LED backlight for large area LCD TV’s

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ABSTRACT

A >30” direct backlight has been developed using Luxeon™ side-emitters from Lumileds. An excellent front of screen (FOS) performance was achieved, by using a mixing chamber within the thin backlight. The light source in the backlight was made up of red, blue and green high power side-emitters on a metal core printed circuit board (MCPCB). This paper describes the key attributes of the backlight that makes it possible to achieve excellent front of screen performance from a “Luxeon Direct” light source.

INTRODUCTION

LEDs provide many benefits as a light source for backlights as outlined in papers [1,2]. The results presented in these papers discuss edge-lighting solutions. These solutions have some disadvantages, especially for the LCD-TV market. For large displays the light-guide is very heavy, can be expensive due to optical quality, and can be inefficient as acrylic has an absorption of approximately 1% per inch for the mean free path.

The direct backlight design addresses many of the concerns mentioned above. In greater detail the merits of “Luxeon direct” can be reviewed in a paper based on a 22” direct backlight [3]. The key factors for improvement were LED efficacy and color mixing. These two factors can in turn, positively impact many other attributes such as improved color uniformity, reduced power, reduced thickness, lower operating temperature, higher brightness, and reduced LED content.

Since then many advances have taken place that allow the benefits mentioned above. Lm/W for high power LEDs is continuing to make significant advances in the InGaN technology and modest improvements in the AlInGaP. This has allowed an improvement in the white Lm/W at 25ºC from 33 to 37, with select LEDs. Also an integrated thermal design minimizes the backlight operating temperature, maximizes the Lm/W of the LEDs at elevated temperatures, and reduces the likelihood of brightness enhancement films wrinkling under cyclic heating.

Color mixing has significantly improved with an increased understanding of the design and function of the direct backlight concept. Most of these changes have come in the form of improved control over the optical surfaces, and a better understanding of the distribution of flux and color over the “Luxeon Direct” source.

This paper discusses direct backlights that are greater than 30” and have a depth of about 50mm.

DESIGN

The high power Luxeon™ side-emitter shown below was integrated into the design. The planar radiation pattern of the device improves color mixing between the discrete LEDs by providing a large luminance distribution on the screen when coupled to a shallow reflective cavity.

Fig. 1. Luxeon™ Side-emitter with ray trace

Fig. 2. Radiation pattern - 1W Blue
The devices were thermally bonded and electrically soldered to a MCPCB. Two of these boards were placed end to end to complete an array of approximately 50 LEDs on a pitch of 12mm. The color sequence of green, red-orange, blue, green... (G, R-O, B, G...) as shown below was repeated along the length of the array.

![Fig. 3. Luxeon Direct Array](image)

The arrays were placed in direct contact with the frame to insure the heat was conducted away from the LEDs, thereby maximizing performance. A reflective metal sheet was then placed directly over the LEDs resting at a height below the LED Lens as seen in Figure 6. This plenum allowed air to enter and exit the frame via holes, creating a convective flow over the arrays, dissipating heat out of the backlight as seen in Figure 5.

![Fig. 5. Luxeon Direct - Thermal path](image)

A direct LED backlight has been developed for a >30” LCD-TV, with an aspect ratio of 16:9 and a depth of 50mm as shown in Figure 4.

![Fig. 4. Typical RGB Layout within frame](image)

The backlight consists of a black conductive aluminum frame providing a shallow cavity where four “Luxeon Direct” arrays were positioned based on brightness profile. The design incorporated horizontal arrays with the inner two arrays 60mm apart and the outer two arrays 90mm from the inner arrays.

Table 1. Side-emitter wavelength and efficacy

<table>
<thead>
<tr>
<th>Luxeon™ Side-emitter</th>
<th>Dominant wavelength</th>
<th>Efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red-orange</td>
<td>617 nm</td>
<td>60 Lm/W</td>
</tr>
<tr>
<td>Green</td>
<td>533 nm</td>
<td>46 Lm/W</td>
</tr>
<tr>
<td>Blue</td>
<td>451 nm</td>
<td>5.5 Lm/W</td>
</tr>
<tr>
<td>White (9000 K, 25˚C)</td>
<td></td>
<td>37 Lm/W</td>
</tr>
</tbody>
</table>

A diffuse reflective film bonded to a highly reflective aluminum sheet is punched with 5.8mm holes allowing placement over the LED lens resting on the body of the LED. E60L diffuse reflective material manufactured by Toray was used. It is important that the E60L is flat and covers the entire back surface only allowing the lens of the LEDs to sit proud above its surface. This reduced the absorption of light caused by the LED body and other non-optical surfaces. The sides of the aluminum frame were also covered with the laminate E60L over reflective aluminum sheet.

A diverter was placed directly above the LED arrays. The purpose of this optical element was to prevent the LED on-axis light from traveling directly to the screen. The diverter consisted of a 2mm thick acrylic sheet where 6mm enhanced specular reflector (ESR) dots were bonded at a location directly above each LED. ESR film from Vikuiti™ has a high specular reflectivity. A cross section of the direct backlight system described above is shown is figure 6.

![Fig. 6. Cross sectional view](image)
A 3mm thick bulk diffuser from Lucite™ covered the optical cavity. The diffuser increased color mixing by recycling some of the light and removed the angular dependence on color. The distance between the tops of the Luxeon™ Direct array to the back of the LCD was approximately 40mm.

Three films were placed on top of the bulk diffuser, which includes a Brightness Enhancement Film (BEF) from Vikuiti™ sandwiched between two weak diffusers from Keiwa™.

RESULTS

The Luxeon™ side-emitter emits approximately 80% of its light within ±20º perpendicular to the optical axis. This planar emission of light 360º about the optical axis maximizes color and brightness uniformity in a shallow reflector cavity.

