The Optimization of Directly-Under-Light Type Backlight Module Structure for Brightness Uniformity

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Abstract. The optimization of the directly-under-light type backlight module structure for brightness uniformity is investigated. All structure parameters of the 32-inch LCD-TV backlight module are chosen by the ray-tracing method for the optimal brightness uniformity. It is shown that the brightness uniformity without optical sheets can be made as high as 87.3%.

Introduction

Because LCD can not radiate by itself, it has to rely on external source to illuminate. Currently, there are two types of lighting module for a LCD. One is the back type, and the other is the front type. The backlight module is further classified into a side-light type and a directly-under-light type according to their locations of light sources. The directly-under-light backlight module is mostly used in a stationary product, such as LCD-TV. Because the light source of a directly-under-light backlight module is located right under neath the displaying area, the profile of the light sources easily causes a non-uniform diffusion so that the shadows or line defects are blurred. To meet the need for brightness uniformity, generally light diffusing sheets are mounted with micro particles of various sizes and densities to scatter the illuminating light. However, the light diffusing sheets reduce the efficiency of illumination. Several alternative approaches were proposed to improve backlight module brightness uniformity [1-7]. Among these papers, the main focus was to modify the component manufacture processes. We have been proposing a new concept to tune the brightness uniformity by varying the lamp spacing, the statures of lamps and the angle of side surface of lighting box [8-9]. It can help to improve the brightness uniformity of the directly-under-light backlight module. It can also improve cost benefit and high optical efficience. The similar approach was applied, to CMO 27-inch LCD-TV as well [10].

In this paper, we will study the optimization of the directly-under-light type backlight module structure for brightness uniformity. We use ray-tracing method to optimize all parameters of the 32-inch LCD-TV backlight module for best brightness uniformity. It is difficult to optimize all parameters under global search by the use of the commercial ray-tracing software. So that we use 2D model and establish ray-tracing program to avoid this problem and to get optimal parameters. Then we apply the commercial ray-tracing software to verify our results.

Simulation Method and Model

To reduce the simulation time of ray-tracing, we simplify 3D direct-light-type backlight module to. The schematic diagram of 2D simulation model of lighting box and essential simulation parameters are shown in Figure.1. That is, we take the cross-sectional view of 3D module in accordance with transverse direction of lamps as 2D model. The simulation parameters is defined as: the initial
position and direction $\alpha(X_i, Y_i, \theta_i)$, the initial, the final position and direction $T(X_f, Y_f, \theta_f)$, lighting box depth $d$, the width of down surface of module $w$, and the inclined angle $Q$.

Figure 1. The definition of the essential lighting box parameters.

Then, we trace and analyze the rays emitting from those lamps. By electromagnetic theory, when rays pass through different medium, there is not all of energy transmitting, it depends on incident angle to get different energy of reflection and refraction. Reflectance $R$ and transmittance $T$ can be written as [11]:

$$R = \frac{1}{2} \left( \frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_t)} \right)^2 + \frac{1}{2} \left( \frac{\tan(\theta_i - \theta_t)}{\tan(\theta_i + \theta_t)} \right)^2$$

(1)

where $\theta_i$ is incident angle, $\theta_t$ is transmission angle and there is no absorption, $T=1-R$. Figure 2 shows the schematic illustration of ray tracing through the PMMA plane parallel sheet. The PMMA plane parallel sheet is put on the upper of the lighting box to conform the real module. The rays pass through both sides and bottom surface would be reflected, and finally transmit through the upper surface. In addition, to analyze the ray tracing results, a detector is considered and away from transmission surface 0.2cm.

Figure 2. The schematic illustration of the ray-tracing through the PMMA plane parallel sheet.

Then we use Visual C [12] to editor program and solve position and direction of each ray exiting the upper transmission surface. After getting positions and directions of all rays on the final transmission surface, we can use program to calculate brightness per unit area for every rays on the upper transmission surface.

