International
IOR Rectifier

REFERENCE DESIGN

Reference Design 0601

IRPLCFL6revC: High Power CFL Ballast using the IR2166

by
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Topics Covered

1. Overview

In recent years the problem of energy saving is predominant in the lighting market (19% of the total power loss is related to lighting systems). High power Compact Fluorescent Lamps (CFL) represent a new and good solution to save energy. High Power CFLs are now available in higher wattages (60W - 120W) and they offer high lumen output, wide assortment of color temperature and end of life protection in both lamp and ballast. They offer 10 times the life and 4 times the efficiency of an incandescent lamp. They are widely used in shop lighting. They also compete with Metal Halide and High Intensity Discharge (HID) lamps in solutions requiring high lumens (outdoor and retail accent lighting applications). They overcome a lot of disadvantages such us long time needed to start, the time needed to cool down the lamp before re-striking, the high voltage required for striking and the difficult starting sequence.

2. Description

The IRPLCFL6 is a high efficiency, high power factor, fixed output electronic ballast designed for driving high power Compact Fluorescent Lamps (CFL). It drives a 105W CFL lamp from a wide input range, 100-250VAC. Different lamp types will require different component values. The design contains an EMI filter, input rectification, active power factor correction, a resonant output stage and a ballast control circuit using the IR2166.

This design offers long lamp life, due to the programmed start with lamp filament preheat, high power factor and low THD (the current harmonics meet GB17625.1-1998 C category standard). Comprehensive protection features such as protection from failure of a lamp to strike, filament failures, end-of-life protection, DC bus under-voltage reset as well as an automatic restart function, have been included in the design.

The circuit is built around the IR2166 Ballast Control IC. The IR2166 is a fully integrated, fully protected 600V ballast control IC designed to drive all types of fluorescent lamps. PFC circuitry operates in critical conduction mode and provides for high PF, low THD and DC Bus regulation. The IR2166 features include programmable preheat and run frequencies, programmable preheat time, programmable dead-time, programmable over-current protection and programmable end-of-life protection.

This demo board is intended to facilitate 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.

3. Features

- Drives 1 x 105W CFL Lamp (QiuTong JL1-3 105W 4U CFL Lamp)
- Wide Input Voltage range: 100-250Vac
- High Power Factor/Low THD
- High Frequency Operation
- Programmed start with Lamp Filament Preheating
- Lamp Fault Protection with Auto-Restart after lamp replacement
- Low AC Line Protection with Auto-Restart after brownout
- End of Lamp Life Detection and Shutdown
- **IR2166** HVIC Ballast Controller

4. Electrical Characteristics

Parameter	Units	Value
Lamp Type		105W 4U CFL lamp (QiuTong JL1-3)
Input Power	[W]	100W
Input Current Imax(rms)	[A]	1.1 @ 100VAC
Lamp running voltage	[Vpkpk]	469
Lamp running current	[Ipkpk]	1.84
Run Mode Frequency	[kHz]	42
Preheat Mode Frequency	[kHz]	58
Typical Preheat Time	[s]	1.4
Input AC Voltage Range	[VACrms]	100-250VAC
Power Factor		>0.99
Total Harmonic Distortion	[%]	<15%
Preheat Current	[Apkpk]	3.4
Preheat Ratio		2.1
Maximum Ignition Voltage	[Vpkpk]	1600
Preheat Lamp Voltage	[Vpkpk]	575
Maximum resonant inductor current	[Apkpk]	7

Vin (VAC)	Pin (W)	Iinrms (mA)	Vbus (V)	Frequency (KHz)	PF	THD
110	100	1000	400	41.75	0.998	8.5
150	100	758	400	41.75	0.997	11.5
180	100	620	400	41.75	0.996	12
220	100	505	400	41.75	0.995	13
245	100	452	400	41.75	0.994	14

5. Circuit Description

The IRPLCFL6 Demo Board consists of an EMI filter, input rectification, 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 powers. The ballast control section also provides the necessary circuitry to perform lamp fault detection, shutdown and auto-restart. The schematics for IRPLCFL6 is shown in figure 5.1 and the Bill Of Materials with the components values is shown in table 5.2.

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 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.

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 (High PF).

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.

