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Method of controlling external electrode fluorescent lamps for local dimming of liquid crystal displays

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ABSTRACT

This paper proposes a method of controlling external electrode lamps (EEFLs) for local dimming of liquid crystal displays (LCDs). In the proposed method, each EEFL is divided into four partitions using external electrodes formed on the outer surface of the lamp. The luminance is controlled by varying the duration of ac power applied to the center electrode of each partition. The shape of the external circuit for the center electrode is designed to have a reliable on/off operation. Balance circuits connected to the grounded electrodes are used to reduce the luminance difference between the left and right parts of each partition. The proposed method was tested on a 42-in. LCD using an EEFL backlight unit (BLU) after dividing the BLU into 24 blocks. The EEFL BLU could operate reliably up to an ac peak voltage of 1.4 kV, while controlling the luminance of each block independently. When one block at the corner was turned on, and the others were turned off, the luminance ratio was ~11.1:1 between the block and the nearest one, and ~9000:1 between the block and the farthest one. These experimental results demonstrate that the proposed method is an effective approach for local dimming of LCDs using EEFL BLUs.

1. Introduction

The backlight unit (BLU) for a liquid crystal display (LCD) should have low cost and low power consumption [1]. BLUs have been fabricated using either cold cathode fluorescent lamps (CCFLs), external electrode fluorescent lamps (EEFLs), or light emitting diodes (LEDs) [2–5]. CCFL and EEFL BLUs have been used widely because they are cheap and have good optical efficiency. LED BLUs are relatively expensive but have several advantages over the CCFL or EEFL BLUs; they are slim and non-polluting, and have a wide color range and fast response time [6–9], so they are gradually replacing CCFL and EEFL BLUs.

The local dimming technique is very useful for reducing power consumption and for increasing the contrast ratio [10–13]. For local dimming of an LCD, the BLU must be divided into several blocks and the luminance of each block must be controlled independently in accordance with the picture data. The local dimming technique has been applied only in LCDs that use an LED BLU, because each LED in the BLU can operate as a point light source. The cost of LED BLUs for local dimming is significantly higher than that of the other BLUs.

The CCFL and EEFL BLUs use long thin fluorescent lamps which require a few drive circuits. To implement local dimming using fluorescent lamps, the number of lamps and drive circuits must be increased in proportion to the number of local dimming blocks, but this increase the BLU's cost intolerably. The cost of BLUs could be reduced significantly by using long thin EEFLs, dividing each EEFL into several dimming partitions, and finding a reliable method of controlling the luminance of each partition. In the case that one EEFL is divided into several partitions using several external electrodes, the discharge spaces for all dimming partitions are connected. So, when one partition has discharge, priming particles can flow into adjacent partitions and cause erroneous discharge which is induced by leakage power through the power switching device. Besides this, an imbalance of discharge impedance between left and right part of the partition occurs when one adjacent partition is turned on and the other is turned off.

This paper proposes a method of controlling EEFLs for local dimming of LCDs. The proposed method uses long thin EEFLs which have been used widely for EEFL BLUs. For the local dimming experiment, each EEFL was divided into four partitions using external electrodes formed on the outer surface of lamp. In each partition, a ground electrode was located at each partition end and one power electrode was located at the partition center. The luminance was controlled by varying the duration of ac power applied to the power electrode. An external metal pattern was connected to the power electrode to provide reliable on/off operation, and two balance circuits were connected to the grounded electrodes to reduce

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the luminance difference between the left and right parts of each partition. The electrode arrangements, circuit structures, and principle of EEFL control for local dimming are described in Section 2. The experimental results on a 42-in. EEFL BLU with 24 dimming blocks are given in Section 3, and a conclusion is given in Section 4.

2. Electrode arrangement and circuit structures for EEFL local dimming

2.1. Electrode arrangement

The discharge tube of the EEFLs for experiment was made of a borosilicate glass; the tube had an inner diameter of 2.4 mm, an outer diameter of 3.4 mm, and a length of 956 mm. The inner wall of the glass tube was coated with a tri-color (red, green, and blue) phosphor. The discharge gas was a mixture of Ne and Ar, with very small amount of Hg additive.

