I-15.3: LED Backlighting for LCD-HDTV

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Abstract

Light Emitting Diodes (LEDs) are used today for backlighting for small displays like PDA's and mobile phones. We show in this paper that a new LED technology can be used for high demanding display backlighting applications like LCD-HDTV as well. Using this new type of emitter, called Luxeon^{TM} Power Light Source, a higher brightness than an edge-lit CCFL backlight can be achieved, while compared to a direct-lit CCFL backlight the thickness is lower and the uniformity better. With the on-going improvements in LED performance over the coming years LED backlights will reach and even outperform the brightness performance of direct-lit backlights while maintaining the benefits of edge-lit solutions at even higher brightness levels.

Introduction

The dramatically lower price of Active Matrix Liquid Crystal Displays (AM-LCD) [1] is turning the LCD based television (LCD-TV) application into a fast growing market segment. Advantages of LCD-TV compared to Cathode Ray Tube (CRT TV) are thickness and weight, high resolution, and power consumption compared to CRT. In particular the ability to hang the display on a wall or integrate it easily into furniture is very appealing.

Compared to CRT-TV, LCD-TV has some drawbacks as well. CRT's reach a peak brightness of 650nits with viewing angles up to a full hemisphere. Current LCD TV's reach at maximum 450 nits, at limited viewing angles. Color performance in terms of color gamut, as well as color consistency (especially over wide viewing angle), is far below CRT performance. And moving image quality is poor due to low switching speed of the LCD material and display electronics. These limitations are imposed by both the LCD, as well as backlight performance.

New LCD technologies [2,3,4] are being introduced which much better performance as concerned to viewing angles and color, but at expense of lower transmission efficiencies. In addition resolution is further increased for high-definition television (HD-TV) and multi media applications, which decreases transmission even lower. As an example: a typical standard resolution, limited viewing angle LCD-TV of a year ago had a transmission of 8% while current high resolution, large viewing angle LCD's have transmissions as low as 3%.

To compensate for the drop in LCD-transmission backlight brightness needs to be much higher than before. In this paper, we will compare the performance of a new type of light emitting diode technology (called Luxeon™ Power Light Source) based backlight with that of conventional cold cathode fluorescent lamp (CCFL) based solutions. For this purpose we will compare an edge-lit based backlight design for the Luxeon™ solution, with both edge lit and direct-lit CCFL backlights.

The use of hot cathode lamps is excluded from this analysis, as the lifetime demands for LCD-TV would require several backlight replacements, which is not regarded as a viable option for the consumer market. LEDs in general, and the Luxeon™ devices more specific, have lifetimes (defined as 50% of initial flux) in the range from 50.000hr to 100.000 hr, depending on temperature and drive conditions, which are longer than CCFL lamps.

In previous papers [5,6], we have discussed the advantages of using red, green and blue (RGB) LEDs compared to CCFL and white (W) LEDs with regard to color gamut and color control. As color performance is important for LCD-TV applications, we limit the comparison in this paper to the RGB Luxeon™ Power Light Source. By replacing a conventional CCFL backlight with a Luxeon™ backlight we have seen increases in color gamut from 65% NTSC to 90% and above without changing color filters, at equal or slightly improved transmission. This indicates that by proper color filter design LED backlight based LCD displays have higher transmissions, but as we have not enough data yet on this we will assume same LCD transmissions for LED and CCFL based backlights in this paper.

We will not discuss the favorable dynamic properties of Luxeon™ based backlights compared to CCFL backlights, with its associated advantages of being able to improve the moving image quality of LCD-HDTV [7] but concentrate on the brightness performance of the various solutions, in conjunction with the power requirements.

CCFL Backlight Technology

An example of a conventional CCFL edge lit backlight is shown in figure 1A. It consists of a 5 to 10 mm-thick light guide *(2)* with one to three CCFL tubes *(1)* along the edge. The lightguide distributes the light from the lamps uniformly over the surface, typically by using a dot-pattern or microstructure array. The lightguide will have a reflector on the back *(3)*, and some optical sheets *(4)* in between the backlight and to LCD *(5)* to improve uniformity and enhance the brightness. By using a lightguide the total thickness of this solution can be very small, while maintaining a very high uniformity independent of lamp variations.

