Flyback topology offers superior balance in LED drivers

Peter B Green, International Rectifier Corp - December 01, 2011

LED-based light fixtures and bulb replacements are now rapidly replacing incandescent, halogen, and CFL (compact-fluorescent-lamp) light sources in many general-lighting applications. Flyback dc/dc converters are the power-supply topologies of choice for a large segment of the LED-driver market because these devices allow electrical isolation between the LEDs and the ac line, which is a safety requirement in most LED lamps.

Almost all LED-based-light-bulb replacements include a large, aluminum heat sink shaped to fit the design, with many fins to maximize the surface area. High-brightness LEDs generate heat, which must radiate out into the ambient air to prevent overheating and to lengthen lifetimes.

Although the LEDs themselves are not accessible, they often electrically connect to the heat sink because any insulator between the two imposes a thermal barrier. Designs using insulators need thin heat sinks to minimize this barrier and thus cannot offer reliable electrical isolation. For this reason, engineers often favor isolated flyback driver circuits over the simpler but nonisolated buck topology. Flyback LED drivers also offer simplicity; low cost; the ability to achieve a high power factor; and, with some additional circuitry, compatibility with common TRIAC (triode-alternating-current)-based dimmers.

The core element of a flyback LED-driver circuit is a coupled inductor (Figure 1). A high-voltage MOSFET switches the primary of the inductor across the dc bus. When the switch is on, current rises in the inductor and energy is stored in the magnetic field. For this scenario to occur, the inductor cores require an air gap. Switching off the MOSFET interrupts the primary current; therefore, current must flow in the secondary winding instead of through the diode and into the output capacitor and load. During this phase, the energy in the inductor transfers to the output. Because current does not flow to the output when the MOSFET is on, a storage capacitor at the output is necessary to provide continuous current in the LEDs.
The inductor’s turns ratio provides neither a step-down nor a step-up function as in a transformer; instead, it must be derived by considering the reflected voltage that appears at the primary winding when the MOSFET is off. The voltage appearing at the drain of the MOSFET must not exceed its maximum drain-to-source-voltage rating under conditions of peak line voltage and maximum LED-output voltage. This voltage is equal to the dc-bus voltage plus the LED-output voltage, multiplied by the turns ratio, which is the reflected voltage. For a 120V-ac circuit, the MOSFET should have a 400V voltage; for a 277V-ac or wide-input-range circuit, the MOSFET should have a 650V voltage. These voltages allow for a practical inductor design that requires fewer turns on the secondary.

Flyback converters continuously store and transfer energy through the inductor. Thus, the inductor operates in only one quadrant of the flux-density-versus-magnetic-field-strength curve. As a result, the core must be larger to transfer a given power than it is in some other more-complex power-supply topologies, which use the cores more efficiently. The flyback approach most suits power levels lower than 50W, which covers all screw-in, LED-based light-bulb-replacement products and many downlights and luminaires (Figure 2). Flyback designs can also operate at higher power levels; however, these designs are more complicated and often use multiple-inductor and MOSFET-interleaved circuits.

As performance standards emerge to cover LED-lighting products, environmental considerations, such as high power factor, also become requirements. A flyback LED driver can provide a power factor of approximately 0.9 using passive-circuit techniques without any preregulating stage, which would add significantly to the cost and size.

To provide a high power factor, you can run the flyback circuit from a full-wave-rectified dc bus with only a small capacitor for high-frequency coupling, or you can add a simple, passive valley-fill circuit comprising two capacitors and three diodes (Figure 3). The first method is cheaper but requires a larger holdup capacitor at the outputs to prevent the LED’s current from dropping out close to the
ac line’s zero crossings. As a result, this method is feasible only when the LED current is 350 mA or less. The second and more common method adds some cost but overcomes the limitation of the first method.

The next important issue to consider is how to regulate the LED current. You can achieve this regulation by using a secondary voltage- and current-sense circuit with an optoisolator to transfer the feedback signal back to the primary-side control IC. Alternatively, you can regulate the primary-side peak current in the MOSFET only and not directly sense the LED voltage or current. Another option is to use a primary-sensing method that provides some current regulation and overvoltage protection but without the need for an optoisolator.

