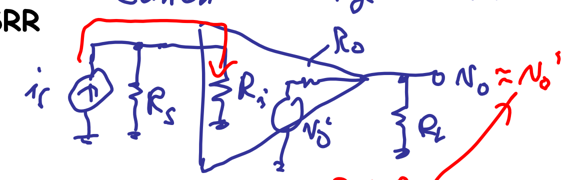
Lecture 25: Feedback I

- Announcements:
- HW#10 due Wednesday at 8 a.m.
- No homework over Thanksgiving break
- HW#11 will be online next week
- Lab#3 (Design Project) due Friday, Dec. 11, at 11:59 p.m.
  - For 240A: use resistor temperature coefficients previously given in lecture
- Pre-Lecture Feedback Loading Handout online
- Lecture Topics:
  - Recognizing Feedback Configurations
  - Effect of FB on Z_i and Z_o
  - Feedback Loading
- --
- Last Time:
- Finished PSRR

Current-to-Voltage: transR



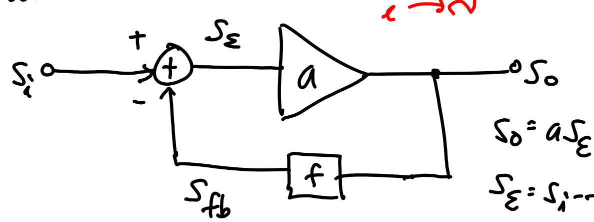
$R_i \ll R_s$ $R_o \ll R_L$

R_i: small ⟶ R_o = large

$i \to v$

Feedback

⇒ we know this:



$S_o = a S_\varepsilon$

$S_\varepsilon = S_i - f S_o$

⇓

$$\boxed{\frac{S_o}{S_i} = \frac{a}{1+af} = A}$$

Benefits of Negative FB

① Stabilizes the gain of the amp against parameter changes & active device variations

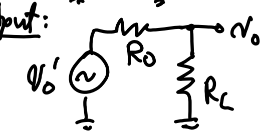
② Modifies R_i and R_o → basically improves their values according to the type of amplifier implemented

e.g., voltage amp: R_i: large, R_o: small

@ input:

If R_i: large, $v_i \approx v_s$.
$(R_i \gg R_s)$

@ output:



If R_o = small, $v_o \approx v_o'$.
$(R_o \ll R_L)$

$v_o = v_o' \left(\frac{R_L}{R_L + R_o}\right)$ " v_o' (when $R_o \ll R_L$)

current-to-voltage amp: R_i = small, R_o = small
voltage-to-current amp: R_i = large, R_o = large
current-to-current amp: R_i = small, R_o = large

③ Reduces distortion; improves linearity.

④ Increases bandwidth (ω_{-3dB}).

Disadvantages of Neg. FB

① Gain is reduced → reduction factor ~ equal to the amount of gain stabilization, distortion reduction, etc...

Solution: Add more stages of gain → but this adds cost & power...

② Feedback causes stability problems (if not compensated properly)

Gain Sensitivity Reduction Via FB

$$A = \frac{a}{1+af} \rightarrow \frac{dA}{da} = \frac{(1+af)-af}{(1+af)^2} = \frac{1}{(1+af)^2}$$ } small

weak by!

For a Δ in op amp gain: δa

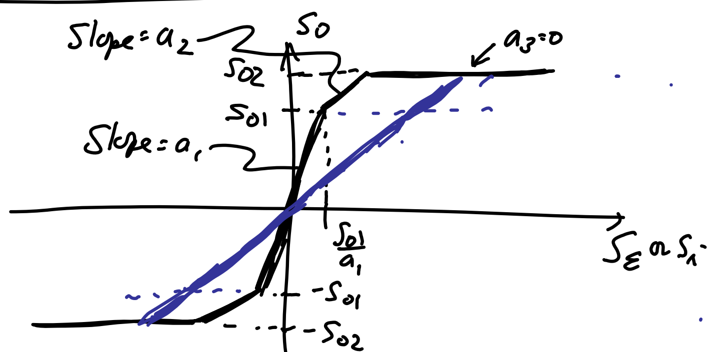
$$\frac{\delta A}{\delta a} = \frac{1}{(1+af)^2} \rightarrow \delta A = \frac{\delta a}{(1+af)^2}$$

much smaller than δa

... and the fractional change:

$$\frac{\delta A}{A} = \frac{1+af}{a}\,\frac{\delta a}{(1+af)^2} \Rightarrow \boxed{\frac{\delta A}{A} = \frac{\frac{\delta a}{a}}{1+af}}$$

