Step-Down LED Driver With Dimming With the TPS621-Family and TPS821-Family

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ABSTRACT

The TPS62150 is used normally as a buck (step-down) voltage regulator. However, it is not limited to the standard voltage regulating topology. This application report demonstrates the TPS62150 as a small, simple, and easy way to implement a high-brightness LED driver. Regulating the LED with a constant current for constant brightness is desired, rather than constant voltage regulation. The desired current must be maintained with an output voltage that varies with changes in the LED forward voltage due to analog dimming or varying temperatures. To achieve current regulation, the voltage across a known resistance (R_{CS}) is regulated. R_{CS} is connected from the feedback pin (FB) to GND. Due to the relatively high FB voltage, the power dissipated by R_{CS} can lower efficiency and reduce battery life. By putting a resistor from the SS/TR pin to GND, the FB voltage can be reduced. The LEDs are connected from the output of the inductor to the FB pin. Dimming can be realized in this application by either analog or PWM methods. This topology can be used with any of the TPS62130, TPS62140, or TPS62150 step-down converters.

Contents

List of Figures

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1 Schematic

Figure 1 shows a TPS62150 low-power, dc-dc buck converter application that drives one high-current LED and includes the capability to dim the LED light output. The resistor values in Figure 1 were calculated using the equations within this application report and the IC's data sheet. For this design, the maximum desired output current is 1 A, and the current may be dimmed from 1 A to 0 A by either analog dimming or PWM dimming. Analog dimming is accomplished by injecting a dc voltage (from the output of a DAC, for example) at the SS/TR pin and PWM dimming is realized by applying a PWM signal to the EN pin. If PWM dimming is not used, simply tie the EN pin to VIN. The LED used is Osram's LW W5SN Golden DRAGON and exhibits a forward voltage of about 3.6 V at 1 A.

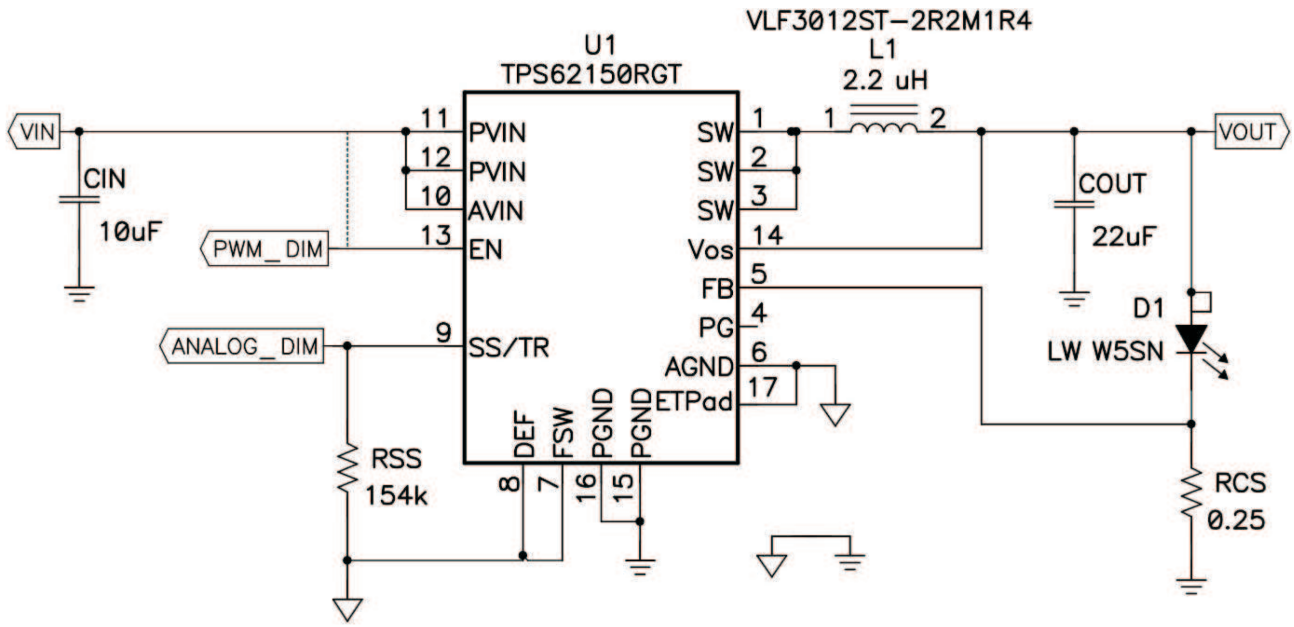

Figure 1. TPS62150 LED Driver Schematic

2 Design Procedure

2.1 LED Current Set

The value of the current-sense resistor, R_{CS}, sets the output current from Equation 1:

$$R_{CS} = \frac{V_{FB}}{I_{OUT}} \quad (1)$$

I_{OUT} = Output current through LED
V_{FB} = FB pin voltage, determined from Equation 3

