ECEN474: (Analog) VLSI Circuit Design
Fall 2011

Lecture 27: Feedback TIAs

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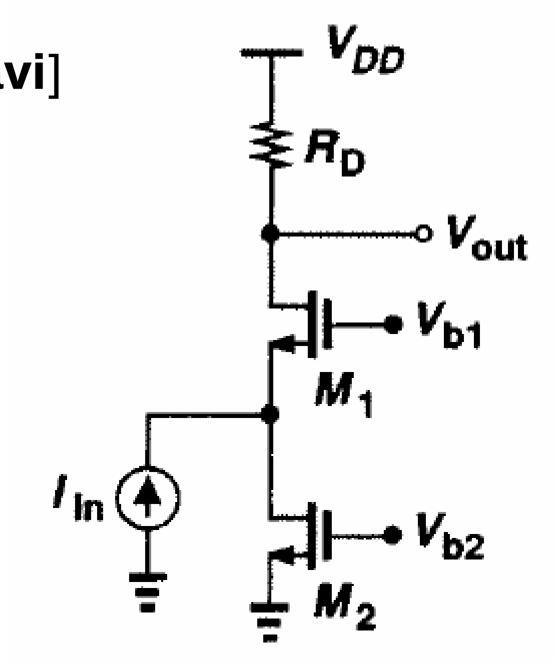
Common-Gate TIA

[**Razavi**]



$$R_T = R_D$$

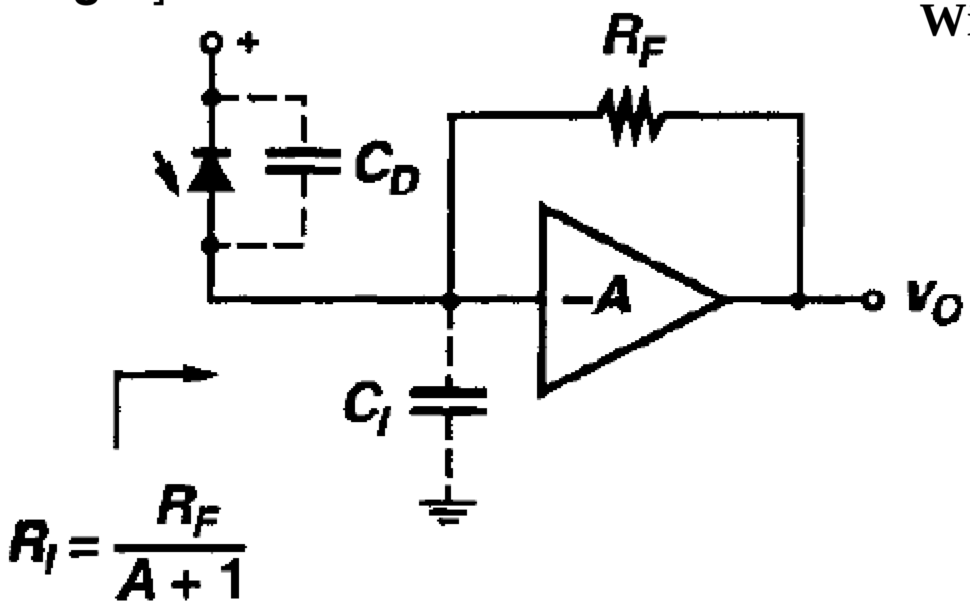
$$R_{in} \approx \frac{1}{g_{m1}}$$

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

- 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

Feedback TIA w/ Ideal Amplifier

[**Sackinger**]



With Infinite Bandwidth Amplifier :

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

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

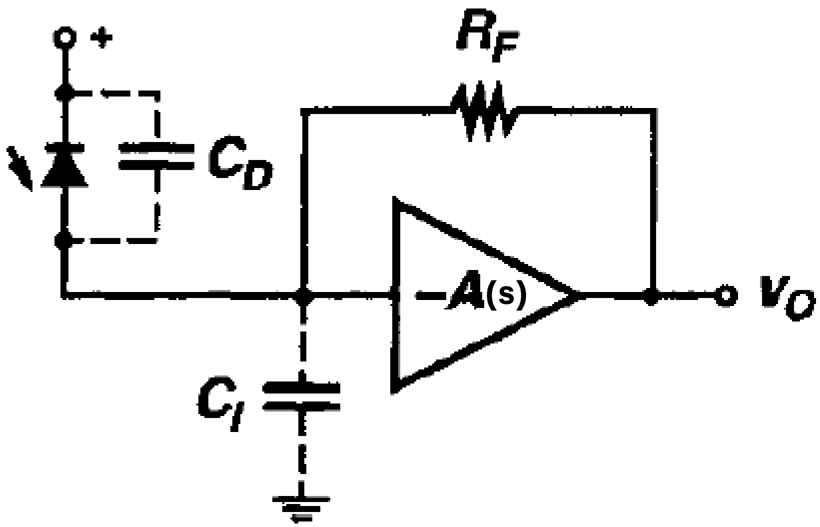
$$R_{in} = \frac{R_F}{A+1}$$

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

- 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 :

