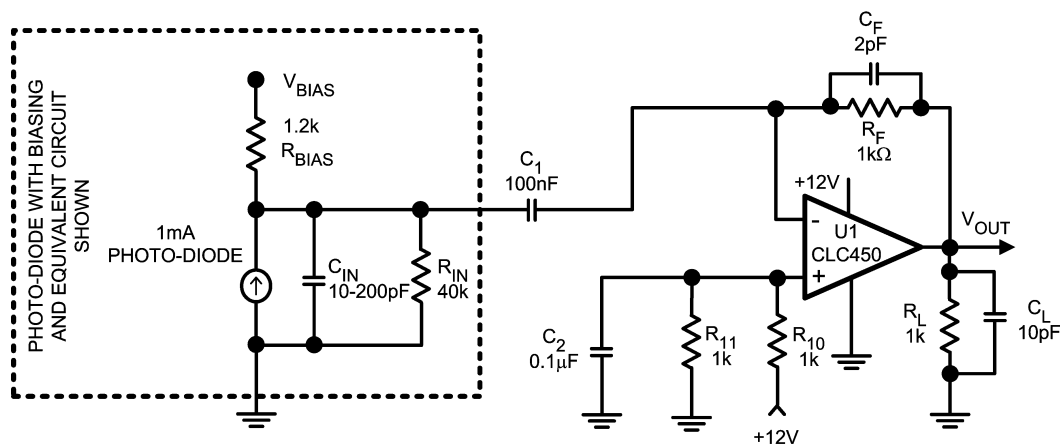# Photo-Diode Current-to-Voltage Converters

Converting the small output current of a photo-diode transducer to a fast responding voltage is often challenging. Here are some ways to use high-speed Current Feedback and Voltage Feedback op amps to do the job

Current Feedback Amplifier Solution

Current Feedback Amplifiers (CFA) are especially suited to implement this function, as shown in *Figure 1*. With an effective internal buffer on the inverting node of the op amp, the output impedance R_O (internal to U1, not shown) and the photo-diode's output capacitance C_{IN} (typically 10-200pF) introduce a zero in the noise gain at approximately $1/2\pi$ x (R_O x C_{IN}). In comparison, the zero produced by a Voltage Feedback op amp in a similar configuration [$1/2\pi$ x ($R_{IN}||R_F||R_{BIAS}$) x C_{IN}] tends to be much lower in frequency and more troublesome. This being the case, C_{IN} has less of an effect on reduction of the converter bandwidth, and achieving stability is easier when using a CFA.

If C_{IN} is sufficiently large, the closed loop phase shift will approach − 180˚ at the cross-over frequency (where open loop transimpedance gain crosses the noise gain function). As with Voltage Feedback Amplifiers, the closed loop amplifier can be compensated by adding a small capacitor (C_F) across R_F. In the case of *Figure 1*, using the CLC450 CFA, C_F was experimentally determined to be around 2pF for about 10% overshoot in the step response. C_F improves stability by counteracting the effect of the zero discussed in the paragraph above by introducing a low frequency pole ($1/2\pi$ x R_F x C_F) and an inconsequential zero ($1/2\pi$ x R_O x C_F).
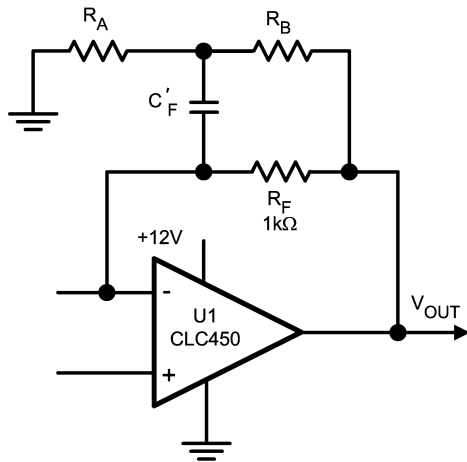

FIGURE 1. Single-Supply Photo-Diode Amplifier Using CLC450 Current-Feedback Amplifier

It is possible to change the required 2pF compensation capacitor to a more practical value, by adding R_A and R_B in a voltage divider, as shown in *Figure 2*. The new value of C'$_f$ is $(1+R_B/R_A)$ x C_F. This relationship holds true as long as $R_B << R_F$.

For this example, select R_A = 50Ω, and R_B = 500Ω. Therefore, C'$_f$ = (1+500/50) x2pF = ~22pF which is a much more practical component value. This value needs to be 'fine tuned' in the real application for proper step response.

