ECEN474: (Analog) VLSI Circuit Design
Fall 2011

Lecture 26: Transimpedance Amplifiers (TIAs)

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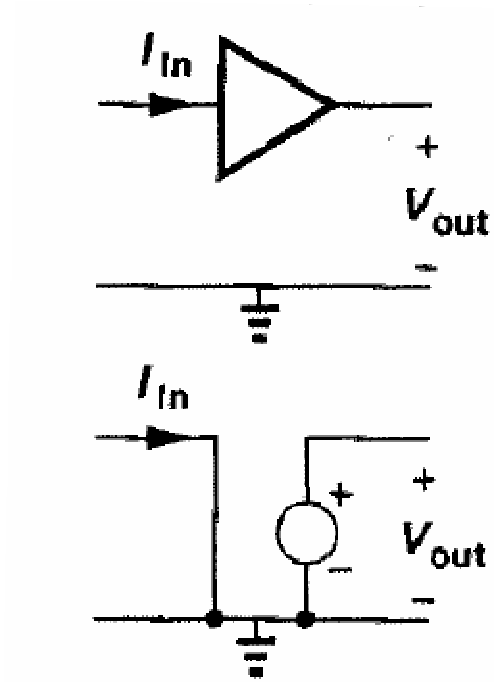
Agenda

- Transimpedance Amplifiers
  - Common-Gate TIAs
  - Feedback TIAs

- Material is related primarily to Project #6

Transimpedance Amplifier (TIA)