Using a secondary voltage- and current-sense circuit is the most accurate method, but it requires the use of an optoisolator and an output-sensing and regulation circuit, all of which affect space and cost. Regulating the primary-side peak current in the MOSFET eliminates a significant number of components but offers a less accurate form of control, which can provide the correct output current to the LEDs at only a specific line input and LED-output voltage. Although this approach may be acceptable in some low-end applications, it offers no protection against an open-circuit condition. The output of a flyback converter can produce high voltages if the load becomes open circuit—for example, when one LED in the chain fails in an open-circuit state—because the voltage continues to rise until the inductor can discharge its stored current.

Manufacturers are now employing the primary-sensing method in smart flyback-control ICs that can sense the current and voltage at the primary side of the circuit and use an algorithm to determine the output current without directly sensing it. An LED driver employing one of these controllers can provide a regulated output current over a range of input-voltage variation, although it still needs to be set to operate for a specific number of LEDs at the output because it cannot adjust for voltage variations. Such controllers can also include circuitry for detection of open-circuit conditions; thus, they limit the output voltage. This method is more accurate than regulating the primary-side peak current in the MOSFET because the controller integrates the added complexity, but it is still less accurate than using a secondary voltage- and current-sense circuit with an optoisolator.

A flyback driver in an LED-based-light-bulb replacement could use any combination of these PFC techniques. However, the current trend is toward products that users can dim from currently installed TRIAC-based dimmers. This approach adds another degree of complexity to the LED-driver design. TRIAC-based dimmers generally work poorly with capacitive loads, such as solid-state power-converter circuits, because, once the TRIAC fires, it continues to pass current only while the current remains above a defined threshold. In LED drivers, some additional circuitry is usually necessary to guarantee the same activity. Without the extra circuitry, the TRIAC tends to fire erratically, which results in flickering.

After addressing this issue, you must then enable the LED driver to adjust the LED’s output current
depending on the dimmer’s position. The most-basic circuit relies on the drop in bus voltage as the dimmer’s level decreases to provide a reduction in output current. However, this approach produces limited performance and operates only over a portion of the adjustment range of the dimmer. It probably makes more sense to design better dimmers that can work with LED drivers rather than to design more complicated LED drivers to work with dimmers that originally operated with incandescent light bulbs. Although this approach seems technically logical, the market is not currently going in that direction.

Many designs now produce good dimming control by adding circuitry that detects the firing angle of the TRIAC and converts it to a dc-control voltage, which then adjusts the output current accordingly. Such implementations, however, currently require many components because they use the method of regulating the primary-side peak current in the MOSFET, often requiring multiple optoisolators. As a result, such products often sell for at least $30. The next generation of dimmable flyback-based designs will most likely use the primary-sensing method as new and more intelligent control ICs enter the market.

Besides finding use in luminaires and downlights, flyback LEDs also serve as fluorescent-tube replacements, which look similar but deliver higher lumens per watt and longer lifetimes (Figure 4). You can, for example, use these LEDs in series in a long chain to give the appearance of a continuous light source. The 24W LED-based product in the figure replaces a 32W T8 fluorescent lamp. At this level, a flyback design provides the best option for a low-cost driver that complies with safety and performance requirements.

Compatibility with TRIAC dimmers is generally unnecessary in this type of LED lighting, which often operates using 0 to 10V analog dimming control or digital-control schemes such as DALI (Digital Addressable Lighting Interface) in more advanced applications. This approach eliminates many of the problems of dimming and allows more precise control of the light output because this scheme can incorporate PWM, linear dimming, or both.

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Author’s biography
Peter B Green is LED-group manager at International Rectifier, where he has worked for 10 years. His responsibilities include LED-driver-IC-productline definition and specification, working with IC designers and application engineers to design new LED-driver controllers and supporting demo boards and writing application notes. Green has a bachelor’s degree in electrical engineering from Queen Mary College, University of London. His personal interests include electronics, computers, popular science, history, and travel.