Lecture 26: Feedback By Inspection

- Announcements:
- HW#11 online soon, due 12/9 @ 8 a.m.
- Pre-Lecture Feedback Loading Handout online
- "Inspection Analysis of Feedback Circuits" Handout online
- Lab#3 (Design Project) due Friday, Dec. 11, at 11:59 p.m. in the 140/240a homework box
  - For 240A: use resistor temperature coefficients previously given in lecture
  - Best to be finished with design by next Monday, so you have plenty of time to write the report
  - Make sure the report is good, since it is what is graded in the end
- Will discuss Final Exam next lecture
- Lecture Topics:
  - Effect of FB on Z_i and Z_o
  - Feedback Loading
  - Feedback By Inspection
- -----------------------------------
- Last Time:
- Effect of FB on Z_i and Z_o
- Continue with this

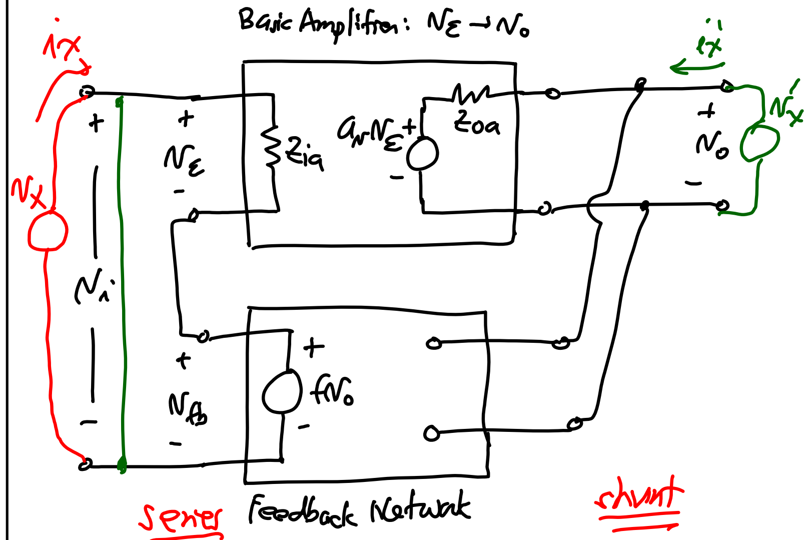
over

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.:

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

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

(as expected)

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

$v_x = v_\varepsilon + v_{fb}$
$= v_\varepsilon + f v_o = v_\varepsilon + f a_v v_\varepsilon = v_\varepsilon(\underbrace{1 + a_v f}_{\text{loop gain}})$

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

$z_i = \frac{v_x}{i_x} = \frac{\cancel{v_\varepsilon}(1+a_v f)}{\frac{\cancel{v_\varepsilon}}{z_{ia}}} = \boxed{z_{ia}(1+a_v f) = z_i}$

closed loop input impedance

original open-loop impedance of op amp

loop gain!

When use series connection @ input } Closed loop input impedance raised by $(1+a_v f)$!

↓

If $z_i \uparrow$ → better voltage amplifier!

↓

at least it accepts a voltage input better

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

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

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

↓

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

orig. amplifier open-loop output impedance

closed-loop output impedance is lowered by a factor $(1+a_v f)$

loop gain

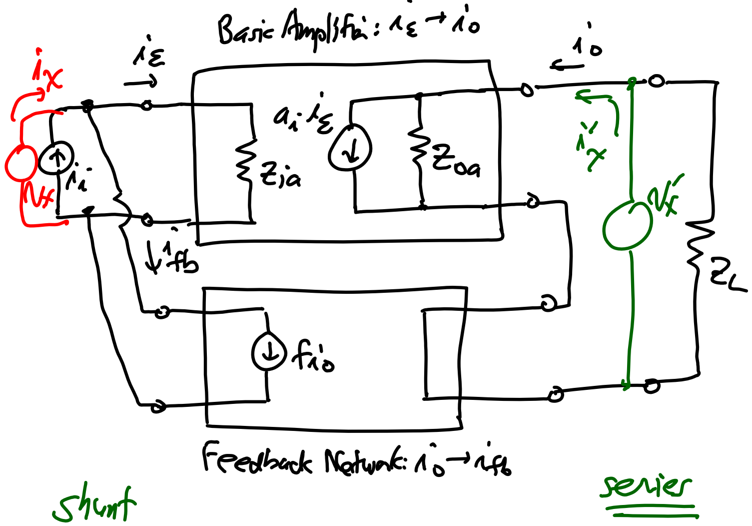
↓

Again, makes for a better voltage-to-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.:

$$\left.\begin{aligned} i_o &= a_i i_\varepsilon \\ i_\varepsilon &= i_i - i_{fb} = i_i - f i_o \end{aligned}\right\} \quad \boxed{\frac{i_o}{i_i} = \frac{a_i}{1+a_i f}}$$

open loop $i \to i$ gain

loop gain

similar to the v-v case, except now $i \to i$

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

$$\boxed{\frac{v_x}{i_x} = \frac{z_{ia}}{1+a_i f} = z_i}$$

open-loop input impedance

loop gain

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

expect a i input!

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 $(1+a_i f)$!

Summary: shunt-series makes for a better $i \to i$ amplifier!

Summary:

T = loop gain

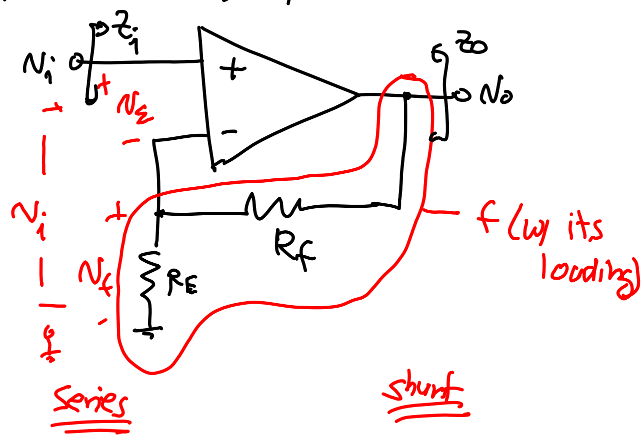
① series connection: $z \to z(1+T)$

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

- Now go through the “Loading from the FB Network” Handout

Determine the FB loading of an Amplifier

Example. Non-Inverting Amplifier



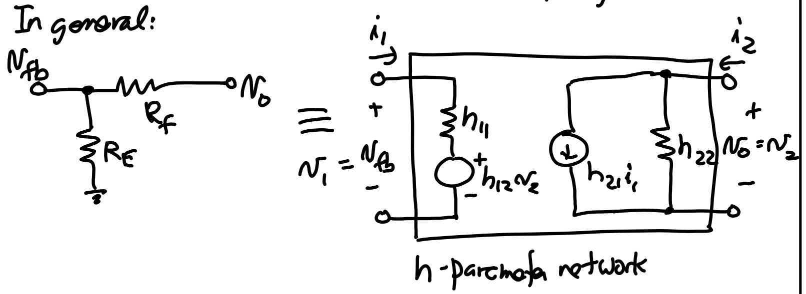
Objective: Use $A_o = \frac{a_v}{1 + a_v f}$ to get A_o.

In order to use this equation, we must know

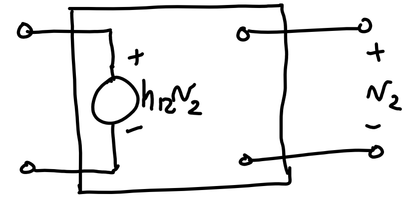
(i) $a_v \triangleq$ gain of the amplifier

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

In general:



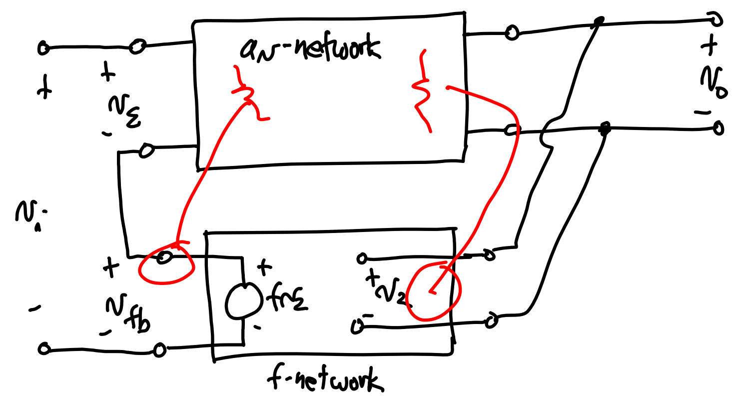
But to simplify things, we would like to be able to represent the feedback network by just:



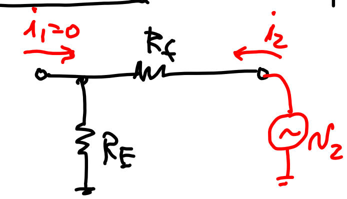
where: ① The small h_{21} is neglected.

