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A Study on the Equivalent Model of an External Electrode Fluorescent Lamp Based on Equivalent Resistance and Capacitance Variation

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ABSTRACT

An External Electrode Fluorescent Lamp (EEFL) has longer lifespan, higher power efficiency and higher luminance than a Cold Cathode Fluorescent Lamp (CCFL). Moreover, it is easy to drive them in parallel. Therefore, the EEFL is expected to quickly replace the CCFL in LCD backlight systems. However, the EEFL has more complex characteristics than the CCFL with a resistive component, because it has both a resistive component by plasma and a capacitive component by external electrode. In this paper, values of resistance and capacitance are measured at several power levels and at several operating frequencies. They are expressed by a numeral formula based on a linear approximation that represents the equivalent resistance and capacitance as a function of power. Then we made block diagram of the equivalent circuit model using numerical expressions. Simulation waveforms and experimental results are presented to verify the feasibility of the equivalent model.

Keywords: EEFL, LCD backlight system, capacitive component, equivalent model, linear approximation

1. Introduction

Electron display devices play an important role as an information display for a man-to-machine interface. With the rapid progress in the information industry, there has been a continuous increase in the demand for new electronic display devices with a large size, high resolution, and high information capacity. Generally, display devices can be divided into two classes as shown in Fig. 1: non-flat panel displays, such as a cathode ray tube (CRT), and flat panel displays (FPD) such as a liquid crystal display (LCD), plasma display panel (PDP), electro luminescent display (ELD), field emission display (FED) and so on. Among these devices, the LCD is light-weight, has a low profile, high resolution, and low power consumption. Therefore, it is superior to other display devices below 50 inches.

Since the LCD panel itself can not emit light, a backlight source that supplies light from behind is required. These days, a Cold Cathode Fluorescent Lamp (CCFL) is commonly used. It does not require preheating of the filament and the electrodes at the end of the bulb stay at a low temperature while emitting light unlike a Hot Cathode Fluorescent Lamp (HCFL). However, as the demand for large LCD panels for digital TV is increasing, many drawbacks appear in the CCFL. The main drawback is the oxidation of the internal electrode due to the

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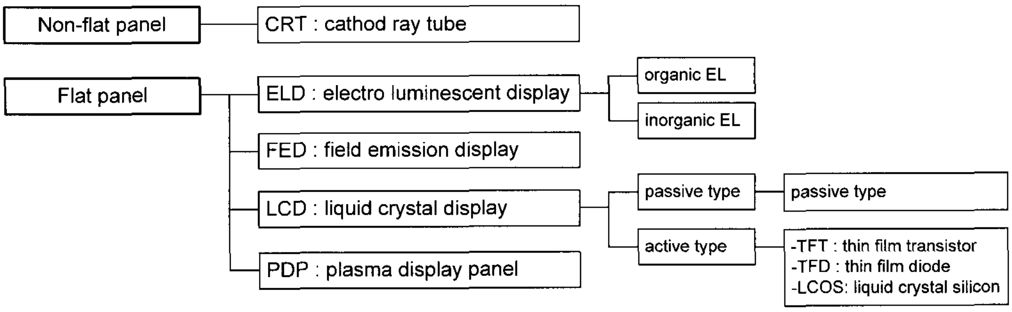


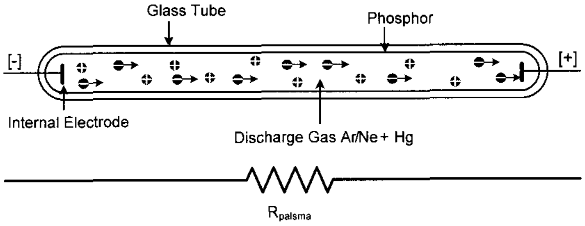
Fig. 1 Classification of various displays

collision of gas particles. This causes CCFL's to have a short lifespan. They must also have a ballast capacitor due to negative resistive characteristics. Moreover, it has an unbalancing current in the parallel driving with one inverter. If the size of the LCD panel is large (about 16~20 CCFLs in a 32-inch LCD TV), corresponding inverter and ballast capacitors are needed. To overcome this problem, recently, an EEFL with external electrodes has been suggested. Since the structure doesn't contain an internal electrode, the EEFL has a longer lifespan, higher power efficiency and higher luminance than the CCFL. Moreover, a small capacitance provided by external electrodes helps the EEFL to operate in parallel like a ballast capacitor. Therefore, the EEFL is expected to quickly replace the CCFL in backlight systems. However, the equivalent circuit model of the EEFL has not been investigated until now. The equivalent circuit model is a useful tool to verify the performance of the backlight inverter under zero voltage switching conditions, conduction loss, and voltage/current stress of active components.

