Solar lantern with dimming achieves 92% efficiency

By Chris Glaser
Applications Engineer

Solar lanterns are becoming increasingly popular, especially for decorative nighttime lighting or in areas with unreliable or nonexistent electrical service. These lanterns charge a battery during the day and then use that stored energy during the night to provide light on outdoor paths and sidewalks, or for indoor activities such as cooking or reading. Since the lanterns typically are powered by low-cost and robust multicell lead-acid batteries, a common problem encountered is how to efficiently convert this chemical energy to lumens (visible light output). To solve this, LEDs are frequently used because they produce many lumens per watt of energy consumed. A switching regulator is usually employed to efficiently convert the variable battery voltage to a regulated yet changeable (dimmable) current in the LED, which creates light. Efficiency must remain high over the battery voltage and dimming range in order to prolong battery life. A complete, cost-effective solution is needed to efficiently convert the 6, 9, 12, or 15 V of a common lead-acid battery pack to light with dimming capabilities.

Single LED versus an LED string

When designing a solar-lantern system, designers must choose whether to produce the desired amount of light with multiple smaller, lower-power LEDs or one larger, high-brightness LED. Typically, a single LED driver drives a string of smaller LEDs in a series configuration. The advantages of this approach are that the current in each LED is exactly the same and the LEDs can be positioned to illuminate a wider area than is possible with a single LED. However, even with equal currents, the LEDs cannot each emit exactly the same color of light unless they are tested and binned before assembly. This is more costly.

A single high-brightness LED emits light to a smaller area, but this can be overcome by a diffuser cover placed over the LED. When pick-and-place costs in assembly are considered, a single high-brightness LED is usually more cost-effective overall than several smaller LEDs. A single LED does not need to be binned, which also reduces costs. This article discusses use of the low-cost, single high-brightness LED. The LED current is set to 800 mA for a dimmable 2.8-W power output, which is typical for solar lanterns.

Easily dimmable

The light output of the solar lantern must be adjustable according to the needs of the user. For instance, more light might be required for reading than for cooking. Dimming the light output draws less energy from the battery and results in a longer battery run time.

Analog dimming and pulse-width-modulator (PWM) dimming are two methods that can be implemented to reduce the LED's light output. Analog dimming reduces the average current in the LED, while PWM dimming operates the LED at full current but varies the duty cycle at which this full current is applied. Thus, PWM dimming creates an average LED current equivalent to the full current multiplied by the duty cycle of the applied PWM signal. The PWM dimming frequency should be above the bandwidth detectable by the human eye so that the viewer does not notice any flicker. In general, analog dimming is more efficient, but PWM dimming eliminates the LED color shift that occurs when the LED is driven at different currents (as in analog dimming). So, the LED light color remains the same across the dimming range. Since both dimming methods have advantages and disadvantages, the ideal solar-lantern LED driver should accommodate both dimming methods. A PWM signal from a microcontroller, which typically is present in the solar-lantern system for battery management and other tasks, should be the single dimming interface with the LED driver for both methods. The Texas Instruments TPS62150 supports analog and PWM dimming from a PWM signal, as shown in Figures 1 and 2 (see next page). Detailed design equations are found in References 1 and 2.

The advantage of these circuits is their similarity. Only small schematic changes and a change to the PWM signal's frequency are needed to implement analog or PWM dimming in a given design. This means that the same LED driver circuit can be used for multiple solar-lantern designs. Simply populate the circuit with different components and load a slightly different code to the microcontroller, and the solar lantern is optimized for either highest efficiency or most constant light color through the use of either analog or PWM dimming.

Another major concern is the dimming linearity. Does the rate of change in the LED current (and thus the light output) across the dimming range correspond to the rate of change of the input signal (in this case, the duty cycle of the PWM signal)? If this is true for the given LED driver, then the code development is quite simple, as a 10% increase in duty cycle results in a 10% increase in light output. If this were not true, then additional testing and code would be needed to correlate a given change in the input signal to the desired change in light output. This

