24VDC Input Dimmable Electronic Ballast

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Introduction

Solar array installations on building rooftops are becoming more popular as the need for green energy increases and the cost of solar energy decreases. Since solar arrays output a direct current this presents a need for electronic devices that can be powered directly from a DC input instead of the traditional AC input. This paper presents a DC input dimmable electronic ballast circuit for fluorescent lighting. A new dimming control method is also presented for closed-loop control of the lamp current over a dimming range of 100% to 10% brightness levels. The final dimming ballast circuit is built and tested for performance and experimental results are included to illustrate circuit functionality.

AC Input Electronic Ballasts

Electronic ballast circuits are traditionally designed to be driven from an AC mains input voltage. Typical AC input voltages include 120VAC/60Hz (US and Japan) and 220VAC/50Hz (Europe and Asia). To convert the low-frequency AC mains input voltage to the high-frequency voltage required to drive fluorescent lamps a five-stage solution is used. The first stage (Figure 1) includes an EMI filter to block ballast generated noise from coupling back on to the AC input voltage. The second stage is a standard full-bridge rectifier necessary to convert the AC input voltage to a full-wave rectified voltage. The third stage is an AC-to-DC boost-type circuit that converts the full-wave rectified voltage to a higher constant DC bus voltage level. The boost circuit is controlled in a way such that the shape and the phase of current matches the shape and phase of the AC mains input voltage. This is necessary to achieve high power factor (PFC) and low total harmonic distortion (THD) at the input. The fourth stage is a half-bridge switching circuit that converts the DC bus voltage to a high-frequency square-wave (50kHz typical), and the fifth stage is a series/parallel resonant tank output circuit used to preheat, ignite, run and dim the lamp.
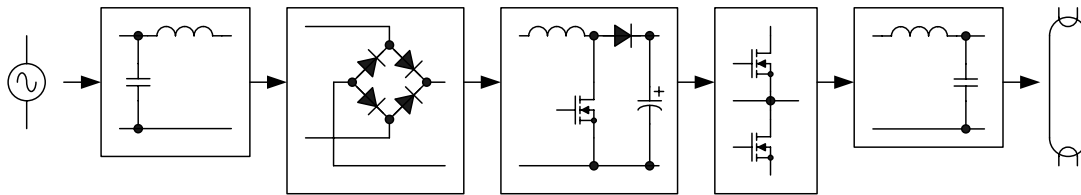

Figure 1, AC input non-dimming ballast block diagram.

To drive the ballast from a DC input, the circuit can be simplified since an input rectifier is no longer necessary. Additional modifications must also be made since the DC input voltage level is much lower than the traditional AC input voltage levels resulting in higher currents (for the same output power level). To select a suitable solution, two possible topologies are analyzed and compared against each other.

DC Input Electronic Ballast Solutions (Boost versus Push-Pull)

Two possible circuit topologies include a boost-type circuit followed by a half-bridge resonant output stage, or, a push-pull step-up circuit followed by a resonant output stage. The boost configuration is the same as the AC input solution (Figure 1) except that the rectifier stage can now be eliminated. The DC input goes to the EMI filter and then directly to the boost stage. The 24VDC is then boosted up to a higher DC bus voltage (400VDC) and then converted into a high-frequency square-wave by the half-bridge switching circuit. The square-wave voltage then feeds the resonant output circuit that is used to drive the lamp. The push-pull configuration (Figure 2) uses a step-up transformer to convert the 24VDC input voltage directly to a high-voltage/high-frequency square-wave in a single step.
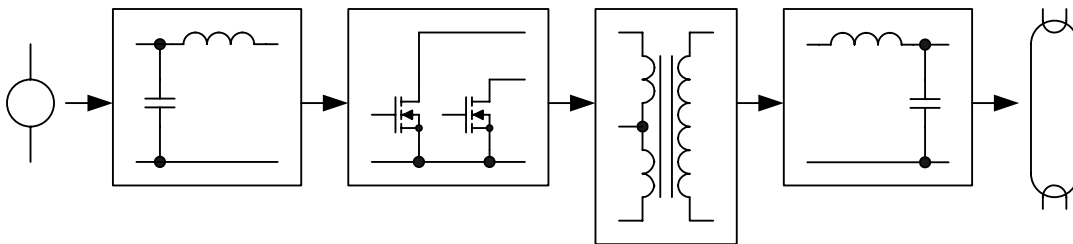

Figure 2, DC input, non-dimming push-pull ballast block diagram.

