5.3: A New Cost-Effective Optical Plate for High Performance LCD-TVs

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Abstract

The objective of the research presented in this paper is to design a highly efficient LCD-TV backlight unit (BLU) which minimizes lamp count without light leakage from the BLU. A new optical plate helps to successfully distribute spatial luminance in a 46inch LCD-BLU consisting of only 20 CCFLs.

1. Introduction

There is no doubt that demand for large panel LCD-TVs is growing rapidly; however, excessive supply has caused pricing pressure on the panel suppliers. The price of large size panels and BLU components are also continuing to fall. As a result, it is desirable to reduce the number of optical elements by combining components within the BLU to cut cost of the backlighting system, which accounts for nearly half of the total cost of an LCD-TV module. The BLU system has several components including light sources such as CCFLs, electrical circuits such as inverters, optical elements, and mechanical structures including a diffuser plate, diffuser films, brightness enhancement film (BEF), dual brightness enhancement film (DBEF), chassis, mold frames, and so on. The CCFLs and their attached components, including inverters and connectors, are important key cost elements in large size BLUs [1]. For competitive pricing of LCD TV, it is obvious that any unnecessary components should be removed or combined, for example the BEF and DBEF in the BLU. However, it has not been possible to reduce the number of CCFLs in large sized BLUs considering the lamp image can be detected if the current module structure's dimension is maintained while decreasing the number of light sources. Therefore we must determine what functions are necessary to reduce the quantity of CCFLs without changing current mechanical dimensions of the BLU, yet maintaining luminance levels over 500 cd/m^2 (nits).

To solve these problems, the following issues should be considered: First, screening of light leakage from CCFLs even though the lamp pitch increases with reduction in the total number of CCFLs. Second is to increase relative luminance even though the total power of the light source has been decreased. For this, we have focused on development of a new concept of a light diffusing plate using practical simulator analysis. The goal of developing the transparent plate is to design the new optical pattern on the surface of the plate. Spatial luminance emitted from the newly developed pattern plate normally stays in the range of less than 10% of luminance fluctuation and converges at the center of the module without assistance from other films. In this way, the new plate, which we call "Lentix", provides BEF-like functionality. It is able to eliminate BEF-type film from the BLU's optical system and can maintain luminance over 500nits.

2. Optical Simulation

2.1 Characterization of optical elements

Basically, we define optical properties for each BLU element including lamps, the reflector sheet, and each element of the plate, and mold frame. Simply, it is assumed that the angular variation of CCFL intensity follows a Lambertian distribution and the reflector sheet also has Lambertian reflectance, but we define optical behaviors of those elements based on actual measurements using a Luxmeter to improve accuracy of optical simulation. First, we define the angular variation of CCFL intensity. A reasonable definition of the intensity distribution has to be based on scattering phenomenon by the lamp phosphor because visible light from the CCFL is generated by phosphor on the glass. However, to reduce CPU simulation run time, we simplify CCFL modeling by using angular variation measurements to define the lamp's intensity distribution according to the ELDIM EZ Contrast system, which is a luminance measurement system based on the theory of Fourier optics [2]. Fig. 1 shows measured CCFL intensity and the lamp model, respectively, the results of which were applied as inputs to the computer model. Second, we define optical behaviors of the reflector sheet. Ideally, the surface of the reflector sheet used in a BLU could be considered to be a completely diffuse surface, which is called a Lambertian scattering surface. In this case, scattered energy distribution does not change as the angle of incidence changes, and the distribution of scattered intensity is given by the following equation [3].

$$I(\theta) = I_0 \cos(\theta) \qquad (1)$$

In reality, however, the surface of the reflector sheet is not completely diffuse. Although incident light on the reflector sheet is perfectly diffused by volumetric scattering, there are imperfections such as voids inside of the reflector sheet, and specular reflection is caused by partially planar surfaces of the reflector sheet.