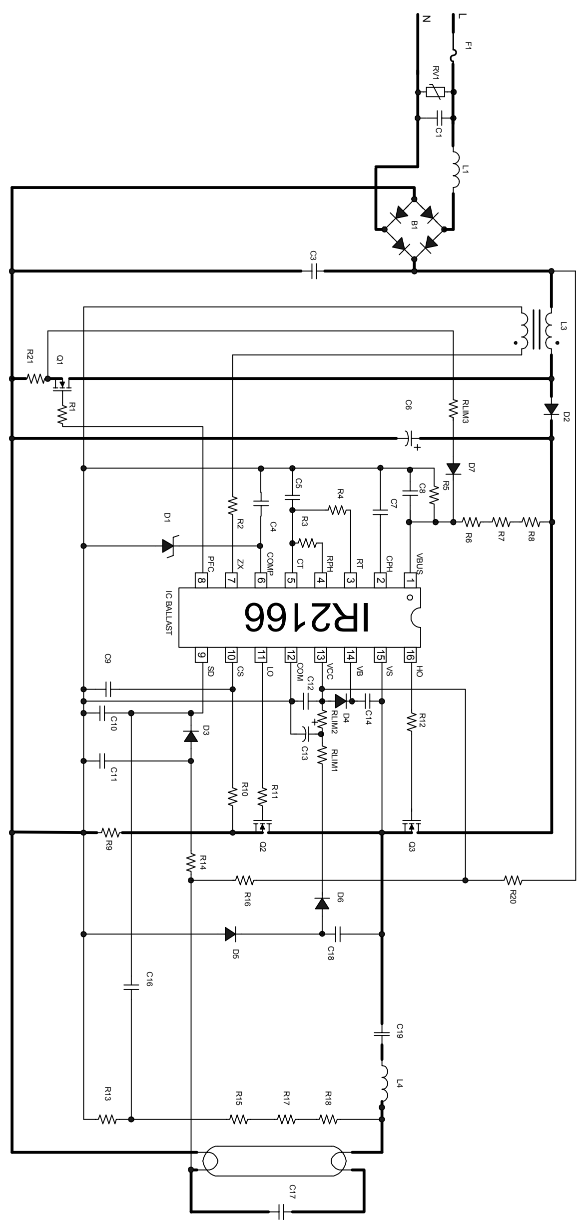

Figure 5.1 IRPLCFL6 Circuit Diagram

Item	Qty	Part rating	Designator	Footprint	Manufacturer	Part Number	Description
1	2	0.1uF/25V	C14, C12	1206	Panasonic	ECJ-3VB1E104K	Capacitor
2	1	0.1uF/400V	C19	Through Hole	WIMA	MKP10 Series	DC Blocking Capacitor
3	1	0.1uF/630VDC	C3	Through Hole	Digi-Key	EF6104-ND	Film Capacitor
4	1	0.33 Ohm/1W	R9	Axial	Fenghua	RJ24 Series	Current Sensing Resistor
5	1	0.15uF/275Vac, X2	C1	Through Hole	Digi-Key	BC1605-ND	EMI Capacitor
6	2	0.47uF	C16, C7	1206	Panasonic	ECJ-3YB1E474K	Capacitor
7	1	1.2KOhm	R13	1206	Panasonic	ERJ-8GEYJ122V	Resistor
8	1	1.15mH	L4	Through Hole	VOGT	0505272102	Resonant Inductor
9	1	Primary: 0.4mH Secondary: 10 turns	L3	Through Hole	VOGT	0505271102	Power Factor Inductor
10	2	1KOhm	R10, RLIM3	1206	Panasonic	ERJ-8GEYJ102V	Resistor
11	4	1N4148	D3, D5, D6, D7	1005	Digi-Key	LL4148DICT-ND	Diode
12	1	15nF/1600V	C17	Through Hole	Digi-key	P10509-ND	Resonant Capacitor
13	1	6.8uF/25V/105C	C13	Electrolytic	Digi-Key	P915-ND	VCC Capacitor
14	1	2A/250V	F1	Through Hole	Digi-Key	WK4957BK-ND	Fuse
15	1	1000V, 2A	B1	d-37	HY	2KBB08	Diode Bridge
16	1	12.1Kohm 1%	R5	1206	Panasonic	ERJ-8ENF1212V	Resistor
17	1	12V	D1	1005	Digi-Key	MA8120CT-ND	Zener Diode
18	1	22KOhm	R2	1206	Panasonic	ERJ-8GEYJ223V	Resistor
19	1	22 Ohm	R11	1206	Panasonic	ERJ-8GEYJ220V	Resistor
20	1	24.9Kohm, 1%	R4	1206	Panasonic	ERJ-8ENF2492V	Resistor
21	1	61.9Kohm, 1%	R3	1206	Panasonic	ERJ-8ENF6192V	Resistor
22	1	47uF/450V/105C	C6	Electrolytic	Jianghai	WAX-450V-47uF	DC Bus Capacitor
23	1	100KOhm	R14	1206	Panasonic	ERJ-8GEYJ104V	Resistor
24	1	0.01uF	C11	1206	Panasonic	ECU-V1H103KBM	Capacitor
25	2	1nF	C8,C10	1206	Panasonic	ECU-V1H102JCH	Capacitor
26	4	220KOhm	R15, R17, R18, R16	1206	Panasonic	ERJ-8GEYJ224V	Resistor
27	1	270uH, 2A	L1	Through Hole	Digi-Key	M6237-ND	EMI Inductor
28	3	390KOhm	R6, R7, R8	1206	Panasonic	ERJ-8GEYJ394V	Resistor
29	1	300KOhm/0.5W	R20	Axial	Digi-Key	P300KBBCT-ND	Resistor
30	1	470pF	C9	1206	Panasonic	ECU-V1H471KBM	Capacitor
31	1	0.68uF	C4	1206	Panasonic	ECY-3YB1E684K	Capacitor
32	1	820pF/25V	C5	1206	Panasonic	ECU-V1H821KBM	CT Capacitor
33	1	1nF/1KV	C18	1812	Digi-Key	399-3445-1-ND	Snubber Capacitor
34	2	600V 2A Fast	D2, D4	SMB	On Semi	MURS260T3	PFC and Bootstrap Diode
35	1	1 Ohm/ 1W	R21	Axial	Fenghua	RJ24 Series	Current Sensing Resistor
36	2	10 Ohm	RLIM1, RLIM2	1206	Panasonic	ERJ-8GEYJ100V	Resistor
37	2	0 Ohm	Ro1, Ro2	1206	Panasonic	ERJ-8GEY0R00V	Jumper Resistor
38	1	IR2166	U1	SO16	IR	IR2166S	IR Ballast IC
39	1		J1	Through Hole			Jumper
40	3	IRF840	Q1, Q2, Q3	TO-220	IR	IRF840	IR MOSFET
41	3		HS1,HS2,HS3		Heat sink plant in Wuxi	Custom	Heat Sink
42	1	RJ	RV1	Through Hole	Panasonic	ERZ-V07D471	Transient Suppressor
43	2	22 Ohm/ 1/4W	R1, R12	Axial	Digi-Key		Resistor

Table 5.2 Bill of Materials

Note1 :

Some components in the pcb may be different from the BOM because of tuning of the pcb during testing to improve performance. This may include:

1) Adjust R3 and R4 to obtain 38K<frun<42K and 50K<fph<54K.
2) Adjust R5 to obtain a bus voltage equal to 420V (R5 can change between 11K and 12.1K)
3) Decrease C4 to 0.56uF to increase the preheat time
4) Decrease R9 to 0.3 ohm 1/2W to increase the maximum ignition voltage
5) Decrease C7 to 0.56uF to speed-up the compensation loop of the power factor correction
6) We used in some pcb a bigger value of C8 (10nF) because a bigger value of C8 can protect the IC from noise in case of fast transition of the AC line at start-up. We suggest using 10 nF.

Note2 :

In this design we used for L3 VOGT PN. 0505271102 and for L4 VOGT PN. 0505272102, however these inductors do not comply with the layout of the IRPLCFL6 pcb and we had to rework these inductors to fit the IRPLCFL6 layout. These inductors are designed to work at 10 KHz, however the working frequency of both inductors is above 40KHz.

The inductors specs to comply with the IRPLCFL6 layout are showed in pg. 6 and 7.

A bigger value of L3 (between 0.42mH and 0.48mH) will benefit the design (PFC behavior at high VAC line) and the inductors should be designed for an operating frequency around 40KHz.

Inductors' Specs

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INDUCTOR SPECIFICATION

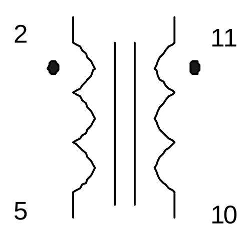
TYPE : PFC Choke 0.43mH – EE30

Reference: L3

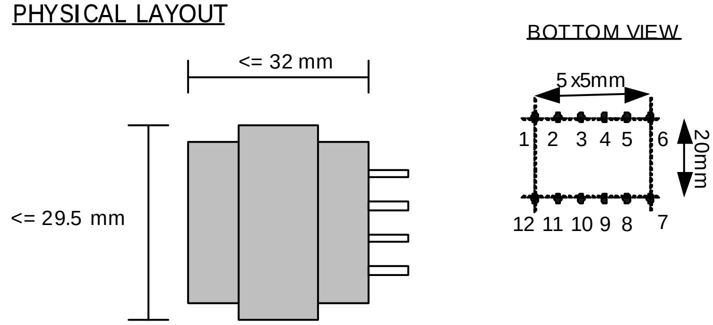
CORE SIZE	EE 30	GAP LENGTH	1	mm
BOBBIN	HORIZONTAL	PINS	12	
CORE MATERIAL	Philips 3C85, Siemens N27 or equivalent			
NOMINAL INDUCTANCE	0.43mH	mH		
MAXIMUM CURRENT	2	Apk		
MAXIMUM CORE TEMPERATURE	100	°C		

WINDING	START PIN	FINISH PIN	TURNS	WIRE DIAMETER (mm)
MAIN	2	5	50	30x0.1 CuLL or 12 strands of AWG 32
ZX	11	10	10	0.25 CuLL

