Application Note AN-1065

Procedures to Design 120VAC CFL Solutions with the IR2520D

By Cecilia Contenti

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This application note (AN) is intended for helping the design of CFL ballasts, 120VAC input using the IR2520D Ballast Control HVIC. The information enclosed will help in adapting the reference design IRPLCFL5U to different lamp types. Please refer to the IRPLCFL5U reference design and to the IR2520D datasheet for additional information on the design, including electrical parameters, state diagram and complete functional description.

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Topics Covered

Overview
Typical Circuit for 120VAC CFL applications
CFL Ballast Design Requirements & Constraints
Evaluation Reference Design IRPLCFL5U
Design procedur to adapt the IRPLCFL5U design to a different lamp
Adapt the design IRPLCFL5U to 18W Lamps
Adapt the design IRPLCFL5U to 32W Lamps
Adapt the design IRPLCFL5U to 42W Lamps



1. Overview

This application note (AN) is intended for helping the design of CFL ballasts, 120VAC input, using the IR2520D Ballast Control HVIC. The information enclosed will help in adapting the reference design IRPLCFL5U to different lamp types.

Please refer to the IRPLCFL5U reference design and to the IR2520D datasheet for additional information on the design, including electrical parameters, state diagram and complete functional description.

2. Typical Circuit for 120VAC CFL applications

The circuit used for driving a CFL lamp from a 120VAC line is always the same, independently on the lamp power. The circuit we suggest is shown in Fig. 2.1.

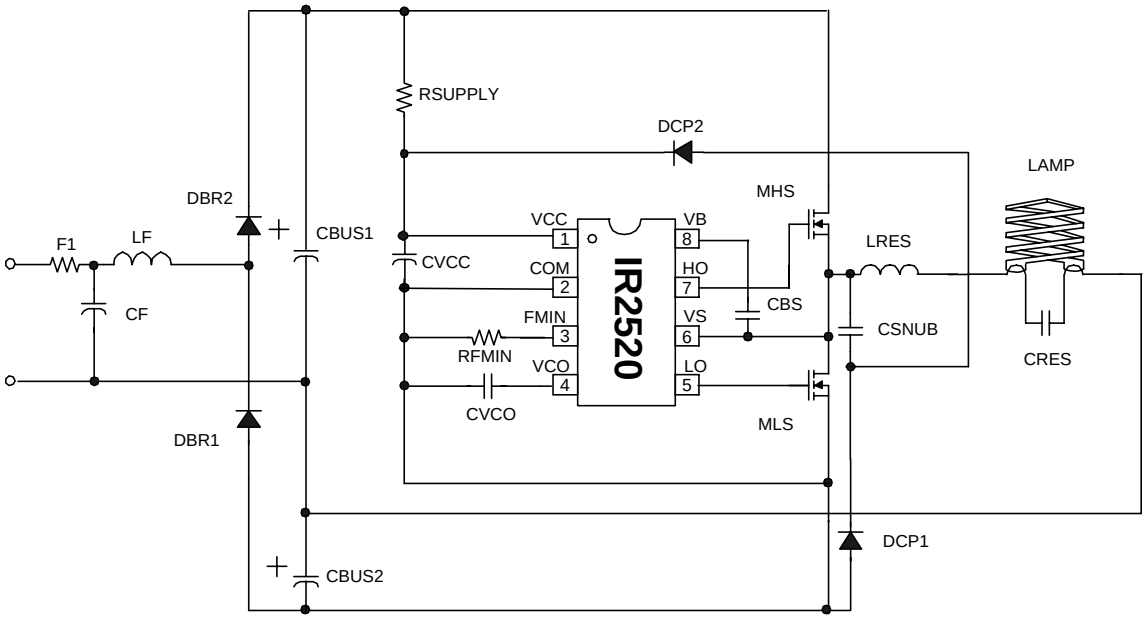


Fig. 2.1: IRPLCFL5U Circuit Diagram

Some components, like the circuit to supply the IR2520 (DCP1, DCP2, CSNUB, RSUPPLY), CBS and CDC, do not need to be changed.

The EMI filter, LF and CF, must be adapted to satisfy the EMI requirements of the application, but we will not get involved on this. The bus capacitors values, CBUS1 and CBUS2, could be reduced for lower powers (< 25W), to save cost and space, and increased for higher powers (>25W), to avoid the bus voltage to drop, but we will always consider 10uF in this AN. The current rating of the MOSFETs, F1, DBR1, DBR2 and LRES must be adapted to the current needed for the different application.

This AN will start from the design IRPLCFL5U and will explain in detail how to adapt the values of CVCO, RFMIN, CRES and LRES to satisfy the specs of a different lamp:preheat time, preheat ratio Rh/Rc, running lamp power, running lamp voltage or current and ignition voltage.

3. CFL Ballast Design Requirements and Constraints

The operation of an electronic ballast follows 3 stages: preheat, ignition and run modes.

