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Distributed circuit model for cold cathode fluorescent lamps in back-light unit of liquid crystal display

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ABSTRACT

This paper presents a distributed circuit model of the cold cathode fluorescent lamps (CCFLs) in the back-light units (BLUs) of liquid crystal displays (LCDs). This model consists of nonlinear resistors and parasitic circuit elements, and it can be used to simulate CCFL BLUs for various input waveforms using standard circuit simulators. The nonlinear resistors were modeled after the measured DC current–voltage characteristics of CCFLs. The coupling effects between CCFLs and between CCFL and the BLU frame were represented using the parasitic capacitances and inductances. For both pulsed and sinusoidal inputs, the voltage error between electrical simulation and measurement was $\leqslant 1.3\%$ and the current error was $\leqslant 5.8\%$. These results demonstrate that the circuit model can be used to simulate the electrical behavior of CCFLs in LCD BLU accurately.

1. Introduction

Cold cathode fluorescent lamps (CCFLs) are used widely as light sources in back-light units (BLUs) for liquid crystal display (LCD) devices [1–3] because they are cheap, durable, and power-efficient. CCFLs use a glow discharge to emit visible light and they are driven by a dc-to-ac converter (inverter). The current–voltage (*I*–*V*) characteristic of the discharge in CCFL is highly nonlinear, so simulation of the electrical characteristics of a BLU circuit is very difficult.

Several models of CCFLs have been proposed [4–6]. They can be classified into two groups: theoretical models which are well suited to numerical analysis [4,5], and circuit models which are appropriate for a steady state analysis [6]. The theoretical models are based on the physical behaviors of CCFL. These models are quite accurate but complex. To predict the electrical behavior of CCFLs accurately, many physical parameters must be determined by measurement. Existing circuit models are very simple and require only a few electrical parameters, such as the inductance, capacitance, and resistance of the CCFL in steady state, so they are very good for steady state analyses but cannot be easily applied to simulate the transient behavior of CCFL for various input waveforms [6] or to analyze the stability of the inverter circuit.

This paper proposes a distributed circuit model of CCFLs which can simulate the performance of CCFL BLUs for various input waveforms using a standard circuit simulator such as PSPICE [7]. The proposed model consists of a circuit model for the plasma in the CCFL, and a few capacitors and inductors which represent the parasitic circuit elements of lamp, the coupling between lamps, and the coupling between lamp and frame of the BLU. The method of modeling the plasma and parasitic elements is described in Section 2, parameter extractions for the circuit from measurements are given in Section 3, a complete circuit model for CCFL BLU and a comparison of simulation with measurement are given in Section 4, and a conclusion is given in Section 5.

2. Distributed circuit model of CCFL back-light unit

2.1. Experimental back-light unit

In the experimental CCFL BLU for 42 in. LCD (Fig. 1), 20 lamps were located at 7 mm above the ground frame. Each lamp was constructed of a glass tube with an inner diameter of 3 mm, an outer diameter of 4 mm, and a length of 970 mm. Two 10-mm-long cylindrical electrodes were located inside the glass tube, one at each end. The space between lamps was 25 mm. The discharge gas was a mixture of Ne, Ar, and Hg. The lamps were driven using two inverters which were located behind the ground plane. All lamps were operated at equal amplitude of current, but the phase difference of current between adjacent lamps was kept at 180°.

