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Design of a Blocking Oscillator for Low Voltage Fluorescent Lighting

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Abstract: A blocking oscillator which makes use of a javelin fluorescent tube rated 12 V DC, 8 W and with dimension (370×45) mm used for a low voltage lighting was improved upon by redesigning the circuit and the pulse transformer. The blocking oscillator was first experimented on to analyse its performance, to determine the following parameters, the time constant, the pulse duration and the efficiency as well as the turns ratio of the pulse transformer. The results obtained from the experiment showed that the efficiency is low. The circuit was redesigned to increase the efficiency. Therefore, with the turns ratio of 1:1at the (collector) primary and (base) secondary and 1:8 at the (collector) Primary and tertiary (High voltage) winding coupled with the necessary changes in the component values as a result of redesigning the circuit to obtain the pulse duration of 10 µs and time constant of 30 µs. The results obtained from the calculations carried out showed an improvement in the efficiency. The efficiency increased from the previous value of 58.2-93.3%.

Key words: Pulse transformer, blocking oscillator, efficiency, low voltage

INTRODUCTION

Circuit analysis is an in dispensable step in the design of non linear circuits (Deswardt and Vander, 1993).

The performance analysis of a blocking oscillator used for a low voltage fluorescent lighting was carried out. The following findings were made; the time constant was 40 µs, the pulse duration was 16 µs, the current drawn from the supply was 0.8 A, the efficiency was 58.2%. The pulse transformer turns ratio of the collector to base winding was 2:1 and collector to high voltage winding was 1:7. An efficiency of 58.2% is low. In order to optimize the available power and increase the efficiency the circuits needs to be re-designed. Therefore, the blocking oscillator is re-designed to increase the efficiency of the circuit. The blocking oscillator is closely related to the two transistor circuit except that it uses only one amplifying device. The other is replaced by a pulse transformer (Glen, 1986; Rulkov and Volkovski, 2001) which provides strong positive feedback at all frequencies. Blocking oscillator circuits are used for generation of short period (Glen, 1986) pulses.

Pulse transformer is used in the blocking oscillator because the primary can withstand the voltage and current. The transformer is wound to realize a 180 degree phase shift between Primary and (Smith, 2000) secondary. The secondary is at the desired output impedance. There is a momentary voltage surge across the primary winding equal to approximately twice the supply voltage.

The pulse transformer used in this design, makes use of the RM10 series ferrite cores, covering three series of square design. This allows maximum board utilization and enable transformer to be constructed to meet the exact customer requirements. The core material is equivalent to the commonly known grades A13-Q3- N28. (RS Components, 2001-2002)

MATERIALS AND METHODS

Power supply unit P59/1 Type L3OB, Oscilloscope OS250B, Digital Multimeter 8010A, Digital voltmeter 7010B, E.H.T. Extra High Tension Voltage, Signal generator Type LFP1, Component meter (Wayne Kerr).

The design was carried out in a moderately small laboratory set up at home in March 2007.

Design considerations: In Fig. 1, the following specific points should be considered in the design of a blocking oscillator.

Voltage output: If the primary (collector) and secondary (base) winding of the pulse transformer have the same number of turns ratio i.e. a 1:1, the output voltage (pulse peak) will be approximately equal to the supply voltage.

Transformer selection: Any transformer can be used with a blocking oscillator provided the primary can withstand the voltage and current and the secondary is at the desired output impedance. Often, special purpose