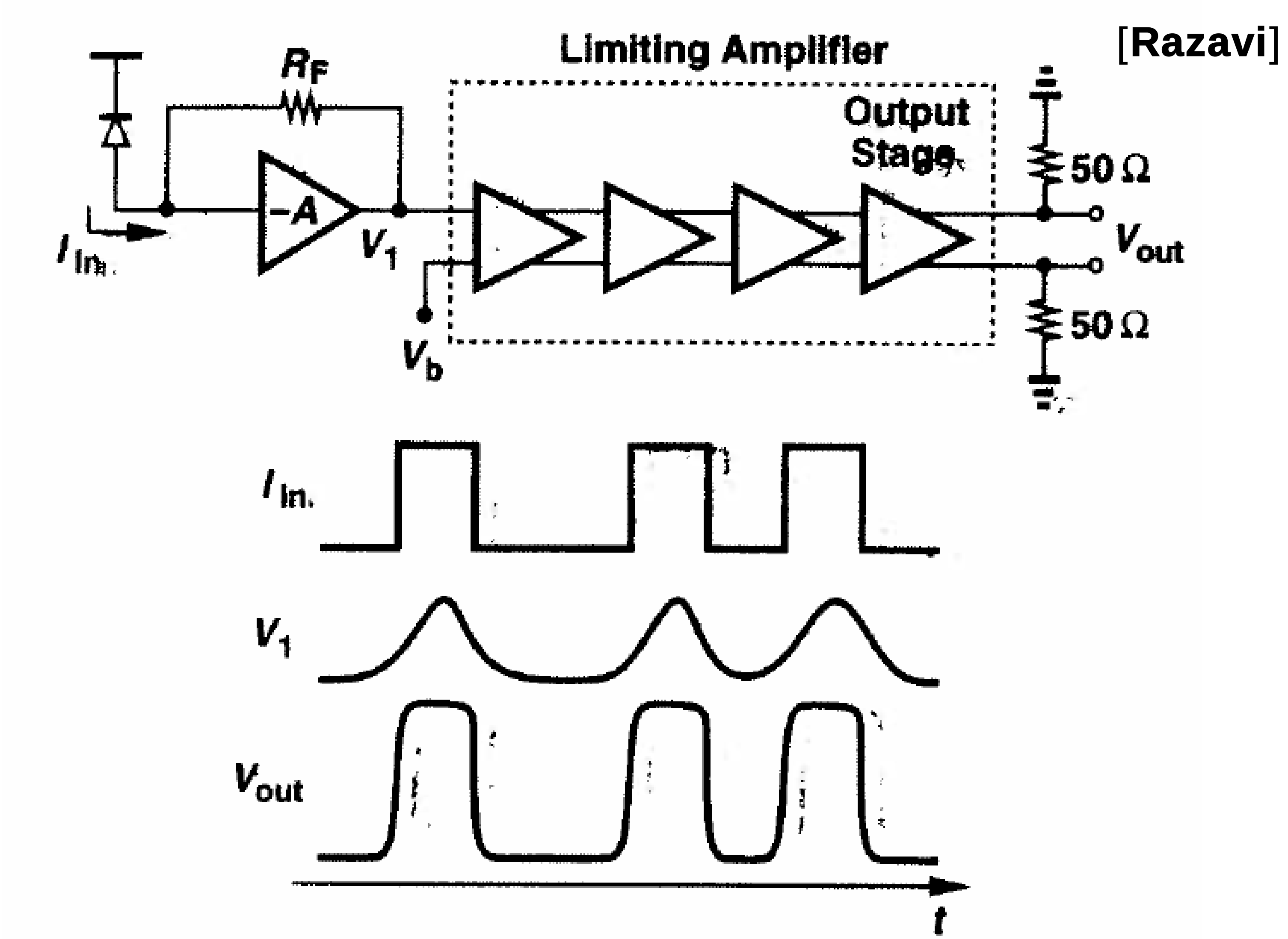


[Razavi]

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

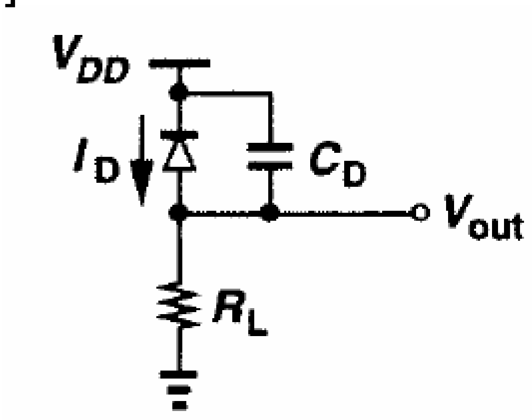
Also expressed in units of dBΩ for $20\log(|Z_T|)$

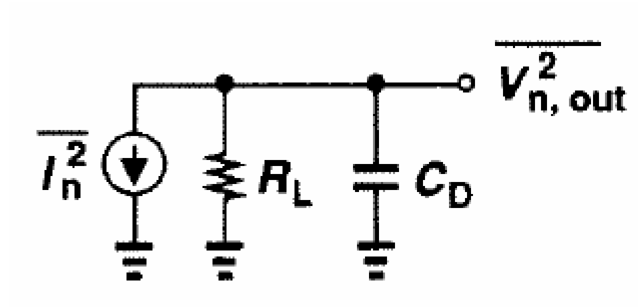
Optical Receiver Front-End



Resistive Front-End

[**Razavi**]





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

$$R_T = R_{in} = R_L$$

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

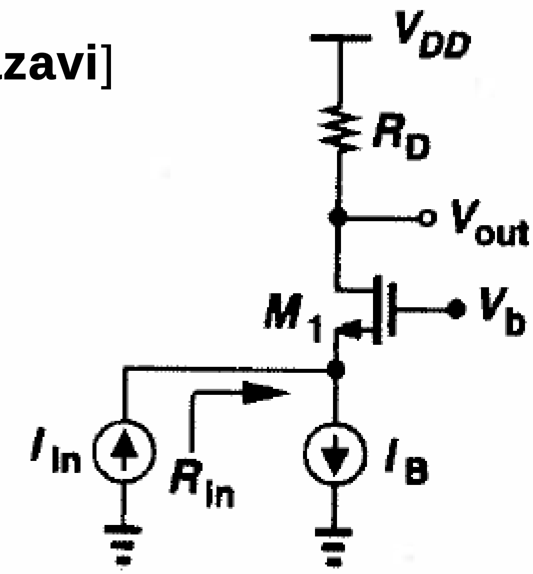
$$BW_{3dB} = \omega_p = \frac{1}{R_{in}C_D} = \frac{1}{R_L C_D}$$