2.2. Equivalent circuit for plasma in CCFL

A piecewise linear *I*–*V* characteristic curve for a dc discharge (Fig. 2) can be divided into a dark discharge region ($P_0 \sim P_2$), where

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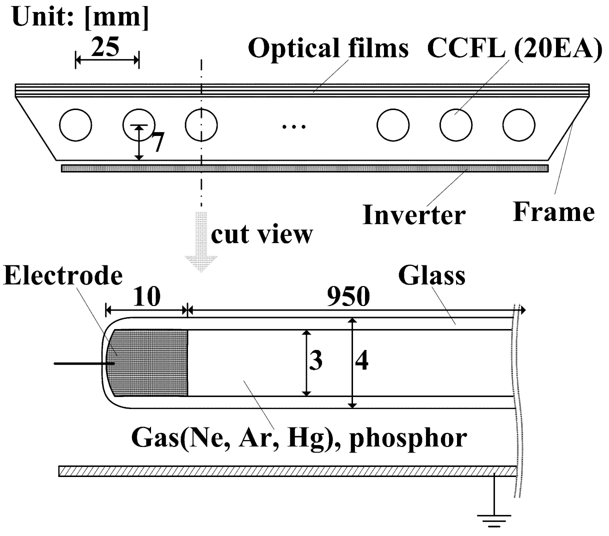

Fig. 1. Structure of experimental CCFL BLU.

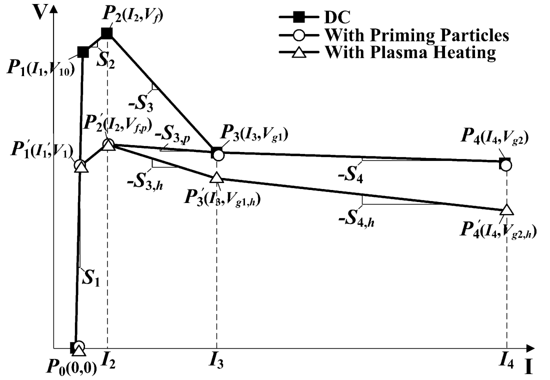

Fig. 2. Typical *I–V* characteristic curve of a dc discharge with and without priming and heating effects.

V increases with I, and a glow discharge region ($P_2 \sim P_4$), where V decreases with an increase of I [8]. The firing voltage V_f for the glow discharge, which is defined as the voltage at P_2, decreases to $V_{f,p}$ when sufficient priming particles exist in the discharge space. The resistance of the glow discharge becomes more negative when the cathode is hot enough to emit electrons by plasma heating [9]. For a discharge with symmetric electrodes, the *characteristic for the reverse discharge is the same as that for the forward discharge.*

The electrical equivalent circuit (Fig. 3) for the plasma in CCFL BLU was constructed using two current-controlled-current-sources (CCCSs) F_1 and F_2, a sub-circuits N_1 which models the priming effects, a sub-circuit N_2 which models the heating effects, and three voltage-controlled-variable-resistors (VCVRs) which realize the piecewise linear *I–V* characteristic of the dc discharge. This circuit is a current-controlled piecewise-linear time-varying resistor R_{pdc}, which is an improved version of the equivalent circuit of plasma proposed by Jung et al. [10].

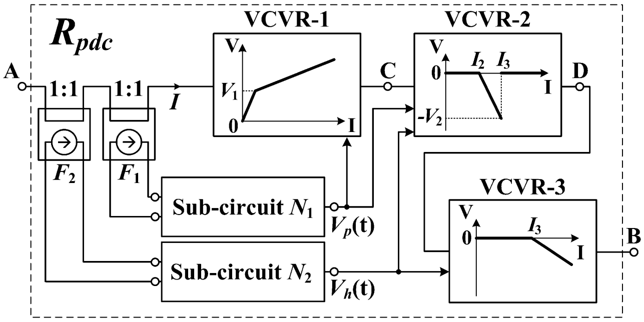

Fig. 3. An electrical equivalent circuit for a dc discharge.

