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How To Design a 250-W HID Electronic Ballast

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Typical outdoor lighting applications today use high-intensity discharge (HID) lighting technology. HID lamps are difficult to control and the design of the electronic HID ballast to drive them is complex. Some of the functions performed by the electronic HID ballast include ignition, warm-up, constant power control, power factor correction, and protection against all lamp and ballast fault conditions. This article describes an electronic ballast circuit for a 250-W HID lamp using the new IRS2573D HID control IC. Fundamental lamp requirements and control methods are presented, as well as complete circuit schematics and waveforms.

HID Lamp Requirements

HID lamps are available in the form of metal halide, mercury or sodium vapor. These lamps are popular because they are efficient and have a high-brightness output. HID metal halide lamps typically have an efficacy greater than 100 lumens/watt and have a lifetime of 20,000 hours. HID lamps produce light using a technique similar to that used in fluorescent lamps where a low-pressure mercury vapor produces ultraviolet light that excites a phosphor coating on the tube. In the case of HID lamps, it is a high-pressure gas, the distance between the electrodes is very short and visible light is produced directly without the need for the phosphor.

HID lamps require a high voltage for ignition (3 kV to 4 kV typical, > 20 kV if the lamp is hot), current limitation during warm-up, and constant power control during running. It is important to have a tight regulation of lamp power to minimize lamp-to-lamp color and brightness variations. Also, HID lamps are driven with a low-frequency ac voltage (<200 Hz typical) to avoid mercury migration and to prevent damage of the lamp due to acoustic resonance. A typical metal-halide 250-W HID lamp has the following requirements:

- Nominal wattage = 250 W
- Nominal Voltage = 100 Vrms
- Nominal Current = 2.5 Arms
- Warm-up Time: = 2.0 secs min
- Ignition Voltage = 4000 Vpk

Figure 1 shows the typical start-up profile for HID lamps. Before ignition, the lamp is open circuit. After the lamp ignites, the lamp voltage drops quickly from the open-circuit voltage to a very low value (20 V typical) due to the low resistance of the lamp. This causes the lamp current to increase to a very high value and should therefore be limited to a safe maximum level. As the lamp warms up, the current decreases as the voltage and power increase. Eventually the lamp voltage reaches its nominal value (100 V typical) and the power is regulated to the correct level.