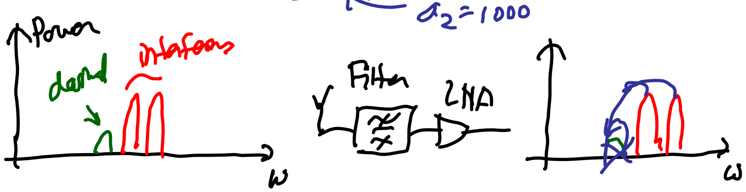
Distortion Reduction via FB



Now, close the loop: (add neg. FB)

$0 < S_o < S_{o1}$: $A_1 = \frac{a_1}{1+a_1 f} \approx \frac{1}{f}$ for a_1 → large ≈ 20K

$S_{o1} < S_o < S_{o2}$: $A_2 = \frac{a_2}{1+a_2 f} \approx \frac{1}{f}$ $a_2 = 1000$



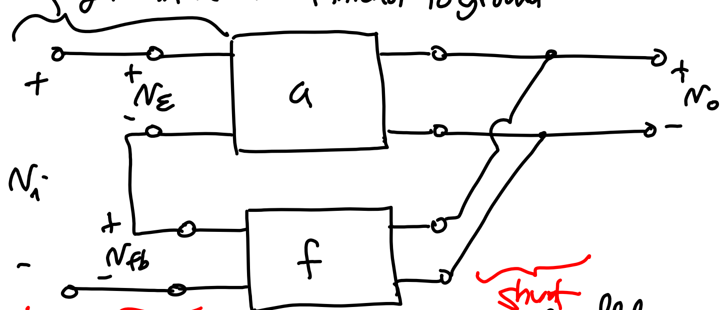
"Inspection" Analysis of FB Ckts.

↓ starts with...

Identification of FB Connection Types

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

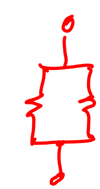
must go thru both the FB port & the amplifier port to get from the node of interest to ground

