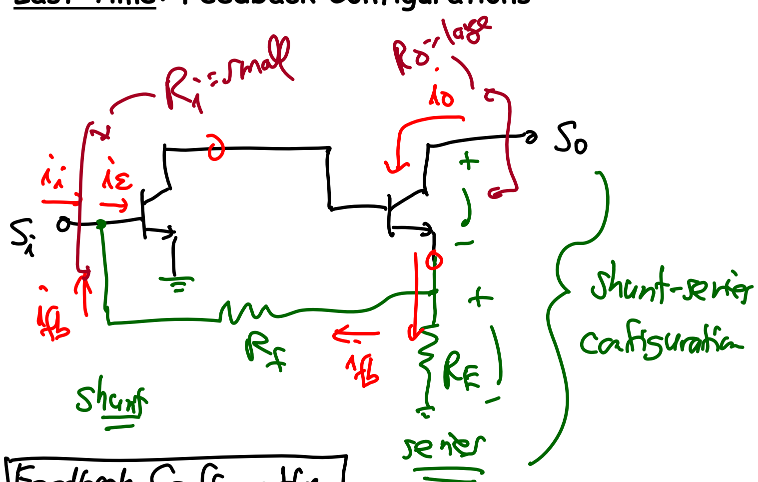
Lecture 26: Feedback Impedance

- **Announcements**:
  - Last HW#12 online (due during RRR week)
  - Yes, I know, but it'll help you on the Final
- **Lecture Topics**:
  - Effect of FB on Z_i and Z_o
  - Feedback Loading
- ------------------------------------
- **Last Time**: Feedback Configurations



$\boxed{\text{Feedback Configurations}}$

Input Variable	Input Connection	Output Connection	Output Variable
voltage	series	series	current
current	shunt	shunt	voltage

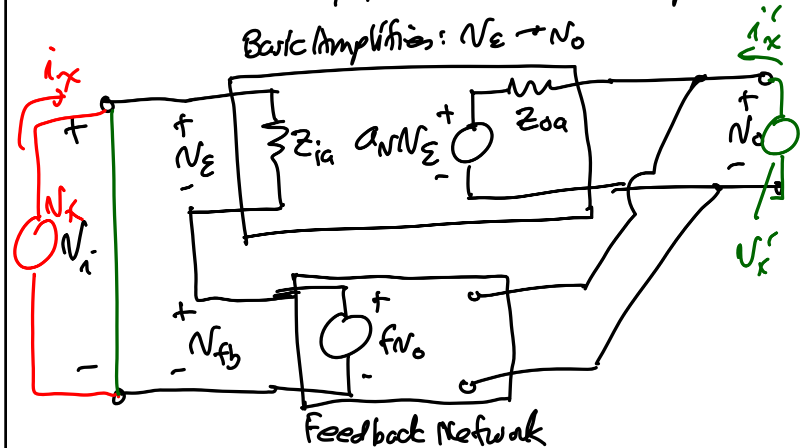
$v \to i$ $\quad$ $v \to v$ $\quad$ $i \to v$ $\quad$ $i \to i$

$\boxed{\text{Effect of FB on } Z_i \text{ \& } Z_o}$

Ex: series-shunt FB

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

Basic Amplifier: $v_\epsilon \to v_o$



Find the T.F.:

$$\left.\begin{aligned} v_\epsilon &= v_i - v_{fb} \\ v_o &= a_v v_\epsilon \\ v_{fb} &= f v_o \end{aligned}\right\} \quad v_o = a_v(v_i - f v_o)$$

$$\Rightarrow \boxed{\frac{v_o}{v_i} = \frac{a_v}{1 + a_v f}} \quad \checkmark$$

(as expected)

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

amplifier alone input impedance

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

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

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

loop gain!

$Z_i = \frac{v_x}{i_x} = \frac{v_\varepsilon(1+a_v f)}{\frac{v_\varepsilon}{Z_{ia}}} = \boxed{Z_{ia}(1+a_v f) = Z_i}$

when use series connection @ input: Input impedance raised by $(1+a_v f)$! → makes for a better voltage amplifier!

