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Cost-Effective Local Dimming Driving Scheme of Xe-Lamp for Low-Power Backlight Unit

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A new driving scheme and circuit for a low-cost local dimming Xe backlight unit are proposed based on the ac-discharge principle that a subsequent discharge can be easily produced under a low voltage condition due to the wall charges induced by the previous discharge. As a result, the proposed scheme only requires 4 transformers for the operation of a 40-in. Xe backlight with 64 local dimming blocks.

Keywords AC-discharge principle; local dimming; Xe flat lamp; low-cost circuit

1. Introduction

Liquid crystal displays (LCDs) require a backlight unit (BLU), as they cannot generate visible light themselves. Various efforts have been made to produce low-cost and high-efficiency BLUs, including a cold cathode fluorescent lamp (CCFL) and light emitting diode (LED). However, the CCFL-type-BLU involves the use of mercury, making it environmentally unfriendly, while the LED BLU is too expensive. In contrast, a Xe backlight unit (Xe BLU) is eco-friendly, due to its use of Xe gas instead of Hg as the main UV source, plus it is cost-effective based on a simple structure [1–4]. Furthermore, with the increasing demand for LCDs with a low power consumption and high contrast, local dimming technology is required for the backlight unit [5–9]. Yet, the application of local dimming technology to a CCFL is difficult, as the mercury in a CCFL is unable to respond to a fast on- and off- operation, whereas the Xe gas in a Xe BLU can provide a fast on- and off-operation. However, the requirement of m + n driving ICs to drive m × n local dimming blocks using the matrix-driving method necessitates high voltage driving in an Xe BLU due to its wide gap structure. As such, the driving circuit requires transformers to amplify the low-voltage waveform, thereby increasing the circuit cost. Yet, when the discharge is

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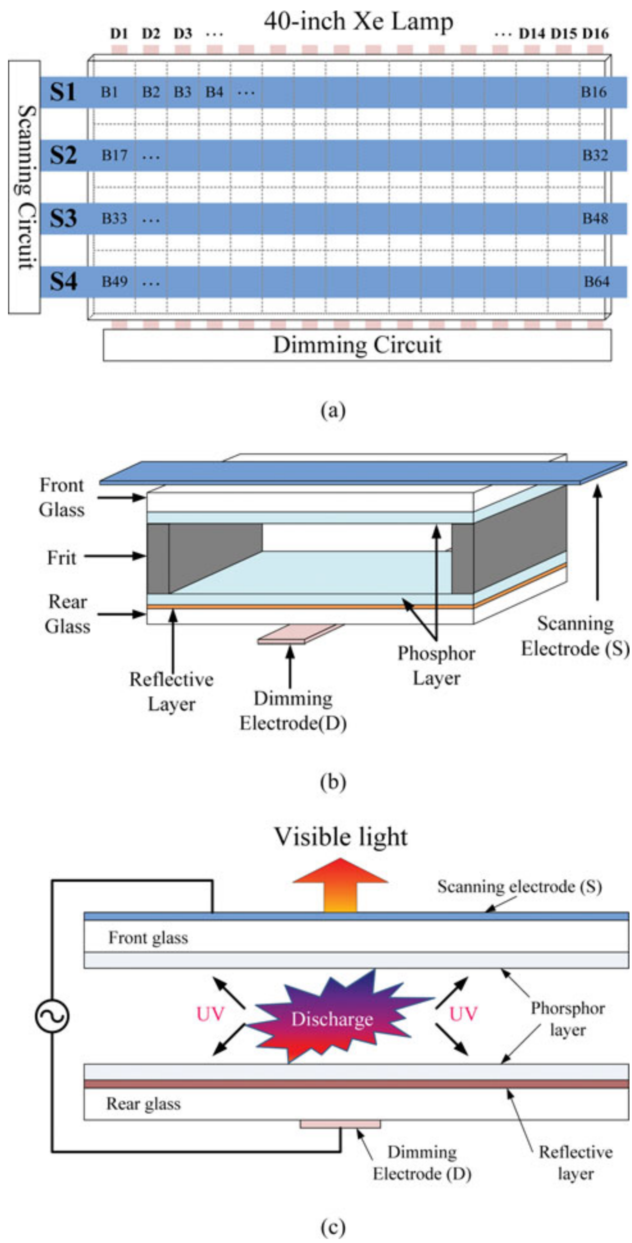