The power dissipation of this resistor is calculated in Equation 2 and must be considered when choosing the package size:

$$P_{DIS} = \frac{V_{FB}^2}{R_{CS}} \quad (2)$$

This power dissipated is a loss in the system and lowers the converting efficiency and battery life. The loss can be reduced by lowering the V_{FB} voltage through the SS/TR pin. In a standard buck converter, the FB voltage is equal to 0.8 V. However, this voltage is proportional to the voltage on the SS/TR pin, until the SS/TR pin reaches approximately 1.25 V. Above this SS/TR voltage, the FB pin voltage remains at 0.8 V, even though the SS/TR voltage continues to increase. When the SS/TR pin voltage is less than 1.25 V, the FB pin voltage is related to the SS/TR pin voltage by the gain factor 0.8/1.25:

$$V_{FB} = V_{SS} \times \frac{0.8}{1.25} \quad (3)$$

V_{SS} = SS/TR pin voltage

The SS/TR pin is simply a constant-current source of typical 2.5 µA and is meant to charge a capacitor. If a resistor (R_{SS}) is placed at the SS/TR pin to AGND, a constant voltage is present at SS/TR due to the constant-current output (I_{SS}). This voltage can be found using Equation 4:

$$V_{SS} = I_{SS} \times R_{SS} \tag{4}$$

Combining Equation 1, Equation 3, and Equation 4, R_{SS} can be calculated using Equation 5 with a given I_{OUT} and R_{CS}:

$$R_{SS} = \frac{R_{CS} \times I_{OUT}}{I_{SS}} \times \frac{1.25}{0.80} \tag{5}$$

To set the output current, R_{CS} is chosen first due to the limited values available for current-sense resistors. It is chosen such that V_{FB} is in a recommended range of 200 mV to 250 mV with the desired full output current. This V_{FB} voltage range is chosen as a good tradeoff of efficiency versus accuracy of the LED current. Lower V_{FB} voltages are more efficient but have less LED current accuracy, because smaller variations in the resistance of the sense resistor (from self-heating effects, etc.) become a larger percentage of the total resistance. With a chosen value for R_{CS}, R_{SS} is found using Equation 5.

For example, using Equation 1 with the designed 1-A output current, R_{CS} = 0.25 Ω can be used which requires V_{FB} = 250 mV.

$$V_{FB} = R_{CS} \times I_{OUT} = 0.25\Omega \times 1A = 0.250\ V \tag{6}$$

Using Equation 5, R_{SS} to the nearest standard value is 154 kΩ.

$$R_{SS} = \frac{R_{CS} \times I_{OUT}}{I_{SS}} \frac{1.25}{0.80} = \frac{0.25\Omega \times 1A}{2.5\ \mu A} \frac{1.25}{0.80} = 156\ k\Omega \approx 154\ k\Omega \tag{7}$$

It is important to note that the PG pin is not valid in this application where the FB pin voltage is being lowered through the SS/TR pin. It is only allowed to go high once V_{SS} is above its 1.25-V threshold. Also to limit inrush current at start up a capacitor can be placed on the SS/TR pin to GND to slow down the start up.

2.2 Output Voltage

The supplied output voltage of the LED driver circuit is approximated by:

$$V_{OUT} = N_{LED} \times V_{LED} + V_{FB} \tag{8}$$

Where:

N_{LED} = number of LEDs in series
V = forward voltage drop of each LED at the maximum desired LED current $_{LED}$
V_{FB} = the FB pin voltage, from Equation 3

This design drives a single LED with V_{LED} = 3.6 V and V_{FB} = 0.25 V. The output voltage is calculated at 3.85 V.

For the TPS62150, usually only one high-current LED can be driven because the maximum allowed output voltage is 6 V. However, it is possible to drive two LEDs in series if the FB pin voltage is designed to be low enough such that the total output voltage is kept within the IC's ratings. This usually involves reducing the current through the LEDs to reduce their forward voltage.

