

Reference Design #0602

IRPLLNR4(rev.B) - A Universal Input Linear Fluorescent Ballast using the IR2166

By

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The IRPLLNR4 is a Universal Input Linear Fluorescent Ballast using the IR2166

Features

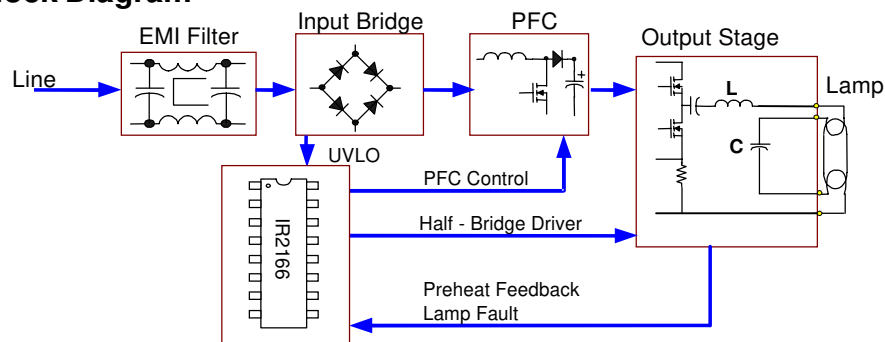
- Drives 1 x 35W TL5 Lamp
- Input Voltage: 80-260Vac
- High Power Factor/Low THD
- High Frequency Operation
- Lamp Filament Preheating
- Lamp Fault Protection with Auto-Restart
- Low AC Line Protection
- End of Lamp Life Shutdown
- IR2166 HVIC Ballast Controller



Description

The IR2166 Demo Board is a high efficiency, high power factor, fixed output electronic ballast designed for driving rapid start fluorescent lamp types. The design contains an EMI filter, active power factor correction and a ballast control circuit using the IR2166. This demo board is intended to ease the evaluation of the IR2166 Ballast Control IC, demonstrate PCB layout techniques and serve as an aid in the development of production ballast's using the International Rectifier IR2166.

Ballast Block Diagram



Demo Board Data Sheet
intended for design information only.
Subject to change without prior notice.

Electrical Characteristics

Parameter	Units	Value
Lamp Type		35W TL5
Input Power	[W]	38
Lamp running voltage	[Vpp]	600
Run Mode Frequency	[kHz]	44
Preheat Mode Frequency	[kHz]	57
Preheat Time	[s]	1
Lamp Preheat Voltage	[Vpp]	660
Ignition Voltage	[Vpp]	1700
Input AC Voltage Range	[VACrms]	90-260VAC
Power Factor		0.995 at 120VAC (rms) 0.971 at 220 VAC (rms)
Total Harmonic Distortion	[%]	<10 at 120VAC (rms) <15 at 220 VAC (rms)

Fault Protection Characteristics

Fault	Ballast	Restart Operation
Line voltage low	Deactivates	Increase line voltage
Upper filament broken	Deactivates	Lamp exchange
Lower filament broken	Deactivates	Lamp exchange
Failure to ignite	Deactivates	Lamp exchange
Open circuit (no lamp)	Deactivates	Lamp exchange
End of life	Deactivates	Lamp exchange

Functional Description

Overview

The IR2166 Demo Board consists of an EMI filter, an active power factor correction section, a ballast control section and a resonant lamp output stage. The active power factor correction section is a boost converter operating in critical conduction mode, free-running frequency mode. The ballast control section provides frequency modulation control of a traditional RCL lamp resonant output circuit and is easily adaptable to a wide variety of lamp types. The ballast control section also provides the necessary circuitry to perform lamp fault detection, shutdown and auto-restart.

Bill Of Materials

Lamp type: TL5/35W, Line Input Voltage: 80-260 VAC

Note: Different lamp types require different frequency programming components.

