Simple Control Circuits for Electronic Ballast Design

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Abstract

Electronic ballasts are designed to fulfill a variety of different input and output specifications depending on their end application and performance requirements. These designs typically include non-PFC, passive PFC and active PFC input stages, and, single, dual or multi-lamp output stages. The input voltage requirements for each design can vary significantly depending on the final application for the ballast, and, several protection circuits must also be included in order to meet the safety standards from various ballast regulatory agencies. This paper describes several simple control circuits for realizing different types of electronic ballast designs. This paper introduces the designer to the main circuit blocks of an electronic ballast, describes the different ballast circuit topologies and their respective control circuit, and provides complete schematics and experimental results for each design.

1. Overview

The functions performed by present day electronic ballasts include electromagnetic interference (EMI) filtering to block ballast generated noise, rectification, power factor correction (PFC), a half-bridge resonant output stage for high-frequency AC control of the lamp, and a control circuit for controlling each of the stages (Figure 1). Power factor correction may or may not be required (depending on the power level) and may be realized using a passive or an active method. Controlling fluorescent lamps also requires additional circuitry necessary for preheating the lamp filaments, igniting the lamp, and end-of-life (EOL) protection. The focus of this paper is on the different ballast circuit topologies and the circuits used to control them.

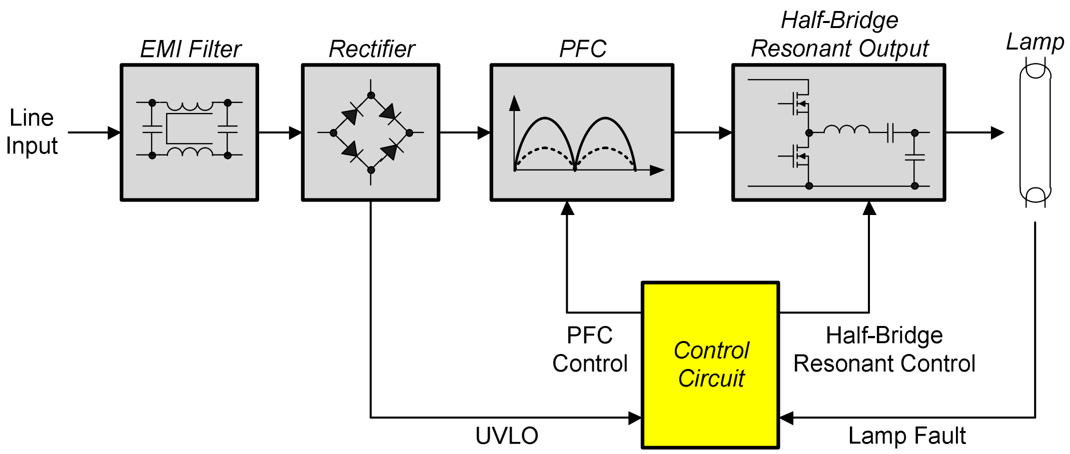

Fig. 1, Electronic ballast block diagram.

2. Control Circuits

The half-bridge resonant output stage is necessary for each ballast topology and is controlled with a voltage-controlled oscillator (VCO) input and a high- and low-side half-bridge driver output (Figure 2). The half-bridge driver operates at a given frequency with a 50% duty cycle and a fixed non-overlapping dead-time. This produces a high-voltage square-wave that feeds the resonant tank and lamp. The frequency of the square-wave first starts at a higher frequency to preheat the lamp filaments, and is then decreased through resonance to ignite the lamp to a final lower frequency for running. The frequency is controlled by the VCO input, which starts at a higher voltage during preheat and is then decreased smoothly to a lower voltage for ignition and running. If PFC is not required (PFC is typically not required for power levels of 25W and below), then this basic control circuit will satisfy all performance requirements for the ballast. Additional lamp/ballast fault protection circuitry is required to fulfill the necessary safety requirements.

