



VIpower: SELF-OSCILLATING CONVERTER USING VK05CFL FOR COMPACT FLUORESCENT LAMPS

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ABSTRACT

This application note introduces a new self-oscillating converter based on VK05CFL device to drive "SE", "DE", and "TE" fluorescent tubes. The design is intended for 5 to 23W fluorescent lamps and 110V, 230V \pm 20% main voltage.

1. INTRODUCTION

Compact fluorescent lamps are the most popular in the consumer market because compared to the traditional incandescent lamps they offer the following advantages:

- Low power consumption (about 80% lower);
- Very high brightness (five times higher);
- Very long life (from five to ten times higher).

The proposed converter is based on the new VK05CFL VIpower device in half bridge configuration and offers the following economical benefits:

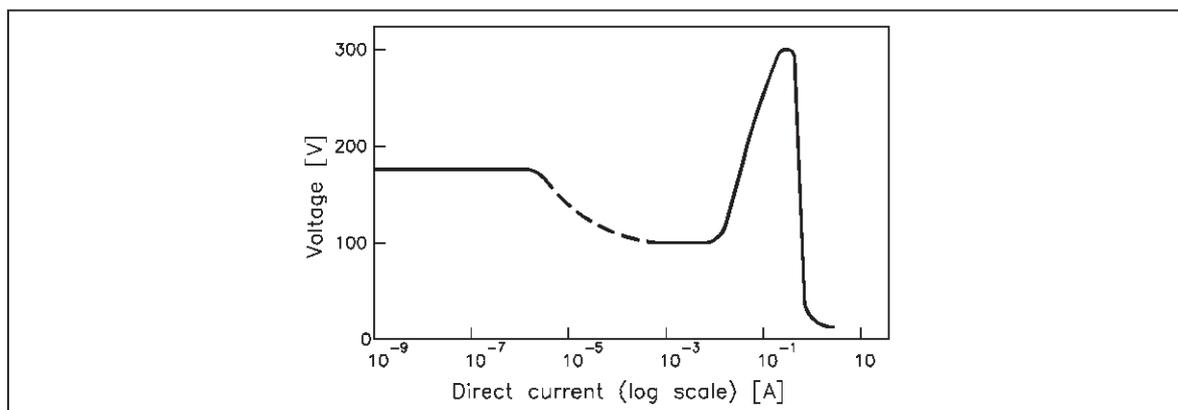
- Monolithic solution with Power and control part on the same chip;
- No saturable coil transformer is required;
- Reduced number of component with consequent PCB miniaturization;
- Single device for all CFL power range, 5W \div 23W.

2. THE BALLAST CONCEPT

When a fluorescent lamp is turned on, the main voltage is not sufficient to cause the initial ionization. An element is needed to provide high voltage across the tube to start the process.

Figure 1 schematically shows the relationship between the voltage and the current of the arc discharge in a fluorescent lamp.

Figure 1: Static volt-ampere characteristic of a gas discharge



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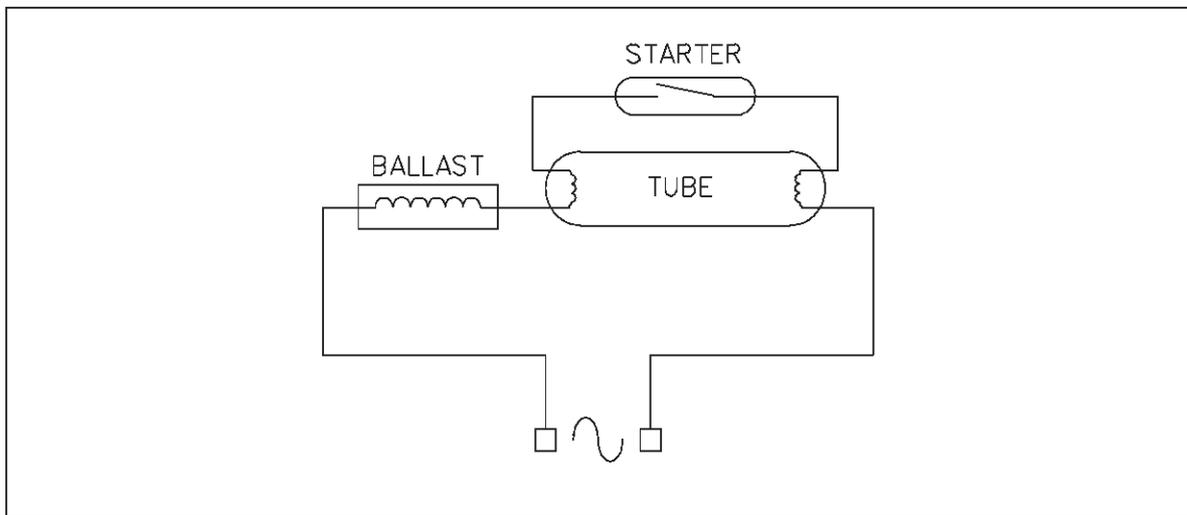
There is a region where the arc discharge characteristic has a negative slope: in this region most of the discharge lamps operate. To prevent current runaway and ensure stable operation from a constant voltage power supply the negative characteristic must be counterbalanced by a circuit element or component having positive characteristic. This element is called ballast.

3. CONVENTIONAL BALLAST

The ballast must be efficient, simple, ensure a proper lamp starting, have no adverse effect on lamp life, and ensure stable lamp run-up and operation. There are several types of ballasts: Resistor ballasts, Capacitor ballasts, Choke-capacitor ballasts, Inductor ballasts. In order to drive fluorescent lamps at 230V, 50 Hz inductor ballasts are used.

Typical circuit using starter and inductor ballast is shown in figure 2.

Figure 2: Circuit with fluorescent lamp using electromagnetic ballast and bimetallic starter



This conventional circuit uses the “starter” to ignite the lamp. The starter initially is in “open” state. When the main voltage is applied to the circuit, the gas around the bimetallic strip is ionized and the current starts to flow. The bimetallic self-heating strip closes the contact and the current flows through the metallic contact; the gas into the starter is de-ionized, the current heats the tube cathodes and simultaneously begins the cooling of the starter. When the starter has cooled down, it reopens its contacts, the ballast generates an overvoltage that ignites the tube.

