AN2018
APPLICATION NOTE

VIPower: 18 - 23W ELECTRONIC BALLAST FOR REMOVABLE TUBES

ABSTRACT

This application note describes electronic high frequency ballast based on VK05CFL designed to drive from 18 to 23W TC DEL and T5 removable fluorescent tubes.

The design was performed for 185÷265 Vac main voltage.

1. DESCRIPTION

The VK05CFL is a dedicated device for realizing low power electronic ballast. In a monolithic structure it integrates the power stage and the logic part for the converter control. Using two VK05CFL and few of external components it is possible to realize a high frequency converter in a very simple way reducing the complexity and the cost of the application. The topology is the standard half bridge in voltage fed operating in zero voltage switching (ZVS) resonant mode, in order to reduce transistor switching losses and electromagnetic interference generated by the output wiring and the lamp. In the proposed ballast the preheating and the End of Life (EoL) function are realized without the use of PTC and high voltage components with system reliability increasing. SMD passive components are used in order to reduce PCB dimensions.

2. ELECTRICAL SCHEME

In Figure 1 the electrical scheme of 23W ballast is reported. The demo-board can be adapted to different needs by connecting or not three jumpers.

Following the obtainable configurations:

1) Pre-heating function requested: J1, J2 closed, and J3 open;

2) Pre-heating not requested: J1, J2 open, J3 closed, C11, R11, D2, R7, R12 not mounted.

2.1 Circuit description

About the circuit description, the used topology was already described in the AN1546 and AN1694, therefore in this paragraph only the main functions will be described.

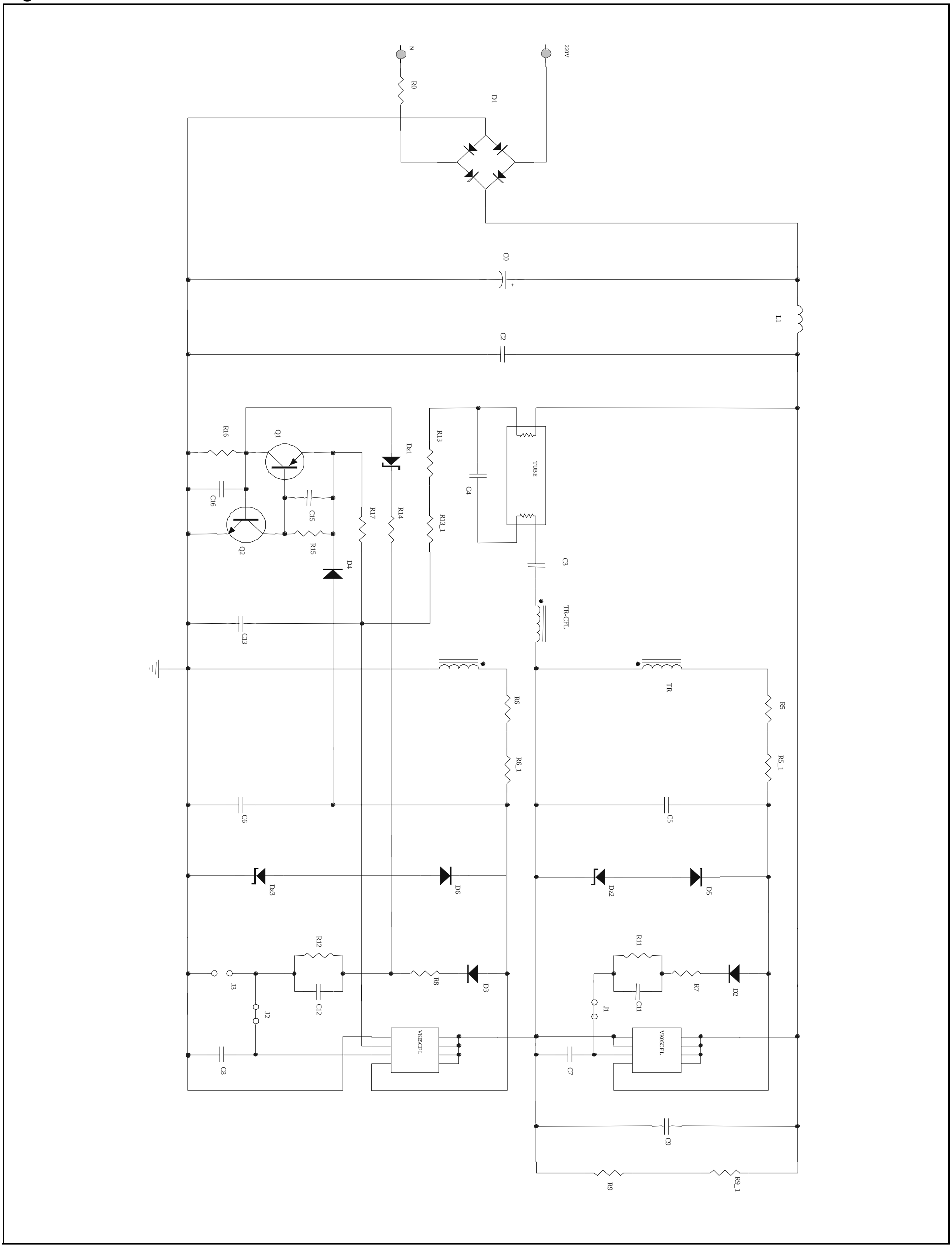
The input section is composed by a fuse resistor R_0 a full bridge diode rectifier D_1, a bulk capacitor C_0 and an input filter L_1C_2 that provide DC voltage and improve EMI performances according to IEC 61000-3-2 standard.

