Application Report
Different Methods to Drive LEDs Using TPS63xxx Buck-Boost Converters

TEXAS INSTRUMENTS

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ABSTRACT

This application note describes how to drive LEDs using standard DC/DC converters. The circuit examples used here are based on devices from the TPS63xxx buck-boost converter family. Buck-boost converters offer high flexibility regarding the supported input voltage range or supported battery configuration. The devices can also support a wide variety of LEDs by using the same circuit optimized for a certain LED forward current.

1 Introduction

Nowadays, there are many applications that use a battery as the power supply to drive an LED, such as wireless security camera or electronic tags. For most of the battery types, the voltage of the battery changes during discharge. If the forward voltage drop of the LED ends up in the middle of the battery voltage range, a buck-boost converter can work as a highly efficient LED driver regardless of the battery voltage being higher or lower than the LED forward voltage. This report illustrates several solutions to drive LEDs using standard DC/DC converters from the TPS63xxx buck-boost converter family.

2 Simple Configuration with Sense Resistor Used for Voltage Feedback
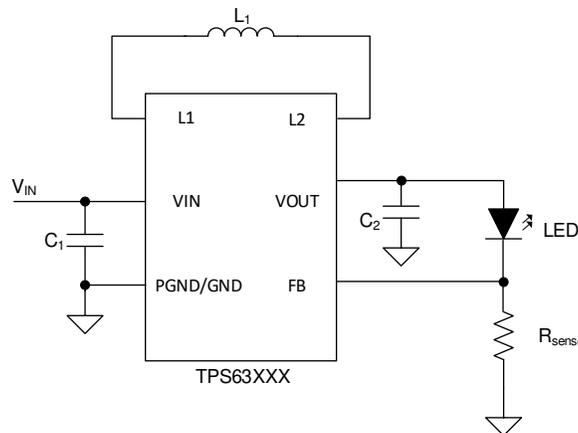

Figure 2-1. Constant Current with Single Sense Resistance

The basic schematic in Figure 2-1 shows the simplest configuration. To configure the DC/DC converter from operating as a voltage source to operating as a current source, the current is measured through a sense resistor and fed back into the control loop. For that, the voltage feedback input is used directly. The sense resistor is placed in series with the LED. Therefore, the LED current is flowing through the sense resistor as well. For calculating the required resistor value for R_{sense} for a given LED current I_{LED}, use Equation 1. V_{FB} is the feedback voltage of the DC/DC converter. In the case of the TPS63xxx devices, V_{FB} is typically 0.5 V or 0.8 V.

$$R_{Sense} = \frac{V_{FB}}{I_{LED}}$$

(1)

Depending on the LED current, the power dissipation can become critical for the resistor. It may be necessary to use a larger resistor, or multiple resistors in parallel or in series, to split the dissipated power. Calculate the power P_S, which must be dissipated by R_{sense}, with Equation 2.

$$P_S = I_{LED}^2 \times R_{Sense}$$

(2)

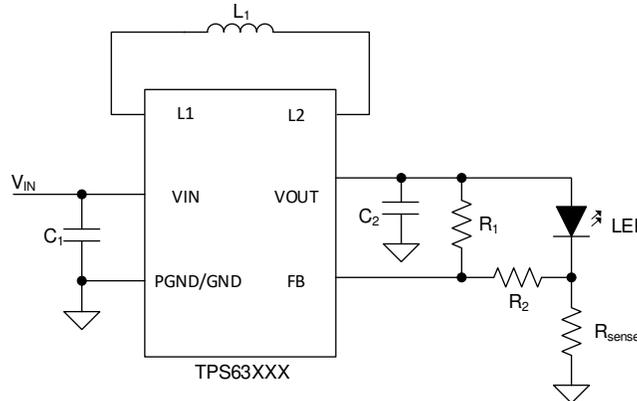## 3 Improving the Power Conversion Efficiency

Figure 3-1. Constant Current with Resistance Net

The power losses in the sense resistor of the circuit explained in Section 2 lower the efficiency of the circuit significantly, which is a major drawback. Although the feedback voltage of most TPS63xxx devices is already low at 0.5 V, it is still causing significant power losses, especially when dealing with high-LED currents.

