

Getting more from fluorescent lamps through resonant converters

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Getting more from fluorescent lamps through resonant converters

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Abstract

High-frequency resonant power converters make it possible to exploit tubular fluorescent lamps without electrodes. This paper outlines a simple approach that puts this situation into perspective in the case of capacitively coupled lamps. A Class-E inverter which is suitable for the electrodeless operation is also described. Comments on experimental results from a 16W converter breadboard with the proposed circuit topology using 2.65MHz and 13.56MHz switching frequencies are made.

1 Introduction

Low-pressure tubular fluorescent lamps are by far the most widespread of the discharge lamp types. They are employed almost universally in all types of commercial, social and civic interiors.

On account of its working principle at low frequencies, the discharge tube of fluorescent lamps has an electrode sealed into each end. The electrodes serve to conduct electrical power into the lamp and provide the electrons which are necessary to maintain the discharge.

During its life, an electrode loses emitter material due to evaporation and scattering. This is the chief cause of eventual lamp failure. Normally, tubular fluorescents have to be replaced after burning about 5000 to 10000 hours (approximately every 2 years). However, if electrode damage is not taken into account, the lamp would be able to operate properly as long as the fluorescent coating is capable to convert ultra-violet into visible radiation. The phosphor material in the coating has a life which is far longer than the electrode deterioration time (about a factor 4).

The advantages of operating fluorescent lamps at higher frequencies have been known for some time [1]. Lamps have been shown to increase in efficiency as frequency is increased up to some kilohertz or beyond [2]. Of even greater importance is the effect of higher frequencies on the lamp operating auxiliaries. The lighting equipment becomes also more efficient, lighter in weight, and minimizes the heat dissipation problem. Nowadays, lamps operating at 28 kHz are quite common. Nevertheless, the electrodes still remain the "Achilles tendon" of such lamps.

Inductively coupled lamps without electrodes have been introduced recently [3,4]. In this paper, it will be shown that resonant power supplies also make it possible to avoid the use of electrodes in capacitively coupled lamps. In fact, experimental results confirm that if tubular lamps are made to function in the megahertz range, *the electrodes can be replaced by capacitors* in a very simple way.

This paper also outlines the design of two different power supplies based on a Class-E inverter [5], one for operation at 16W/2.65MHz, the other at 16W/13.56MHz. These resonant networks provide the necessary alternating current for the lamp to function properly without electrodes. Moreover, on account of resonance, the power supplies also provide the necessary voltage for lamp ignition without any kind of additional circuitry.

2 Replacing electrodes by capacitors

A tubular fluorescent lamp works on the low-pressure mercury discharge principle. It is well known that at higher frequencies (kilohertz and beyond) the lamp behaves more like a pure resistance [1]. Under ac operation in the high frequency range, the electron density in the plasma is not proportional to instantaneous current but rather to rms current. Therefore, the gas ionization density stays reasonably constant and the discharge efficiency approaches closely the dc case.

At frequencies as high as some megahertz it is possible to conduct electric power into the lamp by an alternative way other than by the electrodes, as follows. Suppose that a metal foil of small length is placed at each end of the discharge tube, surrounding the outside tube walls, as depicted by figure 1.

An equivalent electric circuit model for the situation in fig. 1 is given in fig. 2, where C_0 represents the capacitance which is

created by the proximity between two conductors (the foil and the gas discharge) separated by a dielectric (the glass wall). On account of the high frequency behaviour of the lamp, the gas discharge has been represented by a resistor (R_0 in fig. 2).

Extracting approximate values for R_0 and C_0 is straightforward. Ordinarily the manufacturer furnishes the rms lamp current (I_{nom}) and the lamp power (P_{nom}) at nominal operation. Hence,

