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Technical Brief: How to Create Very Small, Controlled TIA Feedback Capacitor Values

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Suppose you are tasked with designing a high-bandwidth and a high-gain trans-impedance amplifier (TIA) to read small currents from a photodiode. Your design requires a TIA gain of one million V/A, and a bandwidth (BW) of 1MHz. The first part is easy, simply picking a feedback resistor (R_f) of 1MΩ.

Knowing that the RC time constant of the feedback network sets the bandwidth, you calculate the required feedback capacitor (C_f) to be 159fF where $C_f = 1 / (2\pi \text{ x } 1M\Omega \text{ x } 1MHz) = 159fF$. See *Figure 1*.

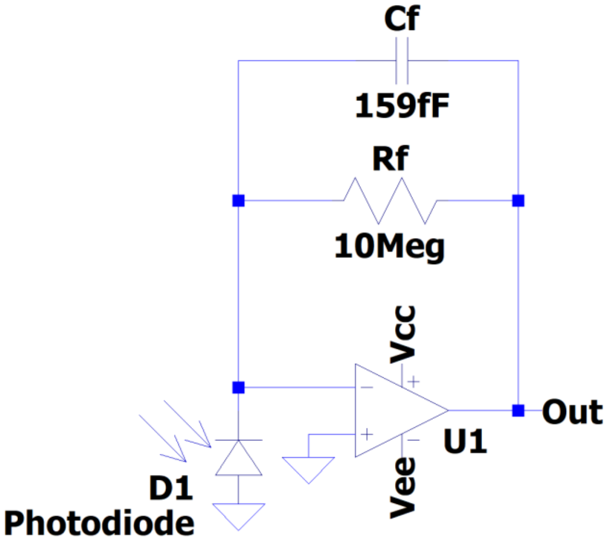

Figure 1: Simple Circuit, High-Gain, High Bandwidth TIA (the photodiode has inherent capacitance across it)

All of a sudden, this isn't so easy. You can't just buy a 159fF capacitor and solder it in parallel with a 1Meg resistor. For example, if R_f is an 0805 surface-mount package, it has about 200fF worth of stray capacitance (which can vary from say 100 to 400fF). With good PCB techniques (as can be seen in the [DC2414A Demo Board Manual](#)), the stray capacitance (C_{stray}) can be reduced. With good layout techniques (which may include some resistors in series for R_f to help reduce the overall C_{stray}), say it gets reduced to 59fF. If we could add an external capacitor across C_{stray} with a value of 100fF, then the total C_f will equal 159fF.

We present two methods by which one can build a well-controlled low value capacitor: (1) the capacitor-Tee method, and (2) the capacitor/resistor divider method. In both of these cases, make sure that your op amp has enough bandwidth for your application.

1) **Capacitor-Tee Method:** See *Figure 2*. The addition of C1, C2, and C3 creates an equivalent capacitance between the op amp output and the inverting input based upon this formula: $C_{equivalent} = (C1 \text{ x } C2)/(C1 + C2 + C3)$. With the values shown, $C_{equivalent}$ equals 100fF. $C_{equivalent}$ is in parallel with the stray capacitance and therefore creates a total feedback capacitance with a value of 159fF which meets the original design requirement.

2) **Capacitor/Resistor Divider Method:** See *Figure 3*. Here, the effective feedback capacitance is reduced by the resistor divider fraction of R1 and R2. The equivalent capacitance is calculated by this formula: $C_{equivalent}$ = ~C1 x R2/R1. Again, with the values shown, $C_{equivalent}$ equals 100fF, and the total feedback capacitance is 159fF.

So which method is better? With a sufficient op amp gain-bandwidth product, both methods yield the same -3dB roll-off frequency as the simple circuit of *Figure 1*. However, the addition of the extra components does add more overall output noise due to voltage gain. In simulations with the values shown (using ideal op amps), the capacitor-Tee is ≈2.4% noisier than the simple circuit, and the capacitor/resistor divider is ≈2.5% noisier than the simple circuit. This is good news, because essentially, one has to pay only a small penalty to have a realizable C_f. In *Figure 2*, if C1 & C2 are reduced to 4pF, C3 then becomes 152pF, and the noise percentage reduces to approximately 0.7%. The same is true in *Figure 3* when C1 changes to 4pF and R2 to 25Ω, then the noise reduces to approximately 0.8%. So, the comparison really depends on the voltage noise gain of the two circuits—which depends on the actual component values.

As usual, for a real design, it would be useful to simulate both circuits in Spice to see which circuit is likely to have lower voltage noise gain. If you're not positive which will have lower noise, you can always switch form one method to the other by changing resistors and capacitors with no extra footprints, components, or wires!

