APPLICATION NOTE

Self Oscillating Circuit for CFL10W and CFL18W Lamps

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TP97036.2/F5.5

Abstract

A description is given of a self oscillating CFL circuit (demo board PR39742), which is able to drive a standard Philips PL-C10W and PL-C18W lamp or similar lamp types. The circuit is based on a Voltage Fed Half Bridge Inverter topology. It is designed for a nominal mains voltage of 230 V_{rms} *where instant-start is applied for instant light output. The Half Bridge switching devices are the bipolar power switching transistors of type BUJ100. The BUJ100 is driven and controlled by a driver transformer. The driver transformer saturates at a defined current level so that the lamp current is controlled in an indirect way. The key drivers for this design are very low cost and low component count.*

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Keywords

Self Oscillating Circuit
Instant-Start
BUJ100
Driver Transformer
CFL
PL-C10/18W

Number of pages: 19

Date: 99-11-22

Summary

In the underlying report a description is given of an electronic instant-start CFL[1] circuit. Furthermore, a printed circuit board is available (PR39742).

The circuit is a Voltage Fed Half Bridge, which has been optimized to drive a standard Philips PL-C10W and PL-C18W lamp or similar lamp types. The circuit has been designed for respectively 11W and 18W input power at a nominal mains voltage of 230 V_{rms}, 50 Hz. The circuit is of the instant-start type to achieve instant light output.

The mains voltage operating range is 200 - 250 V_{rms}. The circuit is able to ignite from a mains voltage down to 150 V_{rms}.

One of the key components is the BUJ100 bipolar power switching transistor. The BUJ100 is designed for use in Compact Fluorescent Lamp circuits and/or low power electronic lighting ballasts. Furthermore, a driver transformer (ring core) is used to drive and control the switching transistors. The driver transformer saturates at a defined current level so that the lamp current is controlled in an indirect way.

1. CFL = Compact Fluorescent Lamp

CONTENTS

1. INTRODUCTION

A very low cost electronic CFL circuit has been designed, which is able to drive a Philips PL-C10W[1] and PL-C18W lamp or similar. A voltage fed half bridge inverter has been chosen as lamp driver circuit. The inverter has been designed for a nominal input voltage of 230 V_{rms} and 50 - 60 Hz. The key component in this circuit is the BUJ100 bipolar switching transistor. Furthermore, a driver transformer is used to drive and control the switching transistors. The driver transformer saturates at a defined current level so that the peak current through the ballast coil is controlled. As a consequence, the lamp current is controlled due to the fact that the ignition capacitance is negligible during the burn phase.

The key drives for this design are a very low cost and low component count CFL application.

2. CIRCUIT & SYSTEM DESCRIPTION

2.1 Block Diagram

The CFL circuit has been designed for a nominal mains voltage of 230 V_{rms}, 50 - 60 Hz. The mains voltage operating range is 200 - 250 V_{rms}. Basically, the circuit consists of three sections: AC bridge rectifier, EMI filter and the half bridge inverter. Figure 1 shows the block diagram of the circuit. The complete schematic diagram is given in figure 4 on page 12.

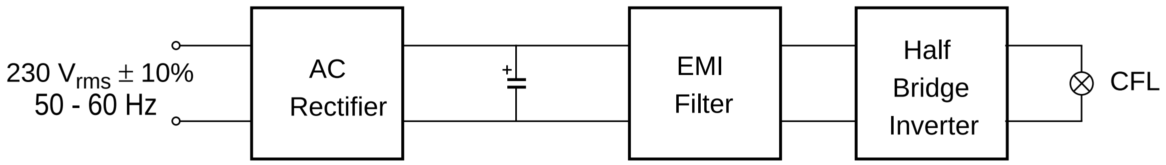


Fig.1 Block Diagram CFL circuit

The AC mains voltage is rectified by four bridge rectifying diodes D1, D2, D5 and D6 and smoothed by the buffer capacitor C4 to get a DC supply voltage for the half bridge inverter. An EMI-filter formed by L1, C1 and C5 is used to minimise the disturbance towards the mains. The half bridge inverter is of the voltage fed type belonging to a group of high frequency resonant inverters, which are very attractive to drive lamp circuits. They can achieve a high efficiency, due to the ZVS[2] principle, so that switching losses of the two switching transistors TR1 and TR2 is substantially reduced.

2.2 Half Bridge Inverter

The circuit is of the **instant-start** type to obtain almost immediate light output. When the mains voltage is applied to the circuit, the startup circuit (§ 2.3) generates a start pulse and the circuit will generate a high AC voltage across the igniter capacitor (§ 2.4) which is connected in parallel with the lamp. Normally, the lamp will breakdown and the circuit operates in the burn phase (§ 2.5).