Figure 1. (a) Schematic diagram of 40-in. Xe test lamp with 4 × 16 local dimming blocks driven by 4 scanning and 16 dimming electrodes, (b) cell structure of 40-in. Xe lamp, and (c) visible light emitted during discharge of Xe lamp.

produced, wall charges are accumulated on the electrodes, which then allow the subsequent discharge to be produced easily under low-voltage conditions [10–12]. Accordingly, this paper uses this discharge concept to develop a new driving method for a low-cost local dimming Xe BLU.

Table 1. Specifications of 40-in. Xe lamp with plate-gap structure

		Structure
Lamp	Lamp Size	40 inch
	Glass Thickness	1.1 mm (Soda line)
	Reflective Layer	Al_2O_3, 60 μm
	Phosphor	White (R + G + B)
	Gap Between Glasses	2 mm
Electrode	Electrode	Mesh type using Cu
	S Electrode Width	80 μm
	D Electrode Width	40 μm
	Gap between Electrodes	5 mm
Gas	Gas Mixture	Xe (18%) + Ne (82%)
	Total Pressure	350 Torr

2. Experimental Methods

2.1. Experimental Observation from 42-in. Test Panel

Figure 1 (a) shows a schematic diagram of the 40-in. Xe test lamp used in this study with 64 local dimming blocks driven by 4 scanning and 16 dimming electrodes, and the plate-gap cell structure is presented in Fig. 1 (b). As shown in Fig. 1 (b), the Xe lamp consisted of two types of electrode (scanning and dimming), where the scanning electrodes (S-electrodes) were arrayed horizontally on the front glass, while the dimming electrodes (D-electrodes) were arrayed vertically on the rear glass. The gases used in the Xe lamp were Xe (18%)-Ne (82%). The specifications of transparent copper electrodes, *i.e.*, the S-electrodes on the front glass used to pass the visible light emitted from the lamp are given as follows. The thickness, resistivity, and transmittance of the S-electrodes were 80 μm, 50 Ω/γ, and above >89%, respectively. The front and rear glasses were coated with white phosphor (R + G + B) at a thickness of 10 and 40 μm, respectively. Plus, a reflective layer of 60 μm was deposited on the rear glass to reflect the visible light. Spacers were also placed between the front and rear glass to maintain the discharge space. Table 1 shows the detailed specifications of the 40-in. Xe test lamp. The electrodes were mesh-type, as the main type of discharge investigated in this study was a plate-gap discharge. The width of the electrodes was 10 μm, and the plate-gap between the front and rear glasses was 300 μm. The electrodes were attached to the outside of the glass, resulting in a dielectric barrier discharge, as the glass was used

Table 2. Driving voltages for 40-in. Xe lamp

Experimental Results	Voltage
Firing voltage	1.4 kV
Minimum sustain voltage	1.0 kV
Voltage margin (V)	400 V

