Lec 24 - Feedback

Output Stage & Incidence & Review

- Clarity of TFs
- Why does a loaded EF clip?
- Lab test setup or a true comparison - backoff, etc.

Op-amp summary
- Have diff input @ low Zo
- Need to gain

Gain stage
- Tend to put in feedback, use -ve

what is stability?
- No oscillations definition
- No. vs. Non-linearity
- Passive systems don't oscillate
- Accidental vs. purposeful FB & spotting stability

Root Locus Intros
- LCG setup
- True gain & steady-state error
- Open-loop vs closed loop gain & poles
- How to work w/ LCGs

Gain & Phase Margin
- Link between Bode & crossing to RHP
- Define Phase Margin (converts)
- Compensation
- Max cap load

Before we start, I want to take any Qs you have about output stages and errors.

lg. where does power MPTT come from? control L: makes not VDD
control S: make 2.10

We also need to revisit impedances in output stages in more detail
- Only one device on in push-pull or class AB
- Looks like weird EF w/ according R(t) + R(t), pick V(t) as avg?

Measuring Rout

Lo need to compute linear spots where only t is on

L x: V2 = (V1 - 0.7) * Rout / Rout + R(t)

Class AB like the or -ve EF, comes w/ I(t) so can get 9g9n I(t)

Fair comparisons
- Compare linearity under same power delivery - initial plan
- Compare under constant input - easier
- You don't need to fix non-linearity, just explain it

L: E(t)

\[
L(t) = I(t) / V(t)
\]

cancel effects @ VE

\[
I(t) = (E(t) - V(t)) / R(t) = \frac{V(t)}{R(t)} + \frac{V(t) - V(t)}{R(t)}
\]
Op-amps have 3 things: differential input with high \( Z_{in} \), infinite gain, zero zero zone.

- Don't have yet.

- DC coupled.
- Uses a level shift.
- Slew rate.

- Compensation cap.
- Large miller cap -> small BW.
- Why there?

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Almost always lose op-amps in feedback which has big implications for gain stage.

That's why any time you hear "feedback" -> think "risk of instability".

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**What is stability**

- Lots of formal definitions: Lyapunov, Nyquist, BIBO.
- For us, means: doesn't latch up, doesn't oscillate (out for clinicians).
- Can see in \( S \) domain: only see energy @ \( S \) we put in (+ harmonics if non-linear).

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Oscillations come from poles on imaginary axis.

- Poles might swing to RHP & back to LHP in describing functions.
- But our amps have LHP poles (exact analysis).
- Feedback moves poles (example in a second).
- We have parasitic feedback -> load rings to make us big -> have high \( f \) excitation @ all times.
Tiny intro to root locus techniques

- Root-locus techniques designed for P control system

\[ \text{Let } G(s) = \frac{G(s)}{s+1}, \text{ note } L(s) = kG(s) \]

\[ \frac{N_o}{V_i} = \frac{kG}{s+1} \]

\[ \frac{kG}{s+1+K} = \frac{kG}{s+1+k} = \frac{kG}{1+k(s+1)} \]

- Can draw pictures showing how
  pole moves called root-locus diagrams

- Good @ drawing diagrams lets us reason abt \( L(s) \) (usually well known)
  w/o thinking about \( Acl(s) \) (usually pain in butt)

- Aside: in op-amp example \( Acl \approx \frac{1}{s} \) — pole location, \( \omega_c \) (k=As)
  \( k = A5 \)

- Smaller \( k \) increases \( \omega_c \) increases gain

- Leads to constant gain -bandwidth product — result of 1st order roll-off
  in op-amps

- \( \omega_c = \frac{1}{\omega_c} \) s\( w_c = \frac{A5}{2} \)

- \( \omega_c \) of \( Acl = \frac{A5}{2} \cdot \frac{1}{s} = \frac{A}{2} \) — constant!

- Pick by setting \( Acl \) closed-loop
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- We don't have full root-locus training, want fast way to get from $L(s)$ to stability.

- Circuit design done w/ awesome hack called phase margin.

- Case where closed loop poles are on low axis or RHP:
  - Definitely unstable if $L(s) = -1$ & $A_{cl} = \infty$
  - If becoming unstable, poles crossing imaginary axis.
  - Can find $L(j\omega) = -1$ to get instability, comes from Bode.

Can easily find $L(j\omega) = -1 \rightarrow |L(j\omega)| = 1 \rightarrow \angle L(j\omega) = -\pi$

- Look for $|L(j\omega)| = 1$ on Bode plot ... called crossover.

- Crossover corresponds to non-unity gain in feedback (opamp comprised of $L(s)$) \rightarrow rolloff in $A_{cl}$.

- Distance from 180° of phase @ crossover is your phase margin.

- How far are you from crossing imaginary axis? \rightarrow $\phi$, dicye in conditionally stable systems.

→ Positive $\phi_m$ usually means stable ←

You try - system w/ 2 widely spread poles, $2^{nd}$ pole @ crossover.

- Can relate $\phi_m$ to peak overshoot.

- $45^\circ$ = very modest $\rightarrow Q = 3 \rightarrow \frac{\omega_n}{\omega} = 0.12$

Coming up:

- Feedback applications \rightarrow oscillators!

- Why do op-amps look like 1 pole? \rightarrow $\phi_m = 45^\circ$ is classy point.