The net R13-R13_1-C13 connected to diac pin realizes the start-up while R7 (R8), D2 (D3), C11 (C12), R11 (R12) perform the preheating function. The ballast working frequency is set by C7 and C8 capacitors. C9 is the snubber capacitor and R9, R9_1 are the pull-up resistor.

The net Q1, Q2, R14, R15, R16, C15, C16, D4, Dz1, detect the lamp failure (EoL) latching the converter.

The devices are synchronized and supplied by two secondary winding turned on ballast choke connect with Sec pins by means input filter, R5, R5_1, C5 and R6, R6_1, C6, that provides a proper supply voltage delaying the Sec pins voltage compared to the secondary winding voltage in order to avoid hard switching condition.

Figure 1: Electrical scheme.



2.2 Component list

In table 1 the material list for both circuits is reported.

Table 1: Component list 18W.

Reference	Value	Description
C0	4.7µF, 450V	Electrolytic Capacitor
C2, C3	100nF, 400V	Capacitor
C4	2.7nF, 400V 5%	Start Up Capacitor
C5, C6, C7, C8	1,2nF, 63V	SMD Capacitor
C9	470pF, 630V	Snubber Capacitor
C11, C12	22µF, 35V	Capacitor
C13, C15, C16	22nF, 63V	SMD Capacitor
D1		SMD Bridge
D2, D3, D4, D5, D6		SMD Diode 1N4148
Dz1	12V	Zener Diode
Dz2, Dz3	20V	Zener Diode
IC1, IC2		**STMicroelectronics VK05CFL**
L1	820µH	Inductor
Q1		Transistor PNP MPSA92A
Q2		Transistor NPN MPSA42A
R0	22Ω 1W	Fuse Resistor
R5, R5_1, R6, R6_1	1KΩ 1/4W 5%	SMD Resistor 1206
R7, R8	10KΩ	SMD Resistor
R14, R17	27KΩ	SMD Resistor
R11, R12	1MΩ	SMD Resistor
R9, R9_1, R13, R13_1	510KΩ 200V	SMD Resistor 1206
R15, R16	33KΩ	SMD Resistor
T1	2.1 mH N1/N2=10:1 5%	Resonant Inductor VOGT (Drawing: LL001 023 21)

Table 2: Component list 23W.

Reference	Value	Description
C0	6.8µF, 350V	Electrolytic Capacitor
C2, C3	100nF, 400V	Capacitor
C4	2.7nF, 400V 5%	Start Up Capacitor
C5, C6	1nF, 63V	SMD Capacitor
C7, C9	1nF	SMD Capacitor
C9	470pF, 630V	Snubber Capacitor
C11, C12	10µF, 35V	Capacitor
C13, C15, C16	22nF, 63V	SMD Capacitor
D1		SMD Bridge
D2, D3, D4, D5, D6		SMD Diode 1N4148
Dz1	13V	Zener Diode
Dz2, Dz3	20V	Zener Diode
IC1, IC2		**STMicroelectronics VK05CFL**
L1	1000µH	Inductor
Q1		Transistor PNP MPSA92A
Q2		Transistor NPN MPSA42A
R0	22Ω 1W	Fuse Resistor
R5, R5_1, R6, R6_1	1KΩ 1/4W 5%	SMD Resistor 1206
R7, R8	9.1KΩ	SMD Resistor
R14, R17	27KΩ	SMD Resistor
R9, R9_1, R13, R13_1	510KΩ 200V	SMD Resistor 1206
R11, R12	1MΩ	SMD Resistor
R15, R16	33KΩ	SMD Resistor
T1	2.1 mH N1/N2=10:1 5%	Resonant Inductor VOGT (Drawing: LL001 023 21)