ELECTRICAL LAYOUT



PHYSICAL LAYOUT



TEST (TEST FREQUENCY = 50kHz)

MAIN WINDING INDUCTANCE TOLERANCES +/- 5%

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

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INDUCTOR SPECIFICATION

TYPE : Resonant Inductor 1.15 mH EE30

Reference: L4

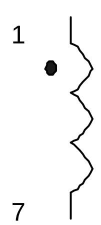
CORE SIZE	EE 30	GAP LENGTH	1	mm
BOBBIN	HORIZONTAL	PINS	14	

CORE MATERIAL: Philips 3C85, Siemens N27 or equivalent

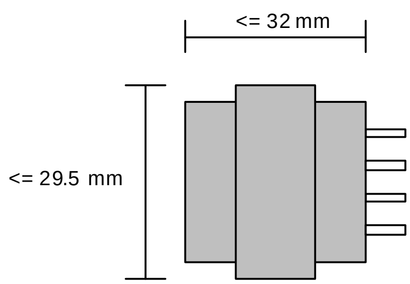
NOMINAL INDUCTANCE	1.15mH	mH
MAXIMUM CURRENT	2	Apk
MAXIMUM CORE TEMPERATURE	100	ºC

WINDING	START PIN	FINISH PIN	TURNS	WIRE DIAMETER (mm)
MAIN	1	7	79.5	12 strands of AWG 32 or 20x0.1 CuLL

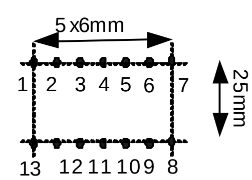
ELECTRICAL LAYOUT



PHYSICAL LAYOUT



BOTTOM VIEW



TEST (TEST FREQUENCY = 50kHz)

MAIN WINDING INDUCTANCE TOLERANCES +/- 5%

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

6. Functional Description

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 R20. During this initial startup when the VCC voltage of the IR2166 is below its rising Under-Voltage Lock-Out (UVLO) threshold, the IR2166 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 (R20). 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 (Q2 ands Q3). When the half-bridge is oscillating, capacitor C18, diodes D5 and D6 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 C13 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 the power factor MOSFET Q1 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 output 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.

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. The resistor between C5 and VCC programs a current which determines the ramp up time of capacitor C5. The downward ramping time of C5 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 R4 and R5. 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 current during the Preheat mode. 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 C7. The ballast remains in the Preheat mode until the voltage on the CPH pin exceeds the Ignition Ramp mode threshold (VCC-4V, about 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 R3 is no longer connected directly in parallel with resistor R4 so the run frequency is determined only with R4. 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 R9, but in any case the ignition frequency must be higher than the run frequency.
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 (VCC-2V, about13V).

Run Mode

During the Run mode the frequency is shifted to the run frequency. The run frequency is determined only by R4. 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 (L4)	(H)
C	=	Lamp resonant circuit capacitor (C17)	(F)
P_{Lamp}	=	Lamp running power	(W)
V_{Lamp}	=	Lamp running voltage amplitude	(V)

Figure 6.1 shows a plot of the half-bridge oscillation frequency as a function of time for all of the normal modes of operation: Startup, Preheat mode, Ignition Ramp mode and Run mode.

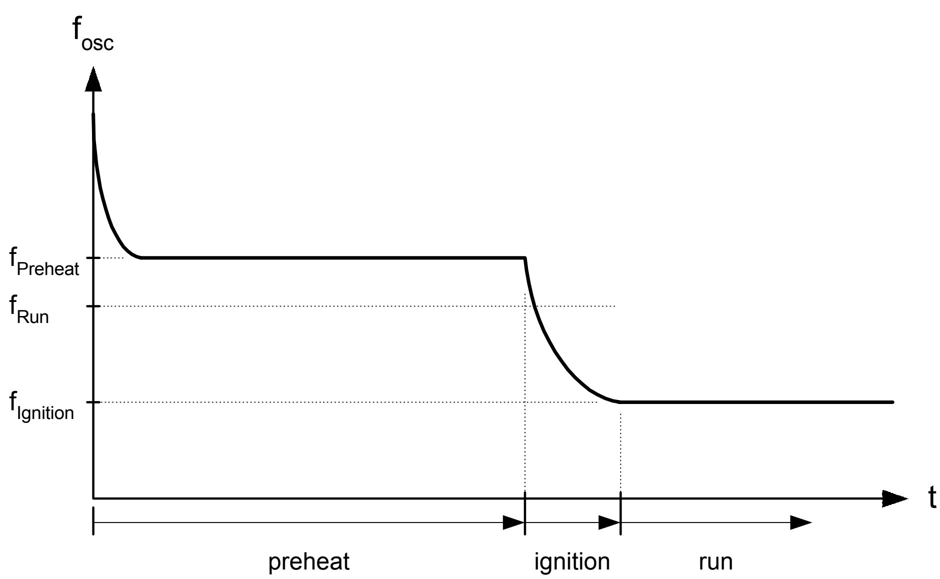


Fig. 6.1: Oscillator frequency versus time, Normal operating conditions

Figure 6.2 shows the voltage across the lamp and the current in the resonant inductor during Startup, Preheat, Ignition and Run mode.

