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Circuit Implements Low-Cost Ballast Control With High Power Factor

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Fluorescent lamps continue to offer a high efficacy (lumens/watt), long lifetime and low cost. T5 fluorescent lamps typically have high working voltages and are driven by an electronic ballast that is used to preheat the lamp filaments, ignite the lamp and provide a high-frequency ac lamp running current. Adding power factor correction (PFC) to the electronic ballast is a requirement at higher power levels and enables the ballast to work like a "resistive" load on the ac mains.

This article describes a novel circuit used to control an entire electronic ballast that includes active PFC as well as complete fluorescent lamp control. This article introduces the designer to the main circuit blocks of an electronic ballast, presents the new circuit control methods, and provides the complete electronic ballast circuit schematic for driving two 54-W T5 lamps. Experimental results are also presented, demonstrating the high power factor, low distortion, and high efficiency achieved by this circuit. Finally, circuit benefits such as small solution size and low cost are discussed.

Overview

The functions performed by present-day electronic ballasts include filtering of electromagnetic interference (EMI) to block ballast-generated noise, rectification, power factor correction (PFC) to generate a "resistive" input current, a half-bridge resonant-output stage for high-frequency ac control of the lamp, and a control circuit (Fig. 1). This is presently one of the most popular approaches to powering fluorescent lamps. Additional circuitry is also necessary for preheating the lamp filaments, igniting the lamp, and protecting against various input and output fault conditions. The focus of this article is on the new circuitry used to control both the boost PFC and resonant output circuit blocks.

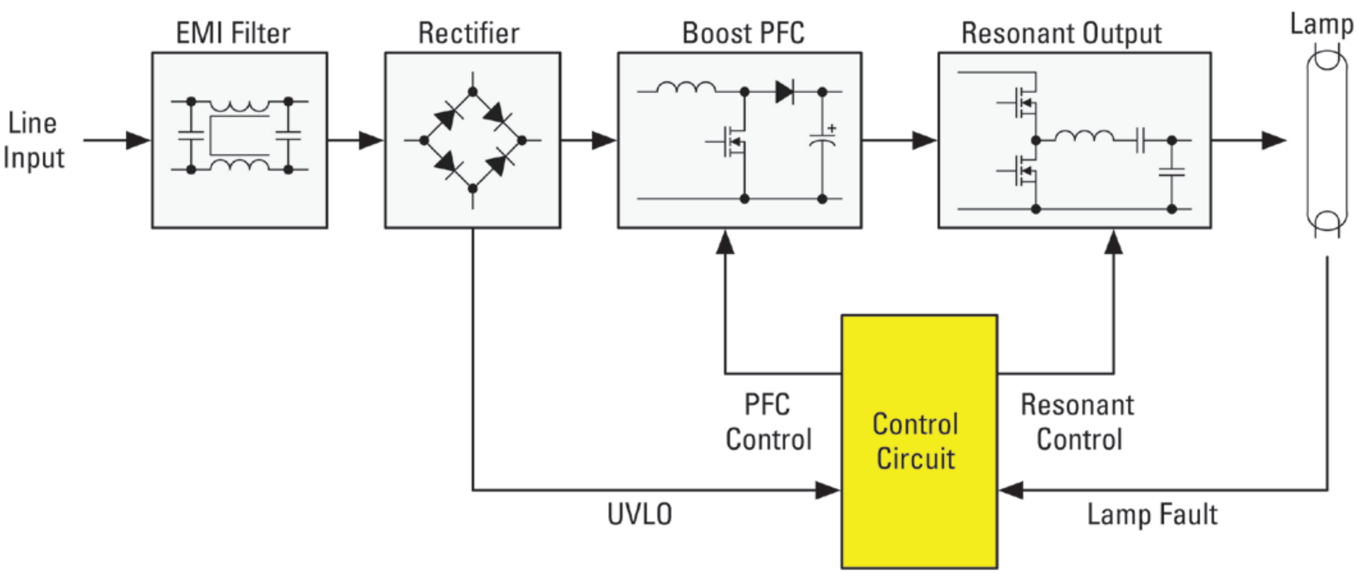

Fig. 1. *Block diagram of electronic ballast.*

New Control Circuit

The PFC circuit consists of a standard boost-type switching converter. As shown in Fig. 2, the boost converter includes an inductor (LPFC) in series with a switch (MPFC), and a diode (DPFC) going from the switching node to the dc bus capacitor (CBUS). The boost converter is controlled by a PFC circuit that controls the on-time and off-time of the boost switch.