The boost configuration is similar to the AC input solution, except that the boost converter circuit has to be re-dimensioned for the higher boost ratio and the power components need to be rescaled to handle the higher current levels due to the lower input voltage. The boost configuration has the advantage that the DC bus is regulated to a constant voltage, independent of the DC input voltage, allowing the circuit to work over a wide range of input voltage. This could be beneficial when driving the ballast from solar cells since the solar cell output voltage can vary depending on the outside sunlight level and temperature. The disadvantage of the boost configuration is the additional cost of the boost circuit, the high frequency filtering of the switches, and the decrease in efficiency due to the additional losses from the boost stage. The push-pull configuration does the boost and DC-to-AC conversion in a single stage using a step-up transformer driven by two primary windings. The push-pull configuration has the advantage that the output is isolated from the input which may or may not be required when driving from solar cells. The push-pull configuration also has the additional advantages of lower cost due to the elimination of the boost circuit (but requires a step-up transformer), and lower voltage rated switches. The disadvantage of the push-pull circuit is that the square-wave voltage feeding the resonant tank will vary with the DC input voltage level which will limit the input voltage range. However, the new dimming method described in the next section provides closed-loop control of the lamp current which will help overcome the dependency on the DC input voltage and widen the input voltage range. For these reasons, the push-pull configuration has been selected as the topology to be used for the final ballast design. A comparison of the two topologies has been summarized in Table I.

New Dimming Control Method

With the push-pull topology selected, the complete dimming design now includes (Figure 3) an input filter for blocking ballast generated noise, a control IC and push-pull step-up circuit for producing a high-frequency/high-voltage square-wave voltage, and a resonant output stage for preheating, igniting and dimming the fluorescent lamp. The additional circuitry needed for dimming includes (Figure 3) an isolated 0-to-10VDC dimming interface, a current-sensing circuit to measure the lamp current, and a closed-loop feedback circuit to keep the lamp current regulated to the user setting by continuously adjusting the output frequency. A closed-loop

system is needed to regulate the lamp current due to the non-linear electrical characteristics of the fluorescent lamp.
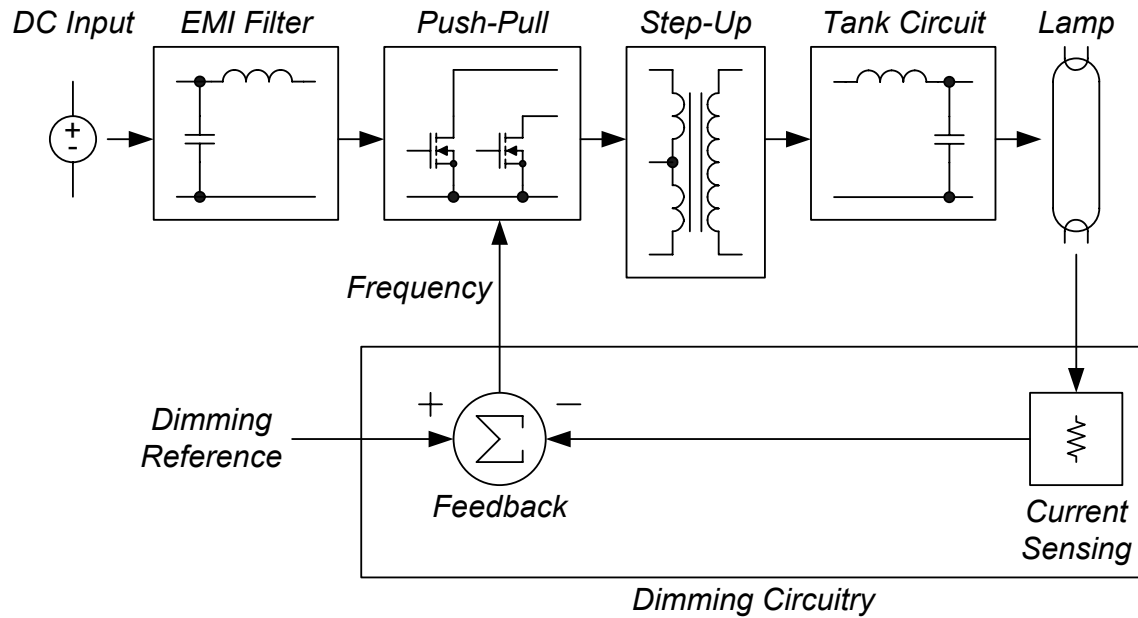