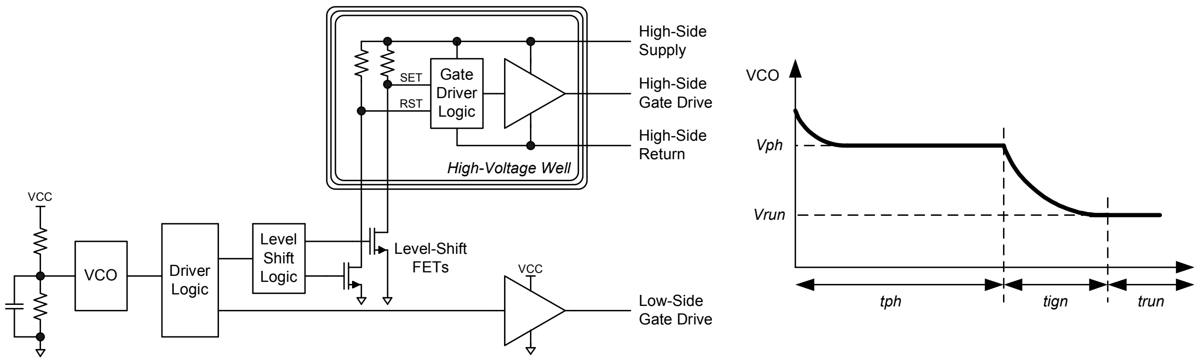

Fig. 2, Voltage-controlled oscillator (VCO) and half-bridge control circuit.

For passive power factor correction (PFC) solutions, a high ripple voltage will occur on the DC bus (Figure 3). The VCO circuit can be used to compensate for the high ripple by continuously adjusting the output frequency as the DC bus increases or decreases. A simple voltage divider (R1 and R2) from the DC bus to the VCO input will automatically increase the frequency when the DC bus increases, and decrease the frequency when the DC bus decreases. This compensation method gives a constant lamp current as the DC bus ripple voltage oscillates up and down during each AC line cycle.

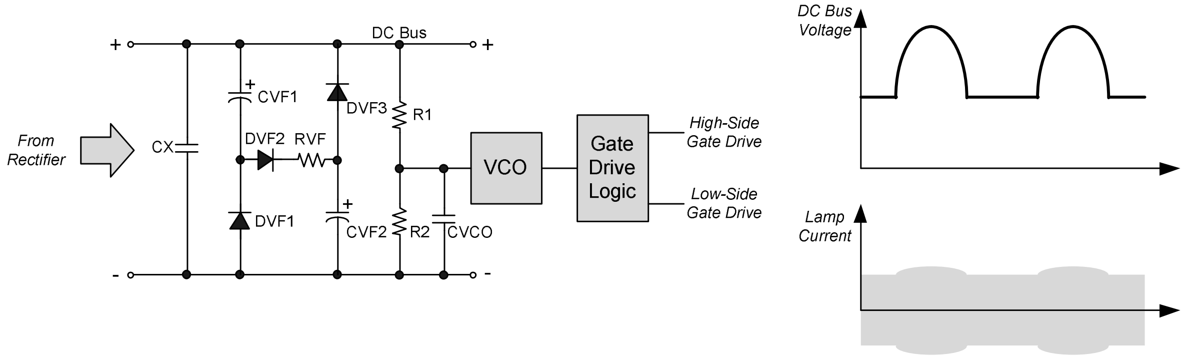

Fig. 3, Passive PFC control circuit.

For active PFC solutions, a boost converter is typically used. The boost PFC circuit (LPFC, MPFC, DPFC) is controlled by separate on- and off-time circuits (Figure 4). The on-time of the boost switch (MPFC) is the time during which the boost inductor (LPFC) is charged. The off-time is the time during which the stored inductor current flows through the boost diode (DPFC) to the DC bus. The DC bus voltage is measured using a resistor divider network (RB1, RB2) and is fed back and compared against a reference voltage. The resulting error voltage (ERR) between the feedback voltage (FB) and reference voltage (VREF) determines how much the on-time of the switch needs to be increased or decreased to keep the DC bus regulated at a constant level. When the inductor current discharges to zero each switching cycle, the boost switch 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 and free-running switching frequency as the AC mains voltage increases and decreases. These high-frequency "triangles" of current are eventually smoothed by the EMI filter at the input to produce a low-frequency AC input current that is in-phase with the AC input voltage.

