SELF-OSCILLATING SOLUTION FOR CFLs WITH RESONANT DRIVING CIRCUIT

R. Scollo - F. Saya

1. ABSTRACT

Among electronically driven lighting equipment available today, compact fluorescent lamps are the most popular and widespread in the consumer market. These lamps offer at least three times higher light output per watt when compared to traditional incandescent lamps. As a consequence, the significant associated energy saving, coupled with a very simple and cost-effective electronic design, is contributing to the success in the market of the compact fluorescent lamps making their yearly growth rate higher than 20%. The numerous solutions currently adopted or under investigation are mainly focused on cutting costs and to further miniaturize the electronic circuit associated to the lamp. This paper describes, after a brief introduction on low-pressure lamp operative conditions, a 25W cost-effective compact fluorescent lamp ballast in a half bridge voltage fed topology.

The proposed solution works by using two auxiliary windings on the inductor in series with the lamp. The aim is to generate the waveform of the resonant driving circuit. The proposed solution allows lamp ballast designers to eliminate the saturable core auxiliary transformer, as well as the start-up network. A comparison with the more traditional self-oscillating topology with auxiliary transformer has also been done. The cost benefits achieved without sacrificing the performance or reducing the expected lifetime of the lamps are evident.

2. COMPACT FLOURESCENT LAMPS.

Figure1: Typical I-V Characteristic of a Low-pressure Fluorescent Lamp at Start-up
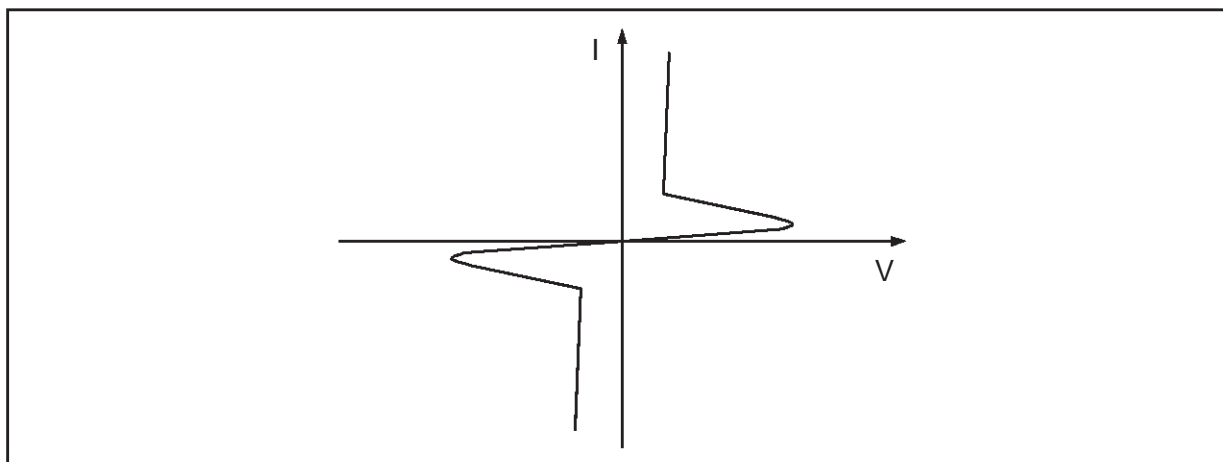
Fluorescent lamps are generally made with a tube filled with a mercury based gas mixture at low pressure. The inner side of the tube is covered by phosphorus or other similar fluorescent elements. At turn-on the two electrodes of the lamp start to warm up and to emit ions that contribute to fully ionize the

gas mixture inside the lamp, facilitating the primer of the arc across the two electrodes. Electrically the resistance of the lamp falls from about one MOhm down to a few hundred Ohms as illustrated in the I-V characteristic of a typical low pressure fluorescent lamp (see figure 1).

Once the arc is established, the mercury gas emits radiations in the ultraviolet spectrum that excites the phosphorous coating in the inner side of the lamp. At this time the phosphorous starts to fluoresce producing the light in the visible spectrum.