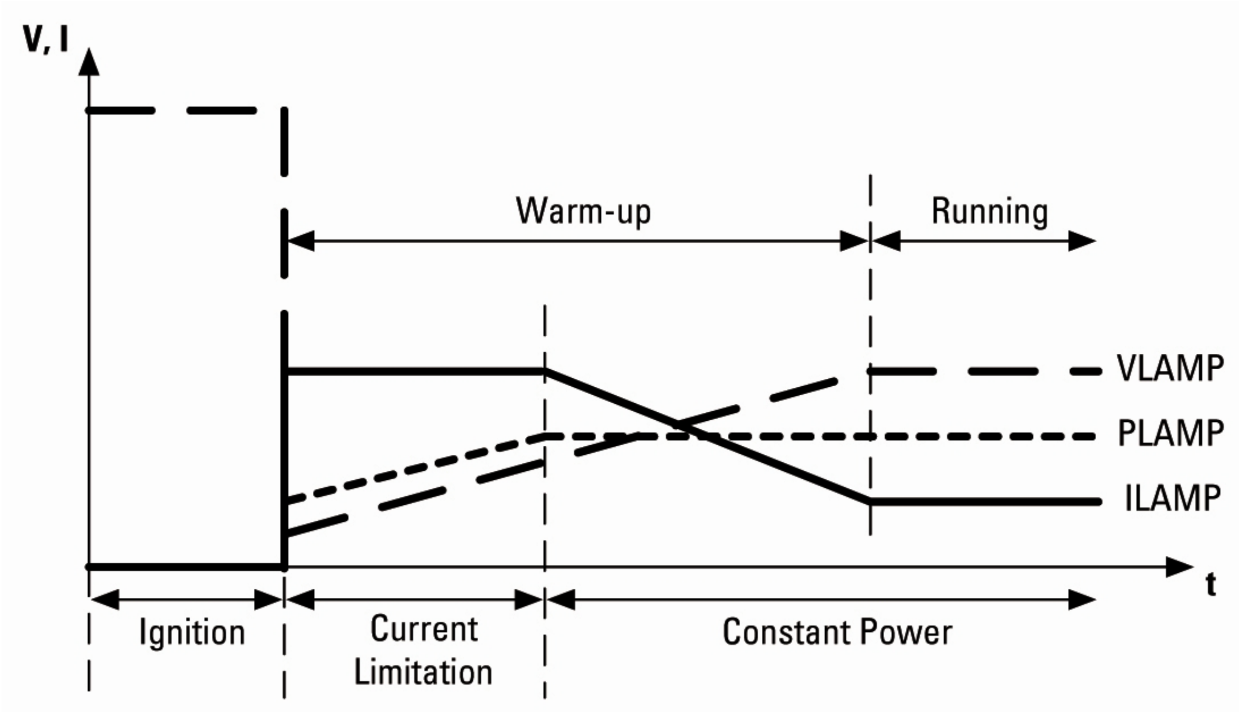


Figure 1. HID lamp ignition, warm-up and running modes.

To satisfy the lamp requirements and different operating modes, an electronic ballast circuit topology is needed that efficiently converts the ac mains voltage to the desired ac lamp voltage, ignites the lamp and regulates lamp power.

HID Ballast Circuit Topology

A typical HID ballast block diagram (Figure 2) includes EMI filtering to block ballast-generated noise, a bridge rectifier to convert the ac mains voltage to a full-wave rectified voltage, a boost PFC stage for power factor correction and a constant dc bus voltage, a stepdown buck converter for controlling the lamp current, a full-bridge output stage for ac operation of the lamp, and an ignition circuit for striking the lamp. A control circuit or IC is necessary for controlling the buck and full-bridge stages and properly managing the different lamp modes. This is presently one of the most standard approaches to powering HID lamps.

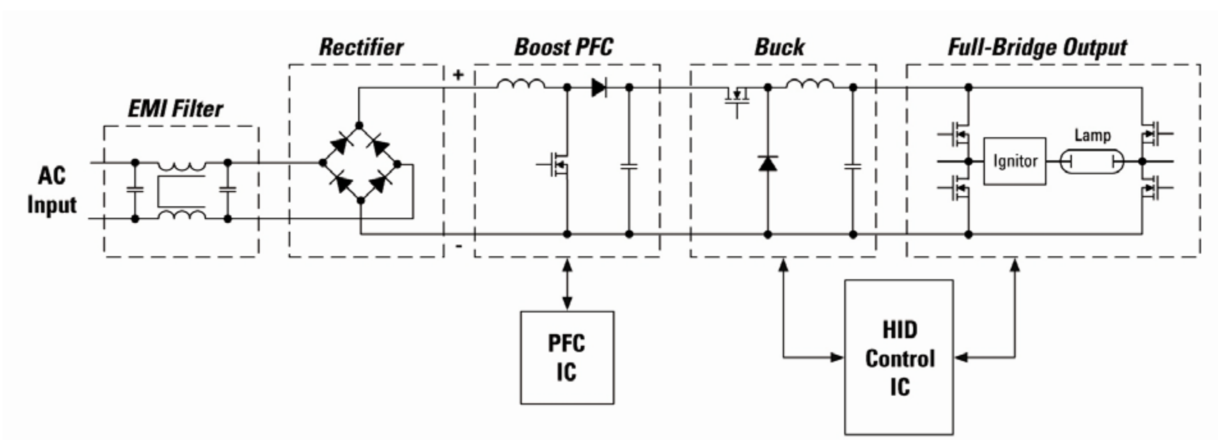


Figure 2. Typical HID ballast block diagram.

The buck control circuit is the main control circuit of the ballast and is used to control the lamp current and power. The buck stage is necessary to step down the constant dc bus voltage from the boost stage to the lower lamp voltage across the full-bridge stage. The buck circuit operates in continuous-conduction or critical-conduction mode, depending on the condition of the load. The lamp voltage and current are measured and multiplied together to produce a lamp power measurement, which is fed back to control the buck on-time.

During the lamp warm-up period (after ignition) when the lamp voltage is very low and the lamp current is very high, the lamp current feedback will determine the buck on-time to limit the maximum lamp current. During lamp steady-state running, the power feedback will then determine the buck on-time to control the lamp power. The continuous-conduction mode allows the buck circuit to supply more current to the lamp during the warm-up without saturating the buck inductor.