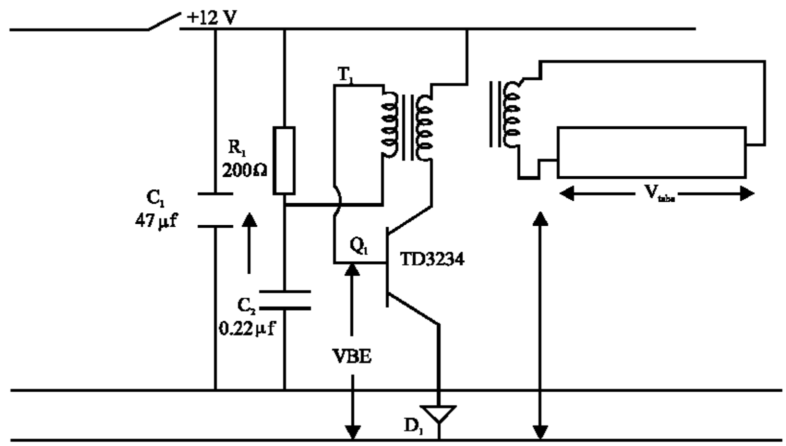

Fig. 1: Analysed blocking oscillator for low voltage fluorescent lighting

transformers are designed for use with blocking oscillators, such transformers are supplied with data for blocking oscillator.

Transistor selection: The transistor must be capable of oscillating at the desired frequency and must be capable of withstanding the full supply voltage continuously.

Bias requirements: The free running blocking oscillators are initially forward biased through resistor R_1, the amount of bias is critical. Once the circuit begins to oscillate, the emitter-base junction is driven into full forward bias and full reverse bias by the charge and discharge of the capacitor C_2.

Operating frequency: The operating frequency is determined by the constant R_1, C_2 and is approximately equal to the reciprocal of the constant.

The value of C_2 should be between 0.1 and 10 µF. In practical design, the circuit should be tested in breadboard form using the desired transformer, transistor and supply voltage. And R_1 should be variable using 0.5MΩ potentiometer. If the frequency is incorrect, adjust R_1 until the desired frequency is obtained. If the pulse duration is too long decrease the value of C_2 and increase the value or R_1.

Design of the pulse transformer: The following parameters are to be specified in the design of the pulse transformer

- Primary voltage and current.
- Secondary voltage and current.
- Tertiary voltage and current.
- Frequency of operation.
- Number of turns.
- Core size.

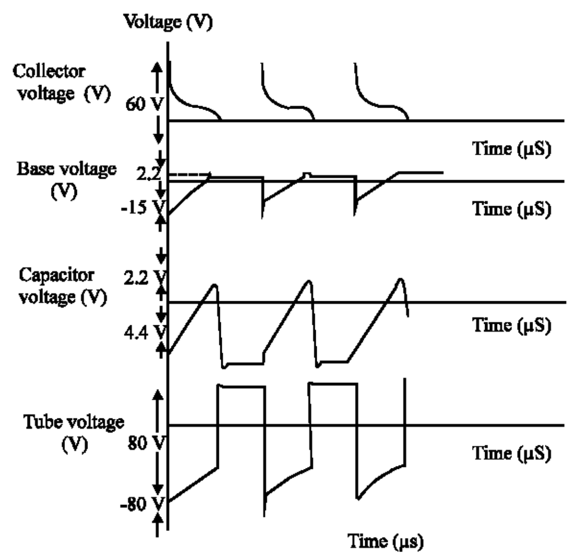

Fig. 2: Collector, base, capacitor and tube voltages against time for the analysed circuit

MEASUREMENTS

For this design, measurement of the collector, base, capacitor and voltage-time relationship waveforms as displayed on the oscilloscope is shown in Fig. 2. A resistor of 0.22 Ω was connected in series with the collector and the base for measurement purposes. The collector and base voltage waveforms as displayed on the oscilloscope are shown in Fig. 3. This is to enable the collector current to be calculated.

Readings: The following readings were taken at the tube striking voltages and steady state condition of the circuit in Fig. 1. The readings are shown in Table 1 and 2.