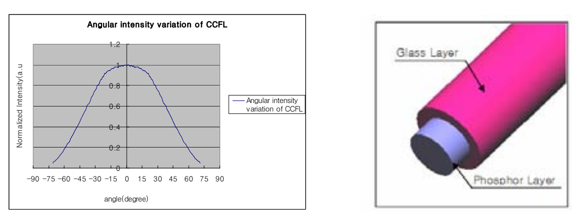


Figure 1. Angular variation of CCFL and model of CCFL; (a) angular variation of CCFL intensity (b) model of CCFL

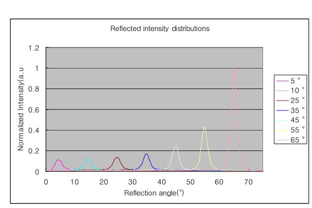


Figure 2. Measurements of the reflected intensity distribution as the angle of incidence changes

Fig.2 shows the measurement of reflected intensity distribution as a function of angle of incidence. The light distribution shows specular reflectance where 0 degrees refers to an on-axis path. Therefore, optical behaviors of the reflector sheet model include specular reflection as well as diffuse reflection. And the most valuable term in defining such complicated reflection is the bi-directional reflectance distribution function (BRDF) [4]. The BRDF is composed of uniform diffuse and near-specular (i.e., specular and directionally diffuse) components, represented as, where α means Fresnel reflectance.

$$f_{bd} = f_{bd-specular} + f_{bd-directional\ diffuse} + f_{bd-uniform\ diffuse} \quad (2)$$

We define the BRDF of the reflective sheet as

$$f_{bd} = \alpha \cdot (f_{bd-specular} + f_{bd-directional\ diffuse}) + (1-\alpha) \cdot f_{bd-uniform\ diffuse} \quad (3)$$

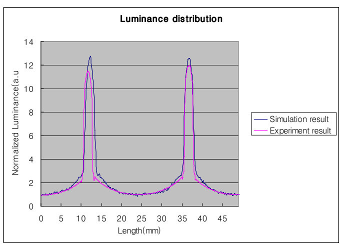


Figure 3. Far-field luminance distribution comparison between the simulation model and measurements for the BLU

Next, we use the BRDF to apply the reflection model to the surface of the reflector sheet. Fig. 3 shows the far-field luminance distribution comparison between the simulation model and Luxmeter measurements for the BLU.

2.2 Modeling of direct-lit backlight system

A conventional 46-inch direct-lit BLU consists of 24 CCFLs, certain optical sheets and plates, and other mechanical structures. In consideration of modeling direct-lit BLU systems, above all, our focus is on reducing CPU run time while increasing accuracy of the optical simulations. The outline dimension of the module is approximately 1030*585 mm and module thickness is 32.5mm from bottom chassis to the panel. However, we only consider the active area for purposes of optical simulation. Furthermore, the modeling of the BLU is devised to simplify the BLU's optical system while maintaining the basic structure as shown in Fig. 4. Fig. 5 compares a conventional BLU with the new BLU system, which is comprised of 24 lamps with a completely different CCFL pitch resulting from reduction in the number of CCFLs. Specifically, layout of the conventional backlight system consists of 24 CCFLs with 23.5mm lamp pitch. Distance from the center of the CCFL to the side mold frame is about 15mm. Dimensions for the new BLU system based on 20 CCFLs are quite different because 17 percent of the CCFLs have been eliminated

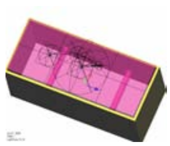
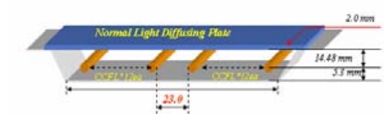
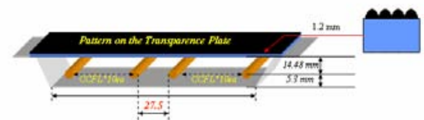


Figure 4. Optical simulation structure of BLU consisting of 12 CCFLs

Thus, we designed a new 46-inch direct light backlight system consisting of 20 CCFLs as shown in Fig. 5(b).