Item #	Qty	Manufacturer	Part Number	Description	Reference
1	1	International Rectifier	DF10S	Bridge Rectifier, 1A 1000V	BR1
2	1	Roederstein	WY0222MCMBF0K	Capacitor, 2.2nF 275 VAC Y Cap	CY
3	1	Dale	CW-1/2	Resistor, 0.5Ohm, 1/.2W	F1
4	1	Roederstein	F1772433-2200	Capacitor, 0.33uF 275 VAC	C1
5	1	Panasonic	ELF-15N007A	EMI Inductor, 1X10mH 0.7Apk	L1
6	2	Wima	MKP10	Capacitor, 0.1uF 400 VDC	C2, CDC,
7	1	Panasonic	ERZ-V05D471	Transient Suppressor	RV1
8	1	Panasonic	EEU-EB2W100	Capacitor, 10uF 450VDC 105C	CBUS
9	1	B.I. technologies	HM00-01761	PFC Inductor, 1.0mH 2Apk	LPFC
10	2	Panasonic	ECJ-2VB1HC104K	Capacitor, 0.1uF SMT 1206	CBOOT, CVCC2
11	3	Panasonic		Capacitor, 0.47uF SMT 1206	CPH, CSD2, CEOL
12	1	Panasonic		Capacitor, 1nF SMT 1206	CSD1
13	1	Panasonic		Capacitor, 0.68uF SMT 1206	CCOMP1
14	1	Panasonic		Capacitor, 0.01uF SMT 1206	CVDC
15	1	Panasonic		Capacitor, 2.2uF 50VDC 105C	CVCC1
16	1	Digi-key		Capacitor, 820pF 1KV SMT 1812	CSNUB
17	1	WIMA	FKP1	Capacitor, 3.3nF 1.6KV	CRES
18	1	Panasonic		Capacitor, 220pF SMT 1206	CCS
19	2			Capacitor, 0.1uF 100V	CH1, CH2
20	1	Panasonic	ECU-V1H471KBN	Capacitor, 820pF SMT 1206	CT
21	2	Digi-key	MURS160DICT-ND	Diode, 1A 600V, SMT SMB	DBOOT, DPFC
22	3	Diodes	LL4148DICT-ND	Diode, 1N4148 SMT DL35	DCP1, DCP2, DSD
23	1			Diode, 11V Zener, 500mW	DCOMP
24	1	International Rectifier	IR2166	IC, Ballast Driver / PFC	IC BALLAST
25	1	B.I. technologies	HM00-01762	Inductor, 4.0mH 3Apk	LRES
26	3	International Rectifier	IRF830	Transistor, MOSFET	MPFC, MHS, MLS
27	3	Panasonic	ERJ-8GEYJ22	Resistor, 22 ohm SMT 1206	RPFC, RLO, RHO
28	1	Panasonic		Resistor, 59Kohm SMT1206	RPH
29	1			Resistor, 360K ohm 1/2 watt	RSUPPLY
30	2	Panasonic	ERJ-8GEYJ680K	Resistor, 680K ohm SMT 1206	RBUS1, RBUS2
31	2			Resistor, 22K ohm SMT 1206	RT, RZX
32	1	Panasonic	ERJ-8GEYJ1K	Resistor, 1K ohm SMT 1206	RLIM
33	1	Panasonic		Resistor, 1.5 ohm SMT 2010	RCS
34	1			Resistor, 220K 1/2W	RPU
35	1			Resistor, 13K ohm 1% SMT 1206	RVDC
36	1			Resistor, 100K ohm SMT 1206	RSD
37	3			Resistor, 220K ohm SMT 1206	REOL1, REOL2, REOL3
38	1			Resistor, 1.2K ohm SMT 1206	REOL4
39	1	WAGO	235-203	Connector, 3 terminal	X1
40	1	WAGO	235-207	Connector, 4 terminal	X2
Total	56				

Inductor Specs

International IOR Rectifier | INDUCTOR SPECIFICATION
TYPE : LPFC

CORE SIZE GAP LENGTH mm

BOBBIN PINS

CORE MATERIAL

NOMINAL INDUCTANCE mH

MAXIMUM CURRENT Apk

MAXIMUM CORE TEMPERATURE °C

WINDING	START PIN	FINISH PIN	TURNS	WIRE DIAMETER (mm)
MAIN	1	6	125	4 strands of AWG 32
ZX	3	8	10	4 strands of AWG 32

ELECTRICAL LAYOUT

PHYSICAL LAYOUT

TEST (TEST FREQUENCY = 50kHz)

MAIN WINDING INDUCTANCE mH mH

MAIN WINDING RESISTANCE Ohms

NOTE : Inductor must not saturate at maximum current and maximum core temperature at given test frequency.

International **IR** Rectifier | INDUCTOR SPECIFICATION
 TYPE : LRES(VOLTAGE MODE)

CORE SIZE GAP LENGTH mm

BOBBIN PINS

CORE MATERIAL

NOMINAL INDUCTANCE mH

MAXIMUM CURRENT Apk

MAXIMUM CORE TEMPERATURE °C

WINDING	START PIN	FINISH PIN	TURNS	WIRE DIAMETER (mm)
MAIN	1	8	250	4 strands of AWG 32
CATHODE (1)	6	7	10	4 strands of AWG 32
CATHODE (2)	4	5	10	4 strands of AWG 32

ELECTRICAL LAYOUT

PHYSICAL LAYOUT

TEST (TEST FREQUENCY = 50kHz)

MAIN WINDING INDUCTANCE mH mH

MAIN WINDING RESISTANCE Ohms

NOTE : Inductor must not saturate at maximum current and maximum core temperature at given test frequency.

Demo board Overview

This demo-board is designed for single TL5/35W Lamp, voltage mode heating (JV1 and JV2 mounted, JC1 and JC2 not mounted). TL5 lamps are becoming more popular due to their lower profile and higher lumen/ watt output. These lamps, however, can be more difficult to control due to their higher ignition and running voltages. A typical ballast output stage using current-mode filament heating (filament placed inside L-C tank) will result in excessive filament current during running. The output stage has therefore been configured for voltage-mode filament heating using secondary windings off of the resonant inductor LRES. The lamp has been placed outside the under-damped resonant circuit loop, which consist of LRES and CRES. The filament heating during preheat can be adjusted with the capacitors CH1 and CH2. The result is a more flexible ballast output stage necessary for fulfilling the lamp requirements. The DC blocking capacitor, CDC, is also placed outside the under-damped resonant circuit loop such that it does not influence the natural resonance frequency of LRES and CRES. The snubber capacitor, CSNUBB, serves as charge pump for supplying the IR2166.

The IR2166 Ballast Control IC is used to program the ballast operating points and protect the ballast against conditions such as lamp strike failures, low DC bus, thermal overload or lamp failure during normal operations. It is also used to regulate the DC bus and for power factor control allowing high power factor and low harmonic distortion.

Power Factor Correction Section

The power factor correction section contained in the IR2166 forms the control for a boost topology circuit operating in critical conduction mode. This topology is designed to step-up and regulate the output DC bus voltage while drawing sinusoidal current from the line (low THD) which is “in phase” with the AC input line voltage (HPF).

Ballast Control Section

The ballast control section of the IR2166 Ballast Control IC contains an oscillator, a high voltage half-bridge gate driver and lamp fault protection circuitry. Please, refer to the datasheet of this IC for the block diagram and the state diagram. Following is a breakdown of the operation of the ballast in all of the different modes of operation.

