AN2835
Application note

70 W HID lamp ballast based on the L6569, L6385E and L6562A

Introduction

This application note describes the electronic lamp ballast for 70 W high intensity discharge (HID) metal halide lamps (MHL) used for general indoor applications. The ballast is composed of a boost converter and an inverter. The inverter is realized by a full bridge driver with a power control circuit.

The booster converter for power factor correction (PFC) is controlled by the L6562A controller (U1). The inverter is a full bridge topology driven by two pairs of half bridge buck converters, L6385E (U3) and L6569 (U4), with the constant power control circuit L6562A (U2).

In this note the dual-buck converter is introduced. One works in high frequency and the other works in complementarity with necessary dead time at a lower frequency.

Figure 1. The demonstration board

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Contents

1 Safety instructions 4

2 The selected solution 5

2.1 The dual-buck converter topology 5

2.2 The power control circuit 6

2.3 Ignition circuit 9

3 Description of demonstration board 10

3.1 Specifications 10

3.2 The PCB layout 10

3.3 Electrical schematic 11

3.4 Bill of material 12

4 Experimental results 15

4.1 Test with HID lamp 18

5 References 19

6 Revision history 20

List of figures

Figure 1. The demonstration board . . . 1
Figure 2. The fundamental diagram for the HID lamp ballast . . . 5
Figure 3. The dual-buck converter . . . 5
Figure 4. The timing chart . . . 6
Figure 5. Input power, output voltage and input peak current . . . 7
Figure 6. Indirect constant power control circuit . . . 8
Figure 7. Average current sense circuit . . . 9
Figure 8. Ignition circuit . . . 9
Figure 9. Electrical characteristics of LIC01 . . . 9
Figure 10. Demonstration board top-side view . . . 10
Figure 11. Demonstration board bottom-side view . . . 10
Figure 12. Schematic diagram of demonstration board . . . 11
Figure 13. Lamp current at warm-up state . . . 15
Figure 14. Load with 30 W during warm-up . . . 15
Figure 15. Load with 50 W during warm-up . . . 15
Figure 16. Load with 100 W in steady-state . . . 16
Figure 17. Load with 140 W in steady-state . . . 16
Figure 18. Steady-state at 110 Vac input . . . 16
Figure 19. Steady-state at 220 Vac . . . 16
Figure 20. The timer circuit . . . 17
Figure 21. Lamp current during start up with HID lamp . . . 18
Figure 22. The lamp current in warm-up state . . . 18
Figure 23. The lamp current in steady-state . . . 18

1 Safety instructions

Warning: The demonstration board must be used in a suitable laboratory by qualified personnel who are familiar with the installation, use, and maintenance of electrical systems.

Intended use

The demonstration board is designed for demonstration purposes only, and must not be used for domestic installations or for industrial installations. All technical data, including the information concerning the power supply and working conditions, should only be taken from the documentation included in the pack and must be strictly observed.

Installation

The installation instructions for the demonstration board must be taken from the present document and strictly observed. The components must be protected against excessive strain, and in particular, no components are to be bent, or isolating distances altered during transportation, handling or use. The demonstration board contains electrostatically sensitive components that are prone to damage through improper use. Electrical components must not be mechanically damaged or destroyed (to avoid potential risk and personal injury).

Electrical connection

Applicable national accident prevention rules must be followed when working on the mains power supply. The electrical installation must be carried out in accordance with the appropriate requirements (e.g. cross-sectional areas of conductors, fusing, and PE connections).

Board operation

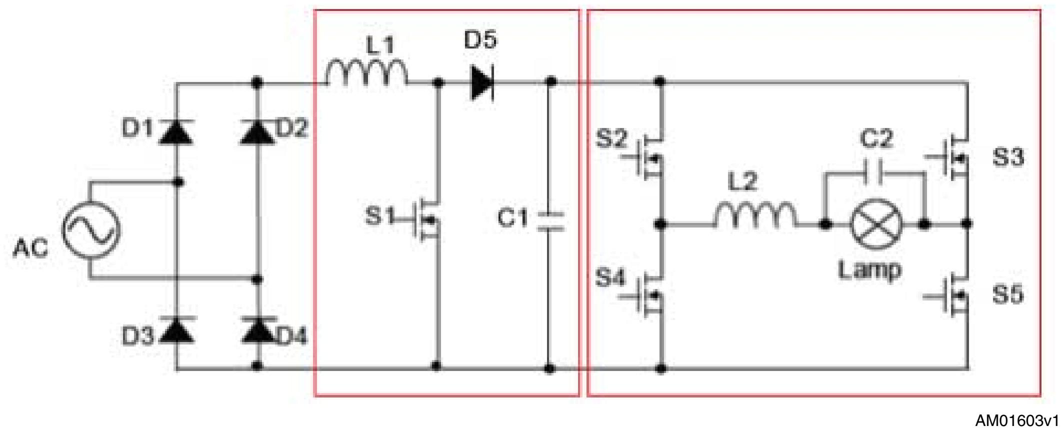
A system architecture which supplies power to the demonstration board must be equipped with additional control and protective devices in accordance with the applicable safety requirements (e.g. compliance with technical equipment and accident prevention rules).