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

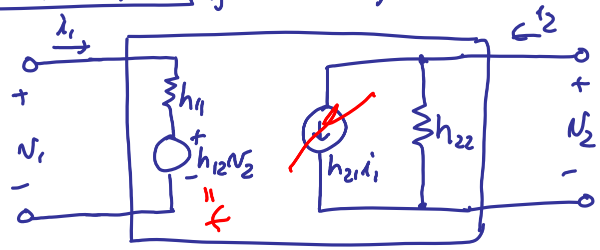
Pictorially:



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:

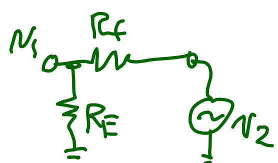
$h_{11} = \left.\frac{v_1}{i_1}\right|_{v_2=0}$ $\quad h_{12} = \left.\frac{v_1}{v_2}\right|_{i_1=0}$

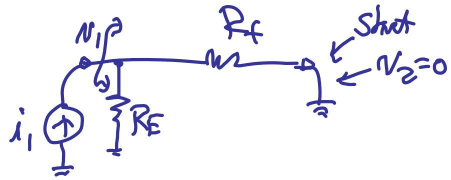
$h_{21} = \left.\frac{i_2}{i_1}\right|_{v_2=0}$ $\quad h_{22} = \left.\frac{i_2}{v_2}\right|_{i_1=0}$

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

↑ Conductance

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

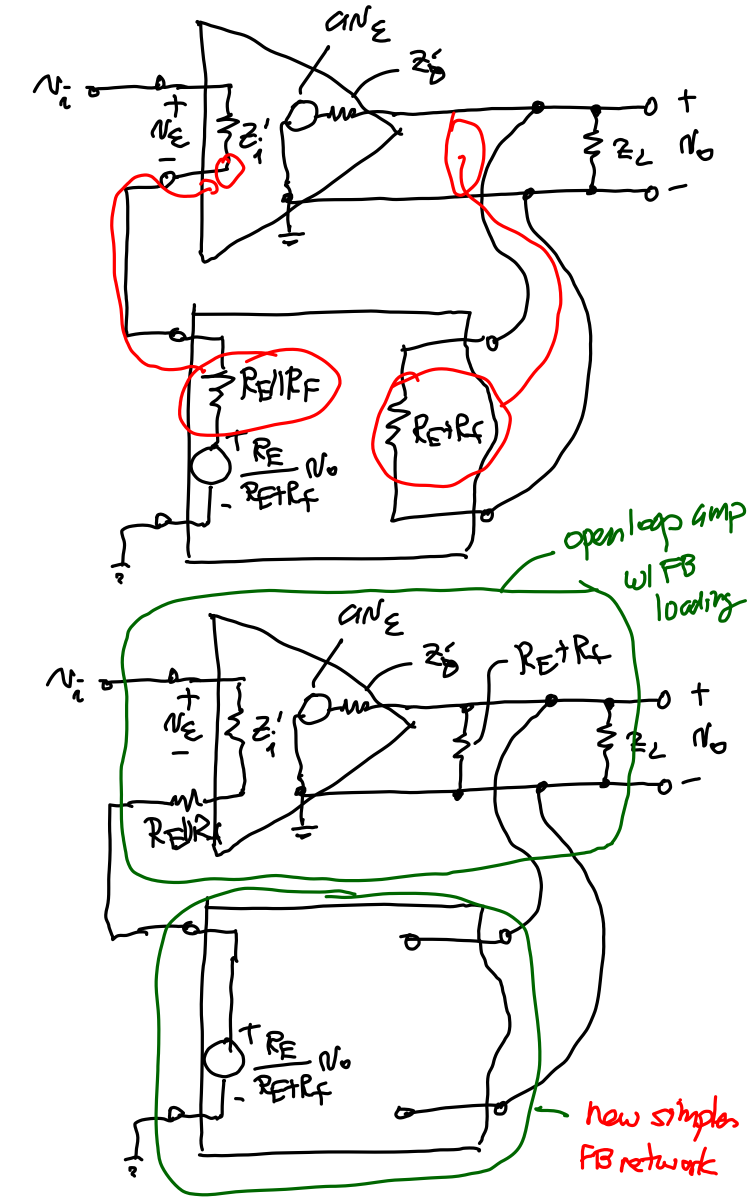




$h_{11f} = \left.\frac{v_1}{i_1}\right|_{v_2=0} = R_E \| R_F$ ← This is the loading @ port 1, i.e., at the amplifier input