The V_{OS} pin must still connect to the anode of the LED(s), as this is the V_{OUT} that the IC is regulating. The ground of the sense resistor, R_{CS}, is a power ground return that must handle the entire output current. This point must be connected to the PGND node at the output capacitor.

2.3 Output Inductor

To maintain loop stability, an inductor must be selected that is within the TPS62150's recommended range. In addition, the inductor value has a direct effect on the ripple current, which affects the maximum achievable output current. To keep the IC from reaching its 1.4-A current limit during normal operation, the recommended 2.2-µH inductor is used in this design.

Once the inductor is chosen, the inductor ripple current (ΔI_L) can be calculated using Equation 9.

$$\Delta I_L = \frac{V_{OUT} \times (V_{INMAX} - V_{OUT})}{V_{INMAX} \times F_{SW} \times L} \quad (9)$$

V_{OUT} = Output voltage, from Equation 8
V_{INMAX} = Maximum input voltage
F_{SW} = Switching frequency of 2.5 MHz typical
L = Output Inductance

The selected inductor has to have sufficient RMS current and saturation current ratings for the application. The inductor's RMS current and peak current can be calculated using Equation 10 and Equation 11.

$$I_{LRMS} = \sqrt{I_{OUT}^2 + \frac{1}{12} \times \left(\frac{V_{OUT} \times (V_{INMAX} - V_{OUT})}{V_{INMAX} \times F_{SW} \times L}\right)^2} \quad (10)$$

$$I_{LP} = I_{OUT} + \frac{1}{2} \times \left(\frac{V_{OUT} \times (V_{INMAX} - V_{OUT})}{V_{INMAX} \times F_{SW} \times L}\right) \quad (11)$$

Using the parameters from this design, V_{OUT} = 3.85 V, V_{INMAX} = 17 V and I_{OUT} = 1 A, the calculated peak-to-peak inductor current, RMS current and peak current are 536 mA, 1.01 A and 1.27 A, respectively. The inductor used is a 2.2 µH TDK VLF3012ST-2R2M1R4, which has an RMS current rating of 1.4 A and saturation current rating of 1.9 A.

2.4 Output Capacitor

To maintain loop stability, an output capacitor must be selected within the recommended range. This application uses the recommended 22-µF ceramic capacitor.

The output capacitor must also be chosen to limit the ripple current in the LED. To find this, first calculate the dynamic resistance of the LED using Equation 12.

$$R_{LED} = \frac{\Delta V_F}{\Delta I_{OUT}} \quad (12)$$

This is the slope of the V/I curve at the operating point and can be found using the LED's data sheet. In this application, the set current (I_{OUT}) is 1 A, and the corresponding forward voltage of the LED (V_F) is 3.6 V. When the forward voltage changes from 3.5 V to 3.6 V, ΔV_F is 0.1 V and ΔI_F is 0.16 A. Therefore, the LED's dynamic resistance is approximately equal to 0.625 Ω.

The output ripple current of the converter is the output inductor peak-to-peak current (ΔI_L). This ripple current is shared by the LED and output capacitor. The impedance of the output capacitor is calculated using Equation 13.

$$Z_{COUT} = \sqrt{R^2_{ESR} + \left(\frac{1}{2\pi \times F_{SW} \times C_{OUT}}\right)^2} \quad (13)$$

R_{ESR} = Equivalent series resistance of output capacitor

Assuming an ESR of 3 mΩ, Z_{COUT} is about 4 mΩ for the ceramic capacitor. Because the impedances of the output capacitor and LED are in parallel, the ripple current is shared between the two. The ripple current flowing in the LED is:

$$\Delta I_{LED} = \Delta I_L \times \frac{Z_{COUT}}{Z_{COUT} + R_{LED} + R_{CS}} \quad (14)$$

For this design, the ripple current in the LED is 3 mA. This shows most of ripple current is shunted through the output capacitor as desired. This is most always the case when using ceramic output capacitors.

2.5 Input Capacitor

The recommended ceramic input capacitor value of 10 µF is used for C_{IN}. The input capacitor value determines the input voltage ripple of the regulator. The input voltage ripple can be calculated using Equation 15:

$$\Delta V_{IN} = \frac{I_{OUT} \times 0.25}{C_{IN} \times F_{SW}} \quad (15)$$

For this design, the voltage ripple is 10 mV. The voltage rating of the input capacitor must be greater than the maximum input voltage and the dielectric must be a quality X5R or X7R. A 10-µF, 25-V, X5R ceramic capacitor is used.