Preheat
During preheat, the lamp filaments must be preheated at the right emission temperature to guarantee a long lamp life (5,000-300,000 number or starts). To maximize the lamp life the following conditions must be verified:
1) High starting frequency to avoid stress on the lamp filaments at startup. This is automatically obtained with the IR2520D because the starting frequency is about 2.5 times the minimum frequency.
2) Preheat ratio (Rh/Rc = ratio between the filament resistance at the end of preheat and the filament resistance with lamp cold) between 4 and 6.5 (sometimes the required Rh/Rc ratio is indicated in the lamp specs). A bigger Rh/Rc ratio guarantees a higher emission temperature and a bigger number of starts.
3) Preheat time as long as requested in the application. The preheat time should never be below 200ms. The typical value of the preheat time is 1 sec.
The Rh/Rc ratio is controlled by setting the values of current and voltage in the lamp filaments at the end of preheat. This is done by selecting the values of LRES and CRES. The preheat time is adjusted by selecting the value of CVCO.

Ignition
During Ignition, the frequency will ramp down through resonance and the voltage across the lamp will increase causing the ignition of the lamp. The lamp specs specify a “Maximum Ignition Voltage” that is the voltage needed across the lamp to ignite the lamp in the worst case (lamp cold). The maximum ignition voltage of the ballast is the voltage at the resonant frequency (if fmin has been settled below resonance) of the output circuit consisting only in LRES and CRES and can be controlled by setting the values of LRES and CRES.

Run Mode
During run mode, the voltage and the current across the lamp must guarantee the nominal current, voltage and power of the lamp. The IR2520D will work at the minimum frequency (fmin), unless non zero-voltage switching (ZVS) occurs. The input power can be adjusted by changing LRES, CRES and the minimum frequency.
Summarizing, the lamp specs to satisfy are:

1) Preheat ratio Rh/Rc
2) Preheat time
3) Ignition voltage across the lamp
4) Running lamp power
5) Running lamp voltage or current

There are also some design constraints to consider:

1) Run Frequency above 40K (to avoid the infrared range)
2) Starting Voltage small enough (below minimum ignition voltage) to avoid ignition during preheat
3) Ignition current below the maximum current Rating of FETs and LRES

4. Evaluation Reference Design IRPLCFL5U

The IRPLCFL5U reference design is an electronic ballast for driving 26W compact fluorescent lamps from a 120VAC line. The Bill Of Materials (BOM) is shown in Table 4.1. Lamp: GE F26DBX/827/4P.

Item #	Qty	Manufacturer	Part Number	Description	Reference
1	2	Diodes Inc	S1MBDITR-ND	1A 1000V SMB Rectifier	DBR1, DBR2
2	1	Dale	CW-1/2	Resistor, 0.5Ohm, 1/.2W	F1
3	1	Panasonic	ECQ-U2A104ML	Capacitor, 0.1uF 250 VAC	CF
		Digikey	P10730-ND		
4	1	Epcos	B82145-A1105-J	EMI Inductor, 1mH 370mA	LF
		Digikey	M5830-ND	RF Chockes 1mH 200mA	
5	2	Panasonic	EEU-EB2D220	Capacitor, 22uF 200V	CBUS1, CBUS2
6	1	Panasonic	ECJ-3VB1H104K	Capacitor, 0.1uF 50V 1206	CBS
7	1	Panasonic	ECJ-3VF1E474Z	Capacitor, 0.47uF 25V 1206	CVCO
8	1	Panasonic	ECY-3YB1E105K	Capacitor, 1uF 25V 1206	CVCC
9	1	AVX	1812AA681J	Capacitor, 680pF 1KV SMT 1812	CSNUB
10	1	Wima	MKP4 Series	Capacitor, 4.7nF 1KV Polypropylene	CRES
11	1	International Rectifier	IR2520D	IC, Ballast Driver	IC BALLAST
12	1	VOGT	5750924800	Inductor, 2.25mH, 5%, 1Apk	LRES
13	2	International Rectifier	IRFU320	Transistor, MOSFET	MHS, MLS
14	2	Panasonic	ERJ-8GEYJ754V	Resistor, 750K, 1206	RSUPPLY1, RSUPPLY2
15	1	Panasonic	ERJ-8ENF6812V	Resistor, 68.1K, 1%, 1206	RFMIN
16	2	Diodes	LL4148DICT-ND	Diode, 1N4148 SMT DL35	DCP1, DCP2
Total	21				

TABLE 4.1) Bill Of Materials IRPLCFL5U reference design.

Step 1) Check running conditions:
Measure the input power and look at the VS pin and at the current and voltage across the lamp (Fig. 4.2).
Verify that:

1) The run frequency is above 40KHz
2) Input power, voltage and current on the lamp are equal to the nominal values in the lamp specs

Input (VAC)	Pin (W)	Iinrms (mA)	Vbusav (V)	Freq. (KHz)	PF	THD (%)
120	25	375	300	40.3	0.55	120