Given a constant input voltage to the buck circuit of 400 V dc (from the output of the PFC boost stage), selecting a buck nominal operating frequency of 70 kHz, and using the 250-W lamp nominal electrical data, the buck inductor value is calculated as:

$$
\begin{aligned}
L_{BUCK} &= \frac{1}{2 \times f \times I_{LAMP}} \left(1 - \frac{V_{LAMP}}{V_{BUS}}\right) \times V_{LAMP} \\
&= \frac{1}{2 \times 70000 \times 2.5} \left(1 - \frac{100}{400}\right) \times 100 \\
&= 214 \mu H \Rightarrow 230 \mu H
\end{aligned}
$$

The full-bridge stage is necessary to produce an ac lamp current and voltage during running. The full-bridge typically operates at 200 Hz with a 50% duty-cycle. The full bridge also contains a pulse transformer circuit for producing 4-kV pulses across the lamp necessary for ignition. The ignition circuit (Figure 3) includes a diac circuit to produce the required ignition pulses. The ignition circuit is activated by turning on MIGN, causing the lower leg of the diac, DIGN, to discharge with a time constant determined by RIGN and CIGN. When the voltage across the diac reaches the diac threshold, VDIAC, then the diac breaks down and a voltage pulse is produced across the primary winding of the ignition transformer, TIGN. This produces the higher 4-kV pulse across the secondary winding of TIGN and across the lamp for ignition.

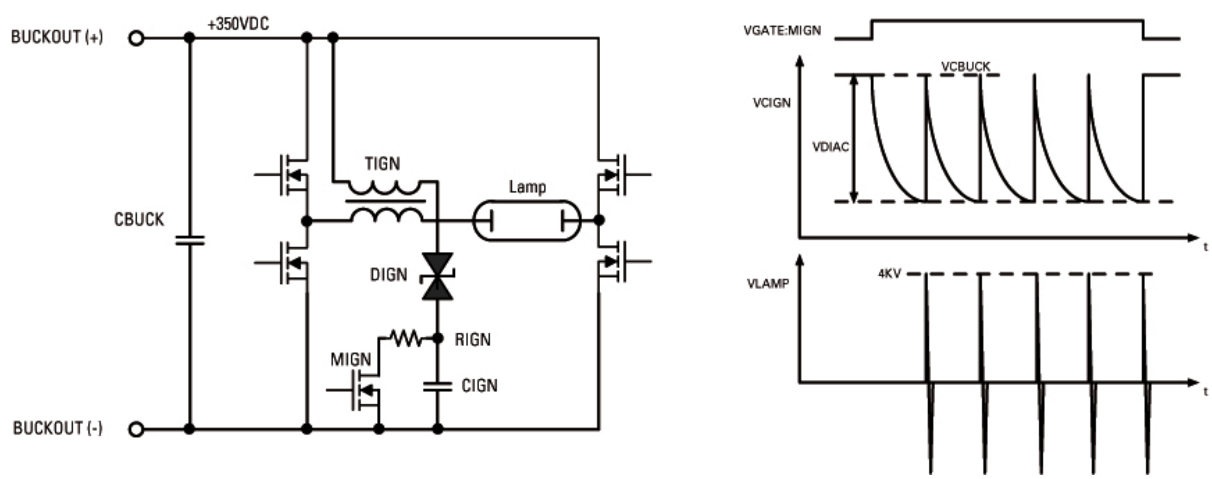


Figure 3. Ignition circuit and timing diagram.

The complete buck and full-bridge control circuit schematic is shown in Figure 4. The circuit is designed around the IRS2573D HID Control IC from International Rectifier. The IRS2573D includes control for the buck stage, the full-bridge, lamp current and voltage sensing, and feedback loops for controlling lamp current and lamp power. The IC includes an integrated 600-V high-side driver for the buck gate drive (BUCK pin) with cycle-by-cycle overcurrent protection (CS pin). The on-time of the buck switch is controlled by the lamp power-control loop (PCOMP pin) or lamp current-limitation loop (ICOMP pin). The off-time of the buck switch is controlled by the inductor current zero-crossing-detection input (ZX pin) during critical-conduction mode, or, by the off-time timing input (TOFF pin) for continuous-conduction mode.

