E151 Lecture 24 – Feedback in Amplifiers

Matthew Spencer
Harvey Mudd College
ENGR151

Disclaimer

These are notes for Prof. Spencer to give the lecture, they were not intended as a reference for students. Students asked for them anyway, so I'm putting them up as a courtesy. Remember that they are not intended as a substitute for attending lecture.

Lab Debrief

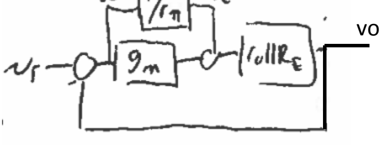
- Base current supply for class AB can limit swing
- 100 ohms in class AB is for rin, bias branch design affects it
- Efficiency very low because load is non-optimal: can't get through cap
- Distortion is especially audible in audio

Why Feedback?

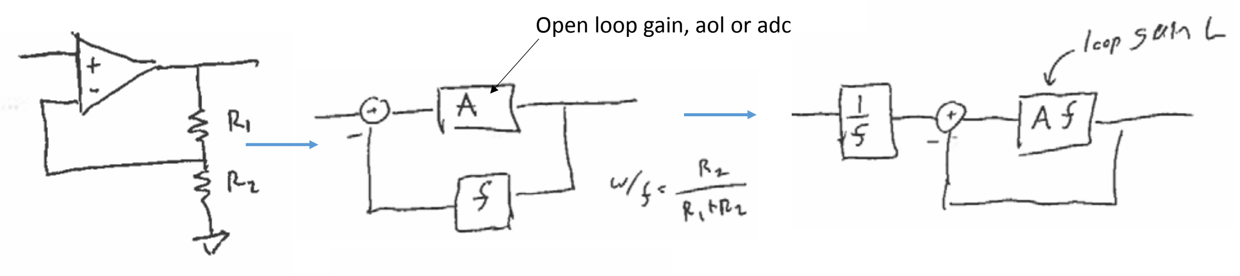
- Risk of stability is bad! What do we get from this?
- Linearity & offset reduction ← not going over it b/c hard to draw
- Repeatable gain
- Input/output impedance modulation
- (This can work w/ single ended amps instead of diff or within a stage)
  - Single ended amps → Miller example
  - Within a stage → EF example (optional, if time)

→ Fwd. path / 1 + L is magic!

$$\frac{v_o}{v_i} = \frac{r_o \| R_E \left(g_m + 1/r_\pi\right)}{1 + r_o \| R_E \left(g_m + 1/r_\pi\right)} \qquad \frac{i_b}{v_i} = \frac{1/r_\pi}{1 + r_o \| R_E \left(g_m + 1/r_\pi\right)}$$



Example of Repeatable Gain (also Static Error)



Open loop gain, aol or adc

w/ $f = \frac{R_2}{R_1+R_2}$

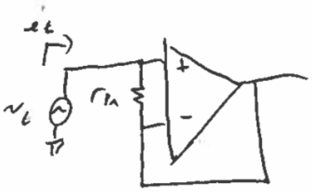
$$\frac{v_o}{v_i} = \frac{1}{f} \cdot \frac{L}{1+L}$$

Closed loop gain, acl

target gain set only by R

causes steady state error $\left(1 - \frac{1}{1+L}\right)$ $\varepsilon \approx 1/L$

Examples of Impedance Modulation



Loop gain of A … f = 1

$$i_t = \frac{v_t - (-A v_t)}{r_{out}}$$

$$r_{out,eff} = \frac{v_t}{i_t} = \frac{r_{out}}{1+A}$$

lowered by loop gain!

SSE, assumes $r_{out} = 0$

$$i_t = \frac{v_t - v_t\left(1 - \frac{1}{1+A}\right)}{r_{in}}$$

$$r_{in,eff} = \frac{v_t}{i_t} = r_{in}(1+A)$$

- rin or rout out can be raised or lowered by loop gain
- Recognize raised/lowered by looking at boosted/reduced swing

What’s Stability?

- Definition of stability
  - Circuit designers usually use BIBO, but breaks down for large signals
  - Lyapunov always works, but it’s a bit out of scope for most designs
  - I like spectral content for bounded inputs –only have output f where input f
- Instability comes from RHP poles in the in closed loop Xfer function
  - That’s the same as 1+L(s)=0
  - Often simplify analysis to look at L(jw)=-1 (mag=1, phase=-180)→Nyquist/PM
- What about the instability we’ve seen? Our amps have LHP poles?
  - Undesired in→out coupling: breadboard or cabling cap, power supply
  - Bypass cap is important for suppressing supply coupling

Examples of Using Phase Margin

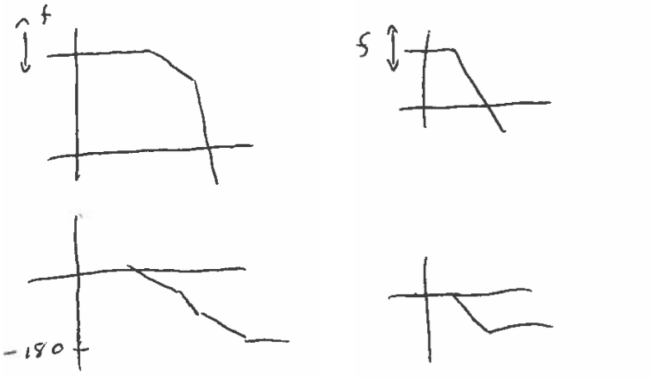
- Uncompensated op-amp often has poor phase margin
- Compensation cap → 90° PM
- 2nd pole in comp amp pushed to higher f by 1/gm, so omit
- Least stable with f=1, more stable with small f (big acl)
- PM= 45° if 2nd pole located at crossover → reasonable Q

Uncompensated

$$a_{ol} = \frac{a_{DC}}{(\tau_1 s+1)(\tau_2 s+1)}$$

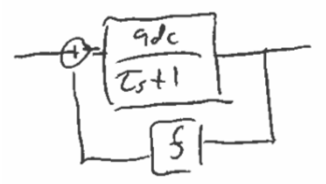
Compensation cap

$$a_{ol} = \frac{a_{dc}}{\tau s + 1}$$



Origin of Gain-Bandwidth Product

- Gain-bandwidth product is not fundamental to op-amps
- GBW originates with dominant pole compensation & big aol



$$\frac{v_o}{v_i} = \frac{a_{dc}/(\tau s+1)}{1+a_{dc}f/(\tau s+1)}$$

$$= \frac{a_{dc}}{\tau s + 1 + a_{dc}f}$$

$$= \frac{1}{f} \cdot \frac{a_{dc}f}{1+a_{dc}f} \cdot \frac{1}{1+\frac{\tau}{1+a_{dc}f}s}$$

$$G \cdot BW \approx \frac{1}{f} \cdot \frac{1+a_{dc}f}{\tau} \approx \frac{a_{dc}}{\tau}$$

Fails if adc*f not >>1
or if not dominant pole