How this can be improved is shown in Figure 3-1. The sense resistor for measuring the LED current, R_{sense}, is still in series with the LED, but the way R1 is connected, a bias current into the feedback network is introduced. This bias current causes a voltage drop across R2, which adds to the voltage drop across the sense resistor R_{sense}. Because the feedback voltage is not changed, the required voltage drop across the sense resistor is lower for a given LED current compared to the solution described in Section 2. Equation 3 gives the calculation for the LED current (I_{LED}). V_{FB} is the feedback voltage of the DC/DC converter, and VLED is the typical forward voltage of the LED.

$$I_{LED} = \frac{V_{FB}}{R_{Sence}} - \frac{V_{LED}}{R_1 + R_2} - \frac{V_{LED} \times R_2}{R_{Sense} \times \left(R_1 + R_2\right)}$$

(3)

The regulated LED current in this circuit depends on the forward voltage of the LED. How much the LED current varies is defined by the forward voltage variation of the LED and the values of resistors R1 and R2. With setting the value of R1 as high as possible and the value of R2 as low as possible, the current variation is at its minimum. The theoretical extreme, when R1 is nonexistent and R2 is shorted, is basically the circuit explained in Section 2, so doing trade-offs is required. Another benefit of the circuit shown in Figure 3-1 is the output voltage regulation in case the LED is disconnected. This is required if the DC/DC converter used does not have a built-in output over-voltage protection. In this case, the maximum output voltage can be programmed with resistors R1 and R2+R_{sense} using the equations of the datasheet for calculating the feedback divider of the respective device. R_{sense} has a value that is significantly lower compared to R1 and R2, so it is negligible.

Programming the LED current is done by selecting the appropriate value for R_{sense}. Equation 4 shows how to calculate the value for R_{sense} and Equation 5 shows how to calculate the losses in R_{sense}, P_S.

$$R_{Sense} = \frac{R_1 \times V_{FB} - R_2 \times \left(V_{LED} - V_{FB}\right)}{I_{LED} \times \left(R_1 + R_2\right) + V_{LED}}$$

(4)

$$P_S = I_{LED}^2 \times R_{Sense} \tag{5}$$

See *PMP15037 Test Results* for detailed design guidance and calculation.

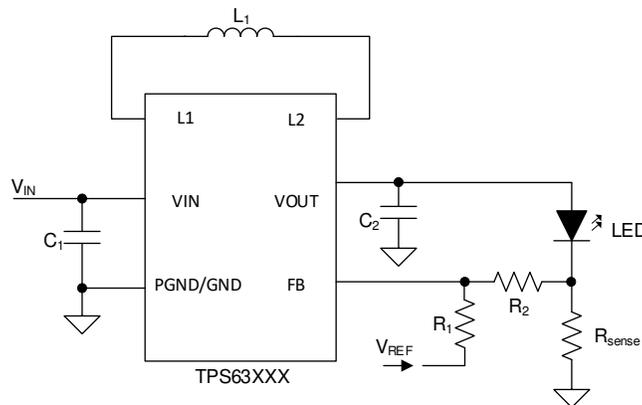## 4 Improving the LED Current Control Accuracy

Figure 4-1. Dimming Solution with Resistance Net

To overcome the problem with the LED current changing with the LED forward voltage, resistor R1 can be connected to any fixed reference voltage; for example, V_{REF} in Figure 4-1. This reference voltage can be implemented with a RC filtered PWM signal from a microprocessor, for example, or just from any available DC source. The only requirement is that it must be higher than the feedback voltage. Together with R1, it feeds in a constant bias current into the feedback node, which generates a constant voltage drop across R2. This voltage adds to the voltage drop across the sense resistor R_{sense}. The sum of both voltages is the feedback voltage. The equation for the LED current is given with Equation 6.

$$I_{LED} = V_{FB} \times \frac{R_1 + R_2 + R_{Sense}}{R_1 \times R_{Sense}} - V_{REF} \times \frac{R_2 + R_{Sense}}{R_1 \times R_{Sense}} \tag{6}$$

According to Equation 6, a change in the reference voltage V_{REF} changes the LED current that might be an advantage in some systems. The output load of this reference voltage is basically defined by the series connection of resistors R1, R2 and R_{Sense}, which usually has relatively high impedance. Therefore, almost any low-power reference voltage source can be used directly; for example, a PWM-controlled output of a D/A converter. Because the sensitivity to reference voltage changes can be programmed by selecting appropriate values for R1 and R2, and of course by selecting the reference voltage level itself, it is also an ideal circuit implementation if the LED current must be calibrated. This, for example, is very beneficial in applications like projectors, where it is required to make sure that the wavelength of the emitted light is at the correct value. For calculating the losses in the sense resistor, use Equation 5.

