43.4: High Brightness Direct LED Backlight for LCD-TV

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Abstract
A novel LED light source, "Luxeon Direct", has been integrated into a highly efficient direct backlight. This concept incorporates one of the latest LEDs released by Lumileds™. This direct backlight approach integrates side emitting LEDs with a highly reflective cavity placed behind the LCD. Prior to this method it has been very difficult to use high power red, green and blue (RGB) LEDs in a direct backlight design due to the high color and brightness uniformity requirements. In this paper a method will be demonstrated that can achieve excellent backlight performance using an indirect illumination approach with high power LEDs.

1. Introduction
Using LEDs as a light source for backlights has a lot of benefits, as discussed in previous papers [1,2]. All the results presented in these papers where based on edge-lighting solutions, where a light guide is used for distributing the light over the full screen. The LEDs, preferably an array of red, green and blue LEDs, are positioned along the edge of a mixing light guide. The light out of this mixing guide is injected into the light guide, which distributes it over the screen.

Such an edge lit approach has some disadvantages, especially for LCD-TV applications. The light guide is made of an acrylic plate, and for large size LCD-TV applications the weight of it becomes too great. Furthermore it needs to be of a good optical quality, resulting in a high cost.

Efficiency is another concern: acrylics absorb light due to the use of thermal stabilizers and UV inhibiters, which cannot be neglected anymore for large screen sizes. This is especially the case when LEDs are used in combination with an additional (acrylic) color mixer.

This paper will describe a solution for LED backlights, which do not use a light guide, but uses an array of LEDs placed in a cavity directly behind the LCD panel. The key issue is controlling the uniformity, both in brightness and color, while maintaining a good optical efficiency.

2. Design
A direct LED backlight has been developed for a 22" LCD-TV, with an aspect ratio of 16:9, and its design is shown in Figure 1.

The backlight size is 503 x 282mm with a thickness of 50mm. It consists of a metal (Aluminum) housing containing two linear arrays of 48 LEDs on a Metal Core Printed Circuit Board (MCPCB). A diffuse reflective film was applied to the inner surface of the cavity only allowing the emitting portion of the LEDs to protrude into this volume. Moving the non-emitting surfaces of the LED behind the diffuse reflective film maximizes efficiency by reducing the re-absorption of light.

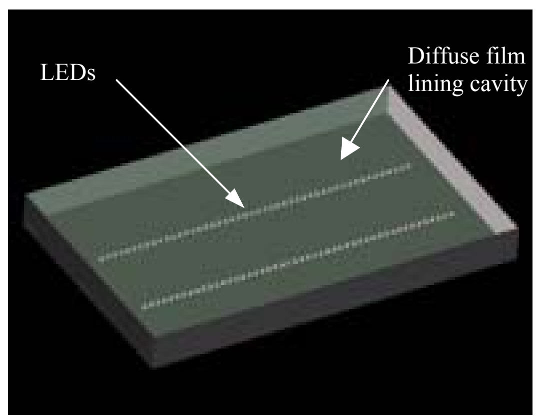

Figure 1: Typical RGB Layout within reflective cavity

Directly above the LED array is a diverter. The purpose of this optical element is to prevent the LED on-axis light from traveling directly to the screen. In most cases this will create color uniformity issues. In front of this cavity a bulk diffuser aids the design by increasing color mixing by recycling some of the light and by removing any angular dependence on color.

Brightness Enhancement Films (BEF) and Liquid Crystal Display (LCD) can be placed in front to complete the optical system.

As previously described, the light source in this example consists of two arrays each composed of separate red, green and blue emitters, on a 9mm pitch as pictured in figure 2. Discrete colored LEDs were used because of their superior color performance (see[1]).

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The side emitting LED was chosen because of three key attributes: planer emission 360º about it optical axis, ability to fill large areas within a shallow optic, and reasonable color mixing in this simple configuration.