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

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

$i_x' = \frac{v_x' - a_v v_\varepsilon}{Z_{oa}} = \frac{v_x' + a_v f v_x'}{Z_{oa}}$

$\frac{v_x'}{i_x'} = \boxed{\frac{Z_{oa}}{1+a_v f} = Z_o}$

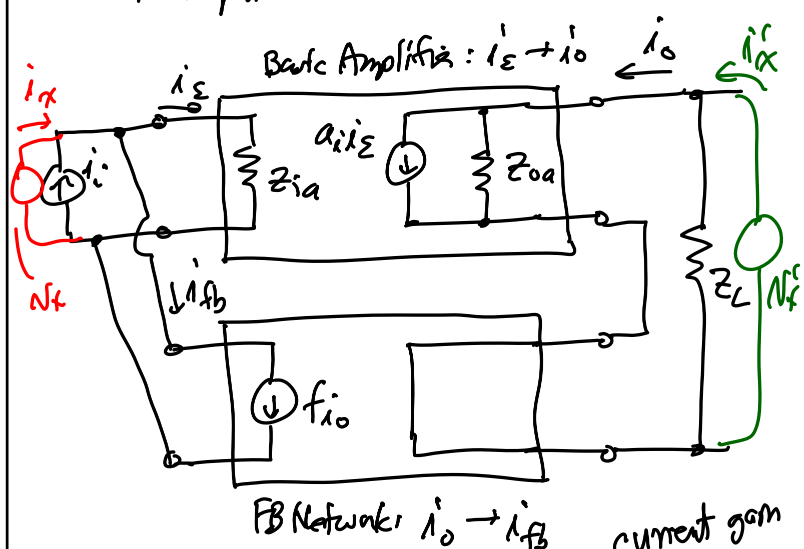
Output impedance lowered by a factor of $(1+a_v f)$

Again, makes for a better voltage amplifier!

Overall, series-shunt FB imposes the impedance characteristics favorable to a $v \rightarrow v$ amplifier: $Z_i \uparrow$, $Z_o \downarrow$ due to series-shunt FB

Ex. Shunt-Series FB

⇒ Again, assume FB network does not load the amplifier



Find T.F.-

$i_o = a_i i_\varepsilon$

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

$\boxed{\frac{i_o}{i_i} = \frac{a_i}{1+a_i f}}$

current gain of amp alone

loop gain

Same form as for $v \rightarrow v$ amp. This is a universal form!

Find Z_i: $\frac{v_x}{i_x}$:

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

→ 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 $(1+a_i f)$

All together → makes for a better $i \to i$ amp (when using shunt-series FB)

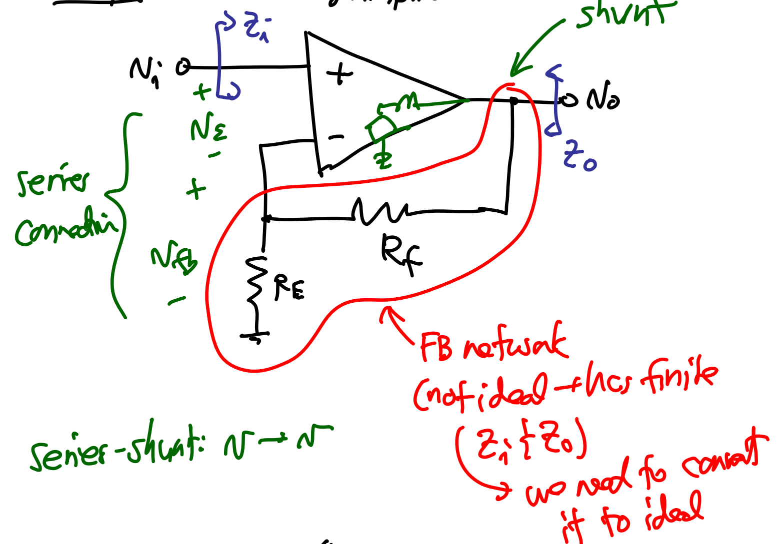
Summary:

① series connection: $z \to z(1+T)$ T = loop gain

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

Determine the FB Loading of an Amplifier

Example: Non-Inverting Amplifier



Series-shunt: $v \to v$

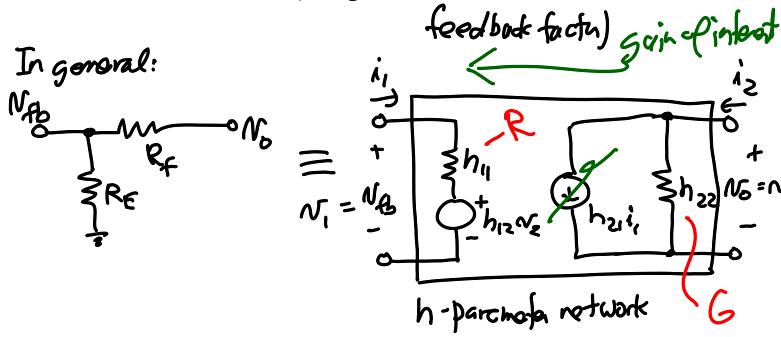
Objective: Use $A_o = \frac{a_v}{1+a_v f}$ to get A_o.

In order to use this equation, we must know

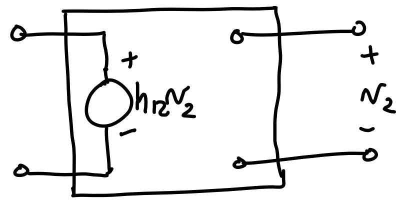
(i) $a_v \triangleq$ gain of the amplifier

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

In general:

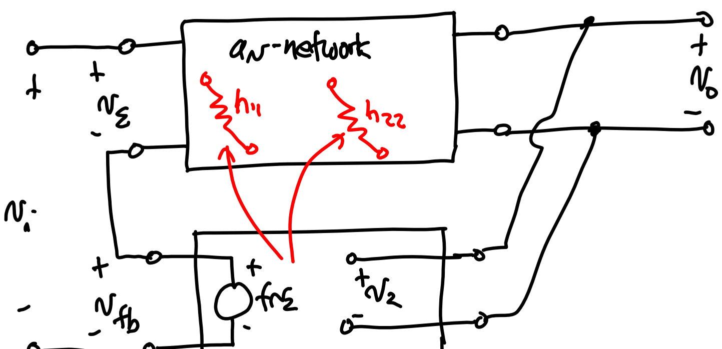


But to simplify things,
we would like to be able to represent the feedback network by just:



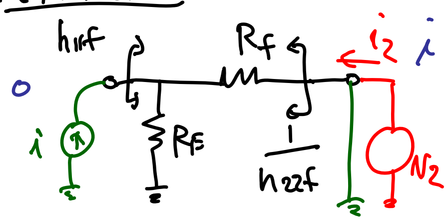
where: ① The small h_{21} is neglected.
② All impedances have been moved out of the f-network and moved to the a_v-network.

Pictorially:

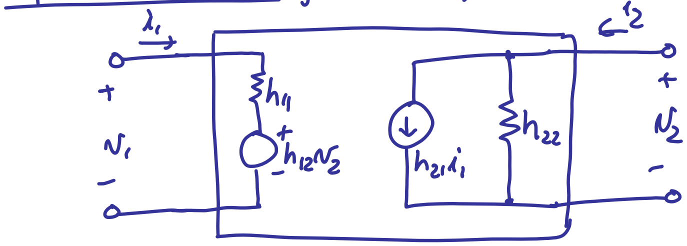


f-network

The FB 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:

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

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

$$h_{22f} = \frac{i_2}{v_2}\Big|_{i_1=0} = \frac{1}{R_E+R_F}$$

(this is the loading @ port 2, i.e., the amplifier output port)

This is a conductance.