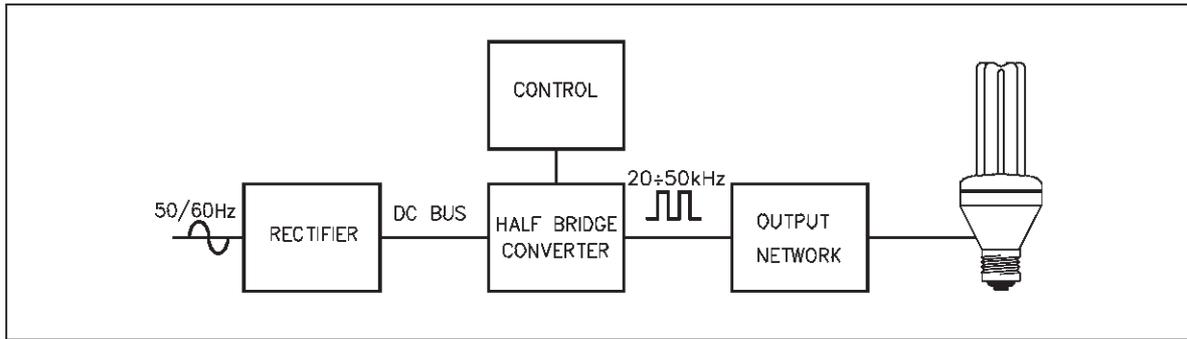
If there is not enough overvoltage to strike the tube there is a false start (starter and main voltage are not synchronized). This phenomenon will repeat itself until the tube ionization is complete. This is a problem for the tube because increasing the number of false start, the lamp life will decrease.

Flickering effect is visible at low frequency. The fluorescent tube turns off when the current is zero: this is the source of the 50Hz flickering in a standard circuit. It is a problem which can lead to visual troubles due to the stroboscopic effect on rotating machines or computer monitors. Moreover in this kind of ballast, the power loss and the dimensions are not negligible. The ballast power loss is about 10 to 20% consequently the ballast efficiency is 80 to 90%. The size and weight of the ballast are determined by its volt-ampere rating: high power lamps operate at high current, requiring larger chokes.

4. ELECTRONIC BALLAST

It is possible to improve the ballast performances driving the tube through an electronic converter. A typical electronic ballast block diagram is shown in figure 3.

Figure 3: Electronic ballast block diagram

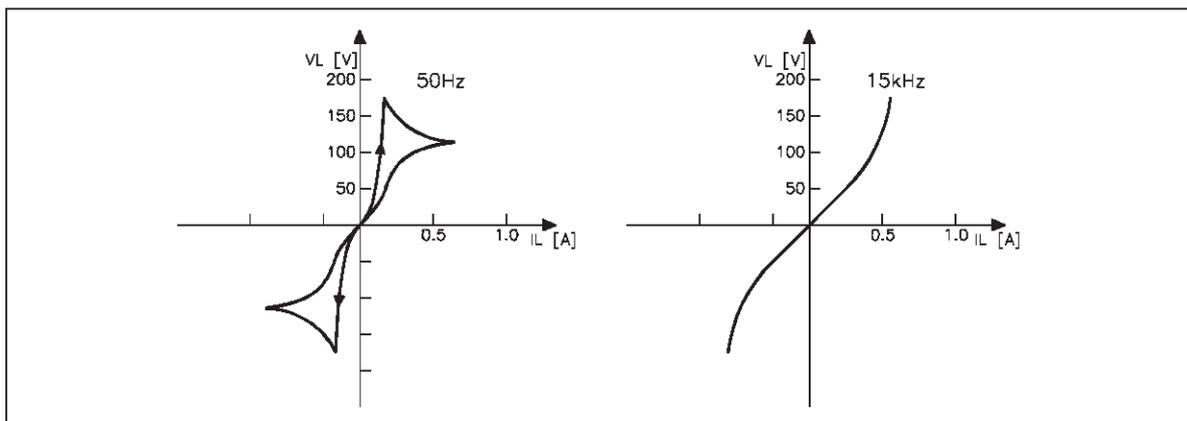


These converters generally operate in the range of 20 ÷ 50 kHz with the following features:

- Improved circuit efficiency, (reduced ballast loss).
- Weight and dimension reduction.
- Improved luminous efficiency.
- Absence of flicker.
- Facility for accurate control of lamp power.
- Starting and operating conditions controlled in order to improve lamp life.

In the fluorescent lamp, at high frequency the ionization state cannot follow the rapid changes of the lamp current. The dynamic lamp voltage-current characteristic tends to become linear and waveform distortion is reduced. In figure 4, the typical characteristics of a fluorescent lamp dynamic volt-ampere characteristics are shown.

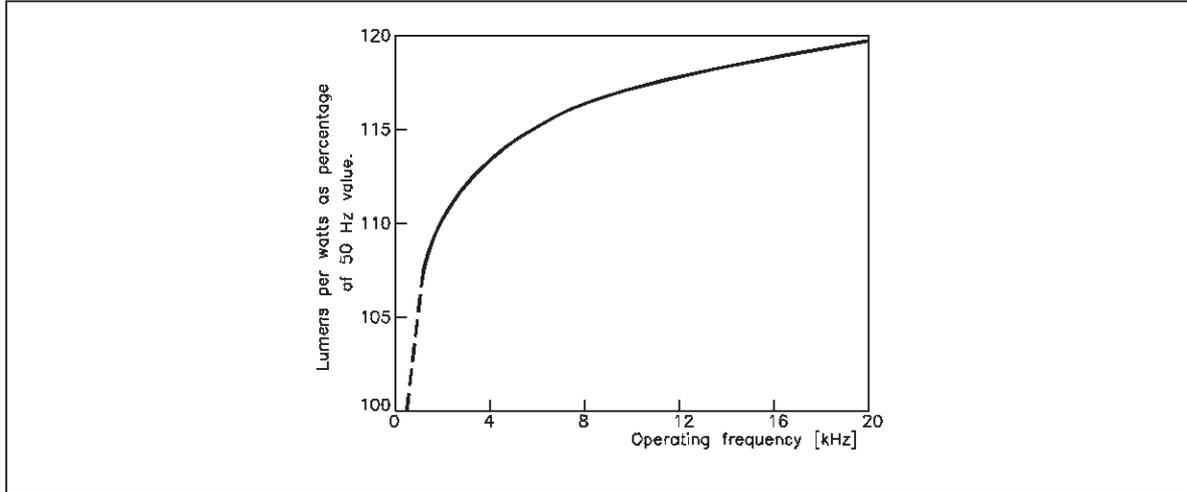
Figure 4: Dynamic volt-ampere characteristic of a fluorescent lamp at 15 kHz



Overall lamp efficiency is improved and above 20 kHz a gain up to 20% can be obtained as shown in figure 5.

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Figure 5: Fluorescent lamps high frequency efficiency



The flickering phenomenon is not visible at high frequencies.

The electronic circuit must drive fluorescent lamps with AC current in order to avoid constant bias of the electrodes decreasing the lamp lifetime. In fact when a unidirectional current flows into the tube the cathode material is absorbed by the electron flow with a strong filament reduction.

The DC-AC converter normally uses dual switch topologies; the most popular are:

- a) Voltage fed series resonant half bridge topology,
- b) Current fed push-pull topology.