2 The selected solution

2.1 The dual-buck converter topology

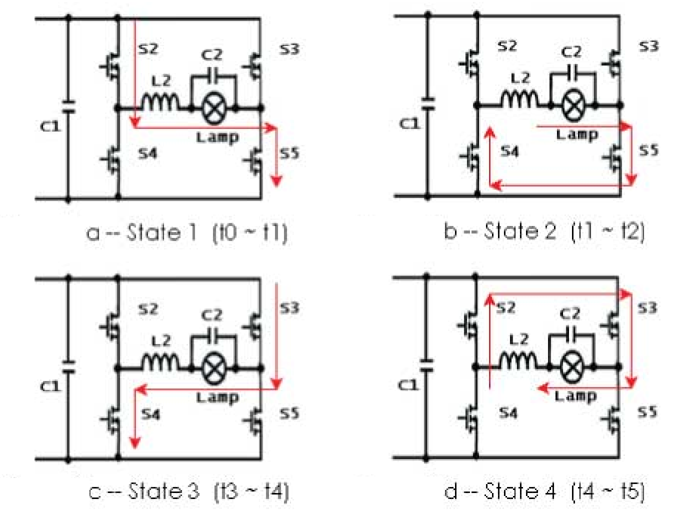
The fundamental application circuit in *Figure 2* is composed of a PFC stage and a power inversion stage. As the boost converter for power factor correction (PFC) is commonly used, only the power inversion stage is introduced in this application note.

Figure 2. The fundamental diagram for the HID lamp ballast



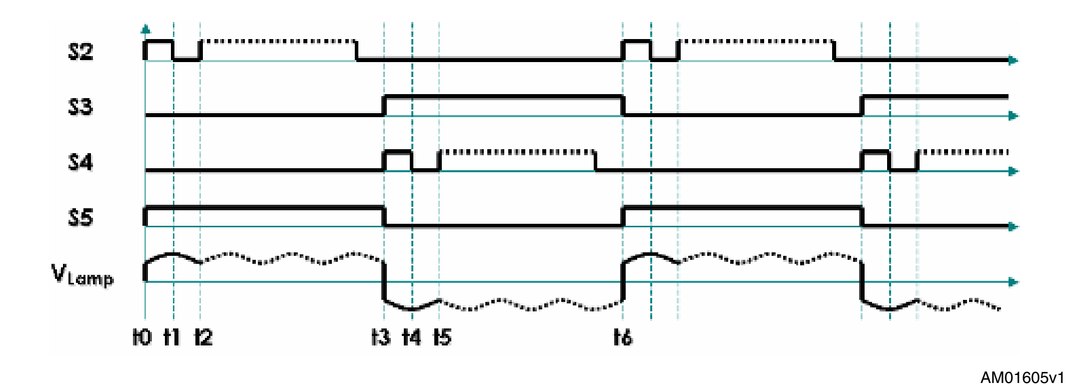
The full bridge inverter consists of two half bridge buck converters. This is shown in *Figure 3*. Both converters have the same L2 load, C2 and lamp. One of the buck converters (S2 and S4) works in high frequency (several tens of kHz) and the second buck converter (S3 and S5) works in complementarity with necessary dead time at a lower frequency (a few hundred Hertz). This kind of full bridge stage is also called dual-buck converter.

Figure 3. The dual-buck converter



The timing diagram in *Figure 4* indicates the relationship of a dual-buck converter and lamp current.

Figure 4. The timing chart



Description of the four operating states

- State 1 in Figure 3a (from t0 to t1, see Figure 4):
  - S3 and S4 in off-state, S2 and S5 are turned on, C1 discharges through S2, L2, Lamp and S5. Certain energy stores to L2 and C2.
- State 2 in Figure 3b (from t1 to t2, see Figure 4):
  - S3 and S4 remain in off-state. S2 is working in high frequency in off-state, and S5 is working in low frequency and remains in on-state. The energy of L2 and C2 keeps on releasing through Lamp, S5 and the reversed body diode of S4. As S2 is working at a higher frequency, state 1 and state 2 is repetitive until the S5 is turned-off at t3.
- State 3 in Figure 3c (from t3 to t4, see Figure 4):
  - S2 and S5 in off-state, S3 and S4 are turned on, C1 discharges through S3, Lamp, L2 and S4. Certain energy stores to L2 and C2.
- State 4 in Figure 3d (from t4 to t5, see Figure 4):
  - S2 and S5 remain in off-state. S4 is working in high frequency in off-state, and S3 is working in low frequency and remains in on-state. The energy of L2 and C2 keeps on releasing through the reversed body diode of S2, then S3 and lamp. S4 is working at a high frequency from t3 to t6, therefore state 3 and state 4 is repetitive until S3 is turned-off at t6. One full operating cycle is completed. Starting from t6, the behavior of t0 is repeated again. From the above analysis, we realize the lamp current flow to this dual-buck converter, and loads to the same L2 inductor, C2 output capacitor, and HID lamp. The lamp current at state 3 and state 4 is in the opposite direction.

2.2 The power control circuit

There are two main functions of the power control circuit. One is constant current control during warm-up and the other is constant power control during steady-state operation.

