White LED Local Dimming Backlight for Aggressive Power Saving and Artifact Minimizing

Dong-Min Yeo*, Yong-hoon Kwon, Eui-Jeong Kang, Se-Ki Park, Byungchoon Yang, Gicherl Kim, and Taeseok Jang
LCD Technology Center, LCD Business, Samsung Electronics Co., LTD.
#200, Myeongam-Ri, Tangjeong-Myeon, Asan-City, Chungcheongnam-Do, Korea
Phone: +82-41-535-3135, e-mail: dm.yeo@samsung.com
Keywords : LED BLU, Local Dimming, Block Luminance Compensation

Abstract

Local dimming driving has advantages in reducing power consumption and improving contrast ratio(CR). In an LED backlight unit(BLU), many small LED blocks are implemented in 2-dimmensional space, and luminance of the blocks is controlled by a local dimming algorithm. However, such a BLU can induce various recognizable artifacts. A new novel algorithm is proposed for exact block luminance calculation to correct local dimming artifacts. Also we discuss modified low-gray-level dimming to achieve much aggressive power saving in a local dimming BLU system.

1. Introduction

Recently there has been a great deal of focus on local dimming LED backlights for high contrast ratio (CR), low power consumption, and wide color gamut [1-3]. However, this approach can induce various recognizable artifacts. For example, when the area around a target block is almost black, the luminance of the target block can be unintentionally reduced. In particular, the boundary of an image is not bright enough and blurred as shown in figure 1(a), where the luminance of all icons has been reduced, and the icons at either end have been severely blurred. This is a natural phenomenon because of insufficient block luminance from the neighboring blocks which are almost turned off by conventional local dimming algorithms. In other words, the blocks expressing a bright image cannot reach the target luminance to express the original image when neighboring LED blocks are locally dimmed. Thus, we propose a method of accurate block-luminance calculation and a new block luminance compensation (BLC) algorithm to correct these local dimming artifacts.

(a) Conventional algorithm (b) Advanced algorithm

Figure 1. Comparison of local dimming algorithms

2. Local Dimming Algorithms

Local dimming performance is directly related to the algorithm, which determines how much power consumption is reduced and CR is increased. For local dimming algorithms, two strategies can be employed. They are low-gray-level dimming and high-gray-level dimming as shown in figure 2.

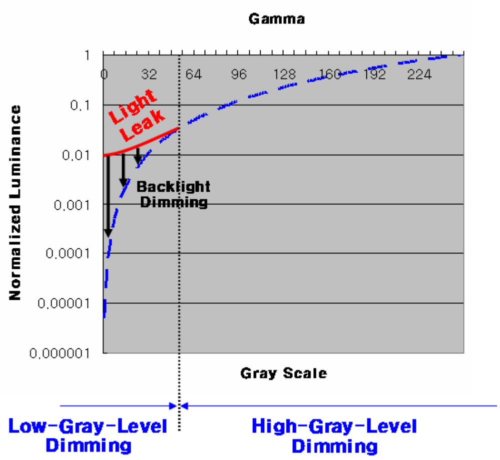

Figure 2. Local dimming strategy

Conventional LCDs have some light leakage at low gray levels, which causes severe CR degradation. In this case, we can reduce backlight brightness to meet ideal gamma characteristics of the LCD as shown in figure 2. This local dimming strategy is called low-gray-level dimming.

On the other hand, high-gray-level dimming can be applied in the region where gamma characteristics are ideal. This local dimming strategy requires complex pixel data compensation. The pixel data gray level must be higher than original values, and panel transmittance must increase enough to compensate the luminance reduced by backlight dimming. Therefore, we must modify pixel data considering content of the entire image and the backlight dimming level.

We adopt the low-gray-level local dimming strategy, because it is simpler and more efficient than the other method. However, the effect of low-gray-level dimming is quite limited in power saving due to its small operating range as shown in figure 2.

For aggressive power saving, we extended the range of low-gray-level dimming to cover the entire gray scales as shown in figure 3. Input pixel data can be converted into new pixel data with higher gray level by the conversion equation in the figure. This causes gamma characteristics to rise up over the entire gray levels, and then backlight is dimmed in most gray levels, allowing even more reduced power consumption compared to the original low-gray-level dimming.

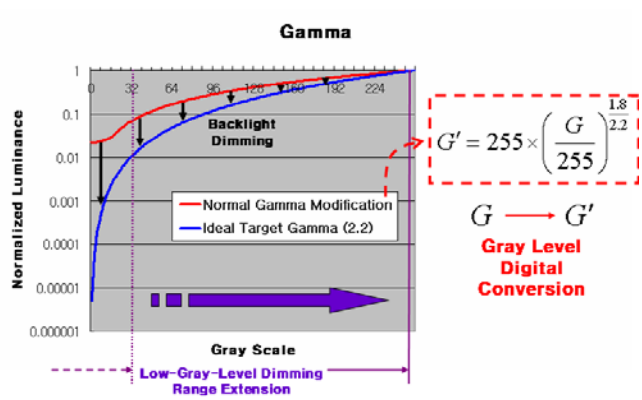

Figure 3. Extension of low-gray-level dimming

Local dimming algorithms are generally comprised of the steps shown in figure 4. It is important to decide how to extract a representative value for pixel data of a block and calculate the block luminance from the extracted value. The extraction method greatly affects the structure of the local dimming algorithm.