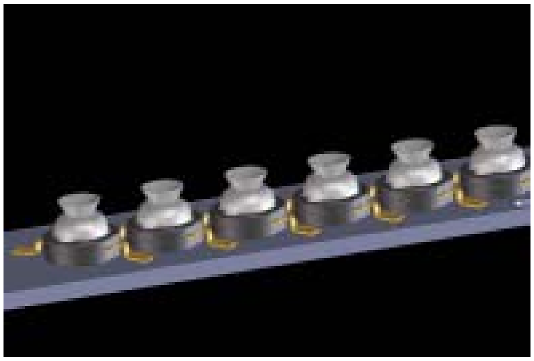

Figure 2: LED Layout without diverter

2.1 Side Emitting LED

An example of the side emitting LED used is shown in figure 3. The lens design is such, that most of the light is emitted to the sides, and only a small part is emitted along the optical axis. Typical intensity profiles (curve in solid red) and cumulative flux (curve in dotted blue) for this device are shown in figure 4. There is a small difference in radiation pattern for the AlInGaP (red and amber) and the InGaN (green and blue) based devices, but they all have maximum intensity around 80°, 0° being the optical axis. For the red, green and blue LEDs the cumulative flux within 45º to the optical axis is below 10%. Each LED has a power of approximately 1W.

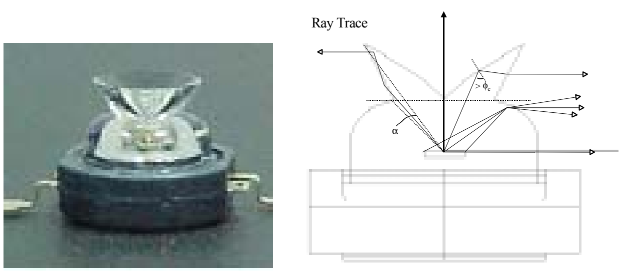

Figure 3: Luxeon™ Side Emitter with ray trace drawing

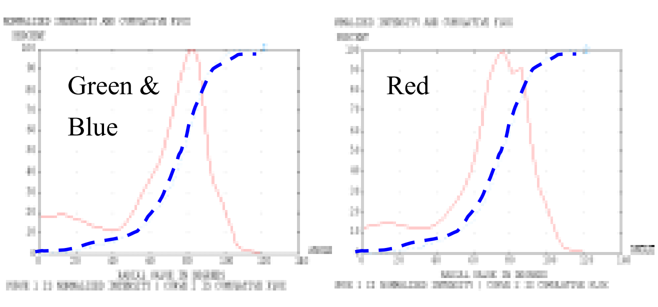

Figure 4: Intensity & cumulative flux

3. LED Direct Backlight Results

An indirect lighting approach was selected to obtain good color mixing within a shallow reflector cavity. This was achieved by using the Luxeon™ High Power Side Emitter, which emits approximately 80% of its light within ±20º perpendicular to the optical axis as shown in figure 5. This plainer emission of light 360º about the optical axis into a shallow reflector cavity maximizes the mean free path for the light while efficiently filling the backlight aperture.

With the discrete colored LEDs on a pitch of 9mm, good color mixing is achieved in very close proximity to the array in all directions except directly above. In this direction the LEDs emit approximately 5% of their light in a relatively collimated distribution towards the screen area. To minimize any color effects directly over the LEDs, a diverter was used to redirect this light back to the LEDs and the lambertian reflector cavity. This redirects the on-axis light from the emitter back into the reflector cavity where the mean free path is increased and additional mixing can take place.

The diverter approach can be very small ~6mm in width to prevent any shadow effects on LCD screen which may affect the brightness profile of the backlight. The diverter is a key optical element in managing the brightness profile. Depending on the size of this diverter it can affect in the order of 6-40% of the light emitted by the side emitter. This allows the arrays to be placed in a common, simple reflective cavity, only having to adjust the diverter to achieve various required brightness profiles. If a 6mm diverter is used to redirect this light in a 50mm deep cavity, approximately 50% of the light emitted by the LEDs will be directly incident on the sidewalls of the 22" cavity. This demonstrates the mixing ability of this design and the planer emission of Luxeon™ Side Emitter.

The distance between the top of the LED to the back of the LCD is approximately 40mm. A bulk diffuser 2mm thick lies between the cavity and the LCD. Best results were obtained with a reflection between 30 – 40% for this diffuser. This level of reflection is required to achieve the high color and brightness uniformity.