(a) Section View of conventional 46inch BLU (24Lamps)



(b) Section View of 46inch BLU (20CCFL)

Figure 5. Comparison of conventional and new optical systems

2.3 Design of the optical plate

A light diffusing plate including scattering agents is commonly used in direct-lit BLU systems. Conventional light diffusing systems have adequate efficiency for screening the light from CCFLs in current module design. Scattering agents are used to create randomness in the light propagation direction to uniformly distribute the lamp output onto the light diffusing plate as shown in Fig. 6.

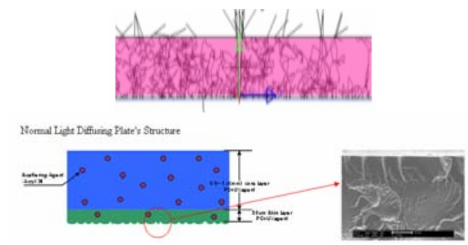


Figure 6. Conventional light diffusing plate and scattering agents in continuous phase such as polystyrene (PS), polycarbonate (PC)

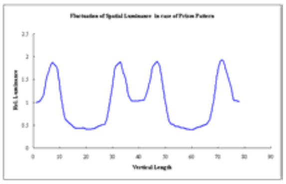
However, total transmittance decreases to the extent that scattering agents are added. Both Table 1 and Figure 7 show the optical properties of a conventional diffusing plate such as straight transmittance, diffused transmittance and haze.

Table1. Optical properties of normal diffusing plate

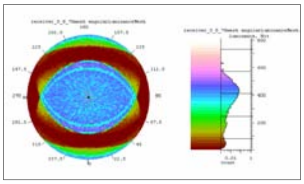
Grade	TT	S.T	D. T	Haze	Core R. I	Scattering Agent R. I	weight % of Beads	Sp. gravity
PS	60%	3.20%	56.80%	93%	1,59	1.49~1.50	2~3%	1.19
PC	60%	3.10%	56.90%	93%	1.59	1,42~1,43	2~3%	2.4

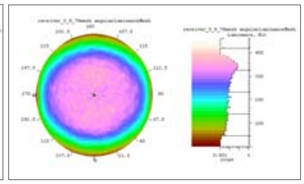
※T,T= Total Transmittance, S,T=Straight Transmittance, D,T=Diffused Transmittance, R,I=Refractive Index,

We reviewed the literature for optical patterns such as prism, semi-circular, and other lens geometries. For optical simulation, we carried out the simulation modeling of a 46-inch direct-lit BLU as shown in Figure 4. We simulated a prism angle and classic semi-circular lens to create a suitable optical structure on the transparent place in the new backlight system. Simulation results showed that the prism pattern has a tendency to split the image of the CCFLs in the module, causing the CCFLs' image to appear doubled as described in Figure 7 (a) and (c), which is a virtual image. On the other hand, the semi-circular cylindrical array has a function of diffusing the light sources, and it partially screens the spatial luminance, but not completely as shown in Figure 7 (b) and (d).



(a) Spatial luminance of prism (b) Spatial luminance of lens





(c) Angular Luminance of Prism (d) Angular Luminance of Prism

Figure 7. Spatial luminance display on the top of the optical plate with prism and semi-circular patterned lenses in BLU consisting of 20 CCFLs.

To design an optimum pattern on the surface of the transparent plate, we conducted design of experiments for the surface texturing with respect to different pitch, height, inner angle and aspect ratio (b/a) as shown in Figure 8. We created several patterns by modifying optical factors, such as changing the aspect ratio (b/a) from 1.3 to 2.1, varying the inner angle from 40 degrees to 46 degrees, and so on.