Compact fluorescent lamps usually require about 600V as peak voltage to strike the arc. Once the arc is established about 100V are enough to sustain it.

In order to avoid the cataphoresis effect, the lamp has to be supplied with sinuosidal waveforms by means of an inductor, the ballast, connected to a DC to AC converter. A capacitive filter is also included to further remove any DC components of the relevant waveforms.

From figure 1 it is also evident that the voltage across the lamp is never equal to the main voltage: at start-up it is much higher, while in the steady state it is quite lower. Consequently, the ballast has the important function to generate the high voltage needed to strike the lamp and after to generate the inductive reactance needed to reduce the voltage across the lamp. Furthermore, the value of inductance L of the ballast must be chosen so that it does not saturate at the operative current of the lamp, even at high temperatures.

The I-V characteristic shown in figure 1 is valid only at start-up or for any traditional magnetic ballasts working at main frequency. In fact, the negative slope in the characteristic occurs at every cycle near the zero crossing of the current. This is due to the de-ionization of the gas.

Figure 2: I-V Characteristic of a Low-pressure Fluorescent Lamp (Switching Frequency > 20kHz)
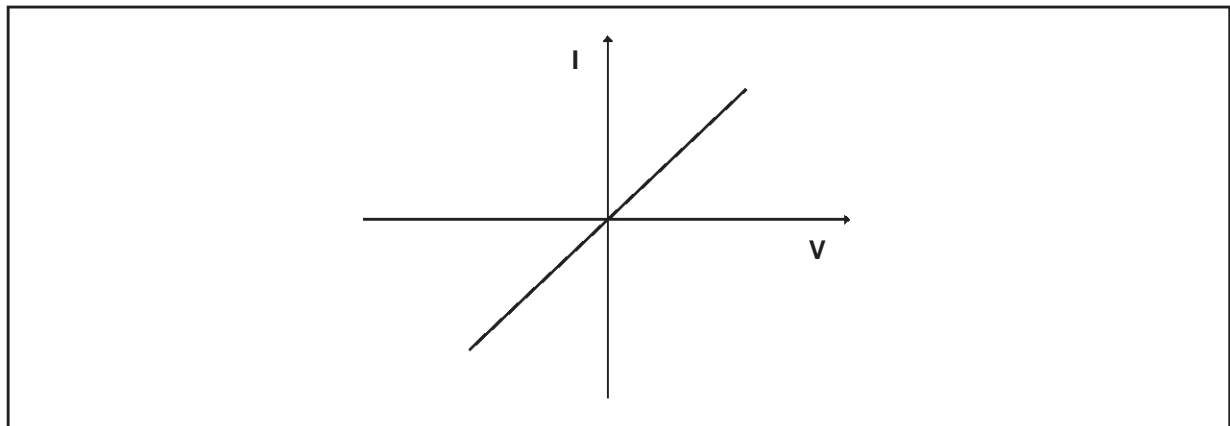

This causes a non-visible 50 or 60Hz flicker effect that can be eliminated by increasing the switching frequency (about 3 order of magnitude). In fact, at frequencies higher than 20kHz there is no time for the de-ionization of the gas, so the characteristic of the arc results linear as shown in figure 2. Also, the higher frequency adoption brings other two important benefits:

- The no de-ionization of the gas leads to lower power consumption (typically 70%) with a consequent longer lifetime of the lamp.

- The inductor in series to the lamp results smaller with a consequent reduction of the weight of the system.