Figure 1. Circuit schematic for analog dimming

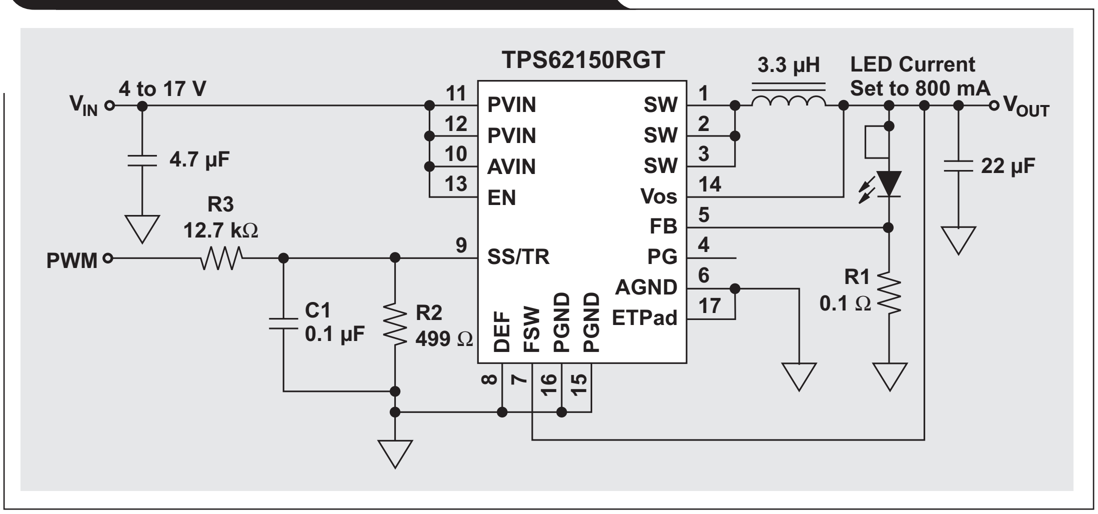
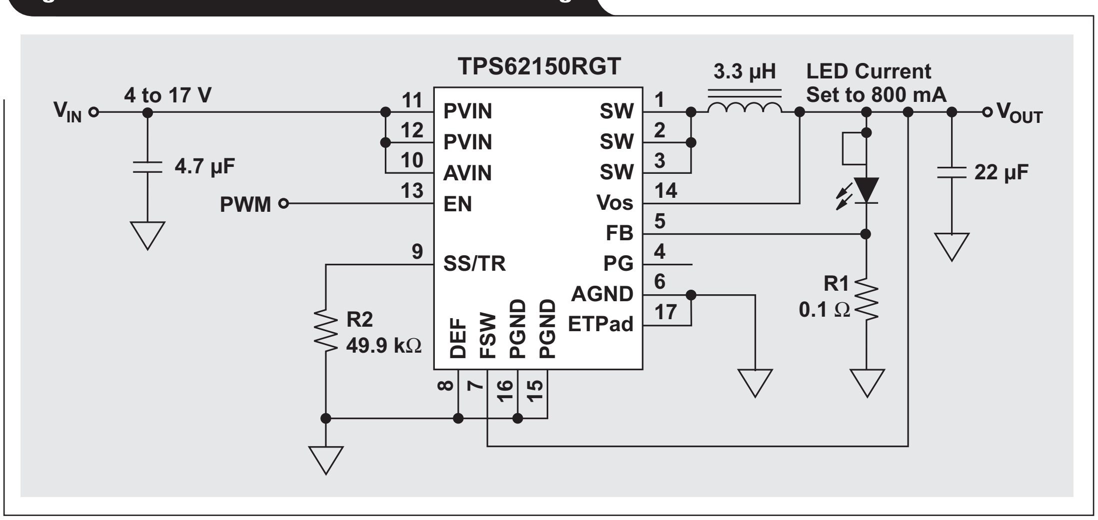


Figure 2. Circuit schematic for PWM dimming



correlation might also vary across the dimming range, resulting in further complications to the dimming algorithm. Fortunately, the circuits in Figures 1 and 2 support very high dimming linearity, as shown in Figures 3 and 4. Each circuit has a coefficient of determination (R^2 value) of 1, which indicates perfect linearity. (The R^2 value is a statistical measure of the variability in a data set, and a value of 1 indicates zero variability.) This results in a very simple code development for the dimming algorithm and provides a pleasant user experience in the smooth dimming behavior of the lantern.