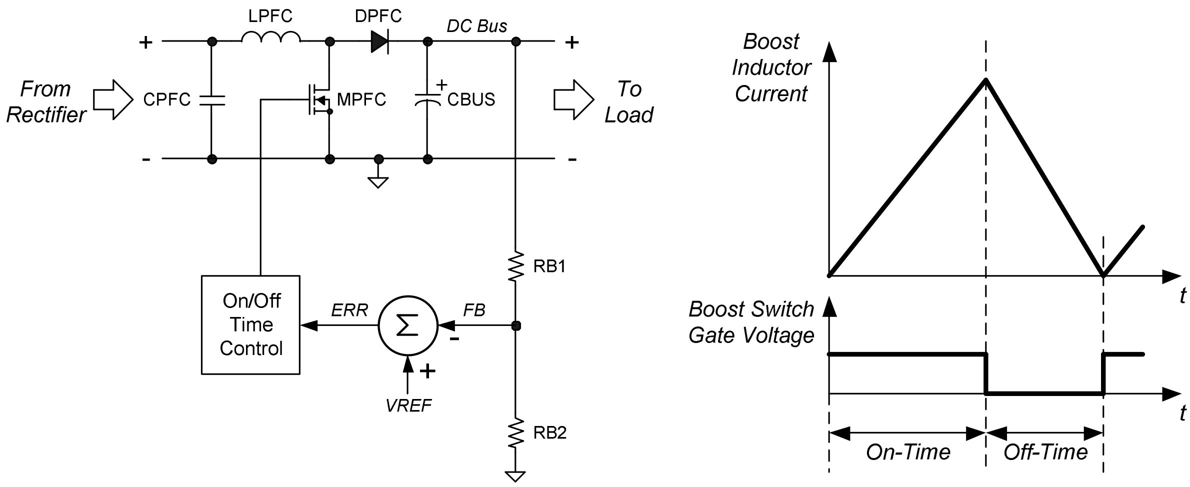

Fig. 4, Boost PFC control circuit.

3. Ballast Design

A 26W electronic ballast circuit without PFC is designed around the IRS2526DS “Mini8” Ballast Control IC. The circuit includes (Figure 5) the complete control for the half-bridge resonant output stage and the lamp. The ‘VCO’ pin sets the frequency of the half-bridge gate driver outputs, ‘HO’ and ‘LO’ pins. A resistor voltage divider at the ‘VCO’ pin programs the desired VCO voltage levels. These voltage levels control the frequency of the internal voltage-controlled oscillator (Figure 2). The internal oscillator signal then feeds into the high- and low-side gate driver logic circuitry to generate the correct preheat, ignition, and running frequencies for the half-bridge and resonant output stage. A lamp voltage resistor divider (REOL1, REOL2, REOL3, RIGN1) and feedback circuit (CIGN1, DR1, DR2, DIGN, REOL, CEOL, DEOL+, DEOL-) are used to provide a constant lamp ignition voltage and to detect a lamp end-of-life fault condition.