The flux efficiency of a CCFL edge-lit backlight (flux out of the backlight divided by flux out of the lamps) depends on the thickness of the lightguide and the number of lamps used. Typically efficiency is 50% for a 3-lamp solution. The brightness of the backlight can be improved by applying brightness enhancement films. Typically a brightness improvement of a factor of 1.4 to 2 can be obtained. For HD-TV application the use of brightness enhancement film is limited, as the viewing angle should be large, especially in horizontal direction. In this paper we will assume that one BEF film is used for the backlight, limiting the viewing angle in vertical direction, but maintaining a wide viewing angle in horizontal direction, resulting in a net gain of about 1.5.

Another way to improve the brightness performance of LCDs is the use of polarization recovery films. These films operate like an efficient polarizer: they transmit the light with the required polarization, and reflect (instead of absorb) the light which has the wrong polarization. This reflected light is depolarized in the backlight, and is applied to the panel a second time after recycling, where roughly half of it is effectively used again. This effective transmission of the LCD panel can be improved by about a factor of 1.5x as well. By combination of one brightness enhancement film and one polarization recovery film the effective brightness enhancement gain is about a factor of 2, which we will use in our comparison.

A direct-lit backlight is shown in figure 1B. This backlight consists of an array of CCFLs *(1)* directly placed behind the LCD *(5).* In order to get to acceptable brightness uniformity levels, the lamps should be not to wide spread (lamp to lamp centers in the range of 10mm to 50mm) and should be not too close to the LCD.

To improve the uniformity of a direct-lit backlight, optical diffuser *(4)* sheets are used between the lamps and the LCD in this backlight, which decrease the direct transmission of the lamps through the LCD, and increase the secondary reflections. In addition, as in the case of edge-lit backlights, direct-lit backlights can be used with brightness enhancement and polarization recovery films *(4)* as well, improving the uniformity further and resulting in a panel brightness efficiency enhancement of a factor of 2.

The thickness of a direct backlight depends on the diameter and pitch of the lamps, the distance between the lamps and LCD, and the uniformity requirements but is for practical solutions between 20 and 50 mm. This is more than twice the thickness of an edge lit backlight. This type of backlight is often used when brightness is the primary concern, and demands on brightness uniformity and thickness can be relaxed.

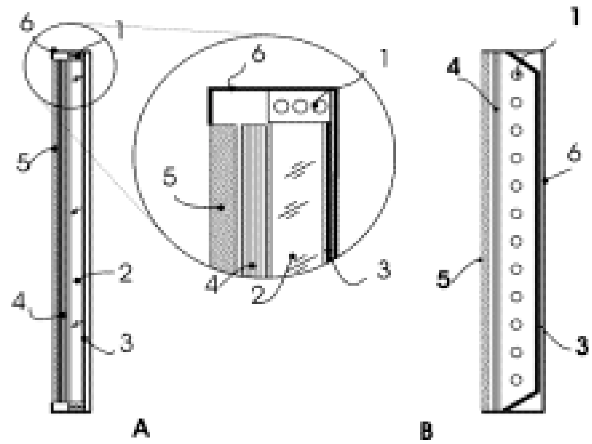

Figure 1 Conventional CCFL backlighting.
(A) Edge-lit CCFL backlight, (B) Direct lit backlight
(1) CCFLs, (2) Lightguide, (3) Reflector,
(4) Optical sheets, (5) LCD, (6) Frame.

Luxeon™ backlighting

The LED backlight that is subject of this paper is shown in Figure 2. The concept is very similar to the CCFL backlight as shown in figure 1A, but instead of CCFL lamps an array of red, green and blue Luxeon™ emitters and color mixer is used. This module is placed behind the lightguide, and by using a 180-degree mirror the light is coupled into the lightguide. As with the CCFL edge lit solution, the Luxeon™ module can be placed on one side, two sides, or (for the very demanding applications) on four sides of the lightguide.