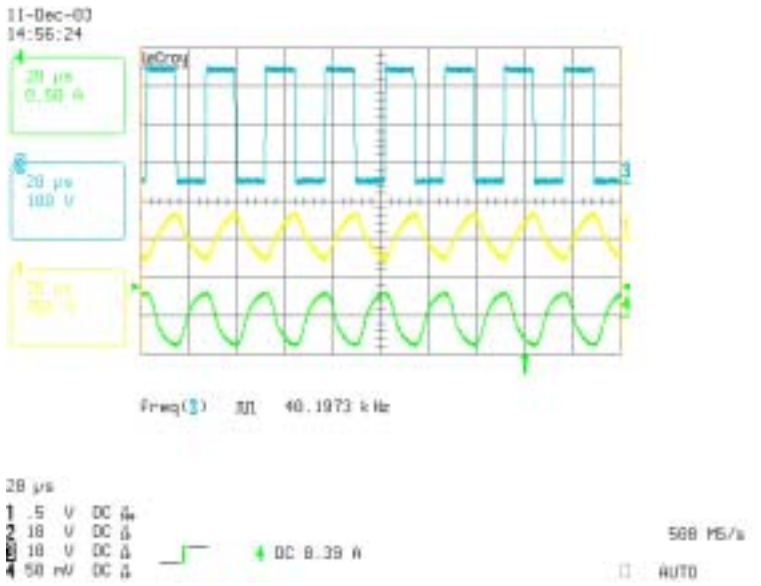


Figure 4.2: VS (blue), lamp voltage (yellow) and lamp current (green) during run mode.

Step 2) Check startup, preheat and Ignition:
Measure voltage and current in the lamp filament at the end of preheat (Fig. 4.3) and voltage across the lamp and resonant inductor current at startup (Fig. 4.4).
Verify that:

1) Preheat time 0.2 sec < t < 1sec; It is 0.8sec.

The preheat time can be measured by looking at Fig. 4.3 or 4.4. It is the length of the rising ramp of voltage and current, before than the voltage and the current decrease.

2) Ignition voltage big enough to guarantee ignition in the worst case

In Fig. 4.4 we can measure the ignition voltage, in this case we do not see the maximum ignition voltage because the lamp ignite before. To see the maximum ignition voltage this measurement must be repeated with no lamp (resistors instead than cathodes or crossed lamps) or with cold lamp. One must verify that the maximum ignition voltage is as indicated in the lamp specs. To simplify the test one can also just try to turn on/off the ballast few times and to turn on the lamp when the filaments are cold and make sure the lamp ignites without problems.

3) Ignition current below FETs and Inductor maximum rating

Measure the ignition current in Fig. 4.4 and add 10%.

4) Preheat ratio between 4 and 6.5

Use the waveform in fig. 4.3. To calculate the ratio Rh/Rc one must calculate Rh = Vpkpk/Ipkpk at the end of preheat. Measure Rc = filament resistance of the lamp off and cold. Ratio = Rh/Rc. It is very difficult to obtain a precise measure with this method.
To have a more precise measurement we suggest:

1) Measure Vpkpk at the end of preheat
2) Calculare Vrms = Vpkpk/2.8284
3) Measure Irms using a Power Supply (PS) and applying at the lamp filament a DC Voltage equal to Vrms
4) Calculate Rh = Vrms/Irms

In this case Vpkpk is 21.4V, Vrms is 7.56V, Irms is 0.38A and Rh is 20.
Rc we measure is 5. The ratio is 20/5, 4. One limitation of this method is that the maximum voltage that one can apply to the filaments with a PS for this test is limited to about 10-12V.
The most practical way we suggest to set the correct preheat is:

1) Chose the value of CRES that allows to strike the lamp with the lower ignition voltage in the requested preheat time
2) Look for a good transition between preheat, ignition and run; the ignition ramp must be clean.
3) Run lamp life tests. Use one of the on-off sequences indicated from the common certifications and verify the number of starts (in the market there are solution with 5,000 starts, 10,000 starts, >30,000 starts; Good solutions must guarantee at least 5,000 starts).

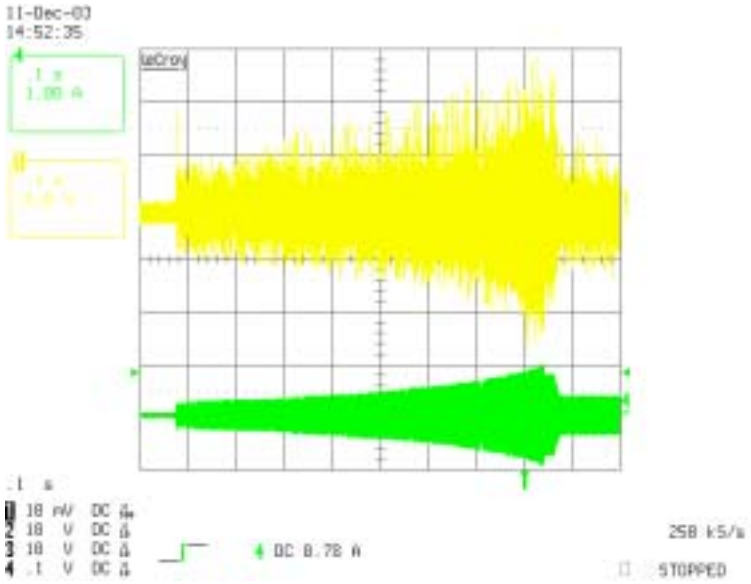


Figure 4.3: Voltage across the lamp filaments (yellow) and current in the resonant inductor (green) at startup