Startup Mode

When power is initially applied to the ballast, the voltage on the VCC pin of the IR2166 begins to charge up. The voltage for the IR2166 is derived from the current supplied from the rectified AC line through startup resistor RSUPPLY. During this initial startup when the VCC voltage of the IR2166 is

below its rising under-voltage lock-out threshold, it is in its UVLO and also its micro-power mode. The micro-power mode of the IR2166 allows the use of a large value, low wattage startup resistor (RSUPPLY). When the voltage on the IR2166 reaches the rising under-voltage lockout threshold (11.5V), the gate driver oscillator is enabled (this assumes that there are no fault conditions) and drives the half-bridge output MOSFETs (MHS and MLS). When the half-bridge is oscillating, capacitor CSNUB, diodes DCP1 and DCP2 form a snubber /charge pump circuit which limits the rise and fall time at the half-bridge output and also supplies the current to charge capacitor CVCC2 to the VCC clamp voltage (approx. 15.6V) of IR2166. When the rising under-voltage lockout threshold of the IR2166 is reached, the power factor control oscillator starts to oscillate and drive MOSFET MPFC to boost and regulate the bus voltage to 400 VDC.

Preheat Mode

When the ballast reaches the end of the UVLO mode, the Preheat mode is entered. At this point the ballast control oscillator of the IR2166 has begun to operate and the half-bridge output is driving the resonant load (lamp) circuit.

There is an initial startup frequency that is much higher than the steady state Preheat mode frequency that lasts for only a short duration. This is done to ensure that the initial voltage appearing across the lamp at the startup of oscillation does not exceed the minimum lamp ignition voltage. If, at the initiation of oscillation of the half-bridge, the voltage across the lamp is large enough, a visible flash of the lamp occurs which should be avoided. This in effect is a cold strike of the lamp, which could shorten the life of the lamp.

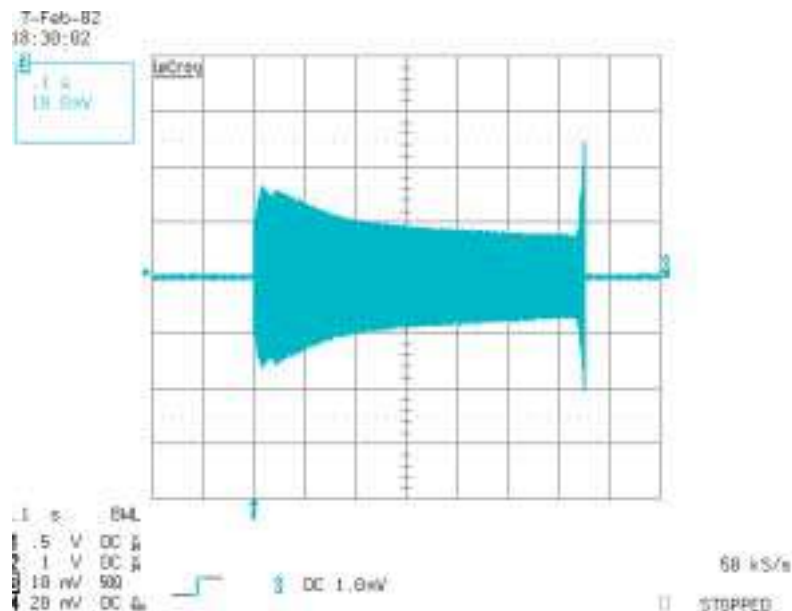


Figure 1: Lamp filament current during Preheat and Ignition Ramp (500mA / div) (crossed lamps)

The ballast control section oscillator of the IR2166 is similar to oscillators found in many popular PWM voltage regulator ICs and consists of a timing capacitor and resistor connected to ground. Resistors RT and RPH program a current which determines the ramp up time of capacitor CT. The downward ramping time of CT is the dead time between the switching off of the LO (HO) and the switching on of the HO (LO) pins on the IR2166. The Preheat mode frequency of oscillation is determined from the parallel between RT and RPH. It is selected such that the voltage appearing across the lamp is below the minimum lamp ignition voltage while supplying enough current to preheat the lamp filaments to the correct emission temperature within the Preheat mode period. The preheating of the lamp filaments is performed with a constant voltage during the Preheat mode. The waveform in Figure 1 shows the lamp filament current while Figure 2 shows lamp filament voltage during the normal Startup, Preheat and Ignition Ramp modes of the ballast.

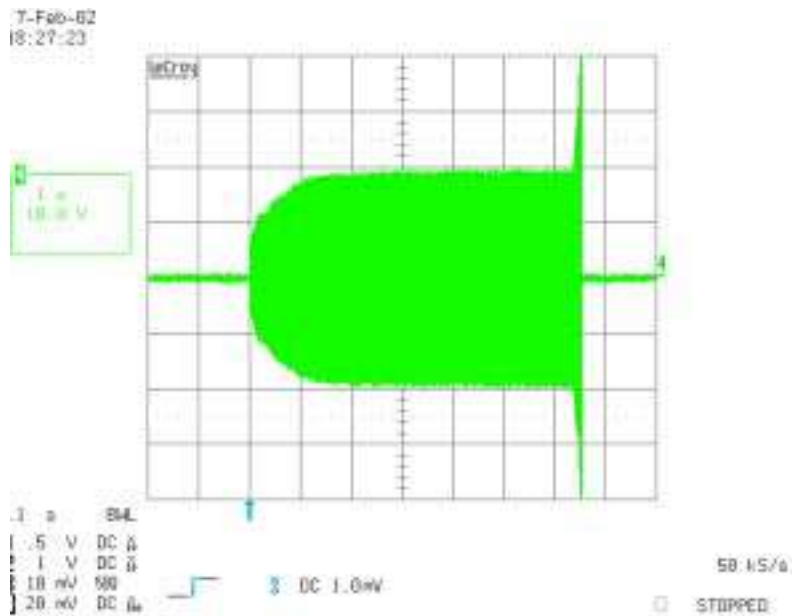


Figure 2: Lamp filament voltage during preheat and Ignition Ramp (crossed lamps)

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Figure 3 shows a plot of the half-bridge oscillation frequency as a function of time for all of the normal modes of operation: Preheat mode, Ignition Ramp mode and Run mode.