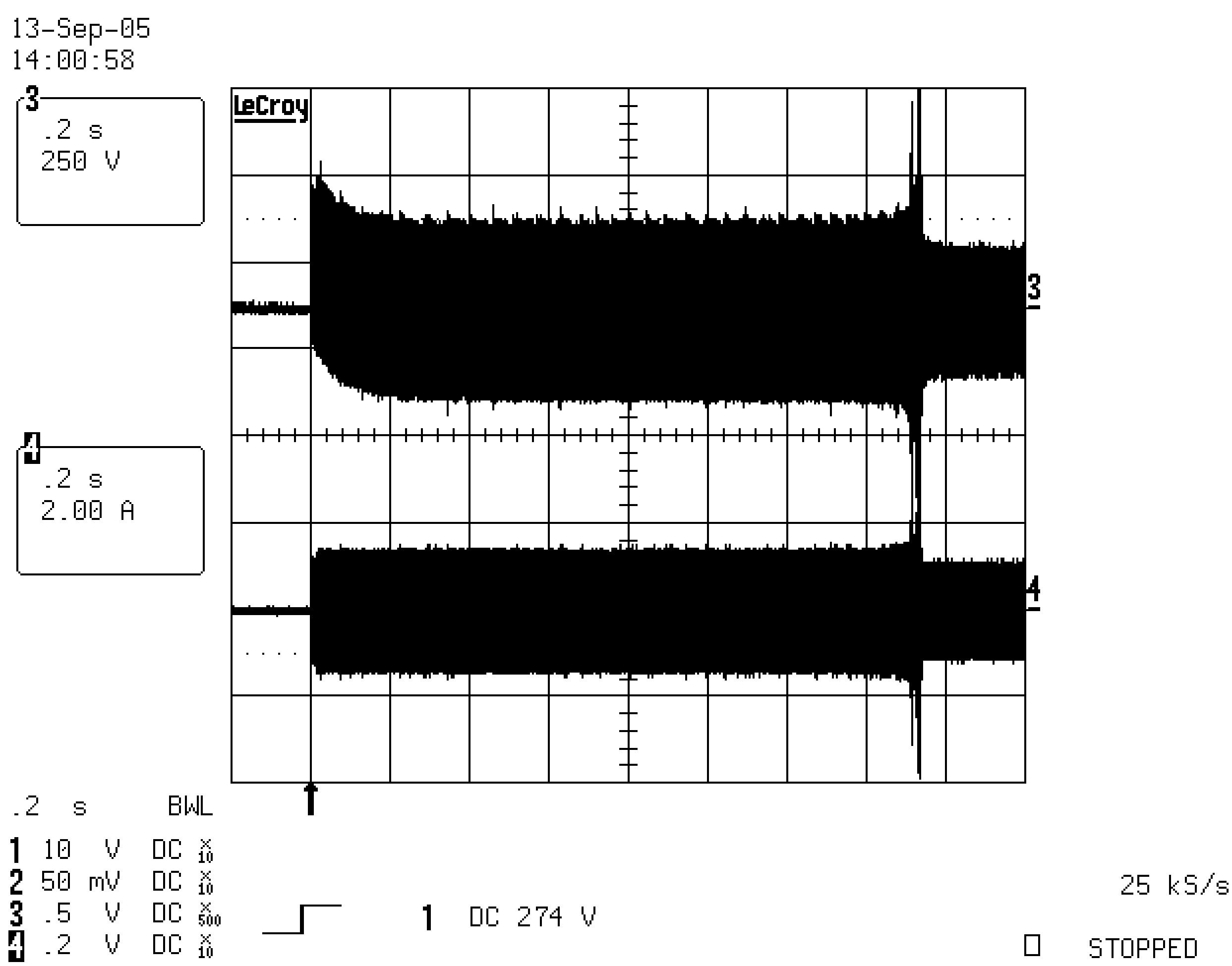


Fig. 6.2: Voltage across the lamp (CH3) and current in the resonant inductor (CH4) during Startup, Preheat, Ignition and Run mode.

Figure 6.3 shows the current and the voltage across the lamp filaments at startup.

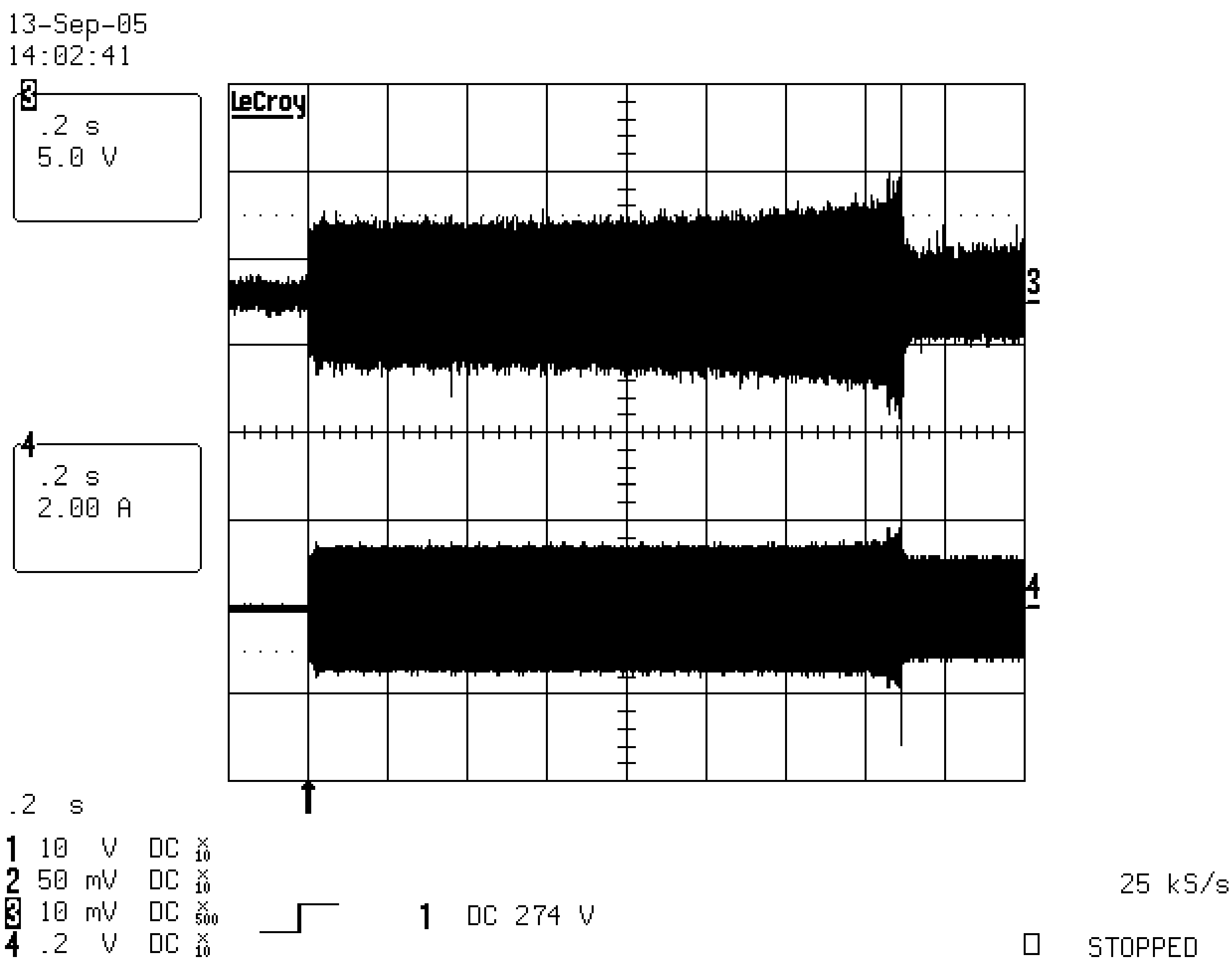


Fig. 6.3: Current (CH4) and voltage (CH3) across the lamp filaments at startup

Figure 6.4 shows the lamp voltage, the lamp current and the Half Bridge VS voltage during normal operation (Run Mode).