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

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

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

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

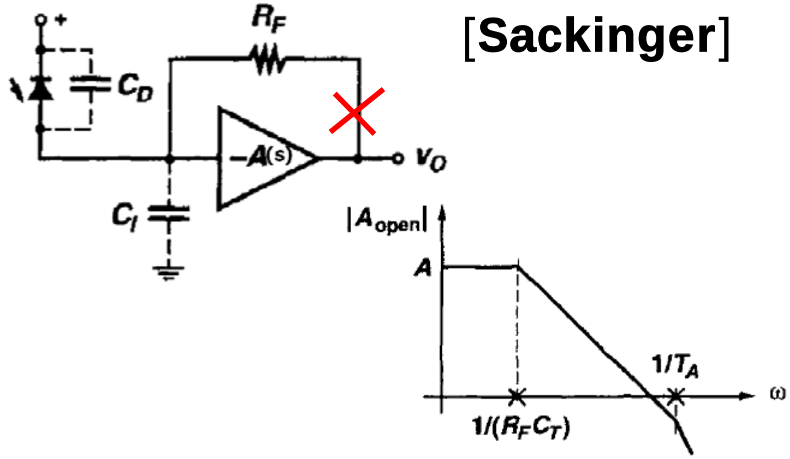
$$Q = \frac{\sqrt{(A+1) R_F C_T T_A}}{R_F C_T + T_A}$$

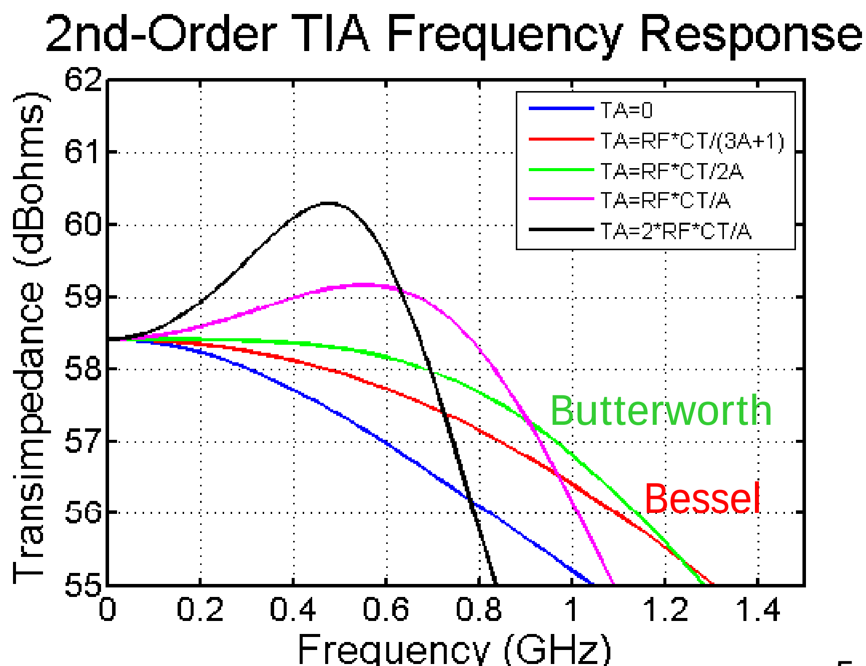
$$R_{in} = \frac{R_F}{A+1}$$

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 mazimally flat frequency response :

$$Q = \frac{1}{\sqrt{2}} \qquad \omega_A = \frac{1}{T_A} = \frac{2A}{R_F C_T}$$

For a Butterworth response :