The side-emitter pitch was increased from 9mm to 12mm. The increased pitch provided a small gain in optical efficiency, while maintaining similar color mixing. The optical efficiency gain is due to the drop in absorption from adjacent LEDs as they were moved further apart. Also, the radiation pattern was less obstructed with the 12mm pitch allowing any one LED to transfer its light to a greater area of the screen. Finally, first results suggested that the required brightness uniformity could be achieved with fewer arrays. The improved radiation pattern of Luxeon Direct at a 12mm pitch created an array that was less obstructive to its adjacent arrays allowing light to pass through with less scattering, resulting in a smooth brightness profile over the entire backlight.

With the color sequence of green, red-orange, blue, and green repeated along the length of the array it was found that the relative flux levels of the last four LEDs, at the end of the arrays, was important in maximizing color uniformity. The arrays should be positioned with an anti-parallel configuration to maximize color uniformity as shown in figure 7.

![Fig. 7. Anti-parallel configuration](image)

The backlight divided by the E60L laminate into a thermal and an optical cavity, allowed the heat to be dissipated very evenly over the back of the backlight as seen in Figure 8. Peak temperature was approximately 57ºC at 160W of Luxeon™ power.

![Fig. 8. Thermal image: back & front of backlight](image)

The optical structure directly in front of the Luxeon™ Direct array provided a key role in improving the color mixing and spreading the light over the entire area of the screen. The direct incident light from the LEDs strikes the acrylic plate at an oblique angle resulting in a high level of fresnel reflection. It is key that the diverter plate is accurately positioned and remains very flat. Both the dots and this fresnel reflection aided in the spreading of light and preventing color non-uniformities.

The bulk diffuser achieved best results when the reflection coefficient was in the range of 30 – 40%. This level of reflection was required to achieve the high color and brightness uniformity.

With four Luxeon™ Direct arrays a peak brightness of >10,000 nits was achieved. The white point for the backlight was set at >10,000 K. Brightness profile min/max of 60% and average to peak of 84% were achieved. The color gamut of the backlight was 143% of NTSC in u’v’.

A Prometric CCD picture of the brightness uniformity is shown in Figure 9. No visible banding or other artifacts in the brightness uniformity was observed.

![Fig. 9. Measured Brightness uniformity](image)

Two drivers controlled the Luxeon™ Direct arrays. This setup allowed the variation of the brightness profile to some degree, which helped to manage the average to peak and min/max targets.

An optical feedback system was incorporated to manage white point. This allows the white point to be maintained over a range in temperature and over lifetime. Also, it allows LCD manufacturers to achieve panel-panel white point consistency without impacting grey scale.
Fig. 10 shows the CCD plot of the color uniformity given in delta u’v’. The total delta in u’v’ was 0.004. The color gradient was very smooth, creating a homogeneous white screen.

![Fig. 10. Measured Color uniformity Δu’v’](image)

This backlight when coupled to an LCD can provide approximately 500 nits based on 5% panel transmission without using Dual Brightness Enhancement Film (DBEF).

The LED backlight using Luxeon™ Direct has achieved excellent FOS performance in both brightness and color uniformity. The backlight design is very simplistic making it easy to move into a manufacturing environment. One reason for the simplicity is that the LED is managing the primary optics. Luxeon™ Direct is ideally suited to fill large areas with a shallow reflective cavity making it very flexible to scale to any screen size.

The table below provides a calculation of screen size versus Luxeon™ power for the LED Direct backlight.

<table>
<thead>
<tr>
<th>Screen Size (inches)</th>
<th>Width of Display (cm)</th>
<th>Display Area (square meters)</th>
<th>Nominal Panel Transmission (%)</th>
<th>Effective Panel Transmission (%)</th>
<th>Targeted Peak Backlight Brightness (nits)</th>
<th>Brightness Efficiency (nits/W)</th>
<th>Total Backlight Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>43.1</td>
<td>0.116</td>
<td>5%</td>
<td>5%</td>
<td>10,000</td>
<td>166</td>
<td>67</td>
</tr>
<tr>
<td>24</td>
<td>51.7</td>
<td>0.167</td>
<td>5%</td>
<td>5%</td>
<td>10,000</td>
<td>115</td>
<td>96</td>
</tr>
<tr>
<td>30</td>
<td>64.6</td>
<td>0.261</td>
<td>5%</td>
<td>5%</td>
<td>10,000</td>
<td>97</td>
<td>135</td>
</tr>
<tr>
<td>34</td>
<td>73.2</td>
<td>0.335</td>
<td>5%</td>
<td>5%</td>
<td>10,000</td>
<td>94</td>
<td>174</td>
</tr>
<tr>
<td>40</td>
<td>86.2</td>
<td>0.464</td>
<td>5%</td>
<td>5%</td>
<td>10,000</td>
<td>86</td>
<td>241</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Development efforts are focused on advancing the Luxeon™ Direct design to optimize the performance in a direct backlight configuration. Development efforts continue on 20-25” with recent emphasis on greater than 30”. The Luxeon™ devices used in this direct backlight design will, in the near future, be able to provide superior front of screen performance for less power than CCFL backlights.

The LCD-TV market is expected to grow very rapidly, and it is believed that the direct backlight solution presented in this paper has attractive features for this market. Luxeon™ direct light source provides long life, wide color gamut (NTSC coverage), no mercury, blinking to reduce motion artifacts, dynamic dimming, and when integrated into a backlight can provide excellent FOS performance at a reasonable power.

**CONCLUSION**

The results show that Luxeon™ Direct high power side-emitters in red, green, and blue can be integrated into large direct backlights providing excellent performance in uniformity both in color and brightness. The design presented is simplistic, scalable, and efficient.

**REFERENCES**


