An X-Y Channel Dimming LED Backlight with Temperature Compensation for LCD TVs

Won-Sik Oh, Deayoun Cho, and Gun-Woo Moon

Display Research Center, Korea Advanced Institute of Science and Technology (KAIST)
350 Gwahangno, Yuseong-gu, Daejeon 305-701, KOREA

Abstract

In this paper, an X-Y channel dimming light emitting diode (LED) backlight with temperature compensation for in LCD TVs is proposed. It shows local dimming effects such as reduced power consumption and high dynamic contrast ratio even with much less number of LED drivers than that of the conventional two-dimensional local dimming method. Moreover, the image distortion caused by temperature variation of LED block can be effectively compensated. The validity of the proposed dimming method is verified by simulation and experimental results based on a RGB-LED backlight of a 32-inch LCD TV.

1. Introduction

Liquid-crystal-display (LCD) is one of the most popular display devices since it has many advantages such as high resolution, low power consumption, light weight, slim size and so on. When looking into an LCD used in monitor or TV applications, a backlight unit (BLU) is usually required. The BLU supplys light to the LCD panel and consumes the most power. The conventional backlight of LCDs illuminates at full luminance regardless of the displayed images, resulting unnecessary power consumption and low contrast ratio due to light leakage in the dark state.

To reduce power consumption and enhance the image contrast ratio of a LCD backlight, several techniques[1]-[10] in relation with adaptive dimming control such as 0-D (uniform dimming or backlight scaling), 1-D (line or channel dimming), and 2-D (block or cluster dimming) methods. In the backlight scaling method [1]-[3], the entire backlight luminance is reduced by a dimming factor k, and at the same time, the transmittance of liquid crystal (LC) is enhanced by a factor $1/k$, according to the input video signal. To reduce the power consumption more effectively, local (channel or block) dimming methods [4]-[9] have been suggested. In these methods, the backlight is divided into local areas (channels or blocks) and backlight scaling method is applied to each local area. The 2-D block dimming method is the best way to reduce power consumption and enhance image contrast ratio. However, it increases the number of drivers to control the luminance of each division block.

On the other hand, the luminance levels of the LED backlight are not stable over temperature and time due to the inherent characteristics of the LED [10]. In order to minimize luminance variation over temperature and time, optical feedback system is a good solution [10]. However, it is difficult to compensate the luminance difference between each LED module. The luminance variation rate between upper and lower part of LED backlight is different because the temperature of upper part of LED backlight is normally higher than that of lower's. Especially, in case of the local dimming LED backlight, the luminance variation rate of each LED blocks is different due to the different temperature variation of each LED block. Therefore, temperature compensated is needed to prevent the image from being distorted.

To solve these problems, a new adaptive dimming X-Y channel

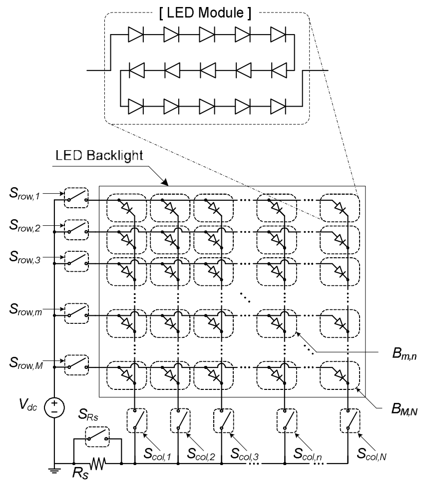


Fig. 1. Configuration of the proposed LED Backlight.

LED backlight system with temperature compensation for LCD TVs is proposed. As shown in Fig. 1, the proposed LED backlight utilizes channel switches to control the luminance of individual division screen and a resistor to sense the current of each LED blocks. By using the proposed technique, low power consumption as well as high contrast ratio is successfully obtained with less number of drivers than that of conventional local dimming method. Moreover, the luminance variation of each LED blocks caused by temperature variation is effectively compensated. In this paper, the characteristics of LED backlight are investigated and a new adaptive dimming algorithm as well as the temperature compensation methods is proposed for the X-Y channel LED backlight.