Figure 3: Schematic Block Diagram of an Electronic Ballast for CFL
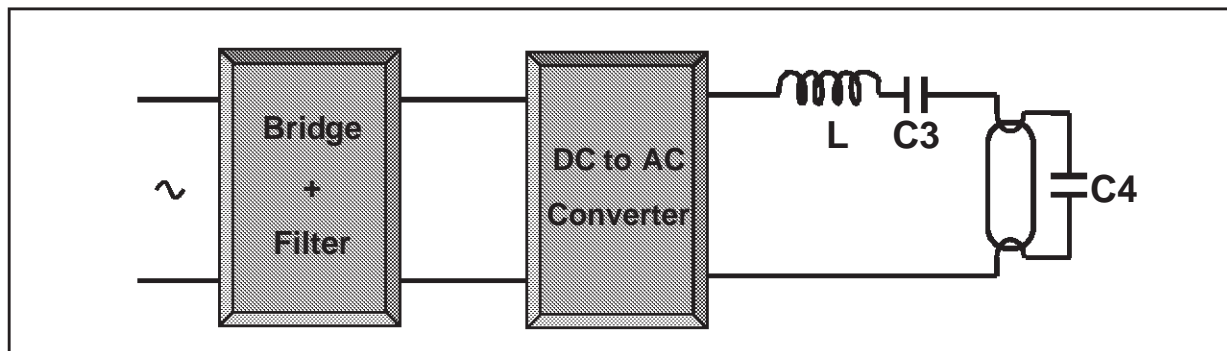
A simplified block schematic diagram is shown in figure 3. It describes a lamp ballast voltage fed topology. In fact, the tube is fed by generating an over-voltage across the capacitor C4 through the circuit formed by the series L, C3 and C4. At start-up the lamp is an open circuit and, since C4 is much smaller than C3, it is C4 that imposes the resonant frequency of the circuit. The imposed over-voltage is high enough to ionize almost instantaneously the gas in the lamp. Once the lamp is on the capacitor, C4 is short circuited by the lamp itself and the natural frequency is determined mainly by the capacitor C3, the working frequency of the circuit is higher and is determined by the DC-AC converter.

3. THE DC-AC CONVERTER.

**Figure 4: CFL Ballast Circuit Based on a Self-oscillating Voltage Fed Topology**
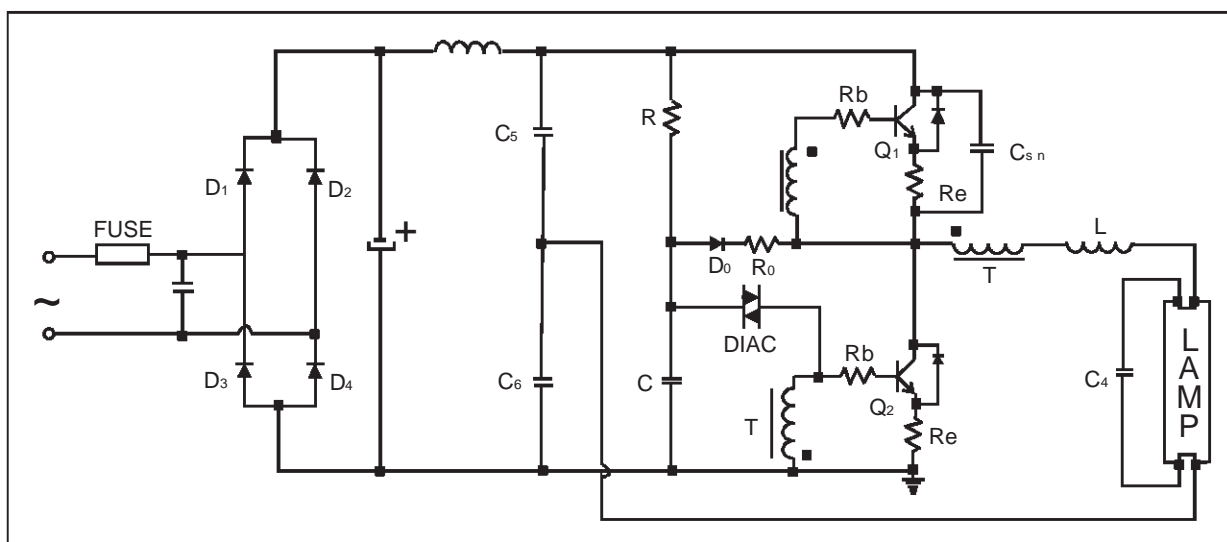
The core of the electronic ballast is the DC to AC converter. In order to describe the basic functions of this converter it is better to refer to the circuit in figure 4. In this circuit the capacitor C3 has been substituted by the two capacitors C5 and C6 (with identical capacitance) to better balance the circuit. At start-up resistor R, capacitor C and the diac supply the first input base current to the transistor Q2. After the start-up the diode Do inhibits the diac and the circuit is maintained in oscillation by the feedback to