The IC also includes a fully-integrated 600-V high- and low-side full-bridge driver. The operating frequency of the full-bridge is controlled with an external timing pin (CT pin). The IC provides lamp power control by sensing the lamp voltage and current (VSENSE and ISENSE pins) and then multiplying them together internally to generate the lamp power measurement. The ignition control is performed using an ignition timing output (IGN pin) that drives an external ignition MOSFET (MIGN) on and off to enable the ignition circuit of the lamp (DIGN, CIGN, TIGN). The ignition timer is programmed externally (TIGN pin) to set the ignition circuit on and off times. Finally, the IC includes a programmable fault timer (TCLK pin) for programming the allowable fault-duration times before shutting the IC off safely when various fault conditions occur. Such fault conditions include failure of the lamp to ignite, failure of the lamp to warm-up, lamp end-of-life, arc instabilities, and open/short circuit of the output.

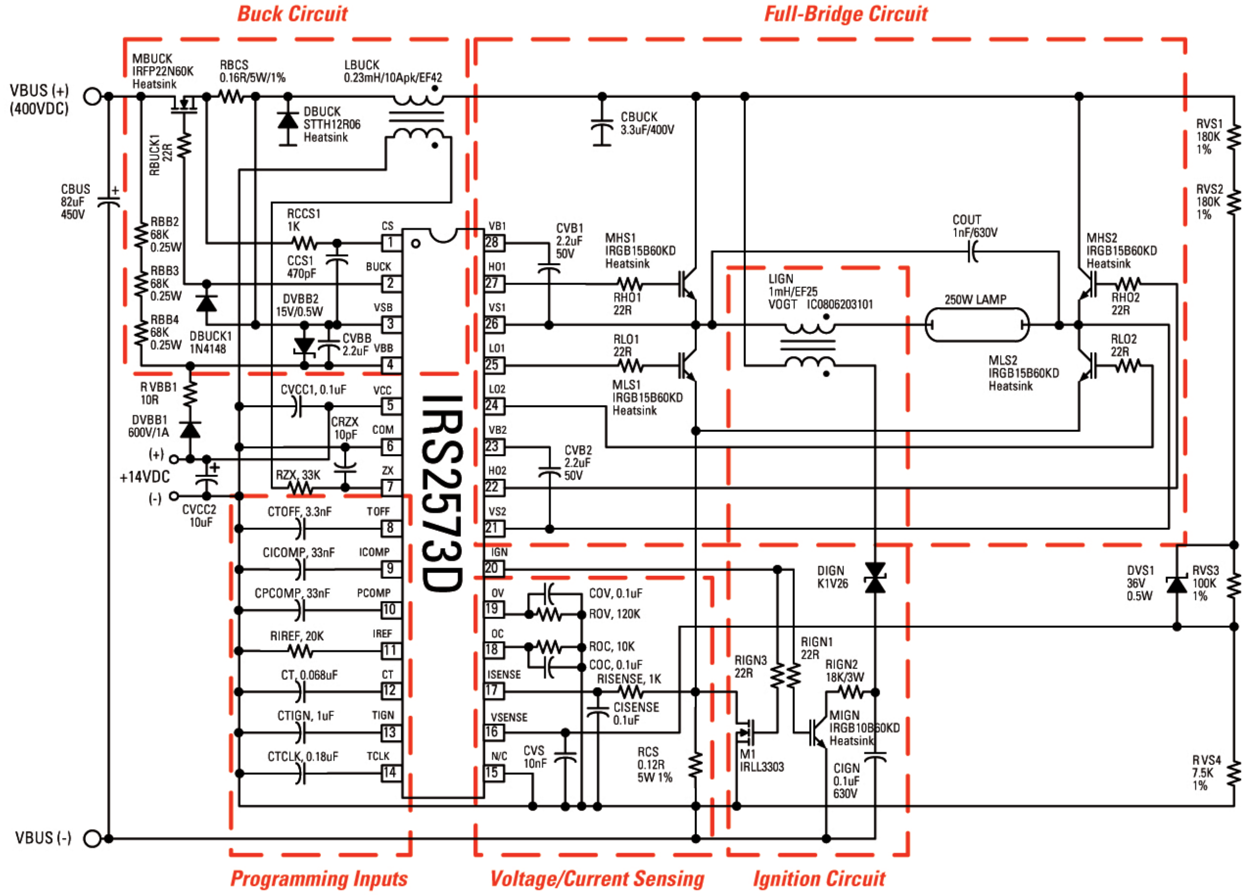


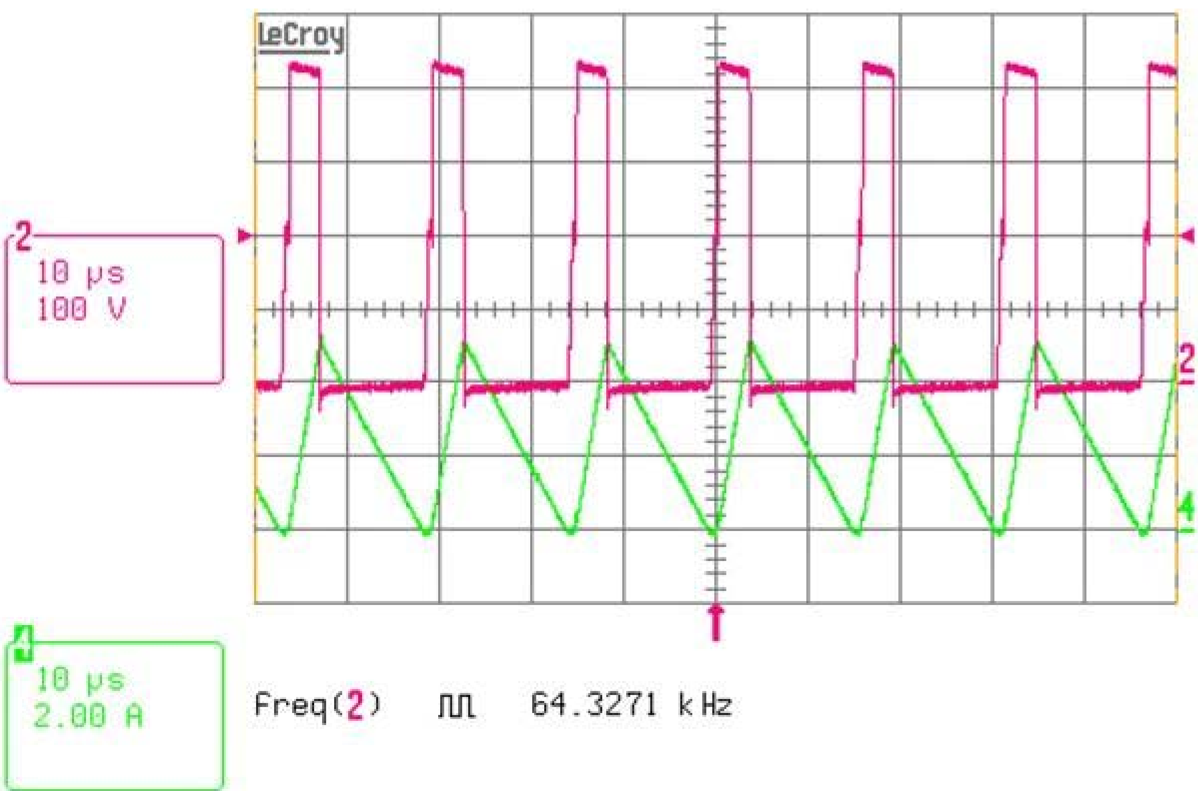
Figure 4. Buck and full-bridge circuit schematic.