2. Proposed LED Backlight System

2.1 Operational Principle

The proposed LED backlight system as shown in Fig. 1 consists of LED modules which have series connected LEDs. These LED modules are connected to each other in a matrix structure with row channels (X channels) and column channels (Y channels). To control each channel, row and column switches are connected at the end of each channel and to an external power source. Therefore, the brightness of each division block can be controlled by a certain combination of row and column switches. The resistor, R_S, and switch, S_{Rs}, are for sensing current of each LED module. The current values sensed by sensing resistor, R_S, are used to compensate luminance variation caused by temperature of each LED blocks.

The operation period is composed of sensing and pulse width modulation (PWM) dimming parts as shown in Fig. 2. The current of each LED module can be sensed during the sensing period, and the luminance of each block can be decided during the PWM dimming period. Since the sensing period is much smaller than the PWM dimming period, the luminance of each block affected by

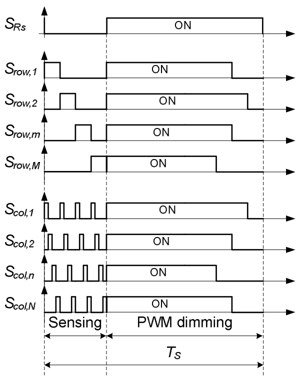
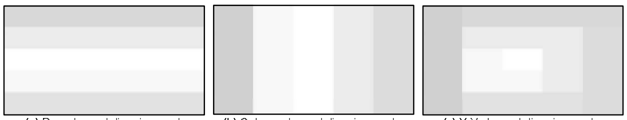


Fig. 2. Timing diagram.



(a) Row channel dimming mode (b) Column channel dimming mode (c) X-Y channel dimming mode

Fig. 3. Backlight image patterns of different dimming mode.

the sensing period can be neglected. During the sensing period, the switch, S_{Rs}, is turned off, and row switches are turn on and off. During one of row switches, $S_{row,m}$, is turned on, the column switches are turned on and off one after the other. Therefore, only one LED block is turned on for an instant and its current can be sensed by a resistor, R_S.

The proposed adaptive dimming method can be operated in three modes; row channel, column channel and row-column (X-Y) channel dimming mode. Fig. 3 shows the backlight brightness patterns in each mode. In the row channel dimming mode, the row switches are PWM switching while column switches are turned on resulting row channel dimming backlight image as shown in Fig. 3 (a). In the column channel dimming mode, the column switches are PWM switching while row switches are turned on resulting column channel dimming backlight image as shown in Fig. 3 (b). In the X-Y channel dimming mode, the row and column switches are operating in PWM simultaneously as shown in Fig. 2. In this mode, the backlight brightness as shown in Fig. 3 (c) is decided by logical 'AND' operation between row and column switches because LED module of each division block, $B_{m,n}$, is turned on when both row and column switches, $S_{row,m}$ and $S_{col,n}$, are turned on. Therefore, the proposed dimming method results in $(M+N)$ drivers as opposed to $(M \times N)$ drivers of conventional block dimming method.

2.1 Dimming Algorithm

A new adaptive dimming algorithm is needed to decide the luminance of each division block for the proposed LED backlight system. The proposed dimming algorithm is composed of three major procedures; finding the maximum level data (MLD) from source image corresponding to each division block of LED backlight, selecting the brightness level of each division backlight, and modifying the image information to preserve the source image.

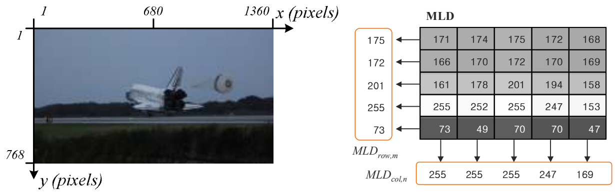
Fig. 4 shows the source image and its maximum level data (MLD) of each block, **MLD**, which is a M by N vector-matrix. From **MLD**, its maximum row and column MLDs, $MLD_{row,m}$ and $MLD_{col,n}$, can be decided as shown in Fig. 4 (b).

