

## DESIGNING PHOTODIODE AMPLIFIER CIRCUITS WITH OPA128

The OPA128 ultra-low bias current operational amplifier achieves its 75fA maximum bias current without compromise. Using standard design techniques, serious performance trade-offs were required which sacrificed overall amplifier performance in order to reach femtoamp (fA = 10<sup>-15</sup> A) bias currents.

### UNIQUE DESIGN MINIMIZES PERFORMANCE TRADE-OFFS

Small-geometry FETs have low bias current, of course, but FET size reduction reduces transconductance and increases noise dramatically, placing a serious restriction on performance when low bias current is achieved simply by making input FETs extremely small. Unfortunately, larger geometries suffer from high gate-to-substrate isolation diode leakage (which is the major contribution to BIFET® amplifier input bias current).

Replacing the reverse-biased gate-to-substrate isolation diode structure of BIFETs with dielectric isolation removes this large leakage current component which, together with a noise-free cascode circuit, special FET geometry, and advanced wafer processing, allows far higher *Difet*® performance compared to BIFETs.

### HOW TO IMPROVE PHOTODIODE AMPLIFIER PERFORMANCE

An important electro-optical application of FET op amps is for photodiode amplifiers. The unequaled performance of the OPA128 is well-suited for very high sensitivity detector designs. A few design tips for photodiode amplifiers may be helpful:

- *Photodiode capacitance should be as low as possible.* See Figure 1: C<sub>J</sub> affects not only bandwidth but noise as well. This is because C<sub>J</sub> and the op amp's feedback resistor form a noise-gain zero (feedback pole).
- *Photodiode active area should be as small as possible so that C<sub>J</sub> is small and R<sub>J</sub> is high.* This will allow a higher signal-to-noise ratio. If a large area is needed, consider using optical "gain" (lens, mirror, etc.) rather than a large area diode. Optical "gain" is essentially noise-free.
- *Use as large a feedback resistor as possible (consistent with bandwidth requirements) to minimize noise.* This seems paradoxical, but remember, resistor thermal noise increases as:

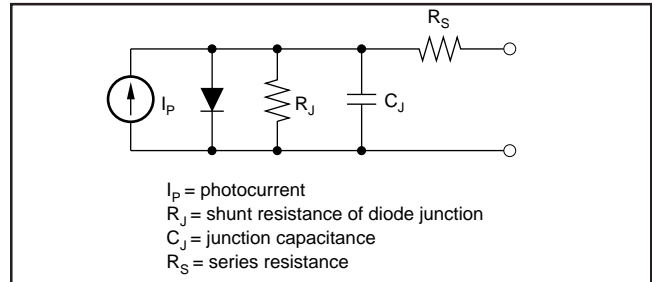


FIGURE 1. Photodiode Equivalent Circuit.

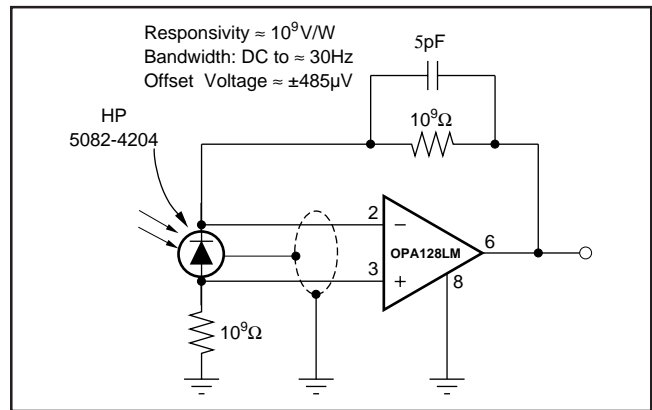


FIGURE 2. High-Sensitivity Photodiode Amplifier.

$$e_{OUT} = \sqrt{4k TBR}$$

k: Boltzman's constant = 1.38 x 10<sup>-23</sup> J/K  
 T: temperature (°K)  
 B: noise bandwidth (Hz)  
 R: feedback resistor (Ω)  
 e<sub>OUT</sub>: noise voltage (V<sub>rms</sub>)

while transimpedance gain (signal) increases as:

$$e_{OUT} = i(\text{signal}) R$$

Signal-to-noise improves by  $\sqrt{R}$ .

- *A low bias current op amp is needed to achieve highest sensitivity.* Bias current causes voltage offset errors with large-feedback resistors. Wide bandwidth circuits with smaller feedback resistors are less subject to bias current errors, but even in these circuits, bias current must be

considered if wide temperature range operation is expected. The OPA128LM specs only  $\pm 2\text{pA}$  max at  $+70^\circ\text{C}$ . Bias current also causes shot noise.

$$i_s = \sqrt{2qi}$$

q:  $1.602 \times 10^{-19}$  coulombs

i: bias (or signal) current (A)

$i_s$ : noise current (A rms)

In most circuits, the dominant noise source will be the thermal (Johnson) noise of the feedback resistor.

- Diode shunt resistance ( $R_J$ ) should be as high as possible. If  $R_J \gg R_F$ , then the circuit DC gain (noise gain) is  $1V/V$ . Low resistance diodes will cause noise, voltage offset, and drift to be amplified by  $1 + R_F/R_J$ .

Since diode shunt resistance decreases at a higher temperature, it can cause unexpected errors. In Figure 3 a diffused-junction GaAsP photodiode is used to maintain  $R_J = 3000\text{M}\Omega$  at  $+60^\circ\text{C}$ . Due to its higher bandgap, GaAsP has a flatter  $R_J$  versus temperature slope than silicon.

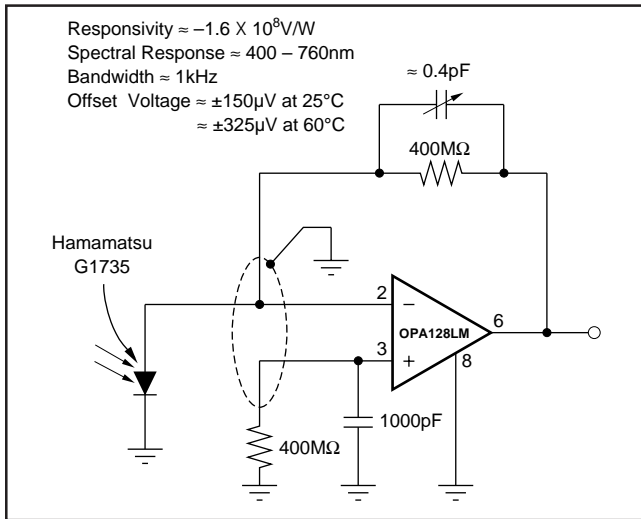


FIGURE 3. Wide-Temperature Range Photodiode Amplifier.

- For highest sensitivity use the photodiode in a “photovoltaic mode”. With zero-bias operation, dark current offset errors are not generated by this (photodiode leakage) current. Zero bias is a slower but higher sensitivity mode of operation. Most photodiodes work quite effectively with zero bias, even those originally designed for reverse-biased operation.
- Fastest response and greatest bandwidth are obtained in the “photoconductive mode”. Reverse bias reduces  $C_J$  substantially and also reduces or eliminates the slow rise time diffusion “tail” which is troublesome at longer wavelengths. Disadvantages of biased operation are: dark current,  $1/F$  noise component is introduced, and the occasional need for an extra bias supply.

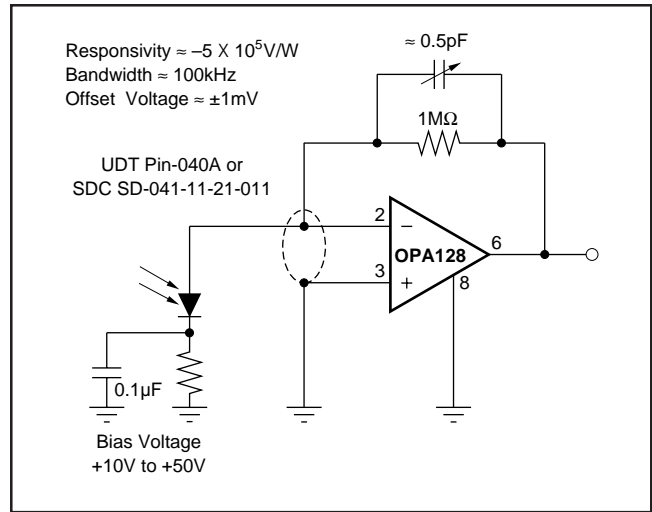


FIGURE 4. Wider-Bandwidth Photodiode Amplifier.

- A very high resistance feedback resistor is MUCH better than a low resistance in a T network. See Figure 5. Although transimpedance gain ( $e_{OUT}/i_{SIGNAL}$ ) is equivalent, the T network will sacrifice performance. The low feedback resistance will generate higher current noise ( $i_N$ ) and the voltage divider formed by  $R_1/R_2$  multiply input offset voltage, drift, and amplifier voltage noise by the ratio of  $1 + R_1/R_2$ . In most electrometer amplifiers, these input specifications are not very good to start with. Multiplying an already high offset and drift (sometimes as high as  $3\text{mV}$  and  $50\mu\text{V}/^\circ\text{C}$ ) by use of a T network becomes impractical. By using a far better amplifier, such as the OPA128, moderate T network ratios can be accommodated and the resulting multiplied errors will be far smaller. Although a single very-high resistance will give better performance, the T network can overcome such problems as gain adjustment and difficulty in finding a large value resistor.

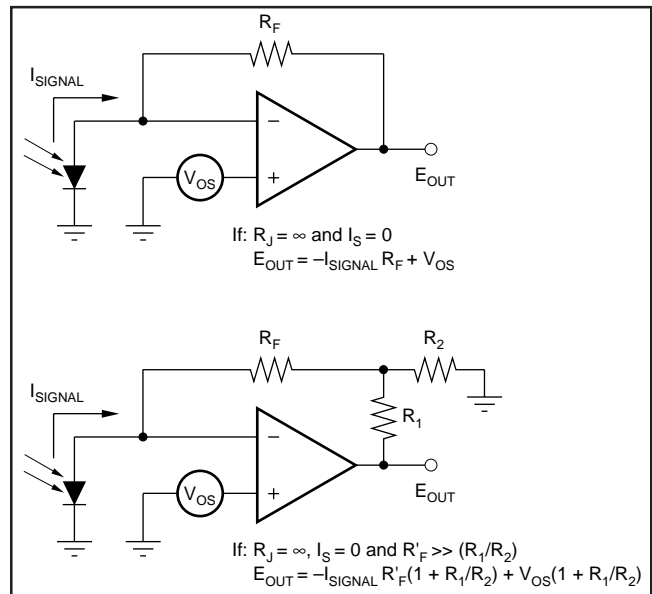


FIGURE 5. Feedback Resistors for Transimpedance Amplifiers.

- *Shield the photodetector circuit in a metal housing.* It is a very high impedance, high sensitivity circuit and it requires good shielding and effective power supply bypassing. This is **not** optional.
- *A small capacitor across  $R_F$  is frequently required to suppress oscillation or gain peaking.* Although it can affect bandwidth, a small amount of capacitance will usually be required to ensure loop stability. This capacitor can be made larger for bandwidth limitation if desired.

## KEY OPA128 SPECIFICATIONS

Bias current .....	75fA max
Offset voltage .....	500 $\mu$ V max
Drift .....	5 $\mu$ V/ $^{\circ}$ C max
Noise .....	15nV/ $\sqrt{\text{Hz}}$ at 10kHz

BIFFET<sup>®</sup> National Semiconductor Corp.; *Difet*<sup>®</sup> Burr-Brown Corp.

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