Brightness is defined that how many luminous flux goes past per solid angle per unit area of light source, the unit is lumen/ m$^2$·Sr, also called nits (cd/ m$^2$) where lumen is the unit of luminous flux. Assume a very small area of light source $dS$ have luminous flux $d\Phi$, solid angle is $d\Omega$ then the brightness $B$ [13] of this small area:

$$B = \frac{d^2\Phi}{dS\cdot d\Omega}$$

(2)

Here assuming optical properties of the surfaces in the lighting box are all reflective except of upper transmission surface, these reflective surfaces are supposed of no scattering. We set each ray illuminating every 0.1 degree from the single lamp; detector is away from transmission surface 0.2cm, and the length of unit pixel on the transmission surface is 0.5 cm. Then we will use the establishing
program to simulate brightness distribution on transmission surface by any giving parameters such as the inclined angle, thickness and size of the lighting box, the positions and height of lamps. After that we will discuss in which parameter that have best brightness uniformity. The brightness uniformity is defined as

\[
B_{\text{uniformity}} = \frac{B_{\text{min}}}{B_{\text{max}}} \times 100\%
\]

We use 81 points to measure brightness uniformity here and the measured view is shown in Figure 3.

**Demonstrative Results and Verification**

Adopting the commercial specification for a 32-inch TV, we facilitate 10 lamps in a lighting box of 25 mm deep. The pitches of lamp for conventional CCFL installation in a backlight unit are equal, the cross-sectional view as shown in Figure 4. To get better brightness uniformity in the normal direction of the upper surface in the module, we optimize the module structure and the stature of the lamps. We assume that the statures of lamps are the same and their adjustable range for optimization is from lowest to half thickness of frame. Notice that when the statures of lamps are higher than half thickness of frame, the stripes of lamps becomes visible and the panel would become bending due to high temperature of lamp heating. This phenomenon is called "pooling mura" [14]. The relative optimal result in the normal direction of the detector by our establishing program is shown in Figure 5. Figure 6 shows the brightness distribution of the detector by a commercial ray-tracing software, using the same parameters as those in Figure 5. One can see that the sectional brightnesses on the two sides are higher than the undistinguished area of the center section. The high brightness in two sides is due to the reflective effect with the inclined angle of side surface of lighting box. The results of brightness uniformity are estimated to be only 63.9% and 62.3% by our establishing program and a commercial ray-tracing software, respectively. The brightness difference can be clearly distinguished by human eyes. Therefore, using lamps of equal spacing can not fulfill the commercial specification unless the light diffusing sheets are added in the module. So lamp position of equal spacing can not produce satisfactory brightness uniformity for design.
Figure 5. The brightness distribution in the normal direction of the detector estimated by our establishing program for module equally spaced lamps.

Figure 6. The brightness distribution of the detector estimated by a commercial ray-tracing software using the same parameters as that in Fig. 5.

Because of influence by reflection from the both sides of the lighting box, the position of lamps which more approaches to both sides, the brightness is higher; the position of lamps which more approaches to middle point, the brightness is lower theoretically. To solve the problem, we consider that the pitches of lamp are variable, the stature of lamp, and the angle of side surface of lighting box are properly tuned. The cross-sectional view and optimal design of the 32-inch backlight module with variable lamps spacing is shown in Figure.7. We use our establishing program in a global search to optimize all the parameters of the 32-inch LCD-TV backlight module for best brightness uniformity. Figure. 8 shows the brightness distribution in the normal direction of the detector as estimated by our establishing program under optimal design process for all considered parameters. The estimated optimal brightness uniformity is 89.1%. Then we verify that by the commercial ray-tracing software using the same parameters. The result of the brightness distribution is shown in Figure 9. The estimated brightness uniformity is 87.3%. The brightness uniformity is satisfied with commercial specification (>75%). Moreover, the estimation by our program is close to that by the commercial ray-tracing software. The difference is only 1.8%. Under this brightness uniformity, the brightness difference maybe can’t be visible to human eyes. Deserve to be mentioned, the simulation time of our establishing program for the 2D model is only $10^5$–$10^6$ times approximately comparing to the simulation time of the commercial ray-tracing software for the real model.
Figure 7. The cross-sectional view of the 32-inch backlight module with variable lamps spacing.

Figure 8. The brightness distribution in the normal direction of the detector with lamps spacing designed by our establishing program.

Figure 9. The brightness distribution of the detector estimated by a commercial ray-tracing software using the same parameters as that in Fig. 8.
Conclusion

The optimization of the directly-under-light type backlight module structure for brightness uniformity is investigated. All parameters of the 32-inch LCD-TV backlight module are chosen by the ray-tracing method for the optimal brightness uniformity. It has been shown that the brightness uniformity of the module without optical sheets can be improved to 87.3%. The result is extremely reliable by the optical software to test and verify. The contribution of our research is to shorten time of simulation and optimization substantially in the directly-under-light type backlight module, and to reduce the component cost of the module. By the brightness uniformity result, the diffusing elements can be reduced or need not. It will have cost benefit and improved optical efficience.

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