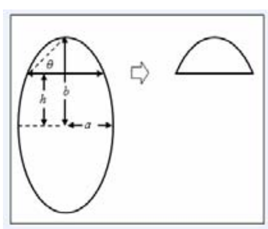
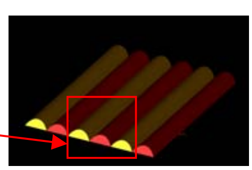


Figure 8. Optical factors for design of experiments

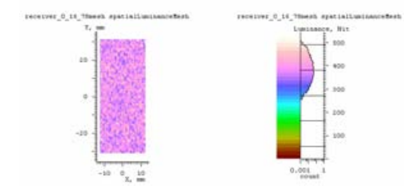
By carrying out optical simulations on the design of experiments (DOEs), we found an excellent pattern by carefully combining the prism and semi-circular lens structures on the plate as described in Figure 9. Finally, we selected the optimized elliptical lens shape considering its ability to screen the lamp's image, its well defined angular luminance, and its ease of fabrication. Here, we use "well-defined angular luminance" to mean the lens's ability to converge a light having arbitrary incident direction to the 0 degree exit direction.



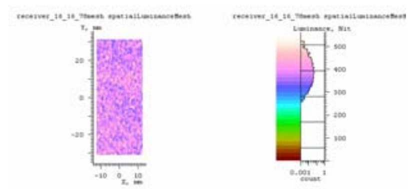
(a) (b)

Figure 9. New design optical pattern on the plate; (a) new design optical plate (b) the pattern on the surface of the optical plate

Furthermore, it is determined by optical simulation that the fluctuation of spatial luminance as a function of viewing angle can be controlled uniformly as shown in Figure 10 below. These two figures assume horizontal lamp orientation and then predict light variation according to different vertical angles of view. Figure 10(a), (b) shows a 2D luminance plot of predicted output at three different vertical angles of view. Figure 11 shows a one dimensional luminance plot predicting light output as scanned along the vertical axis of the module.



(a) Spatial Luminance Image at 0° off-axis



(b) Spatial Luminance Image at 16° off-axis

Figure 10. 2D luminance prediction for new 20 CCFL BLU

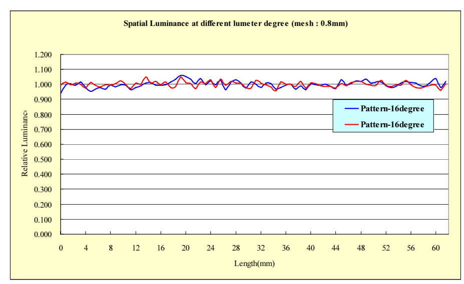


Figure 11. Luminance fluctuation of new 20 CCFLs BLU at different angles of view as scanned normal to lamp orientation

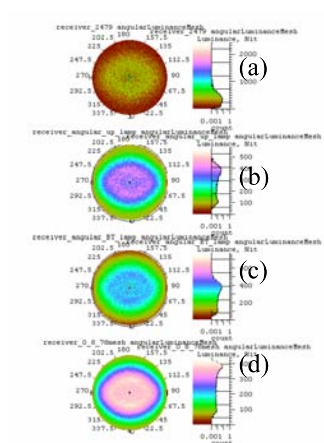


Figure 12. Polar contour chart of new 20 CCFLs BLU; (a) likely ELDIM EZ apparatus, (b) mid-point between CCFLs, (c) above CCFL, (d) overall BLU module

Figure 12 shows angular luminance data obtained from optical simulation. Four measurements were recorded, (a) likely ELDIM EZ apparatus, (b) at a point directly over the CCFL position, (c) at the midpoint between CCFLs, and (d) on the overall module. The new plate's texture converges an incoming ray from any direction to the distribution shown without the need for optical sheets. Therefore, the newly designed plate serves both to uniformly distribute the lamp image and to increase the BLU luminance.

The angular luminance result was confirmed with the 3D raster chart in LightTools, which shows light convergence performance at the center of the module. Fig. 12(c) shows that the side lobe near the northern and southern pole of the module converges to the center. This light convergence is the mechanism used to increase overall module luminance. Thereby we have solved the stated problem, namely, the newly-designed optical plate successfully screens out light leakage from the CCFLs while increasing relative luminance even though one sixth of the CCFLs have been eliminated.