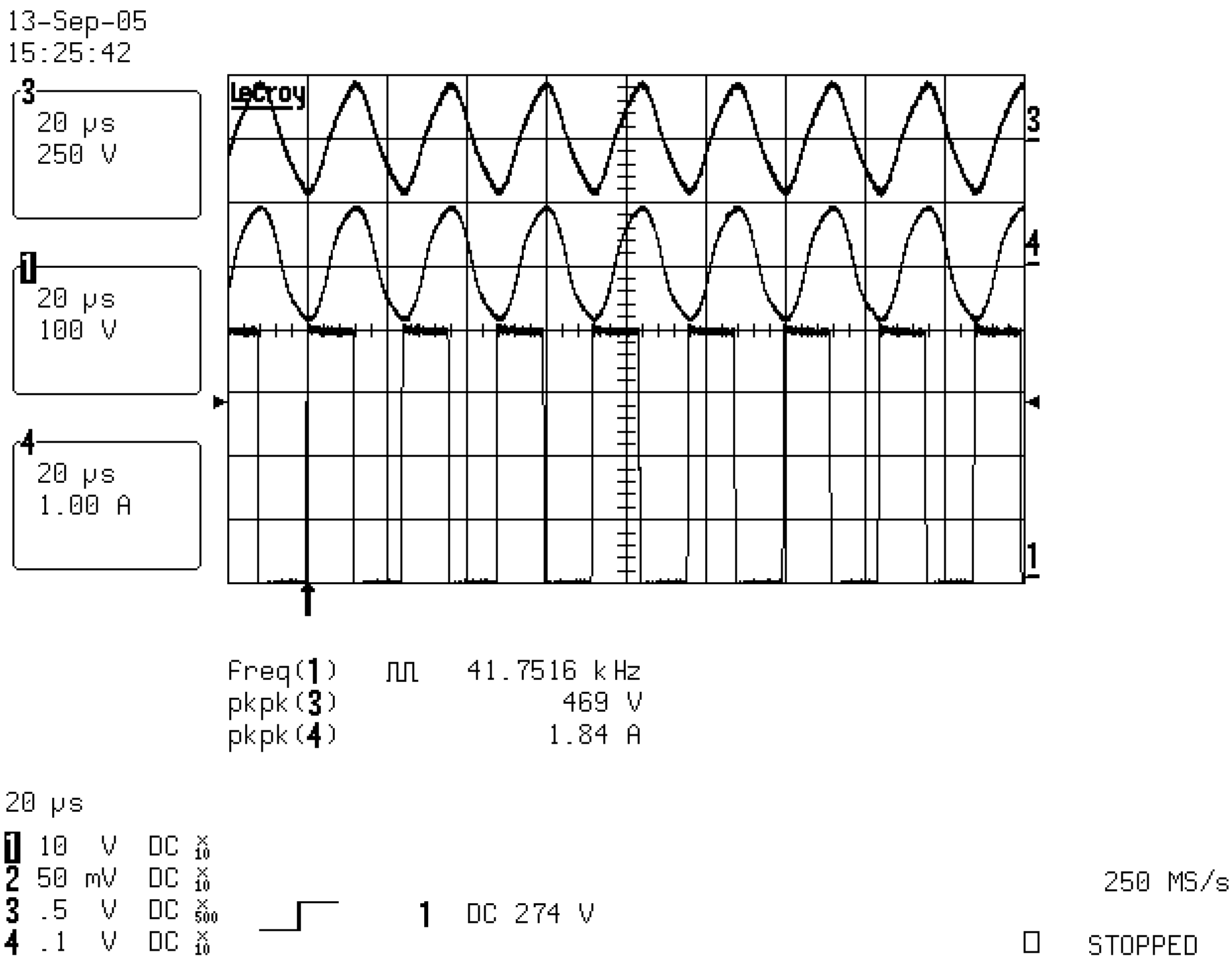


Fig. 6.4 Lamp voltage (CH3), lamp current (CH4) and Half Bridge VS voltage (CH1) during normal operation

7. Fault Mode

Fault Protection Characteristics

Fault	Ballast	Restart Operation
Low AC Input/ Power down	Deactivates	Automatic as normal
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
Over-voltage	Bus voltage non-boosted	Automatic as normal
PFC Over-current	Bus voltage non-boosted	Automatic as normal

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 D1 and of the supply resistor R20 are chosen to discharge VCC below the power down threshold (9.5V) when the AC line falls below a minimum value (that can be set with the value of D1 and R5, R6, R7 and R8) 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. The ballast will restart automatically after a brownout condition as soon as the line voltage increases and the VCC pin will exceed 11.5V. Note that the VBUS pin of the IR2166 is active during all modes of operation.

Lamp Removal and Auto-restart

Resistors R16, R14 and capacitor C11 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 C11 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 5V 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.

PFC Over-Current Protection

In case of fast on/off interruption of the main input voltage or during normal lamp ignition, the DC bus voltage level can decrease below the instantaneous rectified line voltage. Should this occur, the PFC inductor current and PFC MOSFET current can increase to high levels causing the PFC inductor to saturate and/or the PFC MOSFET to become damaged. To protect against these conditions, a current sense resistor (R21) has been inserted between the source on the PFC MOSFET and ground, and a diode (D7) connected from the top of this current-sensing resistor to the VBUS

pin of the IR2166. Should high current occur, the voltage across the current-sensing resistor R21 will exceed the 4.3V over-voltage protection threshold at the VBUS pin and the PFC MOSFET will turn off safely limiting the current. The watchdog timer will restart the PFC automatically as normal. In this design, a current sensing resistor value of 1 Ohm (R21) set the over-current protection threshold to about 5Apk.
Note that the VBUS pin over-voltage of the IR2166 is active during all modes of operation.

Over-Voltage Protection

In case of Over-voltage (due to too high AC line input or to faults), the voltage on the VBUS pin of the will exceed the 4.3V over-voltage protection threshold at the VBUS pin and the PFC MOSFET will turn off. The bus voltage will drop to the non-boosted/unregulated level, equal to the rectified AC line. The watchdog timer will restart the PFC automatically as normal.
Note that the VBUS pin over-voltage of the IR2166 is active during all modes of operation.

Lamp Fault

The ballast driver is shutdown due to the detection of a lamp fault. This is called Fault Mode. 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: open lamp filaments, failure to strike, hard-switching detection and over-current detection (CS pin) and end of life detection (SD pin). The ballast will remain in Fault mode until either the line voltage is reset or a lamp replacement is performed.

Open filaments or Failure to strike

This protection relies on the over-current and hard-switching protection on the CS pin, enabled during Preheat Mode, Ignition Ramp Mode and Run Mode. Resistor R9 in the source lead of the low side MOSFET (Q2) 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 R9 whenever the low side MOSFET, Q2, is turned on or the high side MOSFET, Q3, is turned off. The magnitude of this voltage directly relates to the current in the lamp resonant circuit. If at any time the voltage magnitude across resistor R9 rises above the over-current threshold (1.3V), a lamp fault condition is signaled and the half-bridge output MOSFETs', (Q2 and Q3) are turned off and the ballast goes into Fault mode. A lamp fault condition is signaled only after 25 cycles to avoid triggering this protection in the case of a current transient that can happen during normal ignition.

If the lamp fails to ignite because the lamp is broken and does not arc, an over-current condition will occur while the frequency will approach the resonant frequency of the resonant output stage and the voltage across resistor R9 will exceed 1.3V. The ballast detects a failure to ignite the lamp and goes into Fault mode.

If a cathode is broken (open circuit) the half-bridge output hard-switches and each time the low side MOSFET (Q2) is turned on a large current pulse occurs and thus a large voltage pulse occurs across resistor R9, signaling a fault.

End of Lamp Life

This protection relies on the 1-3V window comparator on the SD pin, enabled at the beginning of the Run mode. The components R13, R15, R17, R18, C16, C10 are used for end of life protection. 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 into Fault mode. The value of R13 is changed so that the lamp voltage during normal running produces a sinusoidal signal with 1.5 Vppk at the point between R13 and R15, were the capacitor C16 connects it to the SD pin. 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 1nF capacitor (C10).