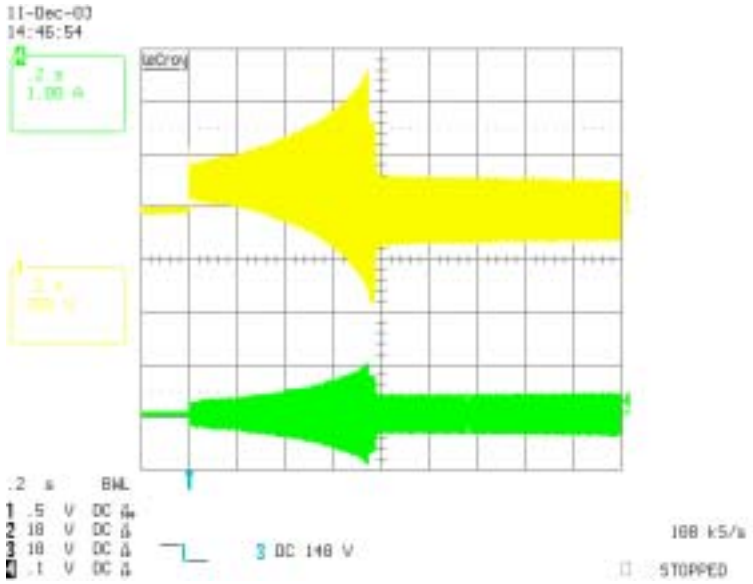


Fig. 4.4: Voltage across the lamp (yellow waveform) and current in the resonant inductor (green waveform) during Startup, Preheat, Ignition and Run Mode

5. Design procedure to adapt the IRPLCFL5U design to a different lamp

The design with the IR2520D is very simple because it only has 2 control pins: VCO (0-5VDC oscillator voltage input) and FMIN (minimum frequency setting). To modify the design for a higher lamp power, you will need to modify RFMIN, CVCO, LRES and CRES. Make sure that FETs and inductors are rated to the current you need with the new lamp and that VCC is stable. To modify the design to a lower lamp power, you will need to decrease RFMIN and only in some case to modify also CVCO, LRES and CRES. In most cases you can use FETs and inductors with lower current ratings.

Pin FMIN is connected to ground through a resistor (RFMIN). The value of this resistor programs the minimum frequency (fmin) of the IC and the starting frequency of the IC (2.5xfmin). The IR2520 will work in run mode at the minimum frequency unless non-ZVS is detected. Generally, to work with constant frequency, the minimum frequency needs to be chosen above the resonant frequency of the low-Q R-C-L circuit. In this case, one can increase the value of RFMIN to decrease the frequency and increase the lamp power, or, decrease the value of RFMIN to increase the run frequency and decrease the lamp power.

Pin VCO is connected to ground through a capacitor (CVCO). The value of this capacitor programs the time the frequency needs to ramp down from 2.5 times fmin (fmax) to fmin. One can increase the capacitor value to increase the preheat time, or, decrease the capacitor value to decrease the preheat time.

The suggested design procedure is as follows:

1) Use the BDA software to calculate LRES and CRES.
   Select the input configuration without PFC, select the IR2156 IC and select single lamp current mode configuration. Select the new lamp in the database or add the lamp parameters by hand selecting the “Advanced” option.
   Calculate the operating point and chose the right values of L and C that satisfy:
   1.1) Run frequency (best working range) 40-50KHz
   1.2) C as small as possible to minimize losses (suggested value 4.7nF)
   1.3) L values you have available
2) While measuring LO, apply 15V from pin VCC to pin COM and adjust the value of RFMIN to obtain the right minimum frequency (it is suggested set fmin = run frequency obtained with the BDA software). Increase RFMIN to decrease the minimum frequency or decrease RFMIN to increase the minimum frequency.

3) Apply the AC input and check preheat, ignition and run states of the lamp.
3.1) If the lamp ignites during preheat, the preheat current is too small or the starting voltage across the lamp is too big, increase the value of CRES to decrease the voltage across the lamp during preheat and startup while increasing the preheat current. LRES may need to be decreased to maintain the same power and the same frequency.
3.2) If the IC works at a frequency > fmin, increase CRES or LRES to decrease the resonant frequency avoiding hard-switching, or, decrease the value of the snubber capacitor CSNUB (a CSNUB minimum value of 680pF is suggested to make sure VCC stays above the UVLO-).
3.3) If VCC drops, increase the value of CSNUB or CVCC
4) Adjust the value of RFMIN to have the right power on the lamp (increase RFMIN to increase power or decrease RFMIN to decrease power) and the value of CVCO to set the correct preheat time (increase CVCO to increase the preheat time and decrease CVCO to decrease the preheat time).
5) Test the ballast over the entire input range and make sure that the frequency does not change dramatically in your working range. Select the value of RSUPPLY to have startup at the correct AC line voltage. Increase the value of RSUPPLY to start the IC at higher AC voltages and decrease the value of RSUPPLY to start the IC at lower AC voltages.
6) Test your lamp life (number of starts). A good design should guarantee at least 5,000 starts. To increase the number of starts, increase CRES or the preheat time (CVCO).