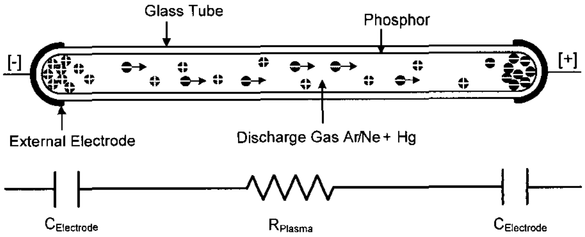
This paper presents an equivalent circuit model of a EEFL based on a linear approximation that represents the equivalent resistance and capacitance as a function of power. A modeling method and numerical equation are presented. Simulation data and experimental results are compared at the end of this paper to verify the feasibility of the proposed model.

2. Equivalent Circuit Model

Fig. 2 shows structure and equivalent circuit models of a CCFL and a EEFL. To ensure a long lifespan, the EEFL has two external electrodes which are capsulated at both ends of the lamp. When the square wave sustain voltage is applied to the EEFL, a gas discharge occurs in the lamp. Because there is no internal electrode, excited gas particles (ions, electrons…) are accumulated at the ends of the lamp. They are called wall charges and they limit the discharge current. Therefore, the two external electrodes operate as a capacitor. Also, gas plasma has an electrically high conductive characteristic, which causes it to operate as a resistor. Therefore, it is assumed that the EEFL electrically has one resistive and two capacitive components as shown in Fig. 2(b).



(a) Structure and Equivalent Cricuit of CCFL



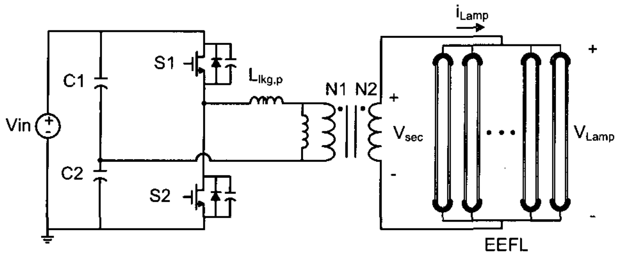
(b) Structure and Equivalent Circuit of EEFL

Fig. 2 Structure and equivalent circuit of fluorescent lamps

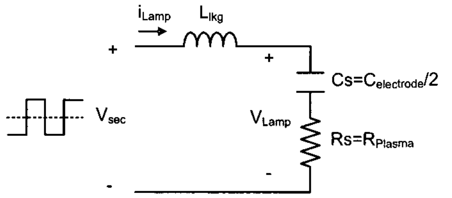
Fig. 3 shows a half bridge series resonant inverter for driving an EEFL and the equivalent circuit. L_{lkg} is the leakage inductor of the transformer. The impedance of EEFL is represented as follows :

$$Z_{Lamp} = Z_r + iZ_i = R_{Plasma} - i\frac{1}{\pi f \times C_{Electrode}}$$

$$= R_S - i\frac{1}{2\pi f \times C_S} \qquad (1)$$



(a) Half bridge series resonant inverter



(b) Equivalent circuit

Fig. 3 Half bridge inverter and equivalent circuit

To find the values of Rs and *Cs*, we should measure the rms current of the lamp ($I_{Lamp,rms}$), the rms voltage of the lamp ($V_{Lamp,rms}$) and the lamp power (P_{Lamp}). From the gathered data, *Rs* and *Cs* can be calculated by equations (2) and (3).

$$R_S = \frac{\frac{1}{T}\int_0^T (V_{Lamp} \times I_{Lamp})dt}{I_{Lamp,rms}^{\ 2}} = \frac{P_{Lamp}}{I_{Lamp,rms}^{\ 2}} \tag{2}$$