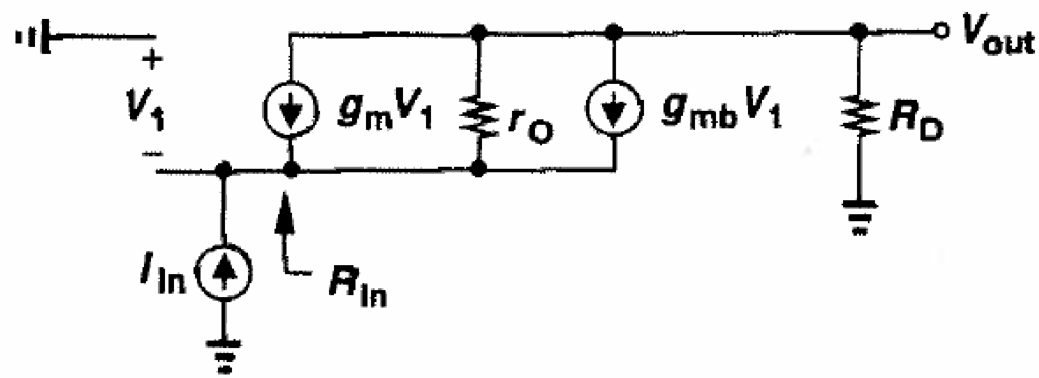
$$I_{n,in,rms} = \frac{\sqrt{KT/C_D}}{R_L}$$

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

Common-Gate TIA

[**Razavi**]



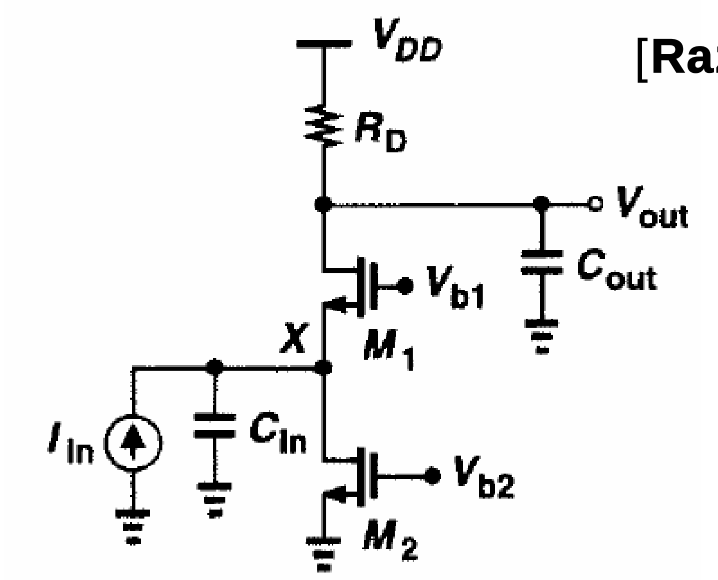


$$R_T = R_D$$

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

- Input resistance (input bandwidth) and transimpedance are decoupled

Common-Gate TIA Frequency Response



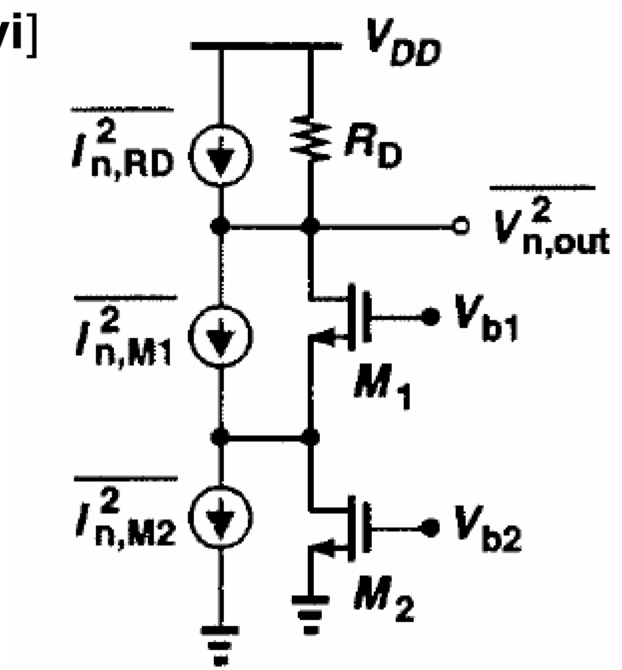
[Razavi]

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

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

Common-Gate TIA Noise

[**Razavi**]



Neglecting transistor r_o :

$$\overline{V^2_{n,out}} = \left(\overline{I^2_{n,M2}} + \overline{I^2_{n,RD}}\right) R_D^2 = 4kT\left(\frac{2}{3} g_{m2} + \frac{1}{R_D}\right) R_D^2 \quad \left(\frac{\mathbf{V}^2}{\mathbf{Hz}}\right)$$

$$\overline{I^2_{n,in}} = 4kT\left(\frac{2}{3} g_{m2} + \frac{1}{R_D}\right) \quad \left(\frac{\mathbf{A}^2}{\mathbf{Hz}}\right)$$