The on-time of the boost switch is the time during which the boost inductor is charged. The off-time is the time during which the stored inductor current discharges and flows through the boost diode (DPFC) into the dc bus capacitor (CBUS). The dc bus voltage is divided down and measured using a resistor divider (RB1 and RB2), and is compared to a reference voltage (VREF). The resulting error voltage (ERR) between the reference voltage and the measured dc bus voltage (FB) is used to steer the on-time of the boost MOSFET. Depending on the error voltage, the on-time of the boost MOSFET is either increased or decreased to keep the dc bus voltage regulated at a constant level.

The off-time is the time it takes for the inductor current to discharge to zero. When the inductor current reaches zero, the boost MOSFET turns on again and the cycle repeats. This type of control is known as critical-conduction mode and results in a triangular-shaped inductor current. The peak of the triangular current follows the envelope of the rectified voltage, resulting in a mains input current that is sinusoidal and in-phase with the mains input voltage.

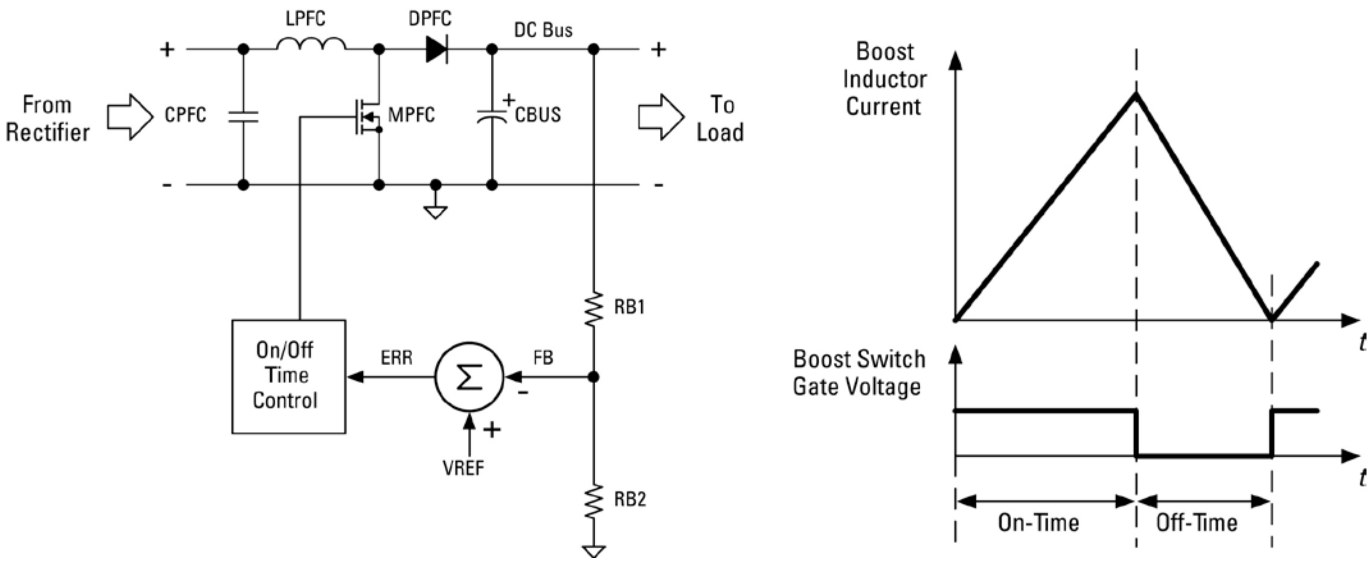

Fig. 2. *Boost PFC control circuit and waveforms.*

To control the fluorescent lamp at the output, a half-bridge circuit is used to excite a series-parallel lamp resonant circuit (Fig. 3). The half-bridge circuit consists of two MOSFETs (MHS and MLS) connected in a totem-pole configuration. The MOSFETs are turned on and off by the gate-driver outputs of the control circuit at a 50% duty cycle and at a given frequency. This frequency is linearly controlled by a dc voltage at the VCO pin.

As MHS and MLS are turned on and off, a square-wave voltage is generated at the mid-point of the half bridge that feeds the resonant tank and lamp. The resonant tank is comprised of a resonant inductor (LRES), a resonant capacitor (CRES), a dc-blocking capacitor (CDC) and the lamp. The frequency of the square wave determines the gain at the output of the tank.