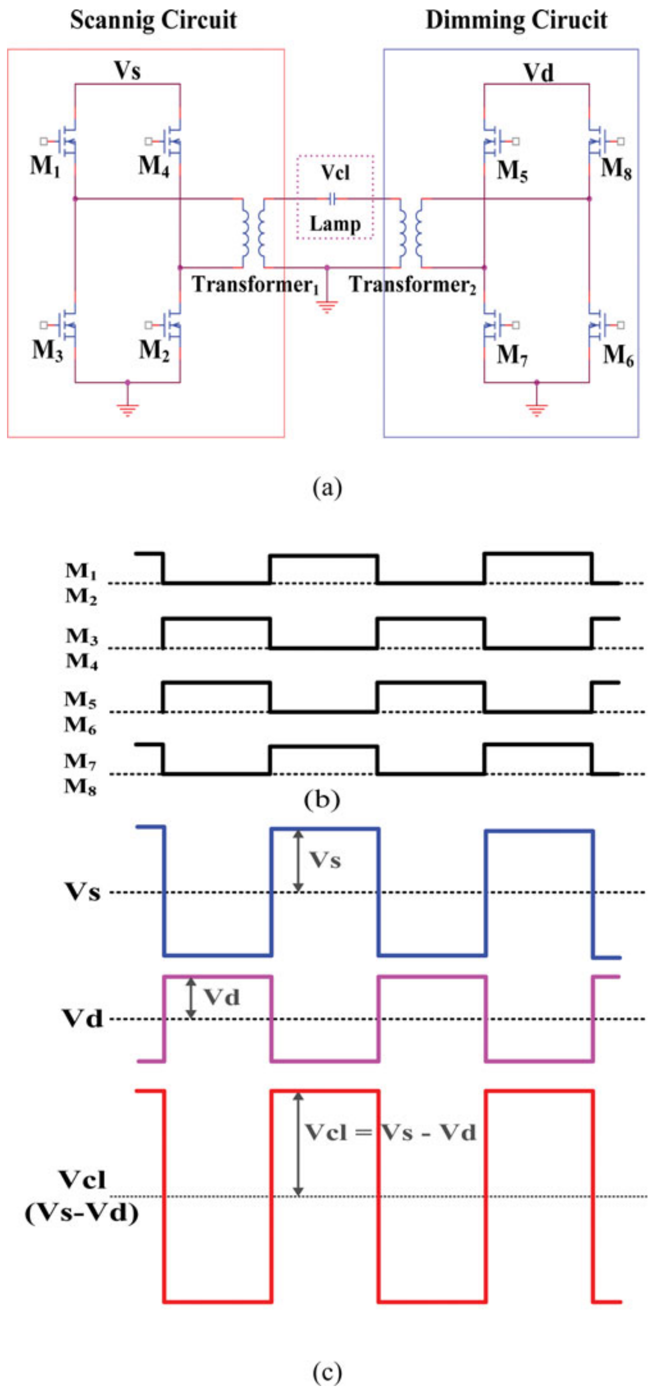
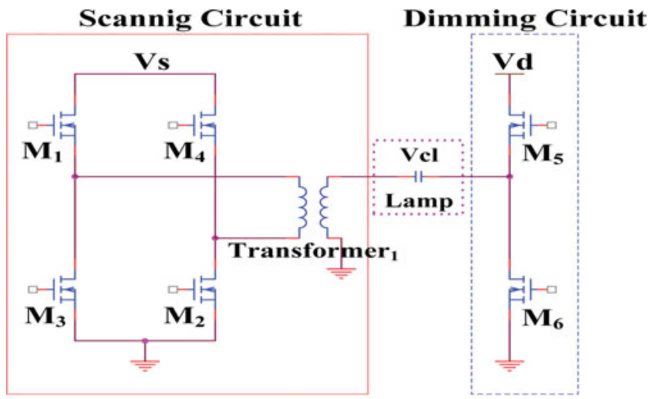
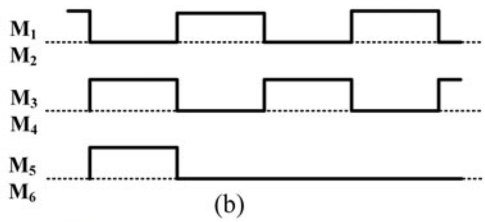


Figure 2. (a) Circuit diagram of scanning and dimming circuits with full-bridge inverter, (b) time switching diagram of 8 switches for operation of scanning and dimming circuits, and (c) voltage waveforms V_s and V_d applied to S- and D-electrodes in scanning and dimming circuits, respectively. The voltage between the S- and D-electrodes is determined by the voltage difference, and a discharge can only be produced by cells where V_{cl} ($= V_s - V_d$) is greater than the breakdown voltage.