the base of the bipolar transistor via the transformer T. In fact, as soon as the transistor Q2 is on the current in the primary of transformer T (that is a ferrite ring with saturable core) starts to increase until the core is fully saturated. At this point the feedback on the base of the transistor is removed and after its storage time the transistor results switched off. In the mean time the feedback of the transformer acts to switch on the transistor Q1. It is evident that once the value of the capacitor C5, and consequently C6, is fixed (according to the power lamp and the range of frequencies to be utilized), the parameters to be taken into consideration in order to correctly fix the operating frequency are:

- The maximum flux density of the core of the transformer
- The storage time of the transistors.
- The resistors in series with the emitter of the transistors.

Figure 5: Waveforms for a Self-oscillating CFL Drive Circuit
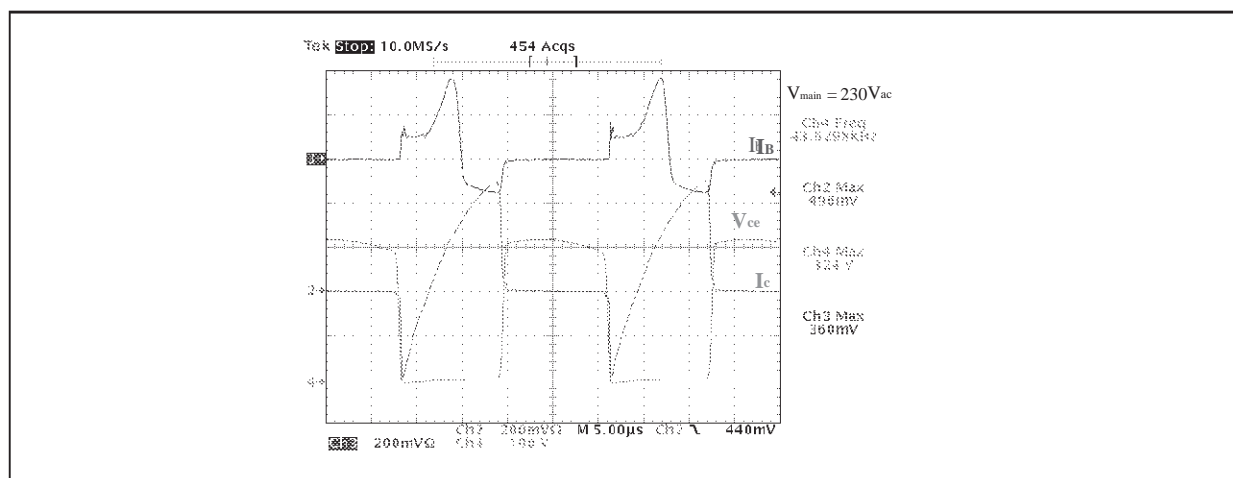