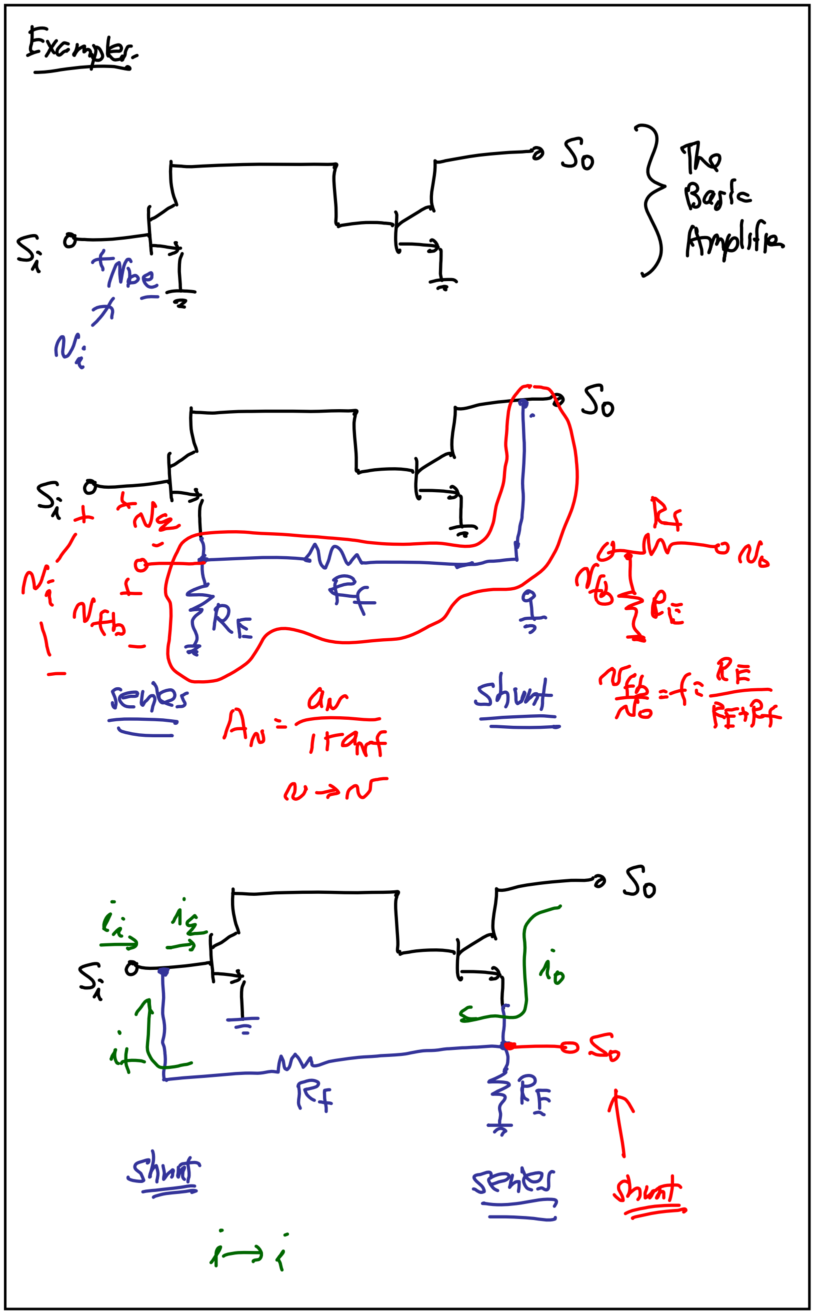


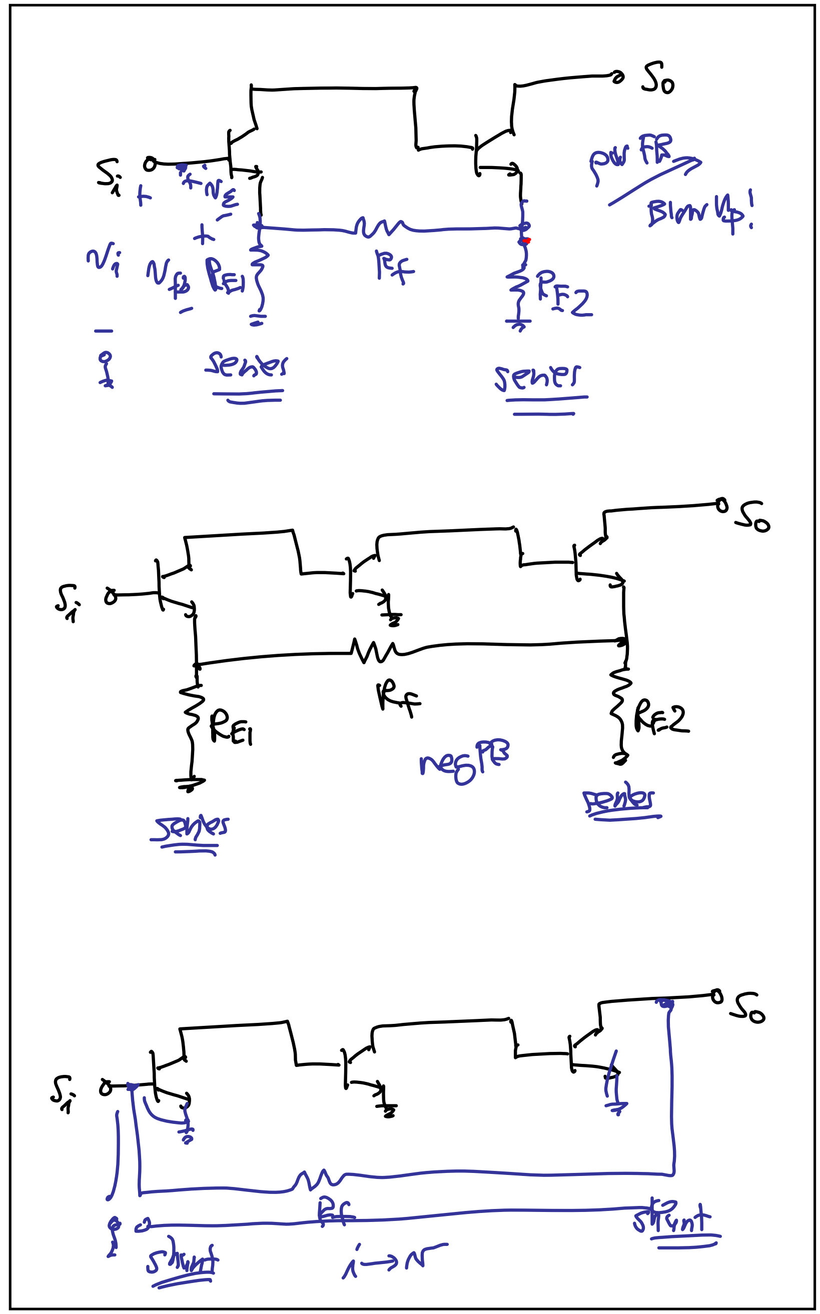
Shunt Connection – FB network port in shunt w/ amplifier port