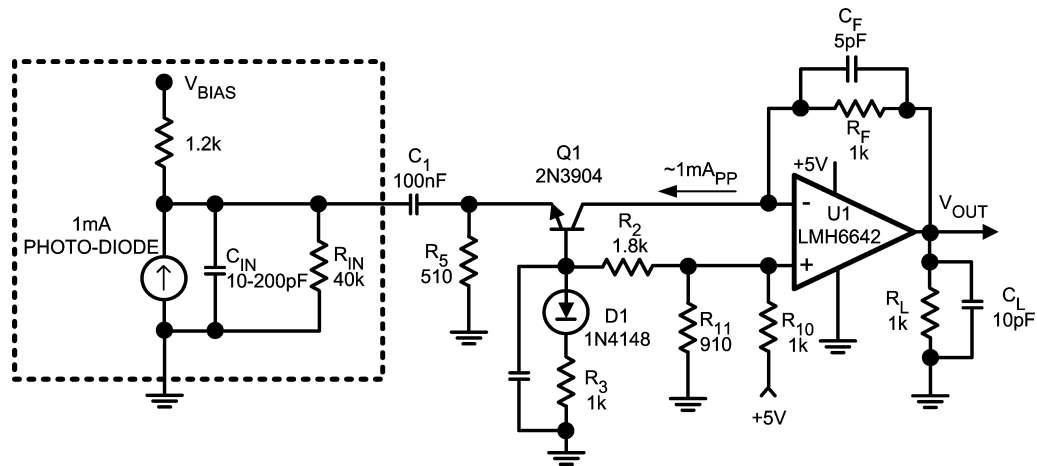## Current Feedback Amplifier Solution (Continued)

FIGURE 2. R_A -R_B Resistor Divider Allows Use of Practical Value for C'_f

Voltage Feedback Amplifier Solution

It's more difficult to design a good current-to-voltage converter using a Voltage Feedback Amplifier (VFA). As discussed above, phase shift caused by photo-diode capacitance is often a source of instability. Furthermore, wide bandwidth usually comes at the expense of supply currents and higher supply voltage. However, the new LMH6642 high-speed low-voltage VFA op amp has excellent performance in a transimpedance gain block, as shown in *Figure 3*. This device can operate down to 2.7V single supply and its −3dB BW (A_V = +1) is more than 100MHz (with a supply current of only 2.7mA)! Because of the 'Dielectric Isolation' process this device is based on, the traditional supply voltage vs. speed trade-off has been alleviated to a great extent allowing low power consumption and operation at lower supply voltages. In addition, the device has Rail-to-Rail output swing capability to maximize the output swing, and is capable of driving ±50mA into the load.

With 5V single supply, the device common mode voltage is shifted to near half-supply using R_{10}-R_{11} as a voltage divider from V_{CC}. The common-base transistor stage (Q1) isolates the photo-diode's capacitance from the inverting terminal, allowing wider bandwidth and easing the compensation required. Note that the collector of Q1 does not have any voltage swing, so the Miller effect is minimized. The diode on the base of Q1 is for temperature compensation of its bias point. Q1 bias current was set to be large enough to handle the peak-to-peak photo-diode excitation, yet not too large as to shift the U1 output too far from mid-supply. The overall circuit draws about 4.5mA from the +5V power supply and achieves about 35MHz of closed loop bandwidth @1V_{PP}. *Figure 4* shows the output large signal step response. C_F can be increased to reduce the overshoot, at the expense of bandwidth.

FIGURE 3. Single-Supply Photo-Diode Amplifier Using LMH6642 Voltage-Feedback Op Amp

Voltage Feedback Amplifier Solution (Continued)

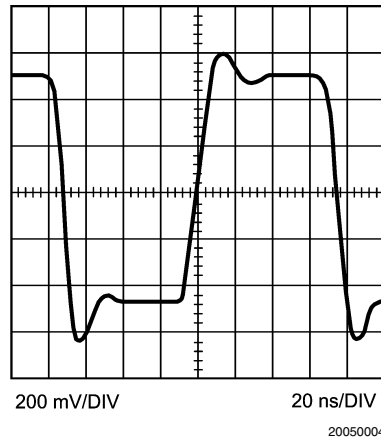200 mV/DIV   20 ns/DIV

20050004

FIGURE 4. Output Step Response 20ns/div, 0.2V/div

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