$$R_0 = \frac{P_{nom}}{I_{nom}^2} \quad (1)$$

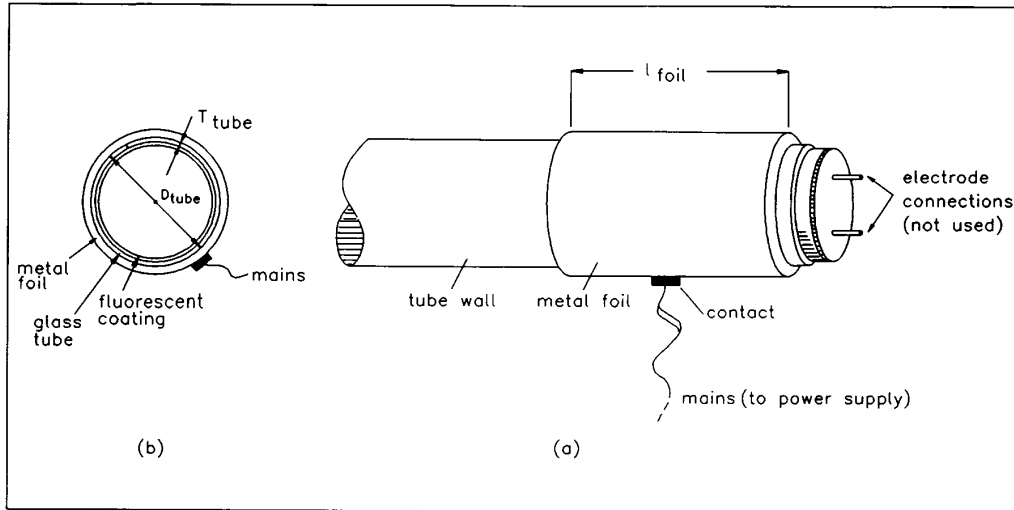


Figure 1: An electrodeless tubular lamp, (a) with a metal foil at each end, (b) cross-section. The electrodes are not electrically connected and thus not operative.

The value of the capacitor C_0 is found to be

$$C_0 = \epsilon_0 \epsilon_r \frac{\pi D_{\text{tube}} \ell_{\text{foil}}}{T_{\text{tube}}}, \quad (2)$$

where

- ϵ_0 = permittivity of vacuum = $8.85 \times 10^{-12} \text{ Fm}^{-1}$,
- ϵ_r = relative permittivity of the glass tube,
- D_{tube} = cross diameter of the glass tube,
- T_{tube} = thick of the glass tube cross-section,
- ℓ_{foil} = length of the metal foil.

For instance, for the standard 16W fluorescent lamp whose characteristics are given at Table 1, and by choosing $\ell_{\text{foil}} = 5.0\text{cm}$, it follows that

$$R_0 = 256\Omega \quad \text{and} \quad C_0 = 69.5\text{pF}.$$

Under the assumption of sinusoidal waveforms, the necessary rms voltage at the lamp terminals (fig. 2) for operation at 2.65 MHz (this is the lowest ISM frequency in the megahertz range [6]) would be

$$U_{\text{lamp}} = I_{\text{nom}} \sqrt{\left(\frac{2}{\omega C_0}\right)^2 + R_0^2} = 437\text{V},$$

a value which is not difficult to reach in a practical situation.

It should be emphasized that the operation at high frequencies makes possible an appreciable reduction in the voltage at the lamp terminals. With a kHz-supply, the construction in figure 1 would lead to restrictive voltage values.

Of course, the electrodes become superfluous when working on the principle outlined above. Furthermore, the necessary voltage at the lamp terminals to start ignition can be provided by the same high-frequency resonant power supply.

Table 1: Parameters of a standard fluorescent lamp.

TLD16W/83HF (Philips)			
P_{nom}	16 W	nominal power	
I_{nom}	0.25 A	nominal current	
D_{tube}	26 mm	cross diameter of the glass tube	
T_{tube}	1 mm	thick of the tube cross-section	
ℓ_{tube}	590 mm	length of the tube	
ℓ_{foil}	50 mm	length of the metal foil	
ϵ_r	2.0	relative permittivity of the glass	

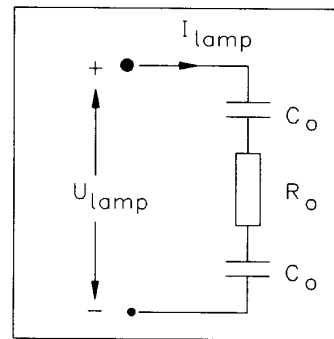


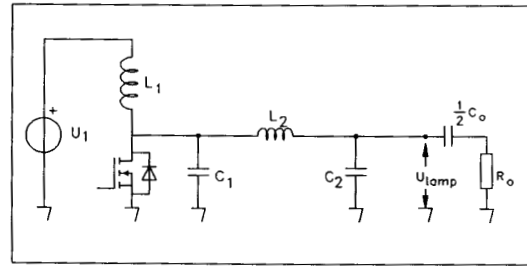
Figure 2: Electric circuit model for the electrodeless tubular lamp operating at high frequencies.

3 Power supply design

Resonant power supplies incorporating an inverter can offer very high efficiencies. Furthermore, electromagnetic interference, radio frequency interference and mains-borne pollution are much reduced compared with square-wave switching.

The Class-E inverter is a load-resonant network suitable for use in lightweight, low power, high efficiency power converters. The circuit is reliable and can be easily designed and built [5].

Details of two prototype Class-E 16W inverters operated from a 24Vdc source, which have been developed to match the power requirements of an electrodeless tubular lamp, are shown in figure 3. Some typical waveforms related to the resonant operation are shown in figure 4.



f_0	U_1	L_1	C_1	L_2	C_2
2.65MHz	24Vdc	50 μ H	830pF	30 μ H	100pF
13.56MHz	24Vdc	9 μ H	156pF	2 μ H	86pF
$R_o = 256\Omega$, $C_o = 69.5\text{pF}$, $P_o = 16\text{W}$.					
Switch : MOSFET IRF830					

Figure 3: Resonant power supplies based on a Class E amplifier.