However, for analog dimming, the linear equations modeling this linearity have a y-axis intercept of 94 mA. This shows another limitation of analog dimming—an inability to dim the LED at very low output currents. To solve this, PWM dimming is used, with a y-axis intercept of –7 mA. This allows very low LED currents to be achieved at very low PWM duty cycles.

Figure 3. Analog dimming linearity

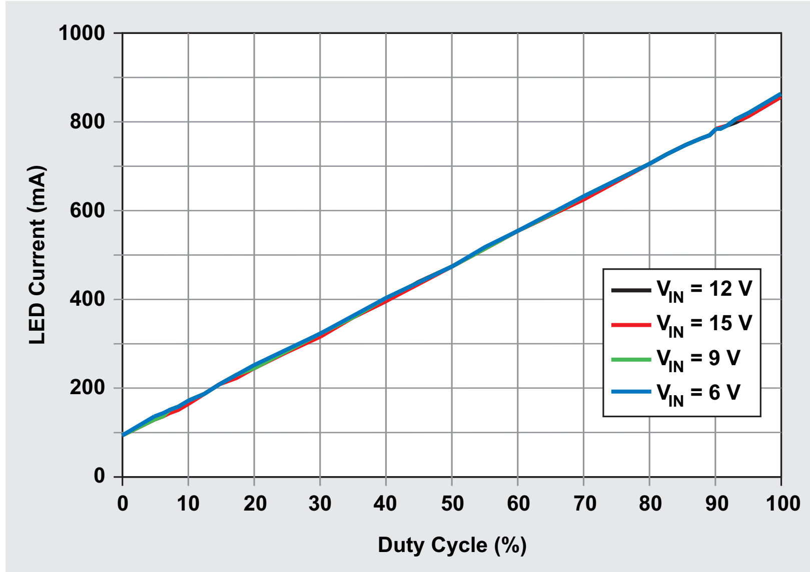
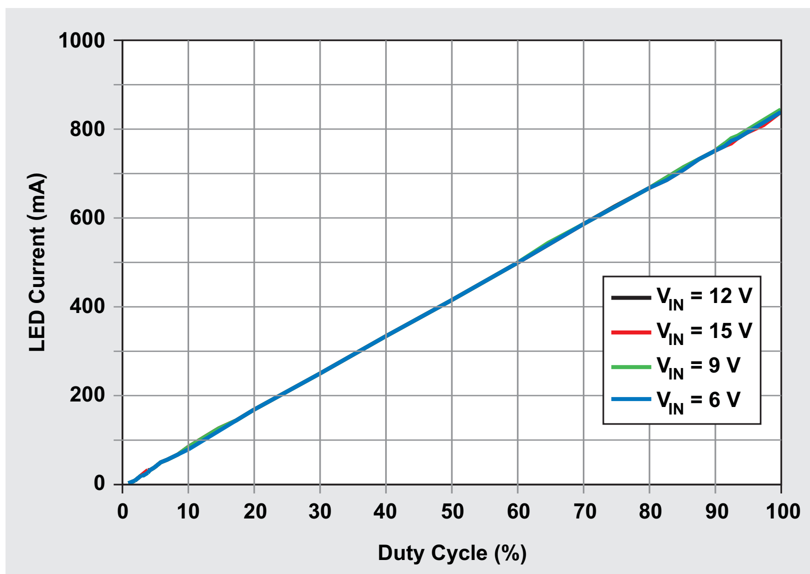