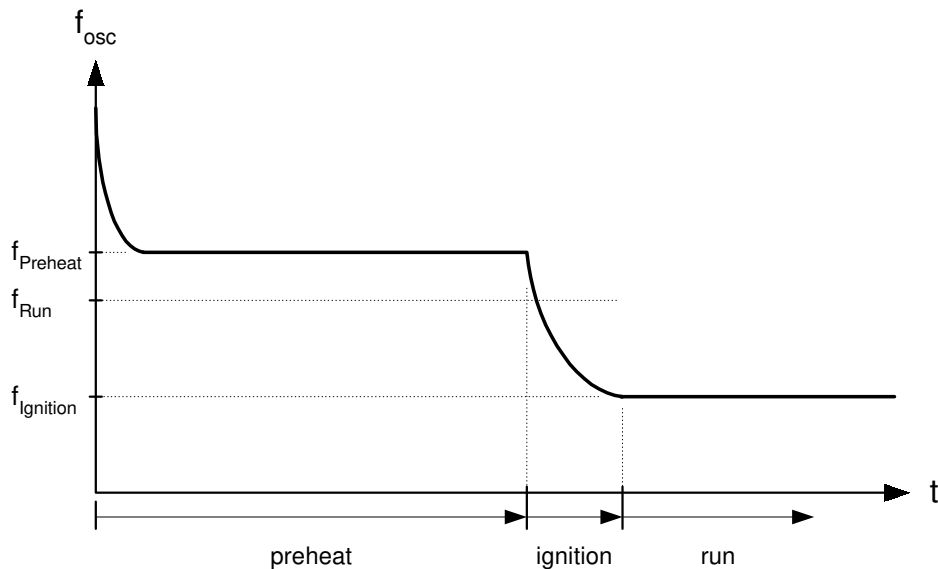


Figure 3: Oscillator frequency versus time, normal operating conditions

The duration of the Preheat mode as well as the mode of operation of the ballast are determined by the voltage on the CPH pin of the IR2166. At the completion of the UVLO mode, Preheat mode is entered and an internal current source is activated at the CPH pin of the IR2166, which begins to charge up capacitor CPH. The ballast remains in the Preheat mode until the voltage on the CPH pin exceeds the Ignition Ramp mode threshold (10V).

Ignition Ramp Mode

At the completion of the Preheat mode the ballast switches to the Ignition Ramp mode and the frequency ramps down to the run frequency. Resistor RPH is no longer connected directly in parallel with resistor RT so the run frequency is determined only with RT. During this ramping downward of the frequency, the voltage across the lamp increases in magnitude as the frequency approaches the

resonant frequency of the LC load circuit until the lamp ignition voltage is exceeded and the lamp ignites. The maximum ignition voltage that can be generated is determined from the value of RCS, but in any case the ignition frequency must be higher than the run frequency. Figure 4 shows the ramping of voltage appearing across the lamp.

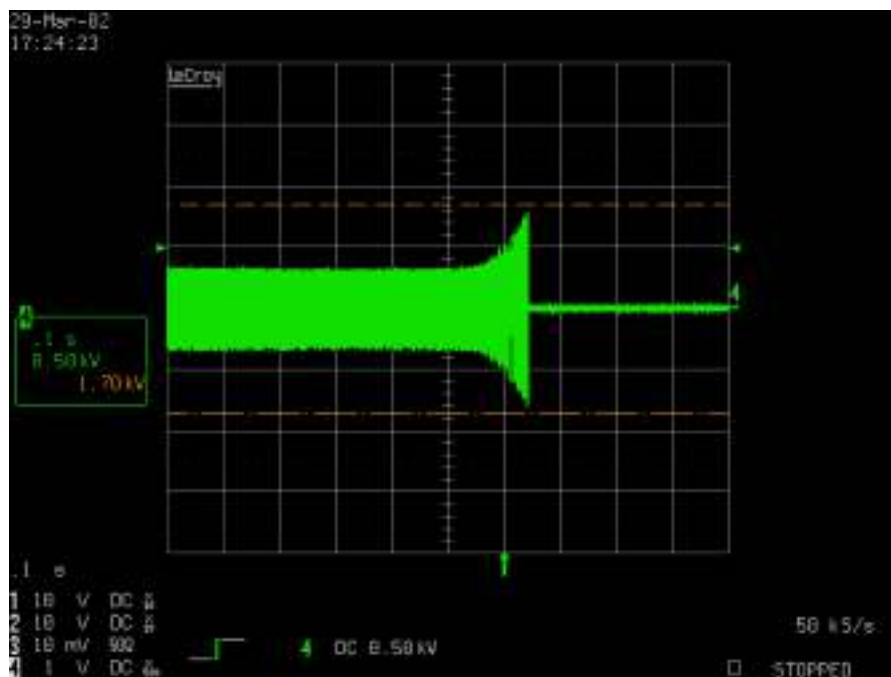


Figure 4: Ignition Ramp (crossed lamps)

During the Ignition Ramp mode the voltage on the CPH pin of the IR2166 continues to ramp up until the voltage at the CPH pin of the IR2166 exceeds the Run mode threshold (13V). Over-current sensing is also enabled at the beginning of the Ignition Ramp mode. A full explanation of the functionality of the over-current sensing is in the section on Fault Mode.

