

# LED-driver considerations

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Many of today's portable electronics require backlight LED-driver solutions with the following features: direct control of current, high efficiency, PWM dimming, over-voltage protection, load disconnect, small size, and ease of use. This article discusses each of these features and how they are achieved, and concludes with a typical circuit that implements each of these features.

## Direct control of current

LEDs are current-driven devices whose brightness is proportional to their forward current. Forward current can be controlled in two ways. The first method is to use the LED V-I curve to determine what voltage needs to be applied to the LED to generate the desired forward current. This is typically accomplished by applying a voltage source and using a ballast resistor as shown in Figure 1. However, this method has several drawbacks. Any change in LED forward voltage creates a change in LED current. With a nominal forward voltage of 3.6 V, the LED in Figure 1 has 20 mA of current. If this voltage changes to 4.0 V, which is within the specified voltage tolerance due to temperature or manufacturing changes, the forward current drops to 14 mA. This 11% change in forward voltage causes a much larger 30% change in forward current. Also, depending upon the available input voltage, the voltage drop and power dissipation across the ballast resistor waste power and reduce battery life.

The second, preferred method of regulating LED current is to drive the LED with a constant-current source. The constant-current source eliminates changes in current due to variations in forward voltage, which translates into a constant LED brightness. Generating a constant-current source is fairly simple. Rather than regulating the output voltage, the input power supply regulates the voltage across a current-sense resistor. Figure 2 shows this implementation. The power-supply reference voltage and the value of the current-sense resistor determine the LED current. Multiple LEDs should be connected in a series configuration to keep an identical current flowing in each LED. Driving LEDs in parallel requires a ballast resistor in each LED string, which leads to lower efficiency and uneven current matching.

## High efficiency

Battery life is critical in portable applications. For an LED driver to be useful, it must be efficient. An efficiency measurement of an LED driver differs from that of a typical power supply. An efficiency measurement of a typical power supply is defined as the output power divided by

Figure 1. Voltage source with ballast resistor

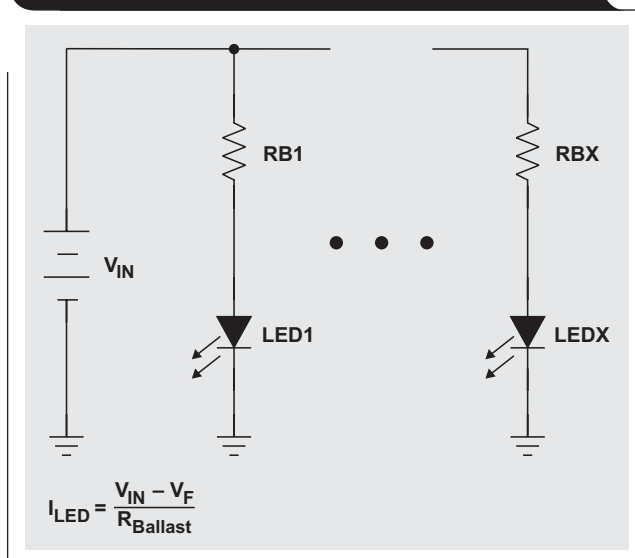
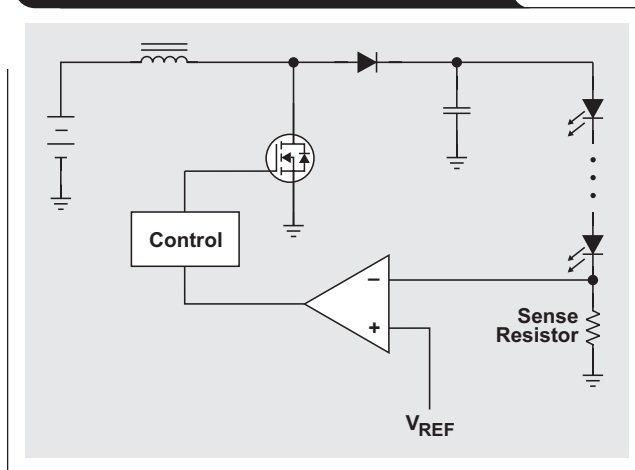


Figure 2. Constant-current source for driving LEDs



the input power. With an LED driver, the output power is not the parameter of interest. What is important is the amount of input power required to generate the desired LED brightness. This is easily determined by dividing the power in the LEDs by the input power. Defining the efficiency in this way means that the power dissipated in the current-sense resistor contributes to the power lost in the

supply. The following equation shows that smaller current-sense voltages contribute to higher-efficiency LED drivers.

$$\text{Efficiency} = \frac{P_{\text{LED}}}{P_{\text{LED}} + P_{\text{Supply\_Losses}} + P_{\text{Current\_Sense}}}$$

Figure 3 shows that choosing a power supply with a 0.25-V reference voltage versus a supply with a 1-V reference voltage improves efficiency. A supply with a lower current-sense voltage is more efficient regardless of input voltage or LED current. With all else being equal, a lower reference voltage significantly improves efficiency and extends battery life.

