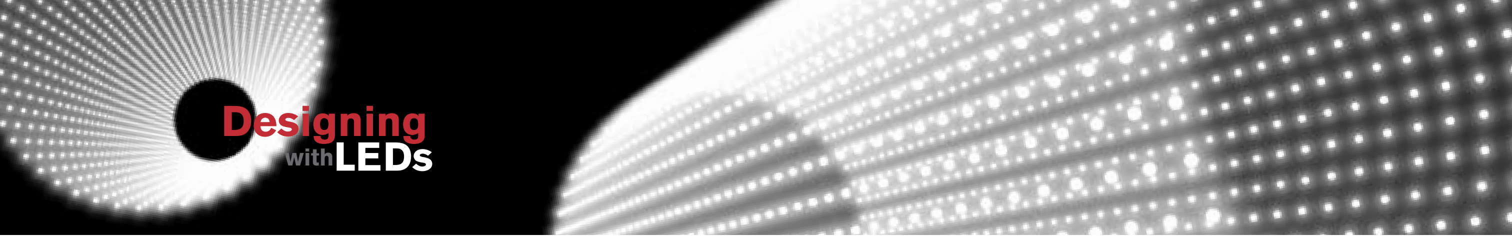


BY SILVESTRO FIMIANI, POWER INTEGRATIONS

Solving the LED-driver challenge for light-bulb replacement

The Department of Energy is offering a prize of as much as $10 million to create the first solid-state replacement for the 60W incandescent light bulb, so you know it's a problem. Here are some suggestions for how to address high-efficiency, power-factor, and phase-dimming-compatibility requirements.

The lighting industry is exploring ways to replace the standard 60W light bulb with a more energy-efficient, HB-LED (high-brightness-light-emitting-diode)-based design. LED lighting offers the prospect of a 10-fold efficiency improvement over incandescent lamps. With a potential lifetime of 100,000 hours, this improvement would virtually eliminate maintenance and replacement costs.

The US government has recognized the potential of LED lighting and intends ultimately to use LED lamps in all government buildings. To provide a stimulus for the development of LED lighting, the US Congress has mandated a prize of as much as $10 million for the first organization or individual to create and validate an LED-based screw-in replacement for the standard Edison-type, 60W incandescent bulb. The new bulb has to contain not only the LED chips, but also the driver circuitry—no easy challenge given the space constraints and potential electrical-noise issues. The lamp must achieve an efficacy of more than 90 lumens per watt, making power-supply performance critical to a successful design.

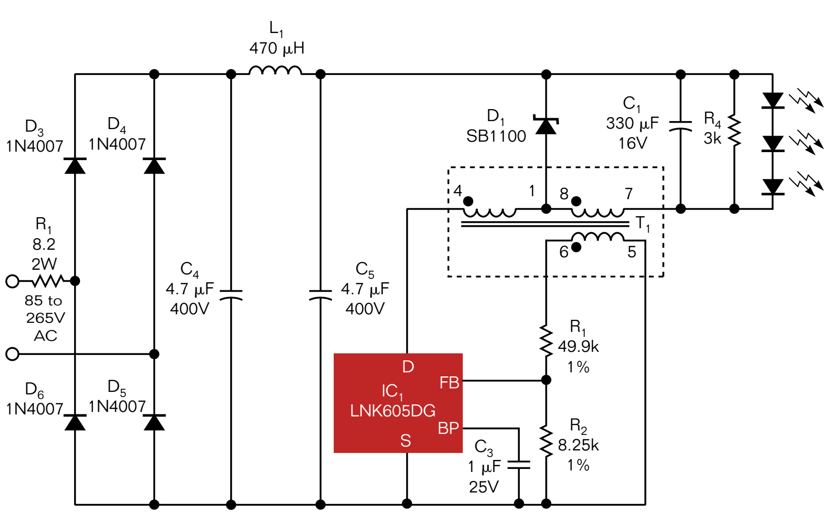


FIGURE 1 Power Integrations based this tapped-buck power supply on the LNK605DG switching IC, which uses just 16 components. This circuit operates over an input-voltage range of 85 to 265V ac, enabling the use of one lamp worldwide.

To provide an even spread of light, an LED lamp typically contains a dozen or more LEDs. The brightness of LEDs is a function of current flow, and LEDs have a typical threshold voltage of 3.4V, with a variation from 2.8 to 4.2V. The LEDs in a lamp connect in series strings, presenting the power supply with a CC (constant-current)-drive requirement across a potentially wide voltage range.