2.6 PWM Dimming

The EN pin is typically used for disabling and enabling the device. By applying a PWM signal to EN, it can be used to dim the LED. With a PWM signal applied directly to the EN pin, the LED current is turned on when the PWM signal is high and off when the PWM signal is pulled low. Changing the PWM duty cycle changes the LED brightness. The PWM signal used must have a high level greater than the minimum V_{EN_H} level of 0.9 V and a low level less than the maximum V_{EN_L} level of 0.3 V.

When dimming with the EN pin, the frequency of the PWM signal is important. It must be kept low enough such that the turnon and turnoff delays of the TPS62150 do not significantly affect the dimming linearity. It also must be high enough to keep the LED flicker from being noticeable to the human eye. A dimming frequency of 100 Hz is recommended. At this low frequency, the turnon and turnoff times, of less than 100 µs total, only slightly impact the dimming linearity.

A 100-Hz PWM signal was applied to the EN pin and the duty cycle was adjusted from 1% to 99% on the circuit in Figure 1, giving the example LED current regulation shown in Figure 2.

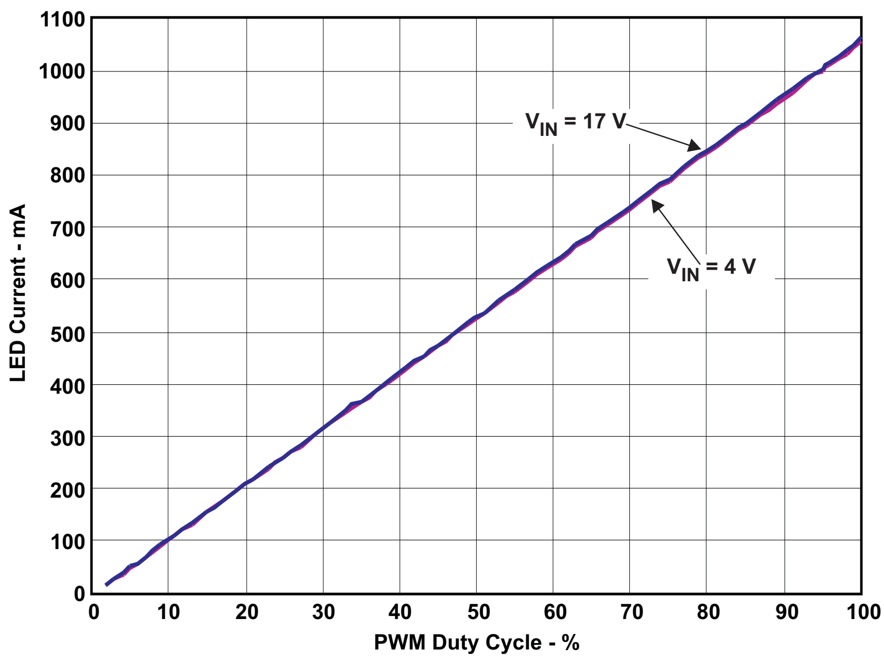

Figure 2. Dimming Linearity With 100-Hz PWM Dimming

2.7 Analog Dimming

Analog dimming is done by applying a voltage to the SS/TR pin, for example, from the output of a DAC. As shown in Equation 3, this directly adjusts V_{FB} which then changes I_{OUT}.

Figure 3 shows the analog dimming linearity of the circuit in Figure 1 when a voltage is applied to the SS/TR pin.