6. Adapt the design IRPLCFL5U to 18W Lamps

Lamp: OSRAM DULUX T/E 18W

Step 1) Check running conditions:
Adapting a design to a lower power can be simply obtained by increasing the run frequency (frun). The only limitations are: frun becomes too big (> 50KHz) or non- zero-voltage switching (ZVS) occurs and causes the IR2520D to work at a frequency higher than the minimum frequency (fmin). If one of these limitations is verified, the value of LRES must be increased. In this case, it is not needed to change the value of LRES because decreasing the value of RFMIN to 53.6K the power at 120VAC is 18W and the run frequency about 49KHz.
Step 2) Check startup, preheat and Ignition:
Verify that the ignition voltage is big enough to allow turn on with lamp cold (try to turn on the lamp several time and with lamp cold) and verify that the preheat is correct.

Looking at the preheat in the lamp (the preheat filaments become red-white during preheat) or looking at the waveforms (the preheat ratio calculated is above 7), one can verify that the preheat is excessive and can damage the filaments. To decrease the preheat, one must decrease the preheat current by decreasing the value of CRES. A smaller CRES means less current in the filaments during preheat and more voltage across the lamp at startup and during ignition. Reducing the value

of CRES to 3.3nF we get the waveforms in fig. 6.1 and fig. 6.2. Fig. 6.1 shows voltage and current across the lamp filaments during preheat and Fig. 6.2 shows voltage across the lamp and resonant inductor current at startup.

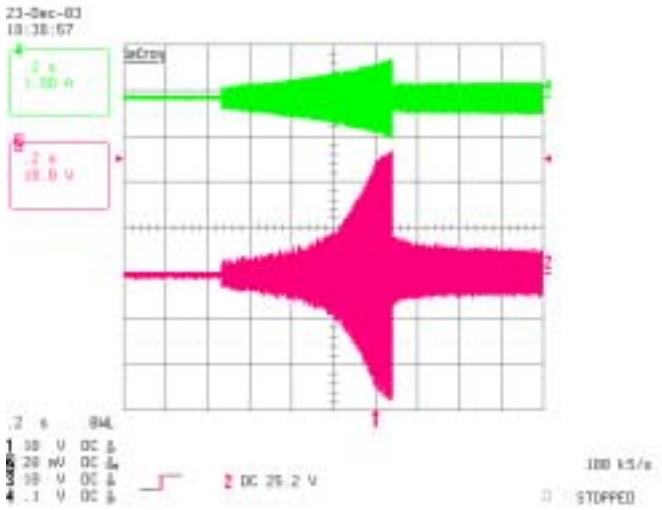


Fig. 6.1: Voltage (red waveform) and current (green waveform) across the lamp filaments during preheat.

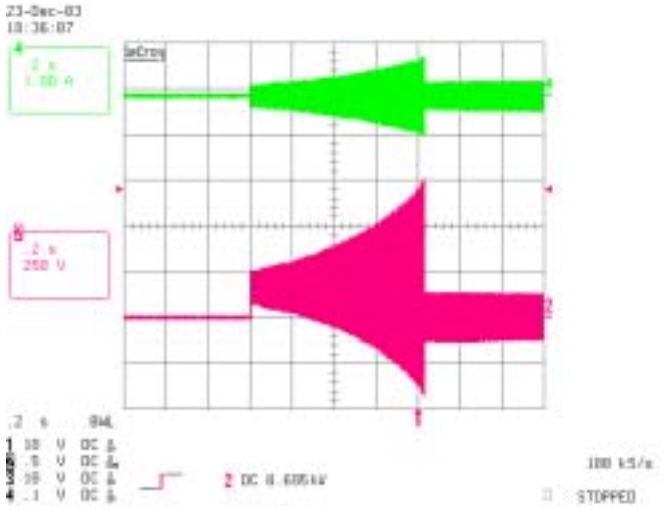


Figure 6.2: Voltage across the lamp (red waveform) and inductor current (green waveform) at startup

The ignition ramp looks very clean, the preheat ratio Rh/Rc is about 4 (Ipkpk = 1.71A, Vpkpk = 50V, Rh = 50/1.71 = 29ohm, Rc = 7 ohm, Ratio = Rh/Rc = 4.2), the preheat time is 0.8sec. The number of starts may be further increased by setting the preheat time 1sec using CVCO = 0.56uF.

Step 3) Verify again running conditions:
We need to go back to step 1 to see if, with the new CRES, we need to change the value of RFMIN again to obtain the right power. We can see that the running conditions are verified. Fig. 6.3 shows pinVS, the voltage and the current across the lamp.