Figure 6: Switch-off Particular
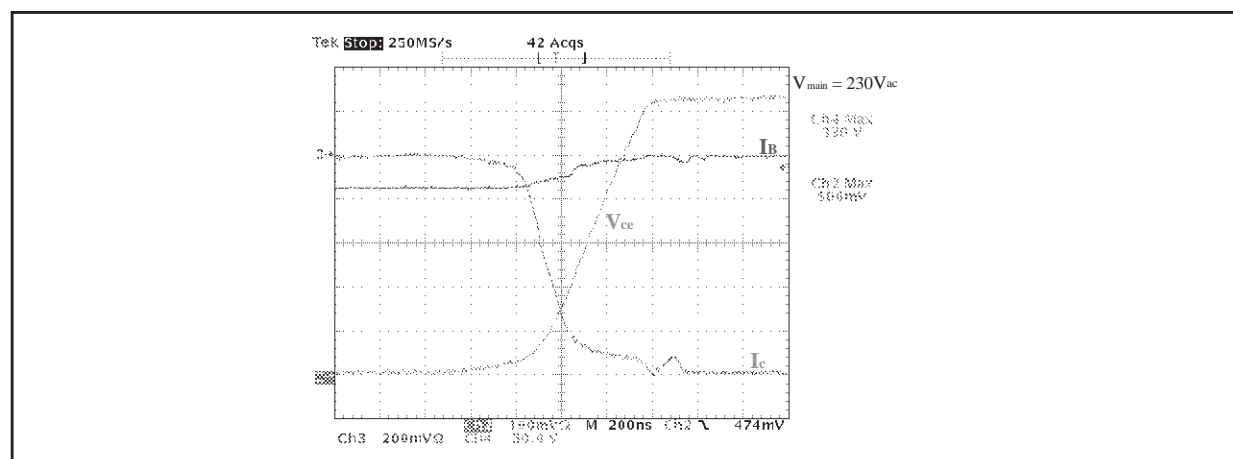
Practical considerations impose that the spread of storage time of the selected transistors must be tight and known. Also the variability of the magnetic flux in the core of the transformer must be taken into consideration to correctly dimension the circuit for the worst-case conditions. Figure 5 shows, as an example, the steady state waveforms related to a 25W, 50Hz - 220V mains CFL driven with the self-oscillating topology before described. Figure 6 illustrates a switch off particular for the same waveforms

depicted in figure 5.

4. THE RESONANT DRIVE SOLUTION

**Figure 7: A Resonant Driving Circuit**
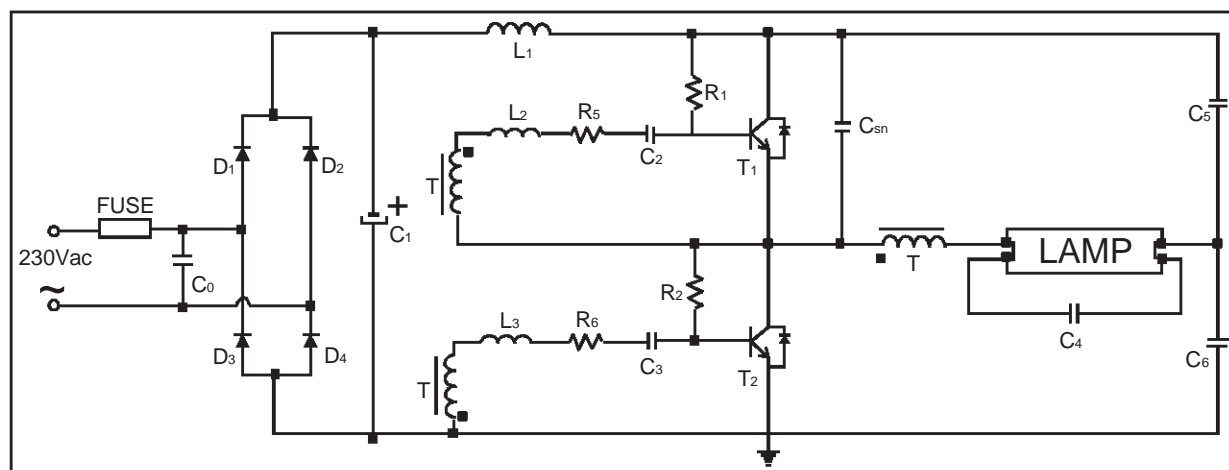
The main objective of the proposed solution is to get free ballast designers of the above-mentioned variability of the saturation in the transformer as well as from the spread of storage time of the transistors. In particular, the suggested driven circuit allows compact fluorescent lamp ballast designers to get rid of the transformer T in figure 4: the feedback to the transistors will be ensured through a modification of the ballast by using two auxiliary wires as shown in figure 7. These additional wires accomplish the task to supply the voltages needed for the base driving of the two transistors. The obtained transformer T must not saturate at the current level needed by the lamp, the working frequency is now achieved by the RLC circuit in series with the base of each transistor with resonant effect.