5. VK05CFL DEVICE APPLICATION

The proposed converter is based on voltage fed series resonant half bridge topology. It uses the VK05CFL device housed in a standard SO-8 package. In the same chip control part and power stage are integrated. The power stage is the Emitter switching composed of a high voltage bipolar darlington in cascode configuration with a low voltage MOSFET. Using this power configuration it is possible to obtain both the bipolar (voltage and current capability) and the MOSFET (switching speed) characteristics.

The application circuit using VK05CFL device is shown in figure 6.

The input section consists in a fuse resistor R_0 a full bridge diode rectifier D_0, D_1, D_2, D_3 , and an L_0C_1 input filter. This filter provides DC voltage and improves EMI performance according to IEC 61000-3-2 standard. Two VK05CFL devices in half bridge configuration compose the converter section. The converter operates in Zero Voltage Switching resonant mode in order to reduce the transistor switching losses and electromagnetic interference.

The proposed circuit does not require a saturable transformer to set the operating frequency, but it is set by the C5 and C6 capacitors. The devices during the ON state charge these capacitors and when the voltage on them reaches 1.6 V, the power stage is turned OFF. If the capacitors C5 and C6 have the same value the circuit will oscillate with a duty cycle of 50%. This is a fundamental condition in order to have symmetrical current flowing into the tube and avoiding cataphoresis effects increasing the lamp life. The devices are triggered and supplied by two secondary windings turned on the ballast choke. The ratio between primary and secondary windings is 10:1. The networks composed by R4-C10 and R5-C11 realize the devices input filter.

It provides a proper supply voltage delaying the sec pins voltage compared to the secondary winding voltage in order to avoid hard switching condition.

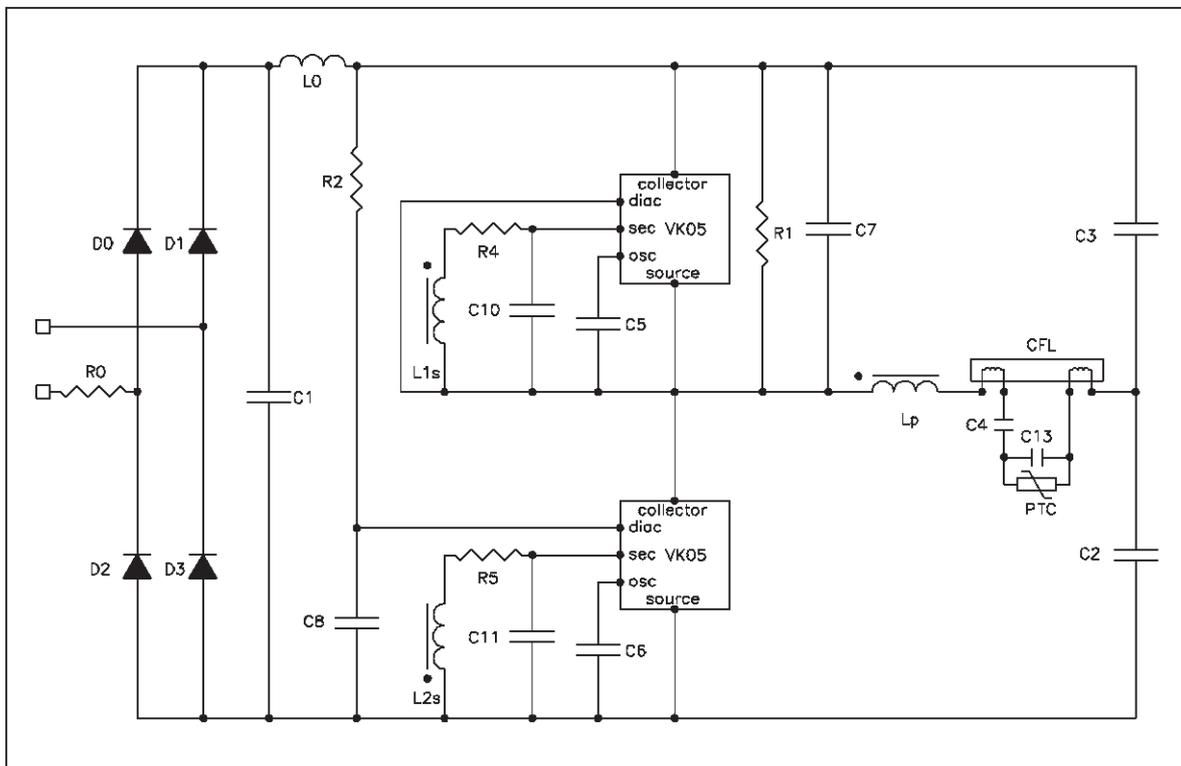
The start-up network is made up by resistor R2 and the capacitor C8. During steady state the C8 capacitor is discharged by means of a high voltage integrated diode connected between the diac pin and the device collector.

R1 is the pull-up resistor and C7 is the snubber capacitor.

The C4, C13 and PTC compose the tube ignition network

There are two methods to ignite the tube: a) cool ignition, b) warm ignition. The first one is realized only when the C4 capacitor is mounted across the tube.

Fig. 6 Application circuit



6. START-UP DESCRIPTION

At start-up the VK05CFL is OFF. When the voltage on C8, connected to DC bus by resistor R2, reaches the internal diac threshold (~30V) the low side device is turned ON making the current flow. The current path in this condition is: C3, ignition network, ballast choke Lp, low side VK05CFL and ground. The voltage drop on Lp is transferred to the secondary windings confirming the "ON" state for the low and the "OFF" state for the high side. In this phase the tube is an open circuit and the system will oscillate at a resonance frequency due to Lp-Ze where Ze is the equivalent impedance due to C4 C13 and PTC (see Fig.6). This frequency is higher than steady state frequency and the secondary voltages switch-off the devices before the capacitors C5-C6 are charged. In this way the system is able to work in start-up and steady state both at different frequencies.

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Since $C_e \gg C_4$

$$C_e = C_2 + C_3 \quad (1)$$

is possible neglect its contribution in the resonance formulae obtaining (cool ignition):

$$f_r = \frac{1}{2\pi \cdot \sqrt{L_p \cdot C_4}} \quad (2)$$

Where: f_r = Start-up resonance frequency.

L_p = Ballast choke.

C_4 = Tube ignition capacitor.

If warm ignition is applied the f_r will be related to the PTC resistance variation.

7. STEADY STATE DESCRIPTION

When the tube is ignited the resonance frequency becomes:

$$f_r' = \frac{1}{2\pi \cdot \sqrt{L_p \cdot C_e}} \ll f_r \quad (3)$$

Where: f_r' = Steady state resonance frequency.

While the steady state frequency is set by two capacitors C_5 and C_6 connected to osc pin. It is possible to calculate the steady state frequency with the following relationship:

$$f = \frac{1}{T} \quad (4)$$

$$\frac{T}{2} = t_{ON} + t_{storage} + t_{dv/dt} \quad (5)$$

Where:

$$t_{ON} = R \cdot C \cdot \ln \frac{5}{2} \quad (6)$$

Where:

R = Internal resistance = 12 k Ω .