Initially, the lamp is an open circuit and the resonant tank is an under-damped series L-C circuit. The frequency of the square wave is set to a higher frequency (above the resonance frequency) to preheat the lamp filaments. After the preheat time has ended, the frequency then decreases toward the resonant frequency to ignite the lamp. The voltage across the lamp will increase until the breakdown voltage of the lamp is reached and the lamp ignites. The resonant tank then becomes a damped series L, parallel R-C circuit.

The frequency is then decreased further to a final lower frequency (50 kHz typical) for running the lamp. The frequency is linearly controlled by a dc input voltage to the oscillator. The circuit then takes the signal from the oscillator and converts it into the necessary high- and low-side gate-drive outputs using standard logic and high-voltage level shifting. The dc voltage at the oscillator input starts at a higher voltage during the preheat phase of the lamp, and then ramps down to a lower voltage for igniting and running the lamp.

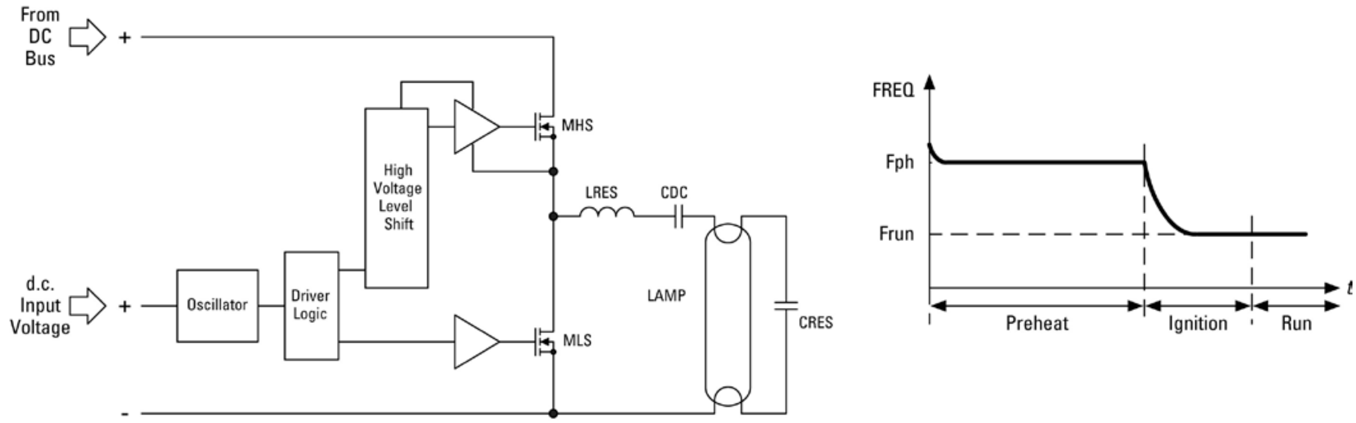

Fig. 3. Half-bridge and resonant-tank control circuit.

Ballast Design

Fig. 4 shows the schematics for a fully-functional 2 x 54-W/T5 electronic ballast designed around the IRS2580DS PFC/Ballast Control IC. The circuit includes control for both the boost PFC at the input and the half-bridge resonant tank at the output.