- Constant current control

  Normally, the lamp current is higher during the warm-up stage than when working at steady-state. But a warm-up current that is too high may cause the electrode to decay and shorten the operating life of the lamp. If warm-up current is too low, the time to steady-state is postponed. Therefore providing a value with 20% higher than the rate of warm-up current during warm-up time is respected. The constant current control is realized by controlling the peak inductor current of the dual-buck converter. Assume the input voltage of the buck converter is V_{bi}, the output voltage is V_{bo}, the duty cycle is D, input peak current is I_{in_pk}, as the buck converter is working at a critical discontinuous mode, and the average input current is:

Equation 1

$$\overline{I_{in}} = \frac{1}{2} I_{inpk} \cdot D$$

And the duty cycle is:

Equation 2

$$D = \frac{V_{bo}}{V_{bi}}$$

The input power becomes:

Equation 3

$$P_{in} = V_{bi} \cdot \overline{I_{in}}$$

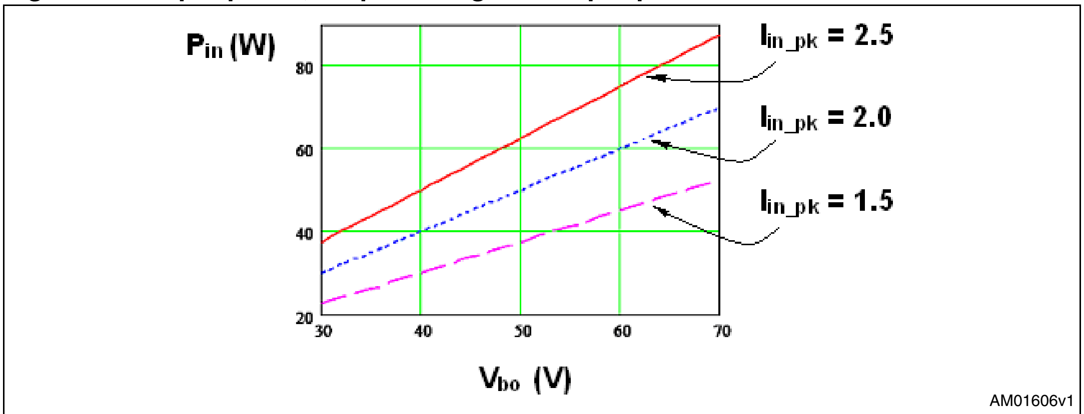
Thus the relationship between the input power (P_{in}), input peak current (I_{in_pk}) and output voltage (V_{bo}) is:

Equation 4

$$P_{in} = V_{bi} \cdot \frac{1}{2} I_{in\_pk} \cdot D = V_{bi} \cdot \frac{1}{2} I_{in\_pk} \cdot \frac{V_{bo}}{V_{bi}} = \frac{1}{2} I_{in\_pk} \cdot V_{bo}$$

If the lamp is operating with a constant current source, once input peak current (I_{in_pk}) is selected, we observe the input power (P_{in}) is proportional to the output voltage (V_{bo}). Despite the power losses, the output power is also proportional to the output voltage.

Figure 5. Input power, output voltage and input peak current

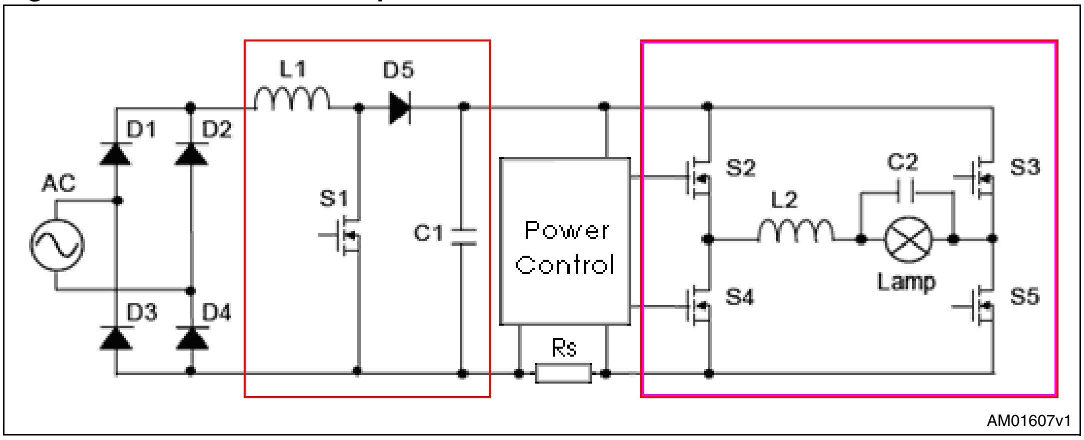


In *Figure 5*, there are three different I_{in_pk} curves, this helps to choose the proper input peak current according to the different types of lamp. After warming-up, the lamp voltage increases slowly to the minimum value of the rated power, the duty cycle increases accordingly. And then the input peak current decreases. In order to power up the lamp in steady-state, the circuit changes from constant current control function to constant power control.

- Constant power control circuit

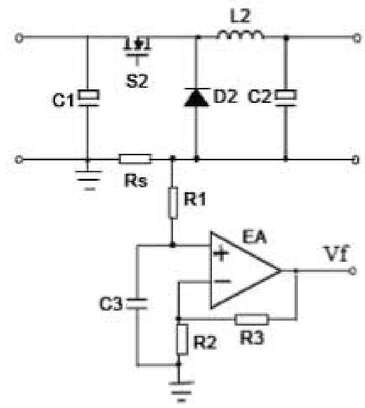
  In this solution, the voltage on pin 3 of U2 (L6562A) is fixed, therefore, during the warm-up time, pin 2 of U2 is clamped at its upper threshold, so the input peak current detected by pin 4 is also fixed. Once the lamp power increases with the lamp voltage increase, pin 2 decreases accordingly, the lamp works at a constant power state. Constant power control assures the output power is constant and stabilizes lamp luminosity without flicker. The lamp operates at the best rated lamp power. Here is an indirect method to perform the constant power control for the lamp. As shown in *Figure 6*, an Rs resistor is connected between the PFC stage and the full bridge stage. If the output voltage of the PFC stage is constant, it means the current of Rs is constant. With the proper controlling of the average current flow through Rs, the current sources from the boost converter (PFC stage) become constant, and the output power in full bridge stage is also constant, assume the power losses of the dual-buck converter (full bridge stage) is constant. Therefore the lamp power has constant control indirectly.