5 Improving the LED Assembly Options

All the applications described above use a sense resistor connecting the cathode of the LED to the GND return of the power circuit. This causes difficulties with mechanical assembly since the cathode needs to be isolated from the ground and most LEDs use the cathode for sinking heat. Designing heat sinks for the LED is much easier if no isolation is required. Figure 5-1 illustrates an LED driver circuit that supports that. In this circuit, the LED current is measured between the output of the DC/DC converter and the anode of the LED. As in all the other circuits shown in this application report, a resistor in series to the LED is used for sensing the current. The differential voltage across this resistor is connected to the input of an current sense amplifier; for example, INA180. This voltage is amplified and directly fed into the feedback pin. Use Equation 7 to calculate the value of the required sense resistor. G in this equation is the input-to-output voltage gain of the current sense amplifier. It is recommended to add the 100-nF capacitor C3 to help the start-up.
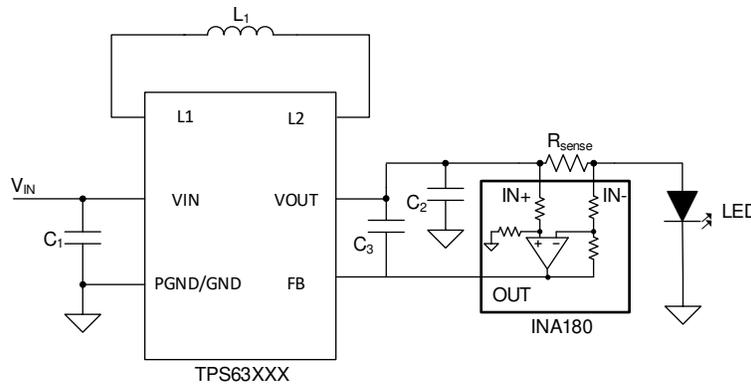
Figure 5-1. High-Side LED Driver Using INA180

$$R_{Sense} = \frac{V_{FB}}{I_{LED} \times G} \qquad (7)$$

The solution based on the INA180 (current sense amplifier) is easy to design with only a few external components. It is flexible to set the sense resistor before or after the LED. This solution achieves high precision and high noise tolerance owing to the INA part. Besides, for LEDs connected in series, if one of the LEDs is shorted, the circuit still works, as this solution controls the current.

$$P_{Loss} = I_{LED}^2 \times R_{Sense} \qquad (8)$$

Users can replace the INA180 with an operational amplifier-based circuit. But this solution needs more external parts, which harms the precision and increases the design complexity. Due to the additional external parts, the solution size is slightly larger.

6 Dimming Solutions with Op-Amp

Some applications need adjustable LED brightness. In security cameras, the LED needs to be dimmed by changing the current to avoid the rolling shutter effect that may occur if PWM dimming is used. Otherwise, the camera catches the flicker. For this purpose, the solution controls the current through the LED with a signal from the MCU or processor. A popular way is to use a reference voltage to control the LED current to achieve the dimming function. Below is a schematic using a TPS63xxx device.
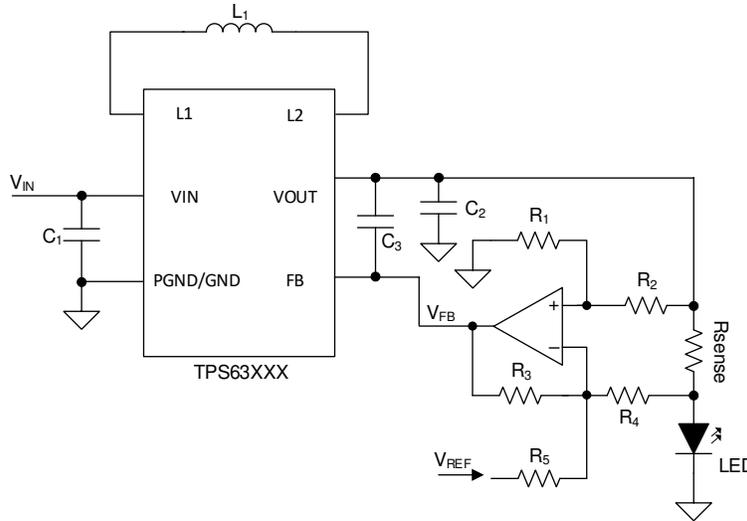
Figure 6-1. Dimming Solution with Op-Amp

$$V_{Rsense} = \frac{R4}{R3} \times V_{FB} + \frac{R4}{R5} \times V_{REF}$$

(9)

$$P_{Loss} = I_{LED}^2 \times R_{Sense}$$

(10)

A larger sense voltage provides better signal-to-noise ratio. However, it brings more power loss. These two have to come together and compromise.