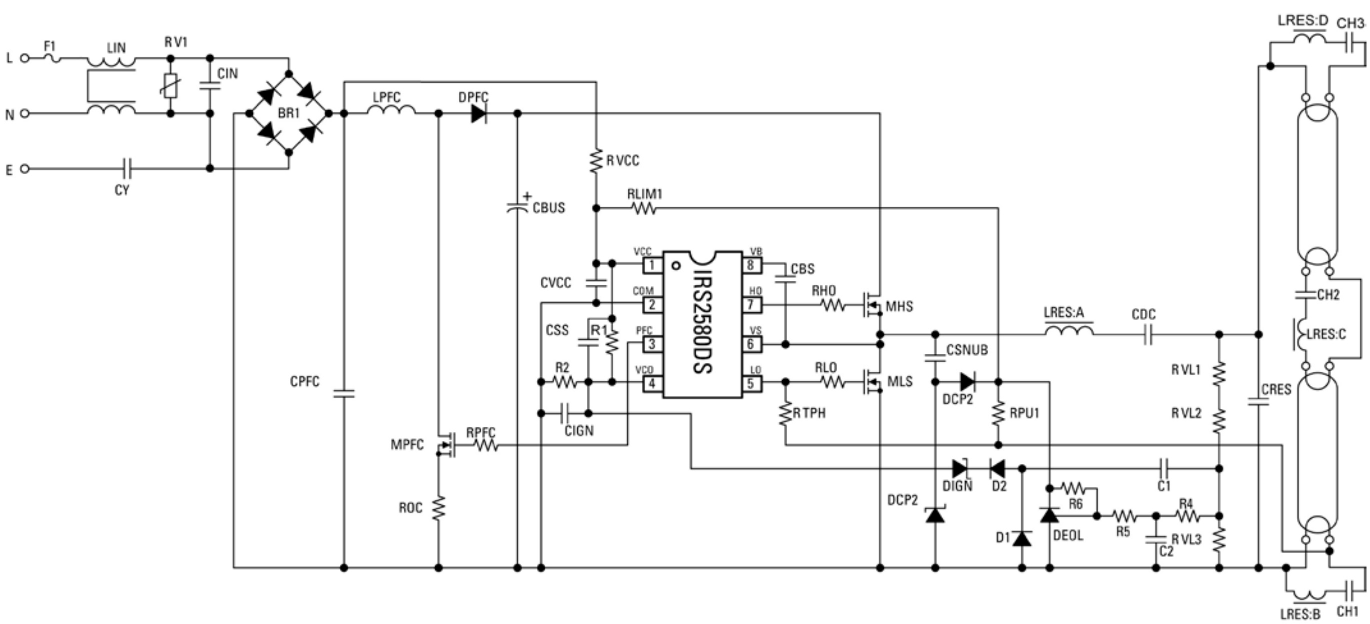

Fig. 4. *Circuit schematic for a 2 x 54-W/T5 dual-lamp electronic ballast based on the IRS2580DS control chip.*

The boost PFC circuit is controlled by the PFC pin of the IC. The internal PFC control loop (see Fig. 2 again) determines the on-time and off-time of the PFC pin. Meanwhile, the VCO pin of the IC sets the frequency of the half-bridge gate-driver output pins (HO and LO). Resistors R1 and R2 form a voltage divider that programs the desired dc voltage levels at the VCO pin. These voltage levels control the frequency of the internal oscillator (Fig. 3 again.)

The internal oscillator signal is fed into the internal high- and low-side gate-driver logic circuitry of the IC to generate the desired preheat, ignition, and running frequencies for the half-bridge and resonant-output stage. Upon normal power up of the IC at the VCC pin, the PFC circuit boosts the dc bus voltage up and maintains it at a constant level, and the half-bridge transitions through the programmed frequencies such that the resonant tank preheats, ignites and runs the lamp.

Resistors RVL1, RVL2 and RVL3 form a voltage divider across the lamp for measuring the lamp voltage. This measurement is used for lamp-voltage feedback during ignition and for lamp end-of-life (EOL) detection.

Finally, the lamps are connected in a series configuration with secondary windings (LRES:B,C,D) from the resonant inductor used for preheating the lamp filaments.

Experimental Results

The evaluation results from the functional ballast show that the boost-PFC stage and resonant-output stage are both working properly. Fig. 5 shows the complete preheat, ignition and run start-up sequence. As the VCO voltage ramps down (blue trace) during ignition, the frequency ramps down towards resonance and the lamp voltage increases until the lamp ignites.