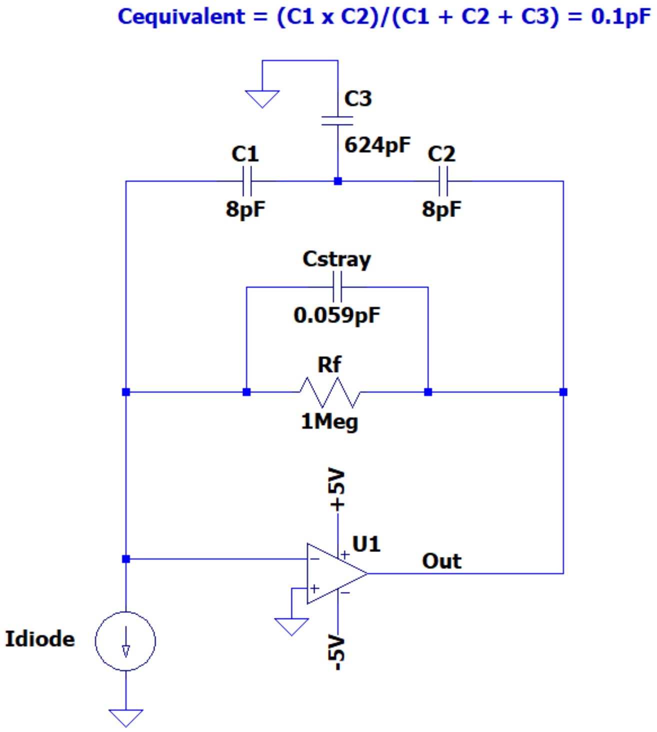

Figure 2: High-gain, high BW TIA with capacitor-Tee (the photodiode has inherent capacitance across it)

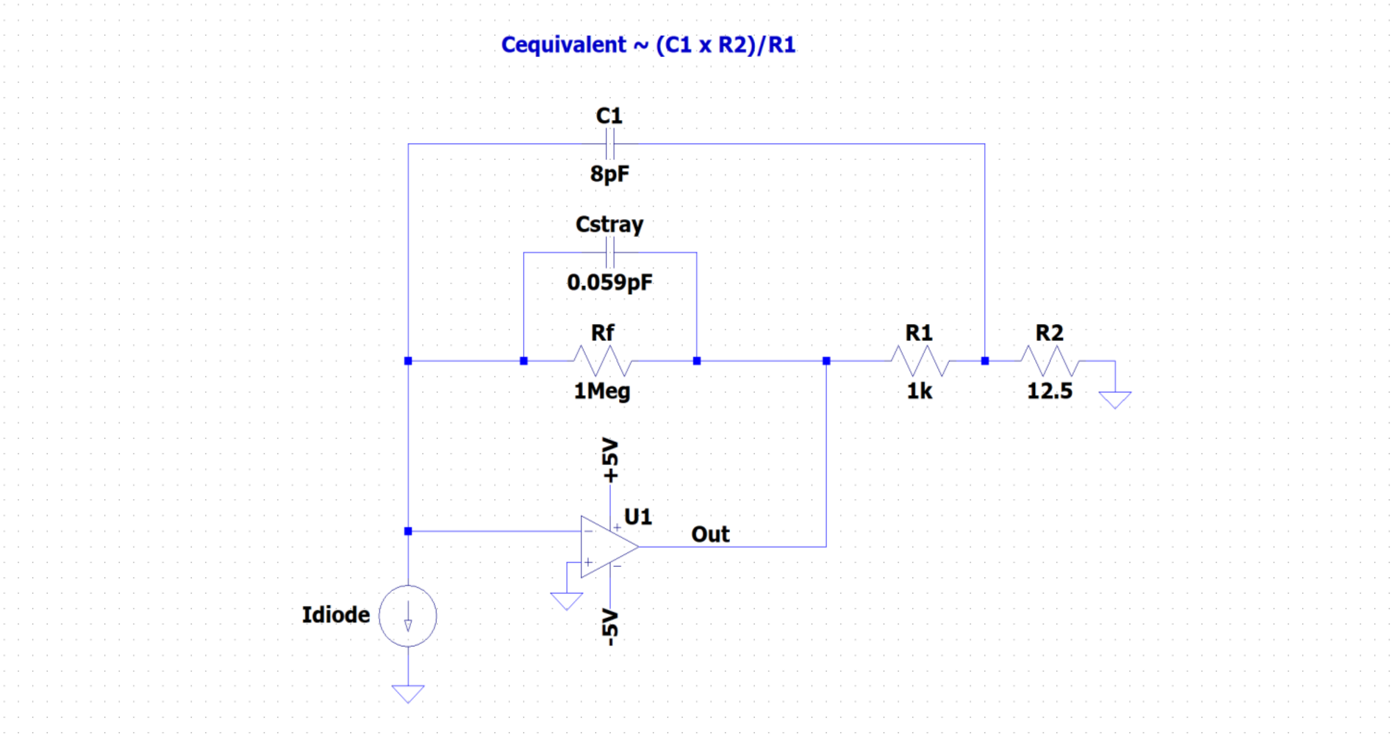

Figure 3: High-gain, high BW TIA with capacitor/resistor divider (the photodiode has inherent capacitance across it)