Run Mode

During the Run mode the frequency is shifted to the run frequency. The run frequency is determined only by RT. The 1-3V window comparator in the SD pin is enabled at the beginning of the Run mode. The full explanation of the functionality of the under-current sensing and end-of-life sensing is in the section on Fault Mode.

The Run mode frequency is that at which the lamp is driven to the lamp manufacturer's recommended lamp power rating. The running frequency of the lamp resonant output stage for selected component values is defined as,

$$f_{run} = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - 2\left(\frac{P_{Lamp}}{CV^2_{Lamp}}\right)^2} + \sqrt{\left[\frac{1}{LC} - 2\left(\frac{P_{Lamp}}{CV^2_{Lamp}}\right)^2\right]^2 - 4\frac{1 - \left(\frac{2V_{DCbus}}{V_{Lamp}\pi}\right)^2}{L^2C^2}}$$

where,

L	= Lamp resonant circuit inductor (L3)	(H)
C	= Lamp resonant circuit capacitor (C14)	(F)
P_{Lamp}	= Lamp running power	(W)
V_{Lamp}	= Lamp running voltage amplitude	(V)

Figure 5 shows the voltage appearing across the lamp during Startup, Preheat, Ignition Ramp and Run modes.

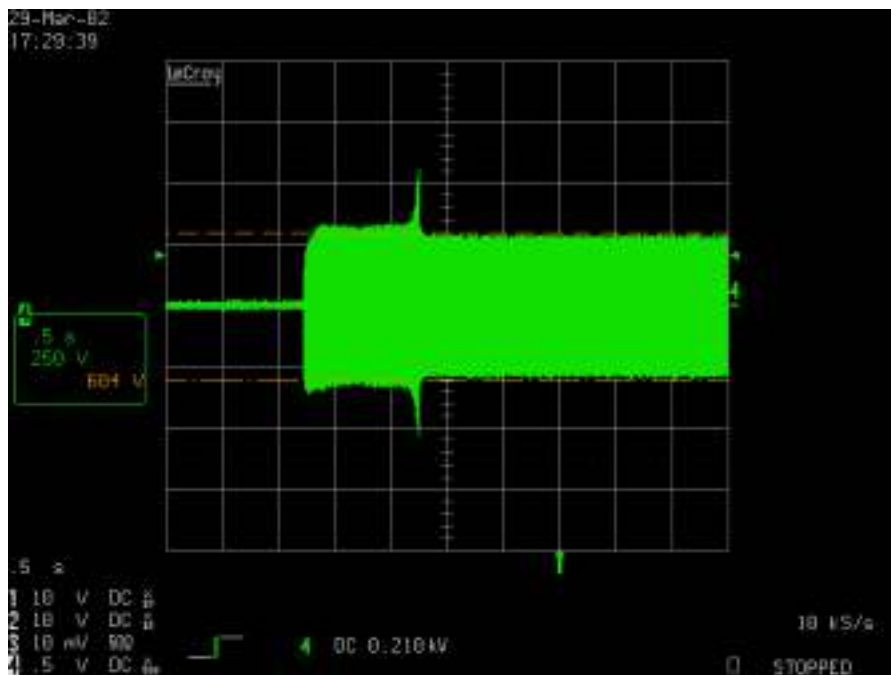


Figure 5: Preheat, Ignition Ramp and Run Voltage in the lamp

Normal Power-Down

A normal power down occurs when the AC line voltage is disconnected from the ballast. When this occurs the voltage on the VBUS pin of the IR2166 drops below the line fault threshold (3V). The value of the zener diode in the COMP pin and of the RSUPPLY resistor are chosen to discharge VCC below the power down threshold (9.5V) then the AC line falls below a minimum value (that can be set with the value of DCOMP and RVBUS) to have latched shutdown. The ballast control oscillator is stopped, the half-bridge driver outputs (LO and HO) are turned off and the IR2166 goes into its UVLO/micro-power mode and the bus voltage collapses.

Lamp Removal and Auto-restart

Resistors RPU, RSD and capacitor CSD1 form a divider/filter network which is used to detect an open lower lamp filament and/or lamp replacement. Under normal conditions, the voltage across CSD1 is close to zero. However, if the lower filament becomes open or the lamp is removed, the voltage at the SD pin increases above the 5V threshold for the SD pin of the IR2166 and signals a lamp removal condition, which in turn sends the ballast into UVLO mode. The ballast remains in the UVLO mode until the lamp replacement is performed. If the lamp is replaced with a lamp with a good lower filament, the voltage on the SD pin of the IR2166 drops back below the threshold and the ballast will go through a restart. Line voltage cycling is also used to restart the ballast for all lamp fault conditions. The ballast will go through a full Preheat, Ignition Ramp and Run mode sequence anytime a restart is performed. Note that the SD pin of the IR2166 is active during all modes of operation.

Fault Mode

Fault mode is when the ballast driver is shutdown due to the detection of a lamp fault. Note that when the ballast is in this Fault mode the power factor correction section of the ballast is also shutdown and the bus voltage will drop to the non-boosted/unregulated level. There are several lamp fault conditions that can put the ballast into the Fault mode.