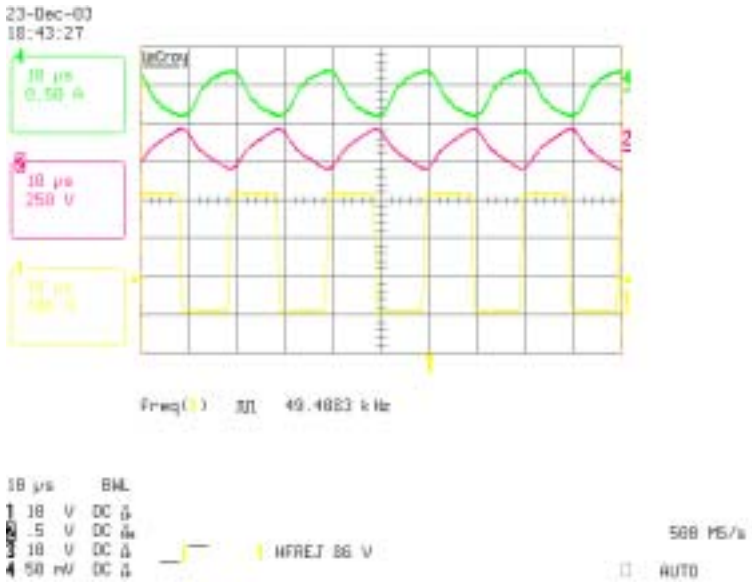


Figure 6.3: VS, lamp voltage and lamp current during run mode

Input (VAC)	Pin (W)	Iinrms (mA)	Vbusav (V)	Freq. (KHz)	PF
120	18.5	290	300	49.4	0.54

The components to change in the BOM of the reference design IRPLCFL5U are: RFMIN = 53.6K and CRES = 3.3nF.

7. Adapt the design IRPLCFL5U to 32W Lamps

Lamp: OSRAM DULUX T/E 32W

Step 1) Check running conditions:

Adapting a design to a higher power can be obtained by decreasing the run frequency (frun). The only limitations are: frun becomes too low or non-ZVS occurs and causes the IR2520D to work at a frequency higher than the minimum frequency. If one of these limitations is verified, the value of LRES must be decreases or the value of CRES must be increased. Using RFMIN = 88.7K, the input power becomes 30W and the running frequency 33KHz. If we try to increase RFMIN further, to increase the input power, the running frequency will not decrease further because the IR2520D detect non-ZVS and starts to work at a frequency higher than fmin. One possibility to avoid non-ZVS is to increase CRES, this will increase also the preheat current in the filaments and will help our design because we can see that the preheat is not visible on the lamp filaments. Using CRES = 6.8nF and RFMIN = 90.9KHz we finally obtain the input power needed, 32W. The running frequency, 32KHz, is a bit low for the application and it would be preferable to rise the running frequency above 40KHz. However, we think that this frequency is still acceptable. If the user prefers to use a bigger frequency, because of EMI or interference, it would be needed to decrease LRES and to decrease RFMIN again until the frequency increases above 40KHz with input power equal to 32W.

Step 2) Check startup, preheat and Ignition:

Verify that the ignition voltage is big enough to allow turn on with lamp cold (try to turn on the lamp several time and with lamp cold) and verify that the preheat is correct. Looking at the preheat waveform (current and voltage on the filaments at startup) and the startup waveforms (inductor current and lamp voltage at startup), one can see that the preheat time is 0.6sec and the Rh/Rc ratio is about 3.8. The voltage in the lamp during ignition is 1054V (Vpkpk) and the current in the resonant inductor is 2.42A (Ipkpk). To improve our design we can increase the preheat time to obtain a bigger preheat ratio Rh/Rc and a lower ignition voltage in the lamp and current in the inductor during ignition, simplifying our design. Using CVCO = 0.56uF the preheat time becomes 0.8sec, the ignition voltage is reduced down to 950V (Vpkpk) and the ignition current to 2.3A (Ipkpk). Fig. 7.1 shows voltage and current across the lamp filaments during preheat and Fig. 7.2 shows the voltage across the lamp and the resonant inductor current at startup.

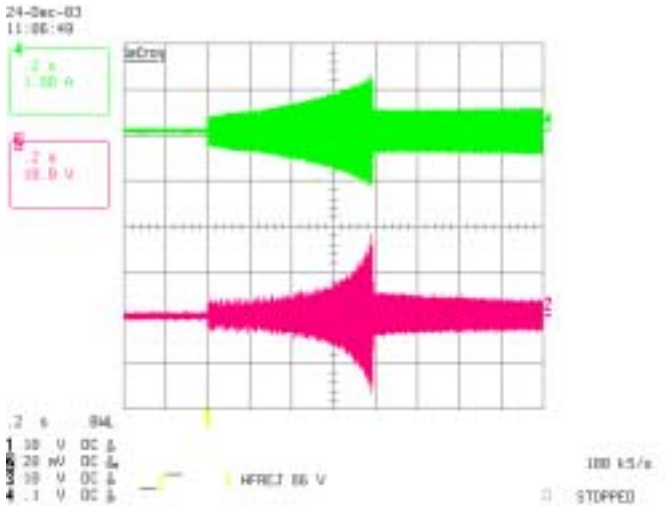


Fig. 7.1: Voltage (red waveform) and current (green waveform) across the lamp filaments during preheat