2.3 Startup Phase

After switch on of the system, the rectified mains voltage is applied to the buffer capacitor C4 via inrush limiter R5. The buffer capacitor smooths the ripple voltage, caused by the (doubled) mains frequency. The result is a high DC voltage V_{hv}, which is an input for the half bridge inverter (power components: TR1, TR2, D3, D8, L2, C3, the lamp, C1 and C5).

1. PL-C = CFL lamp type of Philips
2. ZVS = Zero Voltage Switching

During the startup phase, capacitor C6 is charged, out of the high DC voltage V_{hv}, via the resistor R2. As soon as the voltage across C6 reaches 32 V, diac D7 will breakdown and TR2 is switched on. Resistor R3 takes care that the half bridge voltage is set to V_{hv} before the diac is triggered. Now, the half bridge midpoint voltage changes rapidly from V_{hv} to zero so that a positive voltage is applied to the secondary winding T1-3 and keeps TR2 conducting. After switch-on of TR2, diode D4 discharges C6 to prevent double triggering of TR2. Now the circuit is oscillating and the start circuit is deactivated by diode D4.

2.4 Ignition Phase

After start, L2 and C3 form a series resonance circuit which is able to generate a large voltage across C3. The worst case ignition voltage of both lamps is about 900 V_{pk} for low temperatures. The combination of ballast coil L2 and igniter capacitor C3 has been chosen in such a way that the voltage across the lamp can exceed this high level while the current through the BUJ100 is smaller than 1A. The circuit is able to re-ignite for mains voltages down to 150 V_{rms}.

2.5 Burn Phase

After ignition, the lamp will become low ohmic and is set to the operating point by the ballast coil L2 at a given operating frequency in this case 28 kHz.

The steady state operating point of the lamp used in the 11W circuit is 50 V_{rms} and 190 mA_{rms} resulting in a lamp power of 9.5 W. The operating point of the lamp used in the 18W circuit is 80 V_{rms}, 210 mA_{rms} and 16.5 W.

The value of the ballast coil L2 is determined by the lamp operating point and the operating frequency which is approximately 28 kHz at a nominal input of 230 V_{rms}. During burn, the impedance of the igniter capacitance C3 is high compared to the lamp impedance so that the influence is regarded negligible.

It can be calculated that for the actual value of L2, the total circuit delivers the desired lamp power at 28 kHz. The result is that an inductance of 3.6 mH and 2.8 mH is needed as ballast coil for respectively the 11W circuit and 18W circuit, see appendix 1 for detailed calculations. An igniter capacitor of 2.2 nF performs very well for proper ignition.

2.6 Power Components

The electrolytic capacitor C4 is of the FC series of SANYO because of its small dimensions.

The applied power transistors TR1 and TR2 are of the type BUJ100[3]. The switching losses of the two power transistors are reduced to a minimum, due to the Zero Voltage Switching principle. The duration of the ignition phase is rather small so that the choice of the transistor type is determined by the ballast coil current in the burn phase. The maximum peak current through TR1 and TR2 during ignition should be lower than 1.5 A. The BUJ100 is available in a TO92 envelope.

The ballast coil L2 is of Philips type CE167v. This is a compact coil that suits the small dimensions in CFL circuits.

The driver transformer T1 consists of three coupled inductors T1-1 through T1-3 on a ring core. The core material is 3E5 and the ring core type is TN10/6/4. The primary winding T1-2 saturates and is used to drive the secondary windings T1-1 and T1-3. The secondary windings behave like a voltage transformer in this circuit. The dimensioning of the driver coil is given in table 1 and a drawing in figure 2.

The ignition capacitor C3 of 2.2 nF/1 kV is a ceramic disk capacitor of Philips low loss type designed for applications where high capacitance per volume is desired.

3. A BUJ100 type with integrated reverse diode is available as BUJ***D***100

Circuit	N_{s1}	N_p	N_{s2}
CFL10W	4	4	4
CFL18W	4	3	4

Table 1 Dimensioning of Driver Coil T1

.