- 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

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

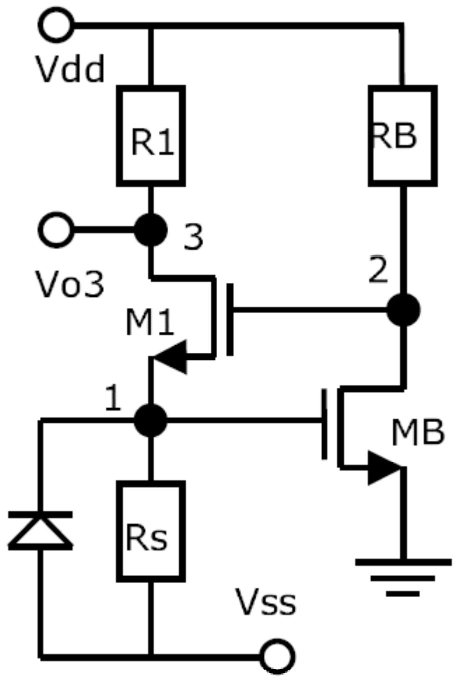


Figure 1. Schematic diagram of the regulated cascode (RGC) input stage

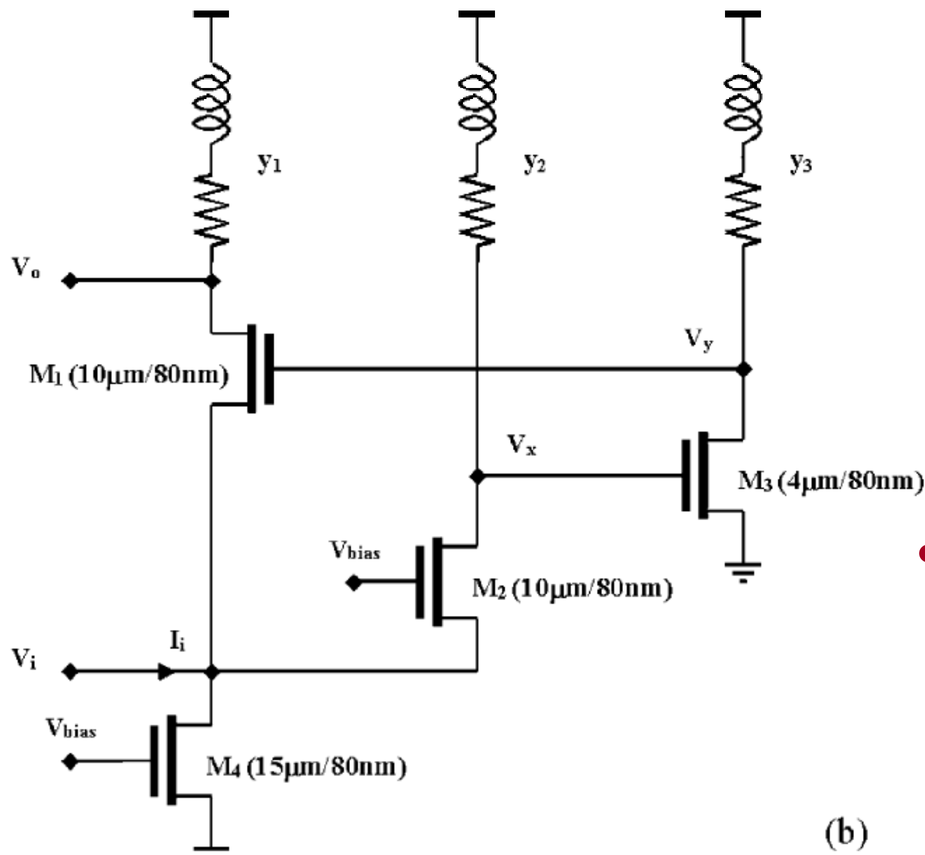
$$Z_{in}(0) \cong \frac{1}{g_{m1}\left(1 + g_{mB}R_B\right)}$$

