Different Methods to Drive LEDs Using TPS630xx Buck-Boost Converters

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ABSTRACT
This application note describes how to drive LEDs using standard dc-dc converters. The circuit examples used here are all based on devices from the TPS630xx buck-boost converter families. 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, especially different color LEDs, by using the same circuit optimized for a certain LED forward current.

1 Simple Configuration With Shunt Resistor Used for Voltage Feedback

The basic schematic shown in Figure 1 shows the most simple configuration which can be used. To change the dc-dc converter from operating as a voltage source to operating as a current source, the current is measured and fed back into the control loop. For that, the voltage feedback input is used directly. To measure the current, a shunt resistor in series with the LED is used. For calculating the required resistor value for R1 for a given LED current (I_LED) Equation 1 can be used. V_FB is the feedback voltage of the dc-dc converter. In the case of the TPS630xx devices, it is typically 0.5 V.

\[
R1 = \frac{V_{FB}}{I_{LED}} \tag{1}
\]

Depending on the LED current, the power dissipation can become critical for the resistor. It may be required to use bigger sizes of resistors or multiple resistors in parallel or in series. The power (P1) which must be handled by R1 can be calculated using Equation 2.

\[
P1 = I_{LED} \cdot I_{LED} \cdot R1 \tag{2}
\]
2 Improving the Power Conversion Efficiency

The drawback of the circuit explained in Section 1 is that the power losses in the shunt resistor can lower the efficiency of the circuit significantly. Although the feedback voltage of the TPS630xx 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 2. The shunt resistor for measuring the LED current is R3. It is still in series with the LED. But the way R1 is connected, a bias current into the feedback node is introduced. This bias current causes a voltage drop across R2, which adds to the voltage drop across the shunt resistor R3. Because the feedback voltage is not changed, the required voltage drop across the shunt resistor is lower for a given LED current compared to the solution described in Section 1. How the LED current ($I_{\text{LED}}$) is calculated is shown in Equation 3. $V_{\text{FB}}$ is the feedback voltage of the dc-dc converter and $V_{\text{LED}}$ is the typical forward voltage of the LED.

$$I_{\text{LED}} = \frac{V_{\text{FB}}}{R3} - \frac{V_{\text{LED}}}{R1+R2} - \frac{V_{\text{LED}} \cdot R2}{R3 \cdot (R1+R2)}$$

Equation 3 shows that 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 of the LED and the values of resistors R1 and R2. If the value of R1 is 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, basically is the circuit explained in Section 1, so doing tradeoffs is required. Another benefit of the circuit shown in Figure 2 is the output voltage regulation in case the LED is disconnected. This could be required if the dc-dc converter used does not have built-in output overvoltage protection. In this case, the maximum output voltage can be programmed with resistors R1 and R2 using the equations of the data sheet for calculating the feedback divider of the respective device. R3 has a value which is significantly lower compared to R1 and R2, so it is negligible.

Programming the LED current finally is done by selecting the appropriate value for R3. Equation 4 shows how to calculate the value for R3 and Equation 5 shows how to calculate the losses in R3, $P_3$.

$$R3 = \frac{R1 \cdot V_{\text{FB}} - R2 \cdot (V_{\text{LED}} - V_{\text{FB}})}{I_{\text{LED}} (R1+R2) + V_{\text{LED}}}$$

$$P3 = I_{\text{LED}} \cdot I_{\text{LED}} \cdot R3$$
3 Improving the LED Current Control Accuracy

To overcome the problems with the LED current changing with the LED forward voltage, resistor R1 can be connected to a fixed reference voltage, for example, \( V_{\text{REF}} \) in Figure 3. This reference voltage just 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 shunt resistor R3. The sum of both voltages is the feedback voltage. The equation for the LED current is shown in Equation 6.

\[
I_{\text{LED}} = V_{\text{FB}} \cdot \frac{R_1 + R_2 + R_3}{R_1 \cdot R_3} - V_{\text{REF}} \cdot \frac{R_2 + R_3}{R_1 \cdot R_3}
\]  

Equation 6 also shows that the LED current can be changed by changing the reference voltage \( V_{\text{REF}} \). The output load of this reference voltage basically is defined by the series connection of resistors R1 and R2, which usually are high impedance. So 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, when it is required to make sure that the wavelength of the emitted light is at the correct value.

For calculating the losses in the shunt resistor, Equation 5 can be used.
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