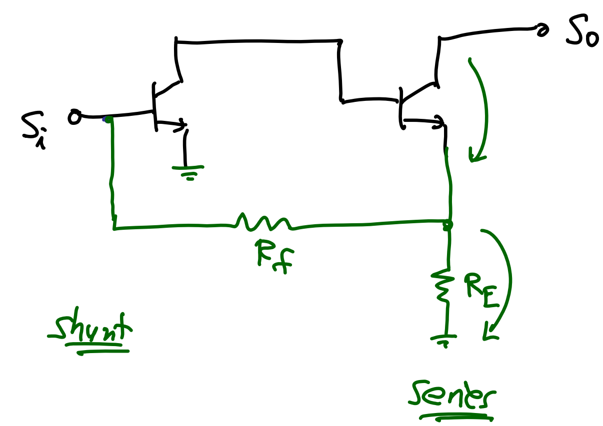
Lecture 26w: Feedback Z and Loading

- **Announcements**:
- This lecture will be 2 hours (2nd lecture to make up for missing Thursday)
- Video of last half hour will be posted
- HW#12 online and due Tuesday, next week
- Lab#3 (your project) due on Friday, May 10, at 5 p.m. in the EE140/240A Homework Box
- Passed out Feedback Inspection Handout
- Pre-Lecture on Feedback Loading online
- **Lecture Topics**:
  - Effect of FB on Z_i and Z_o
  - Feedback Loading
  - Open-Loop Amp w/ Feedback Loading
  - Feedback By Inspection
- --
- **Last Time**:
- Recognizing feedback configurations





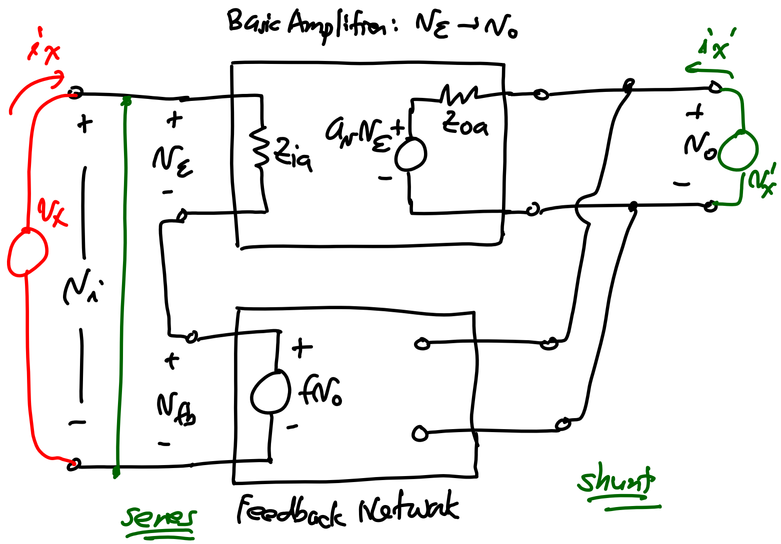
Feedback Configurations

Input: Variable	Input: Connection	Output: Connection	Output: Variable
(Z↑) voltage	series	series	current (Z↑)
(Z↓) current	shunt	shunt	voltage (Z↓)

Effect of FB on Z_i & Z_o

Ex. Series-Shunt FB

Assumption: FB network has ideal impedances
↳ i.e., it does not load the basic amplifier



Find the T.F. -

$$\left.\begin{array}{l} v_o = a_v v_\varepsilon \\ v_\varepsilon = v_i - v_{fb} \\ v_{fb} = f v_o \end{array}\right\} \quad v_o = a_v(v_i - f v_o) \Rightarrow \boxed{\frac{v_o}{v_i} = \frac{a_v}{1 + \underbrace{a_v f}_{\text{loop gain}}}} \text{ (as expected)} \quad \checkmark$$

Find $Z_i = \dfrac{v_x}{i_x}$:

$$v_x = v_\varepsilon + v_{fb}$$

$$= v_\varepsilon + f v_o = v_\varepsilon + a_v f v_\varepsilon = v_\varepsilon(1 + a_v f)$$

$$i_x = \frac{v_\varepsilon}{Z_{ia}}$$

$$Z_i = \frac{v_x}{i_x} = \frac{v_\varepsilon(1 + a_v f)}{\frac{v_\varepsilon}{Z_{ia}}} = \boxed{Z_{ia}(1 + \underbrace{a_v f}_{\text{loop gain!}}) = Z_i}$$

∴ when use series connection @ input } Input impedance raised by $(1 + a_v f)$!