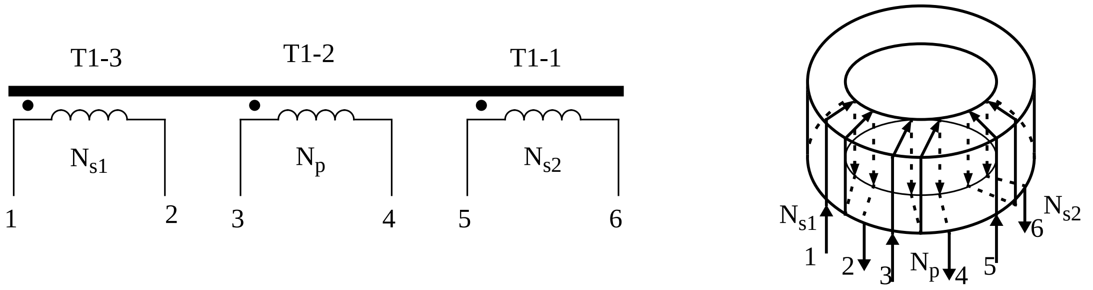


Fig.2 Driver Transformer T1

2.7 Operating Frequency

In general, the operating frequency f_{op} is set by the driver transformer T1 and the emitter resistors R4 and R7, see figure 2 and 3. The primary - and secondary turns N_p and N_s of T1, the core material of T1 and the emitter resistors R4 and R7 are the parameters to adjust f_{op} to the desired value. Besides the electrical parameters, the ambient temperature T_{amb} will have an effect on f_{op} by means of transistor storage-time variation Δt_{st}, transistor base-emitter voltage variation ΔU_{be} and variations in the ferrite core saturation level ΔI_{sat} (~ ΔH_{sat}).

The individual effects of the electrical parameters to determine the frequency operating point f_{op} are:

- The ballast coil current I_{L2} flows through the primary windings N_p of T1-2 and determines the moment of the core saturation I_{sat} (the influence of the secondary transformer current is negligible). An increase in N_p gives a decrease in I_{sat} so f_{op} will increase when N_p increases.
- The drive voltage for the BUJ100 is proportional to the secondary windings N_s. An increase in N_s gives a decrease in f_{op}.
- The core material is principally characterised by the permeability μ and the magnetic field at saturation H_{sat}. The drive voltage is proportional to μ and I_{sat} is proportional with H_{sat}. An increase in μ gives a decrease in f_{op} and an increase in H_{sat} gives also a decrease in f_{op}.

The influence of the ambient temperature T_{amb} is:

- The effect of ΔT_{amb} on the storage charge ΔQ_{st} in the BUJ100 is proportional so the storage time t_{st} will increase when T_{amb} increases. This means that an increase in T_{amb} gives a decrease in f_{op}.
- The effect of ΔT_{amb} on the base-emitter voltage ΔU_{be} of the BUJ100 is inverse proportional so U_{be} will decrease when T_{amb} increases. This means that an increase in T_{amb} gives a decrease in f_{op}.
- The effect of ΔT_{amb} on the flux density ΔB in the ring core is inverse proportional so the drive voltage will decrease when T_{amb} increases. This means that an increase in T_{amb} gives a increase in f_{op}.

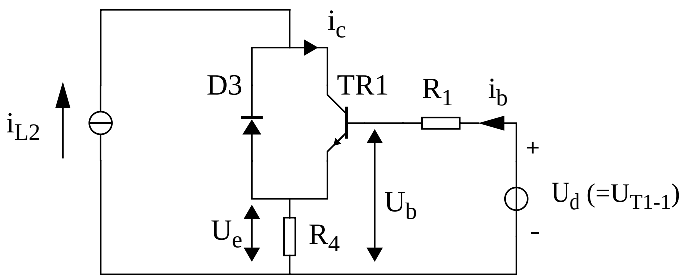


Fig.3 High Side Drive Circuit

3. PCB

The CFL circuit is designed and available on printed circuit board **PR39742** using leaded components. In this chapter the schematic diagram, layout, and parts list are given.