Compared to conventional LEDs, Luxeons™ power light sources are driven at much higher currents

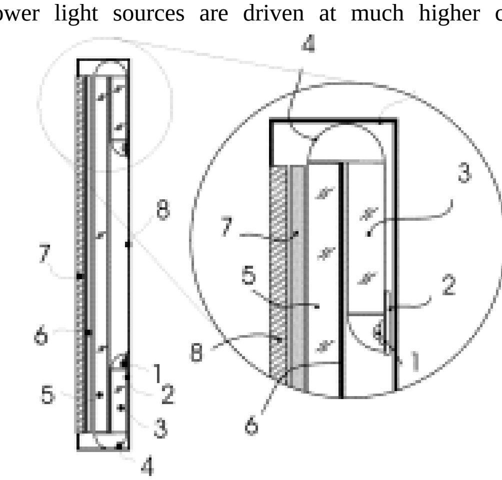

Figure 2 LED backlight module using power Luxeon™ LED technology
(1) Luxeon™ RGB array, (2) Metal-core PCB
(3) Color mixer, (4) 180-degree mirror,
(5) Lightguide, (6) Reflector, (7) Optical Sheets, (8) LCD

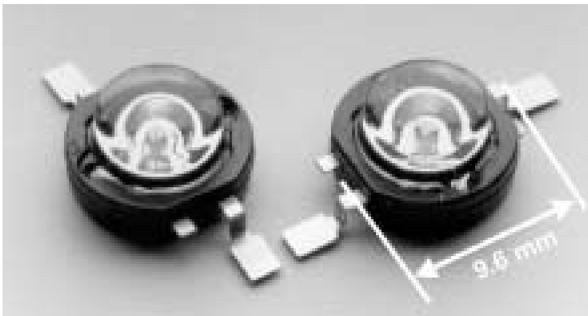

Figure 3 Luxeon™ Emitters

(350mA versus 20-30mA for conventional LEDs, approximately 1 W per device compared to less than 0.1W per conventional LED) and have higher luminous efficacies [8]. This makes these devices very suited for LCD-TV applications as the flux loading over the edge of the lightguide can be made very high. An example of the Luxeon™ emitter is shown in figure 3.

The flux efficiency (flux out of the backlight divided by flux out of the lamps) is on system level comparable with a CCFL edge-lit backlight. To meet NTSC color performance, the best results so far are obtained with blue Luxeon™ emitters with a dominant wavelength of 450nm, green Luxeon™ emitters with a wavelength of 535nm, and red Luxeon™ emitters with a wavelength of 625nm [5]. At these wavelengths a blue Luxeon™ produces between 2 and 5 lumen, the green Luxeon™ between 20 and 40 lumen, and the red Luxeon™ between 30 and 50 lumen. The blue and green Luxeon™ devices don't have strong temperature dependence, the red devices have. To remove the heat from the devices they are preferably mounted on a metal core PCB, with a pitch of about 9mm at minimum.

Besides temperature dependence, light outputs of LEDs vary over production: it is not unusual to see a factor of 2 performance of flux output variation. In order to make this product economically viable it is very important to use full production distribution. Therefore the Luxeons™ are binned (i.e. sorted in different performance categories), and applied in the Luxeon™ backlight array in such a way that in combination with the color mixer the right balance is obtained between color uniformity, brightness and power.

Maximum Brightness and Power Performance

To analyze the performance of the different backlight configurations for LCD-HDTV we have selected two screen sizes: an 18" LCD-HDTV with an aspect ratio of 4:3, and a 22" LCD-HDTV with an aspect ratio of 16:9. For an 18" screen about 40 Luxeon™ emitters per side (top and bottom) can be used and for 22" wide screen LCD-HDTV 54 Luxeon™ emitters per array. For both the edge-lit CCFL as well as the direct-lit backlight solutions the lamps are oriented along the long wide (horizontal) side of the display. In this way the highest efficacy is obtained and the less problems occur with regard to temperature differences. The number of lamps for the edge-lit CCFL array is fixed to 6 (3 at the top edge and 3 at the bottom edge). For the direct backlight the pitch is set to 25mm, resulting in 11 lamps for the 18" and the 22" case. The characteristics of the CCFL lamps used are shown in table 1.

	18"	**22"**
Lamp Length (mm)	*366*	*487*
Power (W)/Lamp	*4.6*	*5.9*
Flux (lm)/Lamp	*207*	*295*

Table 1 CCFL (single lamp) performance data for the edge-lit, and direct-lit backlight solutions.

For a single Luxeon™ backlight module, we have listed the performance characteristics in Table 2. In a double edge-lit solution two of these will be used. The data are supplied on basis of flux output of the total strip at operating temperature. We have distinguished between the base performance (which is the average performance now) and the best performance based on the best devices in laboratory. These best performance data should not be used for actual designs, but are an indication what the progress can be of the performance in a couple of years.