C = C_4 or C_5 .

$t_{storage}$ is the power storage time. It is a function of collector peak current and temperature (see datasheet VK05CFL "ELECTRONIC DRIVER FOR CFL APPLICATION").

$t_{dv/dt}$ is a function of collector peak current snubber capacitor value, and collector voltage

For example if we consider

$$C_5=C_6=1.2\text{nF}; t_{on}=12 \times 10^3 \times 1.2 \times 10^{-9} \times 0.91 = 13\mu\text{s}.$$

$$t_{storage} = 0.4\text{ms}, \text{ and } C_7 = 680\text{nF}, t_{dv/dt} \approx 0.8\mu\text{s}.$$

$$T = 2 \times (13+0.4+0.8) = 2 \times (14.2) = 28.4\mu\text{s}, \Rightarrow f = 35 \text{ kHz}.$$

8. SECONDARY FILTER DESIGN

According to schematic shown in Fig. 6 the R_4 - C_{10} R_5 - C_{11} filters design must perform with the following consideration:

- 1) The sec filtered voltage must achieve the device ON at the end of the negative dV/dt and before the end of the freewheeling diode conduction in order to avoid hard switching or switching-on delay.
- 2) The filtered voltage must be high enough (greater than 5V at the end of t_{on} in order to guarantee the right working frequency.

This second condition is strongly related to the load (power of the tube) because the drop on the choke primary winding decreases increasing the load current (see Fig 16). A good choice is to fix the time constant ($\tau = R \times C$) in the range: $1.5\mu s \div 3.3\mu s$.

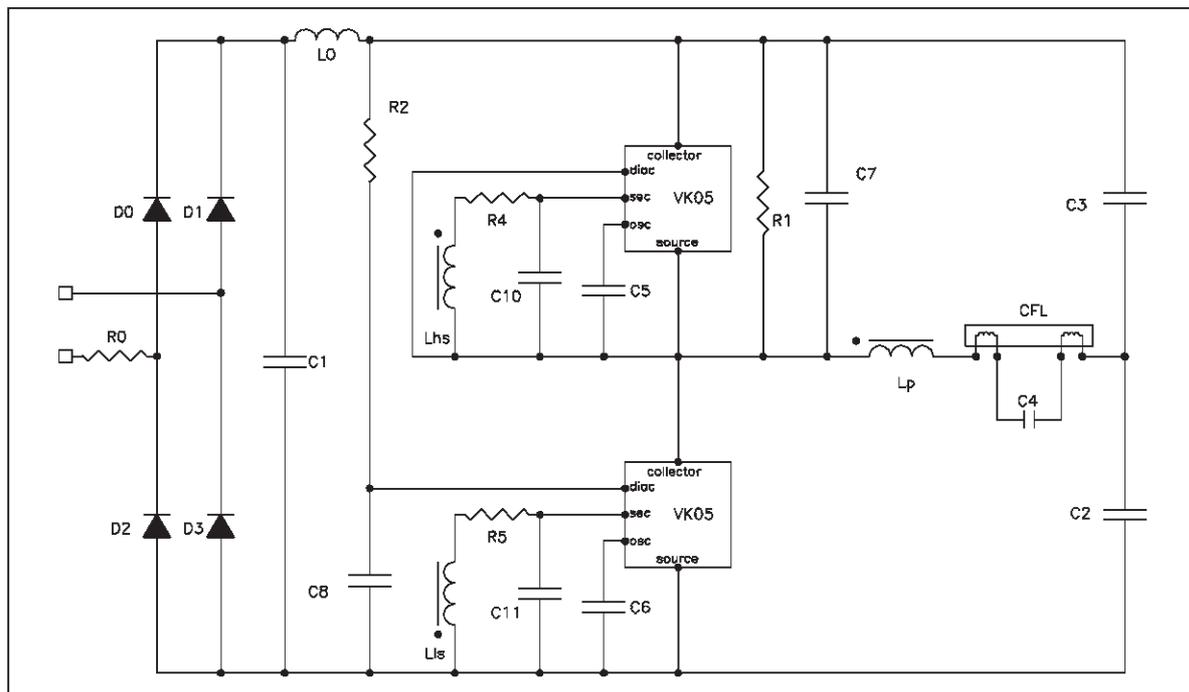
The resistors R_4 , and R_5 must be designed according to power dissipated on them during pre-heating phase (worst case: higher voltage on the secondary winding).

9. IGNITION PHASE

To ignite the lamp two methods are used: a) cool ignition method, b) Warm ignition with cathodes pre-heating.

Cool ignition method.

Figure 7: Application circuit for European market using cool ignition method



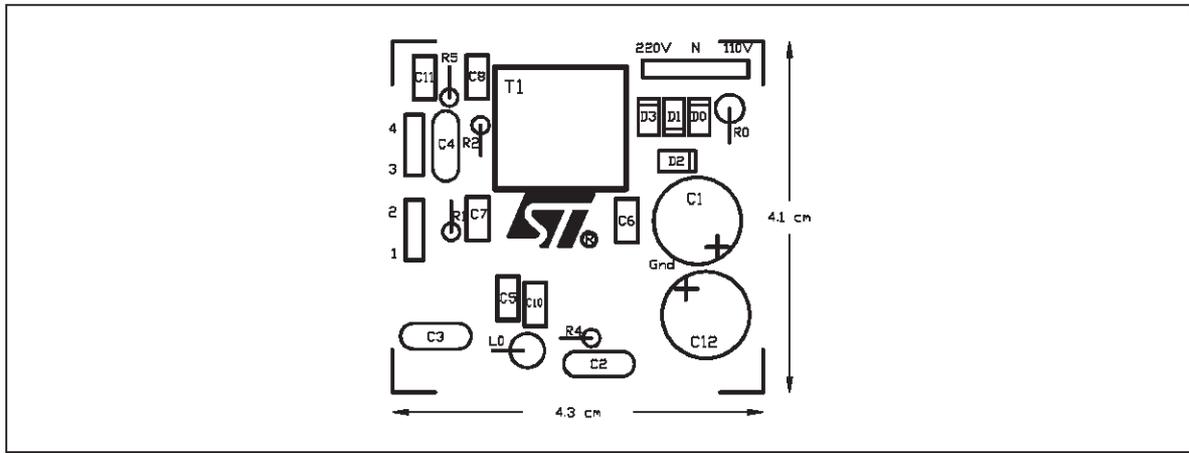
- a) Cool ignition. According to figure 7 when the low side device switches ON the current flows through: C_3 , C_4 L_p VK05 Low side device. L_p and C_4 fix the resonance frequency. The device current increases and after few cycles will generate enough voltage to strike the tube on capacitor C_4 . Its value can exceed 1A.