The lamp fault conditions detected include: hard-switching detection, over-current detection (CS pin) and end of life detection (SD pin). Resistor RCS in the source lead of the low side MOSFET (MHS) serves as the current sensing point for the half-bridge, which is used to detect these lamp fault conditions. In operation when the half-bridge is oscillating, a voltage appears across RCS whenever the low side MOSFET, MHS, is turned on or the high side MOSFET, MLS, is turned off. The magnitude of this voltage directly relates to the current in the lamp resonant circuit. Figure 6 shows the voltage which appears across resistor RCS during normal Run mode conditions. Also shown in Figure 6 are the gate drive signals for the low side MOSFET (LO pin) and the high side MOSFET (HO-VS pin).

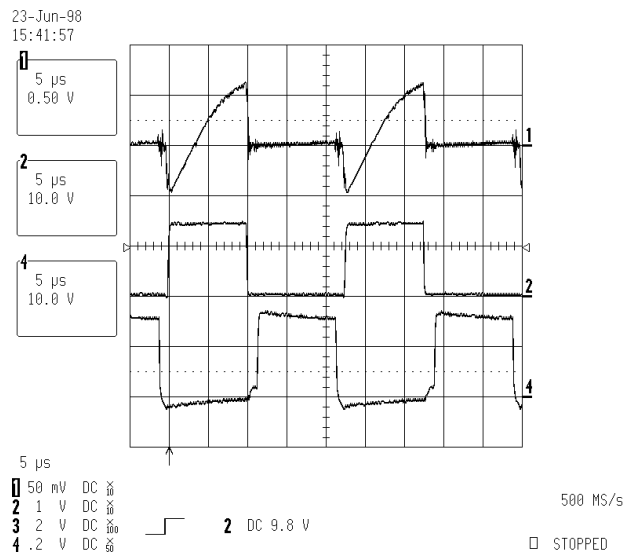


Figure 6: Normal Run mode; Upper trace CS: voltage across RCS, Middle trace: LO pin voltage, Lower trace: HO-VS pin

During the Preheat mode the voltage across resistor RCS is not measured. However, at the end of Preheat mode (the beginning of the Ignition Ramp mode) the hard-switching and over-current detection are enabled. During RUN mode, If at any time thereafter the voltage magnitude across resistor RCS rises above the over-current threshold (1.3V), a lamp fault condition is signaled and the half-bridge output MOSFETs', (MHS and MLS) are turned off and the ballast goes into Fault mode. During Ignition, a lamp fault condition is signaled only after 10 cycles to avoid triggering this protection in the case of a current transient that can happen during normal ignition. An over-current condition can occur if the lamp fails to ignite or the lamp is broken (an open circuit cathode or broken lamp). Figure 7 shows the voltage across resistor RCS and the voltage appearing across the lamp when the ballast detects a failure to ignite the lamp and goes into Fault mode. Figure 8 shows the voltage appearing across the lamp during the tail end of the Preheat mode and the Ignition Ramp mode for a failure of the lamp to ignite condition. If a cathode is broken (open circuit) the half-bridge output hard-switches and each time the low side MOSFET (MHS) is turned on a large current pulse occurs and thus a large voltage pulse occurs across resistor RCS signaling a fault, Figure 9 shows this hard-switching condition. Figure 10 shows the lamp voltage during the Preheat mode and beginning of Ignition Ramp mode for this hard-switching condition when the lamp fault condition is detected. The ballast will remain in Fault mode until either the line voltage is reset or a lamp replacement is performed.

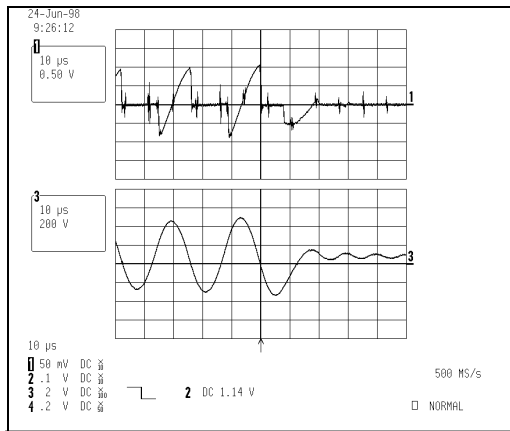


Figure 7: Failure of lamp to ignite condition (lamp filaments good): Upper trace: voltage across RCS, Lower trace: lamp voltage

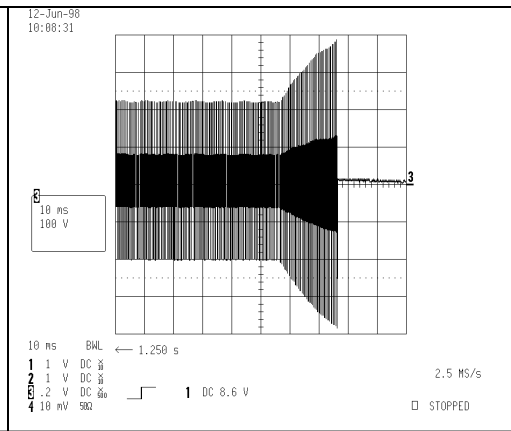


Figure 8: Failure of lamp to ignite condition (lamp filaments good): Lamp voltage during end of Preheat and Ignition Ramp modes