Brightness Enhancement films (BEF) maybe be placed between the diffuser and the LCD to increase the brightness of the screen.

3.1 Theoretical Results

The design in figure 1 was modeled in a ray-tracing program ASAP from Breault Research Organization. The design was optimized for brightness and color uniformity by: positioning the arrays in the cavity, modifying the slope of the back reflector,

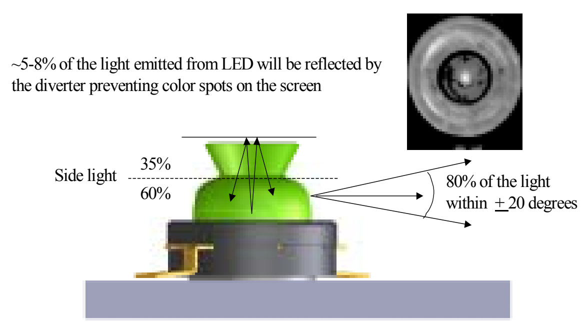

Figure 5: Optical Ray trace with diverter

optimizing the diverter and finally modeling different materials for the optical elements.

The brightness profile is managed by several key elements. The first is the diverter. The larger the diverter the more impact it will have on the brightness profile. Different reflective and transmissive characteristics would significantly affect the brightness profile. A 0º slope on the back reflector with a 90% reflective film (67.5 lambertian and 22.5% specular) achieved the best results with the 6mm wide diverter. The sidewalls of the cavity were specular at 95% reflectivity. The array location was then optimized to provide the required brightness profile. Currently we have focused on two different brightness profiles one being parabolic similar to CRTs and the other one being uniform across the screen. Currently, a brightness uniformity greater than 85% has been achieved.

The figure 6 below illustrates the brightness uniformity for a 22" with a parabolic brightness profile. The average to peak ratio is 70% with a uniformity of 58% based on a 9 point test.

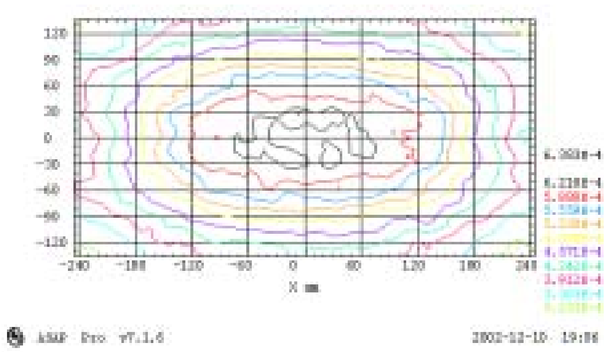

Figure 6: Theoretical brightness uniformity

The total efficiency of the backlight, calculated as flux out of the backlight divided by flux out of the light sources, was calculated to be 69%.

3.2 Measured Results

After learning as much as possible about the design from the theoretical simulations, several LED direct backlights were built. The system as shown in Figure 1 was built and fine-tuned to get optimal brightness and color uniformity.

An array was made up of 48 Luxeon™ Side Emitters with a color sequence optimized to manage color uniformity on the screen. This sequence was repeated until the array contained the 48 LEDs. The two arrays were placed approximately 150mm apart. The 24 red LEDs had a total flux of 1039 Lm, while the 48 green LEDs had 2436 Lm, and the 24 blue LEDs had 109 Lm. All LEDs were driven at 350mA. 33.2Lm/W was achieved at room temperature with a white point at 9000K.

A diffuse reflective film was placed on the back of the cavity, with the sidewalls covered with a specular film. As discovered during the theoretical simulations, the diverter and the diffuser were key elements, which controlled the brightness and color uniformity. These elements were selected very carefully. Best results were obtained with a 2mm thick acrylic bulk diffuser.

The brightness and color uniformity where measured with a Radiant Imaging Prometric CCD camera. These results are shown in Figures 7 and 8. All the measurements where taken without using Brightness Enhancement Films. Peak brightness over 5000 nits was measured, at a power consumption of 70-75 watts.