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- b) Warm ignition. In figure 6 a typical application circuit is shown. The warm ignition heats the cathodes in order to increase the electron emission without striking the tube. In this way the following advantages are achieved: the tube is ignited with a moderate voltage (lower than cool ignition); the lamp life will increase. In the application board the cathodes pre-heating is obtained using a PTC resistor.

10. VK05CFL APPLICATION BOARD

Figure 8: Application demoboard: Component layout



This demo can work with two different main voltages: 230Vrms (Europe) and 110Vrms (USA). For the European market the capacitors C1 and C12 must be replaced with one capacitor connected between the D1 cathode pin and the D3 anode pin. It is possible to drive CFL in the power range from 5W up to 23W.

Figure 9: Top view(not in scale)

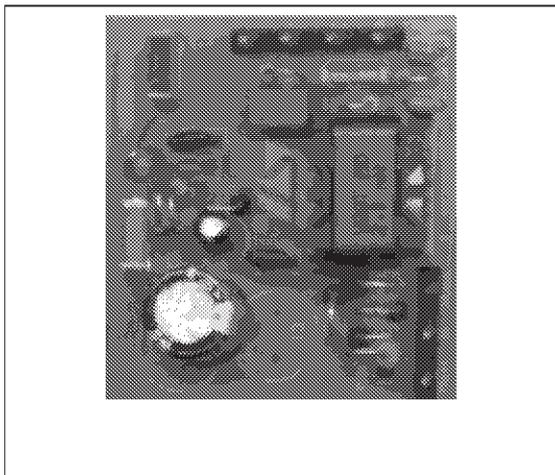
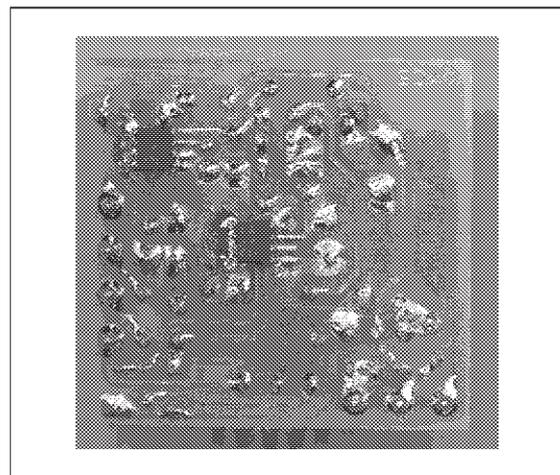


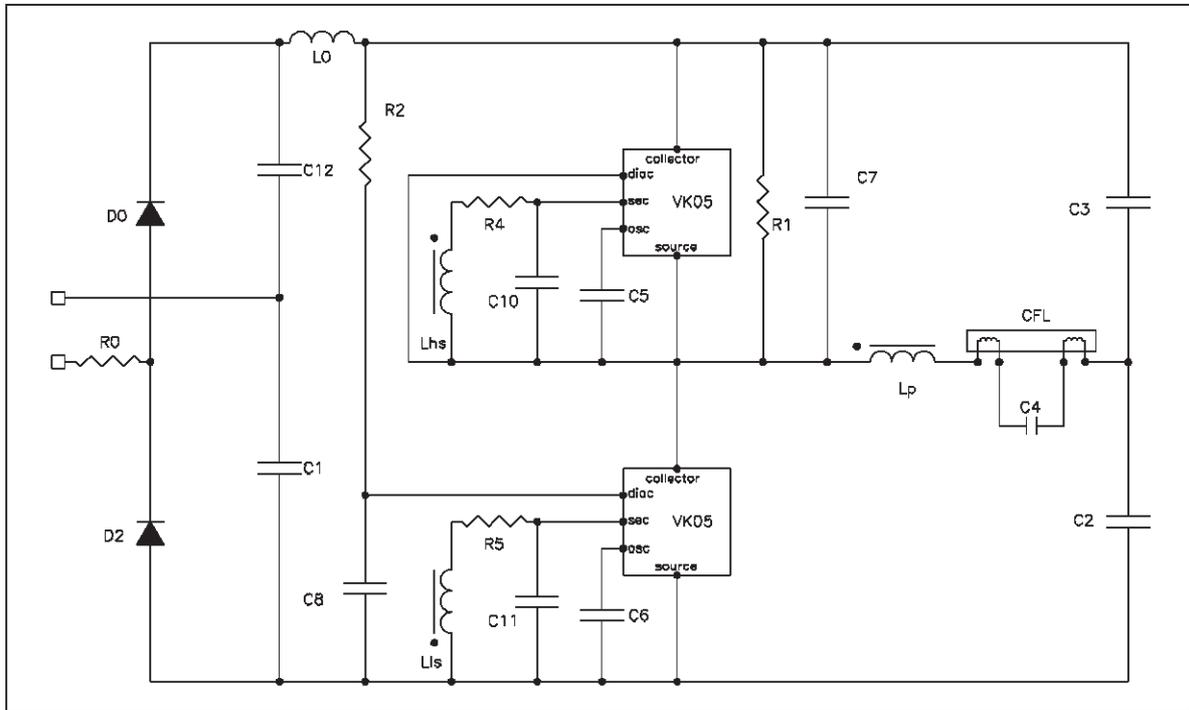
Figure 10: Bottom view(not in scale)



According to figure 7 (cool ignition method), in table 1 and table 2 the European market component list is reported.

For US market the electrical scheme becomes:

Figure 11: Application circuit for US market



In Table 3 and table 4 the US component list is shown.

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Table 1: European component list up 15 W

European market power lamp: 5W ÷ 15W	
Ref.	Value
T1	Lp = 3.1 mH; N1/N2= N1/N3= 10
Lo	820µH
D ₀ , D ₁ , D ₂ , D ₃	1N4007
C1	3.3µF 400V, Electrolytic capacitor
C2, C3	100nF, 250V
C4	2.4nF 630V
C5, C6	1.2nF 63V
C7	470pF 400V
C8	22nF 63V
C10, C11	1.5nF 100V
R0	10Ω, 0.5W
R1, R2	1MΩ, 0.25W
R4, R5	2.2kΩ, 0.25W
U1, U2	STMicroelectronics VK05CFL

Table 2: European component list 15 W ÷ 23W

European market power lamp: > 15W ÷ 23W	
Ref.	Value
T1	Lp = 2.1 mH; N1/N2= N1/N3= 10
Lo	820µH
D ₀ , D ₁ , D ₂ , D ₃	1N4007
C1	6.8µF 400V Electrolytic capacitor
C2, C3	100nF, 250V
C4	2.4nF 630V
C5, C6	1nF 63V
C7	470pF 400V
C8	22nF 63V
C10, C11	1.5nF 100V
R0	10Ω, 0.5W
R1, R2	1MΩ 0.25W
R4, R5	1kΩ, 05W
U1, U2	STMicroelectronics VK05CFL

If preheating cathodes is requested, according to figure 6 a capacitor C13=10nF 630V and a PTC are added to C4 capacitor.