(a)



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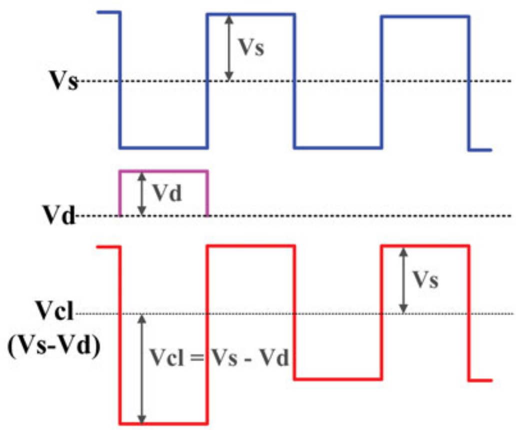

(c)

Figure 3. (a) Diagram of scanning and dimming circuits, (b) time switching diagram of 6 switches for operation of scanning and dimming circuits, and (c) voltage waveforms V_s and V_d applied to S- and D-electrodes in scanning and dimming circuits, respectively, in proposed 40-in. local dimming Xe lamp with 4 × 16 blocks.

as a dielectric [13]. When the driving pulse was applied, the discharge started at the cross point of the scan and dimming electrodes. As shown in Fig. 1 (a), the 40-in. Xe lamp had 64 dimming blocks that were operated by 4 scanning electrodes (S1 ∼ S4) and 16 dimming electrodes (D1 ∼ D16).

Table 3. Devices used with conventional and proposed local dimming circuits

Items		Prior			Proposed		
Scanning Circuit	IC	2(EA)	4 Line	8(EA)	2(EA)	4 Line	8(EA)
	FET	4(EA)		16(EA)	4(EA)		16(EA)
	Transformer	1(EA)		4(EA)	1(EA)		4(EA)
Dimming Circuit	IC	2(EA)	16 Line	32(EA)	1(EA)	16 Line	16(EA)
	FET	4(EA)		64(EA)	2(EA)		32(EA)
	Transformer	1(EA)		16(EA)	0(EA)		0(EA)

2.2. Experimental Observation from 42-in. Test Panel

Figure 1 (c) shows the visible light emitted from the cells of the Xe lamp. When the discharge was produced by applying the breakdown voltage to the two electrodes, a vacuum ultraviolet (VUV) with wavelengths of 147 and 173 nm was produced from the excited Xe atoms, which stimulated the white phosphor, resulting in the emission of white visible light from the white phosphor layer. The driving conditions were frequency of 25 kHz and duty ratio of 30%. For the Xe lamp in Fig. 1 (a), the firing voltage was 1.4 kV, while the minimum sustain voltage was 1.0 kV, meaning that the first discharge was produced at 1.4 kV, whereas the subsequent discharge was produced at 1.0 kV, and this voltage difference was called the ‘voltage margin’, as shown in Table 2. Therefore, the proposed driving scheme seeks to reduce the circuit cost by lowering all the voltages based on the voltage margin, with the exception of the first firing voltage. Meanwhile, to provide the firing voltage into the Xe lamp, an inverter circuit with a transformer was used to convert a low voltage into a high voltage.

3. Results and Discussion

3.1. Circuit Diagram and Key Voltage Waveform

Figure 2 (a) presents a diagram of the scanning and dimming circuits of the 42-inch Xe lamp including a full-bridge inverter, and Fig. 2 (b) shows a time switching diagram for the 8 switches operating the scanning and dimming circuits. Based on the switching operation of the 8 switches for the scanning and dimming circuits, the voltage waveforms, V_s and V_d were simultaneously applied to the S- and D-electrodes, respectively, as shown in

Table 4. Firing and sustain voltages and currents used in scanning and dimming circuits with conventional and proposed local dimming driving schemes

Items	Prior			Proposed		
Firing voltage	Type	Voltage	Current	Type	Voltage	Current
	$V_s + V_d$	1.4 kV	1.4 A	$V_s + V_d$	1.4 kV	1.4 A
	$V_s + V_d$	1.4 kV	1.4 A	V_s	1.0 kV	1.0 A