Figure 6. Indirect constant power control circuit



The average current sense circuit is shown as *Figure 7*. R1 and C3 is the filter used to obtain the average voltage on Rs. The Vf feedback signal is generated to control the on-time of the dual-buck converter. In practice, the operating lamp voltage and current change according to the age of the lamp, but the change in power loss to the dual-buck converter is very small and therefore negligible. This indirect method achieves good performances in a low power application.

Figure 7. Average current sense circuit



2.3 Ignition circuit

A high voltage is required to ignite the HID lamp. The ignition voltage depends on the type of HID lamp. For a MHL (metal halide lamp) it is about 3-5 kV. For a hot lamp re-striking needs about 20 kV. Immediate re-ignition of a hot lamp is not advised. Therefore, a cooling down period for hot lamps is recommended. The ignition circuit is shown in *Figure 8*. The pulse transformer (T1) is used to give the ignition pulse. The LIC01 is specially designed for high voltage pulse generation purposes. At the beginning of turn-on S, with LIC01 in off-state, bus voltage Vdc charges to C1 through R1 until it reaches the breakdown voltage (V_{BO} in *Figure 9*) of LIC01. Once LIC01 breaksdown, C1 discharges and the crowbar current occurs. LIC01 is latched to on-state. The LIC01 is turned off when discharging a current lower than the holding current (IH). Then LIC01 returns to the off-state. In such a case, a voltage pulse is generated on Lp. With the turn ratio 1:n of T1, the high voltage across C2 is generated and remains constant for a very short time. Therefore the lamp obtains a high voltage pulse to ignite. LIC01 returns to the off-state after C1 discharges and another charging to C1 is restarted. After the lamp is ignited, S is turned off and there is no more voltage pulse generation on Lp.

Figure 8. Ignition circuit

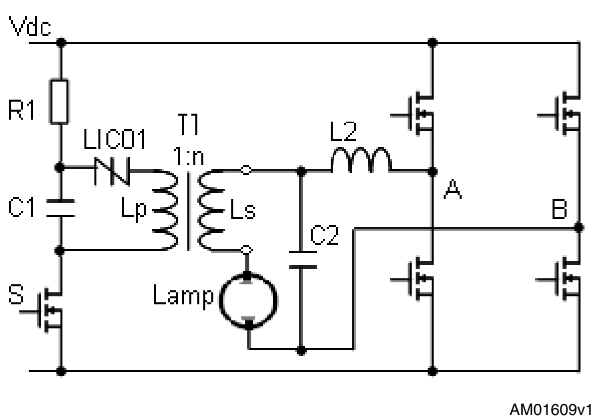
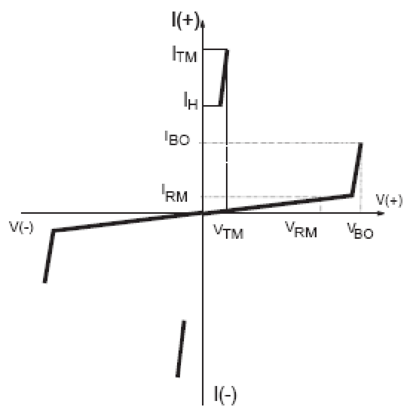


Figure 9. Electrical characteristics of LIC01



3 Description of demonstration board

3.1 Specifications

The demonstration board is designed with open-lamp protection, specifications are shown in *Table 1*.

Table 1. Specifications

Parameter	Value	Unit
Line voltage range	88 to 264	Volt
Line frequency	50 or 60	Hz
Load with HID lamp	70	Watt
Lamp rate voltage	85	Vrms
Power factor	0.98 minimum	-
Efficiency	0.88 minimum	%

3.2 The PCB layout

Figure 10. Demonstration board top-side view

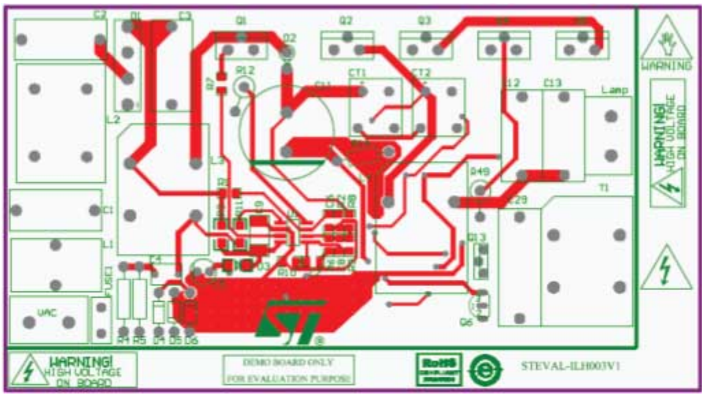


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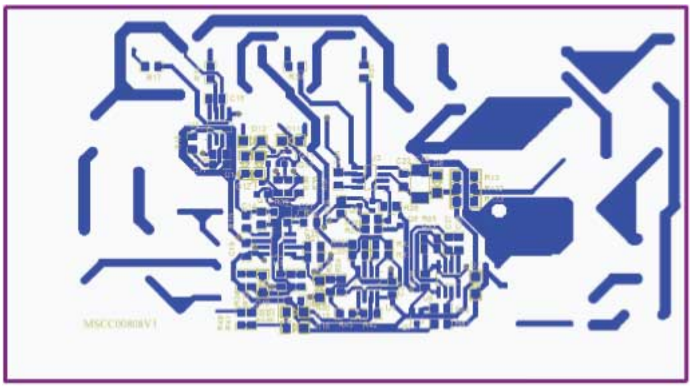
Figure 11. Demonstration board bottom-side view