2.3 Start-up description

When a fluorescent lamp is switched on, the main voltage is not sufficient to cause the initial ionisation and an element is needed to provide high voltage across the tube. Ionised vapour radiates light in the ultra-violet spectrum and is converted to visible light by a fluorescent coating inside the tube.

There are two methods to ignite the tube: cool ignition and warm ignition. Our ballast can perform both methods.

Warm ignition is performed with the cathodes preheating; this method reduces the ignition voltage improving the lamp life. During preheating time the tube presents high impedance and the current flows through the filaments growing their resistance value. There is a simple way to determine the right preheating current/time value: the ratio between the cathode resistance before and after the preheating has to be in the range $3 \div 5$.

In our circuit the start-up network R13, R13_1, C13 is linked to DC bus by the lamp cathode in order to guarantee automatic restart after lamp replacement. At start-up the ballast is in OFF state, when the voltage on C13 reaches the internal diac threshold (~30V) the Low side device is turned ON making the current flow; the voltage drop on the main choke is transferred to secondary windings confirming the Low side ON state and the High side OFF state respectively. In this phase the tube is an open circuit and Lres-C4 fix the system resonance frequency.

2.4 Preheating description

If the cathodes' preheating is requested, our proposed solution performs this function in the following way:

As soon as the sec pin voltage becomes positive, C11-C12 capacitors start to be charged adding current into C7-C8 capacitors with Ton reduction and consequent increasing in the working frequency. Since the preheating network is applied on both devices the fifty percent of duty-cycle is guaranteed.

At the end of preheating time, after ignition occurs, the capacitors C11, C12, thanks to the presence of diodes D2-D3, remain charged at the sec pin voltage stopping the current injection in C7 and C8. The resistors R11, R12 discharge the C11, C12 preheating capacitors allowing a preheating phase when the converter is switched-on again.

During preheating phase the working frequency is higher than the resonance one and the voltage across the tube is lower than ignition one.

Adopting our preheating circuit, the current and frequency are variable during preheating phase, this is due to the fact the injected current is:

$$I_{pre}=(V_{sec}-V_{cappreh}-V_{fdiode})/R$$

thus, this current decreases as the preheating capacitor voltage increases; in this way the working frequency moves towards the resonance frequency in order to guarantee the tube ignition.

After this phase (I_{pre}=0) the preheating circuit and the ballast frequency become steady state frequency fixed by C7, C8.

2.5 EoL description

The ballast shall not impair safety when abnormal and fault conditions happen. Abnormal conditions are classified (European standard) as:

- lamp not inserted
- the lamp does not start because one of the two cathodes are broken;
- the lamp does not start although the cathodes are intact (EoL);
- the lamp operates, but a single cathode is de-activated or broken (rectifying effect).

Third condition is a typical EoL situation and it is verified when the gas inside the tube is exhausted. During the start-up phase, if the lamp doesn't strike, very high current will flow in the circuit with dangerous high voltage appearing across the tube. This anomaly can be damaging on base material also resulting dangerous for the human operator that replaces the tube. For these reasons a protection against faults is necessary. In order to detect EoL condition the method adopted is "voltage sensing detection". In this case we detect an over voltage on Sec pin that activates a latch stopping the oscillation in the ballast. The EoL protection is made monitoring the voltage across the low side preheating capacitor C12. When the tube fails, the voltage across the primary inductance and, consequently, the voltage on secondary winding (with a ratio 10:1) raises with an increase in the C12 average voltage; when Dz1 threshold voltage is reached, the latch circuit is activated switching the converter off. The main latch functions are:

- Keeping sec pin voltage lower than its threshold by means of D4;
- Disable Diac function.