Figure 3, DC input push-pull dimming ballast block diagram.

The new dimming control method includes the lamp current sensing circuit and the closed-loop feedback circuit. A current sense resistor (RCS) is used to measure the AC lamp current (Figure 4). This AC measurement is then coupled to the DC reference through a feedback capacitor and resistor (CFB, RFB). The resulting AC+DC signal is then compared to COM and the frequency is controlled such that the valleys of the AC component are held at COM continuously (Figure 4). If the DC reference is increased, the valley of the AC+DC signal will increase above COM and the feedback circuit will decrease the frequency to increase the gain of the resonant tank. This will increase the lamp current, as well as the amplitude of the AC+DC signal at the DIM pin, until the valley reaches COM again. If the DC reference is decreased, the valley will decrease below COM. The feedback circuit will then increase the frequency to decrease the gain of the resonant tank until the valley reaches COM again. By combining the DC reference with the AC lamp current, a single node can then be used for both reference and feedback functions to achieve closed-loop dimming control.
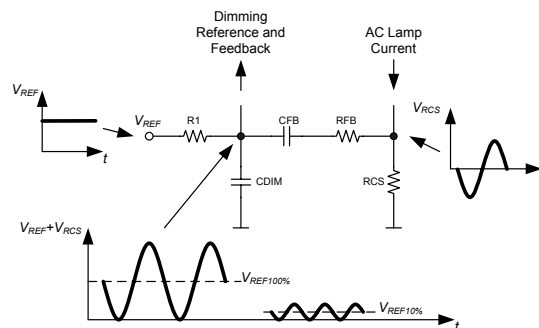

Figure 4, New AC+DC dimming control method.

To preheat, ignite and dim the lamp, the operating frequency is used as the control parameter. During preheat and before the lamp ignites, the resonant tank circuit is a series L-C with a high-Q (Figure 5). During dimming, the resonant tank circuit is a series L, parallel R-C, with a low-Q at high dimming levels (100%) and a high-Q at low dimming levels (10%).
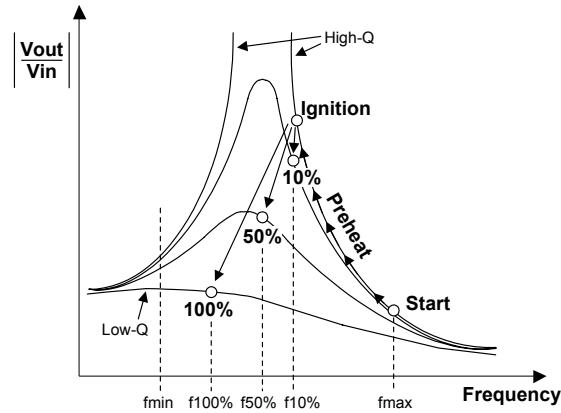

Figure 5, Resonant tank Bode plot with dimming operating points.