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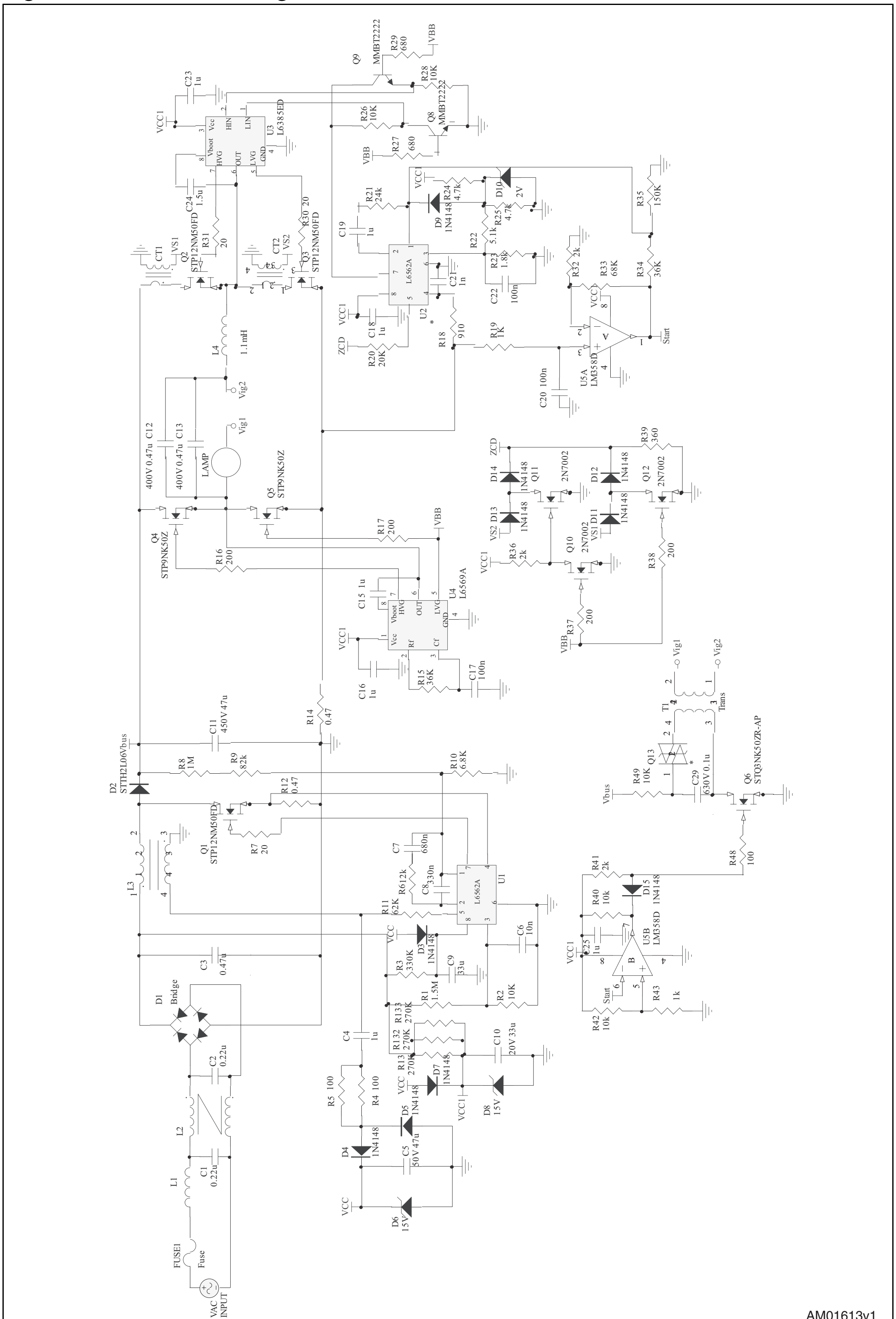
3.3 Electrical schematic