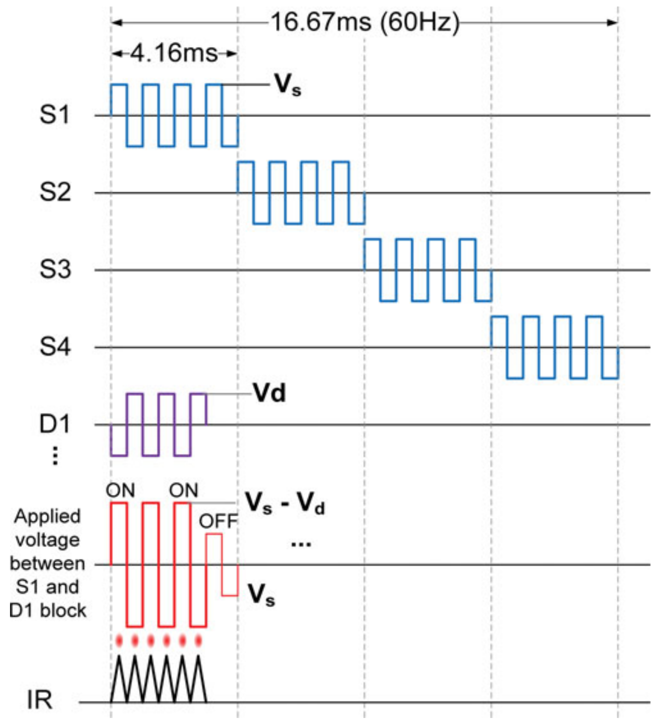

Figure 4. Conventional local dimming driving scheme using full-bridge inverters in both scanning and dimming circuits.

Fig. 2 (c). The voltage applied between the S- and D-electrodes was determined by the voltage difference, $V_s - V_d$. For local dimming, the discharge was only produced by the cells where V_{cl} ($= V_s - V_d$) was greater than the breakdown voltage. For the scanning circuit in Fig. 2 (a), the low voltage was amplified to V_s at transformer 1 after turning on switches M_1 and M_2, thereby being applied to the scanning electrodes. Simultaneously, in the dimming circuit, the low voltage was also amplified to V_d at transformer 2 after turning on switches M_7 and M_8, thereby being applied to the dimming block. When the resultant voltage, V_{cl} ($= V_s - V_d$), being greater than the breakdown voltage, was applied to the dimming block, it produced the discharge for emitting white visible light. However, even though this conventional driving method is quite simple, it requires many driving devices, making it very expensive. Furthermore, its power consumption is relatively significant, as a high voltage, such as V_{cl} ($= V_s - V_d$), which is greater than the breakdown voltage, is always applied to the dimming block. Consequently, to compensate for these drawbacks, a new cost-effective driving method is proposed that uses the voltage margin, as shown in Fig. 3. The basic concept is explained below. Once an ac discharge is produced by the firing voltage, the minimum sustain voltage, which is much lower than the firing voltage, can then maintain the subsequent discharge thanks to the wall charges. Thus, based on the ac-discharge principle, only two switches (M_5, M_6) were used to operate the dimming circuit, while the scanning circuit remained exactly the same, as shown in Fig. 2 (a). As such, with the proposed driving scheme, only one pulse was applied to the D-electrode, whereas pulses were continuously applied to the S-electrode. Plus, instead of a full-bridge inverter, a half-bridge inverter was used in the dimming circuit. Notwithstanding, sustain discharges were

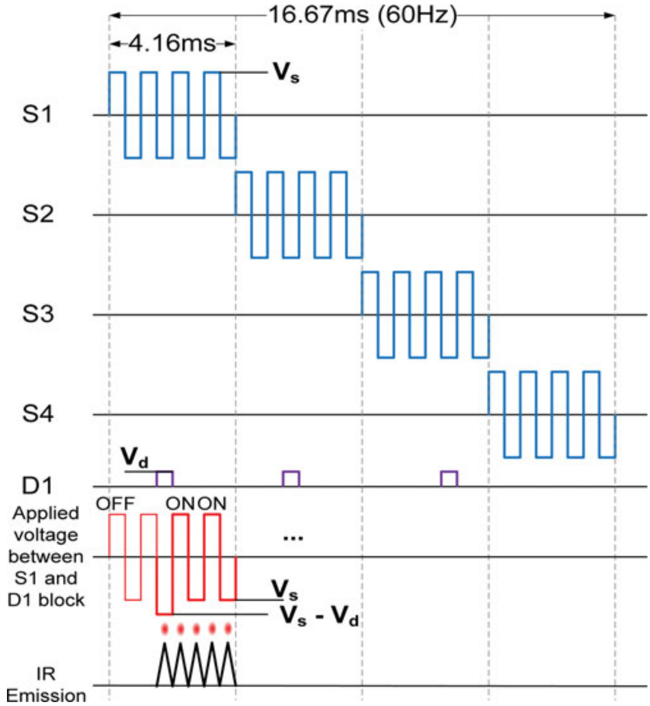

Figure 5. Proposed local dimming driving scheme using half-bridge inverter without transformer in dimming circuit and full-bridge inverter in scanning circuit.