Several companies have recently developed primary-side switch-mode-control configurations, an example of which is the tapped-buck topology (**Figure 1**). The key advantages of the tapped-buck topology are that it lends itself to a smaller PCB (printed-circuit board), a smaller inductor core, and greater efficiency—more than 80% for 4.2W—than an isolated flyback converter. EMI (electromagnetic-interference) filtering is also simpler due to less common-mode noise generation. In the tapped-buck topology, the load connects in series with the inductor—in this case, T_1 windings 1, 2, 3 4, 7, and 8—and the primary switching element, a 700V MOSFET, which the SMPS (switched-mode-power-supply) controller, IC_1, incorporates. When IC_1, a Power Integrations (www.powerint.com) LNK605DG, turns off, the energy in T_1 induces a current to flow in the output winding (pins 7 and 8). The current in the output winding steps up by a factor of the inductor's turns ratio and flows from the output winding, through freewheeling diode D_1, and the load.

IC_1 switches at a rate as high as 88 kHz, minimizing the size requirements of the inductors and capacitors. In CV (constant-voltage) mode, the circuit generates 12V±5% to 350 mA when it switches into CC mode. This operating mode is the normal one for LED loads, and the circuit

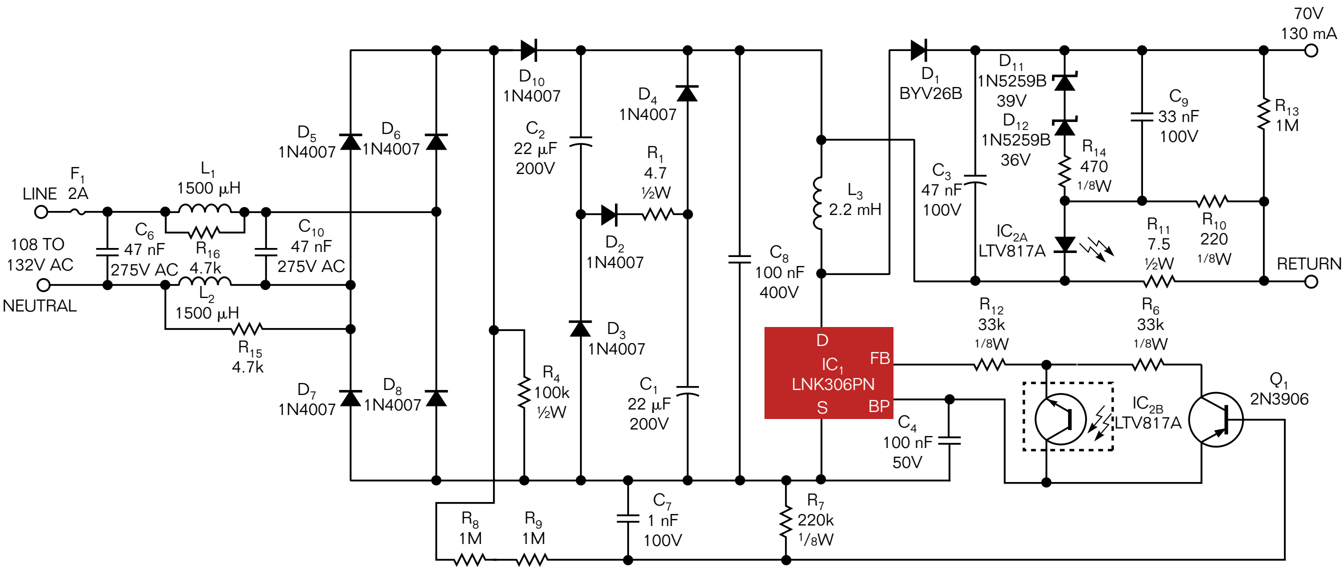


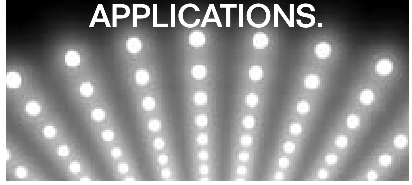
FIGURE 2 This 9W LED driver uses a valley-fill circuit for an improved power factor, which a draft version of the Energy Star requirements for solid-state lighting requires.

maintains 350 mA±10%. The key to this simple design is the control circuitry within IC_1. The circuit implements feedback control using only input from the bias winding (pins 5 and 6) in T_1. It requires no sense resistor to generate the CC output, and it needs neither an optocoupler nor secondary control circuitry. The control method compensates for variations in the inductor and other component tolerances and for input-voltage variations.