Based on these lamp data, the backlight performances for the backlights are shown in Figure 4. We have assumed a brightness gain of a factor of 2 compared to a Lambertian source due to the use of a polarization recovery film and one brightness enhancement film (to limit the angle in vertical direction, not in horizontal direction). For the flux efficiencies of the edge-lit solutions 50% is used (both Luxeon™ and CCFL edge-lit) and 60% for the direct lit backlight. The brightness data are given for the 3 cases of LCD-HDTVs. For the Luxeon™ backlights the performance is given for both the base case (current average performance), and the best (lab result) performance data, which represents future performance. On the right axis of this

	18"	**22"**
Length (mm)	*370*	*490*
Power (W)	*45*	*60*
Flux (lm)	*1125*	*1500*
Best Lab Flux(lm)	*2000*	*2700*

Table 2 Luxeon™ backlight module performance. ***Performance is distinguished between base (current) performance and best performance (best lab results, as indication of future performance).***

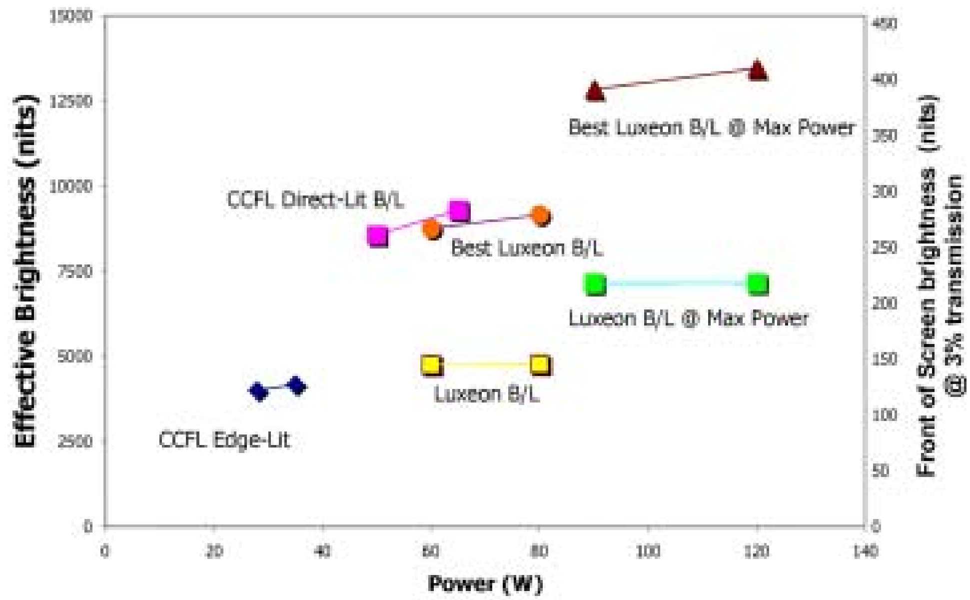

Figure 4: Brightness vs. Power Curves for the Different Backlight Solutions.
***Left Points 18", Right Points (22")*.**

graph, an indication of the expected front of screen brightness is given, for an LCD-HDTV with a transmission of 3%.

The Luxeon™ backlight solutions outperform CCFL edge-lit solution in all cases. Brightness in an edge-lit Luxeon™ backlight is between 10% and 300% higher than an edge-lit CCFL array. For a direct-lit backlight the Luxeon™ backlight performance is lower now, but with the best performance lab data we have been able to out-perform the direct-lit backlight as well.

The power for the different backlights is shown at horizontal axis of Figure 4. For the Luxeon™ cases we have distinguished two power levels: a normal power level based on a solution where no fan is used, and a maximum power level (indicated by @Max Power), limited by the number of Luxeons™ which can be fit in the Luxeon™ module. In this last case fans have to be used to limit the maximum temperature. As a maximum power limit for a fan-less solution we have taken a value of 600 W/m^2. For all screens sizes, the Luxeon™ based backlight power is between 10 and 30% higher than a direct-lit backlight and between 2 and 4 times higher than an edge-lit backlight.

Conclusions

From figure 4 it is clear that backlighting for LCD-HDTV, with its associated low transmissivity, poses very high demands on the light sources. If high brightness is the primary concern, the best solution for now is a direct backlight. However, taking the best Luxeon™ devices available in labs, which are indicative of the performance to come, Luxeon™ LEDs will start to challenge the position of direct backlights, combining the advantages of high brightness, and thin size and uniformity of edge lit backlights.

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