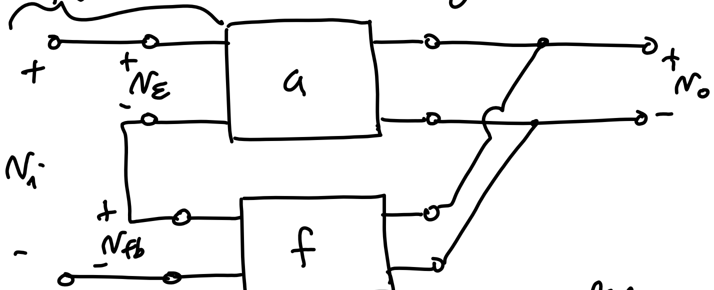
- **Announcements**:
  - Project is due this Friday, 5/1, at 8 p.m.
- **Today**:
  - Effect of Feedback on Z_i and Z_o
  - Feedback loading
  - Procedure for inspection analysis of FB

Last Time -

Identification of FB Connection Types

Series Connection - FB network port in series w/ amplifier port

↳ must go thru both the FB port & the amplifier port to get from the node of interest to ground



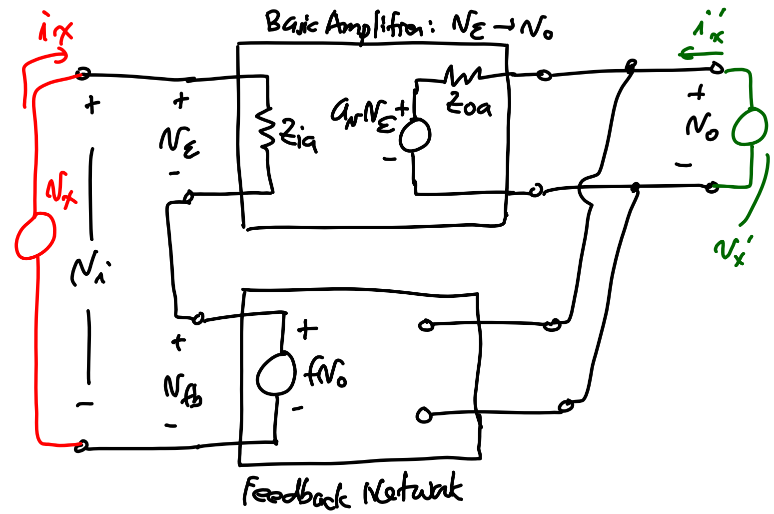
Shunt Connection - FB network port in shunt (parallel) w/ amplifier port

↳ can get from the node of interest to ground via either FB network port or the amplifier port

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. -

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

$v_o = a_v(v_i - f v_o)$

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

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

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

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

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

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

$(1 + a_v f)$ ← loop gain!

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)

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

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

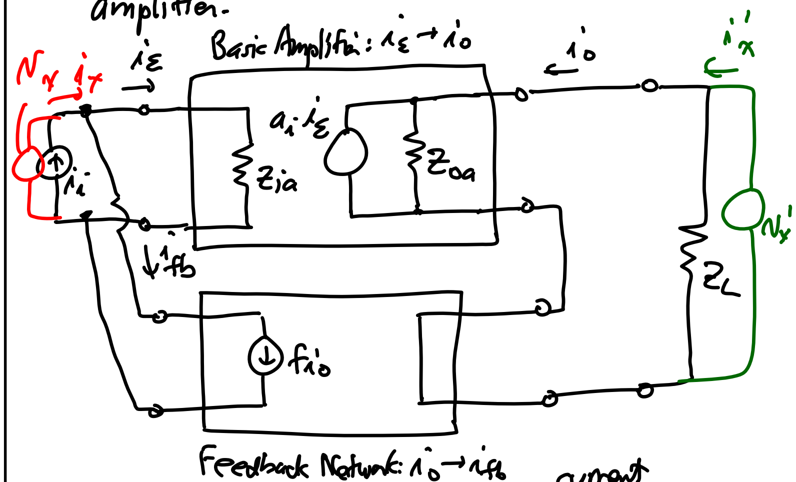
$\frac{v_x'}{i_x'} = \frac{z_{oa}}{1 + a_v f} = z_o$ ← Output impedance lowered by a factor of $(1+af)$

⇒ 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 FB network does not load the amplifier.



Find the T.F.:

$i_o = a_i i_\epsilon$

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

} $\frac{i_o}{i_i} = \frac{a_i}{1 + a_i f}$ (current gain; current gain)

↳ Same as with $v \rightarrow v$.
↳ It's a universal form!

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

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

$(1 + a_i f)$ ← 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 $(1+a_i f)$

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

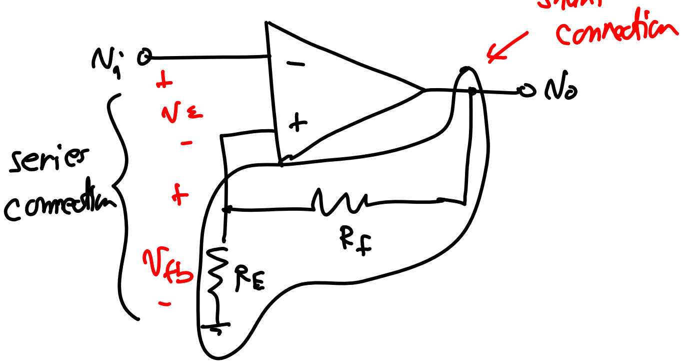
Summary.