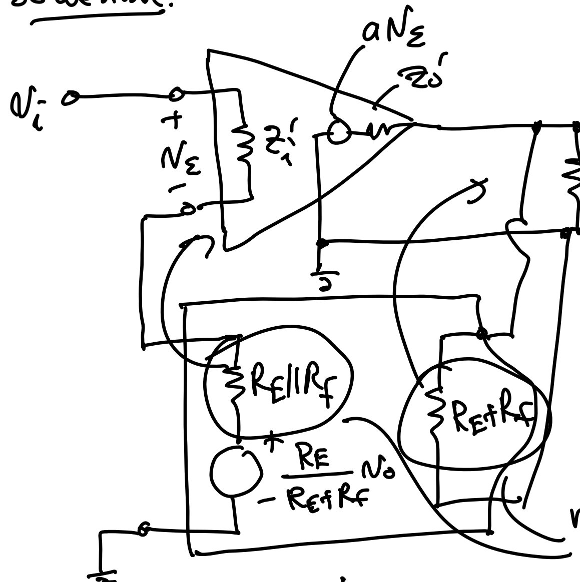
$$h_{12f} = \frac{v_f}{v_2}\Big|_{i_1=0} = \frac{R_E}{R_E+R_F} = f$$

(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 input port)

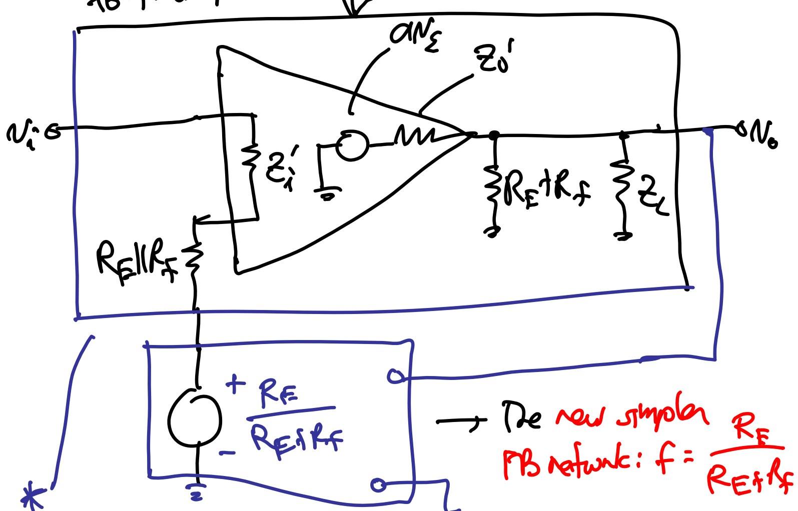
So we have:



Next Stage Impedance

move all the impedance f/ FB network to amp

Move R's f/ FB to the amplifier

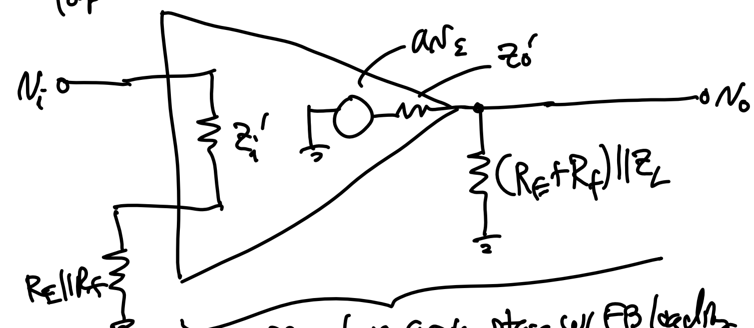


→ The new simpler FB network: $f = \frac{R_E}{R_E + R_F}$

* The new a_v-network → use this to determine a_v, z_{ia}, & z_{oa}

The amplifier w/ FB loading (open loop)

$A_o = \frac{a_v}{1 + a_v f}$



open-loop gain stage w/ FB loading

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

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