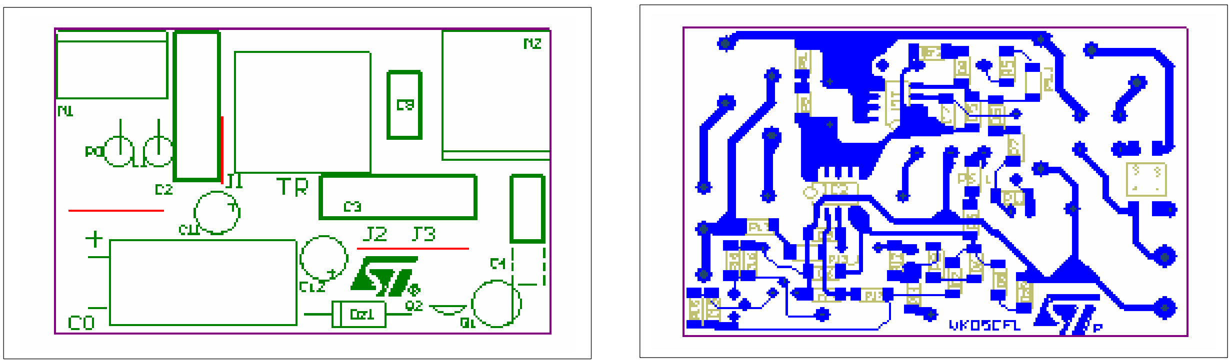
The latch sustaining current is coming from R13. With this technique we are able to maintain the control on the device current avoiding transformer core saturation. Diodes D5, D6, Dz2, Dz3 are added in 18W and 23W demo-board in order to avoid negative over-voltage on Sec pins during EoL (See datasheet VK05CFL for further details).

Figure 2: PCB photos

3. PCB DEFINITION

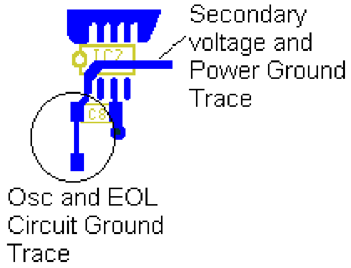
Figure 3: PCB Layout

PCB through hole component side (not in scale) | PCB SMD component and copper side (not in scale)



In layout design some simple rule have to be follow for components placement. The first one is related to frequency capacitor placement that must to be mounted as close as possible to the VK05CFL Osc pin; and the second one is related to signal and power ground paths that have to be different in order to avoid interference on the logic part.

Figure 4: Ground trace placement.



The copper area lived on the device collector for heat sink in this application is 1cm^2.

4. EXPERIMENTAL RESULTS

The results have been obtained in the following conditions

a) Main voltage Vmain=230Vrms

b) Ambient temperature T_{amb}=25 °C

c) Lamp power Plamp= 23W

4.1 Pre-heating

The pre-heating frequency is 112KHz, it is higher than the resonance one f_{res}=66.8KHz (L_{res}=2.1mH, C_{res}=2.7nF). Pre-heating time is less than 1s, in this case pre-heating time is 880 ms and it is possible to set it by changing C11-C12 capacitors and/or R7-R8 resistance. Figure 5 shows how the working frequency starts to preheating one, and it moves towards resonance frequency during pre-heating phase until ignition occurs; after that the working frequency is set by frequency capacitors.

Figure 5: Resonant curves.

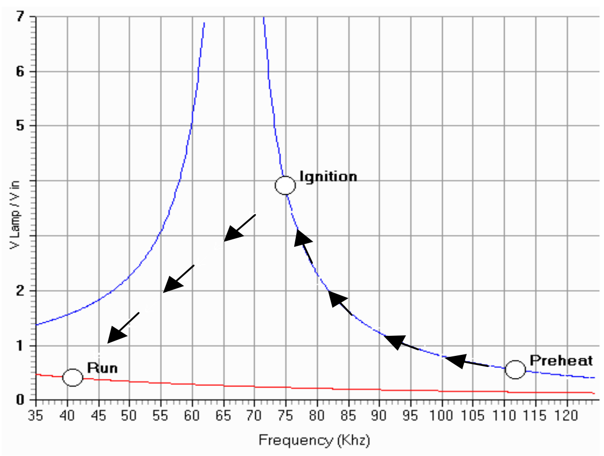


Figure 6 shows the start up phase when pre-heating function is used.