1. series connection: $z \to z(1+T)$ ← T: loop gain
2. shunt connection: $z \to \frac{z}{1+T}$

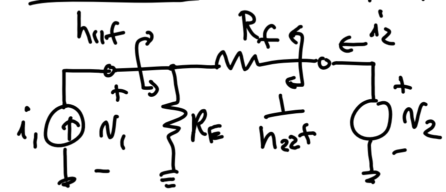
⇒ looked @ the handout & the prepared notes on "FB Loading".

Determine the FB Loading of an Amplifier

Ex. Non-Inverting Amplifier



The FB Network: (in terms of h-parameters)

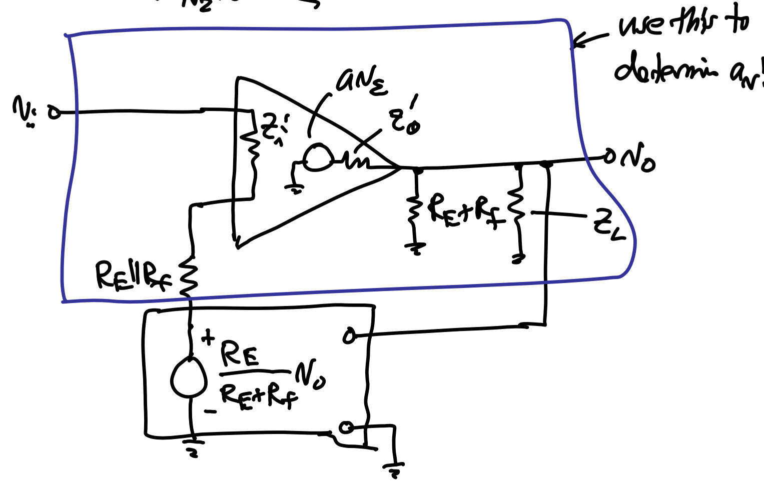


$$h_{22f} = \frac{i_2}{v_2}\Big|_{i_1=0} = \frac{1}{R_E + R_F} \quad \text{(this is loading)}$$

↑ This is a conductance.

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

$$h_{11f} = \frac{v_1}{i_1}\Big|_{v_2=0} = R_E \| R_F \quad \text{(this is loading)}$$

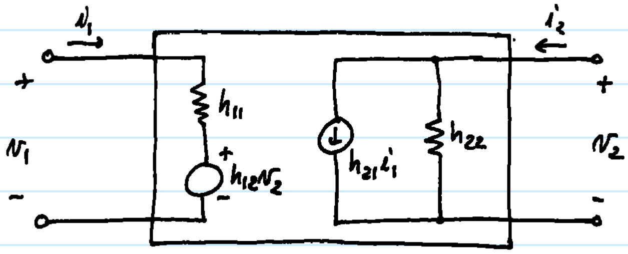


Loading from the FB Network

Ex. Series-Shunt FB (now including loading from the FB network)

- Series Connection: resistors & voltage sources add when in series → so represent amplifier & FB networks by R's & v's to make the math simpler
- Shunt Connection: conductances & current sources add when in parallel → so represent amplifiers & FB networks by G's & i's to make the math simpler

For these representations, use h-parameter networks for a & f.



Port Equations:

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

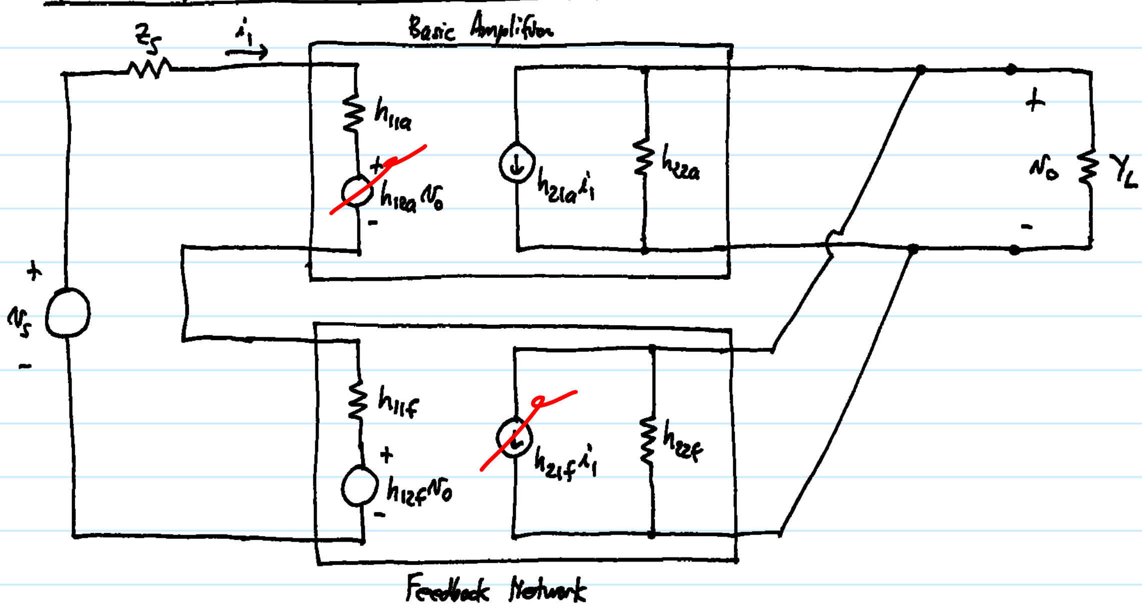
$i_2 = h_{21}i_1 + h_{22}v_2$

Elements:

$h_{11} = \left.\frac{v_1}{i_2}\right|_{v_2=0}$ $\quad h_{12} = \left.\frac{v_1}{v_2}\right|_{i_1=0}$

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

h-parameter representation of the series-shunt FB ckt:

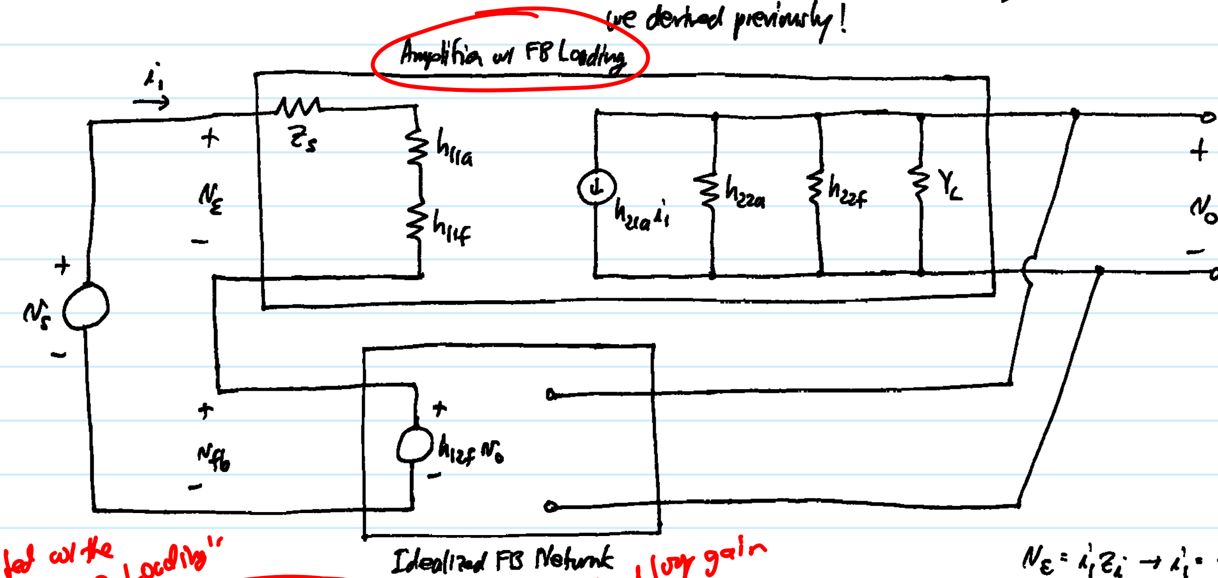


In general, transistor amplifiers & FB networks are uni-directional → they have large gains in the forward direction, but very small gains in the reverse:

$$|h_{12a}| \ll |h_{12f}| \rightarrow \text{neglect } h_{12a} \text{ (set to 0)}$$

$$|h_{21a}| \gg |h_{21f}| \longrightarrow \text{neglect } h_{21f} \text{ (set to 0)}$$

⇒ move impedances to idealize the FB network → once ideal, we can use the general equations we derived previously!



Associated w/ the "Amplifier w/ FB Loading" →

$$Z_i = Z_s + h_{11a} + h_{11f}$$

$$Y_o = Y_L + h_{22a} + h_{22f}$$

closed loop gain:

$$\frac{v_o}{v_s} = A = \frac{a}{1+af}, \text{ where } \begin{cases} a = -\dfrac{h_{21a}}{Z_i Y_o} \\ f = h_{12f} \quad \left(= \dfrac{v_{fb}}{v_o}\right) \end{cases}$$

$v_\varepsilon = i_1 Z_i \rightarrow i_1 = \dfrac{v_\varepsilon}{Z_i}$

$v_o = -h_{21a} i_1 / Y_o$

$\therefore \dfrac{v_o}{v_\varepsilon} = a = \dfrac{-h_{21a} i_1}{Y_o Z_i i_1}$

Thus, the key to inspection analysis of FB ckts: Xfer FB impedances to load the basic amplifier, then use our "inspection" formulas.