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

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

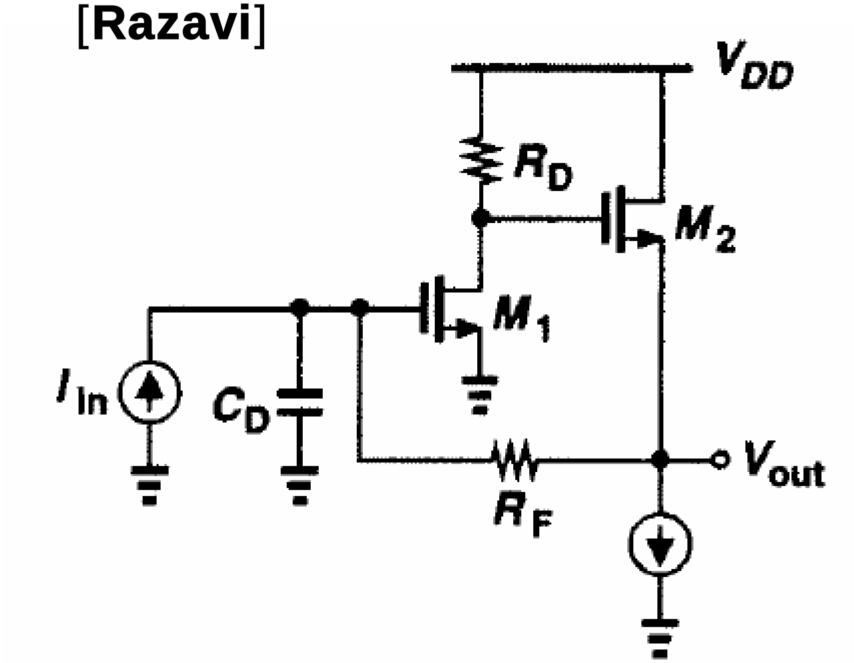
$$\sqrt{\frac{(A+1)\omega_A}{\left(\frac{A+1}{A}\right) R_T C_T}} \geq \omega_{\mathbf{3dB}}$$

$$\boxed{\textbf{Maximum } R_T \leq \frac{A\omega_A}{C_T \omega_{3dB}^2}}$$

- 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

[**Razavi**]



Assuming that the source follower has an ideal gain of 1

$$A = g_{m1} R_D$$

$$R_T = \frac{g_{m1} R_D}{1 + g_{m1} R_D} R_F$$

$$R_{in} = \frac{R_F}{1 + g_{m1} R_D}$$

$$R_{out} = \frac{1}{g_{m2}(1 + g_{m1} R_D)}$$

Common-Gate & Feedback TIA

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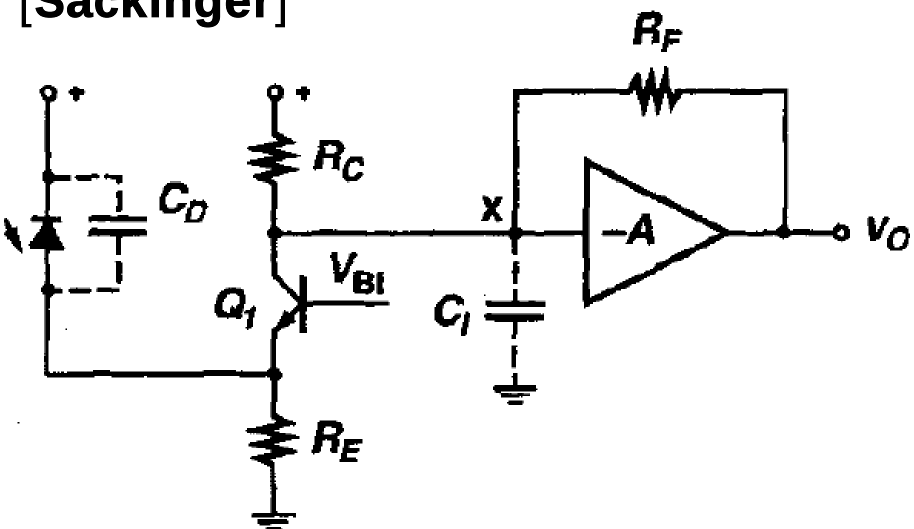