still produced continuously and stably, implying that the subsequent discharges, excepting the first, were produced based on just the voltage applied to the S-electrode, thanks to the wall charges accumulated by the prior discharge. Table 3 shows that the devices used in the scanning circuit are exactly the same for both driving schemes, but, in the case of the dimming circuit with the proposed driving scheme, the ICs are reduced from 32 to 16 and the FETs are also reduced from 64 to 32.

3.2. Circuit Diagram and Key Voltage Waveforms

Figure 4 shows the conventional local dimming driving scheme [5]. As shown in Fig. 4, a scanning pulse was applied to each scan electrode progressively, one period was 16.67 ms (60 Hz), and each scan electrode was assigned 1/4 of one period (= 4.1 ms). Simultaneously, a dimming pulse with a 180-degree phase difference relative to the scanning pulse was applied to the dimming electrode. In this case, the voltage applied to the lamp was the sum of the scanning and dimming pulses, and when this applied voltage exceeded the firing voltage of the lamp, this started the discharge [10]. In addition, when the applied voltage was lowered to the minimum sustain voltage, the discharge disappeared. The number of discharges is controlled by the local dimming driving. The luminance of the lamp was linear against the number of discharges, like a plasma display panel (PDP). Thus, by controlling the number of dimming pulses, each dimming section became brighter or darker. Nonetheless, this method required 20 transformers (4 scanning electrodes + 16 dimming electrodes) to create the high-voltage scanning and dimming pulses. These

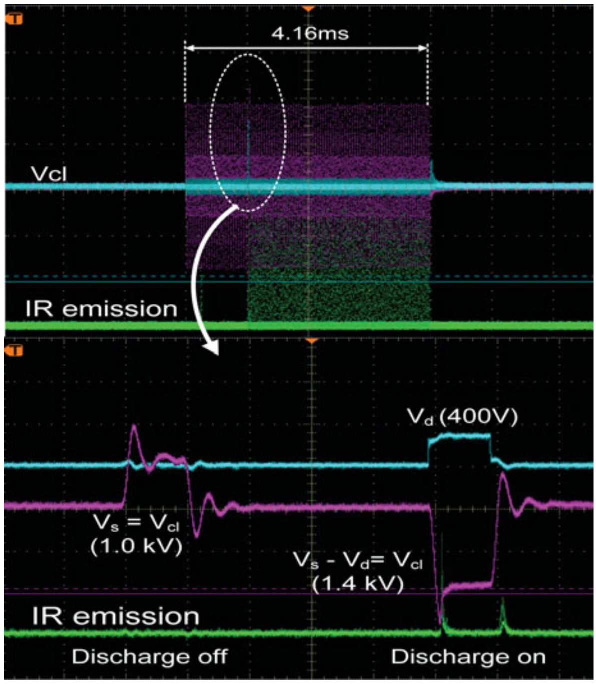

Figure 6. Measured data pulse, V_{scan}, and corresponding IR emission waveform when discharge is in off-state at V_{cl} (1.0 kV) [= V_s (1.0 kV) + V_d (0 V), while discharge is in on-state at V_{cl} (1.4 kV) [= V_s (1.0 kV) + V_d (400 V)].

transformers are expensive, thereby increasing the circuit cost. Figure 5 shows the proposed low-cost local dimming driving scheme. As shown in Fig. 5, a low voltage without the need for a transformer was used for the dimming electrodes. Meanwhile, the scanning method was the same as that used in the conventional method. A dimming pulse with a very low voltage was synchronously applied only once along with the application of a negative scanning pulse during the scanning period. Thereafter, the scanning pulse alone