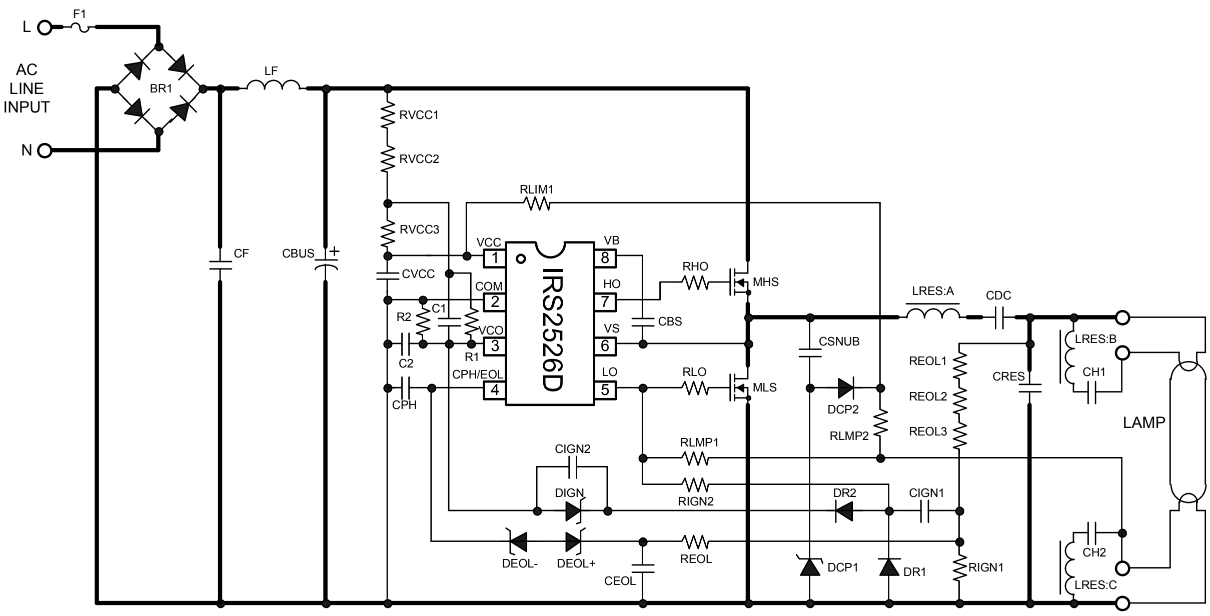

Fig. 5, 26W electronic ballast circuit schematic.

A 2x54W/T5 ballast with active PFC is designed around the IRS2580D “Combo8” PFC+Ballast Control IC. The circuit includes (Figure 6) the control for both the boost PFC and the half-bridge resonant stages. The boost PFC circuit is controlled by the ‘VS’ and ‘PFC’ pins of the IC. The ‘VS’ pin measures the DC bus voltage during the on-time of the high-side half-bridge MOSFET (MHS). This measurement is fed back to the internal PFC control loop (Figure 4) to determine the on-time of the ‘PFC’ pin. The ‘VCO’ pin sets the frequency of the half-bridge gate driver outputs, ‘HO’ and ‘LO’ pins. A resistor voltage divider at the ‘VCO’ pin programs the desired VCO voltage levels. These voltage levels control the frequency of the internal voltage-controlled oscillator

(Figure 2). The internal oscillator signal then feeds into the high- and low-side gate driver logic circuitry to generate the correct preheat, ignition, and running frequencies for the half-bridge and resonant output stage.

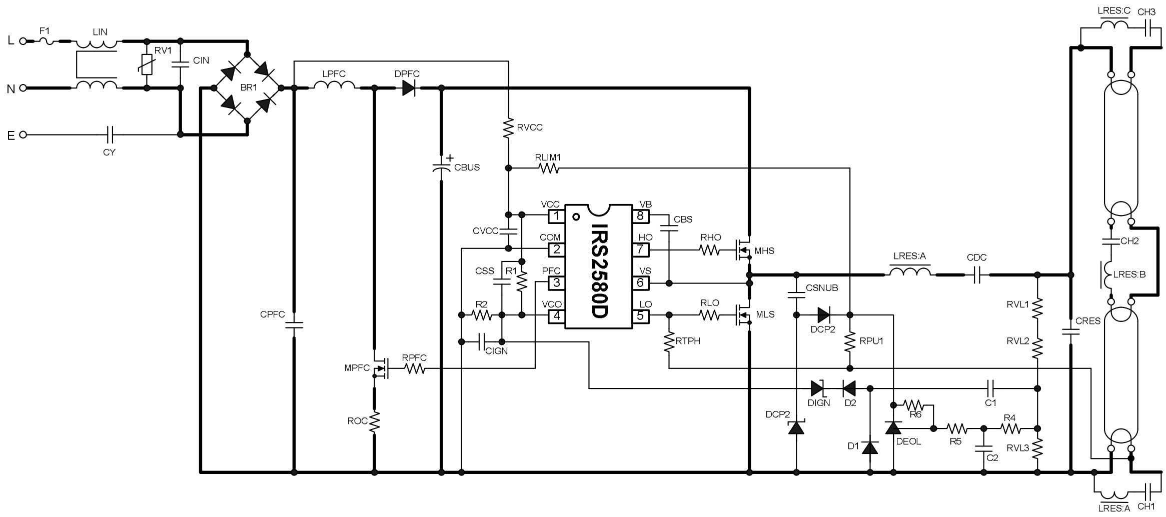

Fig. 6, 2x54W/T5 electronic ballast circuit schematic.