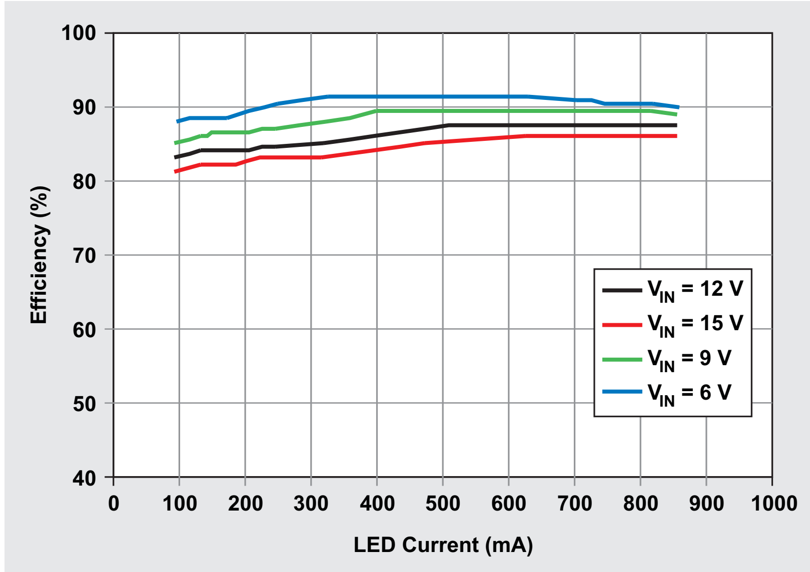
Figure 4. PWM dimming linearity



Achieving high efficiency

Efficiency is critical in any battery-powered system, but especially in a solar lantern. Since it cannot be assumed that every day will have sunlight, the batteries have to last for more than one day at a time without a recharge. By an efficient conversion of stored chemical energy to light and a reduction of the light output through dimming, the LED driver increases the battery run time. In addition to supporting dimming, an efficient LED driver should (1) operate at a relatively low switching frequency to reduce the switching losses, (2) have a power-save mode to boost the efficiency at low light levels, and (3) have a cost-effective method to reduce the losses in the current-sensing resistor, R1 in Figure 1. The TPS62150 is a good choice because it has these three features and produces the efficiency shown in Figures 5 and 6. Due to a higher voltage drop when the LED is driven at its full current, and due to reduced efficiency during the turn-on and turn-off of the IC, the efficiency of PWM dimming is lower than that of analog dimming.

Figure 5. Analog dimming efficiency



Conclusion

This article has presented an efficient 2.8-W solar-lantern solution that drives a single high-brightness LED and provides either analog or PWM dimming from a PWM signal. Analog dimming achieves better efficiency over the entire dimming range, while PWM dimming allows very low LED currents (for very low light levels) at low PWM duty cycles and has the best efficiency at full output power. Both dimming circuits are extremely linear. This design is well-suited for solar lanterns powered from rechargeable lead-acid, nickel, or lithium batteries.

References

For more information related to this article, you can download an Acrobat® Reader® file at www.ti.com/lit/*litnumber* and replace "*litnumber*" with the **TI Lit. #** for the materials listed below.

Document Title	TI Lit. #
1. "Using the TPS62150 as step-down LED driver with dimming"	SLVA451
2. "Design tool for analog dimming using a PWM signal"	SLVC366
3. "3-17V 1A step-down converter in 3×3 QFN package," TPS62150/1/2/3 Datasheet	SLVSAL5

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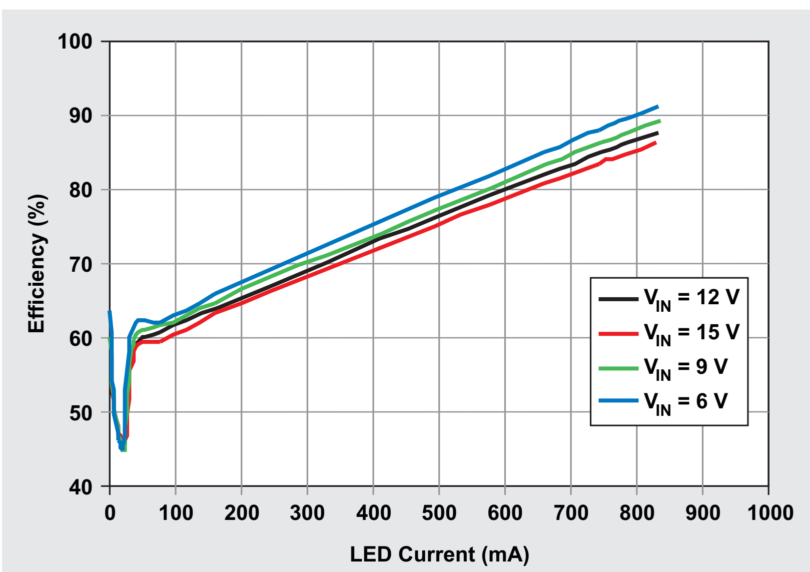
Figure 6. PWM dimming efficiency



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