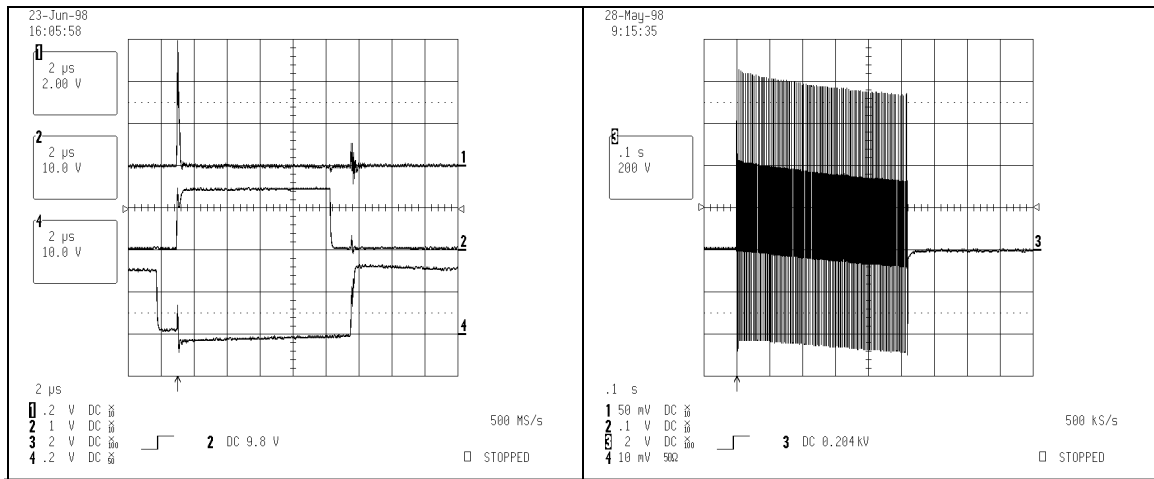


Figure 9: Hard-switching condition (upper filament open): Upper trace: voltage across RCS, Middle trace: LO pin voltage, Lower trace: HO-VS pin voltage

Figure 10: Hard-switching condition (upper filament open): Lamp voltage during Preheat mode and beginning of Ignition Ramp mode when lamp fault is detected

The components REOL1, REOL2, REOL3, REOL4, CEOL are used for end of life protection. The end-of-life window comparator is enabled at the beginning of the Run mode. In case of end-of-life the voltage on pin SD of the IR2166 will fall outside the range of the internal window comparator 1-3V causing it to go to Fault mode (fig. 11).

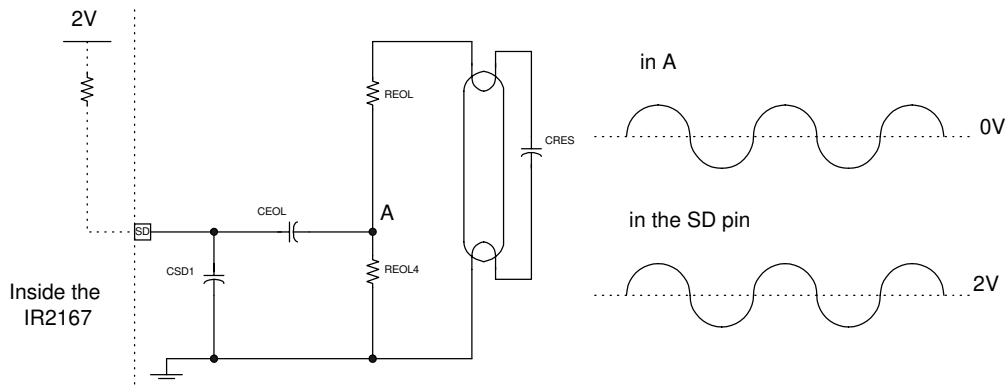


Figure 11: End-of-Life circuit

The value of REOL4 is changed so that the lamp voltage during normal running produces a signal with 1.5 Vppk at the point (A) where the capacitor CEOL connects it to the SD pin. For a T5/35W lamp 1.2Kohm at REOL4 provides the correct voltage.

The SD pin is internally biased at 2V with 1Mohm impedance and therefore at the SD pin a signal varying between 1.25V and 2.75V will normally be present due to the AC coupling of the 100nF capacitor (CEOL).

During end of life the lamp voltage may increase either symmetrically (AC end of life, due to a similar deterioration in both cathode) or asymmetrically (DC end of life, due to a deterioration only in one cathode). This circuit has the advantage of detecting both failure modes.

The peak to peak voltage at the SD pin will increase (with 2V DC offset) in either case until the positive peak exceeds 3V and/or the negative peak drops below 1V, therefore triggering the window comparator shutdown. The threshold of end of life can be adjusted by changing the value of REOL4 (usually 30% Vlamp is required).

Figure 12 shows the voltage in the SD pin and the voltage on the lamp in these 4 cases: no end of life, DC end of life (upper cathode deteriorated and lower cathode deteriorated) and AC end of life (both filaments deteriorated in the same way).

