Announcement

• Project phase 1 will be posted later this week.

• You’re welcome to use other real technologies if you have access to them.
  • Just clearly note it on your project reports.
Note: Equation v.s. Simulation

• Equation-based design approach:
  • Make design decisions based on analytical equations.
  + Offers circuit insights and fundamental tradeoffs.
  + Very fast.
  - Only works on simple circuits; usually need to make simplifying assumptions.
  - Accuracy is limited by how valid your assumptions are.
  - It is non-obvious as to how to design your circuit to be robust to variations.
Note: Equation v.s. Simulation

• Simulation-based design approach:
  • Make design decisions based on simulation results.
  + As accurate as you can get; the “Gold standard”.
  + Easy to adapt to design across process corners/variations.
  - Easy to fall into “Spice Monkey Trap,” just blindly do things without knowing what you’re doing.
  - Slow (especially if many iteration loops are involved).
Inverter-based TIA design

- Assume given gain/BW spec.
- How to choose feedback resistance?
- How to choose inverter size?
- Transistor ratios/DC bias left as exercise.
TIA Analysis

- What kind of feedback is this?
- What is the feedback factor?
- How do we do the feedback analysis? What do we have to be careful about?
- Lookup: Return-Ratio, Asymptotic Gain Model, Blackman’s formula.
TIA Analysis

- Ignore $C_{gd}$.
- We will derive analytical equations with KCL to guide our design decisions.
- Only two-poles; second order systems are studied to death.
KCL results

- \( A_0 = g_m r_o \)

- \( \frac{v_{out}}{i_{in}} = R_{dc} \cdot \frac{1}{1+2\zeta s/w_n+s^2/w_n^2} \)

- \( R_{dc} = -\frac{A_0 R_f}{1+A_0} + \frac{r_o}{1+A_0} \)

- \( w_n = \sqrt{\frac{1+A_0}{r_o R_f C_i C_L}} \)

- \( \zeta = \frac{1}{2\sqrt{1+A_0}} \left( \sqrt{\frac{r_o C_i}{R_f C_L}} + \sqrt{\frac{r_o C_L}{R_f C_i}} + \sqrt{\frac{R_f C_i}{r_o C_L}} \right) \)
Second order system

• Given a closed-loop second order system response $H(s) = \frac{1}{1 + 2\zeta s/w_n + s^2/w_n^2}$:

• $w_{3db} = w_n\sqrt{(2\zeta^2 - 1)^2 + 1 - (2\zeta^2 - 1)}$

• $\phi_{PM} = \tan^{-1}\left(\frac{2\zeta}{\sqrt{4\zeta^4 + 1 - 2\zeta^2}}\right)$

• Now we have a complete description of the system, how do we design? Which value should we try to change first?
Varying $R_f$

- What’s going on for small $R_f$?
- Observation: $W_{3db}$ seems monotonic (or at least unimodal).
- Seems like it’s always stable…?
Unstable TIA

- Now we have a “region of instability”
  - Does this make sense?
- How do we check if our TIA could be unstable or not?
Stability Criterion

- From Calculus/AM-GM, $\zeta_{min} = \sqrt{\frac{1+C_i/C_L}{1+A_0}}$

- Observations:
  - Possibility of instability does not depend on $R_f$ or $r_0$.
  - $C_i$, $C_L$, and $A_0$ doesn’t really change much.

- Design strategy:
  - Check if it’s possible to go unstable.
  - If so, find the “region of instability”, and make sure $R_f$ does not fall into that range.
Varying amplifier size

- Given 3dB bandwidth spec.
- Sweep amplifier size, for each size, find largest $R_f$ that meets BW spec.
  - Why largest $R_f$?
- Plot result
Varying amplifier size

- Maximum gain is achieved for a particular size.
- Beyond this point, increasing size only improve phase margin.