At the beginning of each switching cycle, IC_1 switches on, and current ramps up until it reaches IC_1's current limit, when the switch in IC_1 turns off. With IC_1 off, the energy in T_1 induces a current to flow in the output winding, not only maintaining the current through the load, but also stepping it up by means of the turns ratio. Capacitor C_1 filters the load current and removes the switching component. The on/off-control-state machine and switching frequency vary in response to the feedback voltages at the FB input. In CC mode, as the output voltage and, therefore, the flyback voltage across the bias winding increase, the feedback-pin voltage increases. This increase produces a reduction in the switching frequency, thus providing a constant output-current regulation. In CV operation, the controller regulates the output voltage using the on/off-state machine.

The CV characteristic of IC_1 operates at start-up as the IC ramps up to CC mode and ensures output-overvoltage protection. A fault condition can cause the part's die temperature to rise to more than a nominal 142°C, initiating a hysteretic thermal shutdown. The circuit is an efficient and effective approach to powering a plug-in Edison-replacement LED lamp, providing compliance with EMI standard EN (European Norm) 55015 Class B, with 10 dB of margin. At this power level, you can implement the Energy Star requirements for power-factor control using a valley-fill circuit (**Reference** 1 and **Figure** 2). Note that this circuit introduces additional passive components that increase the board size and, more seriously, reduce conversion efficiency.

A PFC CIRCUIT GIVES THE SUPPLY A POWER FACTOR GREATER THAN 0.92, WHICH MEETS THE REQUIREMENTS OF ENERGY STAR SSL FOR COMMERCIAL APPLICATIONS.



Energy Star recently introduced a proposal that SSL (solid-state-lighting) replacement lamps should be dimmable (**Reference** 2). Adding this function would require additional circuitry and would have a negative impact on efficiency. You can add the dimming capability by introducing a circuit to detect the phase of the rising edge that the SCR (silicon-controlled rectifier) generates, but you must carefully perform this task to ensure compliance with power-factor and harmonic-current limits. A buck-boost circuit can meet these requirements. The buck-boost supply provides a CC output as high as 9W at a maximum output voltage of 70V dc from 108 to 132V ac and includes phase-detection logic for use with SCR dimmer controls. A passive-valley-fill PFC (power-factor-correction) circuit gives the supply a power factor greater than 0.92, which meets the requirements of Energy Star SSL for commercial applications. The high-output-voltage design helps to boost efficiency and compensate for additional losses due to the valley-fill circuit. The supply also meets EN 55015B EMI requirements.

In this circuit, switching controller IC_1 uses an on/off control. Current-sense resistor R_{11} generates a voltage across the diode of optocoupler IC_{2A}. This feedback signal goes to IC_1's FB pin through IC_{2B} and R_{12}. D_{11}, D_{12}, and R_{14} clamp the output voltage under no-load conditions to approximately 80V, achieving a CV/CC characteristic. The phase-detection logic takes advantage of the on/off control to use the SCR phase angle to inhibit switching, thereby reducing the load current and accomplishing dimming. D_{10} isolates the line voltage from the bulk capacitors, thus allowing you to obtain conduction-angle information. R_7, R_8, and R_9 form a voltage-divider network. C_7 averages the voltage across R_7. As a dimmer reduces the line voltage, the voltage across C_7 also decreases. This reduction in turn reduces the voltage on the base of Q_1 to less than 5.1V, at which point Q_1 turns on, pushes current into the FB pin, and inhibits switching.

D_2, D_3, and D_4, along with C_1 and C_2, form the valley-fill circuit and provide power-factor correction. The valley-fill circuit shapes the input current to improve the power factor. C_1 and C_2 charge in series as the line voltage rises and discharge in parallel when it falls. Thus, input-current flow remains the same from 30 to 150°C and 210 to 330°C. This continuous current greatly improves the system's THD (total harmonic distortion) and power factor.

These applications illustrate two approaches to implementing an LED replacement for the standard incandescent light bulb. The first example requires few components and produces a universal lamp for all supply voltages. The second application adds a dimmable lamp and perhaps a more compatible replacement for the standard light bulb. Although more complex, it is still capable of better-than-85% efficiency at full load. Alternative approaches to dimming, such as three-wire systems or replacing SCR dimmers with IGBTs (insulated-gate bipolar transistors), offer less compatibility but are more technically elegant and efficient. For further information on power supplies for LED lighting, see **Reference 3**.

References

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2 "Low-Cost Dimmable LED Ballast Using the Valley-Fill Current Shaping Circuit," Power Integrations Inc, www.powerint.com/sites/default/files/PDFFiles/di171.pdf.

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Silvestro Fimiani is product-marketing manager of appliance and industrial applications at Power Integrations. Before joining the company in 2005, he served as director of engineering of high-power products at International Rectifier. He holds a bachelor's degree in physics from the University of Naples (Italy).