During end of life the lamp voltage may increase either symmetrically (AC end of life, due to a similar deterioration in both cathodes) or asymmetrically (DC end of life, due to a deterioration only in one cathode). 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 R13 (usually 30% Vlamp is required).

Figure 7.1 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).

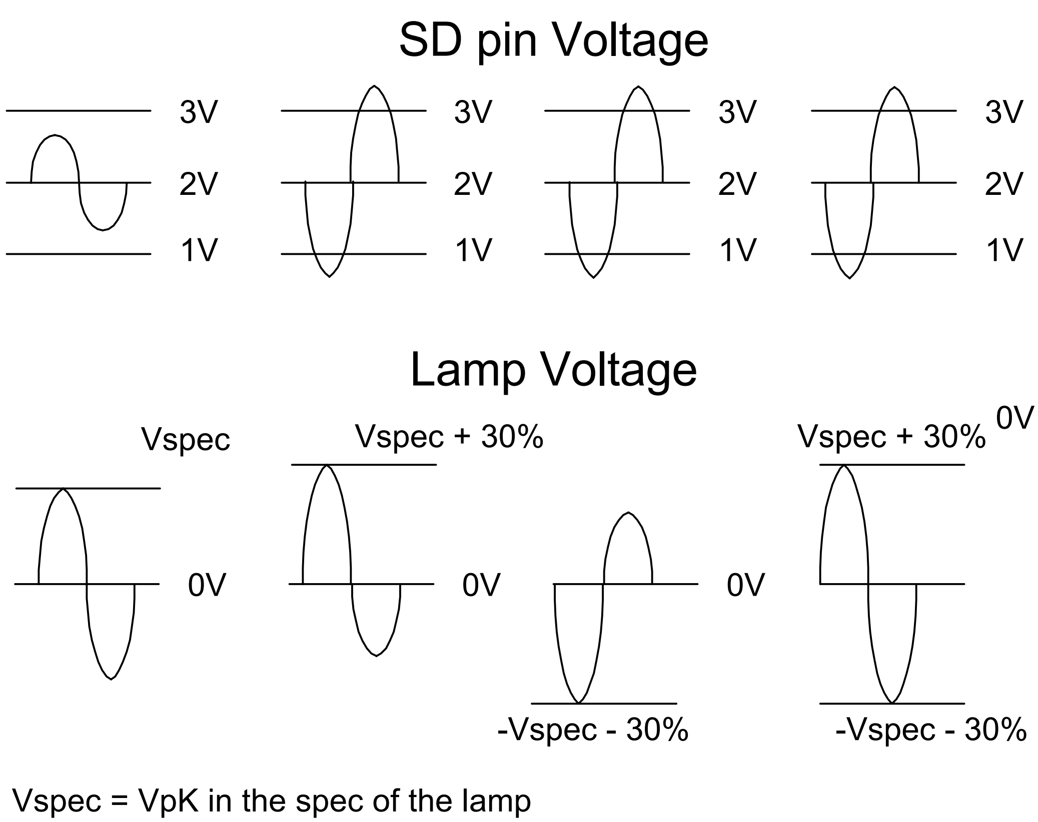


Figure 7.1: Voltage in the SD pin and voltage on the lamp in these 4 cases: no end of life, DC end of life and AC end of life.

8. Design Evaluation

During the design, a lamp broken condition is simulated (using resistors instead of the lamp filaments) to set the correct maximum ignition voltage of the ballast and the right preheat on the lamp filaments.

The maximum lamp voltage in this condition needs to be adjusted equal to the ignition voltage that is needed to turn on the lamp in the worst condition (lamp cold). Figure 8.1 shows the voltage appearing across the lamp and the current in the resonant inductor when the ballast detects a failure to ignite the lamp and goes into Fault mode. An important parameter is also the voltage across the lamp during preheat. It needs to be lower than the minimum ignition voltage of the lamp to avoid ignition during preheat. In this case the maximum ignition voltage is 1600 Vpkpk and the lamp voltage during preheat is 575 Vpkpk.

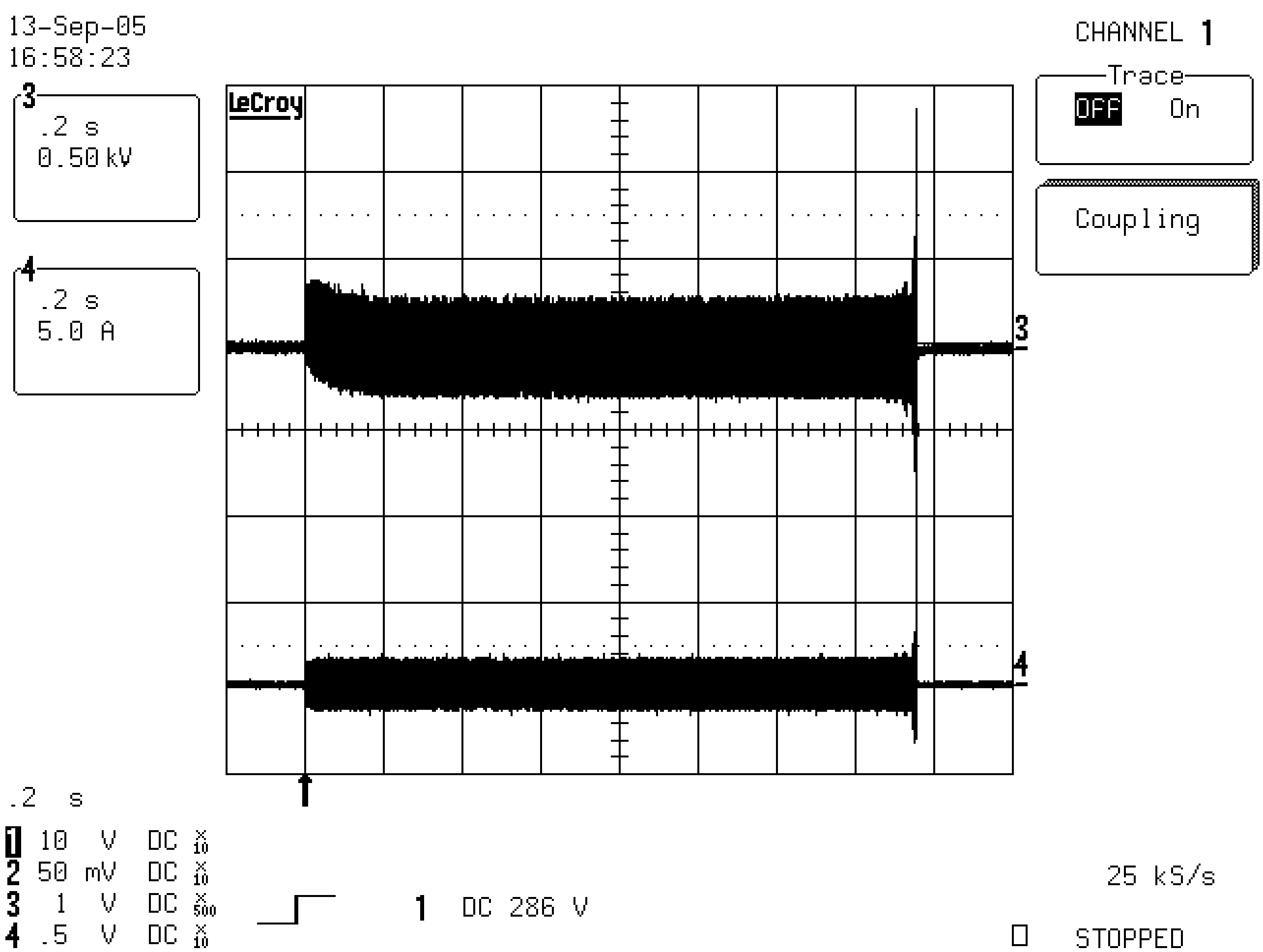


Fig. 8.1: Voltage across the lamp (CH 3) and current in the resonant inductor (CH4) when the ballast detects a failure to ignite the lamp and goes into Fault mode.