From gamma curve and $MLD_{row,m}$ and $MLD_{col,n}$, the duty ratio of each row and column switches can be determined and expressed as equations (1) and (2), as follows

$$D_{row,m} = [MLD_{row,m}/255]^{\gamma}\ , \qquad (1)$$

$$D_{col,n} = [MLD_{col,n}/255]^{\gamma}\ . \qquad (2)$$

Then, the dimming factor of each block, $k_{m,n}$, can be decided by the minimum value of $D_{row,m}$, and $D_{col,n}$, and can be expressed as in equation (3).



(a) Source image (b) MLDs of source image

Fig. 4. Information of source image.

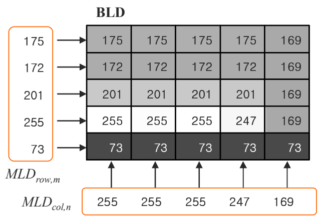
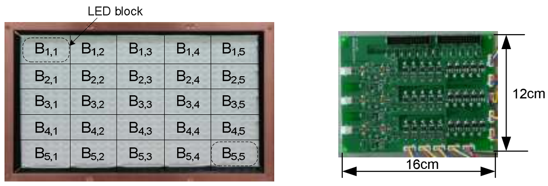


Fig. 5. Gray level data of the backlight luminance.



(a) RGB LED backlight (b) LED driver

Fig. 6. Implemented LED backlight and its driver.

$$k_{m,n} = \min(D_{row,m}, D_{col,n}) \qquad (3)$$

From this equation, theoretical power reduction rate compared to the conventional LCD system can be expressed as

$$\text{Power Reduction Rate} = 1 - \sum_{m=1}^{M}\sum_{n=1}^{N} k_{m,n}/(M \times N) \quad (4)$$

Fig. 5 shows the gray level data of backlight luminance, **BLD**, which is a M by N matrix after adaptive dimming. Here, the gray level data of each block luminance, $BLD_{m,n}$, can be expressed as

$$BLD_{m,n} = 255 \times k_{m,n}{}^{1/\gamma} \qquad (5)$$

For the perceived image after backlight dimming to be identical to that of the original source image without backlight dimming, the code value of the source image, $cv_{m,n}$, corresponding to each division block, $B_{m,n}$, of the backlight should be enhanced as

$$cv'_{m,n} = \frac{cv_{m,n}}{k_{m,n}{}^{1/\gamma}}\ . \qquad (6)$$

3. Temperature Compensation Method

3.1 Characteristics of Implemented LED Backlight

The proposed adaptive dimming method is adapted for a 32-inch LCD TV. The RGB-LEDs are used as the backlight source and the backlight is divided into 5 by 5 blocks as shown in Fig. 6 (a). Each LED block has 20 RGB-LED clusters which comprises 1 red, 2 greens and 1 blue small size LEDs. To drive the LEDs, 30 drivers as shown in fig. 6 (b) are used. Note that 75 drivers are needed in the conventional block dimming method. The three power sources for red, green and blue LED strings are used.

To compensate the luminance variation due to the change of temperature, the luminance-current characteristic with a constant voltage of each red, green and blue LEDs is investigated as shown in Fig. 7. In this figure, point A refers to normal temperature, T_L and point B refers to saturated temperature, T_H. As can be seen in this figure, the LED luminance can be a linear function of LED current when a constant voltage is supplied. Therefore, the luminance of each block can be expected by measuring the current of each LED block and expressed as

$$L_{m,n} = \alpha \cdot i_{m,n} + \beta \qquad (7)$$

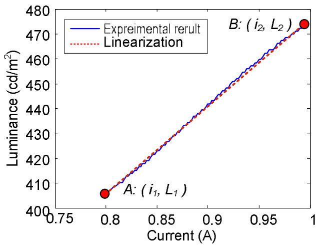


Fig. 7. Luminance and current characteristic of green LED.

where, $\alpha = M \times N \cdot \dfrac{L_1 - L_2}{i_1 - i_2}$ and $\beta = \dfrac{i_1 \cdot L_2 - i_2 \cdot L_1}{i_1 - i_2}$.