Figure 12. Schematic diagram of demonstration board



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3.4 Bill of material

Table 2. Bill of material

Name	Value	Rated	Type
C1, C2	0.22 µF	275 V	Panasonic ECQU2A224KL
C3, C12, C13	o.47 µF	400 V	Falatronic CL21
C4	1 µF		
C5, C9, C10	47 µF	50 V	
C6	10 nF		SMD (0805)
C7	680 nF		SMD (0805)
C8	330 nF		SMD (0805)
C9, C10	33 µF	20 V	Tantalum
C11	47 µF	450 V	Panasonic EEUEE2W470S
C15, C16, C18, C19, C23, C25	1 µF		SMD (0805)
C17, C20, C22	100 nF		SMD (0805)
C14, C21	1 nF		SMD (0805)
C24	1.5 µF		SMD (0805)
C29	0.1 µF	630 V	Falatronic CBB21
R1	1.5 mΩ		SMD (0805)
R2, R26, R40, R42	10 kΩ		SMD (0805)
R3	330 kΩ		SMD (1206)
R4, R5	100 Ω	1 W	
R6	12 kΩ		SMD (0805)
R7	20 Ω		SMD (0805)
R8	1 MΩ		SMD (0805)
R9	82 kΩ		SMD (0805)
R10	6.8 kΩ		SMD (0805)
R11	62 kΩ		SMD (1206)
R12, R14	0.47 Ω	1 W	
R13, R132, R133	270 kΩ		SMD (1206)
R15	36 kΩ		SMD (0805)
R16, R17, R37, R38	200 Ω		SMD (0805)
R18	910 Ω		SMD (0805)
R19, R43	1 kΩ		SMD (0805)
R20	20 kΩ		SMD (0805)

Table 2. Bill of material (continued)

Name	Value	Rated	Type
R21	24 kΩ		SMD (0805)
R22	5.1 kΩ		SMD (0805)
R23	1.8 kΩ	1% ¼ W	SMD (0805)
R24, R25	4.7 kΩ		SMD (0805)
R27, R29	680 Ω		SMD (0805)
R28	10 kΩ		SMD (0805)
R30, R31	20 Ω		SMD (0805)
R32	2 kΩ	1%	
R33	68 kΩ	1%	
R34	36 kΩ	1%	
R35	150 kΩ	1%	
R36, R41	2 kΩ		
R39	360 Ω		
R44, R45, R46, R47	N.C.		
R48	100 Ω		
R49	10 kΩ	1 W	
D1	2KBP06	2 A, 600 V	Bridge rectifier
D2	STTH2L06	Ultra-fast diode	STMicroelectronics
D3, D7, D9, D11, D12, D13, D14, D15	1N4148		Mini MELF
D4, D5	1N4148		DO-35
D6, D8	15 V Zener diode	15 V	Mini MELF
D10	2 V Zener diode	2 V	Mini MELF
D16	N.C.		
Q1, Q2, Q3	STP15NM60ND	Power MOSFET	STMicroelectronics
Q4, Q5	STP9NK50Z	Zener protected MOSFET	STMicroelectronics
Q6	STQ3NK50ZR	Zener protected MOSFET	STMicroelectronics
Q7	N.C.		
Q8, Q9	MMBT2222		SOT-23
Q10, Q11, Q12	2N7002	Power MOSFET	STMicroelectronics
Q13	LIC01-215H	Light ignition circuit	STMicroelectronics
U1, U2	L6562AD	Power controller	STMicroelectronics
U3	L6385ED	HB driver	STMicroelectronics
U4	L6569AD	HB driver	STMicroelectronics

Table 2. Bill of material (continued)

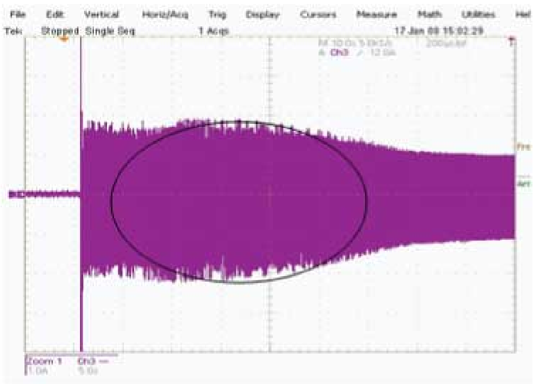
Name	Value	Rated	Type
U5	LM358D	comparator	STMicroelectronics
FUSE 1		500 mA	
CT1, CT2	CT101		TDK CT101
L1	200 µH	2 A	TDK SF-T8-60L-02-PF
L2	7.5 mH	1.5 A	TDK HF2318-A752Y1R5-01
L3 (1)	600 µH		inductor
L4 (2)	1.1 mH		inductor
T1 (3)	400 µH		transformer

1. Core: PC40EF25-Z or equivalent; bobbin: EF-25; winding: AWG30*4, 100 turns and AWG29*2,8 turns; air gap: about 1 mm
2. Core: PC40EF25-Z or equivalent; bobbin: EF-25; winding: AWG27*2, 150 turns; air gap: about 1.8 mm
3. Core: PC40EF25-Z or equivalent; bobbin: EF-25; winding: ~; air gap: about 1 mm

4 Experimental results

Figure 13 shows the lamp current during start up. This warm-up current is higher than the steady-state current. This current should be constant during the warm-up stage (the circled area) before it enters the steady-state. During warm-up, the equivalent resistor for a 70 W HID lamp can vary from 20 Ω to 70 Ω.

Figure 13. Lamp current at warm-up state



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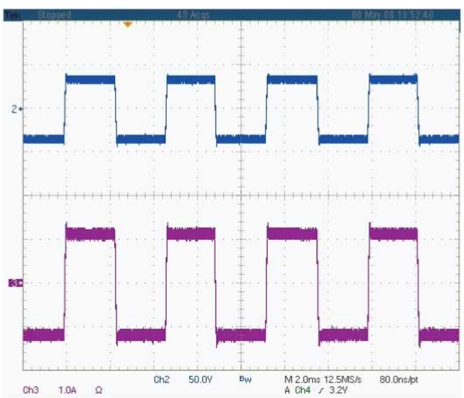
Since the HID lamp needs constant current control during the warm-up state and constant power control during steady-state, designers, therefore, used a 30 Ω and 50 Ω dummy load to evaluate the performance of the warm-up state. *Figure 14* is the test with a 30 Ω dummy load and *Figure 15* is the test with a 50 Ω dummy load. Obviously the current values during warm-up equal 1.1 A constantly, and therefore the constant current control is well achieved.