3.1 Schematic Diagram

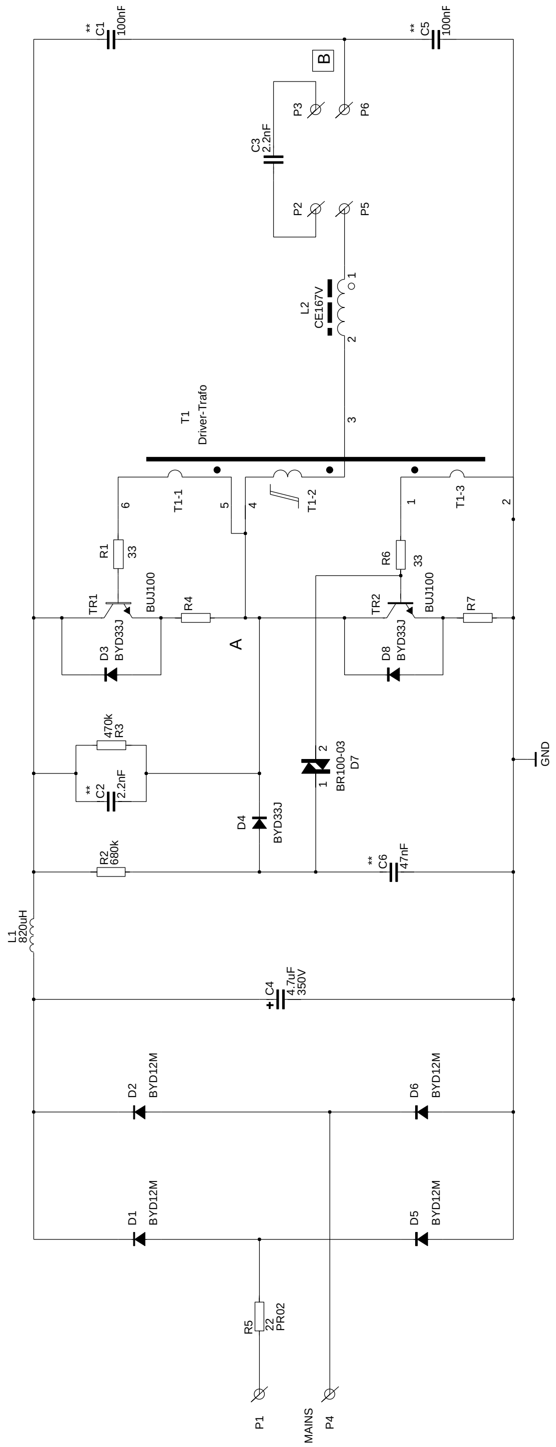


Fig.4 Schematic Diagram Circuit

3.2 Layout

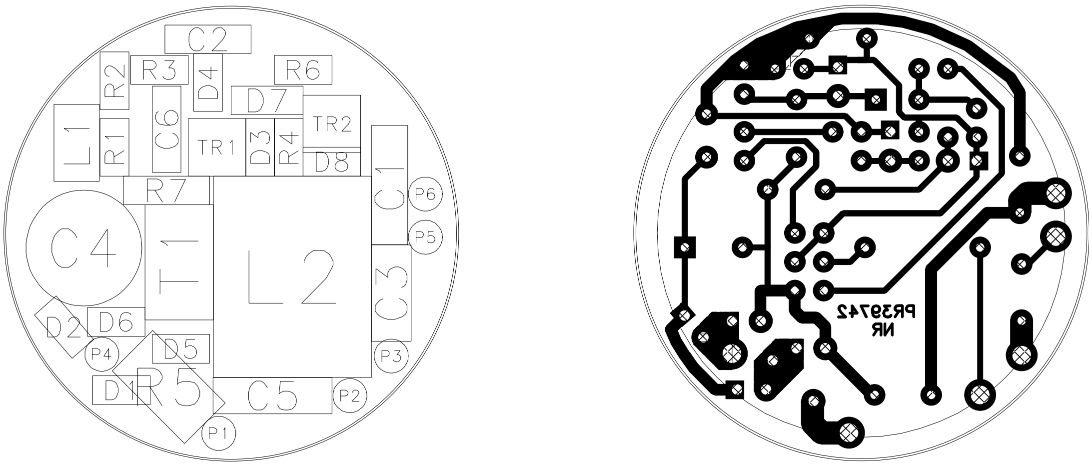


Fig.5 Component- and Copper Side of PR39742

The actual diameter of the PCB PR39742 is 4 cm.

3.3 Parts List

Component	Value	Rating	Type	Philips Order Code (12nc)
Components for the 11W board				
C1, C5	100nF	250 V	MKT 465	2222-465-90001
C2	2.2nF	400 V	MKT 370	2222-370-65222
C4	4.7µF	350 V	Elcap	SANYO
C3	2.2nF	1000 V	Cer. Disc. Low Loss	2252-701-15226
C6	47nF	100 V	MKT 370	2222-370-21473
R5	22Ω	2W	PR02	2306-198-13229
R2	680kΩ		SFR25H	2322-186-16684
R3	470kΩ		SFR25H	2322-186-16474
R4*, R7*	1.5Ω		SFR25H	2322-186-16158
R1,R6	33Ω		SFR25H	2322-186-16339
L1	820 µH	140 mA	Micro Choke	Siemens
L2*	3.6 mH		CE167V	8228-001-34711
T1*				
D1,D2,D5,D6	BYD12M	SOD120	Contr. Aval. Rect.	9340-552-67143
D3, D4, D8	BYD33J	SOD81	Fast Rec. Rect.	9338-123-00115
D7	BR100-03	SOD27	Diac	
TR1, TR2	BUJ100	TO92	Bip. Power Trans.	9340-555-72412
*** Component changes for the 18W board**				
R4, R7	1Ω		SFR25H	2322-186-16108
L2	2.8 mH		CE167V	8228-001-34721
T1				

Table 2 Parts List

4. PERFORMANCE

All measurements described in this chapter are carried out at an ambient temperature of 20 - 25 °C and after stabilisation of the lamp.

