QUICK CONTROL FOR HIGH INTENSITY

High-Intensity Discharge (HID) lamps are becoming more and more popular due to their very high brightness, good colour rendering and long lifetime. Tom Ribarich guides us through the development of a ballast circuit for a HID lamp using a new control IC

In lighting applications such as retail and accent lighting, HID lamps are replacing older halogen technology due to their equivalent colour temperature and brightness with four times less power consumption. 150 W halogen lamps, for example, are now replaceable with 35 W HID lamps that produce the same light output. These low-power HID lamps require an electronic ballast to ignite, warm-up and maintain a constant power through them during steady state. This article describes an off-line 35 W HID electronic ballast circuit designed around the new IRS2573D HID Control IC.

HID lamp requirements

HID lamps are available in the form of metal halide, mercury or sodium vapour. These lamps are popular because they are efficient and have a high-brightness output. HID metal halide lamps are typically five times more efficient than incandesents and last 20 times longer. HID lamps produce light using a technique similar to that used in fluorescent lamps where a low-pressure mercury vapour 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 the light is produced directly without the need for the phosphor.

HID lamps require a high voltage for ignition (3 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 minimise lamp-to-lamp colour 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 35 W HID lamp has the following requirements:

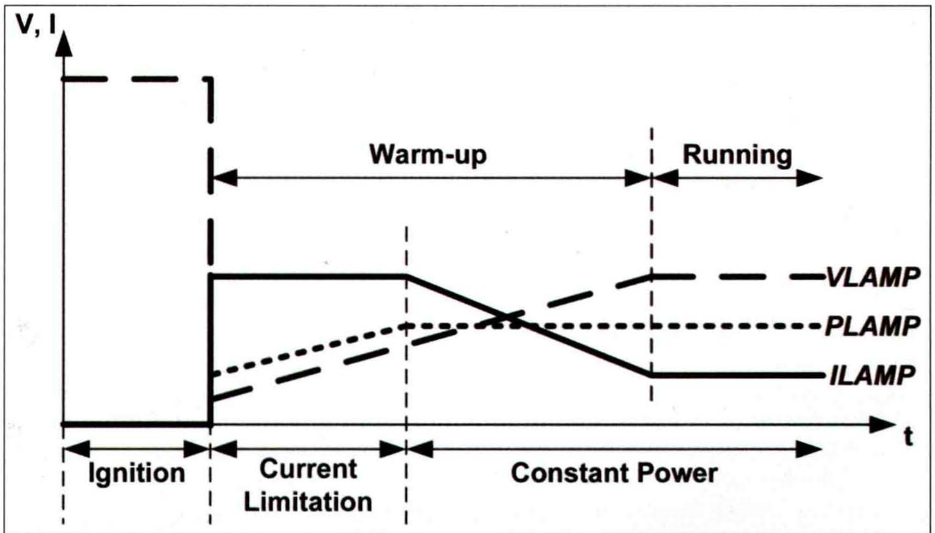

Figure 1, HID lamp ignition, warm-up and running modes

Nominal Wattage (W):	35
Nominal Voltage (Vrms):	100
Nominal Current (Arms):	0.35
Warm-up Time (min):	2.0
Ignition Voltage (Vpk):	4000

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.

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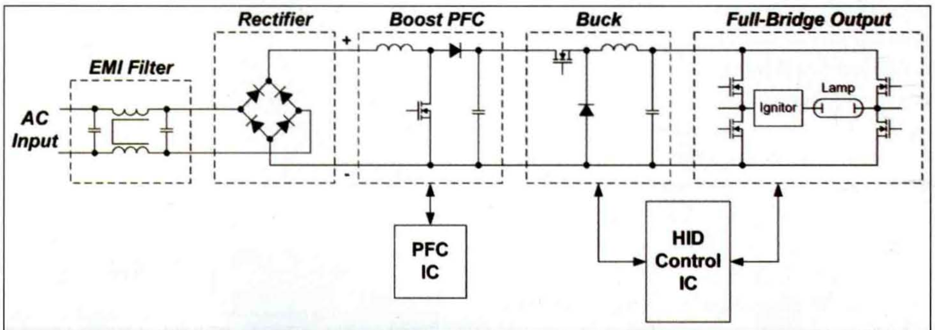

Figure 2, Typical HID ballast block diagram

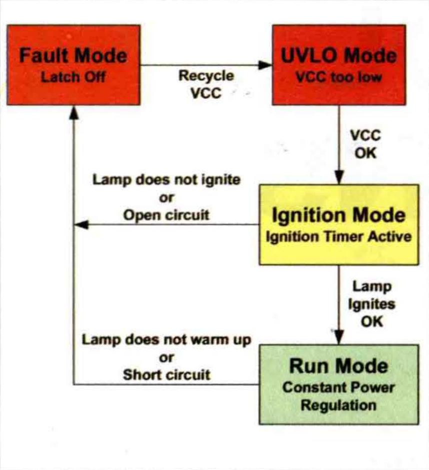

Figure 3, Simplified IRS2573D state diagram

In order to satisfy the lamp requirements and different operating modes, an electronic ballast 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 topology

A typical HID ballast block diagram (Figure 2) includes electromagnetic 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 step-down 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. Control ICs are then used to control the boost PFC stage and the buck/full-bridge stages. This is presently one of the standard approaches to powering HID lamps with a low-frequency AC voltage.

