High-Efficiency LED Lighting is Not a High-Cost Proposition
…If You Use the Right Approach

Two LED driver designs illustrate that great strides are being made to increase efficiency and reduce the cost of LED lighting

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LED lighting is a mainstream technology for automotive use and is gaining ground in mains-powered domestic and commercial applications. It is considered a green technology because of its exceptionally high efficiency in converting electricity to visible light. Properly designed LED lights wear out more slowly than the fixtures they are mounted in; simply put, this means that LED lamps do not need to be readily accessible to be replaced. Architects and designers are now free to create completely new and innovative concepts in lighting for both living and working environments.

There are, however, significant challenges to overcome before LEDs can take over from the incumbent incandescent and fluorescent lighting. The operating temperature of LED light fixtures is much lower than that of incandescent lights; despite this, an internal temperature of 100°C is not uncommon. This can be a problem for the reliability and lifetime of the driver circuit if care is not taken in the choice of components. Achieving a higher efficiency for the driver circuit would clearly be beneficial to reduce both fixture temperatures and electricity usage.

The operating life of an LED driver, which may consist of 40 or more components, is limited by the component with the shortest lifetime. Two classes of components often used in LED drivers typically exhibit short lifetimes in high ambient conditions: electrolytic capacitors and opto-isolators. It would be advantageous to eliminate these components from LED drivers for long-life applications, such as architectural use or street lighting where maintenance cost has a significant bearing on the return on investment calculation that often governs the decision to change to solid-state lighting.
The final challenge is cost. LEDs themselves are getting progressively cheaper and much work is underway to take cost out of the complete LED lighting solution – which means the power supply is coming under ever-increasing scrutiny. For the LED driver circuit, the goal is to increase efficiency, lower power consumption, and achieve long operating life, while at the same time reducing overall power supply cost.

**Current driven**

LEDs are current-driven devices with a nominal forward voltage drop of typically 3.2 V. However, production variations mean that the LED forward voltage for this nominal output can easily vary by ±0.5 V. For most lighting applications, LEDs are connected in strings – often up to 30 LEDs, depending on the power of the individual LEDs and the light output required from the luminaire. The power supply must convert the AC mains input to a constant output current which will remain constant.

Various national and international authorities long ago imposed tight requirements on the power factor and harmonic distortion¹ of the input current waveform. These requirements are strictly enforced in the United States, Europe, and parts of Asia, and are steadily tightening in other regions as well. So the driver must pair a power factor correction (PFC) stage at the input and a constant-current driver stage for the output. The typical two-stage approach comprising a PFC boost converter, followed by an isolated or non-isolated buck converter driving the output, limits the efficiency that can be achieved for the relatively low powers seen in most lighting applications. The complexity of these circuits also makes it difficult to reduce cost. A highly simplified view of the circuit blocks that comprise a typical combination of PFC boost stage and isolated flyback (buck) converter is shown in Figure 1.
Figure 1 shows the basic elements of a two-stage LED driver with a boost PFC stage followed by a constant-current driver – in this case, a flyback converter. Each stage in the driver introduces losses which cascade through the system. The boost PFC stage would typically achieve a maximum efficiency of 95% and the constant-current driver might achieve 90%, making an overall efficiency of approximately 85%.

The circuit contains two inductors, two power switches, and two controllers, plus a boost diode and boost choke. In both the PFC stage and the flyback that follows it, a MOSFET switch is used to control current flow. The PFC stage uses a slow control loop and forces the input current to approximate to a sine wave. The flyback converter with a very fast loop adjusts the amount of energy that is transferred to the output stage during each switching cycle in order to regulate the output. If these two switching functions could be combined into a single switching stage, making use of the different time constants of the two control loops, then a greatly simplified power conversion stage with fewer components and losses would result. Single-stage converters using an approach have been around for a while and are starting to get a lot of attention for LED lighting because of some profound benefits they bring to the application. An idealized circuit using a single-stage PFC and CC conversion approach is shown in Figure 2.
Figure 2 is a single-stage combined PFC and constant-current LED driver using a LinkSwitch-PH device produced by Power Integrations (PI). The monolithic IC incorporates a 725 V power MOSFET, together with integrated control, driver and protection circuitry. Using LinkSwitch-PH, the circuit is capable of achieving an overall conversion efficiency of 92% and requires far fewer components than the two-stage approach. It eliminates the high-voltage electrolytic capacitor across the DC power bus and, being primary-side controlled, does not require opto-isolators from the feedback path. So the two component types that are the Achilles heel of long lifetime in LED lighting can be eliminated with this topology.

Control

Driving a combined PFC and CC circuit is challenging, PI has overcome this problem with the use of continuous conduction mode (CCM) PFC controlled by a proprietary technique known as a delayed-linear ramp. PI uses a primary-side charge transfer control technique to provide an accurate constant-current control. These techniques are made possible because of the tight integration of the control circuitry, together with the MOSFET in the monolithic device.