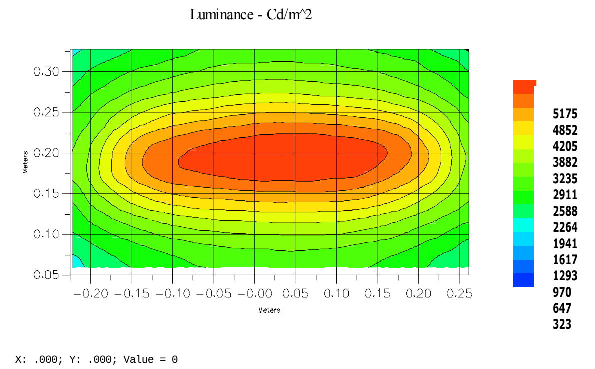

Figure 7: Measured Brightness uniformity

As can be seen, this backlight has a brightness profile close to parabolic. The average to peak was measured at 71% with a uniformity of 57% based on the 9-point test. This was very similar to the theoretical results that were simulated.

Below is the CCD plot of the color uniformity given in delta u'v'. The total delta in u' v' based on the 9-point test was 0.008. This is due to the reduced color mixing at the end of the array. This can be reduced through binning of the LEDs.

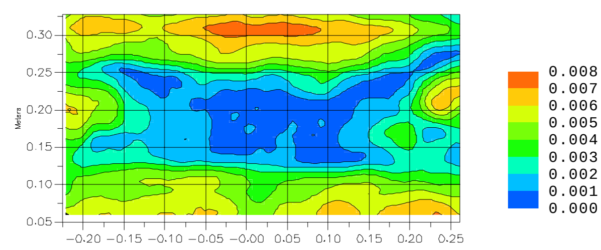

Figure 8: Measured Color uniformity Δu'v'

A complete backlight design can be summarized in table 1, a table that contains all of the assumptions and inputs to determine front of screen performance. This LED direct backlight achieved 10,000 nits with BEF and DBEF films. This backlight when coupled to an LCD should provide approximately 500 nits and 75 watts based on 5% panel transmission.

These initial LED direct Backlight prototypes have demonstrated the ability to achieve good brightness and color uniformity with a 70% optical efficiency. The backlight design is simple making it very attractive for the customer to build and develop on their own. This simplicity is achieved by the primary optics being moved back to the LED.

Inputs - Screen	
	Feb '03
BEF III	50%
DBEF (if yes enter "0.53" if no enter "0")	30%
Min/Max Brightness Ratio	50%
Average to Peak Brightness Ratio	70.0%
Aspect Ratio (e.g. 4:3 = 1.33)	1.78
Diagonal Screen Size (inches)	22
Width of Display (cm)	48.7
Display Area (square meters)	0.133
Luxeon / Luxeon Direct performance	
	Feb '03
Targeted Peak F.O.S. Brightness	500
Panel Transmission (%)	5.0%
Targeted Peak Backlight Brightness	10000
lm/W (9000K) @ 25'C	33.5
Lightsource Flux (lm) {Hot}	2149
Lightsource Flux (lm) @25'C	2528
Power (W) Luxeon Light Source Only	**75.5**
Power (W) after implementating AI (saves 25% power)	56.6
Brightness Efficacy (nits/W)	132.5
Optical Efficiency	70%
Derating Hot/Cold Factor	85%
nits/lm	4.65
Driver Efficiency (%)	85%
TOTAL Power {LEDs + LED Driver} (W)	**88.8**

Table 1: System Calculation model

4. Discussion

Development efforts are focused on higher optical efficiency (lower power) and thinner direct backlight designs. Luxeon™ devices used in this direct backlight design will, in the very 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 the direct backlight solution presented in this paper has attractive features for this market. Luxeon™ direct backlight has: long life (customers expect an LCD-TV to last as long as a CRT), wide color gamut (NTSC coverage), and is very efficient and bright. In addition, it does not contain mercury, like CCFL. In previous papers at SID, backlight timing schemes have been suggested to improve moving image quality of LCD screens. LEDs can be switched very quickly (several orders of magnitude faster than video frame times) and are ready for the implementation of these dynamic backlight control features.

5. Conclusion

The results show that Luxeon™ high power Side Emitters in red, green, and blue can be integrated into a direct backlight design providing excellent performance in uniformity both in color and brightness. This was achieved with an optical efficiency of ~ 70%.

6. References

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