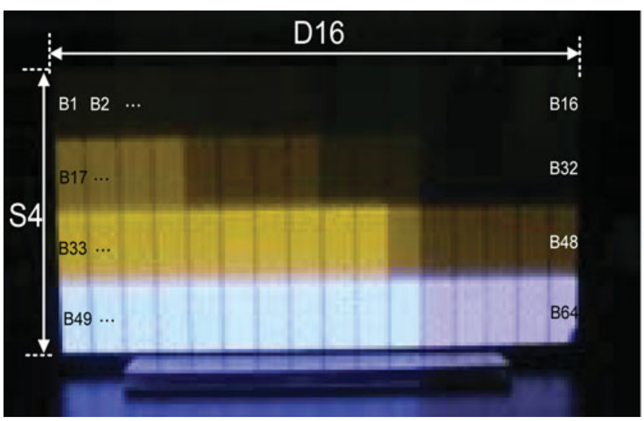

Figure 7. Operating image of 40-in. Xe lamp with 16 × 4 local dimming blocks.

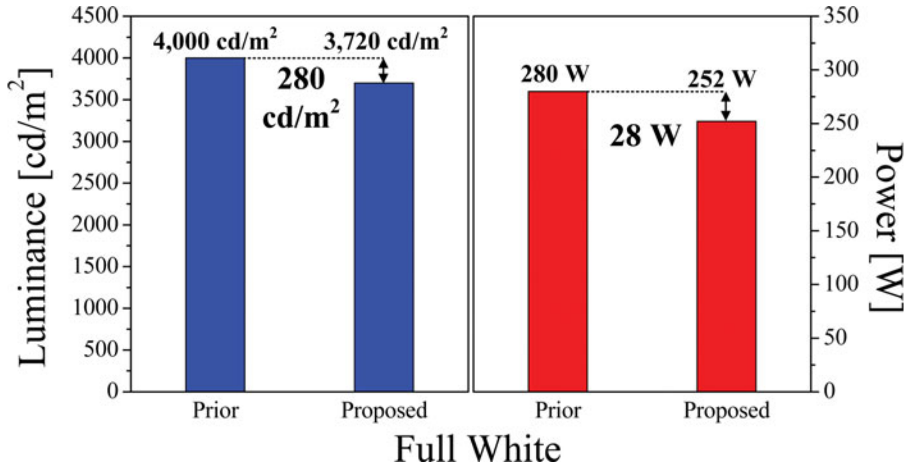

Figure 8. Comparison of luminance and power consumption when applying conventional and proposed local dimming methods.

was able to produce the subsequent discharges without any additional dimming pulses. Once the discharge occurred, it was not extinguished due to the accumulated wall charges [10]. Consequently, since the low-voltage dimming pulse did not require any transformers in the dimming circuit, this enabled low-cost local dimming driving of the Xe lamp. In addition, the gray scale expression could be increased by simply controlling the timing of the dimming pulses. Figure 6 shows the applied voltage with/without a dimming pulse and the corresponding infrared (IR) emission waveforms when adopting the proposed local dimming method. The frequency of the pulses was 25 kHz, the duty cycle was 3 ms, and the firing voltage of the lamp was 1.3 kV. When the amplitude of the positive scanning pulse was 1.0 kV, no discharge was produced. However, even when the amplitude of the negative scanning pulse (= V_s) was 1.0 kV, a discharge was produced with the synchronous application of a dimming pulse (= V_d) of 400 V, as shown in Fig. 6, which was confirmed by monitoring the IR emission. Fig. 7 shows the successful operational image of the 40-in. Xe lamp with 16 × 4 local dimming blocks when adopting the proposed driving scheme. Plus, Fig. 8 shows a comparison of the luminance and power consumption under full white image conditions when applying the conventional and proposed local dimming. While the luminance with the conventional local dimming was far higher than that with the proposed local dimming, the power consumption with the proposed local dimming was slightly decreased by about 28W.

Conclusion

A new driving method and circuit were proposed for a low-cost local dimming Xe backlight unit. The basic concept of the proposed driving method is that subsequent discharges can be easily produced under a low voltage condition, thanks to the wall charges induced by the previous discharge. Thus, after a dimming pulse, the ensuing discharge can be produced by scanning pulses alone, without any additional dimming pulses. As a result, a test 40-inch BLU with 64 local dimming blocks was able to display using only four transformers. In addition, the gray scale expression could be increased by controlling the number of dimming pulses.

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