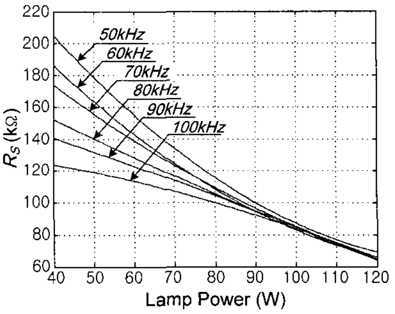
$$C_S = \frac{1}{2\pi f_s \sqrt{(\frac{V_{Lamp,rms}}{I_{Lamp,rms}})^2 - R^2}} \tag{3}$$

Experimental data were obtained through a LeCroy WaveSufer 434, employing a half bridge series resonant inverter according to Fig. 3. The summarized prototype parameters are described in Table 1. The data were acquired at several power levels from 40 watts to 120 watts, and at several switching frequencies from 50kHz to 100kHz. The power variation was achieved through the line voltage control maintaining full discharge.

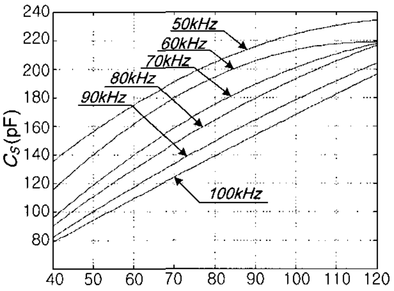
Table 1 Parameters of prototype.

L_{lkg}	76.82mH
Lamp length	722mm
Electrode length	20mm * 2
Lamp diameter	4mm
Number of lamp	20

The values of *Rs* and *Cs* are represented in Fig. 4. At all driving frequencies, *Rs* becomes smaller and *Cs* becomes larger as the lamp power increases. Physically, the variation in resistance means there is an increase of conductivity in the plasma due to the increase of the plasma particles. The change of capacitance means there is a decrease of Debye length between the external electrode and the gas plasma.



(a) R_S versus Lamp Power

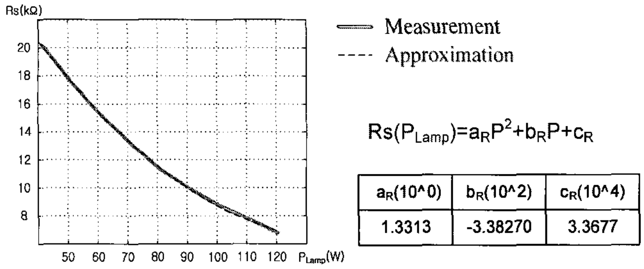


(b) C_S versus Lamp Power

Fig. 4 Experimental data (a) *Rs* (b) *Cs*

Table 2 Coefficients of *Rs* and *Cs*.

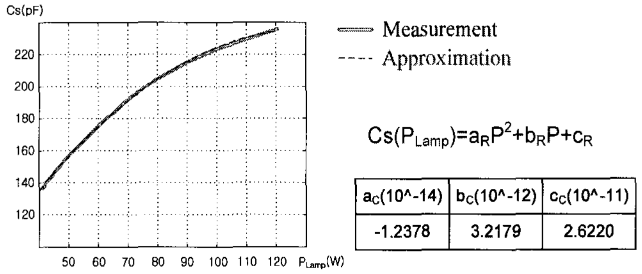
Coefficient of *Rs*			
fs	$a_R(10^1)$	$b_R(10^2)$	$c_R(10^4)$
50kHz	1.3313	-3.8270	3.3677
60kHz	1.0979	-3.2555	2.9882
70kHz	0.6505	-2.3852	2.5870
80kHz	0.1664	-1.3694	2.0458
90kHz	-0.1305	-0.7436	1.7235
100kHz	-0.3564	-0.1716	1.3661
Coefficient of *Cs*			
fs	$a_C(10^{-14})$	$b_C(10^{-12})$	$c_C(10^{-11})$
50kHz	-1.2378	3.2179	2.6220
60kHz	-1.7202	4.0478	-1.9542
70kHz	-1.1487	3.3689	-2.1113
80kHz	-0.6816	2.6731	-6.1190
90kHz	-0.3939	2.1569	1.9706
100kHz	-0.0888	1.6159	1.5282