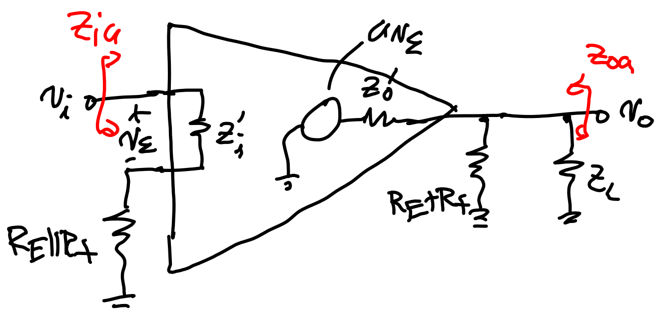
↑ resistance

So we have:



Want $A_o = \dfrac{a_v|_{OL\ w/\ FB\ loading}}{1+a_v|_{OL\ w/\ FB\ loading}\times f}$

Determine $a_v|_{OL\ w/\ FB\ loading}$:



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

$$\boxed{\frac{v_o}{v_i}\bigg|_{OL\ w/\ FB\ loading} = \left(\frac{Z_i'}{Z_i'+R_E\|R_F}\right) a \left(\frac{(R_E+R_F)\|Z_L}{(R_E+R_F)\|Z_L+Z_o'}\right) = a_v|_{OL\ w/\ FB\ loading}}$$

we have: $\boxed{f = \dfrac{R_E}{R_E+R_F}}$

Get closed-loop gain A_o:

if $a_v|_{OL\ w/FB\ load}$ = large

$A_o = \dfrac{v_o}{v_i}$

$\underbrace{1+a_v|_{OL\ w/FB\ load} f}_{\text{must use if } a_v|_{OL\ w\ FB\ load} \text{ not large}}$ — R_E

What about Z_i & Z_o?

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

$Z_{ia} = Z_i' + R_E\|R_F$
$Z_{oa} = Z_o'\|(R_E+R_F)\|Z_L$
} open-loop amp w/ FB loading

⇒ For closed-loop, just $\underbrace{\text{multiply or divide}}_{\text{depends on the type of FB connection}}$ by $(1+a_v f)$

series: $\boxed{Z_i = Z_{ia}(1+\overset{a_v|_{OL\ w/FB}}{a_v} f) = (Z_i'+R_E\|R_F)(1+a_v f)}$

shunt: $\boxed{Z_o = \dfrac{Z_{oa}|_{OL\ w/FB}}{1+a_v|_{OL\ w\ FB} f} = \dfrac{Z_o'\|(R_E+R_F)\|R_L}{1+a_v|_{OL\ w/FB}\times f}}$

What about ω_{-3dB}?

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

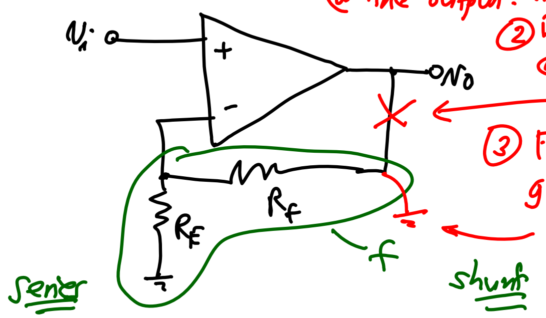
To determine loading by FB:

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

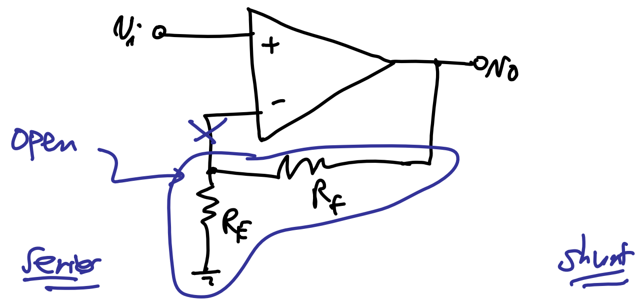
② Break the loop @ the output.

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.)

- 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
  - Be able to fluently go between different types of gain, from v → v, to i → v, etc.