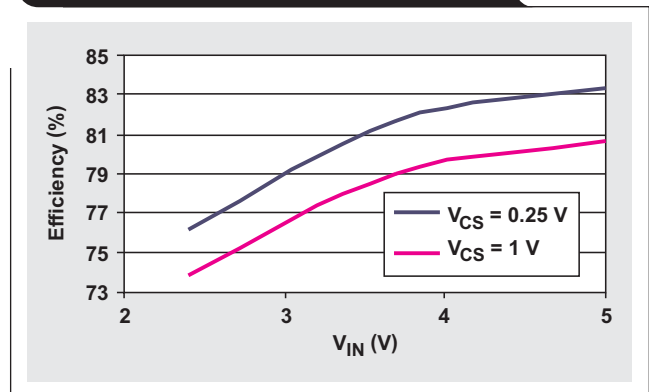
## PWM dimming

Many portable LED applications require dimming. In applications such as LCD backlighting, dimming provides brightness and contrast adjustment. Two types of dimming are available: analog and PWM. With analog dimming, 50% brightness is achieved by applying 50% of the maximum current to the LED. Drawbacks to this method include LED color shift and the need for an analog control signal, which is not usually readily available. PWM dimming is achieved by applying full current to the LED at a reduced duty cycle. For 50% brightness, full current is applied at a 50% duty cycle. The frequency of the PWM signal must be above 100 Hz to ensure that the PWM pulsing is not visible to the human eye. The maximum PWM frequency depends upon the power-supply startup and response times. To provide the most flexibility and ease of integration, the LED driver should be able to accept PWM frequencies as high as 50 kHz.

## Overvoltage protection

Operating a power supply in a constant-current mode requires overvoltage protection. A constant-current supply generates a constant output current regardless of load. If the load resistance increases, the supply's output voltage also must increase to supply a constant current. If the supply encounters an excessive load resistance, or if the load is disconnected, the output voltage can increase above the voltage rating of the IC or of the other discrete circuit components. Several overvoltage protection schemes are available for constant-current LED drivers. One scheme is to place a zener diode in parallel with the LEDs. This limits the output voltage to the zener's breakdown voltage plus the supply's reference voltage. During an overvoltage condition, the output voltage increases to the point where the zener breaks down and begins to conduct. The output current flows through the zener, then through the current-sense resistor to ground. The supply continues to generate the constant output current while the zener limits the maximum output voltage. A more preferred method of overvoltage protection is to monitor the output voltage and shut down the supply when the overvoltage trip point is reached. Shutting down the supply under an overvoltage condition reduces power dissipation and extends battery life in the event of a fault.

**Figure 3. LED driver efficiency versus current sense voltage**



## Load disconnect

An often overlooked feature in an LED-driver supply is load disconnect. Load disconnect electrically removes the LEDs from the power supply when the supply is disabled. This is important in two situations: shutdown and PWM dimming. As shown in Figure 2, during shutdown of a boost converter, the load is still connected to the input through the inductor and catch diode. Since the input voltage is still connected to the LEDs, a small current continues to flow, even when the supply is disabled. Even small leakage currents significantly reduce battery life during extended periods of off time. Load disconnect is also important during PWM dimming. During the off time of the dimming period, the supply is disabled; but the output capacitor is still connected across the LEDs. Without load disconnect, the output capacitor discharges through the LEDs until the dimming pulse turns the supply on again. Since the capacitor is partially discharged at the beginning of each dimming cycle, the supply must charge up the output capacitor at the beginning of each dimming cycle. This creates a spike of inrush current during each dimming cycle. The inrush current lowers system efficiency and creates voltage transients on the input bus. With load disconnect, the LEDs are removed from the circuit so there is no leakage current when the supply is disabled, and the output capacitor remains fully charged during PWM dimming. A load-disconnect circuit is best implemented by placing a MOSFET between the LEDs and the current-sense resistor. Placing the MOSFET between the current-sense resistor and ground creates an additional voltage drop that manifests itself as an error in the output-current setpoint.

