Lecture 28: Feedback TIAs

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Announcements

• Project
  • Preliminary report will be handed back on Wednesday with feedback
  • Final report due Dec 7
    • Only one ideal current source for biasing allowed (not tail current source)
    • Cadence schematic of key circuits

• Exam 3 on Dec 3
  • Reference exams posted today
Agenda

• Feedback TIAs

• Material is related primarily to Project #6
Common-Gate TIA

- Input resistance (input bandwidth) and transimpedance are decoupled
- Both the bias current source and RD contribute to the input noise current
- RD can be increased to reduce noise, but voltage headroom can limit this
- Common-gate TIAs are generally not for low-noise applications
- However, they are relatively simple to design with high stability

\[ R_T = R_D \]
\[ R_{in} \approx \frac{1}{g_{m1}} \]
\[ I_{n,in}^2 = 4kT\left(\frac{2}{3} g_{m2} + \frac{1}{R_D} \right) \left(\frac{A^2}{Hz}\right) \]

[Razavi]
Feedback TIA w/ Ideal Amplifier

[Sackinger]

With Infinite Bandwidth Amplifier:

\[ Z_T(s) = -R_T \left( \frac{1}{1 + s/\omega_p} \right) \]

\[ R_T = \frac{A}{A+1} R_F \]

\[ R_{in} = \frac{R_F}{A+1} \]

\[ \omega_p = \frac{1}{R_{in} C_T} = \frac{A+1}{R_F(C_D + C_I)} \]

- Input bandwidth is extended by the factor \( A+1 \)
- Transimpedance is approximately \( R_F \)
- Can make \( R_F \) large without worrying about voltage headroom considerations
Feedback TIA w/ Finite Amplifier Bandwidth

With Finite Bandwidth Amplifier:

\[ A(s) = \frac{A}{1 + \frac{s}{\omega_A}} = \frac{A}{1 + sT_A} \]

\[ Z_T(s) = -R_T \left( \frac{1}{1 + s/(\omega_o Q) + s^2/\omega_o^2} \right) \]

\[ R_T = \frac{A}{A+1} R_F \]

\[ \omega_o = \sqrt{\frac{A+1}{R_F C_T T_A}} \]

\[ Q = \sqrt{\frac{(A+1)R_F C_T T_A}{R_F C_T + T_A}} \]

\[ R_{in} = \frac{R_F}{A+1} \]

[Sackinger]
Feedback TIA w/ Finite Amplifier Bandwidth

- Non-zero amplifier time constant can actually increase TIA bandwidth!!
- However, can result in peaking in frequency domain and overshoot/ringing in time domain
- Often either a Butterworth (Q=1/sqrt(2)) or Bessel response (Q=1/sqrt(3)) is used
  - Butterworth gives maximally flat frequency response
  - Bessel gives maximally flat group-delay

[Sackinger]
Feedback TIA Transimpedance Limit

If we assume a Butterworth response for maximally flat frequency response:

\[ Q = \frac{1}{\sqrt{2}} \quad \omega_A = \frac{1}{T_A} = \frac{2A}{R_F C_T} \]

For a Butterworth response:

\[ \omega_{3dB} = \omega_0 = \sqrt{\frac{(A+1)\omega_A}{R_F C_T}} = \frac{\sqrt{(A+1)2A}}{R_F C_T} \approx \sqrt{2} \text{ times larger than } T_A = 0 \text{ case of } \frac{A+1}{R_F C_T} \]

Plugging \( R_T = \frac{A}{A+1} R_F \) into above expression yields the maximum possible \( R_T \) for a given bandwidth:

\[ \sqrt{\frac{(A+1)\omega_A}{(A+1)\frac{A}{A+1}R_T C_T}} \geq \omega_{3dB} \]

Maximum \( R_T \leq \frac{A \omega_A}{C_T \omega_{3dB}^2} \)

- Maximum \( R_T \) proportional to amp gain-bandwidth product
- If amp GBW is limited by technology \( f_T \), then in order to increase bandwidth, \( R_T \) must decrease quadratically!
Feedback TIA

Assuming that the source follower has an ideal gain of 1

\[ A = g_m R_D \]

\[ R_f = \frac{g_m R_D}{1 + g_m R_D} R_F \]

\[ R_{in} = \frac{R_F}{1 + g_m R_D} \]

\[ R_{out} = \frac{1}{g_m (1 + g_m R_D)} \]

[Razavi]
Common-Gate & Feedback TIA

[Sackinger]

- Common-gate input stage isolates CD from input amplifier capacitance, allowing for a stable response with a variety of different photodetectors

- Transimpedance is still approximately $R_F A/(1+A)$
CMOS Inverter-Based Feedback TIA

[Sackinger]
Next Time

- Bandgap References
- Distortion