Table 1: Tube striking voltages and currents

Transformer winding	Voltage (V)	Circuit (A)
Transformer primary	50	2.000
Transformer secondary	50	0.160
Transformer tertiary	400	0.100

Table 2: Steady state voltages of the circuit

Transformer winding	Voltage (V)
Transformer primary	16.5
Transformer secondary	16.5
Transformer tertiary	60.0

Table 3: Collector voltages at different time intervals

Time (μs)	Collector voltage (mV)
0	300
15	500

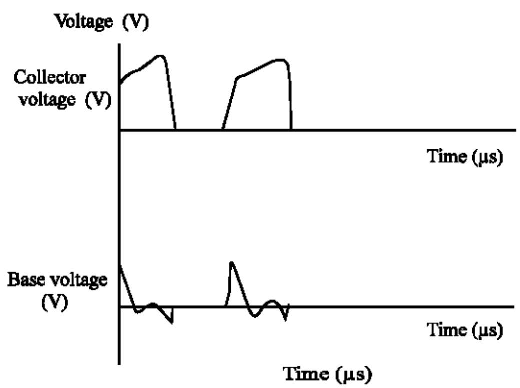

Fig. 3: Collector and base voltage against time for the analysed circuit

The tube striking voltages and currents are used in the design specifications of the pulse transformer. This is to enable the pulse transformer to withstand these high starting voltages and currents, before settling down to steady state condition.

The design of the pulse transformer: For magnetically coupled circuits or coils; the voltage developed in a mutually inductive coil or circuit is given by

$$Vcc = \frac{Ldi_c}{dt} \quad (1)$$

Where, Vcc = supply voltage or collector voltages (V), L= inductance (H) of collector winding,

$\frac{di_c}{dt}$ = Rate of charge of collector current.

The induced voltage in an N- turn coil is

$$Vcc = \frac{N d\phi}{dt} \quad (2)$$

Where, N= Number of turns of the collector winding

$\frac{d\phi}{dt}$ = Rate of charge of the flux.

Using RM series ferrite core data book also

$$V_{cc} = \tfrac{1}{2} LI \quad (3)$$

Where, I = Collector current.

L = Inductance of collector winding

Calculation of the number of turns of the primary (collector), secondary (base) and tertiary windings of the pulse transformer: To calculate the number of turns required for the primary (collector) winding. A resistor of 0.22Ω was connected in series with the collector for measurement purposes. Direct measurement of the collector voltages and time from the display on the oscilloscope based on the scale of V= 20 mV/Div×10Probe and t =10 μs Div^{-1}.

The following readings in Table 3 were obtained from the displayed collector voltage against time in Fig. 3. At

$t_1 = 0$ μs., $V_1 = 0.3$ V

$t_2 = 15$ μs, $V_2 = 0.5$ V

$dt = t_2 - t_1$

$= 15 - 0$ μs

$= 15$ μs

Calculation of collector currents: From Ohms law

$$V = IR \quad (4)$$

$$I = \frac{V}{R} \quad (5)$$

At $t_1 = 0$ μs

Collector current $I_{C1} = \frac{0.3}{0.22} = 1.36$ A

At $t_2 = 15$ μs,

Collector current $I_{C2} = \frac{0.5}{0.22} = 2.27$ A

Calculation of rate of change of collector current and the inductance of the coil: Rate of change of collector current = $\frac{di_c}{dt}$

$$\frac{di_c}{dt} = \frac{2.27 - 1.36}{15 \times 10^{-3}} = 60580 \ \text{A/t}$$

From Eq. 1, $Vcc = L\frac{di_c}{dt}$

The inductance L of the coil, $L = Vcc \times \frac{dt}{di_c}$

Vcc= supply voltage =12V,

$$L = \frac{12}{60580} = 1.981 \times 10^{-4}\,H$$

Calculation of the number of turns of collector winding: From the RM series ferrite cores data sheet for inductor, Eq. 6 is applicable:

$$N = \left(\frac{L}{A_L}\right)^{½} \tag{6}$$

N = Number of turns of collector winding
L = Inductance in nH (10^{-9}H)
A_L = Inductance factors nH turns^{-1}

$$\therefore N = \left(\frac{L}{A_L}\right)^{½}$$

L = nH
L = 1.98×10^{-5}nH

From Eq. 6 and RM series ferrite cores data sheet for inductors
A_L = 400 for core size of RM10 series
From Eq. 6

$$N = \left(\frac{L}{A_L}\right)^{½} = \left(1.98\times10^{-5}/400\right)^{½} = 22 \text{ turns}$$

No. of turns for the primary winding (collector) = 22 turns
No. of turns for the secondary winding (base) = 22 turns

The voltage of the primary winding is equal to the voltage of the secondary winding = 50 V, therefore they are of the equal number of turns.