Figure 6: Start-up phase. Ch1=Sec pin voltage; Ch2=diac pin voltage; Ch3=Mid point voltage; Ch4=Choke current

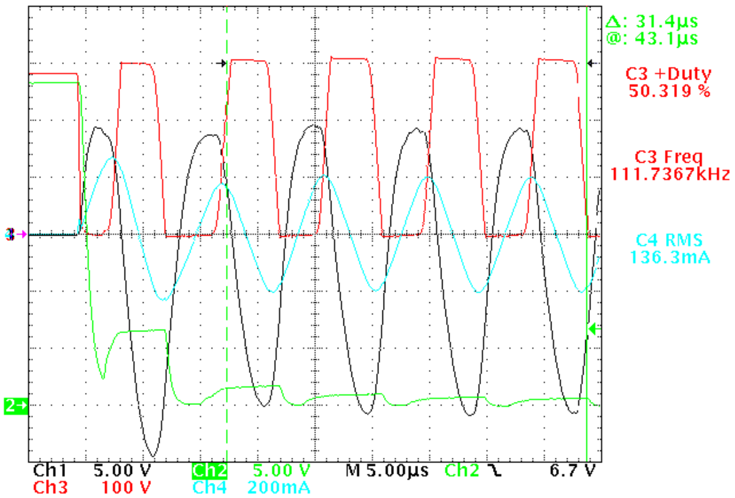
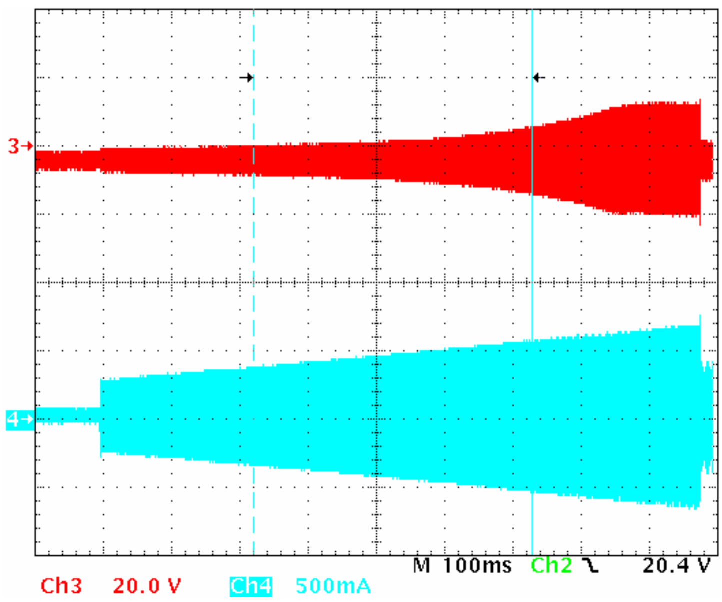


Figure 7 shows the current and the voltage across the cathode during pre-heating. The cathode resistance at the end of the preheating is about 3 times higher than its initial value ensuring the cathodes heating.

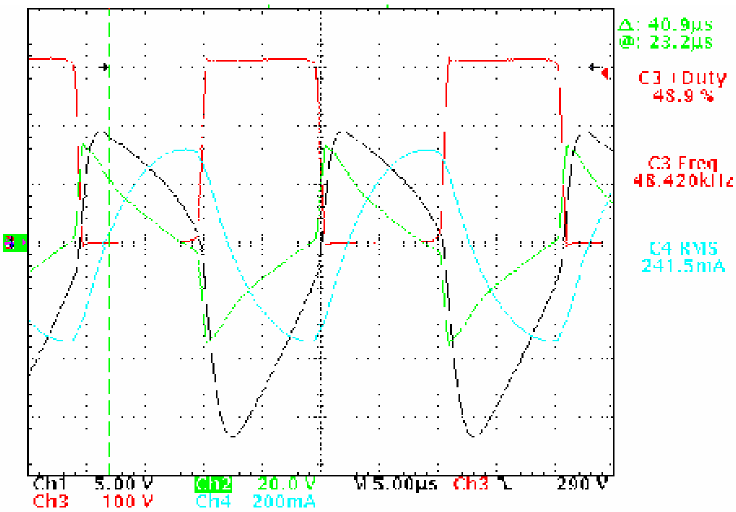
Figure 7: Pre-heating phase Ch3=Cathode voltage; Ch4 Cathode current.



4.2 Steady state

In figure 8 the steady state waveforms are shown.

Figure 8: Steady State Ch1=Sec pin voltage; Ch2=Secondary winding voltage; Ch3 Mid point voltage; Ch4=choke current.