The right preheat can be programmed measuring the ratio between the lamp filament resistance at the beginning and end of preheat (it should be between 2 and 6, depending on the lamp type and on the number of starts required). Figure 8.2 shows the current through the lamp filaments and the voltage across the lamp filaments during preheat. In this case the preheat ratio is 2.1 and the preheat current is 3.4Apkpk. An important parameter is also the maximum current across the resonant inductor. It is the current across the resonant inductor before shutdown. In this case it is 7Apkpk.

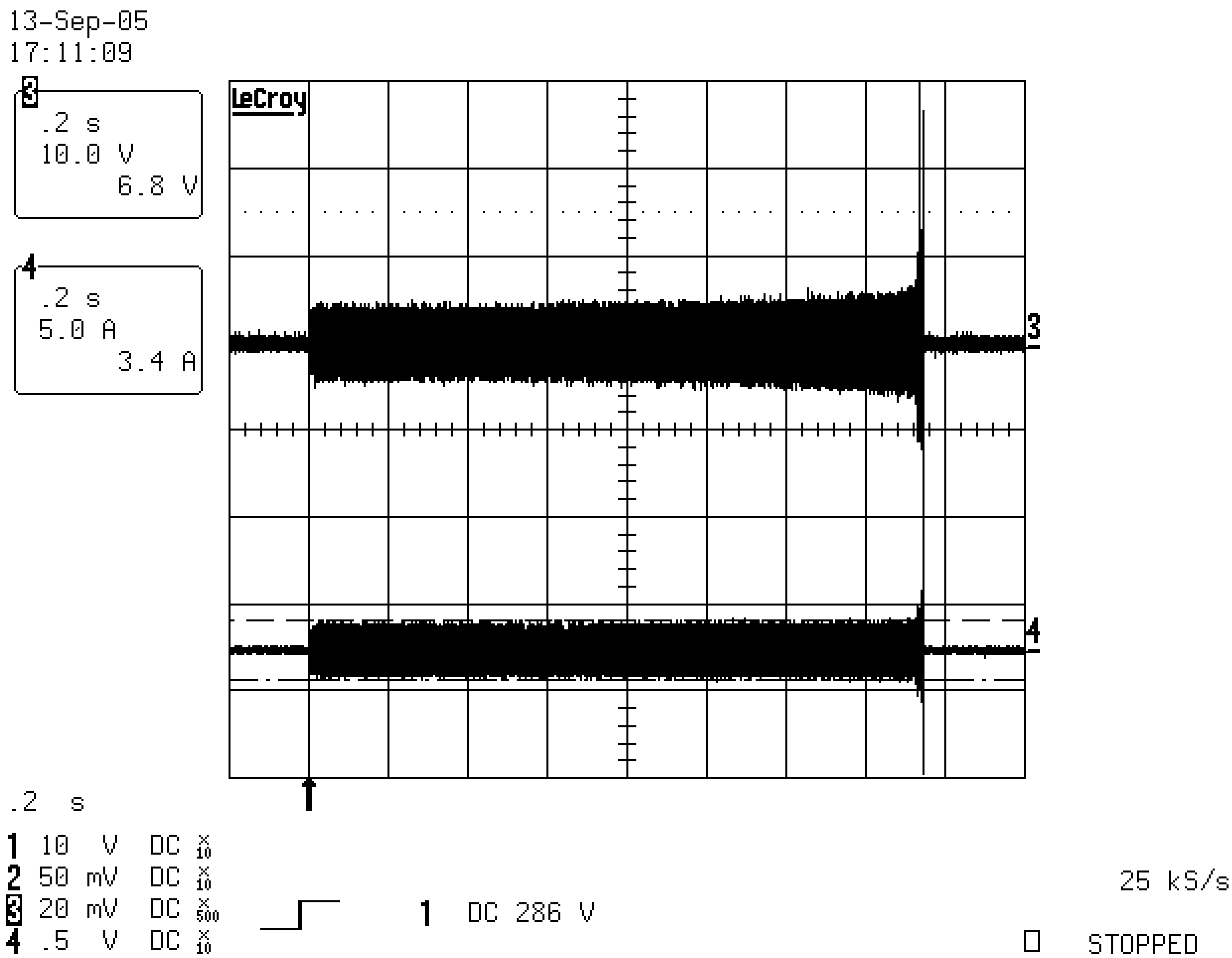


Fig. 8.2: Current (CH4) and voltage (CH3) across the lamp filaments during preheat.

In this design we give up some performance to save PCB space and component costs. Further improvements of the design (adding costs) could be:

1) Use a resonant inductor able to handle 7Apkpk. In our design we have partial saturation of the resonant inductor during ignition in the worst case (peak in the current and voltage in Fig. 8.1). This will require a bigger core and therefore a more expensive inductor.
2) Improve the preheat ratio to increase the lamp life. This cannot be done simply by decreasing the preheat frequency (because the lamp voltage during preheat cannot be further increased to avoid ignition during preheat) or increasing the value of the capacitor at the CPH pin (because the preheat time is already 1.4 seconds) but it requires increasing the resonant capacitor and decreasing the resonant inductor to maintain the operating frequency around 42KHz.
3) Change the value of the resonant inductor and capacitor (bigger capacitor and smaller inductor) so that the lamp power does not change excessively for small change of the run frequency. This will avoid problems with tolerances in production.
4) If possible, decrease the typical preheat time to 1 second, while maintaining a preheat ratio higher than 2.
5) Increase the lamp power. This cannot be done simply by decreasing the run frequency (because the ballast frequency should be at least 42KHz to avoid interference) but it requires increasing the resonant capacitor and decreasing the resonant inductor to maintain the operating frequency around 42KHz.

The latter 4 points will require a resonant capacitor with higher value (bigger, more expensive and causing more losses) and a resonant inductor with smaller value (handling less current when using the same core).

9. Thermal Issues

High power density ballasts present a lot of thermal issues. The following are some suggestions to handle these issues:

1) Use wide traces for the high current paths (in bold in the schematic in Fig. 5.1) to obtain a better thermal dispersion by copper PCB trace.
The flow of current through a trace will cause the temperature of the trace to increase. The temperature increment will depend on the square of the current and on the resistance of the trace that is a non-linear function of its cross-sectional area. While the current is heating the copper, it is cooling through the combined effects or radiation, convection and conduction through its surface.

2) Use surface mount components to obtain a better thermal dispersion of the components
The surface mount components are very close to the surface of the PCB and this facilitate the dispersion of the thermal on the component.