During preheat, the output frequency starts at a maximum level and is then decreased linearly (Figure 6). As the frequency decreases, the lamp filaments are preheated by the resonant tank circulating current. As the frequency decreases further towards the resonance frequency of the resonant tank circuit the output voltage across the lamp increases. The lamp ignites when the output voltage exceeds the lamp ignition threshold voltage. Lamp current begins to flow and the closed-loop feedback circuit controls the lamp current to the desired dimming level.
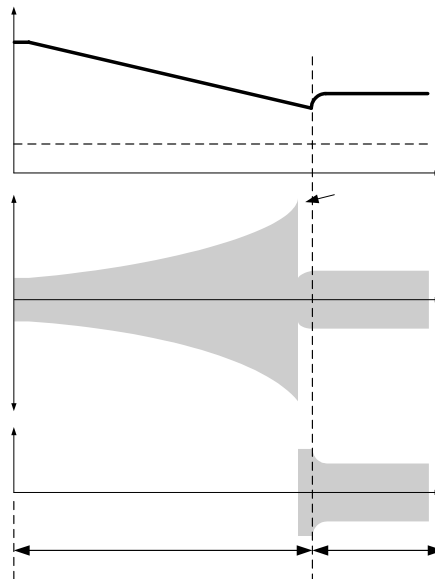

Figure 6, Preheat, ignition and dimming timing diagram.

30W Dimming Ballast Design

The complete schematic is shown in Figure 7. The 24VDC input voltage first goes through the EMI filter (CF and LF) followed by the dc bus capacitor (CBUS). The push-pull switching stage (M1 and M2) is controlled by the IRS2530D IC for preheating, igniting and dimming the lamp. Resistor RS provides the necessary current for the VCC supply of the IC. The drains of the push-pull MOSFETs are connected to a centered-tapped primary winding of the step-up transformer (TSU). The 24VDC bus is then stepped-up and converted to a high-frequency, 300Vp-p square-wave voltage across the secondary winding, which is used to drive the resonant output stage. The resonant tank circuit (LRES and CRES) provides the necessary transfer function for generating high voltages for lamp ignition and low-pass filtering for dimming. A dc blocking capacitor (CDC) ensures that the lamp current is always AC to prevent mercury migration which can cause lamp end blackening and a shortened lamp life. Secondary windings from the resonant inductor (LRES:A,B) and capacitors (CH1 and CH2) are used to heat the lamp filaments during preheat and dimming. The filament heating circuits also separate the lamp current from the filament current allowing for a single current-sensing resistor (RCS) to be used to sense the lamp current. The AC lamp current measurement across RCS is coupled to the DIM pin through a feedback capacitor and resistor (CFB and RFB). Finally, resistors RSD1 and RSD2 are used to detect if the lamp has been removed and to automatically restart the ballast when the lamp is re-inserted. Protection against all other ballast fault conditions such as failure to strike, open filament, and input voltage brown-out, are included internally to the IRS2530D to further reduce component count and increase reliability.
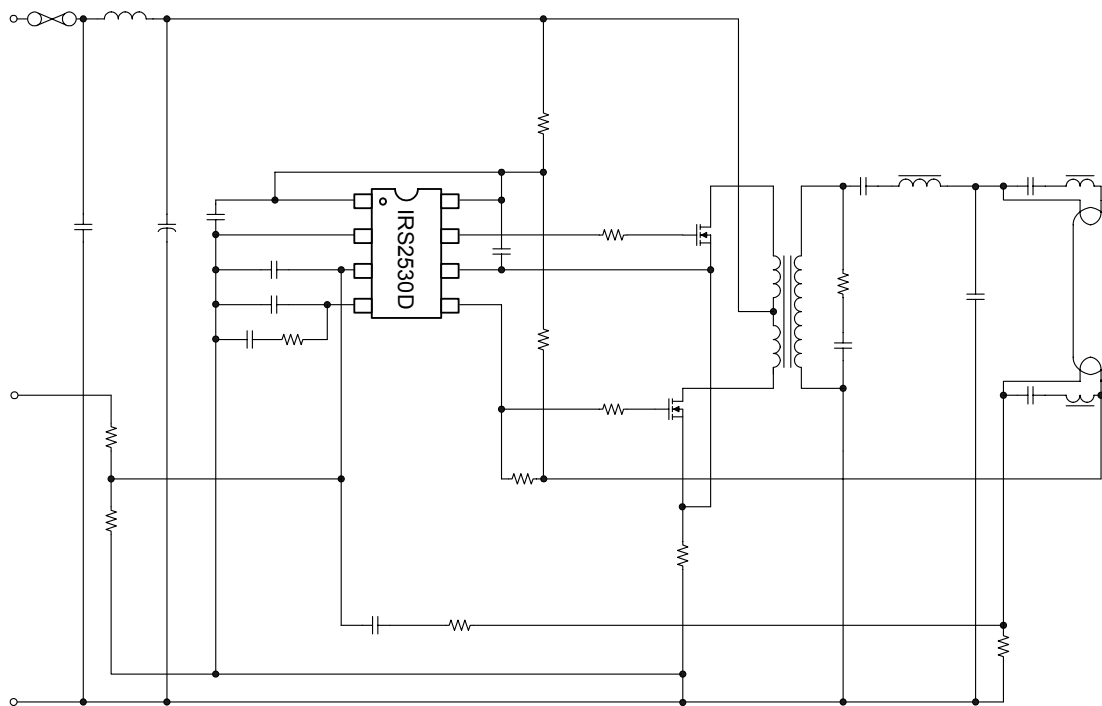

