

Transimpedance Amplifiers for Wide Range Photodiodes Have Challenging Requirements

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Photodiodes are used in a wide variety of applications to transform light into a current or voltage which can then be used in electronic circuits. These range from solar cells to optical data networks, from precision instruments to chromatography to medical imaging. All of these applications share a need for circuitry to buffer and scale the photodiode output. For applications requiring high speed and high dynamic range, transimpedance amplifier (TIA) circuits like the one shown in Figure 1 are often used. In this figure, the feedback capacitance is shown as a parasitic capacitance. For many applications, this is a deliberately placed capacitor to ensure stability.

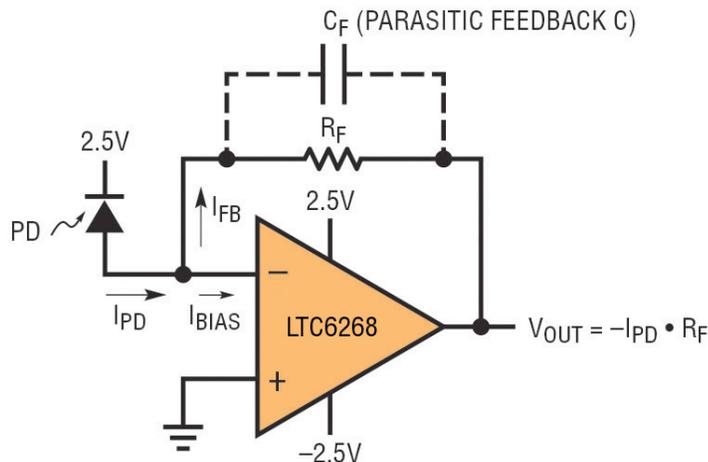


Figure 1: Transimpedance Amplifier

This circuit has the photodiode in “photoconductive mode” with a bias voltage applied to the cathode. The virtual connection between the two op amp inputs holds the anode at ground, thus applying a constant reverse bias voltage across the photodiode. A photodiode can be thought of as a current source (proportional to light intensity), a capacitor, a large resistor, and a so-called dark current all connected in parallel. The larger the bias voltage across the diode, the smaller the photodiode capacitance tends to become. While this is good for speed, it is limited in practice by the capability of a photodiode to withstand large reverse voltages.

The current generated by the photodiode (I_{PD}) is amplified by the TIA circuit and converted to an output voltage through the transimpedance gain resistor (also referred to here as the feedback resistor, or R_F). Ideally all of this current flows through R_F (i.e., $I_{FB} = I_{PD}$), but in practice the amplifier “steals” some of this current in the form of op amp input bias current.

This bias current results in an error voltage at the output and limits dynamic range. The larger the gain resistor, the greater this effect. It is important to select an amplifier with sufficiently low bias current (as well as input offset voltage and input offset voltage drift) to achieve the required dynamic range and overall accuracy.

One other consideration is the effect of op amp input current variation over temperature. Op amps with bipolar input stages have fairly constant input current. But this current is so high even at room temperature (nA or even μA) that unbuffered bipolar amplifiers are not suitable for many high transimpedance gain applications. For this reason, op amps with a FET input stage are often preferred over bipolar amplifiers because they have inherently lower input current – often in the single digit picoampere range or even lower at room temperature. But input ESD protection diodes leak as they get hot, causing the input current to rise exponentially with temperature. It is not unusual for an op amp with pA bias current at room temperature to have nA input current at 125°C . An op amp that addresses this problem by bootstrapping the ESD diodes is described later in this article. Another alternative is to use a discrete FET to buffer the photodiode at the amplifier input, but this requires an additional component and the associated board space and has relatively high input capacitance.

Since dynamic range is the ratio of maximum output signal to noise, it is also important to select an op amp with sufficiently low noise. Op amp current noise and voltage noise both matter, in varying degrees depending on the value of R_F and C_{IN} . The input capacitance, C_{IN} (see Figure 2), is a combination of the photodiode capacitance, the amplifier input capacitance, and stray board capacitances. In transimpedance amplifier circuits, the current noise is multiplied by R_F , causing noise to appear as an output voltage error. Also, the amplifier's voltage noise is multiplied by the noise gain. So for higher R_F values, current noise (i_n) becomes more dominant, and for circuits with high C_{IN} , voltage noise (e_n) dominates. Finding an op amp with both low current noise and low voltage noise can be challenging.