3. Experiments and Discussion

Calendering is a process for manufacturing films and plates by pressing the molten polymer between rotating rolls. The calender usually consists of four rolls, which may be arranged in many different ways. The molten polymer mass is fed between the gap of the first two rolls. It emerges as a plate below this pair and passed over and between the remaining rolls. The first gap controls the feed rate; the second and the third set the final product thickness. Transfer from one roll to the next is accomplished by a combination of temperature, speed, and surface finish differences between rolls. Surface temperature of the rolls is carefully controlled by using drilled rolls – that is, axially drilled holes all around the periphery – in which a temperature controlling liquid is circulated [5].

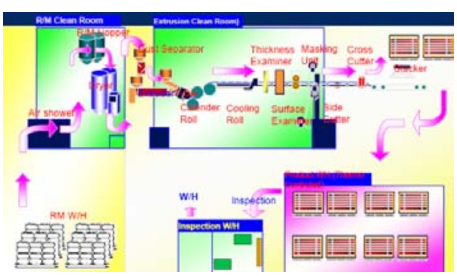


Figure 13. Conventional extrusion process for manufacture of light diffusing plate

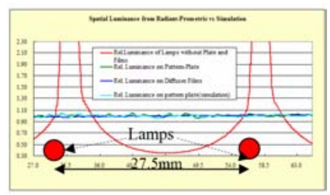
Above all, the calendering roll process is of utmost importance for mass production of the pattern on the surface of the optical plate. The most important aspect of the calendering roll process as shown in Figure 13 is accurate replication of the pattern on the surface of the transparent plate. First, during the processing, the molten polymer could not infiltrate completely to the carved pattern on the second calendering roll due to high viscosity of the polymer. When molten polymer flows into the pattern, its own viscous friction hinders the stream of molten polymer. Second, the polymer has some elastic properties which influence its restoration during the cooling process. Third, quenching (cooling rate) is another key factor for maintaining the plate shape after the molten polymer goes through the calender roll gap. According to the polymer properties and processing conditions, we examined the relationship of temperature, speed, quenching and thickness in the extrusion to determine how to most accurately replicate the pattern. Processing temperature in each zone of the extrusion processing is determined by rheological properties of molten polymer. Viscous and elastic properties of the polymer can be controlled by zone-based temperature control. The extrusion line speed plays an important role in controlling the temperature of the core plate as the pattern is built through the process.

<-Processing temperature> : In the extruded polycarbonate, we observed the replicated pattern's shape while varying temperature conditions of the extrusion, T-die, and calendering roll.

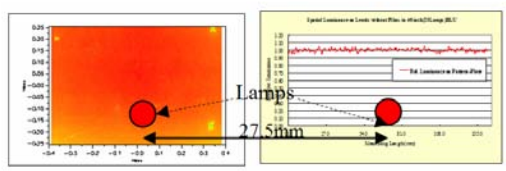
<-Line speed> : To produce the best optical plate quality, we optimized the extruding condition by observing replicated pattern accuracy while varying volumetric flow from the T-die.

4. Conclusion

A prototype of the transparent plate was manufactured and data were compared with the simulation results. Based on measured data, the pattern on the surface of the transparent plate uniformly distributed the light from the CCFLs, even though the lamp pitch has been increased from 23.0 mm to 27.5mm. We evaluated the new optical plate in the 46inch BLU mock-up by using the Radiant Prometric and ELDIM EZ apparatus. It is verified that the simulation result is consistent with the measured BLU data as shown in Figure14.



(a) Comparison of spatial luminance between simulated and measuring data for BLU consisting of 20 CCFLs



(b) Appearance of BLU consisting of 20 CCFLs measured with Radiant Prometric apparatus; cross section data from BLU

Figure 14. New BLU luminance data and appearance

In order to reduce system cost, we have removed 4 out of the original 24 lamps from the 46-inch BLU and we do not use any extra BEF film. We have successfully and efficiently split the lamp image, and the combination of DBEF and Lentix enables luminance of 540cd/m^2 even after eliminating 17 percent of the BLU's lamps. We verified that the new pattern on the transparent plate helps to distribute the light from CCFLs uniformly in the BLU.

5. References

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