↳ makes for a better voltage amplifier!

Find $Z_o = \dfrac{v_x'}{i_x'}$ (w/ input shorted)

$$v_\varepsilon + v_{fb} = 0 = v_\varepsilon + f v_x' \rightarrow v_\varepsilon = -f v_x' \qquad \text{shunt}$$

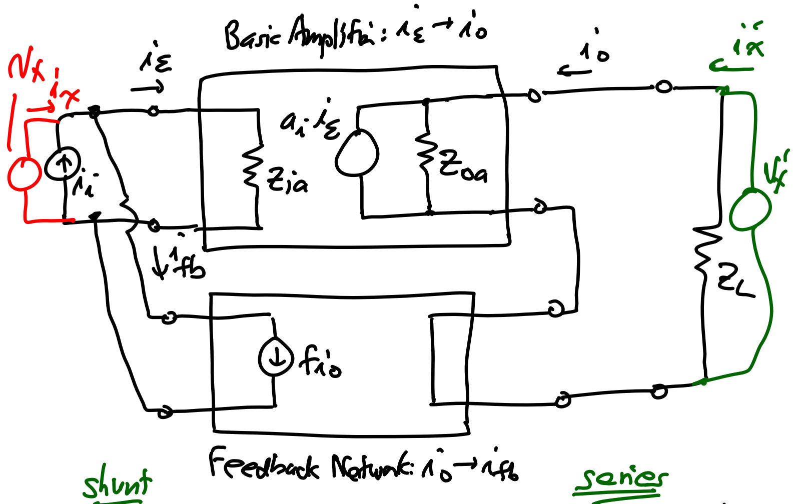
$$i_x' = \frac{v_x' - a_v v_\varepsilon}{Z_{oa}} = \frac{v_x' + a_v f v_x'}{Z_{oa}} \Rightarrow \frac{v_x'}{i_x'} = \boxed{\frac{Z_{oa}}{1 + \underbrace{a_v f}_{\text{loop gain!}}} = Z_o}$$

Output impedance lowered by a factor of $(1 + a_v f)$! } again, makes for a better voltage amplifier!

Overall, series-shunt FB improves the characteristics of a $v \to v$ amplifier: $z_i \uparrow$, $z_o \downarrow$ due to FB

Ex. Shunt-Series FB

⇒ Again, assume the FB network does not load the amplifier



Find the T.F. –

$i_o = a_i i_\varepsilon$

$i_\varepsilon = i_i - i_{fb} = i_i - f i_o$

$$\boxed{\frac{i_o}{i_i} = \frac{a_i}{1 + \underbrace{a_i f}_{\text{loop gain}}}}$$

current gain

This is a universal form.

Find $z_i = \frac{v_x}{i_x}$:

$$\boxed{\frac{v_x}{i_x} = \frac{z_{ia}}{1 + \underbrace{a_i f}_{\text{loop gain}}} = z_i}$$

shunt

⇒ Again, a shunt connection reduces the impedance by $(1 + a_i f)$!

Find $z_o = \frac{v_x'}{i_x'}$:

$$\frac{v_x'}{i_x'} = \boxed{z_{oa}(1 + a_i f) = z_o}$$

series connection raises the impedance by $(1 + a_i f)$!

everything together makes for a better $i \to i$ amplifier when using shunt-series FB!

