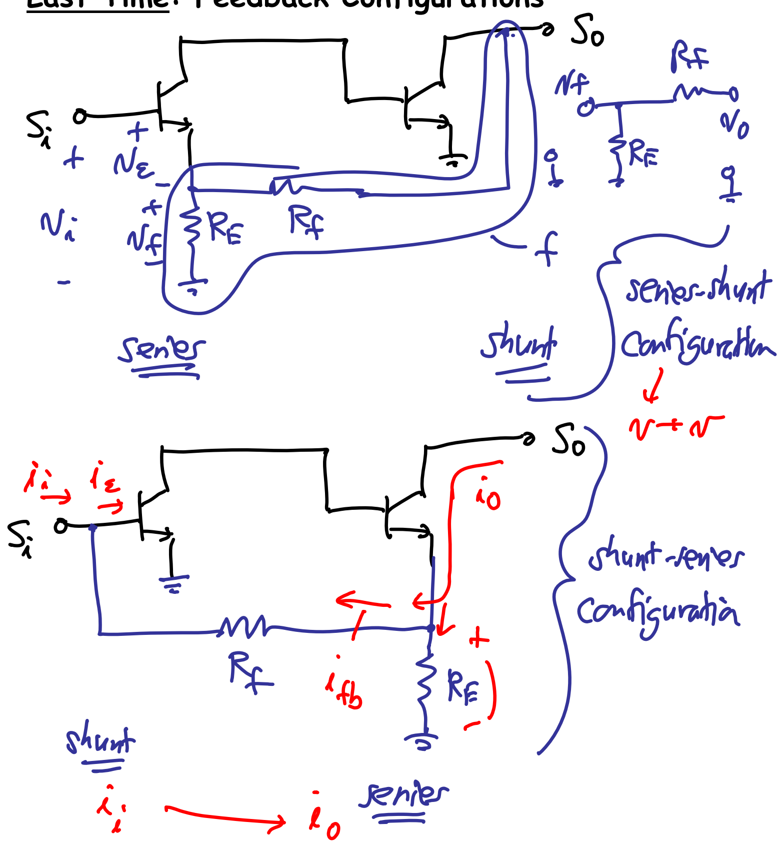
Lecture 26: Feedback Z

- Announcements:
- HW#11 due today; project due next Friday
- HW#12 online: your last HW, due during RRR week
  - Yes, I know, yet another homework
  - But this will help you for your final exam
- Lecture Topics:
  - Effect of FB on Z_i and Z_o
  - Feedback Loading
- ---------------------------------------
- Last Time: Feedback Configurations



Feedback Configurations

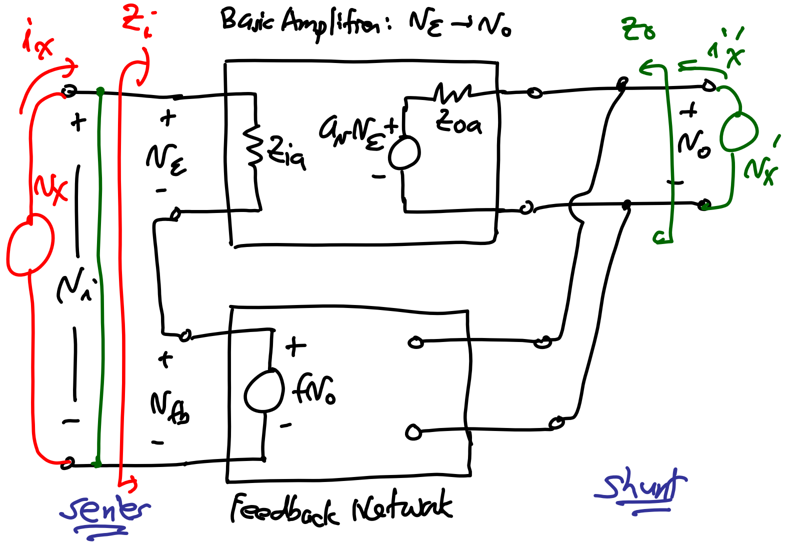
Input Variable	Input Connection	Output Connection	Output Variable
voltage	series	series	current
current	shunt	shunt	voltage