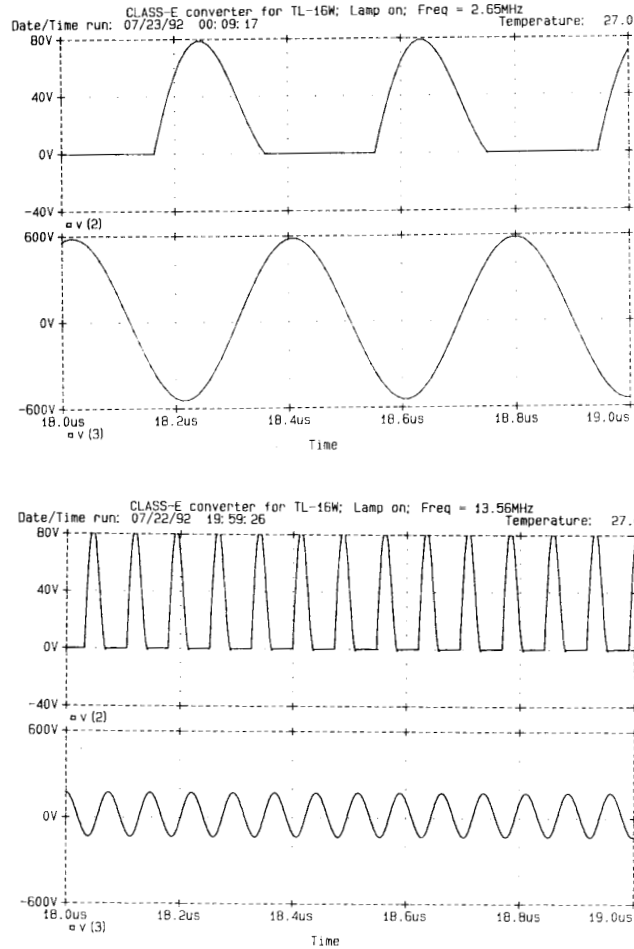


Figure 4: Some typical waveforms related to the circuit in figure 3. $v(2) \equiv U_{DS}$ (drain to source voltage at the power switch) ; $v(3) \equiv U_{lamp}$ (voltage at lamp terminals).

4 Practical results

Experimental results confirm that electrodeless operation at 2.65 MHz is possible (see figure 5). In account of the high-frequency operation, gas discharge ignition occurs at voltage levels at the lamp terminals that are far below the necessary value for nominal outlast. Dimming was also possible to achieve easily, even at very low power levels, by changing smoothly the circuit operating frequency or by changing the input dc voltage.

For the purpose of verifying the influence of the capacitive coupling on the phosphor material, a set of 16W tubular lamps was put on a lifetime test. After burning about 1000 hours, darkening of the fluorescent coating under and at the borders of the metal foils was observed visually, which makes it restrictive to put the lamps to practical use.

In order to further examine this event we have used another power supply operating at 13.56MHz, which is the next available ISM frequency above 2.65MHz.

It looks like that the operation at 13.56MHz is less critical than at 2.65MHz, because it seems possible to reach a longer burning period without darkening phenomena. Therefore, for the purpose of improving the effective outlast time, the operation at higher frequencies and the remotion of the phosphor under the metal foil are suggested. It is also the feeling that the foil geometry might have influence on the phosphor darkening, but we have not yet dealt with this possibility.

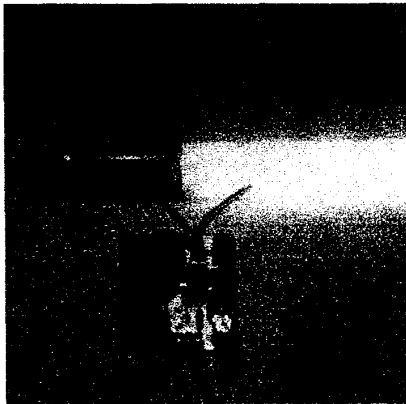


Figure 5: An electrodeless capacitively coupled tubular lamp in operation.

5 Conclusion

The operation without electrodes of *existing* fluorescent lamps is possible, as outlined in this paper. The overall results at higher frequencies for the lighting equipment are small size, lighter weight and reduced wattage loss.

The biggest deterrent to greater commercial application of lighting at frequencies in the megahertz range would be the problems of interference with communication circuits. Fortunately, there is no reason to say that this interference can not be brought to acceptable levels. In fact, the electric field components are the predominant ones in capacitively coupled lamps. In this situation, EMI shielding problems are easier to solve than for inductively coupled lamps. Therefore, a sharp power supply design in combination with an adequate luminaire design, and their integration with the complete lighting system, would keep the related electromagnetic compatibility from becoming a problem in most applications.

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