4.1 Ratings

The circuit performance measurements are done with an AC power source at 50 Hz. The quantities used in table 3 and 4 are:

- V_s = AC power source output voltage
- P_s = AC power source output voltage
- P_{la} = lamp power
- η_{sys} = system efficiency = P_{la} / P_s

4.1.1 Ratings CFL10W Circuit

V_s [V]	P_s [W]	P_{la} [W]	η_{sys} [%]
200	9.5	8.3	87
210	10.0	8.6	86
220	10.4	9.0	87
230	10.9	9.3	85
240	11.4	9.7	85
250	11.9	10.0	84

Table 3 Circuit Performance CFL10W Circuit

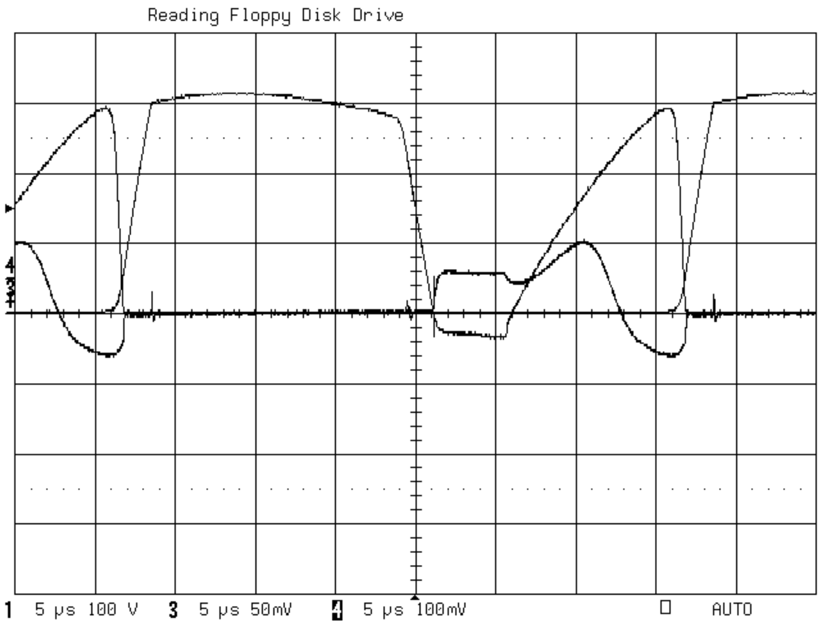
4.1.2 Ratings CFL18W Circuit

V_s [V]	P_s [W]	P_{la} [W]	η_{sys} [%]
200	15.2	13.5	89
210	16.2	14.3	88
220	17.1	15.0	88
230	18.0	15.8	88
240	19.0	16.7	88
250	19.9	17.4	87

