- **Announcements**:
  - Project is due this Friday, 5/1, at 8 p.m.
- **Today**:
  - Feedback: Pros & Cons
  - Inspection Analysis of FB Ckts
  - Effect of Feedback on Z_i and Z_o

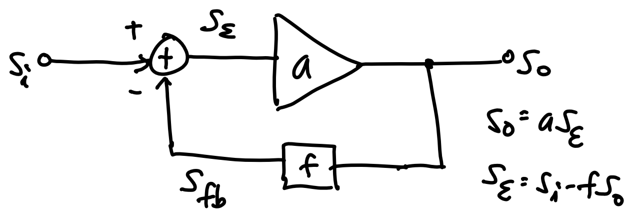
Last Time -

→ finished CMOS op amp design

↓ New Topic (well, not entirely new... but there's a lot more important stuff to know)

Feedback

⇒ we know this:



$S_o = a S_\varepsilon$

$S_\varepsilon = S_i - f S_o$

⇓

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

Benefits of Negative FB

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

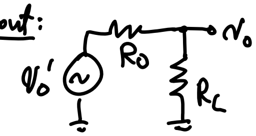
② Modifies R_i and R_o → basically improves their values according to the type of amplifier implemented

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

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

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

For a Δ in op amp gain: δa

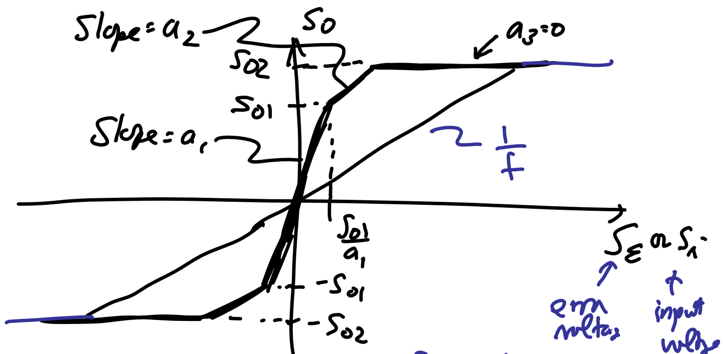
$$\frac{\delta A}{\delta a} = \frac{1}{(1+af)^2} \rightarrow \delta A = \frac{\delta a}{(1+af)^2}$$

↑ 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



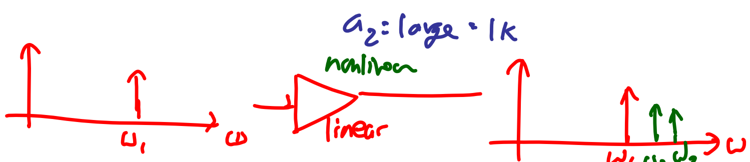
Now, close the loop:

for a_1 = large = 20K

$0 < S_o < S_{o1}$: $A_1 = \frac{a_1}{1+a_1 f} \approx \frac{1}{f}$

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

a_2 = large = 1K



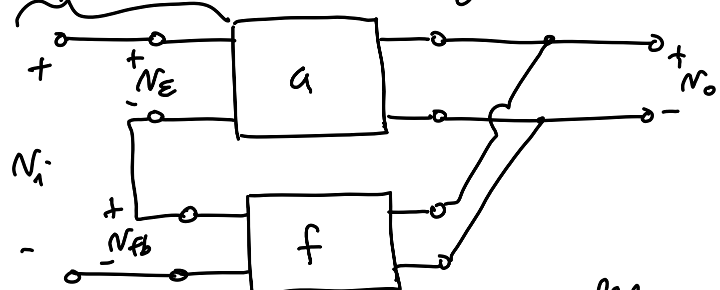
"Inspection" Analysis of FB Ckts.

↓ start with...

Identification of FB Connection Types

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

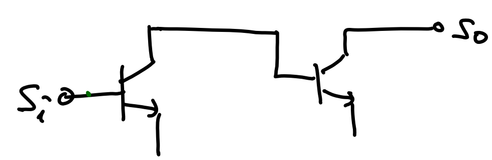
↳ must go thru both the FB port & the amplifier port to get from the node of interest to ground



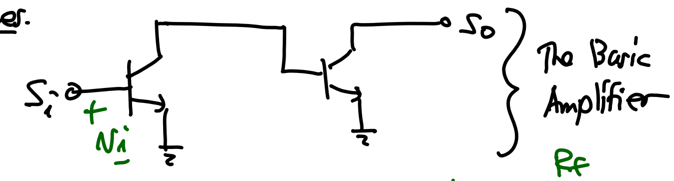
Shunt Connection – FB network port in shunt (parallel) w/ amplifier port