Furthermore, thanks to the capacitor in series with the base of each transistor, two resistors connected between the collector and the base of each transistor can easily substitute the start-up network formed by the diode, the capacitor and the diac in figure 4. In fact the capacitor in series with the base acts as high impedance element during the first instant of the start-up. To work well this kind of circuit prefers low driving currents, the bipolar transistors to be used must have high gain (typically in normal operation they must work with a forced gain ranging from about 10 to 20). In fact, since the inductance in series with the base of the transistors is high (about 220µH) the losses associated with the input circuit can be minimized only through a Iboff as low as possible.

Some important considerations come out from the comparison of the switching waveforms related to the two driving circuits. To make the results consistent with the same bipolar transistor, the BULD118D-1, has been chosen for both topologies. The two circuits drive the same lamp. The base current in figure 5 exhibits the typical behavior related to the storage time of the transistor, in particular the Iboff assumes the rectangular shape visible in figure 5.

Figure 8: Resonant Driving Waveforms
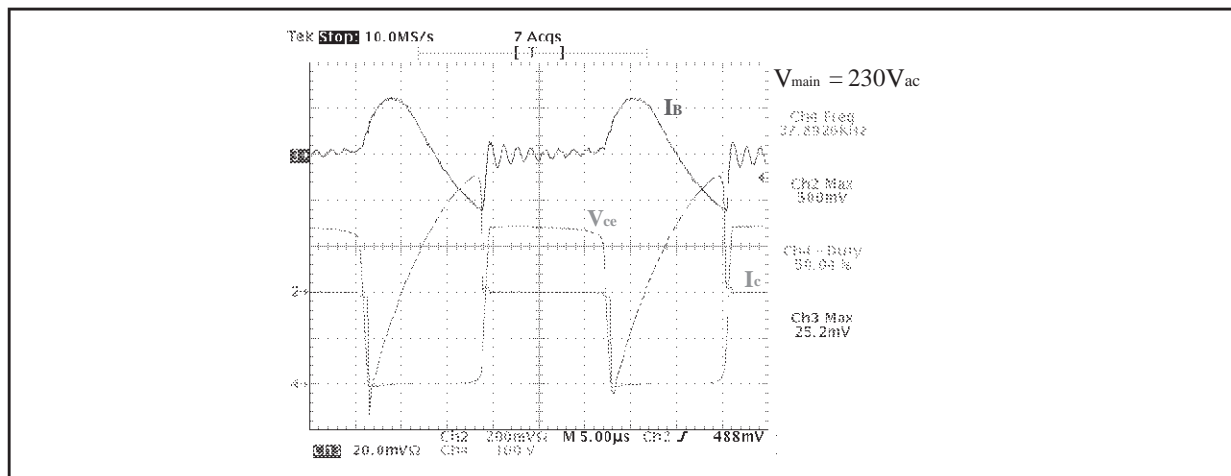
In the circuit the transistors work with forced gain equal to four to establish the correct storage time and to ensure at the same time that the current on the secondary of the transformer is high enough to not saturate quickly, in order to achieve the requested working frequency.