Table 4 Circuit Performance CFL18W Circuit

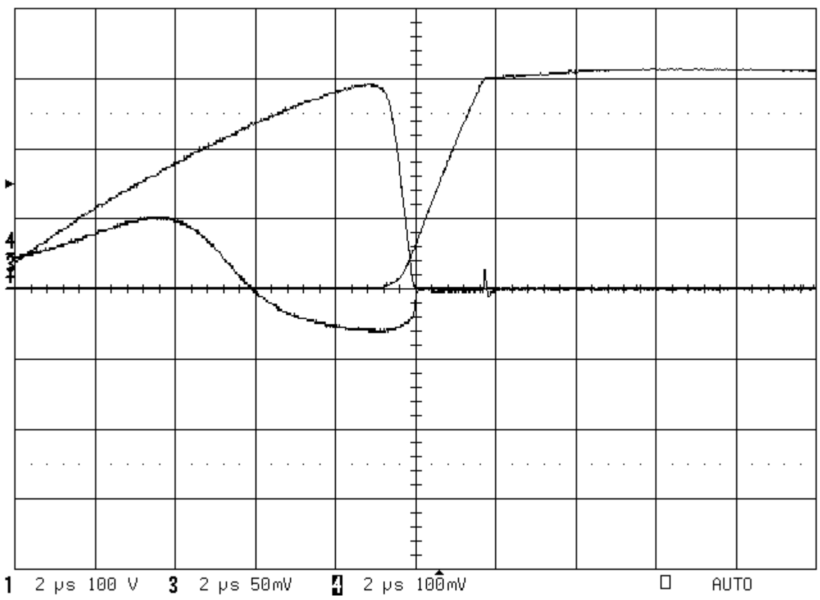
4.2 Oscillograms

4.2.1 Oscillograms CFL10W Circuit



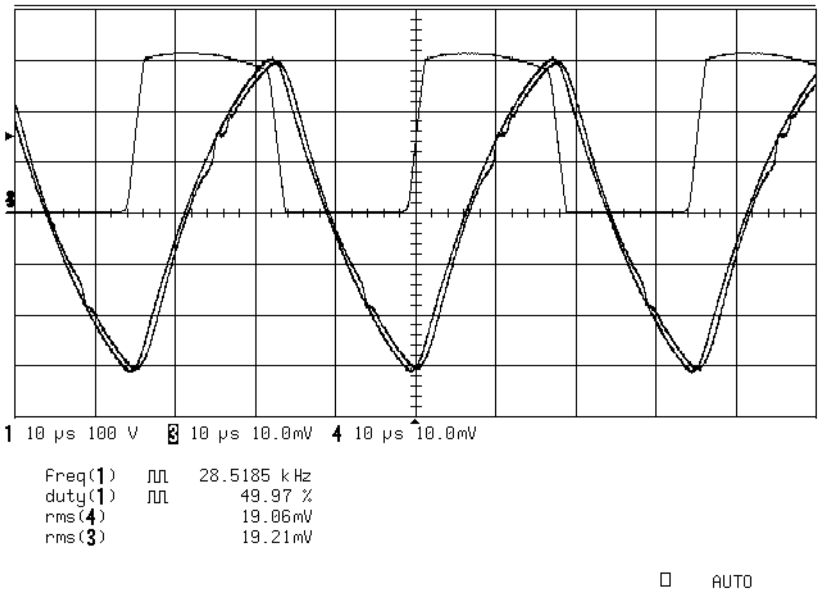
1.	U_A	half bridge voltage	DC	200 V/div	5 µs/div
2.	I_C	collector current	AC	100 mA/div	5 µs/div
3.	I_B	base current	AC	50 mA/div	5 µs/div

Fig.6 Switch Behaviour of TR2, CFL10W circuit



1.	U_A	half bridge voltage	DC	100 V/div	2 µs/div
2.	I_C	collector current	AC	100 mA/div	2 µs/div
3.	I_B	base current	AC	50 mA/div	2 µs/div

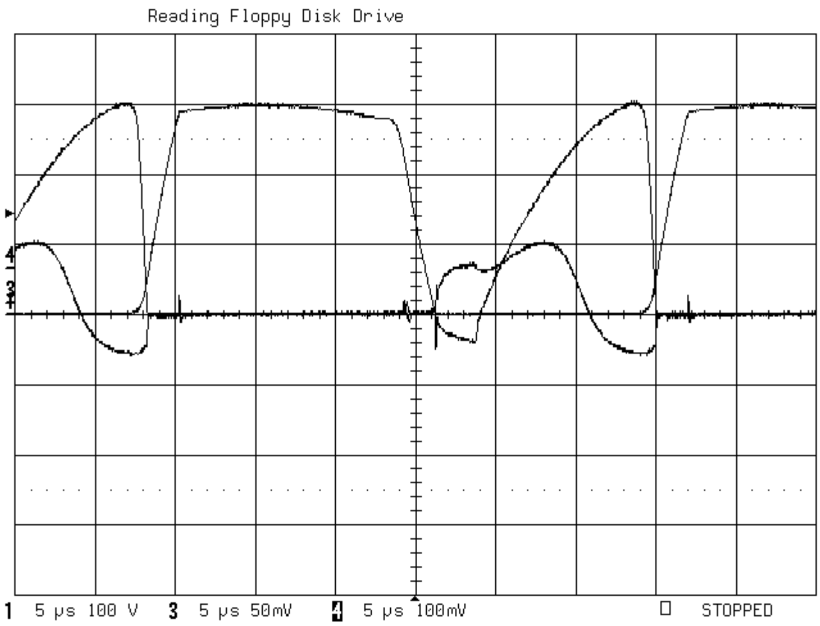
Fig.7 Switch-off Behaviour of TR2, CFL10W circuit



1.	U_A	half bridge voltage	DC	100 V/div	10 µs/div
2.	I_{L2}	ballast coil current	AC	100 mA/div	10 µs/div
3.	I_{la}	lamp current	AC	100 mA/div	10 µs/div

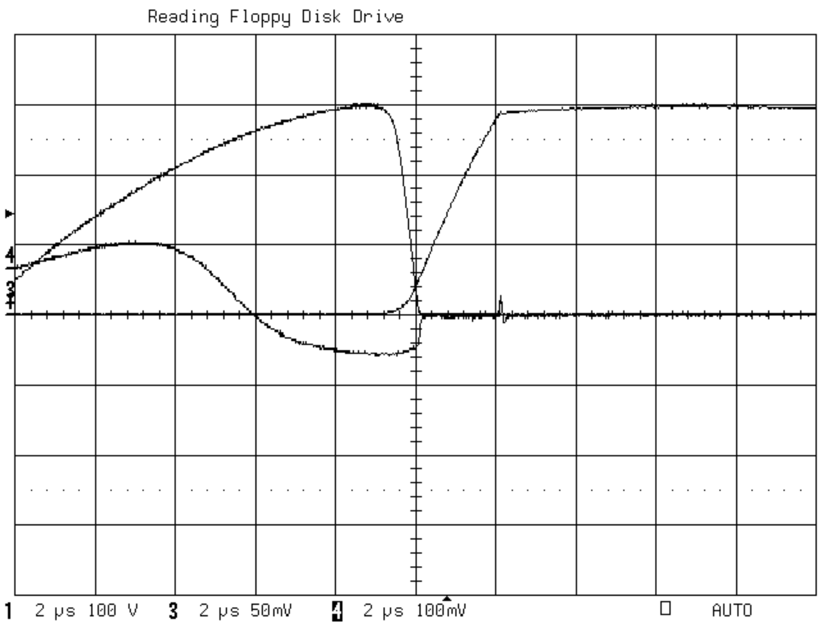
Fig.8 Lamp current and Ballast Coil Current, CFL10W circuit