$R_S(P_{Lamp})=a_RP^2+b_RP+c_R$

a_R(10^0)	b_R(10^2)	c_R(10^4)
1.3313	-3.38270	3.3677

(a) R_S value



$C_S(P_{Lamp})=a_RP^2+b_RP+c_R$

a_C(10^-14)	b_C(10^-12)	c_C(10^-11)
-1.2378	3.2179	2.6220

(b) C_S value

Fig. 5 Experimental data and approximation

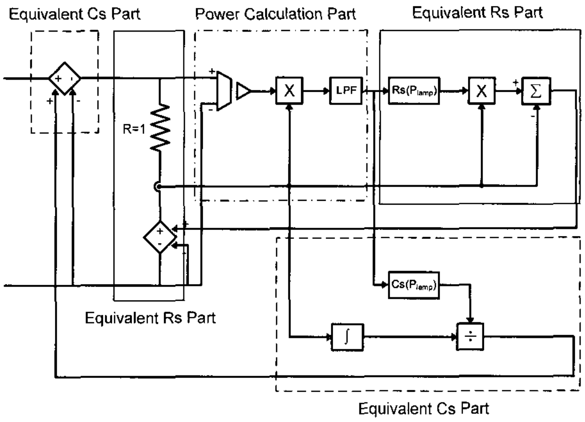


Fig. 6 Block diagram of EEFL equivalent circuit model

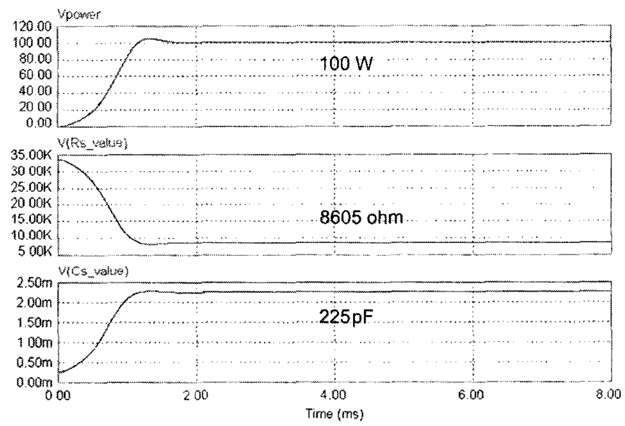


Fig. 7 Simulation results: lamp power, Rs value, Cs value

These curves can be expressed as a function of lamp power using linear approximation. *Rs* and *Cs* are expressed as equation (4) and (5).

$$R_S(P_{Lmap})=a_RP_{Lamp}{}^2+b_RP_{Lamp}+c_R \tag{4}$$

$$C_S(P_{Lamp})=a_CP_{Lamp}{}^2+b_CP_{Lamp}+c_C \tag{5}$$

Each coefficient is listed in Table 2.

Fig. 5 shows experimental data and an approximation using equations (4) and (5) at 50kHz. We can determine an approximation based on the experimental data.

Fig. 6 shows the block diagram of the EEFL equivalent circuit model used for the simulation. The block diagram is composed of three parts which are the power calculation part, the equivalent *Rs* part, and the equivalent *Cs* part.

In the power calculation part, the instantaneous lamp power P_{inst} (6) is first obtained by multiplying the lamp voltage by the lamp current. The lamp power P_{Lamp} (7) is calculated by averaging the instantaneous lamp power.

$$P_{inst}(t)=V_{Lamp}(t)\times I_{Lamp}(t) \tag{6}$$

$$P_{Lamp}=\frac{1}{T}\int P_{inst}(t)dt \tag{7}$$

In the equivalent *Rs* part, the value of *Rs* can be calculated using equation (4) and P_{Lamp}. The circuit diagram with resistor and dependent voltage source is made to satisfy equation (8).