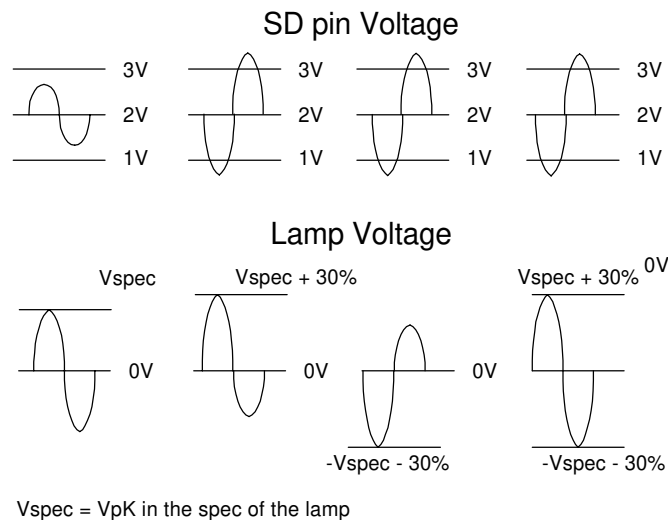
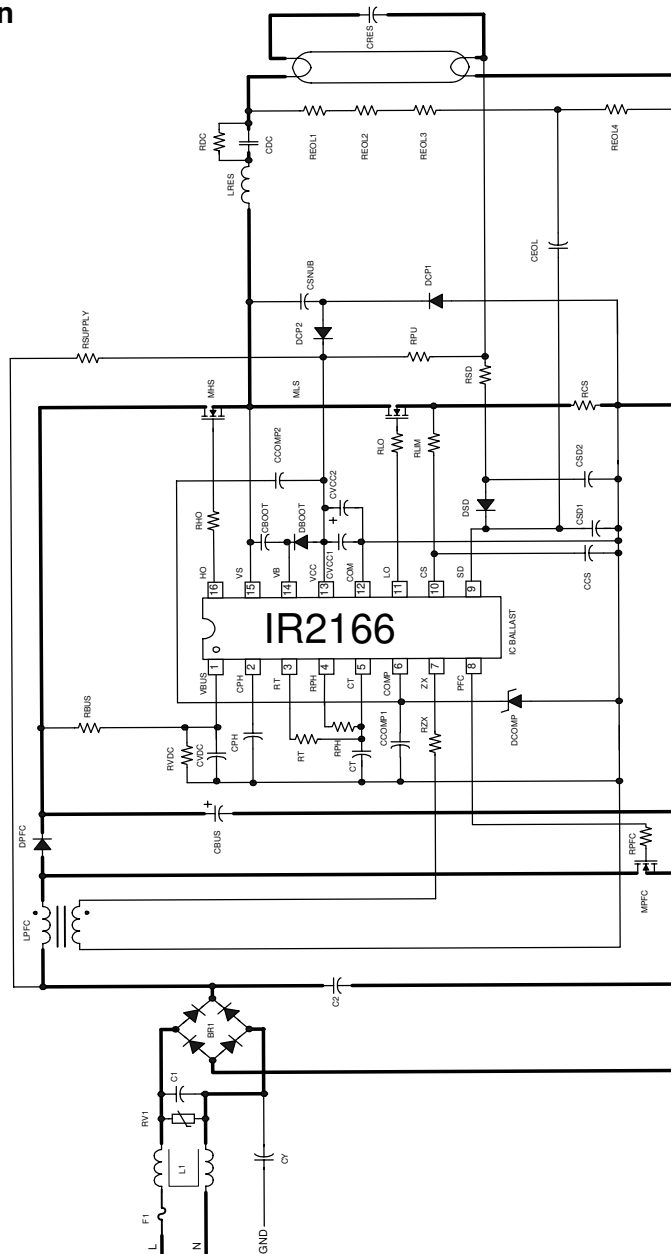


Figure 12: Voltage in the SD pin and voltage on the lamp in these 4 cases: no end of life, DC end of life and AC end of life.

Current mode configuration

The same PCB can be configured for current mode heating. It is needed to remove the Jumpers JV1 and JV2 and to introduce the Jumpers JC1 and JC2. It could be also usefull to add a resistor RDC in parallel to CDC because in this configuration after initial start-up you could have some striations (visible dark rings) on the lamps for a short period (a few minutes) particularly when the lamp has been off for some time and is cold. The value should be in the order of 100kOhm 0.5W.

We suggest the use of the Ballast Designer software to determine the values of the components to use in this configuration.



Note: Thick traces represent high-frequency, high-current paths. Lead lengths should be minimized to avoid high-frequency noise problems

Design Procedure to adapt the design to different lamp types

To adapt the design to different types of lamps you need to adjust the values of: LPFC, MPFC, MLO, MHO, CPH, RT, RPH, RCS, CT, REOL4, CRES and LRES. Do not change any others values!

- 1) Use the Ballast Designer Software to set the values of LRES, CRES, LPFC, MPFC, MLO and MHO, CT, and to set the starting values of CPH, RT, RPH, RCS and LPFC.

Cross both lamps (i.e. connect a filament or resistor to each lamp cathode position but not a good lamp) and measure the lamp voltage at ignition using a storage oscilloscope.

- 1) Set RCS to get the right maximum ignition voltage (decrease RCS to increase the ignition voltage) Cross both lamps (i.e. connect a filament or resistor to each lamp cathode position but not a good lamp) and measure the lamp voltage at ignition using a storage oscilloscope.

Connect both lamps correctly and measure the input power

- 2) Set RT to set the power on the lamp (increase RT to decrease the frequency and increase the power on the lamp)
- 3) Set RPH to set the right preheat frequency (increase RPH to decrease the preheat frequency and increase the preheat current)

In the case of voltage mode heating, increase CH1 and CH2 to increase the preheat voltage (use 6-7 turns in the secondary of LRES).

- 4) Select CPH to set the preheat time (increase CPH to increase the preheat time)
- 5) Verify the value of LPFC at each limit of the line/load range:

maximum input voltage: If the COMP pin becomes less than 400mV the PFC will not operate in a stable manner and it is necessary to increase LPFC.

minimum input voltage: If the PFC does not operate in a stable manner and audible noise can be heard from LPFC, it is necessary to decrease LPFC.

- 6) Set ROL4 to set the End of life protection to a percentage of the lamp voltage. For example, to set the protection threshold to 30% of the lamp voltage:

The value of REOL4 is chosen to have the SD pin varying between $2-0.7V$ and $2+0.7$ during normal operations and exceeding the window comparator limits (less than 1V or more than 3V) with 30% change in the voltage of the lamp.

(Fine tuning of this threshold can be done by trying different REOL4 values on the test bench)