T1 (Lp=3.1mH):

Supplier: **VOGT electronic AG**
 Inductance: **3.1 mH ± 5%**
 Drawing n°: **LL 001 023 41**

T1 (Lp=2.1mH):

Supplier: **VOGT electronic AG**
 Inductance: **2.1 mH ± 5%**
 Drawing n°: **LL 001 023 21**

Table 3: US component list up 15 W

USA market power lamp: 5W ÷ 15W	
Ref.	Value
T1	Lp = 3.1 mH; N1/N2= N1/N3= 10
Lo	820µH
D0, D2	1N4007
C1	10µF 200V
C12	10µF 200V
C2, C3	100nF, 250V
C4	2.4nF 630V
C5, C6	1.2nF 63V
C7	470pF 400V
C8	22nF 63V
C10, C11	1.5nF 100V
R0	10Ω, 0.5W
R1, R2	1MΩ, 0.25W
R4, R5	2.2kΩ, 0.25W
U1, U2	STMicroelectronics VK05CFL

Table 4: US component list 15 W ÷ 23W

USA market power lamp: > 15W ÷ 23W	
Ref.	Value
T1	Lp = 2.1 mH; N1/N2= N1/N3= 10
Lo	820µH
D0, D2	1N4007
C1	22µF 200V
C12	22µF 200V
C2, C3	100nF, 250V
C4	2.4nF 630V
C5, C6	1nF 63V
C7	470pF 400V
C8	22nF 63V
C10, C11	2.7nF 100V
R0	10Ω, 0.5W
R1, R2	1MΩ, 0.25W
R4, R5	1kΩ, 05W
U1, U2	STMicroelectronics VK05CFL

T1 (Lp=3.1mH):

Supplier:
Inductance:
Drawing n°:

VOGT electronic AG
3.1 mH ± 5%
LL 001 023 41

T1 (Lp=2.1mH):

Supplier:
Inductance:
Drawing n°:

VOGT electronic AG
2.1 mH ± 5%
LL 001 023 21

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11. EXPERIMENTAL RESULTS

In this section the evaluation of the dynamic board is reported. The results have been obtained considering the following conditions:

- | | |
|------------------------|---------------------------------------|
| a) Main voltage | $V_{\text{main}} = 230V_{\text{rms}}$ |
| b) Power lamp | $P_{\text{lamp}} = 23W$ |
| c) Ambient temperature | $T_a = 25^\circ\text{C}$ |

11.1 START-UP PHASE

Figure 12 shows the first cycle after the system switch-on; as it is possible to notice when the low side diac pin voltage reaches 30V the device switches on and the converter begins the oscillations. During the first cycle an integrated diode discharges the diac capacitor keeping the voltage low during a normal operation. When the main voltage is switched off, the system resets its state and the start-up network (R2-C8) is able to restart the converter.

Figure 12: $V_{\text{in}} = 230V$, Ch1= Mid point voltage, Ch2= diac voltage

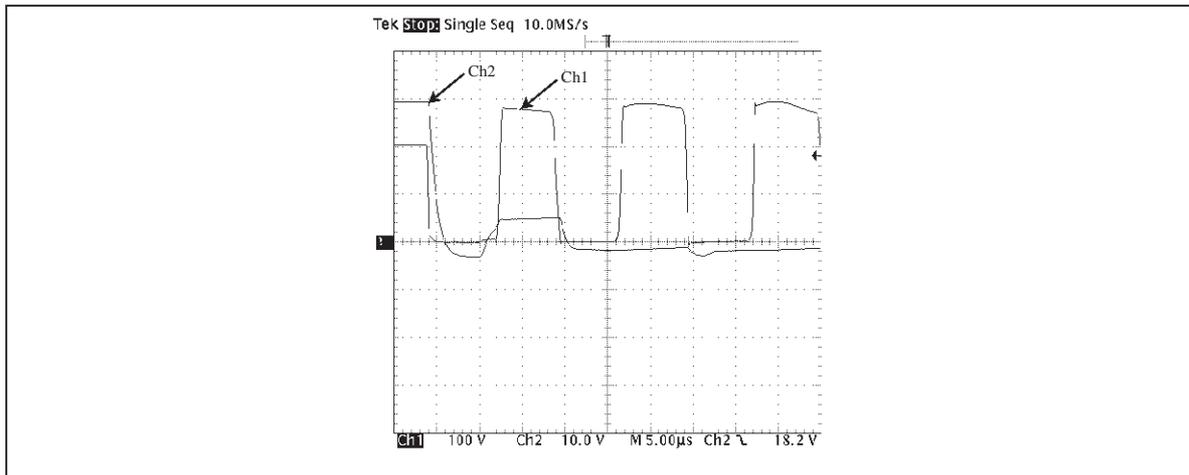
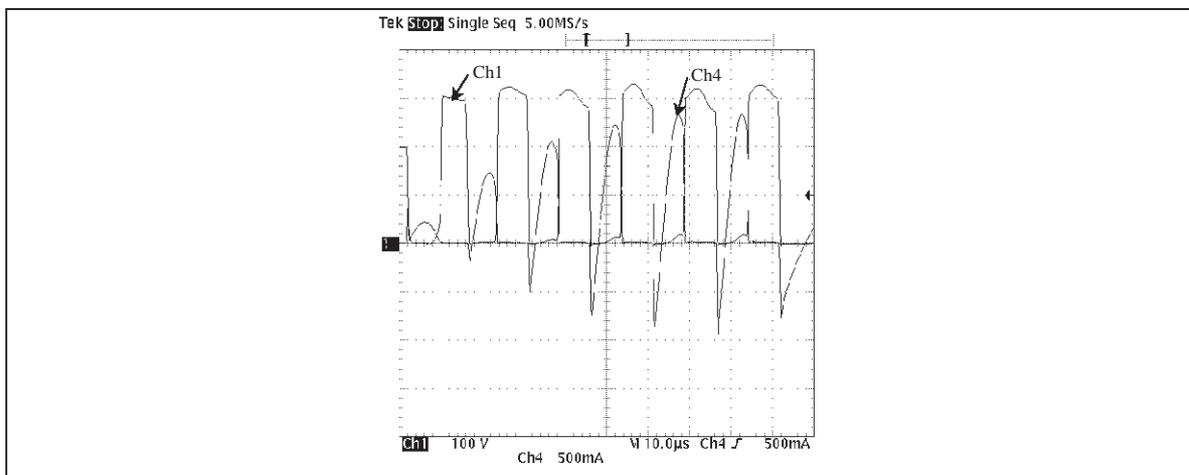
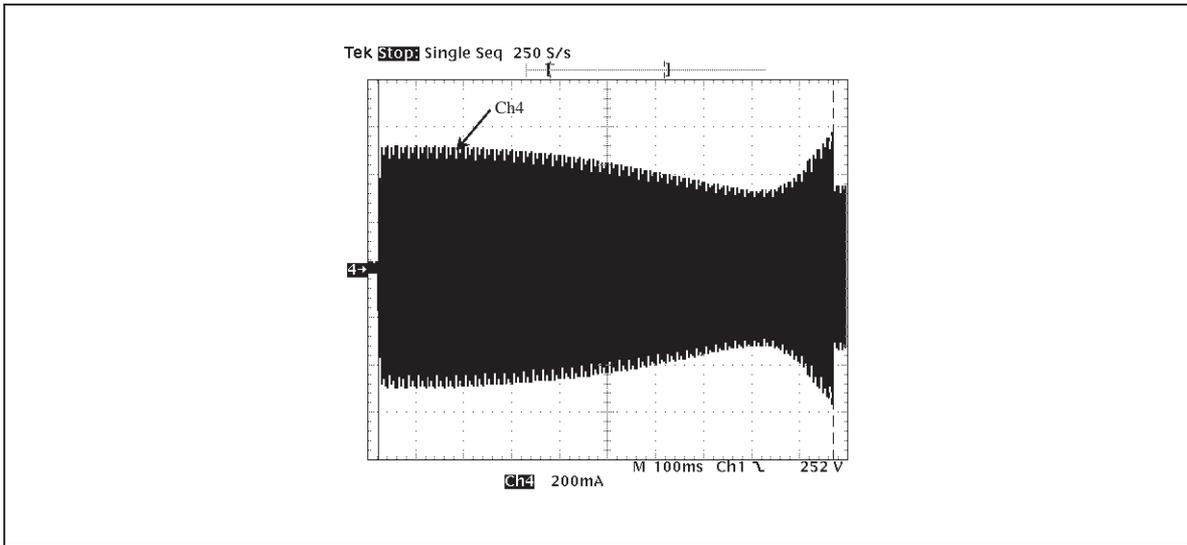