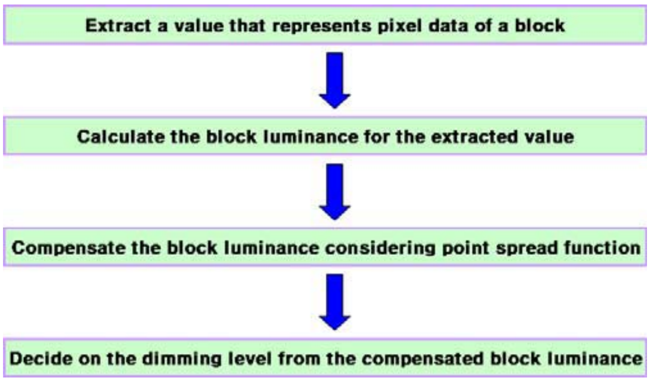

Figure 4. General local dimming algorithm

In our case, we decided to extract the representative value by averaging all the pixel data within a block. In order to calculate the block luminance efficiently, we propose a new method, in which ideal target gamma characteristics are used for calculation of the block luminance. If ideal target gamma is 2.2, the luminance that we should meet on the panel for a block after local dimming is calculated by equation (1).

$$Y_R = Y_{R=255} \times \left(\frac{\bar{R}}{255}\right)^{2.2} \quad [cd/m^2]$$
$$Y_G = Y_{G=255} \times \left(\frac{\bar{G}}{255}\right)^{2.2} \quad [cd/m^2] \qquad (1)$$
$$Y_B = Y_{B=255} \times \left(\frac{\bar{B}}{255}\right)^{2.2} \quad [cd/m^2]$$

Compared to the rather conventional RGB-to-YCbCr transform matrix for block luminance calculation, this method gives us an exact value more efficiently. Since the RGB-to-YCbCr transform matrix has a tiny transform coefficient especially for blue gray level, it is too difficult to take luminance of blue into account exactly.

In the next step, we have to compensate the block luminance considering panel transmittance and point spread function (PSF) that means the light spreading profile of a discrete block in the BLU. The backlight luminance of one block affects that of the neighboring blocks according to the PSF.

Finally, we can determine dimming level from the compensated block luminance. However, we encountered notable local dimming artifacts, one of which is image blurring demonstrated in figure 1(a). The issue has been a typical local dimming artifact.

To correct these artifacts, we propose a new novel local dimming algorithm complemented with what we call block luminance compensation (BLC), and it is illustrated in figure 5.

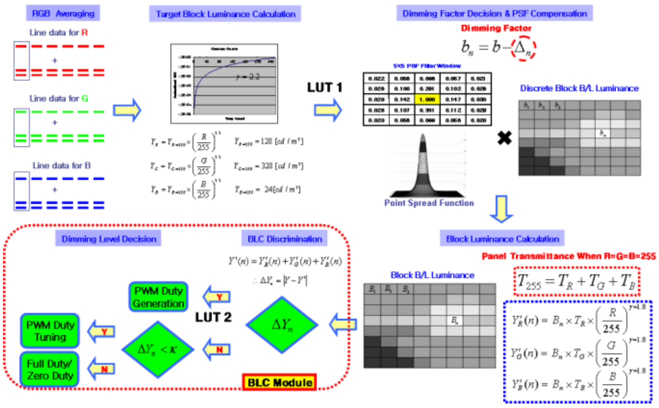

Figure 5. Block luminance compensation algorithm

First, target block luminance is calculated from the representative value extracted by averaging all pixel data from each block.

Second, we calculate the required backlight difference between ideal and target luminance for each discrete block on the panel. We refer to this value as dimming factor (κ). The backlight luminance of each discrete block can be determined from the dimming factor.

Third, we compensate the backlight luminance of each block considering the PSF, and then the compensated luminance of each block on the panel can be calculated according to panel transmittance with the gamma characteristics of modified low-gray-level dimming.

Fourth, we calculate the difference between the target luminance and the calculated luminance for each block. This difference is referred to as the BLC parameter (κ). If the BLC parameter satisfies some criterion, the dimming factor, determined in the second step, is considered to be valid.