The boost PFC stage runs in critical-conduction mode. During this mode, the boost stage operates with a constant on-time and variable off-time resulting in a free-running frequency across each rectified half-wave of the AC line cycle. The frequency range is typically from 200 kHz near the valley of the half-wave to 50 kHz at the peak. The on-time is used to regulate the DC bus to a constant level and the off-time is the time it takes for the inductor current to reach zero each switching cycle. The triangular shaped inductor current is filtered by the EMI filter to produce a sinusoidal input current at the AC mains input for high power factor and low harmonic distortion.

The buck control circuit is the main control circuit of the ballast as it is used to control the lamp current. 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. This particular buck circuit has the ability to run in continuous or critical-conduction operating modes, 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.

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 HID Control IC includes a complete state diagram (Figure 3) to ignite and run the lamp, as well as shutdown when fault conditions occur. The IC initially starts in under-voltage lock-out (UVLO) mode when the supply voltage to the IC is below the turn-on threshold. When VCC increases high enough, the IC exits UVLO mode and enters ignition mode, and the on/off ignition timer is activated to deliver high voltage pulses to the lamp for ignition. If the lamp ignites successfully, the IC transitions into run mode and the lamp is regulated to a constant power level. If fault conditions occur such as open/short circuit or the lamp fails to ignite or warm-up, then the IC will enter fault mode and shutdown safely before any damage occurs to the ballast.

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 high-side driver for the buck gate drive (BUCK pin) and high-side buck cycle-by-cycle over-current 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. Such fault conditions include failure of the lamp to ignite, failure of the lamp to warm-up, lamp end-of-life, and open/short circuit of the output.

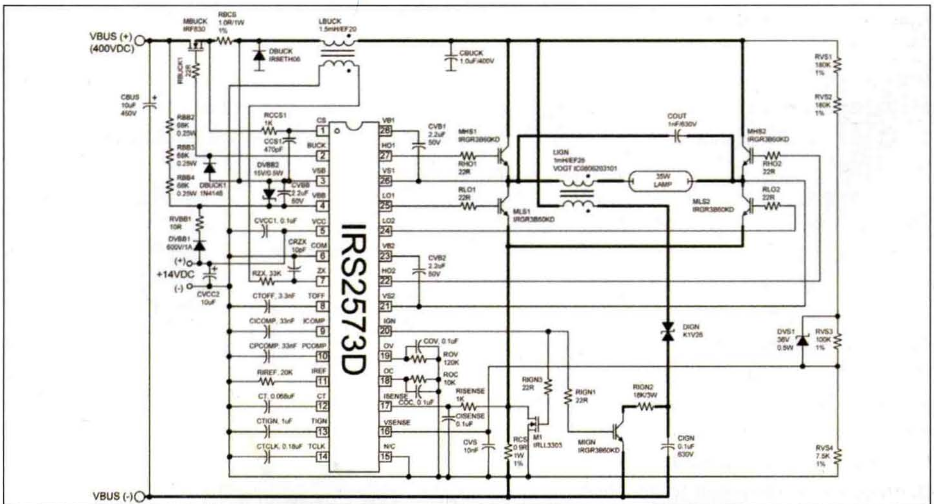

Figure 4, Buck and full-bridge control circuit schematic

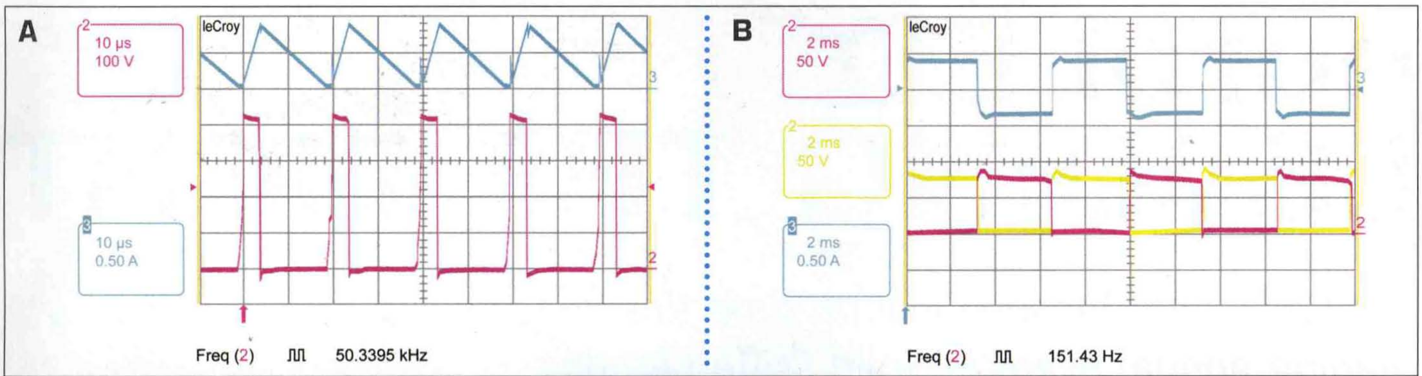

Figure 5(A)(B). Buck, full-bridge and lamp waveforms during steady state running

Experimental results

The experimental results are shown in Figure 5. Figure 5A shows the buck inductor current (ILBUCK, upper trace) and the voltage across the buck diode (VDBUCK, lower trace) during steady state running conditions. The buck is working in critical-conduction mode at a switching frequency of about 50 kHz. The on-time is controlled by the constant power feedback loop. Figure 5B shows each half-bridge switching node (VS1, VS2, lower trace) and lamp current (upper trace) during steady state running conditions. The full-bridge produces the necessary low-frequency (150 Hz) AC lamp current and voltage.

Conclusions

HID lighting is a growing market with many applications. Retail lighting is especially attractive due to the long life-time, high-brightness and energy savings that these lamps 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 3-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 realise 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 ideal for designers to accelerate their products into the marketplace.

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