Summary:

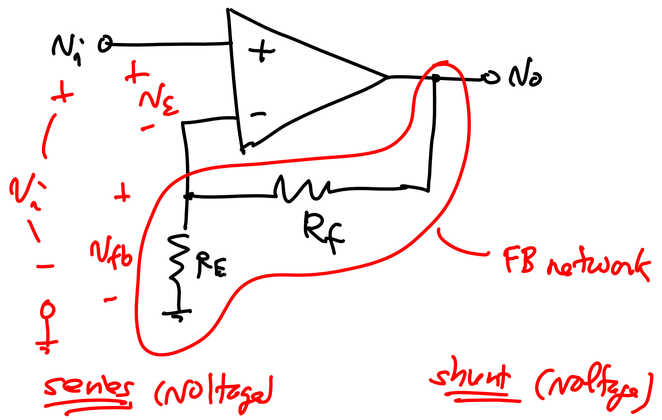
T = loop gain

① series connection: $z \to z(1+T)$

② shunt connection: $z \to \frac{z}{1+T}$

Determine the FB Loading of an Amplifier

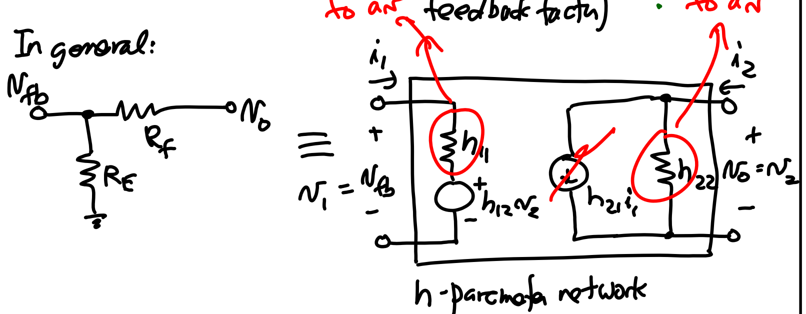
Example. Non-Inverting Amplifier



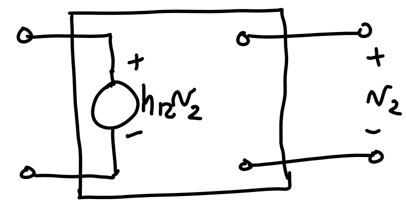
Objective: Use $A_0 = \frac{a_v}{1+a_v f}$ to get A_0. ← closed loop gain

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:

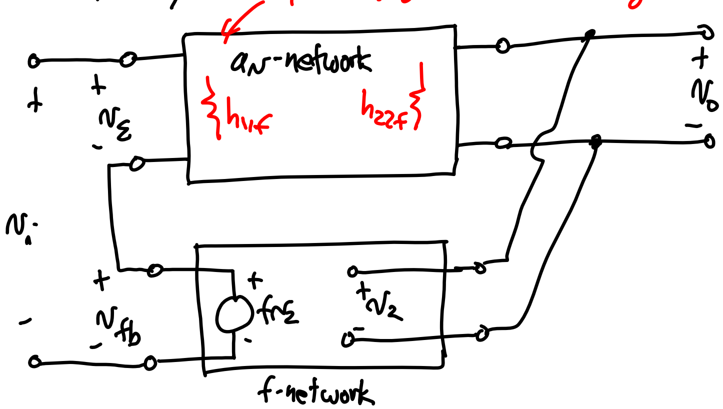


But to simplify things,
we would like to be able to represent the feedback network by just:

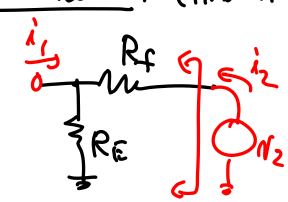


where: ① The small h_{21} is neglected.
② All impedances have been moved out of the f-network and moved to the a_v-network.