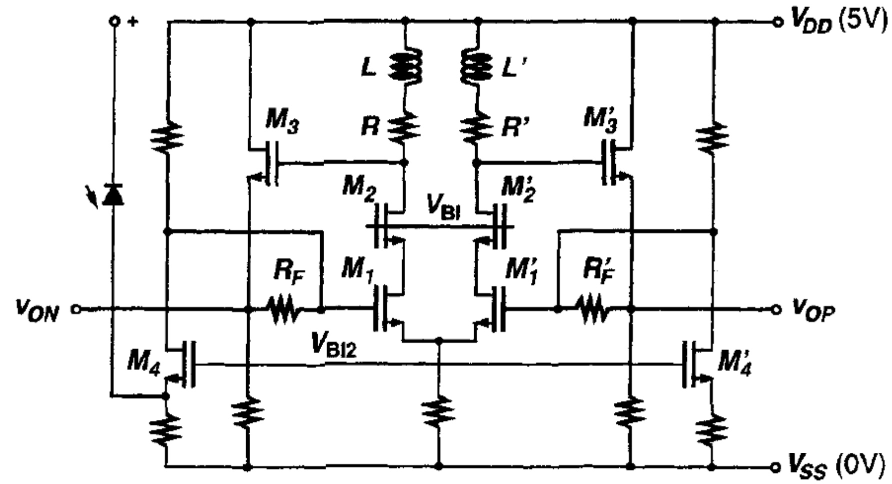

- Common-gate input stage isolates CD from input amplifier capacitance, allowing for a stable response with a variety of different photodetectors
- Transimpedance is still approximately $R_F A/(1+A)$

CMOS Inverter-Based Feedback TIA

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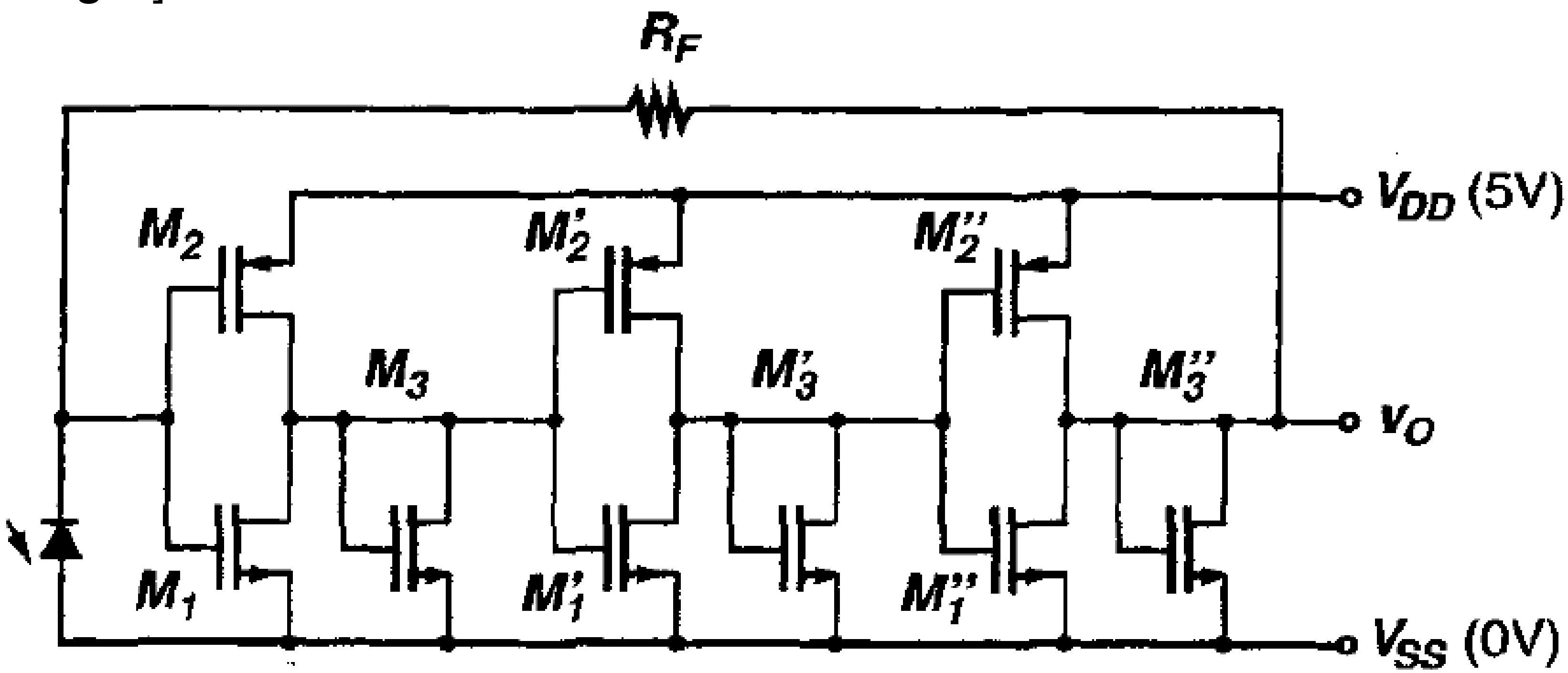

Next Time

- Bandgap References
- Distortion