4. Experimental Results

The evaluation results from the functional ballasts show that both non-PFC and active PFC circuits are working properly. The waveforms include (Figure 7) the half-bridge switching voltage, the AC lamp voltage and AC lamp current during running at maximum (left waveforms) and minimum (right waveforms) dithering frequencies. The conducted EMI measurements are also shown (Figure 8) for a wide range of measured frequencies (9kHz to 300MHz). The circuit demonstrates proper fluorescent lamp control with conducted EMI below the allowed limits using only a single-winding filter inductor.

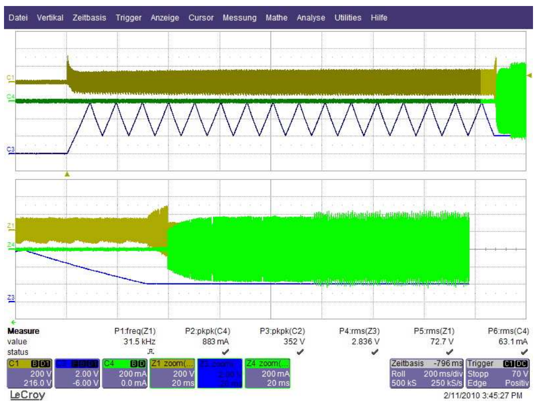

Fig. 7, 26W ballast waveforms. Lamp current (green trace) and lamp voltage (yellow trace) during normal preheat ignition and run modes.

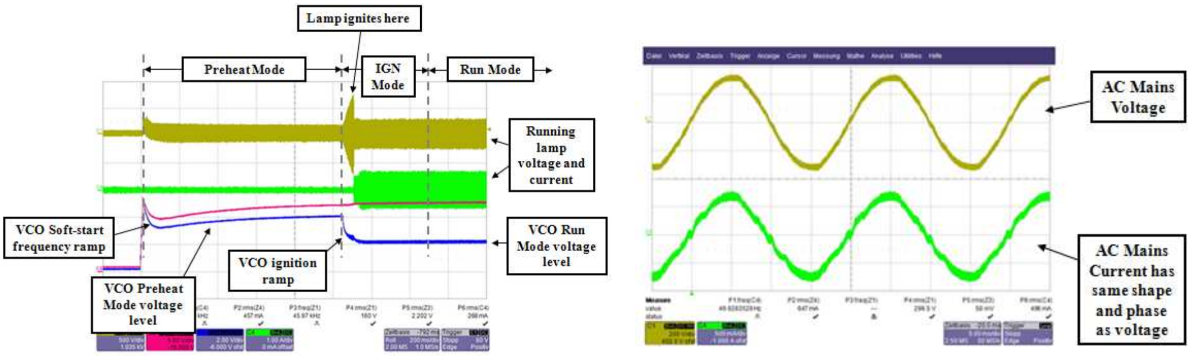

Fig. 8, 2x54W/T5 ballast waveforms. Normal preheat, ignition, run output waveforms (left waveforms) and AC mains input voltage and current (right waveforms).

5. Conclusions

Several simple control circuits have been presented for different electronic ballast designs for fluorescent lamps. Each control circuit demonstrates proper control for ballast designs with and without PFC. These control circuits have been incorporated into two new ballast control ICs, IRS2526DS and IRS2580DS, allowing a complete family of ballast products to be easily realized on a single design platform. The ICs also include all of the necessary fault detection circuitry to further simplify the design. All of these control features combined in small 8-pin ICs offer a large reduction in cost and size as well as increased reliability and manufacturability.

6. Literature

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