The three VCVRs have different structures and electrical characteristics (Fig. 4). The resistance of VCVR-1 is R_1 for $|V_{AC}| \leqslant V_1$ because the diodes D_1 and D_2 are reverse biased, and it is $R_1R_2/(R_1+R_2)$ for $|V_{AC}| > V_1$. Here, V_1 is the voltage at P'_1 and V_{AC} is the voltage of node A with respect to node C. VCVR-2 realizes a negative resistance for the current range of $I_2 < |I| \leqslant I_3 = I_2 + V_2/R_3$; the current flowing through R_3 is $I - I_2$ in this current range, because all diodes in VCVR-2 are reverse biased. Therefore the voltage of node C with respect to node D (V_{CD}) is $-R_3(I - I_2)$, which gives the desired negative resistance of $-R_3$. Here, I_2 is the discharge current at P_2, I_3 is the discharge current at P_3, and $V_2 = R_3|I_2 - I_3|$. The resistance of VCVR-2 becomes 0 Ω for the other current ranges, because diodes D_4 and D_6 are forward-biased for $|I| \leqslant I_2$, and D_3 and D_5 are forward-biased for $|I| > I_3$. VCVR-3 realizes a negative resistance for $|I| > I_3$. Its resistance is 0 Ω for $|I| \leqslant I_3$ and $-R_4$ for $|I| > I_3$. The dc *I–V* characteristic in Fig. 2 is realized by connecting the VCVRs in series and by choosing the resistances as $R_1 = S_1$, $R_1R_2/(R_1 + R_2) = S_2$, $R_3 = -S_3 + R_1R_2/(R_1 + R_2) \equiv R_{3o}$, and $R_4 = -S_4 + R_1R_2/(R_1 + R_2) \equiv R_{4o}$.

The priming effect moves P_1 to P'_1 and P_2 to P'_2, which decreases the slope S_3 to $S_{3,p}$. The plasma heating decreases V_{g1} to $V_{g1,h}$ at P_3, and V_{g2} to $V_{g2,h}$ at P_4. Therefore the plasma heating changes the slopes $S_{3,p}$ to $S_{3,h}$ and S_4 to $S_{4,h}$. These changes of slope due to the heating and priming effects were realized using the voltage-controlled-voltage-sources (VCVSs) V_1 in VCVR-1 and V_2 in VCVR-2, and using the voltage-controlled-time-varying-resistors (VCTVRs) R_3 in VCVR-2 and R_4 in VCVR-3.

The sub-circuits N_1 and N_2 generate the control voltages $V_p(t)$ and $V_h(t)$ for V_1, V_2, R_3, and R_4. They have the circuit structure shown in Fig. 5, where the subscript x stands for p for N_1 and h for N_2. The circuit (Fig. 5) inputs the discharge current I sensed by either F_1 or F_2 in Fig. 3, rectifies I, converts I to a voltage source using the current-controlled-voltage-source (CCVS) H_1, and outputs the following voltage:

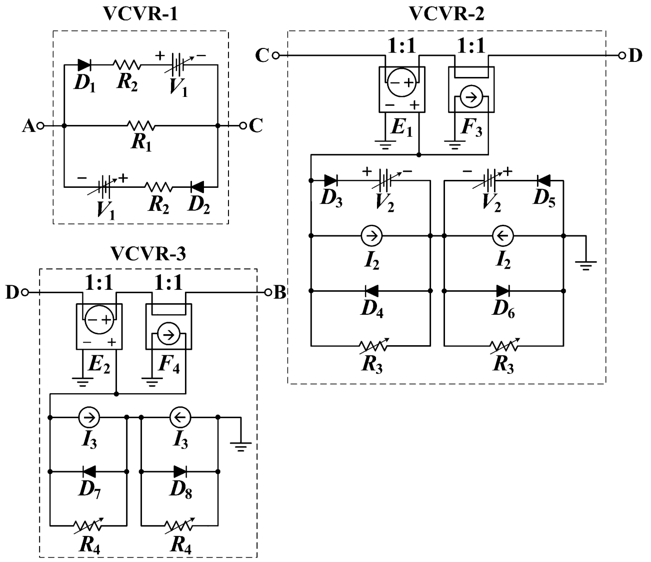

Fig. 4. Implementation of voltage-controlled-variable-resistors.