4.2.2 Oscillograms CFL18W Circuit



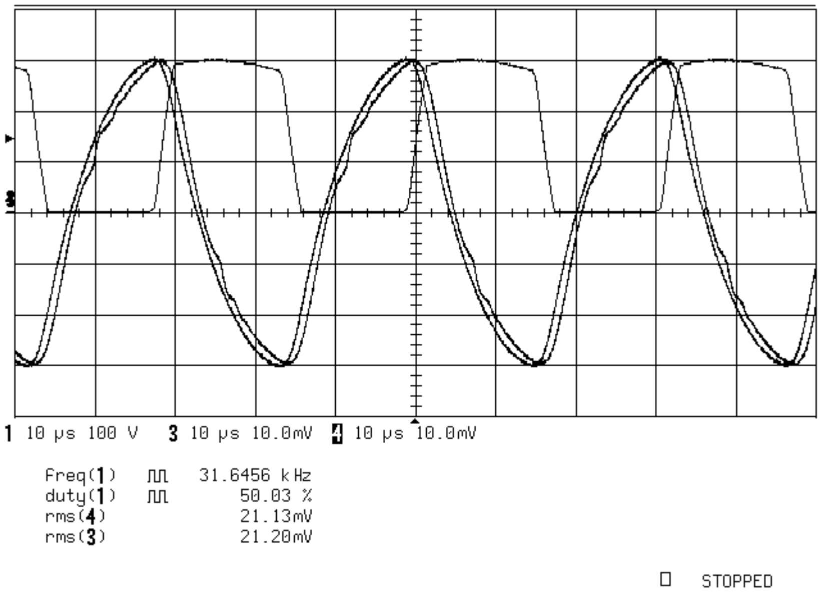
1.	U_A	half bridge voltage	DC	200 V/div	5 µs/div
2.	I_C	collector current	AC	100 mA/div	5 µs/div
3.	I_B	base current	AC	50 mA/div	5 µs/div

Fig.9 Switch Behaviour of TR2, CFL18W circuit



1.	U_A	half bridge voltage	DC	100 V/div	2 µs/div
2.	I_C	collector current	AC	100 mA/div	2 µs/div
3.	I_B	base current	AC	50 mA/div	2 µs/div

Fig.10 Switch-off Behaviour of TR2, CFL18W circuit



1.	U_A	half bridge voltage	DC	100 V/div	10 µs/div
2.	I_{L2}	ballast coil current	AC	100 mA/div	10 µs/div
3.	I_{la}	lamp current	AC	100 mA/div	10 µs/div

Fig.11 Lamp current and Ballast Coil Current, CFL18W circuit

APPENDIX 1 DIMENSIONING BALLAST COIL

The load circuit is formed by an RLC circuit where R_{la} is the lamp resistance, L the ballast coil L2 and C the igniter capacitance C3. The impedance of C3 at 28 kHz is negligible compared to the lamp resistance R_{la}. So the load circuit is formed by the lamp and the ballast coil.

The half bridge circuit is supplied by the voltage across C4 denoted as E volts. In fact, E is the average voltage on C4 because the voltage on C4 contains a 100Hz ripple caused by the mains rectification. So the voltage supplied to the load circuit U_{AB} is $(U_A - U_B)$, see figure 4. The voltage at node U_A is a square wave voltage with a peak-peak amplitude of E volts and a duty cycle of 50% so the DC component is equal to $E/2$ volts. The voltage at node U_B is equal to $E/2$ volts. So the voltage supplied to the load circuit U_{AB} is a square wave voltage with a peak-peak amplitude of E volts and a DC component of 0 volts. The equivalent circuit is given in figure 12.

