Agenda

• Transimpedance Amplifiers
  • Common-Gate TI As
  • Feedback TI As

• Material is related primarily to Project #6
Transimpedance Amplifier (TIA)

Transimpedance $Z_T = \frac{v_{out}}{i_{in}} \quad (\Omega)$

Also expressed in units of dB$\Omega$ for $20 \log(|Z_T|)$
Optical Receiver Front-End

[Diagram of optical receiver front-end with components labeled and time plots showing input $I_{in}$, $V_1$, and output $V_{out}$ over time $t$.]

[Razavi]
Resistive Front-End

\[ R_T = R_{in} = R_L \]

\[ BW_{3dB} = \omega_p = \frac{1}{R_{in}C_D} = \frac{1}{R_LC_D} \]

- Direct trade-offs between transimpedance, bandwidth, and noise performance

\[ \overline{V_{n,\text{out}}^2} = \int_0^\infty I_n^2Z_Tdf = \int_0^\infty \frac{4kT}{R_L} \left( \frac{R}{1 + j2\pi fRC} \right)^2 df = \frac{kT}{C_D} \]

\[ \overline{I_{n,\text{in}}^2} = \frac{\overline{V_{n,\text{out}}^2}}{R_L^2} = \frac{kT}{R_L^2C_D} \]

\[ I_{n,\text{in,\text{rms}}} = \frac{\sqrt{KT/C_D}}{R_L} \]
Common-Gate TIA

\[ R_T = R_D \]
\[ R_{in} = \frac{r_o + R_D}{1 + (g_m + g_{mb})r_o} \approx \frac{1}{g_m} \]

- Input resistance (input bandwidth) and transimpedance are decoupled
Common-Gate TIA Frequency Response

Neglecting transistor $r_o$: 
\[ \frac{v_{out}}{i_{in}} = \frac{R_D}{\left(1 + s \frac{C_{in}}{g_{m1} + g_{mb1}}\right)(1 + sR_D C_{out})} \]

- Often the input pole may dominate due to large photodiode capacitance (100 – 500fF)
Common-Gate TIA Noise

- 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

Neglecting transistor $r_o$:

$$V_{n,\text{out}}^2 = (I_{n,M2}^2 + I_{n,RD}^2)R_D^2 = 4kT \left( \frac{2}{3} g_{m2} + \frac{1}{R_D} \right) R_D^2 \left( \frac{V^2}{\text{Hz}} \right)$$

$$I_{n,\text{in}}^2 = 4kT \left( \frac{2}{3} g_{m2} + \frac{1}{R_D} \right) \left( \frac{A^2}{\text{Hz}} \right)$$

[Razavi]
Regulated Cascode (RGC) TIA

A packaged low-noise high-speed regulated cascode transimpedance amplifier using a 0.6μm N-well CMOS technology

Sung Min Park and C. Toumazou

Figure 1. Schematic diagram of the regulated cascode (RGC) input stage

\[ Z_{in}(0) \equiv \frac{1}{g_{m1}\left(1 + g_{mB}R_B\right)} \]
• Inductors provide bandwidth extension at zero power cost, but very large area cost.

\[ Z_i \approx \frac{1}{g_{m1} (1 + |A_2A_3|) + j\omega C_{i,\text{tot}}} \]

\[ A_2 = g_{m2}R_2 \quad A_3 = -g_{m3}R_3 \]
Feedback TIA w/ Ideal Amplifier

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

[Sackinger]

With Finite Bandwidth Amplifier:

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

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

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

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

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

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

• Feedback TIA Examples
• Multi-Stage (Limiting) Amplifiers
• Bandgap References
• Distortion