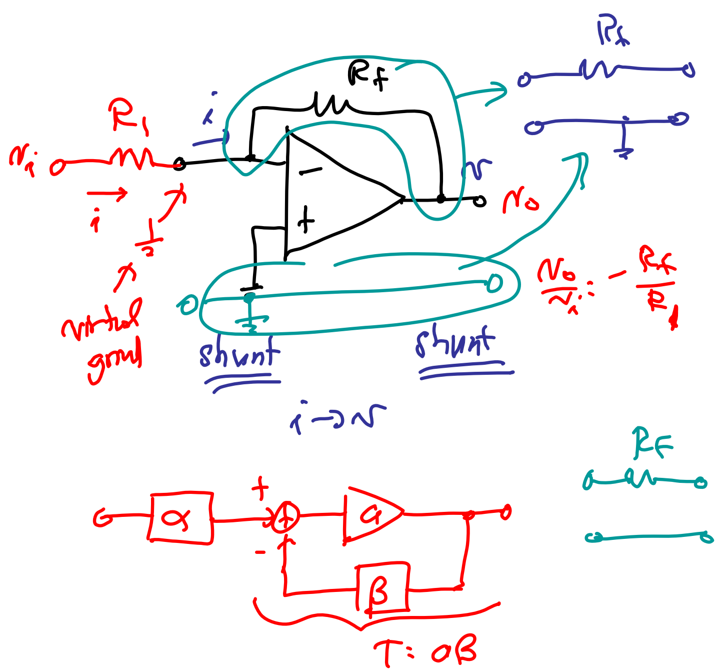
can get from the node of interest to ground via either FB network port or the amplifier port

over




Examples.
The Basic Amplifier
series
shunt
$A_v = \frac{a_v}{1 + a_v f}$
$v \to v$
$\frac{v_{fb}}{v_o} = f = \frac{R_E}{R_E + R_f}$
shunt
series
shunt
$i \to i$


pos FB
Blow Up!
series
series
neg FB
series
series
shunt
shunt
$i \to v$



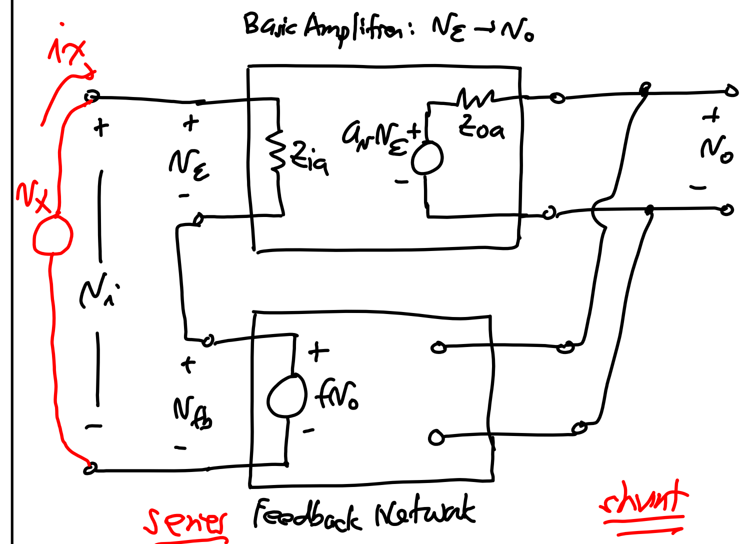
Feedback Configurations

Input Variable	Input Connection		Output Connection	Output Variable
voltage	series	$v \to i$	series	current
current	shunt	$i \to i$, $i \to v$, $v \to v$	shunt	voltage

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.:

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

$v_o = a_v (v_i - f v_o)$

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

(as expected)

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

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

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

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

closed loop input impedance

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

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 accept a voltage input better