$v \to i$, $i \to v$, $i \to i$, $v \to v$

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. –

$v_\varepsilon = v_i - v_{fb}$
$v_o = a_v v_\varepsilon$
$v_{fb} = f v_o$

$v_o = a_v(v_i - f v_o)$

$$\Rightarrow \boxed{\frac{v_o}{v_i} = \frac{a_v}{1+a_v f}}$$ ✓ (as expected)

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

$v_x = v_\varepsilon + v_{fb}$
$= v_\varepsilon + f v_o = v_\varepsilon + a_v f v_\varepsilon = v_\varepsilon(1+a_v f)$

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

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

closed-loop input impedance

orig. open-loop input impedance

loop gain!

When use series connection @ input: Input impedance raised by $(1+a_v f)$!
↓
If $Z_i \uparrow$ → better voltage amplifier!

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

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

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

↓

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

orig. open-loop output impedance

closed-loop output impedance Z_o lowered a factor of $(1+a_v f)$

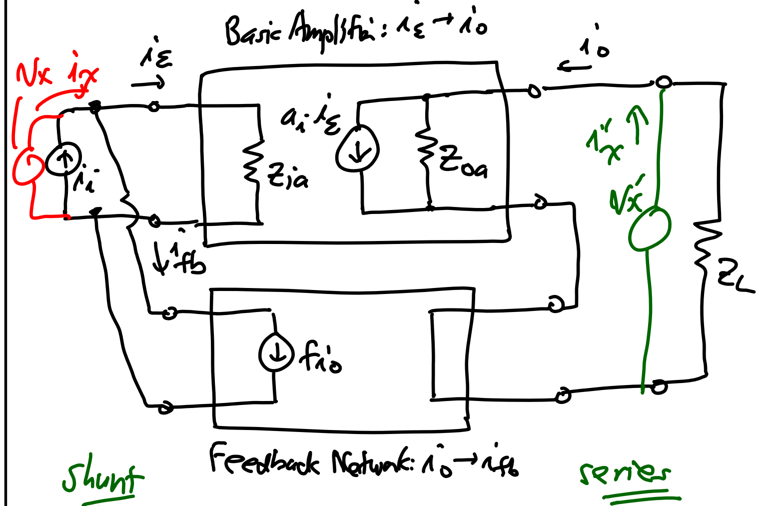
loop gain

↓
Again, makes for a better voltage amplifier!

Overall, series-shunt FB improves the impedance characteristics of a $v \rightarrow v$ 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.:

$i_o = a_i i_\varepsilon$

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

open-loop current gain

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

loop gain

Similar form to the v→v case, except now for i→i.

Find $Z_i = \frac{v_x}{i_x}$: open-loop input impedance

$$\boxed{\frac{v_x}{i_x} = \frac{Z_{ia}}{1 + a_i f} = Z_i}$$

loop gain

→ Again, a shunt connection reduces impedance by a factor of $(1 + a_i f)$!

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

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

↳ series connection raises the impedance by a factor of $(1 + a_i f)$!

Shunt-Series

Everything together makes for a better i→i amplifier!