Figure 9: Switch-off Particular
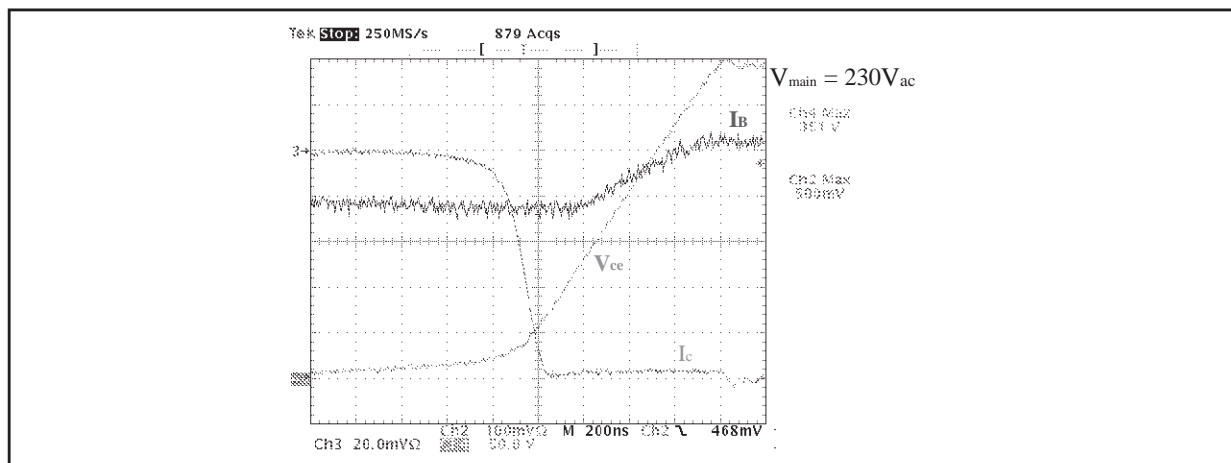
The resonant driving circuit in figure 8 imposes the extraction of the charges from the base, making less important any consideration about the storage time of the transistors. The base current now assumes the triangular shape illustrated in figure 8. The main advantage of this is evident comparing the switch off behavior shown in the figures 6 and 9: the effect of the variation of the storage time in the resonant drive solution is drastically reduced leading the transistors to operate with good switching performances.
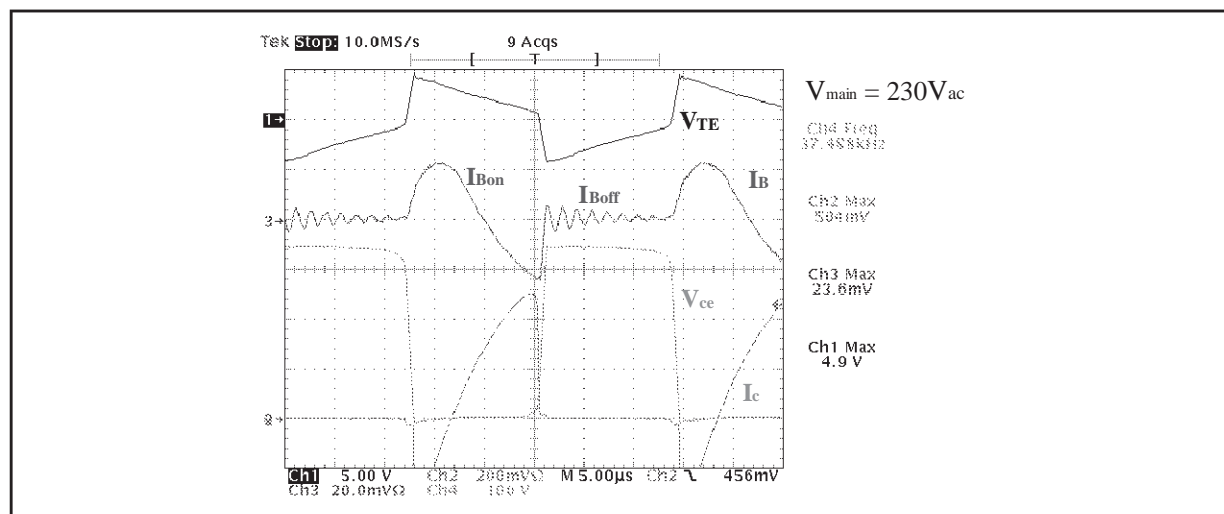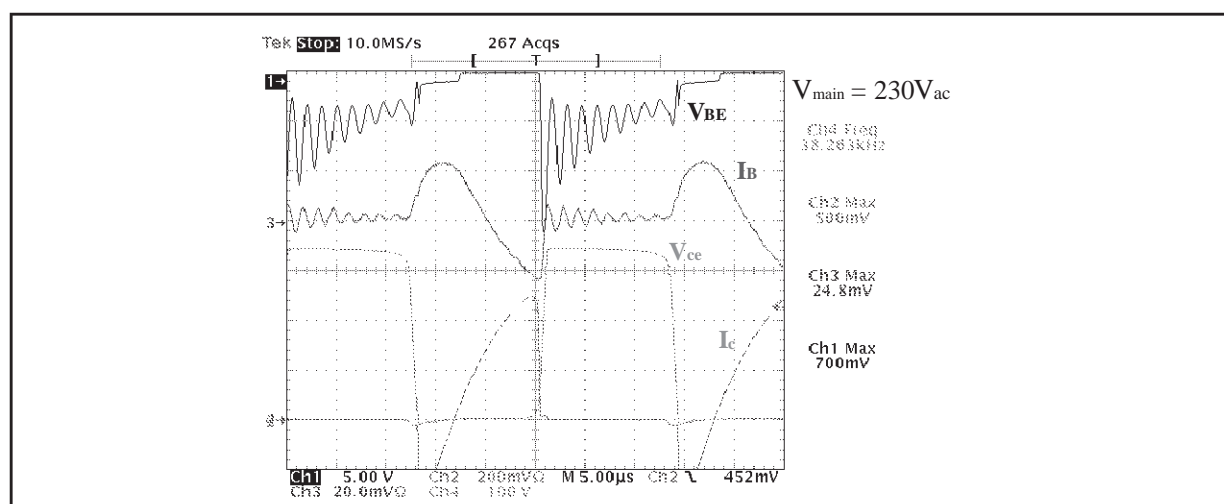
Figure 10: Resonant Driving Waveforms