3) Study carefully the component structure and the ballast housing to obtain a better thermal dispersion by mechanical structure.
The structure of the system and the housing structure of the ballast are very important to reduce the temperature by convection. The ballast needs to include an air-flow and the housing needs to include some holes to facilitate the convection between the hot air inside the housing and the cool air outside, cooling the ballast system. For high power CFL, the ballast is integrated with the lamp and the radiation due to the lamp is a big thermal source. Choosing the material between lamp and ballast that has resistance effect and isolating the lamp and the ballast by air may reduce the heating due to the lamp.

4) Reduce the thermal dissipation of the components by reducing the power losses of the system.
The IR2166 guarantees zero voltage switching, so the power losses of the MOSFETs are very low, and the quiescent current of the IR2166 is about 150uA, so the power loss in startup stage (in the supply resistor) are generally very low.

Temperature measurements for the IRPLCFL6 demoboard

Test Conditions:
worst-case input voltage = 100VAC - highest current through MOSFET-PFC
open air (Tc=25°C)
temperatures are measured after one hour running with lamp turned on

MOSFETS
$T_{MOSFET\text{-}PFC}$=55°C
$T_{MOSFET\text{-}HB\text{-}H}$=51°C
$T_{MOSFET\text{-}HB\text{-}L}$=50°C

PFC inductor
T_{LPFC}=42°C

Resonant inductor
T_{LRES}=58°C

10. Layout

The Layout of the reference design IRPLCFL6 is shown in figure 10.1.

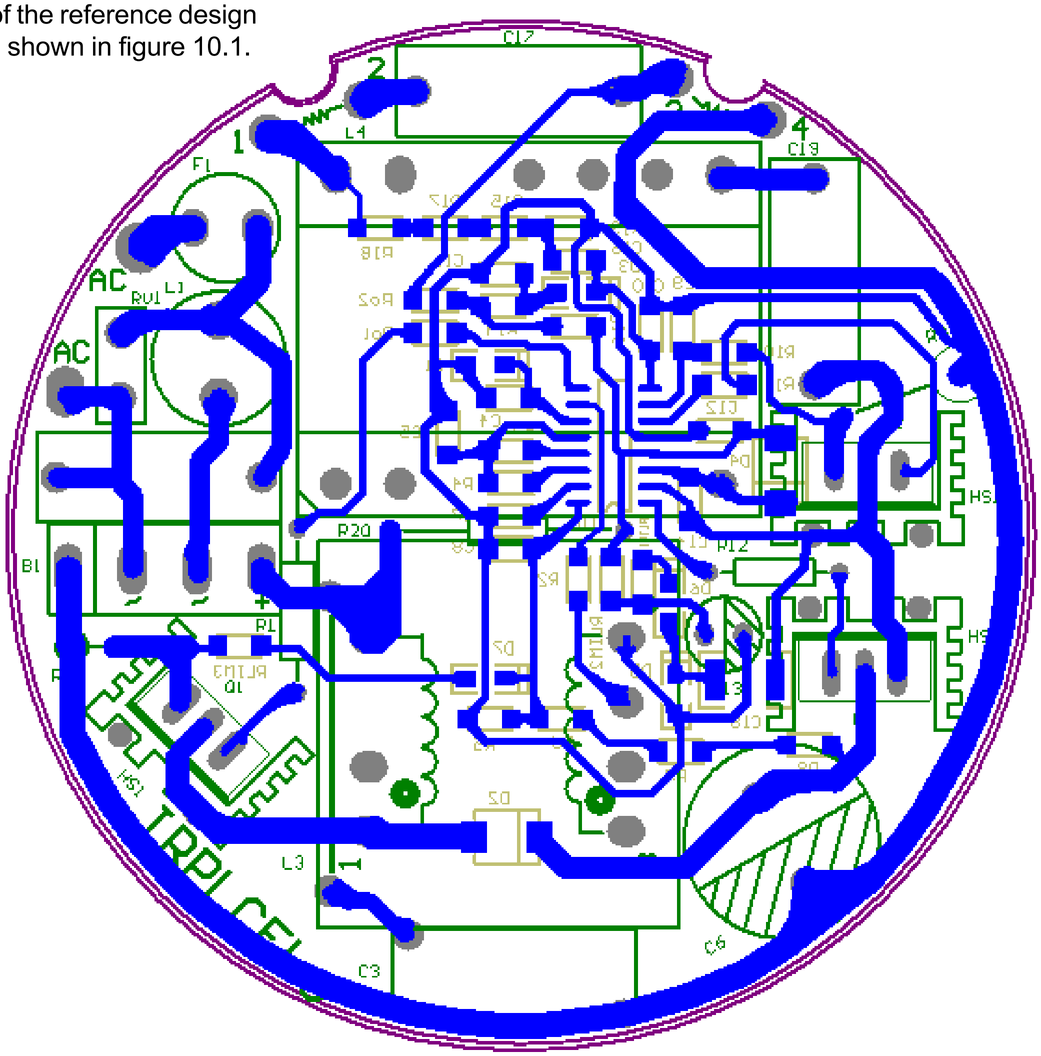


Fig. 10.1: IRPLCFL6 Layout

The PCB Layout is very critical for High Power CFL. A good layout will benefit the system performance such as EMI, reducing the radiation interference, will avoid fake triggering of the protections (especially at the SD and CS pin) due to noise, and will reduce the temperatures by helping the heating dissipation.

When laying out the PCB for this type of ballast it is important to allow the high current carrying traces (in bold in the schematic in Figure 5.1) to be as wide and as short as possible. The control IC COM should be a start point connected to the COM end of R9. The IC COM should be connected directly to this point via a very short track. The negative side of C6 should also be connected as close to this point as possible. The C12 decoupling capacitor should be connected directly between VCC and COM and R5, C8, C7, R4, R3, C5, C4, D1, C12, C13, C9, C10, C11, R13 should all be connected back to the start point. Tracks around the IC should be kept short as far as possible except the gate drives and VS and VB, which can be a little longer, if necessary. It is also important to keep traces that are carrying high switching currents away from sensitive components around the IC as much as possible.

11. 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: L3, Q1, Q2, Q3, C7, R3, R4, R9, C5, R13, L4 and C17. Do not change any others values!

1) Use the Ballast Designer Software to set the values of L4, C17, Q1, Q2, Q3 and C5, and to set the starting values of C7, R3, R4, R9, L3 and R13.

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.

2) Set R9 to get the right maximum ignition voltage (decrease R9 to increase the ignition voltage)
   Connect both lamps correctly and measure the input power
3) Set R4 to set the power on the lamp (increase R4 to decrease the frequency and increase the power on the lamp)
4) Set R3 to set the right preheat frequency (increase R3 to decrease the preheat frequency and increase the preheat current)
5) Select C7 to set the preheat time (increase C7 to increase the preheat time)

6) Verify the value of L3 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 L3.

   minimum input voltage: If the PFC does not operate in a stable manner and audible noise can be heard from L3, it is necessary to decrease L3.

7) Set R13 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 R13 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 R13 values on the test bench)

It could be also useful to add a resistor RDC in parallel to C19 because 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 in the order of 100kOhm 0.5W.

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