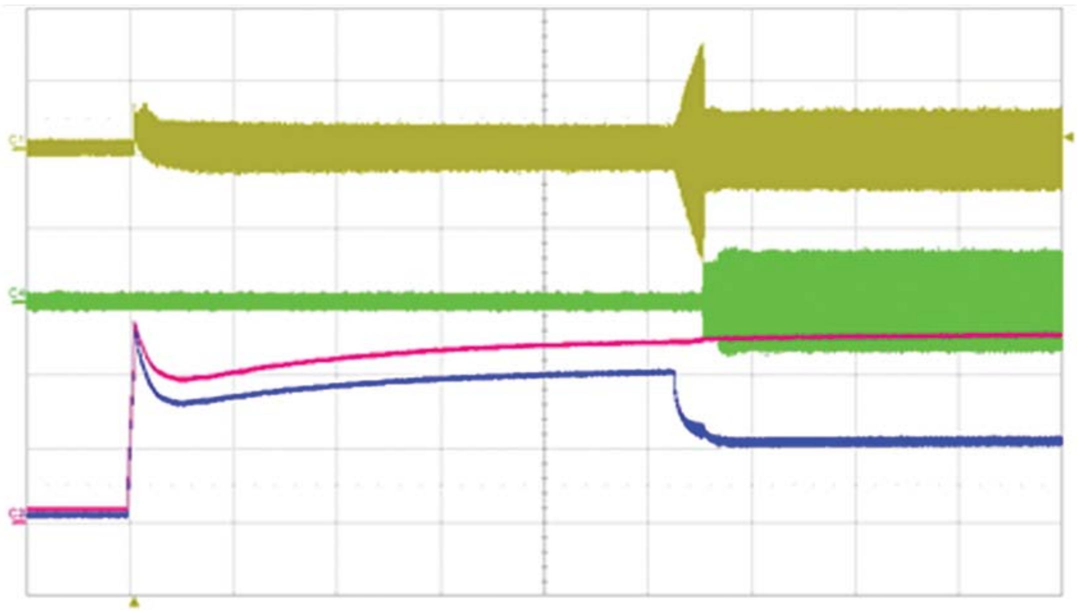

Fig. 5. Lamp voltage (yellow trace, 500 V/div) and current (green trace, 1 A/div), VCC (red trace, 5 V/div), and VCO (blue trace, 2 V/div) during normal preheat, ignition and run lamp modes. Timescale = 200 ms/div.

Fig. 6 shows the voltage and current at the ac line input (left) during running, and, the half-bridge and lamp voltage at the output (right) during running.

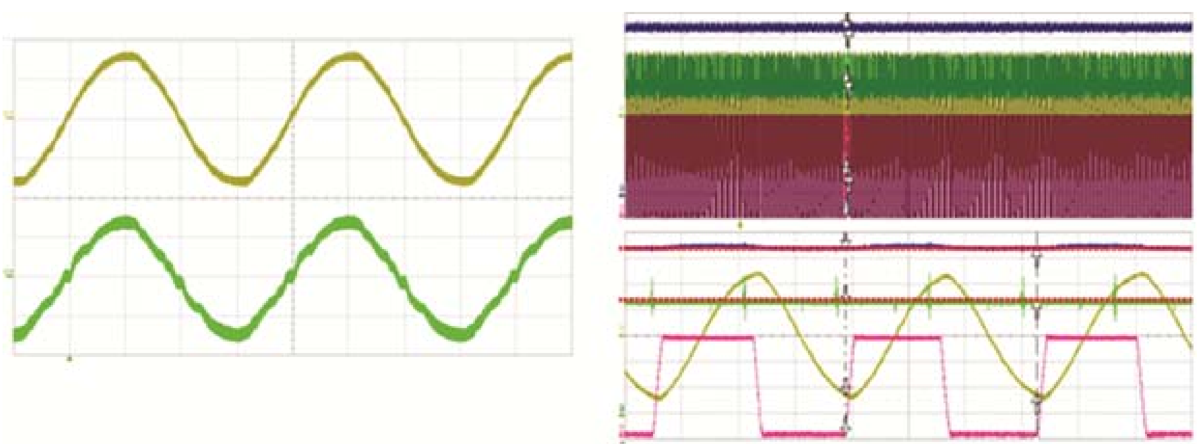

Fig. 6. *Left waveforms: Mains voltage (yellow trace, 200 V/div) and mains current (green trace, 500 mA/div) during normal lamp running conditions. Timescale = 5 ms/div.*

Right waveforms: Half-bridge voltage (red trace, 100 V/div) and lamp voltage (yellow trace,100 V/div) during normal lamp running conditions. Timescale = 5 µsec/div.

A summary of the measured electrical data for the test circuit in Fig. 4 appears in the table. These experimental results were obtained with the circuit operating from a standard 230-Vac/50-Hz mains input voltage. As these results demonstrate, the circuit achieves high power factor and low THD at the mains input, while maintaining stable lamp operation at the output and high efficiency.

Table. Ballast electrical data summary table.

Parameter	Units	Value
Lamp type		2 x 54 W/T5
Vin	Vac and Hz	230 V/50 Hz
Pin	W	112.8
Lamp current	mA	425
Lamp power	W	103.7
Efficiency	%	91.9
Power Factor	No units	0.996
THD	%	3.9
DC bus voltage	Vdc	406.8
Preheat frequency	kHz	85.0
Run frequency	kHz	47.0
Open-circuit output voltage	Vpp	2000

Conclusion

A new and simplified control circuit has been presented for powering fluorescent lamps. This control circuit demonstrates complete control of the ballast, including all necessary PFC and lamp functionality. The simplicity of the circuit allows for the complete control circuit to be realized in a small 8-pin IC. This offers further cost and size reduction of electronic ballasts as well as increased reliability and manufacturability. The circuit allows for control of all fluorescent lamp types (T5, T8, T12, CFL), and has excellent performance over a wide input-voltage and/or output-load range. Dimming can also be implemented using additional external circuitry.

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, search by Design Guide Category, and select "Lighting" in the Application category.