## Ease of use

Ease of use is a relative concept. A circuit's ease of use not only encompasses the complexity of the initial design but also involves any future effort required to modify the circuit quickly and reuse it for other programs that may have slightly different requirements. In general, hysteretic controllers are very easy to use. A hysteretic controller

eliminates the need for the complicated frequency compensation required in a classical power-supply design. While frequency compensation is not difficult for an experienced power-supply designer, most novice power-supply designers find it tedious. Since the optimal compensation changes for different input and output conditions, a classical power-supply design does not lend itself to quick modifications for different operating conditions. A hysteretic controller is inherently stable and requires no changes as input and output conditions change.

### Small size

Small size is an important feature for portable circuitry. Several factors contribute to the size of the circuit components. One factor is switching frequency. Higher switching frequencies allow the use of smaller passive components. A modern LED driver intended for portable applications should be able to switch at frequencies of up to 1 MHz. Switching at frequencies greater than 1 MHz is not typically recommended because it does not significantly reduce circuit size; but it does reduce efficiency and lower battery life due to the higher switching losses. Integration of features into the control IC is the single most important factor that contributes to a small-driver solution. If all the features

described in the preceding paragraphs were implemented with discrete components, the board area required would take up more space than the power supply itself. Integrating these features into the control IC significantly reduces the overall driver size. A second but equally important benefit of feature integration is a reduction in the total solution cost. Implemented discretely, all desirable features in an LED driver can add an additional sixty to seventy cents in component cost. When integrated into the control IC, these features typically add only pennies to the cost of the IC.

### Practical solution

The TPS61042 is an excellent example of a modern LED-driver control IC. Figure 4 is a block diagram of the TPS61042 with a highly integrated control IC. Q1 is a low-resistance, integrated power FET. The low resistance of this component contributes to an extremely high efficiency. The 0.25-V reference voltage reduces losses in the current-sense resistor. PWM dimming is easily implemented with this IC by applying a PWM signal to the CTRL pin at frequencies as high as 50 kHz. Q2 implements the integrated load-disconnect circuitry. Since it is integrated, this circuitry is perfectly synchronized to the PWM dimming frequency.