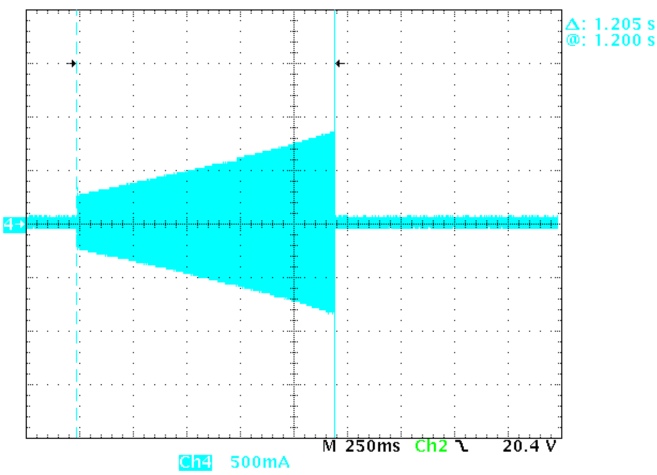


The working frequency is 48 KHz with duty cycle of 49%. Using the proposed input filter the sec pin voltage is higher than 4.5V at the end of Ton time.

4.3 End of Life

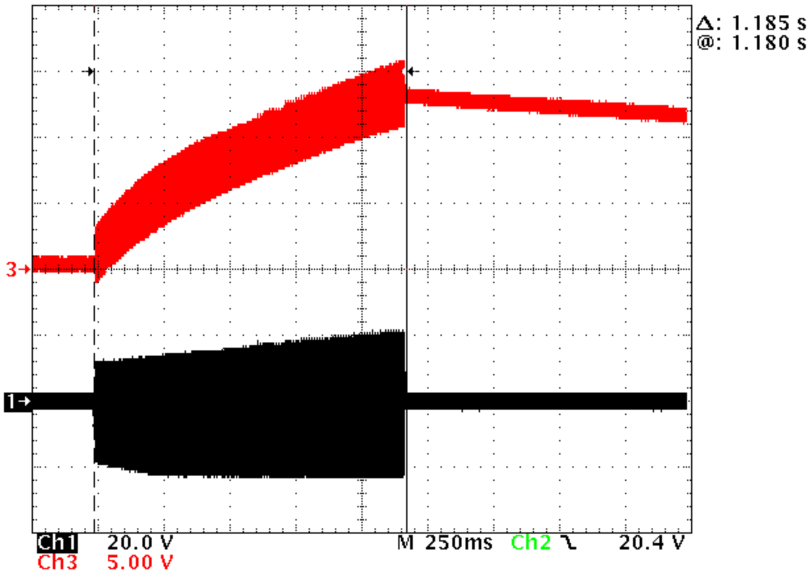
In figure 9 choke current is shown. It is worth noting that the system goes in EOL condition a latching the converter in 300ms, after preheating phase. Zener value can be tuning in order to modify the EOL intervention time.

Figure 9: EoL condition. Ch4= Choke current



In figure 10 Sec pin voltage and voltage across the preheating capacitor (C12) are shown. Negative Sec pin voltage is clamped at -20V in order to avoid negative over voltage.

Figure 10: EoL condition. Ch1= Sec pin voltage, Ch3 = Preheating capacitor voltage.



4.5 THERMAL BEHAVIOUR

The thermal behavior analysis has been performed measuring the real devices temperature in application, using thermocouples K type soldered on top of the packages.

The measurement has been performed driving a 23W tube at 55°C ambient temperature. In table 4 results are summarized distinguishing between low side and high side device temperature and copper sink area.

Table 4: Thermal behaviour analysis

VK05CFL	Device Temperature (°C)	Sink area (mm^2)
Low side	97.5	63
High side	107.5	95

4.6. EMI and Harmonics current

Conducted EMI and Harmonics currents measurements have been performed according to EN55015 and IEC 61000-3-2.

The instruments used are: Agilent spectrum analyser and oscilloscope Tektronics.

In figure 11 current shape and Class D mask are shown, current is not sinusoidal than it has some harmonics components at frequencies multiple than the fundamental. It is possible to observe that our system fits class D specification according to IEC 61000-3-2.

Figure 11: Input current shape (normalized) and class D mask.

The conducted noise measurements have been performed on the 23W at nominal 230Vac input voltage. Results are shown in figure 12 and it is possible to notice that ballast passes the test on conducted emissions according to EN55015.

Figure 12: Main terminals disturbance voltage: Conducted noise and EN55015 quasi peak limits.