Therefore, the luminance variation ratio between normal and high temperature, $kt_{m,n}$, can be expressed as

$$kt_{m,n} = \frac{L_1}{L_1 + \Delta L} = \frac{\alpha \cdot i_1 + \beta}{\alpha \cdot (i_1 + \Delta i) + \beta} \qquad (8)$$

Here, i_1 can be decided by a reference value, and Δi can be measured by sensing resistor, R_S, in Fig 1. and 2. From the temperature compensation factor, $kt_{m,n}$, it is expected that the luminance of $B_{m,n}$ is enhanced by a factor, $1/kt_{m,n}$.

3.2 Temperature Compensation Methods

There are two methods to compensate backlight luminance from temperature variation. One is to compensate backlight luminance by adjusting duties of row and column switches from equations (1) and (2), and the other is to compensate the image, cv, from equation (6).

3.1.1 Backlight luminance compensation method

From the temperature compensation factor, $kt_{m,n}$, the maximum temperature compensation factors of each row and column channels, $kt_{row,m}$ and $kt_{col,n}$ can be obtained. Then, temperature compensated MLDs can be expressed as

$$MLD_{row,m} = \max(MLD_{m,1} \times kt_{m,1}{}^{1/\gamma}, MLD_{m,2} \times kt_{m,2}{}^{1/\gamma}, \cdots$$
$$, MLD_{m,N} \times kt_{m,N}{}^{1/\gamma}), \qquad (9)$$

$$MLD_{col,n} = \max(MLD_{1,n} \times kt_{1,n}{}^{1/\gamma}, MLD_{2,n} \times kt_{2,n}{}^{1/\gamma}, \cdots .$$
$$, MLD_{M,n} \times kt_{M,n}{}^{1/\gamma}). \qquad (10)$$

Then, the dimming factor of each block, $k_{m,n}$, of equation (3) can be corrected to equation (11).

$$k_{m,n} = \min(D_{row,m}, D_{col,n}) / kt_{m,n} \qquad (10)$$

3.1.2 Backlight luminance compensation method

From equation (5), the total luminance distribution of backlight resulting from temperature variation can be expressed as

$$BL\_kt(x,y) = \sum_{m=1}^{M} \sum_{n=1}^{N} kt_{m,n} \times BL_{m,n}(x,y). \qquad (11)$$

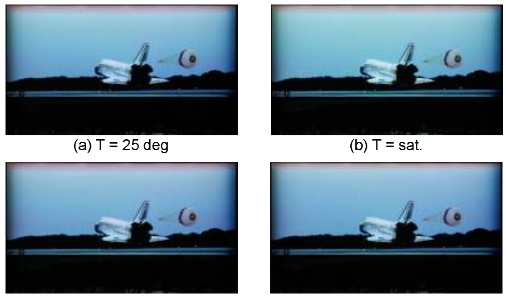
Therefore, from equation (3), equation (4) can be corrected to

$$cv\_kt(x,y) = cv(x,y) \times \frac{1}{BL\_kt(x,y)^{1/r}}. \qquad (12)$$

4. Experimental Results and Concluding Remarks

Fig. 8 (a) and (b) are the panel images at normal temperature and saturated temperature of 30 minutes later, respectively. Fig. 8 (b) becomes brighter than Fig. 8 (a). Fig. 8 (c) and (d) are compensated images from distortion image of Fig. 8 (b), using backlight luminance compensation method and image processing compensation method, respectively. These two compensated images look similar to the image of Fig. 8 (a). To make sure the validity of the proposed temperature compensation methods, the green color levels of panel images as shown in Fig. 8 at x = 680 pixels are plotted in Fig. 9. From this figure, the luminance variation by temperature can be well compensated by the proposed compensation method.