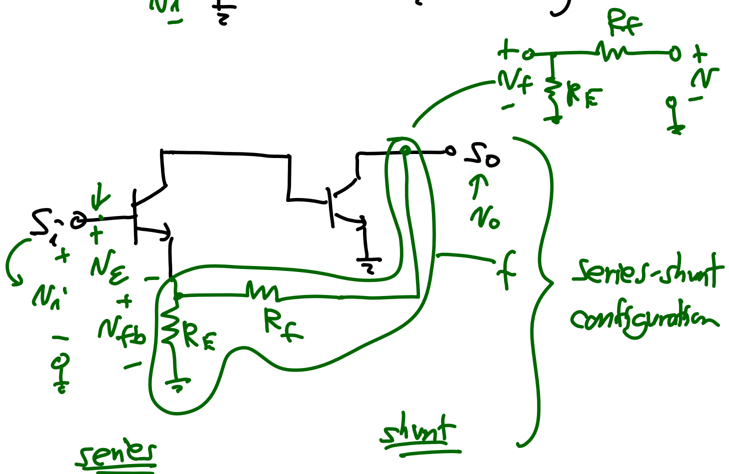
↳ can get from the node of interest to ground via either FB network port or the amplifier port

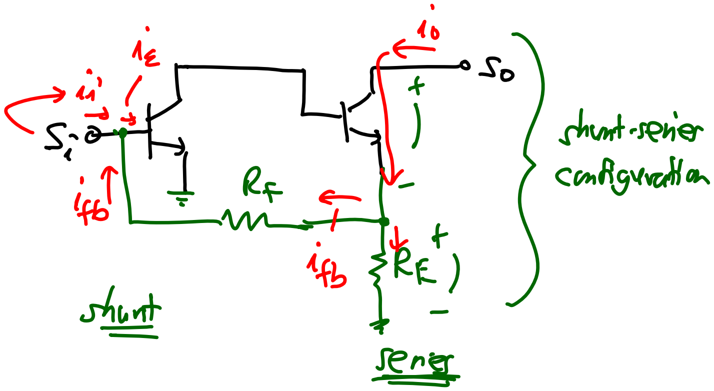
↳ over

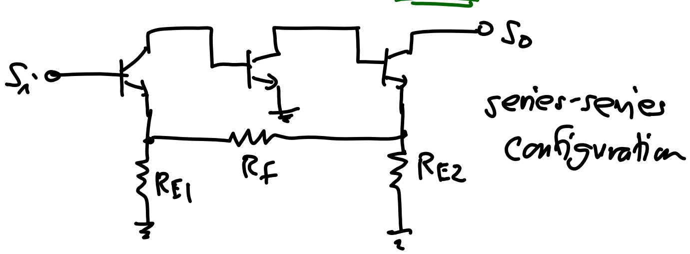


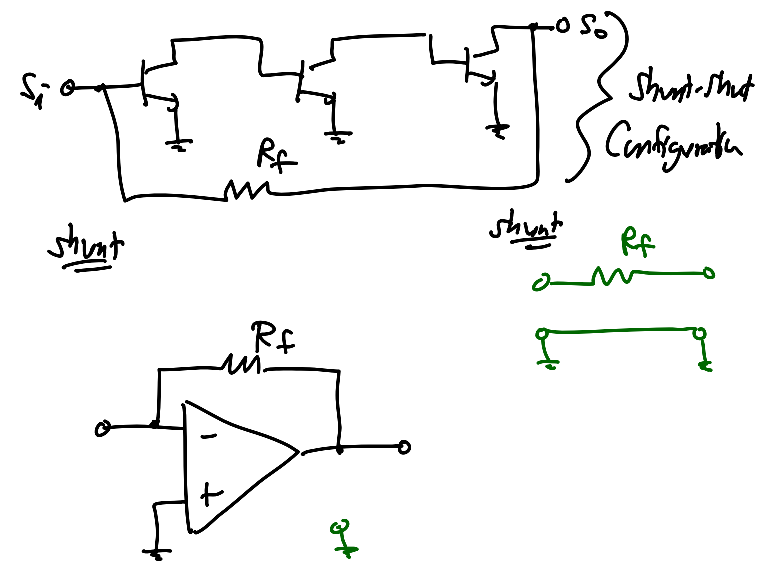
Examples.











→ From the above, we can surmise four different combinations:

Feedback Configurations

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

$v \to i$ (series–series); $i \to i$ (shunt–series); $i \to v$ (shunt–shunt); $v \to v$ (series–shunt)

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