**Figure 4. Block diagram of TPS61042 with high level of integration**

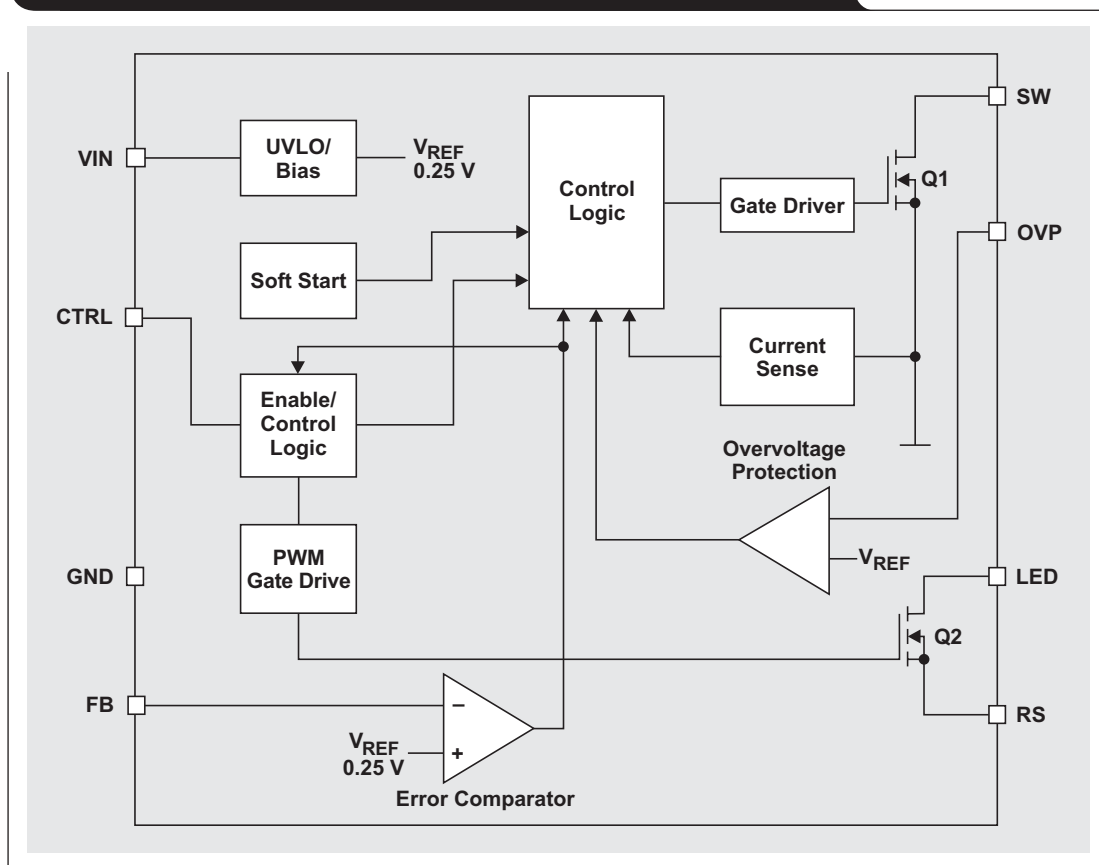
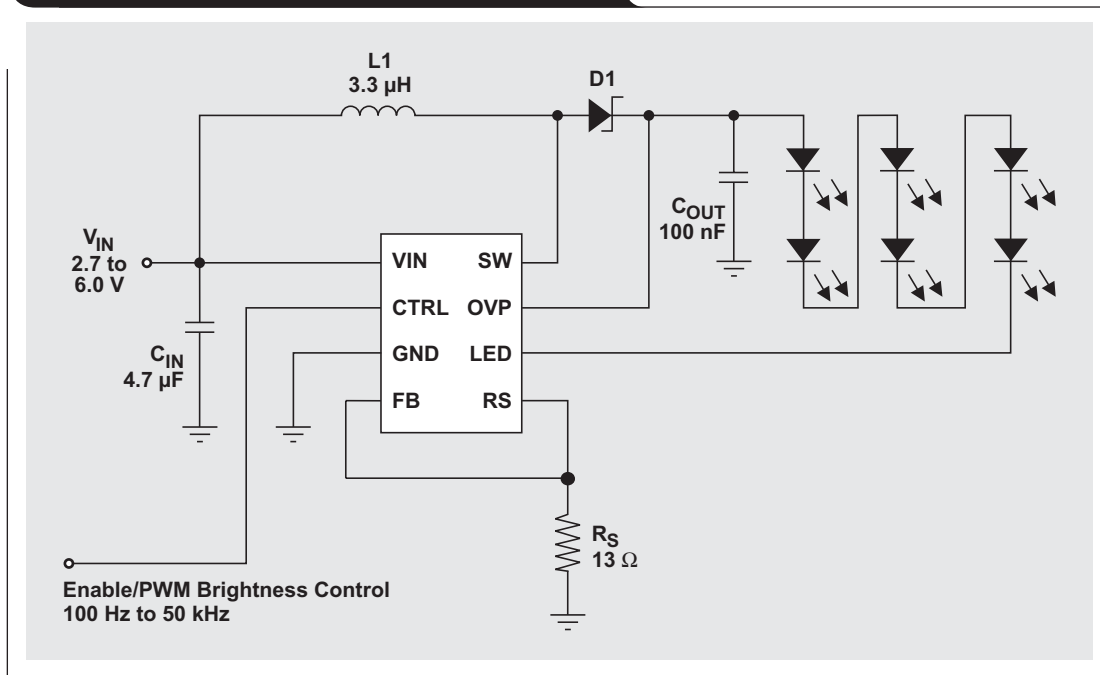


Figure 5. Typical TPS61042 LED-driver solution



Overvoltage protection is also integrated into the IC. Most seasoned power-supply designers will note the absence of an error amplifier and any associated compensation circuitry. This function has been replaced by the error comparator. This IC operates with hysteretic-control feedback topology, which requires no compensation and is inherently stable. Not shown in the block diagram is the physical size of the IC. All control circuitry and features are integrated into a 3 mm × 3 mm QFN package. Figure 5 shows a typical LED-driver application that drives four LEDs with 20 mA of forward current and operates from an input voltage range of 1.8 to 6.0 V. The entire circuit consists of the control IC,

two small ceramic caps, an inductor, a diode, and a current-sense resistor. This small circuit shows the high level of integration that is achieved with today's LED drivers. The primary power-supply functions and the secondary features such as load disconnect, overvoltage protection, and PWM dimming have been implemented with a control IC and five small surface-mount passive components.

### Related Web sites

[analog.ti.com](http://analog.ti.com)

[www.ti.com/sc/device/TPS61042](http://www.ti.com/sc/device/TPS61042)

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