Each EEFL was divided into four partitions of equal length using external electrodes which were formed on the outer surface of lamp (Fig. 1a). In each partition, two ground electrodes were located at the partition ends and one power electrode was located at the partition center (Fig. 1b). The power electrodes had a half-pipe shape and were located at bottom of the glass tube to secure the light paths from discharge. The length of power electrode was 30 mm. The ground electrodes were a 15 mm-long metal cylinder. The gap between the electrode and the BLU metal chassis was 3 mm. To control the luminance of each partition, the duration of high voltage ac power applied to each power electrode was controlled independently using four power switches S1–S4. The discharge current I_d supplied by the power electrode was divided into I_l and I_r which were collected by the ground electrodes located on the left and right partition ends, respectively.

2.2. Power switch circuit

The ac voltage source V_a for driving the EEFL had amplitude <1.5 kV and a frequency of 60 kHz. The power switching circuit (Fig. 2) was composed of two identical power n-MOSFETs (FQU2N100, Fairchild semiconductor Co.), a pulse-width-modulation (PWM) circuit, and a floating amplifier. The n-MOSFET has a built-in protection diode between the drain and source. The PWM circuit generates 5 V control signals. The floating amplifier inputs the control signals, amplifies the control signals to 15 V, and outputs the gate signals for the n-MOSFETs.

When the control signal is 0 V, the n-MOSFETs are turned off and the ac power is supplied only through two serially-connected MOSFET output capacitor C_{out} s and protection diodes. Otherwise, the n-MOSFETs connect the ac power to the power electrodes.

2.3. Erroneous discharge suppression circuit

Light emission of the experimental EEFL versus the root-mean-square (rms) voltage applied to the power electrode $V_{p,rms}$ was measured at points close to the power (open circle) and ground electrodes (open square) (Fig. 3), while keeping the frequency of the ac voltage source at 60 kHz. The response was hysteretic. When voltage was increased, the discharge started at the discharge space near the power electrode when $V_{p,rms}$ > 342 V. It spread toward the

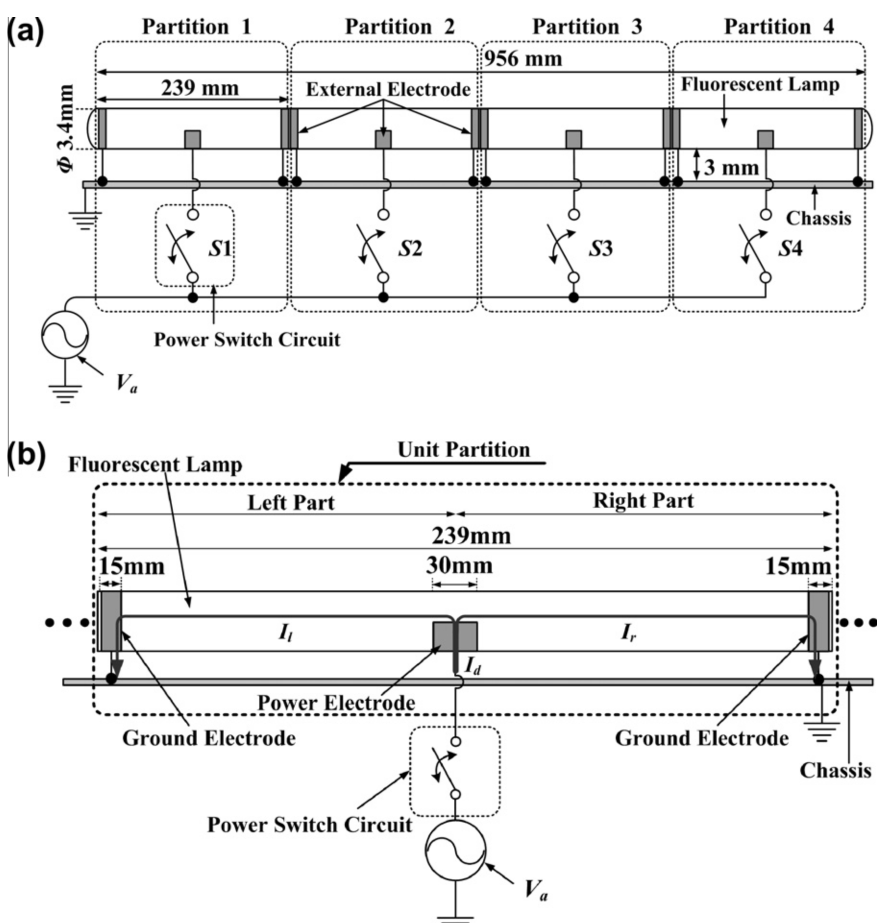

Fig. 1. The experimental EEFL: (a) electrode arrangement and drive circuit for lamp experiment and (b) detailed structure of a partition of the EEFL.