Figure 14. Load with 30 Ω during warm-up



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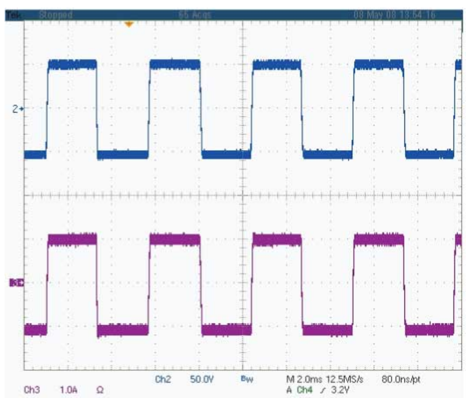
Upper: Output voltage 50 V/div
Lower: Output current 1.0 A/div

Figure 15. Load with 50 Ω during warm-up



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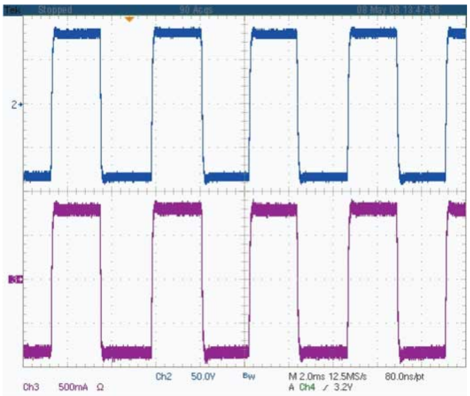
Upper: Output voltage 50 V/div
Lower: Output current 1.0 A/div

For constant power control to the 70 W HID lamp, the rated voltage of the lamp is 85 V and the rated current is 0.82 A. Therefore, the equivalent resistor for the lamp equals 103.6 Ω. As the equivalent resistor for a new or old lamp varies, the typically varied range can have a

20% difference to the rated value. Therefore a 100 Ω and 140 Ω dummy load is chosen for constant power evaluation on bench. Please refer to *Figure 16* and *17* for test results of the lamp voltage and lamp current.

Figure 16. Load with 100 Ω in steady-state



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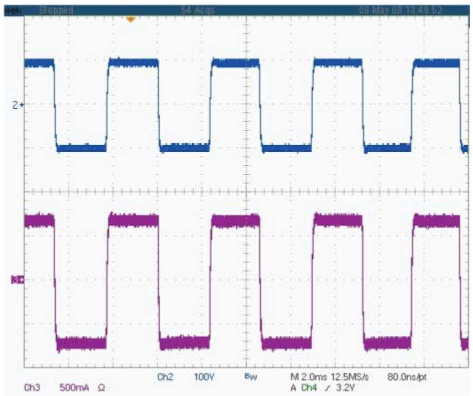
Upper: Output voltage 100 V/div
Lower: Output current 500 mA/div

Figure 17. Load with 140 Ω in steady-state



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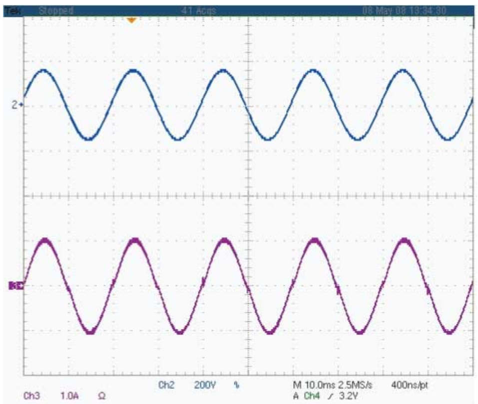
Upper: Output voltage 200 V/div
Lower: Output current 500 mA/div

Figure 18 shows the input line voltage and current waveforms at 110 Vac and *Figure 19* for 220 Vac, both bench measurements show the AC input simultaneous waveform, the input current plot is very good and has extreme low distortion.

Figure 18. Steady-state at 110 Vac input



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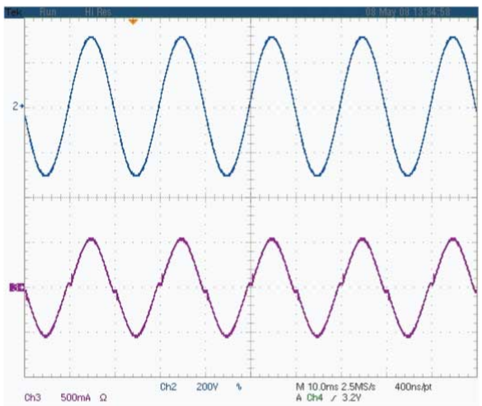
Upper: Output voltage 200 V/div
Lower: Output current 1.0 A/div

Figure 19. Steady-state at 220 Vac



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Upper: Input voltage 200 V/div
Lower: Input current 500 mA/div

In steady-state, the input power (Pin), output power (Pout), operating efficiency and power factor under 110 Vac and 220 Vac is shown in *Table 3*. Obviously the efficiency is over 88% and the power factor is higher than 98%.