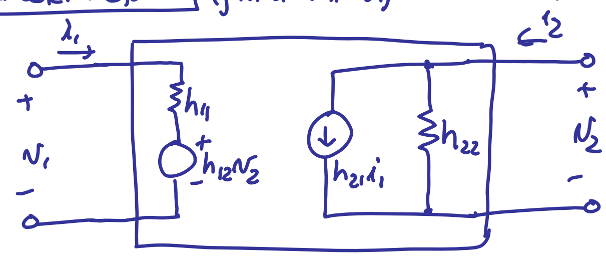
Pictorially: open loop gain w/ FB loading



The FB Network: (find h-parameter representation)



h-parameter Network (just a reminder)



Port Equations:

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

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

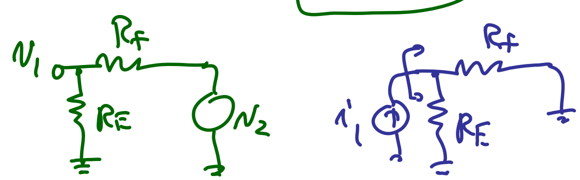
Elements:

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

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

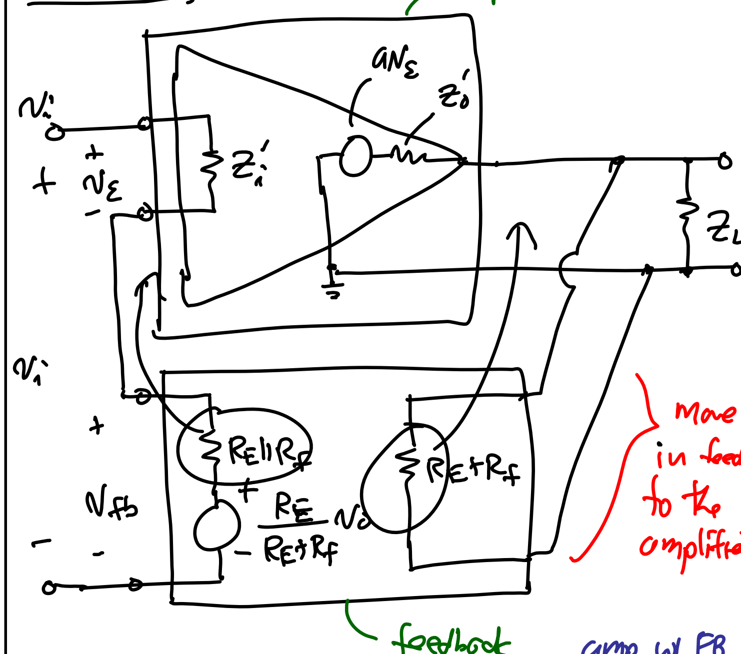
$h_{22f} = \frac{i_2}{v_2}\Big|_{i_1=0} = \frac{1}{R_E+R_F}$ ← This is the loading @ port 2, i.e., at the amplifier output port.

$f = h_{12f} = \frac{v_1}{v_2}\Big|_{i_1=0} = \boxed{\frac{R_E}{R_E+R_F} = f}$



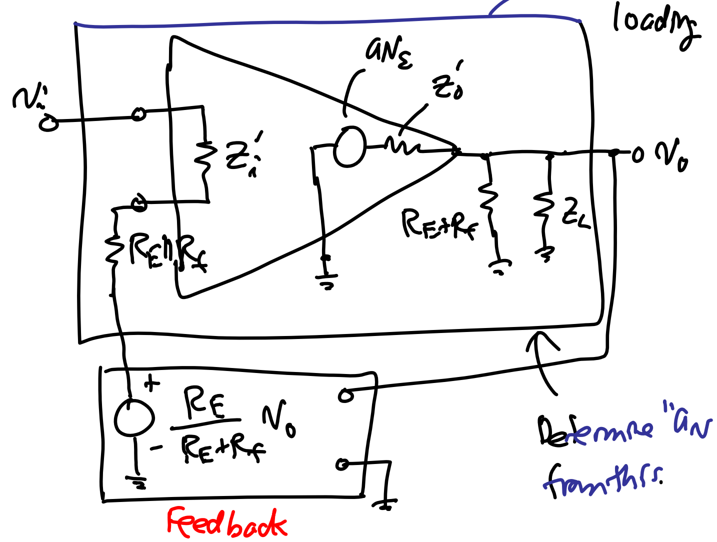
$h_{11f} = \frac{v_1}{i_1}\Big|_{v_2=0} = R_E \| R_F$ ← This is the loading @ port 1, i.e., the input port of the amplifier.