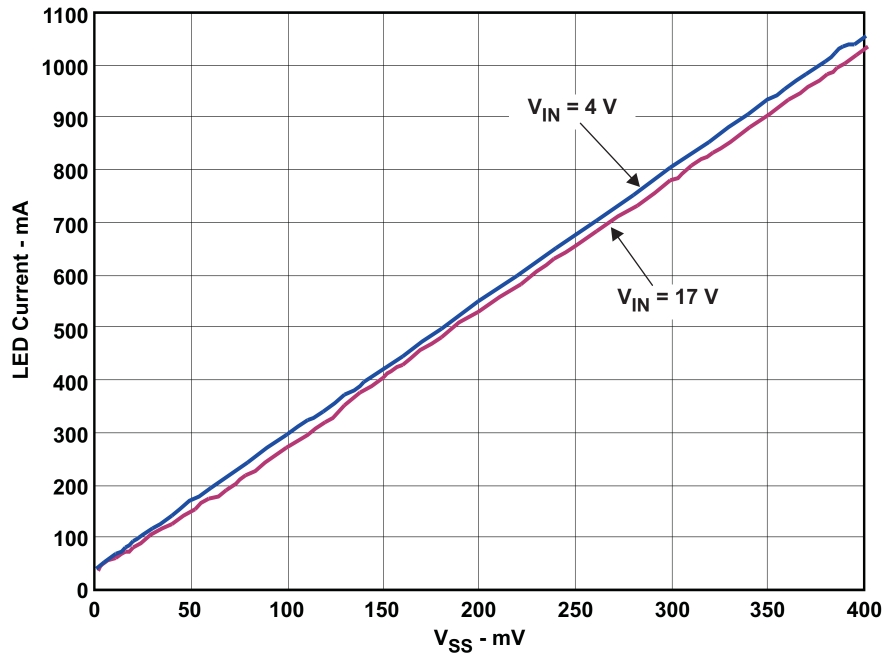

Figure 3. Dimming Linearity With Analog Dimming

2.8 Comparison Between Dimming Methods

Efficiency data through the entire output current range was taken using the two dimming methods at both the maximum and minimum input voltage. This is shown in Figure 4.

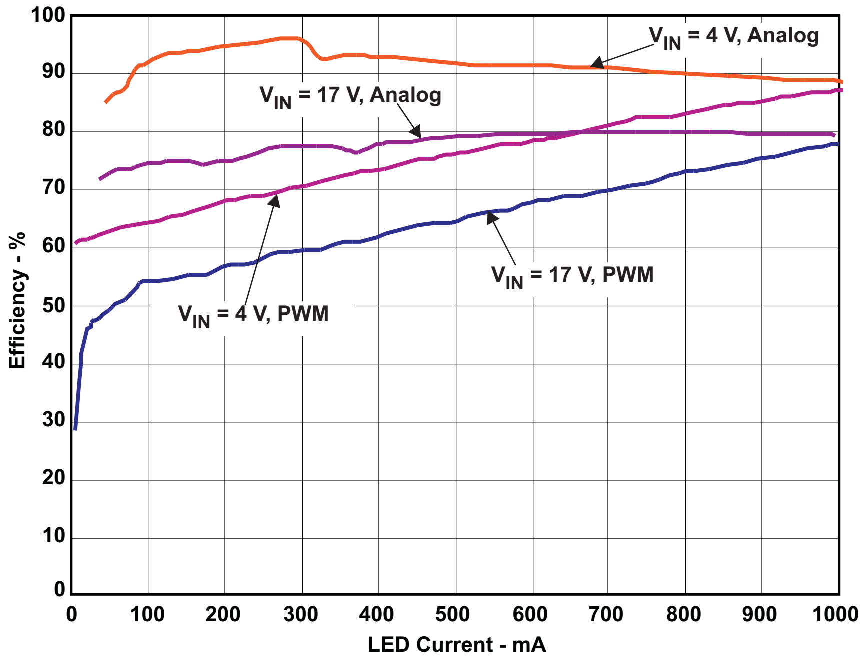

Figure 4. Efficiency With Analog and PWM Dimming

As can be seen in Figure 2, Figure 3, and Figure 4, the main tradeoff is between efficiency and dimming linearity. PWM dimming gives an accurate dimming linearity throughout the entire range of currents but is significantly less efficient at low LED brightness. Analog dimming, on the other hand, has a higher efficiency that stays relatively constant throughout the range. The increased efficiency is due to lower forward voltage of the LEDs. However, it has worse dimming linearity especially at very low LED currents.

3 Extending Battery Life with TPS62150 LED Driver

Additional methods to size R_{CS} to minimize power dissipation are described in the application report SLEA004.

4 Conclusion

This application report describes how to choose the external components to implement the TPS62150 as a small and simple high-brightness LED driver. This is done by regulating the voltage across a known resistance R_{CS}. Efficiency is improved and battery life is increased by lowering V_{FB} through the SS/TR pin and properly sizing R_{CS}. Analog dimming is realized by applying a voltage to the SS/TR pin and PWM dimming is performed through the EN pin.

5 References

1. *3-17V 1A Step-Down Converter In 3X3 QFN Package*, Datasheet (SLVSAL5)
2. *Extending Battery Life With the TPS61040 White Light LED Driver* (SLEA004)
3. *TPS54160 60-V, Step-Down LED Driver* Design Guide (SLVA374)

Revision History

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

Changes from Original (November 2011) to A Revision	Page
• Changed title of application report.	1

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