In some cases, the system needs to control the LED current more precisely for smaller currents. It needs a larger gain or larger sense resistor to meet this requirement. A larger gain causes a larger bias offset by the offset voltage and bias current of the amplifier. As a drawback, the larger R_{sense} increases the losses and lowers the efficiency.

In that case, this application report recommends the circuit shown in Figure 6-2. This circuit is derived from the prior solution with a small change. The difference is that R5 is connected to the positive input of the op amp. Here, an increase of V_{REF} decreases I_{LED}. For this circuit, the gain could be much smaller. There is no need to just amplify the V_{sense} to target V_{FB} when the current is low, as V_{REF} helps to lift the voltage.
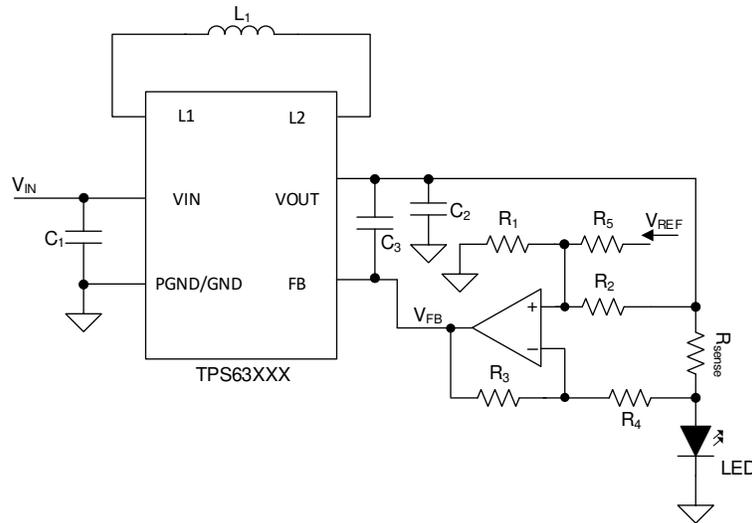
Figure 6-2. Another Dimming Solution with Op-Amp

The calculations are similar to the previous solution. If R3 = R1||R5 and R2 = R4 then:

$$V_{Rsense} = \frac{R4}{R3} \times V_{FB} - \frac{R4}{R5} \times V_{REF} \tag{11}$$

$$P_{Loss} = I_{LED}^2 \times R_{Sense} \tag{12}$$

Both circuits show high efficiency, but the efficiency of the second solution is slightly higher. Both achieve analog dimming with simple circuit design and calculations. As both control the current of the LED well, they also work well even if one of the LED in series is shorted. That is another benefit when compared to the discontinuous current dimming solution, which only adjusts the duty cycle of LED but keeps V_{out} fixed.

Moreover, for the last dimming solution, zero V_{REF} leads to the maximum LED current. It might be necessary to consider this in a system, as it might add risk.

7 Summary

This application report demonstrates several solutions for driving LEDs using an IC out of the TPS63xxx device family. Depending on the design requirements, such as cost, efficiency, or size, some solutions have advantages over the others. This is summarized in Table 7-1.

Table 7-1. Comparison of Different Solutions for Driving LEDs

	Constant Current Figure 2-1	**Constant Current** Figure 3-1	**Res. Based Dimming** Figure 4-1	**INA180 Solution** Figure 5-1	**Dimming Solution with Op-Amp** Figure 6-1, Figure 6-2
Dimming	No	No	Analog dimming	No	Analog dimming
Design complexity	Easy	Easy	Medium	Easy	Complex
Additional components	Sense resistor only	Three resistors	Three resistors	Current sense monitor	op-amp and resistors
Efficiency	Low	Medium	Medium	High	High
Cost	Low	Low	Low	High	Medium
Solution size	Small	Small	Small	Medium	Large
Operation with shorted LEDs	Remains well	Fails to work	Remains well	Remains well	Remains well
Sense side	Low side	Low side	Low side	High/Low side	High/Low side

References

- Texas Instruments, *Dynamically Adjustable Output Using TPS63000 Application Report*
- Texas Instruments, *PMP15037 Test Results*
- Texas Instruments, *Analog Engineer's Circuit Cookbook: Op Amps*
- Texas Instruments, *TPS63802 2-A, high-efficient, low IQ buck-boost converter with small solution size Data Sheet*

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (July 2019) to Revision D (August 2021)	Page
• Updated the numbering format for tables, figures and cross-references throughout the document	1

Changes from Revision * (June 2010) to Revision C (July 2019)	Page
• Updated app report for clarity	1
• Rewrote sections 2 and 3	1
• Added sections 5, 6, and 7	4

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