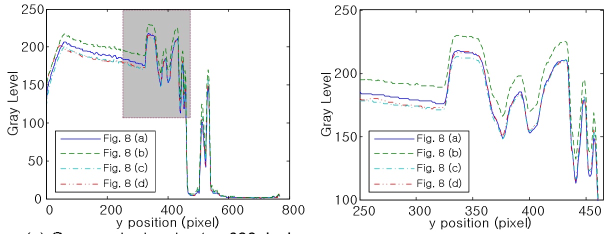
A novel X-Y channel dimming method with temperature compensation for LED backlight system in LCD TVs is proposed.



(a) T = 25 deg (b) T = sat.

(c) Backlight compensation (d) Image compensation

Fig. 8. Luminance and current characteristic of RGB LEDs.



(a) Green color levels at x=680pixel (b) Detail green color levels

Fig. 9. Luminance and current characteristic of RGB LEDs.

Since the proposed dimming method results in *(M+N)* drivers as opposed to *(M×N)* drivers, low cost and compact design of LED drivers can be achieved with power reduction and high dynamic contrast ratio. Furthermore, the luminance variation due to change in temperature can be compensated by sensing the current of each LED block. Therefore, the proposed adaptive dimming method with temperature compensation is well suited for LED backlight system in LCD TVs.

Acknowledgment

This work was supported by Samsung LCD Business, Korea, under Display Research Center program.

Reference

[1] Wei-Chung Cheng, Pedram M., "Power Minimization in a backlit TFT-LCD display by concurrent brightness and contrast scaling", IEEE Transaction on Consumer Electronics, Vol. 50, no. 1, pp. 25-32, Feb. 2004.

[2] A. Konno, Y. Yamamoto, and T. Inuzuka, "RGB Color Control System for LED Backlight in IPS-LCD TVs", SID 05 Digest, pp.1380, 2005.

[3] Naehyuck Chang, Inseok Choi, and Hojun Shim, "Dynamic Backlight Luminance Scaling of Liquid Crystal Display", IEEE Transactions on Very Large Scale Integration System, Vol. 12, no. 8, pp.837-846, 2004.

[4] T. Shiga, S. Mikoshiba, "Reduction of LCTV Backlight Power and Enhancement of Gray Scale Capability by Using Adaptive Dimming Technique", SID 03 Digest , pp.1364-1367, 2003.

[5] Hanfeng Chen, Junho Sung, Taehyeun Ha, Yungjun Park, and Changwan Hong, "Backlight Local Dimming Algorithm for High Contrast LCD TV", ASID' 06 Digest, pp.168-171, 2006.

[6] T. Shirai, S. Shimizukawa, T. Shiga, and S. Mikoshiba, "RGB-LED Backlight for LCD-TVs with 0D, 1D, and 2D Adaptive Dimming", SID 06 Digest, pp.1520-1522, 2006.

[7] D. Cho, W. S. Oh, K. M. Cho, and G. W. Moon, "New X-Y Channel Driving Method for LED Backlight System in LCD TVs", Proceeding of KIPE Power Electronics Annual Conference, pp. 147-149, 2007.

[8] D. Cho, W. S. Oh, K. M. Cho, G. W. Moon, B. Yang and T. Jang, "New X-Y Channel Driving Method for LED Backlight System in LCD TVs", Proceedings of IMID 2007, PP. 1001-1004, Aug., 2007.

[9] W. S. Oh, K. M. Cho, D. Cho, G. W. Moon, B. Yang and T. Jang, "A Novel Adaptive Dimming Technique with X-Y Channels for LED Backlight System of LCD TVs", Proceedings of ICPE 2007, pp. 710-713, Oct., 2007.

[10] K. C. Lee, S. H. Moon, B. Berkeley and S. S. Kim, "LED-backlight feedback control system with integrated amorphous-silicon color sensor on an LCD panel", Journal of the SID, pp. 161-168, 2006.