Figure 13: $V_{\text{in}} = 230V$, Ch1= Mid point voltage, Ch4= Collector device current



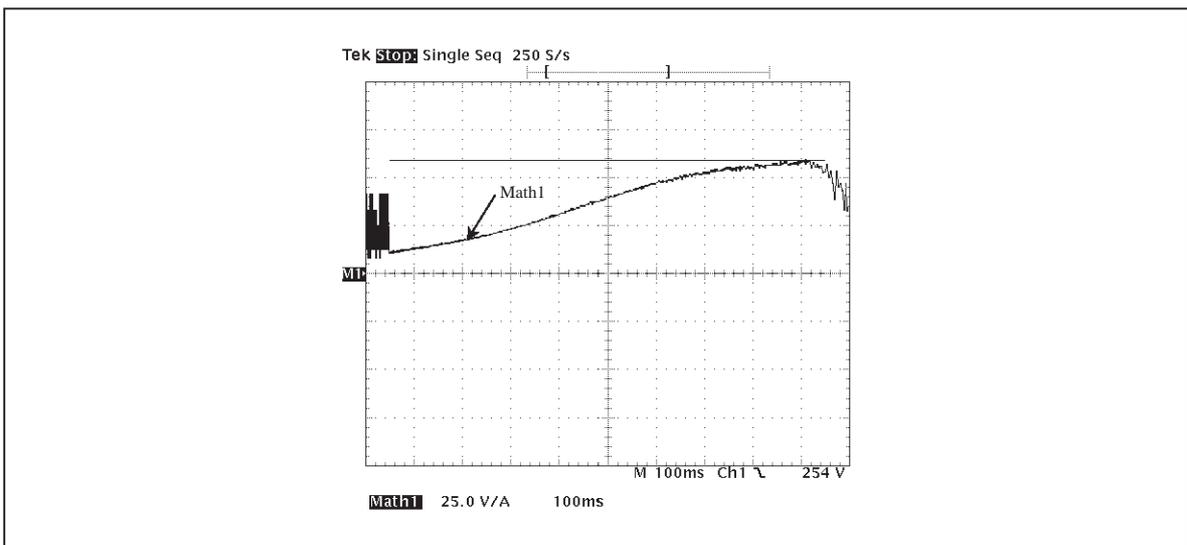
In figure 13 the start up phase with 23W lamp is shown using cool ignition method. The device current (Ch4) rapidly increases; after six cycles its value is able to generate an overvoltage to ignite the tube, using a start-up capacitor.

Figure 14: Vin = 230V, Ch4= Cathodes current during pre-heating phase



In figure 14 the start up phase using 23W lamp with warm ignition method is shown. The ignition time of the lamp is lower than 1s. The current lamp with pre-heating circuit is about 3 times lower than the cool ignition, ensuring the heating of the cathodes. Figure 15 shows the cathodes resistance variation in this phase. The hot/cold cathode resistance ratio is about 5.

Figure 15: Vin = 230V Math1 = Cathodes resistance during pre-heating phase

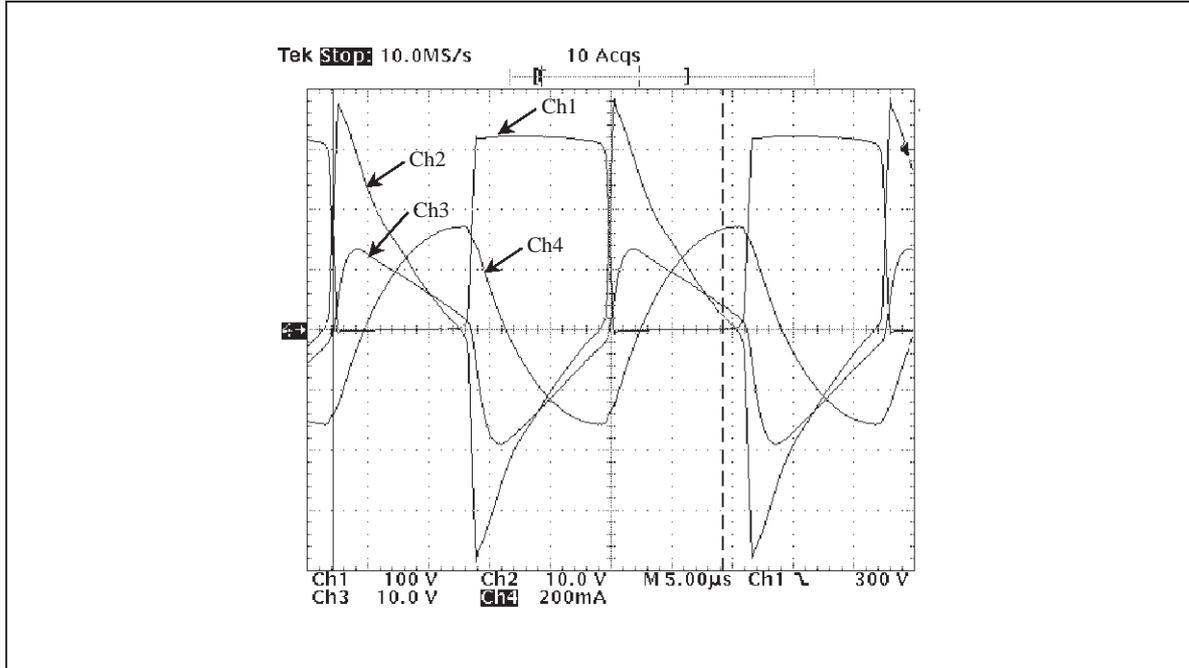


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11.2 STEADY STATE PHASE

In figure 16 steady state waveforms are shown.