Figure 7, Dimming mini-ballast circuit schematic.

The measured ballast waveforms are shown in Figure 6. Figure 6A shows the VCO pin voltage, lamp voltage and lamp current during normal preheat, ignition and dimming modes. The VCO pin and lamp voltage ramp up during preheat and ignition to preheat the lamp filaments and then to ignite the lamp when the lamp ignition voltage threshold is reached. Lamp current starts to flow immediately after ignition at the start of dimming. Figures 6B and 6C show the half-bridge output voltage (VS) together with the DIM pin voltage during 100% and 10% dimming conditions. The DIM pin voltage amplitude decreases (together with the lamp current) from 100% down to

10% and the operating frequency is continuously adjusted to keep the valley of the sinusoid regulated at COM.
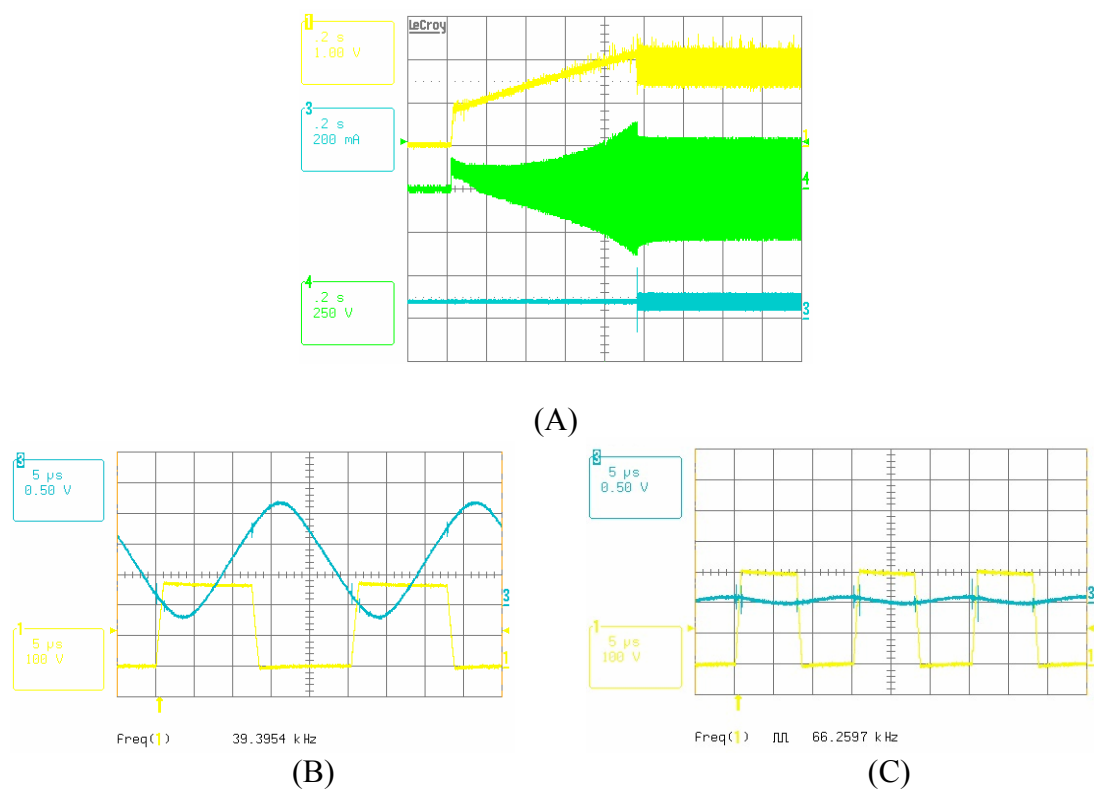