Circuit Waveforms

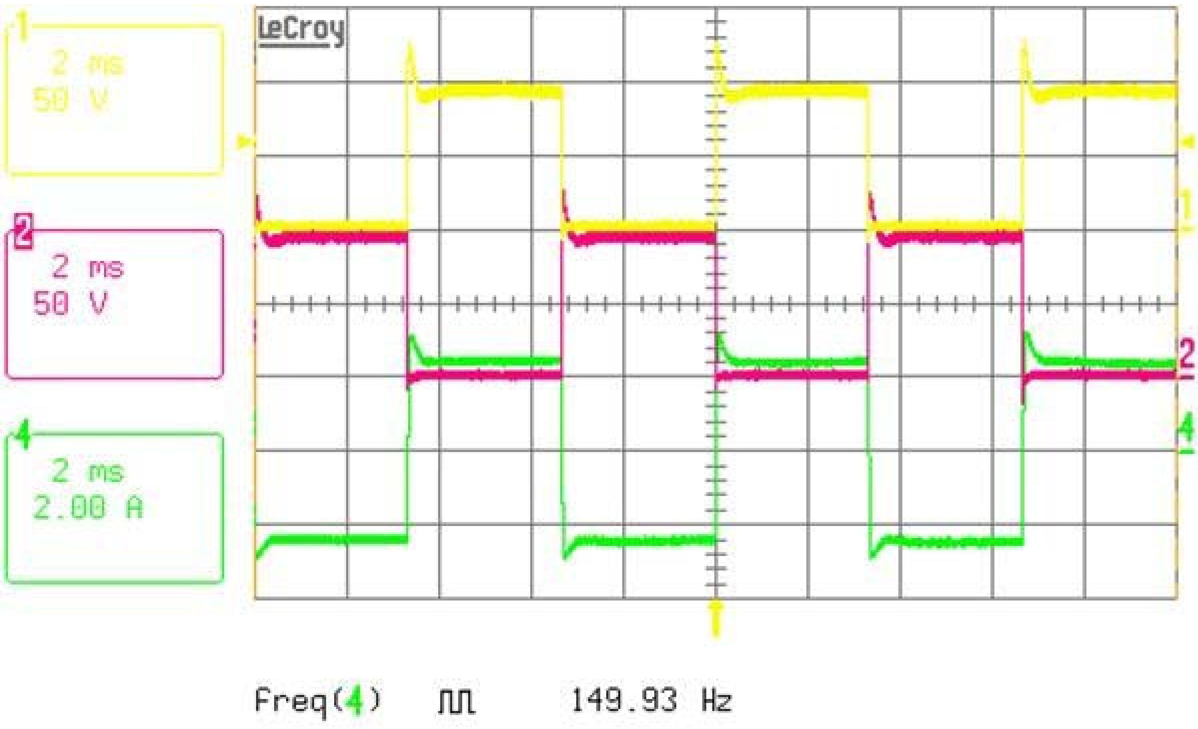
The experimental results are shown Figure 5. Figure 5a shows the buck switching-node voltage (upper trace) and buck current (lower trace) during lamp warm-up. The buck on-time during this mode is controlled by the buck current-limitation feedback loop. Figure 5b shows the buck switching-node voltage (upper trace) and buck current during steady-state running conditions. The buck is working in critical-conduction mode during running conditions and the on-time is controlled by the constant-power feedback loop. Figure 5c shows each half-bridge output voltage (upper and middle traces) and ac lamp current (lower trace) during normal lamp-running conditions.


LeCroy
2
20 µs
100 V
4
20 µs
2.00 A
Freq(2)
21.9385 kHz

(a)


LeCroy
2
10 µs
100 V
4
10 µs
2.00 A
Freq(2)
64.3271 kHz

(b)



(c)

Figure 5. Buck, full-bridge, and lamp waveforms during warm-up and running conditions.

Conclusions

HID lighting is a growing market with many applications. Street lighting is especially attractive due to the long lifetime and high brightness that these lamps deliver and the enormous energy-saving benefits that electronic ballasts offer. The lamp requirements are critical and the ballast requirements are challenging, making the design of the electronic ballast a difficult task.

The design presented in this article is a low-risk approach due to the standard three-stage topology used, and, it contains a highly-integrated control IC to greatly simplify the circuit. This solution also allows for scalability of design so that the same basic circuit can be used as a platform to realize a family of electronic ballasts for many lamp types and power levels. The new IRS2573D control IC contains the complete HID system-in-a-chip, including lamp control, lamp ignition, and all fault protections, making this solution very reliable and well suited for designers seeking to accelerate their products into the marketplace.

About The Author

Since joining International Rectifier (IR) in 1996, Tom Ribarich has been the director of IR's Lighting IC Design Center where he is responsible for developing control ICs for the global lighting market, including fluorescent, halogen, HID, LED and LCD backlighting applications.

Prior to that, Tom was employed by Knobel Lighting Components in Switzerland where he designed dimmable electronic ballast systems for a variety of applications. Tom holds a BSEE degree from California State University, Northridge and a Master's degree in ASIC design from University of Rapperswil, Switzerland.

For further reading on power conversion in lighting applications, see the How2Power Design Guide, and search the Application category and the Lighting subcategory."