Figure 16: $V_{in} = 230V$ Ch1= Midpoint voltage, Ch2= secondary winding voltage, Ch3= V_{k05} sec pin input voltage, Ch4= Lamp current.



The working frequency is 43 kHz with duty 50%. Using the proposed input filter the voltage at the end of the T_{on} is about 4.5 V. This condition allows to drive the converter from the capacitors' frequency in all the main voltage range.

11.3 THERMAL ANALYSIS

The thermal board analysis has been performed in order to verify the temperature of the real devices in the application. In order to sink the heat, the copper area dedicated is: Low side device: 128mm^2 ; High side device: 69mm^2 . In figure 17 the PCB + devices thermal map when 18W tube is driven is shown.

Figure 17 shows that the high side device temperature is 52°C and the low side device temperature is 55°C . The ΔT between the two devices is due to the presence of inductor pin soldered on the same copper area.

11.4 DEMOBOARD EFFICIENCY

Using a 23 W tube the demoboard efficiency has been estimated at 90%.

11.5 HARMONIC ANALYSIS

The FFT analysis has been performed on the board input current in order to evaluate its harmonic spectrum.

The analysis has been performed using TEKTRONICS oscilloscope. The setting of the input filter has been chosen to drive a 18W tube: $C_1=3.3\mu\text{F}$; $L_0=820\mu\text{H}$; $R_0=10\Omega$ satisfying IEC 6100-3-2 requirements. The input measured power is 19 W. In table 5, test results are summarized.

Figure 17: Vin = 220V; P2= High side device; P3= Low side device; Tube 18W

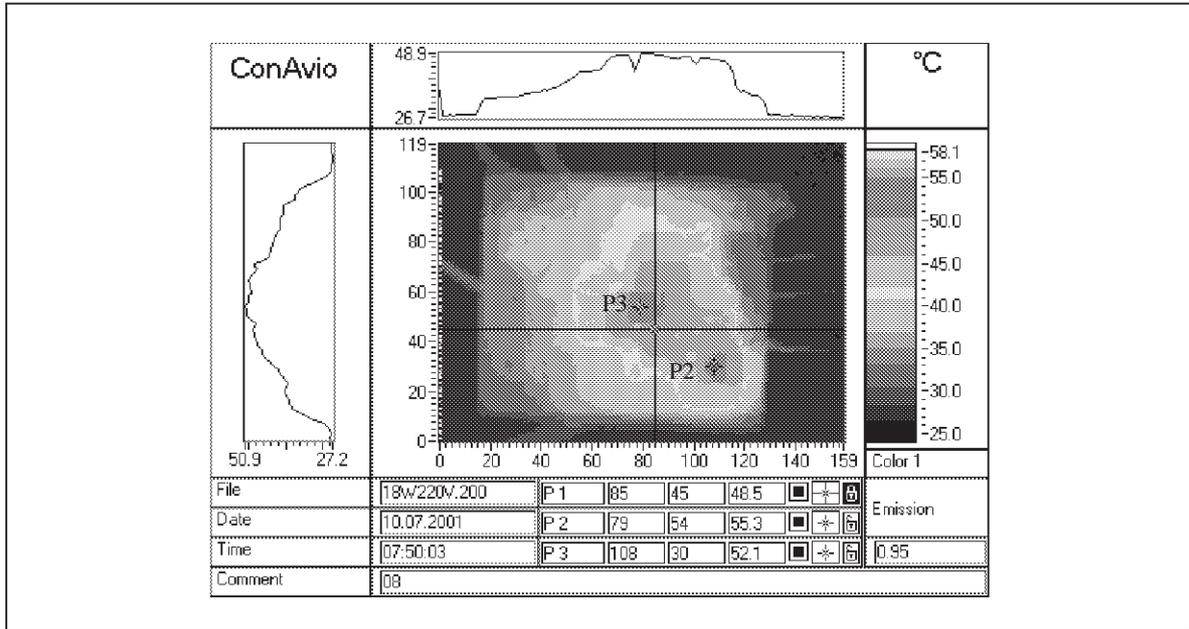


Figure 18: Vin = 220V; P2= Input current harmonic spectrum

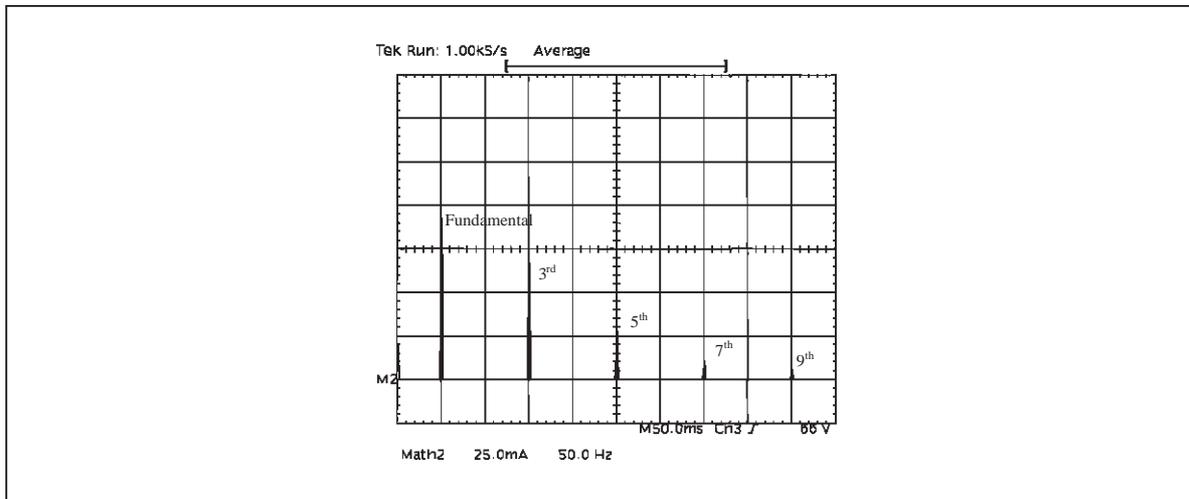


Table 5: Vin = 220V; Tube 18W. Harmonic current

Harmonic order	mA	mA/W	IEC limits mA/W
Fundamental	91	---	
Third	65	3.4	3.4
Fifth	27	1.42	1.9
Seventh	11.5	0.6	1
Ninth	4.5	0.24	0.5

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