Figure 11: Resonant Driving Waveforms

To better understand how the resonant driving circuit works we can refer to figure 10, where the waveforms related to the input circuit have been reproduced.

The V_{TE} is the voltage across the transformer referred to the emitter of the bipolar transistor in figure 7. This assumes the quasi-trapezoidal behavior depicted in figure 10. Consequently, the base current I_B associated to the RLC input circuit shows a sinuosidal behavior during the on-state (I_{BON}). The base current shows also some oscillations across the zero during the off-state (I_{Boff}). These oscillations are not dangerous since the circuit imposes the voltage between the base and the emitter of the bipolar (V_{BE}) to never exceed -2V as shown in figure 11. This implies that even in the presence of small input currents re-conduction does not occur during the off-state.

5. CONCLUSION

The resonant drive circuit has been successfully tested in a 25W compact fluorescent lamp. The proposed circuit not only cuts the cost of the board but is able also to simplify the circuit and reduce the design time window freeing the designers to test the circuit with limit sample transistors in storage time needed to properly fix the switching frequency and the input circuitry.

APPENDIX 1

List if the components used in the resonant driving circuit

SYMBOL	NAME / VALUE
$D_1 = D_2 = D_3 = D_4$	1N4005
C_0	47nF
C_1	22μF, 350V
TR_1	2mH
$C_2 = C_3$	100nF
$C_5 = C_6$	220nF, 400V
$L_2 = L_3$	220μF
$R_1 = R_2$	150KOhm
$R_5 = R_6$	56KOhm
$T_1 = T_2$	BULD118D-1
C_4	8.2nF, 1000V
C_{sn}	1nF

APPENDIX 2

Suggested bipolar transistors in CFL applications

TOPOLOGY	Part Number	Package	CFL Power Range
Self-oscillating	STBV68	TO-92	7W - 9W
	STBV45	TO-92	9W - 11W
	STBV42	TO-92	11W - 13W
	STBV32	TO-92	13W - 17W
	ST13003	SOT-32	17W - 20W
	BUL118	TO-220	20W - 25W
	BUL128D-B*	TO-220	>25W
Resonant	BULD118D-1*	IPAK	Up to 25W

*The suffix D indicates integrated freewheeling diode

STMicroelectronics GROUP OF COMPANIES
Australia - Brazil - China - Finland - France - Germany - Hong Kong - India - Italy - Japan - Malaysia - Malta - Morocco - Singapore - Spain - Sweden - Switzerland - United Kingdom - U.S.A.

http://www.st.com