Fifth, if not valid, we have to compensate the block luminance. When the BLC parameter is smaller than the maximum change of the block luminance which is called dimming level decision parameter (κ), the output PWM duty is tuned by equation (2).

$$Y > Y':$$

$$Duty' = \frac{(b-\Delta_n)\times\left\{T_R\times\left(\frac{R}{255}\right)^{1.8}+T_G\times\left(\frac{G}{255}\right)^{1.8}+T_B\times\left(\frac{B}{255}\right)^{1.8}\right\}+\Delta Y_n}{(b-\Delta_n)\times\left\{T_R\times\left(\frac{R}{255}\right)^{1.8}+T_G\times\left(\frac{G}{255}\right)^{1.8}+T_B\times\left(\frac{B}{255}\right)^{1.8}\right\}}\times Duty$$

(2)

$$Y < Y':$$

$$Duty' = \frac{(b-\Delta_n)\times\left\{T_R\times\left(\frac{R}{255}\right)^{1.8}+T_G\times\left(\frac{G}{255}\right)^{1.8}+T_B\times\left(\frac{B}{255}\right)^{1.8}\right\}-\Delta Y_n}{(b-\Delta_n)\times\left\{T_R\times\left(\frac{R}{255}\right)^{1.8}+T_G\times\left(\frac{G}{255}\right)^{1.8}+T_B\times\left(\frac{B}{255}\right)^{1.8}\right\}}\times Duty$$

The dimming level decision parameter is calculated by equation (3).

$$Y > Y':$$

$$\kappa = \Delta_n\times\left\{T_R\times\left(\frac{R}{255}\right)^{1.8}+T_G\times\left(\frac{G}{255}\right)^{1.8}+T_B\times\left(\frac{B}{255}\right)^{1.8}\right\} \quad (3)$$

$$Y < Y':$$

$$\kappa = (b-\Delta_n)\times\left\{T_R\times\left(\frac{R}{255}\right)^{1.8}+T_G\times\left(\frac{G}{255}\right)^{1.8}+T_B\times\left(\frac{B}{255}\right)^{1.8}\right\}$$

If the BLC parameter is larger than the dimming level decision parameter, the output PWM duty is changed according to equation (4).

$$Y > Y': \quad Full\ Duty$$

$$Y < Y': \quad Zero\ Duty \quad (4)$$

The proposed BLC algorithm shows great improvement in correcting artifacts compared to the previous local dimming algorithm. Performance of the new algorithm with BLC is shown in figure 1(b). In contrast with figure 1(a), the boundary is plainer and the image is much brighter. More detailed measurement results for various images are provided below.

3. Measurement Result

Several images have been used to analyze performance of the proposed local dimming algorithm. The new algorithm provides the same luminance as the original images except for very dark areas when local dimming is applied. The degree of image distortion at high luminance levels has been alleviated while dark images at low luminance levels have become darker as intended.

Figure 6 shows one of several test images with a large dark region. The blue dots show luminance measurement points.

Figure 6. Dark temple

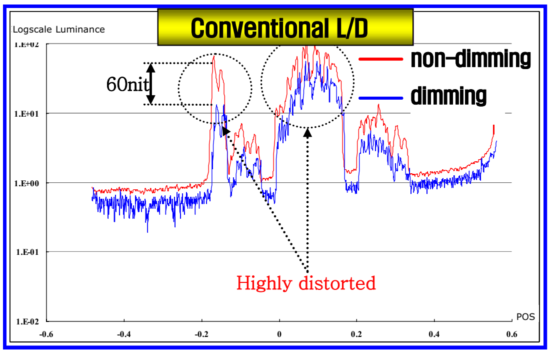

Figure 7. Comparison of luminance profiles for conventional local dimming algorithm

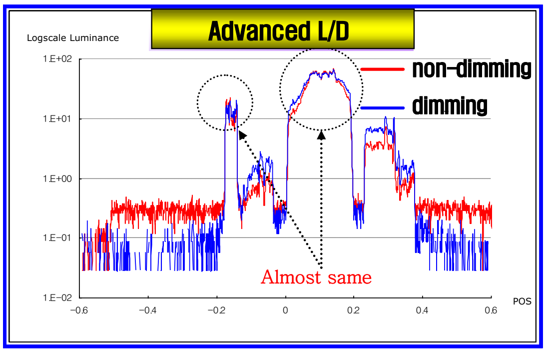

Figure 8. Comparison of luminance profiles for new advanced local dimming algorithm

Conventional local dimming algorithm causes severe distortion at the boundary between dark and bright areas. The image at the boundary is blurred and has lower luminance than the original image. Figure 7 shows a comparison between non-dimmed and locally dimmed luminance profiles. In this case, the non-dimmed luminance of a point near the boundary is about 70 nits while the locally dimmed value is about 10 nits, indicating that the locally dimmed image is 80% darker than it should be. Figure 8 shows non-dimmed and then locally dimmed values according to our new BLC algorithm. The luminance profiles of non-dimmed and new locally dimmed match, showing that the kind of distortion from conventional local dimming algorithms can be eliminated with the new technique.

4. Summary

Accurate calculation of target block-luminance and a new block luminance compensation (BLC) algorithm have been applied to a local dimming LED backlight system and its performance has been evaluated. The BLC algorithm substantially reduces artifacts of conventional local dimming

5. References

1. H. Seetzen, L. A. Whitehead, and G. Ward, *SID'03 Technical Digest*, p.1450-1453 (2003).
2. T. Shirai, S. Shimizukawa, T. Shiga, S. Mikoshiba, and K. Kalantar, *SID'06 Technical Digest*, p.1520-1523 (2006).
3. Pierre de Greef and Hendriek Groot Hulze, *SID'07 Technical Digest*, p.1332-1335 (2007).