The voltage of the pulse transformer tertiary winding = 400 V

Therefore, the number of turns of the tertiary winding (high voltage) = 22×8=176 turns.

Calculation of number of turns of heater windings: From the transformer principles;

$$\frac{V_2}{V_1} = \frac{N_1}{N_1} = \frac{I_1}{I_2} \tag{7}$$

Table 4: Transformer winding identification number

Terminal	Start	Finish
Collector	4	5
Base	6	3
Fluorescent tube	2	1
Heater	8	7

Table 5: Specifications of the redesigned blocking oscillator

	Tube striking		Steady state	
Transformer winding	Voltage (V)	Current (A)	Voltage (V)	No. of turns
Transformer primary	50	2.000	16.5	22
Transformer secondary	50	0.160	16.5	22
Transformer tertiary	400	0.100	60.0	176
Core size				RM10
Time constant				33 µs
Frequency of operation				30.3 kHz
Pulse duration				10 µs
Supply voltage				12 V DC

Where, V_2, V_1, N_2, N_1, I_2 and I_1 represent the transformer secondary and primary voltages, turns ratio and currents. V_1=50 V, V_2=12 V, N_1=22 turns

$$N_2 = \frac{N_1 V_2}{V_1} = \frac{12\times22}{50} = \frac{264}{50} = 5.28 \text{ turns} = 5 \text{ turns}$$

The number of turns of the heater winding = 5 turns
The pulse transformer windings identification is shown in Table 4.

Determination of the component values
C_2 : 0.1 µF≤C_2≤10 µF
R_1 : R_1≤0.5 MΩ

C_2 is fixed at 0.1 µF and R_2 varied.

A variable capacitance box and resistance box were connected in place of C_2 and R_1. The capacitance was set to 0.1 µF and the resistance was varied until the desired output achieved.
The value of R_1 was fixed at 330Ω and C_2 = 0.1 µF.

Specifications of the redesigned blocking oscillator circuit: The specifications are shown below in Table 5.

RESULTS AND DISCUSSION

The following readings were obtained from Fig. 4 as shown in Table 6 after the blocking oscillator had been re-designed.

An oscilloscope was used to display the voltage-time relationship waveforms for the collector, base, capacitor and fluorescent tube as shown in Fig. 5 and a direct measurement of the time constant and pulse duration from the display on the oscilloscope based on the scale of V = 10 V Div^{-1} and t = 10 µs Div^{-1}.

Table 6: Improved blocking oscillator

Supply voltage (V DC)	Supply current (A DC)	Voltage across the tube (V AC)	Current through the tube (mA)	Voltage across the primary (collector) winding (V AC)	Voltage across the secondary (base) winding (V AC)	Heater voltage (V AC)
11.79	0.64	62	95.9	16.59	16.59	12

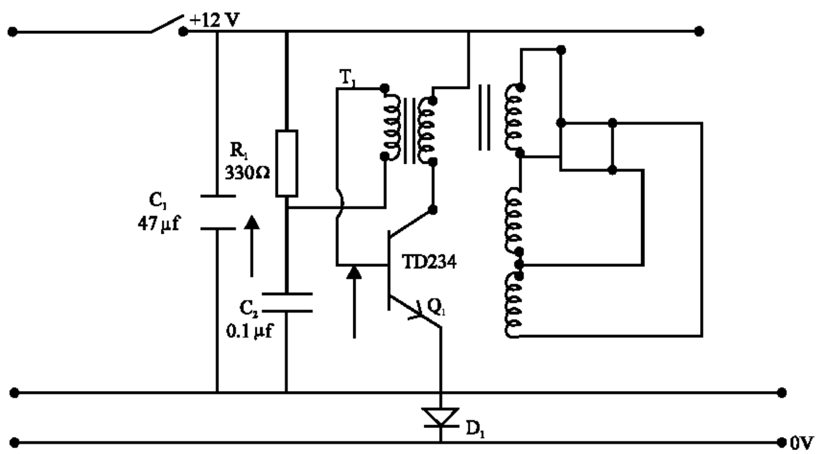

Fig. 4: An improved blocking oscillator circuit for low voltage fluorescent lighting

showed that:

The time constant	=	10×3.3
	=	33 µs
The pulse duration	=	10×1
	=	10 µs

Calculation of the efficiency

$$\text{The efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100 \quad (8)$$

$$= \frac{62 \times 95.9 \times 10^{-3}}{0.64 \times 11.98} \times 100$$

$$= 93.3\ \%$$

The circuit diagrams of the analysed and the designed blocking oscillators are shown in Fig. 1 and 4. The values of capacitors C_2 and resistors R_1 in the analysed and the designed blocking oscillators are 0.22 µF, 200Ω and 0.1 µF, 330Ω. From the graph of the waveforms of the collector, the base, the capacitor and the fluorescent tube voltages against time in Fig. 5, the time constant and the pulse duration were found to be 30 and 10 µs.

The supply current and the current through the fluorescent tube as shown in Table 5 are 0.64 A and 95.9 mA. The efficiency of the blocking oscillator was found to be 93.3%. The turns ratio of the pulse transformer winding were found to be 1:1 for the primary (collector) to secondary (base) and 1:8 for the primary (collector) to tertiary (high voltage) with inclusion of

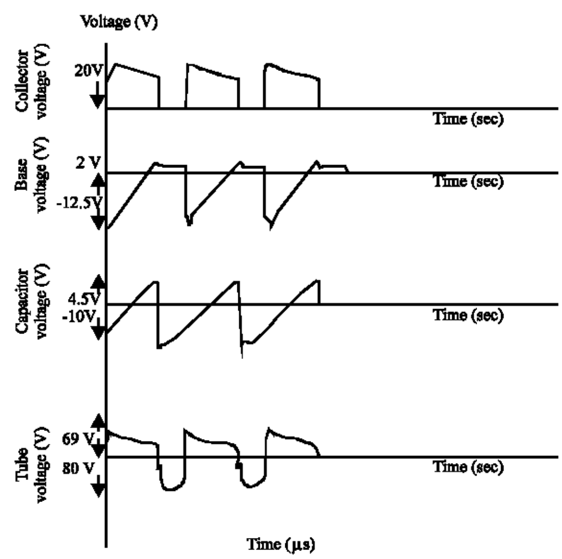

Fig. 5: Collector, base, capacitor and tube voltages against time for the improved circuit

5 turns of heater winding. Therefore, with the changes in the values of the components and the turns ratio of the pulse transformer winding. The following observations are made: Reduction in time constant and the pulse duration from 40-33 and 16-10 µs. This is a major advantage for short pulse generating circuits, where the limit of the acceptable pulse duration allowed is between 0.05 and 25 µs and where little current is drawn between pulses and high pulse current may be drawn from the output for short duration without exceeding the power capability of the transistor.

Twenty percent reduction in the current drawn from the supply.

Significant increase in the efficiency from 58.2-93.3% because of lesser current drawn from the supply, therefore less input power. The primary and secondary windings of the pulse transformer have the same number of turns, that is, 1:1 turns ratio in order to avoid loading of the circuit and increase the efficiency. The output voltage (Pulse peak) will be approximately equal to the supply voltage.

CONCLUSION

In this design, a blocking oscillator used for a low voltage fluorescent lighting was re-designed. The following conclusions are made:

The time constant and the pulse duration were found to be 10 and 33 μs, respectively. The current drawn from the supply and the current flowing through the fluorescent tube were 0.64 A and 95.9 mA. The efficiency of the circuit is 93.3%.

The turns ratio of the pulse transformer primary (collector) to secondary (base) winding is 1:1 and the primary (collector) and tertiary (High voltage) is 1:8.

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