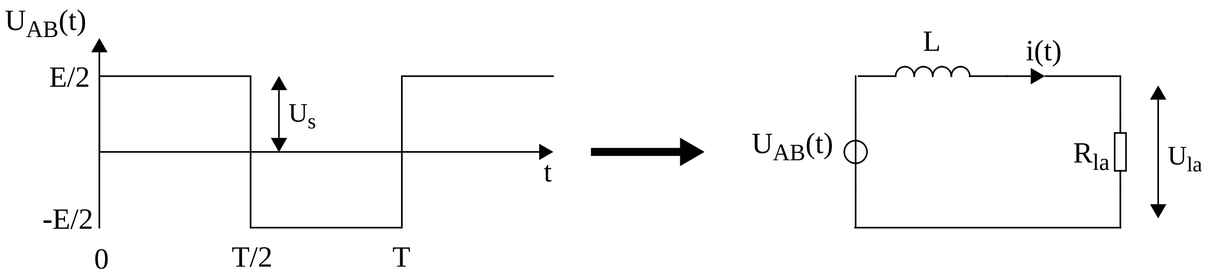


Fig.12 Equivalent Load Circuit.

The steady state solution for $i(t)$ in the interval 0 < t < T/2 is given by:

$$
\begin{aligned}
i(t) &= -(\hat{I} + I_0)\cdot e^{-\left(\frac{t}{\tau}\right)} + I_0 \\
\hat{I} &= I_0 \cdot \tanh(\alpha) \\
P_{la} &= U_s \cdot I_0 \cdot \left[1 - \frac{\tanh\alpha}{\alpha}\right]
\end{aligned}
\quad \text{with} \quad
\begin{cases}
I_0 = \dfrac{U_s}{R_{la}} \\
\tau = \dfrac{L}{R_{la}} \\
\alpha = \dfrac{T}{4\tau}
\end{cases}
\tag{1}
$$

The desired power P_{la} in the lamp, the applied voltage U_s and substitute variable I_o are all known so α can be calculated. Figure 13 gives a plot of $P_{la}(\alpha)$ for the examples on the next page.

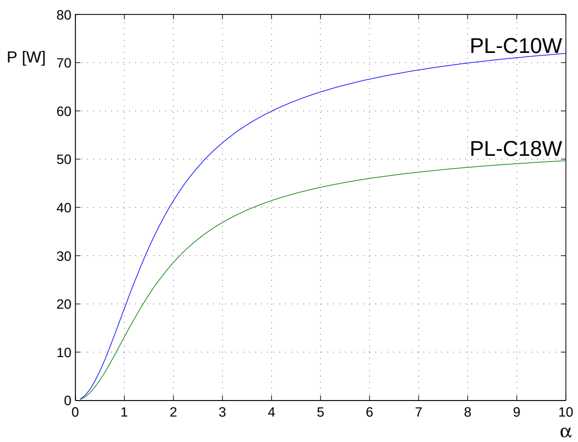


Fig.13 The Lamp Power as function of α

The value for α is obtained by a numerical method because the inverse function of $P_{la}(\alpha)$ can not be written in an explicit form. Now, the ballast coil L is completely determined for a given operating frequency f $(= 1/T)$. The expression for L is

$$L = R_{la} \cdot \tau = R_{la} \cdot \frac{T}{4\alpha} = \frac{R_{la}}{4 \cdot \alpha \cdot f} \qquad (2)$$

Example CFL10W

Data CFL11W	$U_{la} = 50V, I_{la} = 190mA, E = 290V, f = 28kHz$
Derived Quantities	$P_{la} = 9.5W, R_{la} = 263\Omega, U_s = 145V, I_0 = 550mA$

Substitution of the data in *(1)* gives

$$9.5 = 80 \cdot \left[1 - \frac{\tanh\alpha}{\alpha}\right] \qquad (3)$$

Solving for α gives $\alpha = 0.645$.

Substitution of the data in *(2)* gives

$$L = \frac{263}{4 \cdot 0.645 \cdot 28\times10^3} = 3.6mH \qquad (4)$$

Example CFL18W

Data CFL18W	$U_{la} = 80V, I_{la} = 210mA, E = 290V, f = 28kHz$
Derived Quantities	$P_{la} = 16.8W, R_{la} = 381\Omega, U_s = 145V, I_0 = 380mA$

Substitution of the data in *(1)* gives

$$16.8 = 55 \cdot \left[1 - \frac{\tanh\alpha}{\alpha}\right] \qquad (5)$$

Solving for α gives $\alpha = 1.2$.

Substitution of the data in *(2)* gives

$$L = \frac{381}{4 \cdot 1.2 \cdot 28\times10^3} = 2.8mH \qquad (6)$$

APPENDIX 2 CFL13W APPLICATION

The CFL10W circuit can also be used to drive a Philips PL-C13W lamp. The operating frequency will shift from 28 to 30 kHz. For more information on the PL-C13W application contact Nicholas Ham, application engineer discrete semiconductors at Philips Semiconductors Hazel Grove.