Table 3. Test results of power factor and efficiency

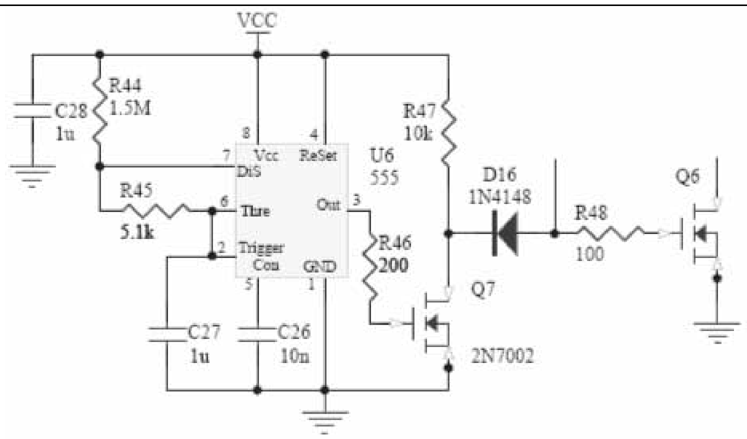
Conditions	Pin	Pout	Efficiency (Pout/Pin)	PF
	Watts	Watts	%	~
At 110 Vac	77.8	68.9	88.5	0.99
At 220 Vac	76.9	68.9	89.6	0.98

From *Section 2.3*, we know that high voltage pulse generates continuously before it steps into steady-state. Once the HID lamp is in open-circuit or absent from the system board, there is no chance to step into steady-state. In such a condition, the ignition circuit is not only continuously generating high pulse voltage, but also the full bridge circuit is working at low frequency (about 200 Hz) as the output of U2 stays high before pin 4 of U2 detects a current signal.

To avoid a hazard from 3~5 kV on the system board while the HID lamp is in open-circuit or the HID lamp is absent from the system, the building of a timer to abort this high voltage pulse generation may be important.

If it is necessary to abort the high voltage pulse generation, a NE555 timer (see *Figure 20*) is used to set up a limited time (normally 5 minutes) to turn-off the circuit at the scheduled time, or apply an MCU in digital solutions. The microcontroller gives more flexible and precise time control compared to one with a simple hardware solution.

Figure 20. The timer circuit



4.1 Test with HID lamp

The test was done at 220 Vac line input with a HID lamp at room temperature. The test lamp is a powerball HCI-T 70W/830 WDL from OSRAM. *Table 4* shows the test results. The input power for the 70 W HID lamp is 76.4 W and the power factor achieved is 0.98.

Table 4. Test results of power factor

Results Conditions	Vin	Iin	Pin	PF
	Volts	Amperes	Watts	~
T_{AMB} = 25 °C	220	0.347	76.4	0.98

The lamp current during start up is shown in *Figure 21*. The detail of warm-up current is shown in *Figure 22* and the steady-state current is shown in *Figure 23*.

Figure 21. Lamp current during start up with HID lamp

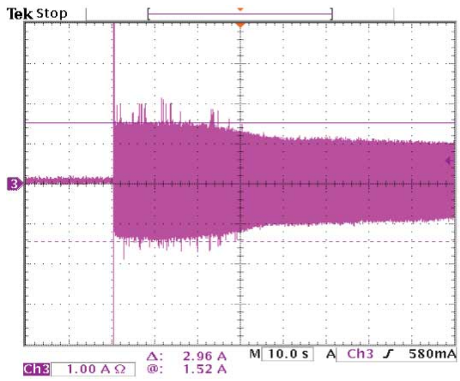
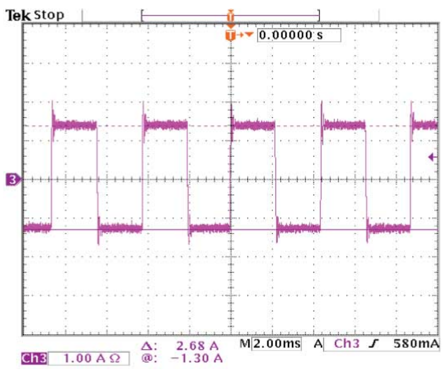
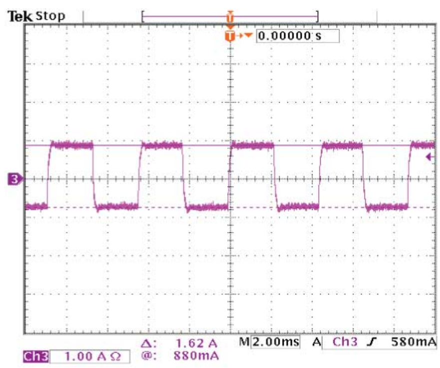


Figure 22. The lamp current in warm-up state



Vertical: lamp current 1 A/div
Horizontal: time 2 ms/div

Figure 23. The lamp current in steady-state



Vertical: lamp current 1 A/div
Horizontal: time 2 ms/div

5 References

1. AN2747
2. L6562A datasheet
3. L6569 datasheet
4. L6385E datasheet
5. LIC01 datasheet
6. LM358 datasheet
7. STTH2L06 datasheet
8. STQ3NK50ZR datasheet
9. STP9NK50Z datasheet
10. STP15NM60ND datasheet
11. 2N7002 datasheet.

6 Revision history

Table 5. Document revision history

Date	Revision	Changes
13-May-2010	1	Initial release