CMOS 20GHz TIA

IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 39, NO. 6, JUNE 2004 885

A Low-Power 20-GHz 52-dBΩ Transimpedance Amplifier in 80-nm CMOS

Christian Kromer, *Member, IEEE*, Gion Sialm, Thomas Morf, *Member, IEEE*, Martin L. Schmatz, *Member, IEEE*, Frank Ellinger, *Member, IEEE*, Daniel Erni, *Member, IEEE*, and Heinz Jäckel, *Member, IEEE*



(b)

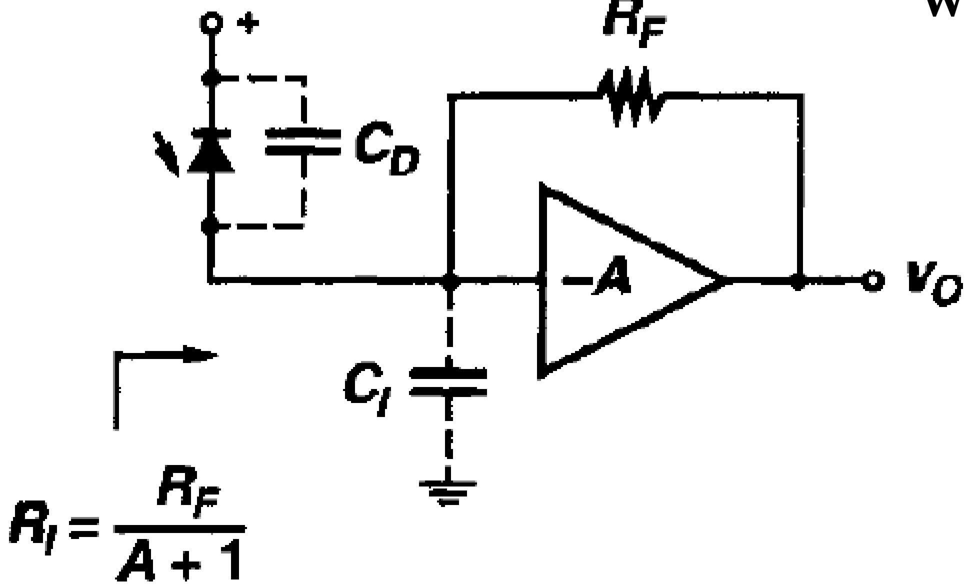
$$Z_i \approx \frac{1}{g_{m1}\left(1+|A_2A_3|\right)+j\omega C_{\mathrm{i,tot}}}$$

$$A_2 = g_{m2}R_2 \qquad A_3 = -g_{m3}R_3$$

- Inductors provide bandwidth extension at zero power cost, but very large area cost

Feedback TIA w/ Ideal Amplifier

[**Sackinger**]



With Infinite Bandwidth Amplifier :

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

$$R_T = \frac{A}{A+1}R_F$$

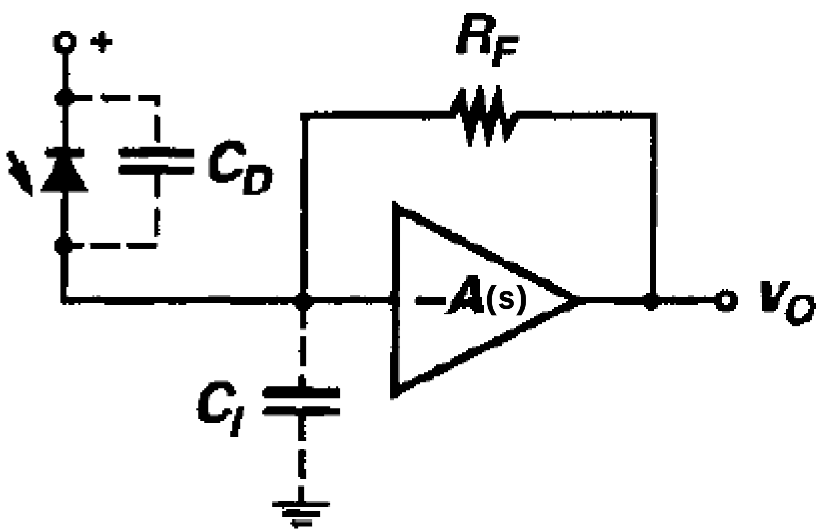
$$R_{in} = \frac{R_F}{A+1}$$

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

- 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

[**Sackinger**]



With Finite Bandwidth Amplifier :

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

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

$$R_T = \frac{A}{A+1}R_F$$

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

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

$$R_{in} = \frac{R_F}{A+1}$$

Next Time

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