Summary: T = loop gain

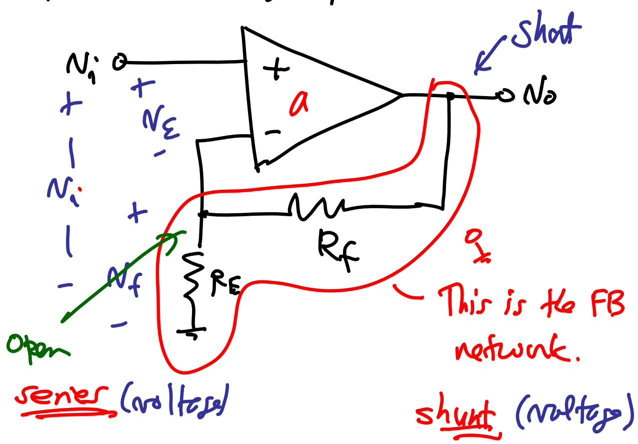
① series connection: $Z \to Z(1+T)$

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

· Now go through the handout on feedback loading

Determine the FB loading of an Amplifier

Example. Non-Inverting Amplifier



closed loop gain, open-loop gain, feedback factor

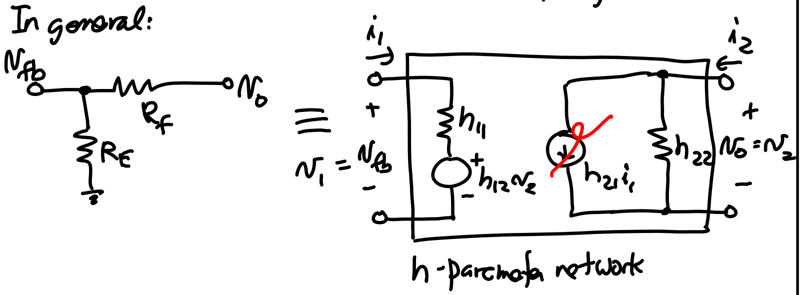
Objective: Use $A_o = \frac{a_v}{\underbrace{1 + a_v f}}$ to get A_o.

In order to use this equation, we must know

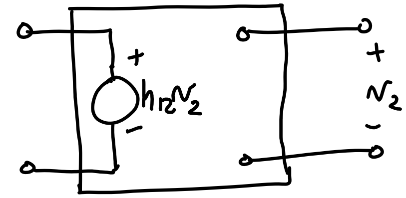
(i) $a_v \triangleq$ gain of the amplifier

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

In general:



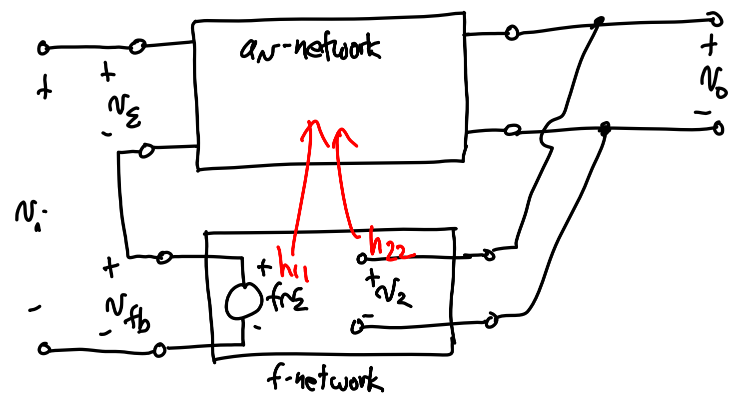
But to simplify things,
we would like to be able to represent the feedback network by just:



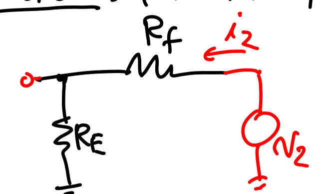
where: ① The small h_{21} is neglected.

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

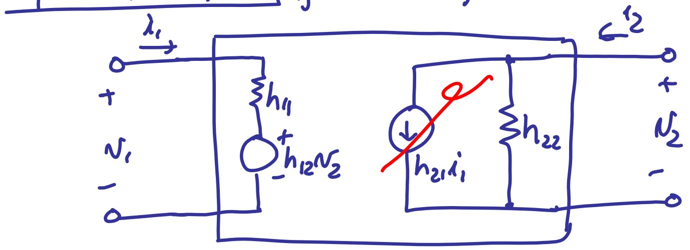
Pictorially:



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:

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

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

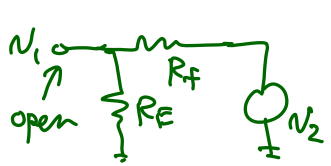
$$h_{22f} = \frac{i_2}{v_2}\Big|_{i_1=0} = \frac{1}{R_E+R_F}$$

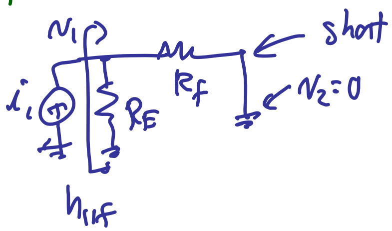
(This is the loading @ port 2, i.e., at the amplifier output port)

↑ 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 input port)

So we have: