Using Transimpedance Amplifiers for Ambient Light Sensing in Automotive Displays

Operational amplifiers (op amps) in a transimpedance, or photodiode, configuration are frequently used for backlighting control throughout the car to provide a comfortable viewing experience for the driver and to save power. Using an op amp instead of a more complex light sensor leads to greater flexibility and customization. The automotive display systems—the head unit, remote display, cluster, or head-up display (HUD)—use the ambient light level detected by the circuit to adjust the backlight brightness according to light intensity or time of day, usually through an analog-to-digital converter (ADC) or a microcontroller unit (MCU).

The goal of the photodiode amplifier circuit is to transform low-level current from a photodiode into useful voltage. To do this, the op amp is designed in a photodiode configuration, as depicted in Figure 1. The photodiode can detect many different light sources, including visible light, infrared, and ultra-violet. The photodiode will produce a larger current when it is exposed to more light, increasing the output voltage of the circuit. Selecting the best current-to-voltage op amp is vital to the performance of the system. The transimpedance amplifier isolates the photodiode from the op amp’s output voltage and decreases the impedance seen by the photodiode. Typically, this design implements a JFET or CMOS input op amp with a low bias current to reduce DC errors and decrease the noise due to decreased input current noise.

The simplest transimpedance amplifier consists of only a feedback resistor and a feedback capacitor, as can be seen in Figure 1. The feedback resistor sets the gain of the op amp, and can be calculated using the desired maximum and minimum voltages, as well as the maximum current that will be seen from the photodiode. A feedback capacitor is always necessary to maintain the stability of the circuit, compensating for the photodiode capacitance at the inverting input of the op amp. The value of the capacitor used should be based both on the feedback resistor value that was chosen and the required bandwidth of the amplifier. A pole will be formed due to the combination of the feedback resistor and the feedback capacitor, and the amplification will decline above this pole frequency. It is then necessary to calculate the op amp gain bandwidth that is necessary for the circuit to be stable. This gain bandwidth depends on the junction capacitance of the photodiode, the differential input capacitance of the op amp, and the common-mode input capacitance of the inverting input as well as the values chosen for the feedback resistor and capacitor.

![Figure 1. Typical Transimpedance Amplifier Circuit](image)

For an automotive function, it is necessary to apply a small bias voltage to the op amp’s non-inverting input so that the output does not saturate at the negative supply rail when there is no input current, as would occur in the dark. Often, a resistor divider from the positive voltage supply is used to bias the non-inverting input above ground, as can be seen in Figure 2. Generally, a 0.1-V bias voltage is considered acceptable, and the bias network resistors can be designed to achieve this voltage at the non-inverting op amp input. Additionally, one further capacitor is needed to filter the $V_{ref}$ voltage and is placed in parallel with the resistor that is connected directly to ground. The capacitor’s value directly affects the corner frequency, and should be designed so that it is low enough to prevent power supply noise from passing to the output. This reverse bias will cause a reduced photodiode junction capacitance from the zero reverse biased case, but the response of the circuit will be faster. Additionally, the reverse bias improves the high frequency performance. Further methods for proper design of the circuit can be found in this [Photodiode Amplifier Circuit Design](#). In-depth analyses on previous photodiode amplifier circuits are also available.
The photodiode amplifier allows designers to customize the circuit based on their needs. By strategically choosing any automotive-rated op amp or modifying the components in the circuit, designers can control the gain, ensure the correct input bias current, or add compensation to fix any unique stability issues. For example, designers can tailor the gain of the photodiode amplifier circuit to maximize the range of the input to the specific ADC that is used. Additionally, there are many automotive-rated op amps available that are ideal for each specific application. For example, TI’s TLV6001-Q1 is specifically designed for very low level photodiode current at 75 μA and can operate over an extended bandwidth of 1MHz. Alternatively, TI’s LM2904-Q1 consists of two independent, frequency-compensated op amps with a gain bandwidth product of 0.7 MHz. Using operational amplifiers provides an economic solution to automatic adjustment: these op amps cost less than $0.25 per 1ku while an integrated circuit that performs the same function can cost $1.14 per 1ku with very little increase in performance. TI has a variety of op amp solutions to fit each specific need.

Photodiode amplifier circuits are a simple and flexible way to automatically adjust the backlighting for many automotive systems. TI’s extensive library of op amps and resources to aid in the proper circuit design enable you to tailor the perfect solution for your backlight control. A transimpedance configuration in an automotive display system will lead to automatic backlight control that is simple, inexpensive, and effective.

Table 1. Alternative Device Recommendations

<table>
<thead>
<tr>
<th>Device</th>
<th>$V_{CC}$</th>
<th>$V_{inCM}$</th>
<th>$V_{out}$</th>
<th>$V_{OS}$</th>
<th>$I_q$ (mA/Ch)</th>
<th>$I_b$ (nA)</th>
<th>UGBW (MHz)</th>
<th>SR</th>
<th>#Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLV6001-Q1</td>
<td>1.8 to 5.5 V</td>
<td>Rail-to-Rail</td>
<td>Rail-to-Rail</td>
<td>4.5 mV</td>
<td>0.075</td>
<td>0.001</td>
<td>1 MHz</td>
<td>0.5</td>
<td>1, 2, 4</td>
</tr>
<tr>
<td>LM2904-Q1</td>
<td>3 to 26 V</td>
<td>Rail-to-Rail</td>
<td>Rail-to-Rail</td>
<td>2 mV</td>
<td>0.35</td>
<td>250000</td>
<td>0.7 MHz</td>
<td>0.3</td>
<td>2</td>
</tr>
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