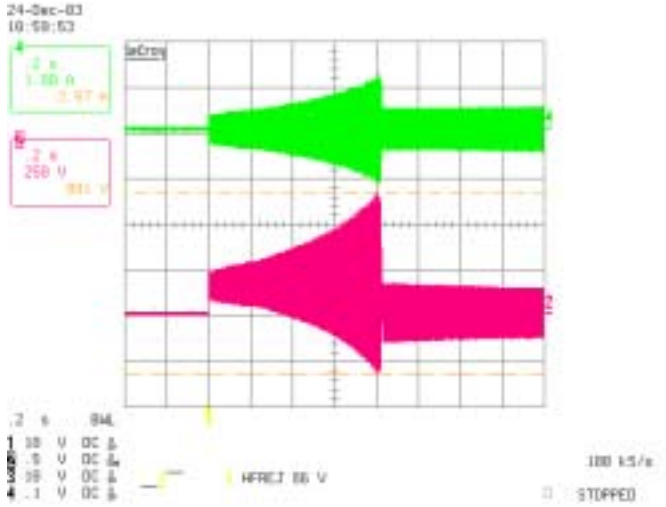


Figure 7.2: Voltage across the lamp (red waveform) and inductor current (green waveform) at startup

The ignition ramp looks very clean, the preheat ratio Rh/Rc is about 4.26 (Ipkpk = 2.3A, Vpkpk = 35.3V, Rh = 35.3/2.3 = 15.3ohm, Rc = 3.6 ohm, Ratio = Rh/Rc = 4.26), the preheat time is 0.8sec. To increase the number of starts the preheat time could be increased to 1sec using CVCO = 0.68uF.

Step 3) Verify again running conditions:

We can see that the running conditions are verified. Fig. 7.3 shows pin VS, the voltage and the current across the lamp.

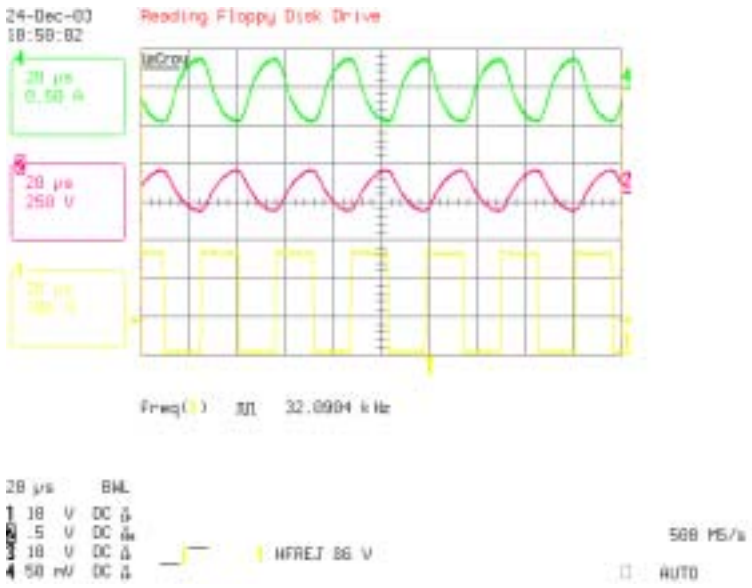


Figure 7.3: VS, lamp voltage and lamp current during run mode

Input (VAC)	Pin (W)	Iinrms (mA)	Vbusav (V)	Freq. (KHz)	PF
120	32	450	280	32	0.58

The components to change in the BOM of the reference design IRPLCFL5U are: RFMIN = 90.9, CRES = 6.8nF and CVCO = 0.56uF.

8. Adapt the design IRPLCFL5U to 42W Lamps

Lamp: OSRAM DULUX T/E 42

Step 1) Check running conditions:

We need to increase the power from 25W to 42W. To obtain a very big step in power at a working frequency 30-50KHz, we must decrease the value of LRES. Using LRES = 1.4mH and CRES = 4.7nF we can see that the ballast will operate at frequency > 55KHz at 120VAC because of frequency shift due to non-ZVS. To eliminate non-ZVS we must increase CRES to 6.8nF. We can see that using LRES = 1.4mH, CRES = 6.8nF and RFMIN = 53.6K, we obtain the right power, 41W, at 120VAC input, working at 49.5KHz. In reality there is still non-ZVS at low AC line (90- 110VAC) and to work constant frequency in the working range 90-140VAC the value of CRES must be increased further to 8.2nF (frequency shift would cause a very low power at low AC line), this will allow also a shorter preheat time. In this AN we will use 6.8nF. One can see that the working frequency is > 50KHz for the first 10minutes after startup. This is not a problem and, instead, it will avoid overdriving the lamp at startup.

Step 2) Check startup, preheat and Ignition:

You can verify that the ignition voltage is high enough. Looking at the preheat waveform (current and voltage in the lamp filaments at startup) and at the startup waveforms (inductor current and lamp voltage at startup), one can see that the ignition ramp looks very clean, the preheat time is 1.1sec and the Rh/Rc ratio is about 4.12 (Rh = 52V/3A = 17.3ohm, Rc = 4.2, Rh/Rc = 17.3/4.2 = 4.12). To improve our design we can decrease the preheat time to less than 1 sec, but this would require CRES = 8.2nF. A bigger CRES will allow a bigger Rh/Rc ratio, and consequentially a bigger number of starts, with the same preheat time.

Fig. 8.1 shows voltage and current in the lamp filaments during preheat and Fig. 8.2 shows voltage across the lamp and the resonant inductor current at startup.