So we have:



Move R's in feedback to the amplifier

amp w/ FB loading

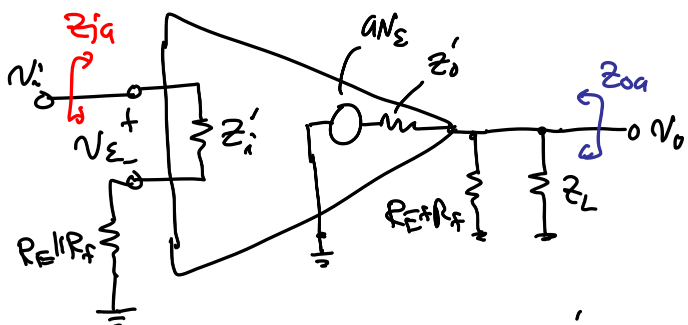


Determine "a_v" from this.

Use the box in blue to determine "a_N"

in $A_o = \frac{a_N}{1+a_N f}$; $Z_i = Z_{ia}(1+a_N f)$; ...

Determine the "a_N" gain:



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

$$\boxed{\therefore \left. \frac{v_o}{v_i} \right|_{FB\ loading} = \left(\frac{Z_i'}{Z_i' + R_E \| R_F} \right) a \left(\frac{(R_E+R_F)\|Z_L}{(R_E+R_F)\|Z_L + Z_o'} \right) = a_N}$$

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

Get closed loop gain A_o:

$$A_o = \frac{v_o}{v_i} = \frac{a_N}{1+a_N f} \approx \frac{1}{f} = 1 + \frac{R_F}{R_E}$$

→ for large a_N → ; if not large, use this

What about R_i & R_o?

⇒ first, for the open-loop amplifier w/ FB loading:

$$Z_{ia} = Z_i' + R_E \| R_F \rightarrow \boxed{Z_i = (Z_i' + R_E \| R_F)(1+a_N f)}$$

$$Z_{oa} = Z_o' \| (R_E+R_F) \| Z_L \rightarrow \boxed{Z_o = \frac{Z_o' \| (R_E+R_F) \| Z_L}{(1+a_N f)}}$$

Freq. Response:

$$\boxed{\omega_{-3dB}\Big|_{closed\text{-}loop} = \left\{ \omega_{-3dB}\Big|_{\substack{open\ loop \\ w/\ FB\ loading}} \right\} \times (1+a_N f)}$$

To determine loading by FB:

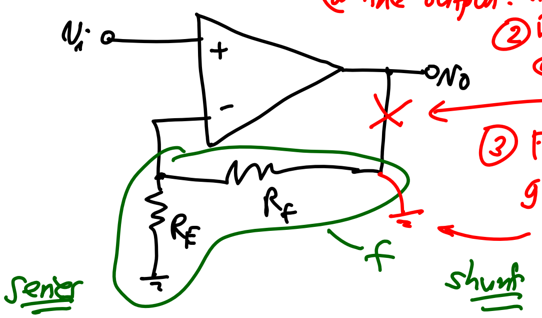
Input Loading:

① Determine the feedback type @ the output. (Here, it's shunt.)

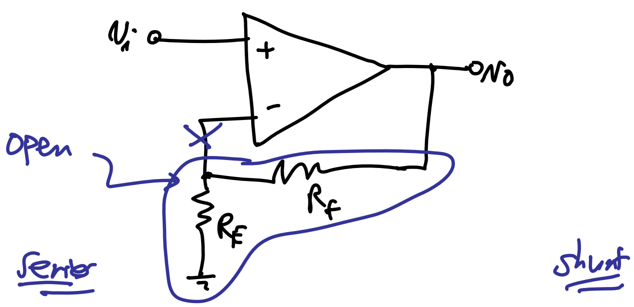
② Break the loop @ the output.

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.)