(A)

(B)

(C)

Figure 6, Mini-ballast measured waveforms.

The 0 to 10VDC user dimming input voltage versus the r.m.s. lamp output current (Figure 7) shows good linearity over the entire dimming range.
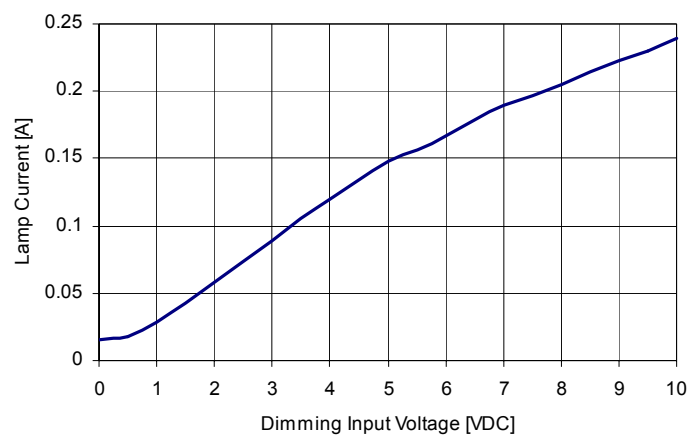

Figure 7, Dimming input versus lamp current output graph.

Conclusion

Electronic ballasts driven off of a DC input have the advantages of no input rectification required and no PFC stage required. Simplifying the design further using a three-stage push-pull topology has the additional benefits of eliminating the boost stage to reduce cost, providing isolation, and increasing lumens/watt. The new closed-loop lamp current control method maintains good regulation of the lamp current and therefore allows for a wide DC input voltage range without the need for a constant DC bus voltage. The final ballast design performs well over the complete input voltage range, including dimming and protection against all fault conditions.

Further improvements to the design for consideration include adding an auxiliary supply for VCC to achieve a lower DC input voltage level. Also, the same solution can also be used for HID and LED lighting applications.

References

1) P. Green, AN-1038: Low Voltage DC Supply Dimmable Ballast for 1x36W Lamp, http://www.irf.com/technical-info/appnotes/an-1038.pdf.

2) IRS2530D Dimming Ballast Control IC, Datasheet, www.irf.com.

3) T. Ribarich, J. Ribarich, *A New Model for High-Frequency Ballast Design,* in IEEE-IAS *Conf. Rec.,* 1997, pp. 2334-2339.

4) International Rectifier, *IRPLDIM4E and IRPLDIM5E*, Reference Design Kits, 2009, www.irf.com.

5) Elenbaas, W., ed., *Fluorescent Lamps*, Second Edition, Philips Technical Library, Eindhoven, The Netherlands 1971.