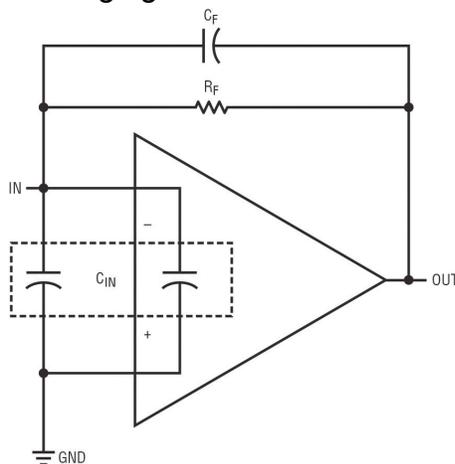


Figure 2: Input capacitance includes sensor, board, and amplifier capacitance

Input capacitance also limits bandwidth. One way to think about this is to consider the impedance of the input capacitor as the gain resistor (R_G) in a conventional inverting op amp configuration. The larger the capacitor, the smaller the impedance and the larger the effective gain the op amp “sees” ($1+R_F/R_G$), often called the noise gain. Since an amplifier’s bandwidth is inversely proportional to gain due to the constant nature of the gain-bandwidth product, this means that a large input capacitance limits the circuit bandwidth. This can also be thought of in terms of stability. Capacitance at an op amp input can create a pole in the frequency domain or a lag in the time domain. This pole can be compensated to make the circuit stable by adding a (deliberate, rather than parasitic) feedback capacitor (C_F). The larger this capacitance, the more limited the circuit bandwidth. Thus it is important to choose an amplifier with low input capacitance and to carefully lay out the board to avoid stray input capacitance and feedback capacitance. See pages 14 and 15 of the LTC6268 data sheet for some practical ideas for reducing stray feedback capacitance which in practice achieves greater than 4x improvement in circuit bandwidth.

The new LTC6268 femptoamp bias current op amp is a good example of an amplifier that is optimized for the performance required by high speed, high dynamic range photodiode circuits described in this article. It achieves extremely low input current by bootstrapping the on-chip ESD protection diodes. By creating a buffered replica of the input voltage and feeding that into split ESD diodes, diode voltage and current are kept extremely low during normal operation. The result is guaranteed max input current of 0.9pA at 85°C and 4pA at 125°C. Typical input current performance is shown in Figure 3. While this current still increases over temperature, it is orders of magnitude lower than that of other amplifiers. The LTC6268 offers 500MHz gain bandwidth, enabling the single-stage circuits shown in the LTC6268 data sheet from 20k Ω transimpedance gain with 65MHz bandwidth to 499k Ω transimpedance gain with 11.2MHz bandwidth. With just 0.45pF input capacitance, the LTC6268 contributes only a small portion of the total circuit capacitance, preserving high bandwidth. The input referred voltage and current noise of the LTC6268 is 4.3nV/ $\sqrt{\text{Hz}}$ at 1MHz and 5.5fA/ $\sqrt{\text{Hz}}$ at 100kHz, respectively. Also, the wide bandwidth, low distortion, and high slew rate of the LTC6268 makes it suitable for high speed digitizing applications.

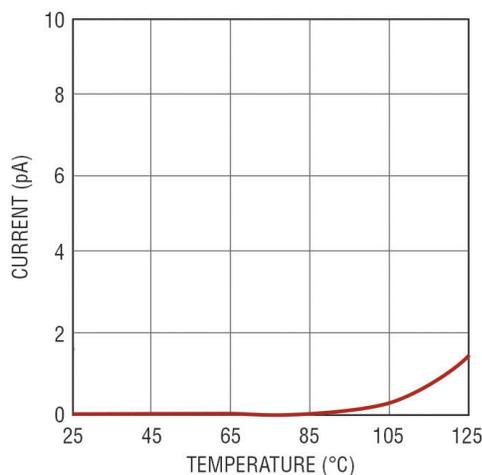


Figure 3: LTC6268 input bias current remains low over temperature

Although hundreds, if not thousands, of op amps are available on the market, finding a suitable transimpedance amp for high speed, high dynamic range photodiode circuits can be remarkably challenging. Each requires its own unique set of performance characteristics, including extremely low input bias current and input current temperature drift, high speed (e.g., gain bandwidth product and slew rate), the right balance of low voltage and current noise, and low input capacitance. Special attention should also be given to board layout to minimize leakage currents and stray capacitances, which would limit the accuracy and speed of the circuit. The LTC6268 represents a new class of op amps that is optimized for high performance TIA applications.