The implementation of Figure 2 in practice will be shown by reference to two examples that are differentiated by the contrasting ways that the output is driven: an isolated, low-voltage flyback converter and a high-voltage, non-isolated buck-boost design.

Figure 3: 15 W flyback LED driver using LinkSwitch-PH LNK407EG
Figure 3 is a complete isolated 15 W LED driver in a flyback topology. It provides a 500 mA constant current output at a nominal 30 V from a 90 to 265 VAC input. The driver achieves a power factor of greater than 0.9 and full load efficiency of 89.6% at 115 VAC and 90.6% at 230 VAC input. It meets IEC 61000-4-5 ring wave, easily meets IEC 61000-3-2 Class C, and EN55015 B conducted EMI. The PCB (Figure 4) is designed to fit inside a PAR38 enclosure.

![Figure 4: 15 W LED driver PCB](image)

Mounted inside the lighting enclosure, the driver is expected to operate at elevated temperatures during its operating life. To achieve the longest possible service life, no electrolytic capacitors or opto-isolators were used in the design.

The PFC function is driven by the voltage input to the Voltage Monitor (V) pin. Peak AC line voltage detection is provided by D1, C10, C11, R2, R7, and R13. The bias winding in T1 provides drive and output voltage information to the LinkSwitch-PH (U1) via the Bypass (BP) pin and a current feedback loop to the Feedback (FB) pin. Diode D7, C14, R11, VR2, C12, R12, and Q1 provide a disconnected load / overvoltage shutdown function.

**Tube replacement**

The second example is a 25 W non-isolated LED driver designed to fit within a T8 tube lamp. The circuit diagram is shown in Figure 5.
Figure 5: Schematic for a 25 W buck-boost LED driver using LNK409EG

Figure 5 is a complete non-isolated 25 W PFC LED driver employing buck-boost topology. It provides a 250 mA constant current output at a nominal 100 V from a 180 to 265 VAC input. The driver achieves a power factor of greater than 0.9 and full load efficiency of 91.3%. It also meets the power factor, harmonics, and conducted EMI standards noted in the flyback example.

In this case, the physical design is remarkable (see Figures 6 and 7). The circuit board is only 19.5 mm wide and 10 mm high.
The buck-boost configuration enables a high output voltage to be driven without compromising the PF or harmonic distortion performance. An inherent advantage of the buck-boost topology is that it continuously draws power from the AC input so the input current is near sinusoidal even for high output voltages. Consequently, the design achieves a THD of less than 25% at 230 VAC. Once again, there is no opto-isolator or electrolytic bulk capacitor in the input stage.

The buck-boost power circuit with floating output is composed of U1, output diode D6, output capacitors C5 and C7, and output inductors T1 and T2. Two inductors are used to meet the space constraints of the tube. T1 and T2 together provide the required buck-boost inductance, and the bias winding in T1 provides the supply current to U1 and output voltage information. This part of the circuit also provides protection in the event of a disconnected load or other overvoltage condition via R14 and VR1.

Diode D1 and C3 detect the peak AC line voltage. The voltage across C3, along with R3 and R4, sets the input current fed into the V pin. This current is used by U1 to detect line undervoltage (UV) and overvoltage (OV), and both V-pin and FB-pin current are used in the control algorithm to provide constant current to the LED load. R7 through R10, Q1, C6, and D5 comprise a voltage-to-current converter network providing the current feedback loop to the FB pin.

The CCM PFC function of LinkSwitch-PH, together with frequency jittering which spreads the fundamental switching frequency across a range to reduce noise peaks, combine to generate a low EMI signature. This enables the EMI filtering to be simple and small enough to fit within the confines of the T8 tube.

**Conclusion**

The two examples of production-ready LED drivers demonstrate that single-stage conversion produces an LED driver of smaller size, with fewer components, higher efficiency, and lower cost than traditional two-stage solutions. The designs also address reliability and lifetime concerns through generating a lower temperature rise within a luminaire and eliminating all opto-isolators and high-voltage electrolytic bulk capacitors. Using buck-boost topology, a high-
voltage output constant-current drive is achieved at extremely high efficiency and with exceptionally low THD, yet fits within a T8 tube.

References
1. IEC 61000-3-2 Class C harmonics.
2. LNK403-409EG/413-419EG LinkSwitch-PH Family LED Driver IC, Single-Stage PFC, Primary-Side Constant Current Control and TRIAC Dimming/Non-Dimming Device Options, November 2010.
3. DER-278: No Electrolytic Capacitor, High Efficiency (>90%), High Power Factor (>0.9) 15 W LED Driver Using LinkSwitch-PH LNK407EG, April 2011.

About the Author
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