Using Photodiode Amplifiers for Ambient Light Sensing in Automotive Displays

Texas Instruments

Operational amplifiers (op amps) in a transimpedance, or photodiode, configuration are frequently used for backlighting control throughout the car. They provide a comfortable viewing experience for the driver, and save power. Using an op amp instead of a more complex light sensor leads to greater flexibility and customization. Automotive display systems include:

- The head unit
- The remote display
- The cluster
- The heads-up display (HUD)

These systems 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. As shown in Figure 1, the op amp is designed in a photodiode configuration to accomplish this. The photodiode can detect many different light sources, including visible light, infrared, and ultra-violet. The photodiode produces a larger current when it is exposed to more light, which increases the output voltage of the circuit. Selecting the best current-to-voltage op amp is vital to system performance. The transimpedance amplifier isolates the photodiode from the output voltage of the op amp, and decreases the impedance the photodiode encounters. Typically, this design implements a JFET- or CMOS-input op amp with a low bias current to reduce DC errors and decrease the noise caused by decreased input-current noise.

As can be seen in Figure 1, the simplest transimpedance amplifier consists of only a feedback resistor and a feedback capacitor. 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 the photodiode encounters. A feedback capacitor is always necessary to maintain the stability of the circuit, as it compensates for the photodiode capacitance at the inverting input of the op amp. The value of the capacitor used must be based both on the chosen feedback resistor value, and the required amplifier bandwidth. A pole is formed due to the combination of the feedback resistor and the feedback capacitor, and the amplification declines 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.

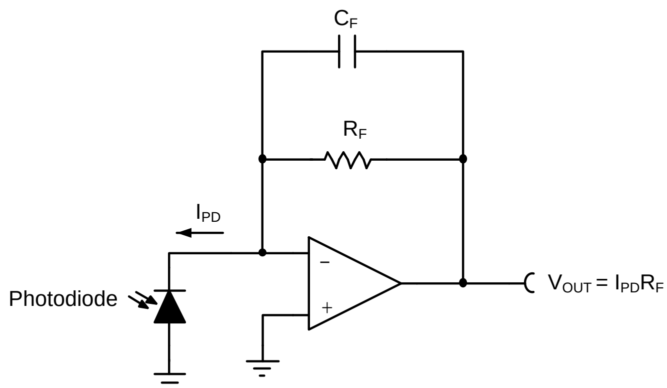

Figure 1. Typical Transimpedance Amplifier Circuit

For an automotive function, it is necessary to apply a small bias voltage to the non-inverting input of the op amp so that the output does not saturate at the negative supply rail when there is no input current, as would occur in the dark. As shown in Figure 2, a resistor divider from the positive voltage supply is often used to bias the non-inverting input above ground. 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 value of the capacitor directly affects the corner frequency, and must be designed so that it is low enough to prevent power supply noise from passing to the output. This reverse bias causes a reduced photodiode junction capacitance from the zero-reverse biased case, but the response of the circuit is 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 Application Report*. In-depth analyses on previous photodiode amplifier circuits are also available in *Automating circuit designs for photodiode amplifiers*.

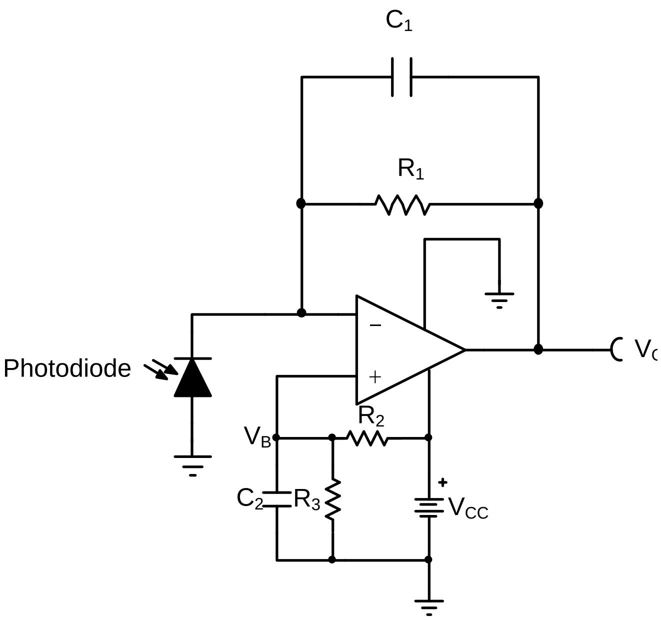

Figure 2. Typical Photodiode Amplifier Circuit

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 currents at 75 µA, and can operate over an extended bandwidth of 1 MHz. Alternatively, TI's TLV9002-Q1 consists of two independent, frequency-compensated op amps with a gain bandwidth product of 1 MHz. Using operational amplifiers provides an economic solution to automatic adjustment: these op amps cost less than $0.25 per 1 ku, while an integrated circuit that performs the same function can cost $1.14 per 1 ku 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 designers to tailor the backlight control perfect solution. A transimpedance configuration in an automotive display system leads to automatic backlight control that is simple, inexpensive, and effective.

Table 1. Alternative Device Recommendations

Device	V_{CC}	V_{inCM}	V_{out}	V_{OS}	I_q	I_b	UGBW	SR	#Channels
TLV6001-Q1	1.8 to 5.5 V	Rail-to-Rail	Rail-to-Rail	4.5 mV	0.075 mA/Ch	0.001 nA	1 MHz	0.5 V/us	1, 2
TLV9002-Q1	1.8 to 5.5 V	Rail-to-Rail	Rail-to-Rail	1.6 mV	0.06 mA/Ch	0.005 nA	1 MHz	2 V/us	2, 4

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