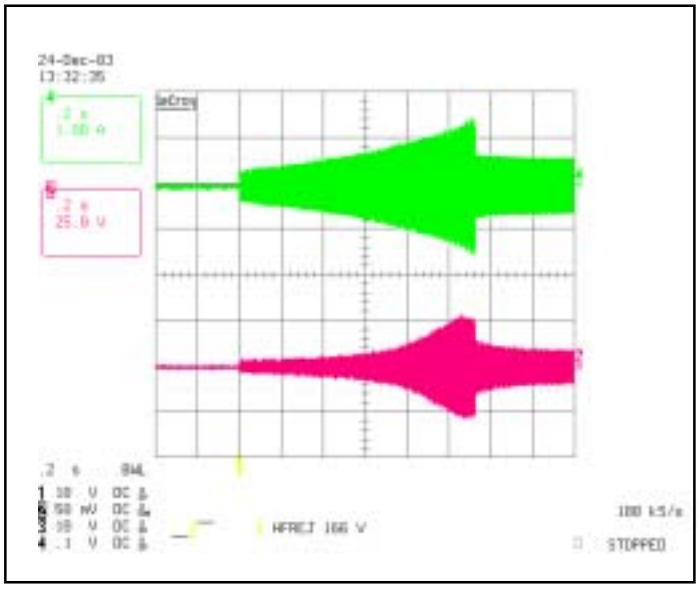


Fig. 8.1: Voltage (red waveform) and current (green waveform) in the lamp filaments during preheat.

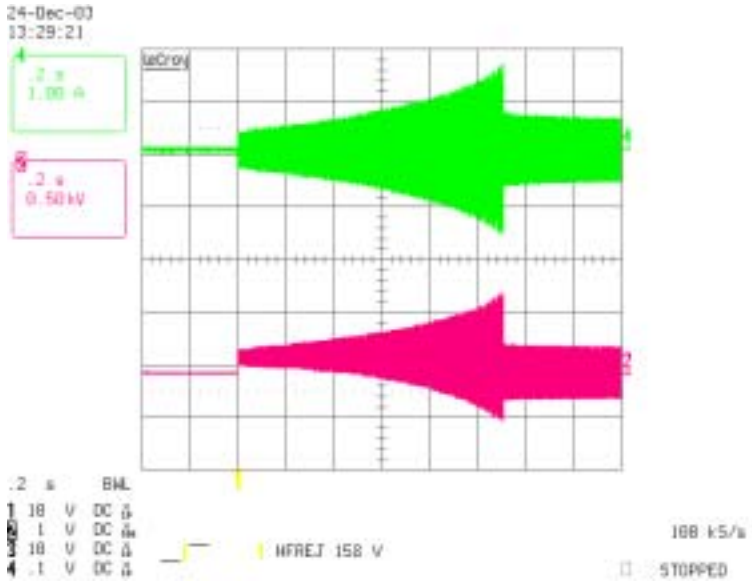


Figure 8.2: Voltage across the lamp (red waveform) and inductor current (green waveform) at start up

Step 3) Verify again running conditions:
We can see that the running conditions are verified. Fig. 8.3 shows pin VS together with the voltage and the current across the lamp.

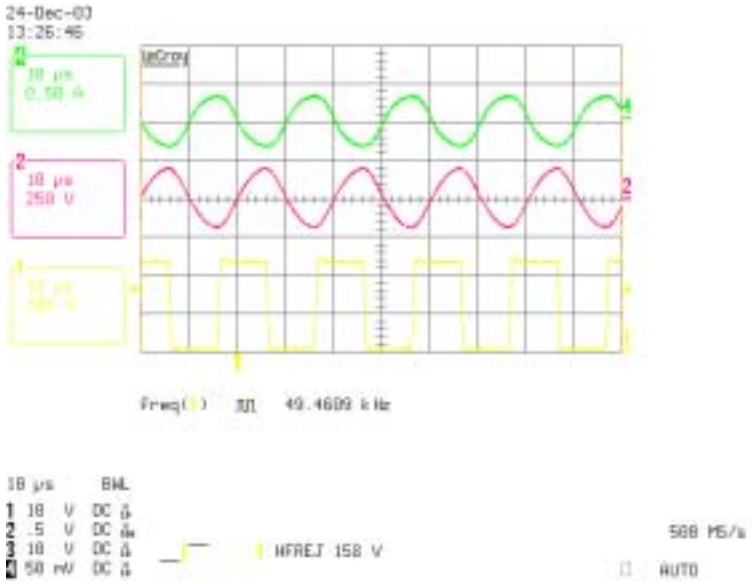


Figure 8.3: VS, lamp voltage and lamp current during run mode

Input (VAC)	Pin (W)	Iinrms (mA)	Vbusav (V)	Freq. (KHz)	PF
120	40.5	570	280	49.4	0.585

The components to change in the BOM of the Reference Design IRPLCFL5U are: RFMIN = 53.6K, CRES = 6.8nF and LRES = 1.4mH.
As for LRES, we suggest to use: VOGT, P/N 5750924700PN (1.4mH, saturation at 1.8Apk).