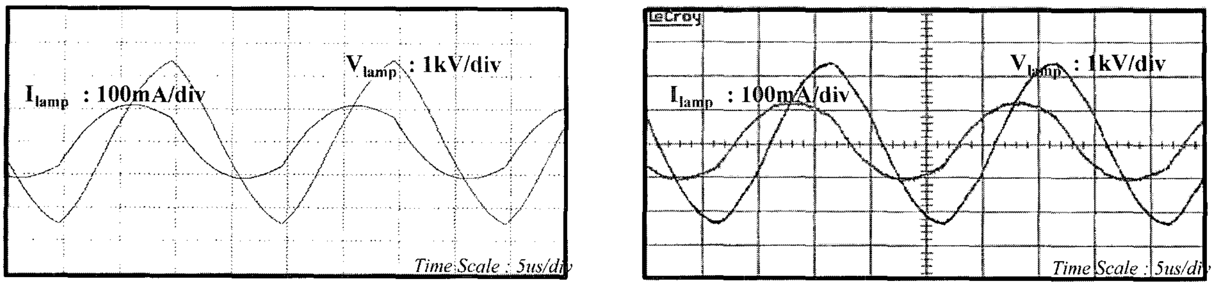
$$\begin{aligned} V(R_S) &= 1\times I_{Lamp}+I_{Lamp}\times R_S(P_{Lamp})-I_{Lamp} \\ &= I_{Lamp}\times R_S(P_{Lamp}) \end{aligned} \tag{8}$$

In the equivalent *Cs* part, the value of *Cs* can be calculated using equation (5) and P_{Lamp}. The circuit diagram with capacitor and dependent voltage source is made to satisfy equation (9).

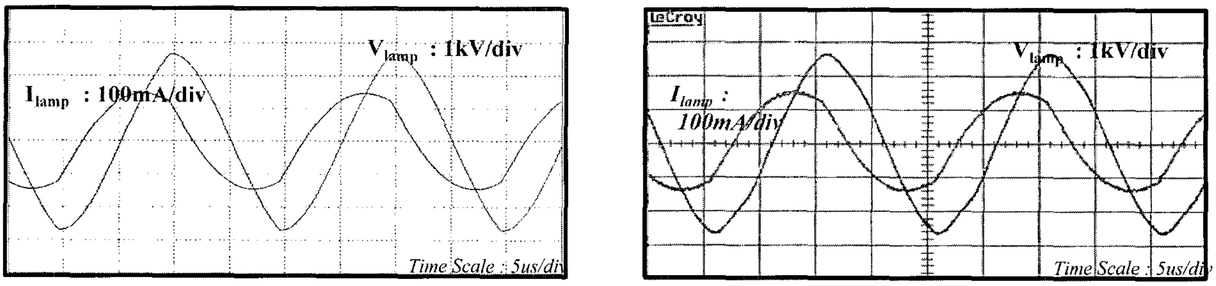
$$V(C_S)=\frac{1}{C_S(P_{Lamp})}\int I_{Lamp}(t)dt \tag{9}$$

3. Simulation and Experimental Results

The simulation results of the EEFL equivalent circuit



(a) 80W : simulation waveforms (b) 80W : experimental waveforms



(c) 100W : simulation waveforms (d) 100W : experimental waveforms

Fig. 8 Key waveforms of simulated and experimental results

model are shown in Fig. 7. The specification for the simulation is the same as Table 1. The lamp power is obtained by averaging the instantaneous lamp power. The values of the equivalent resistance and capacitance are calculated in exactly the same way as the experimental data by using the lamp power. Fig. 8 shows the simulation and experimental waveforms at 80watts and 100watts. We can see that the simulation waveforms coincide with the experimental results very well.

4. Conclusion

As an LCD backlight source, an EEFL has many advantages over a CCFL. Therefore, it seems that it will be widely used in the near future. However, an EEFL has both resistive and capacitive characteristics unlike a CCFL. This causes many difficulties in the design of LCD backlight systems. In this paper, we first investigated values of resistance and capacitance at several operating frequencies and then demonstrated them at them at numerical expressions. Finally, we made a block diagram of the equivalent circuit model using numerical expressions. Therefore, the equivalent circuit modeling of an EEFL will be very useful for designing LCD backlight systems.

Analyzing the simulations, we can conclude that the simulation waveforms agree with the experimental results. Therefore, the proposed equivalent circuit model of an EEFL becomes very useful for designing LCD backlight systems.

Acknowledgment

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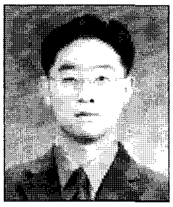

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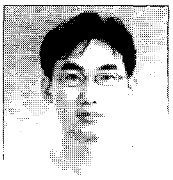

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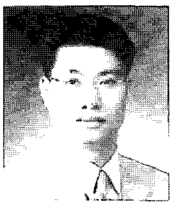

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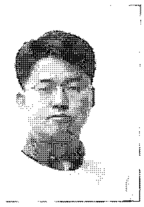

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