LP.2: High Performance LCD Backlighting using High Intensity Red, Green and Blue Light Emitting Diodes.

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Abstract

By using red, green, and blue (RGB) light emitting diodes (LEDs) instead of cold cathode fluorescent lamps in edge lit LCD backlights brightness and color performance (gamut) of LCD displays can be improved considerably. However: the design of an RGB-LED backlight and electronic control need special attention: the colors of the separate LEDs need to be mixed well to obtain a good spatial color uniformity while a good balance between the red, green and blue levels has to be maintained to stabilize the white point. Additional features of an RGB-LED backlight solution are: dynamic white point control (tune color point of backlight to LCD and/or displayed material), large dimming range, long lifetime, ruggedness, and the absence of mercury.

1. Introduction

Up to now the use of LEDs for LCD backlighting or front lighting has been limited to small size panels due to the limited flux that could be generated per LED package. Either the required flux per unit length could not be obtained (in case of edge lighting) or the number of LEDs became very large (direct backlighting), and in the latter case color homogeneity becomes a serious issue. Nowadays, cold cathode fluorescent lamps (CCFLs) are used for the larger size panels. We have studied the use of new high intensity LEDs in large panel LCD edge lit backlights in order to determine if brightness and color demands could be fulfilled. We compared the use of white LEDs where white light is generated by phosphor conversion of blue LEDs (PC White) with white generated by mixing red, green and blue LEDs (RGB White). It turns out that both the required brightness as well as the color points of the primaries (as defined by the NTSC standard, the EBU standard or the HDTV standard) can easily be obtained only by utilizing this RGB White approach.

2. LED vs. CCFL performance

Progress in LED efficacy during the past years has been impressive and is expected to continue. Although it will take some more time before LEDs are used for general lighting [1], for specific applications like LCD backlighting LEDs offer important system advantages that make them applicable for next generation products. With close packing of LEDs, or by using high intensity LEDs, edge illuminance of a light pipe can outperform CCFL performance. A comparison of light output for various types of LEDs and a typical cold cathode lamp is shown in Table 1. From this table it can be concluded that for 5 mm lamps and single chip LED lamps linear light output is less than for a CCFL, but that with 3 in 1 chip LED lamps and Luxeon™ Power LED lamps linear light output is actually a factor of 2 to 3 higher than for a single CCFL. Furthermore it should be noted that environmental considerations are leading to increased search for mercury-free lamps and that state of the art Hg-free CCFLs show about 50% lower efficacy [2] which makes the LED solution even more favorable. Other options for mercury-free backlights have also been presented [3,4] but these still suffer from drawbacks like a limited color gamut, short life time, low efficacy, electromagnetic interference or temperature dependence. LED lit backlight systems are expected to have lifetimes beyond 50000 hours. For automotive and avionics applications there is a strong demand for extreme dimming capability and cold start-up [5,6]. These requirements can be met particularly well by LEDs.

	Length mm	Power W	Flux lm	Linear Flux Output lm/cm
5 mm lamps	5	0.1	1.5	3
Chip LED	2.7	0.1	1.5	5
3 in 1 Chip LED	3	0.28	4.2	14
Luxeon™	8	1.1	16.5	18
CCFL	370	4.4	217	6

Table 1: Linear light output for different LED types and an CCFL lamp
(typical values, flux is average flux per LED for using red, green and blue LEDs to create 9500K white)

3. Power consumption

Backlights with LEDs have a higher optical efficiency than conventional backlights because a higher injection efficiency into the light pipe can be realized. In a conventional backlighting system between one and three lamps per side of the light pipe are used and a reflector is used to direct the light to the edge of the light pipe. For three lamps per side (lamp diameter 2.6mm, light

	Effiacy lm/W	Flux lm	Effective Linear Flux lm/cm
6 CCFL's	42	1116	15
6 CCFL+ invertor + reflector	29	771	10
Total out of light guide excluding any films	20	532	7

Table 2: Performance of a 6 CCFL 18” 10mm thick backlight

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pipe thickness 10mm) the maximum light transmission to the edge is only 80% and a maximum of about 75% is injected into the light guide. Using thinner light guides reduces this number even further and increasing the number of lamps has a dramatic impact on efficiency. Table 2 shows measured data of an 18” backlight that are indicative for the performance of such systems.

In case of LEDs as light sources an injection efficiency of more than 90% can easily be obtained at a comparable linear flux level of three CCFLs. With the trend to use thinner light guides, e.g. 6 mm, not more than 2 CCFLs per side can be used. With this thickness still more than 90% of the LED output can be coupled into the light guide. It should even be possible to go down to 4 mm without severe light loss which is impossible using 2 CCFLs per edge. With a 5 mm thick light guide and 2 CCFLs per side, about 10 lm/cm at the acrylic edge can be taken as the benchmark. This results in about 20 backlight output lumens per Watt. In case of LEDs this depends strongly on the actual LED efficacies which over time continue to improve dramatically. With the currently available high flux LEDs more than 15 lm/cm at the acrylic edge can be obtained which potentially results in a 1.5 times higher screen brightness. The backlight output efficiency then is about 10 lm/W, but with the continuous improvement in InGaN LED technology, as also is indicated by extrapolation of the efficacies that have been obtained during the last years [1], it is expected that the benchmark performance will be beaten within two years as is shown in Figure 1. Here the power required by CCFLs for comparable backlight brightness is indicated as a reference, assuming a 5% annual improvement of these lamps.

4. Color Performance

Composing white by using red, green and blue LEDs (RGB White) is better suited for LCD backlighting than using phosphor converted white LEDs (PC White). This is shown in Fig. 2 where the spectrum of a white LED is compared with typical transmission spectra of LCD color filters and separate red, green and blue LEDs. The figure shows typical backlight spectra obtained with AlInGaP transparent substrate red LEDs, with an average peak wavelength at 630nm and a full-width-half-maximum (FWHM) bandwidth of 22nm, green InGaN LEDs with an average peak wavelength of 535 nm and bandwidth of 43nm (FWHM), and blue InGaN LEDs with an average peak wavelength of 460nm and bandwidth of 24nm (FWHM). As can be seen in the figure these wavelengths match the peak transmissions of typical color filters quite precisely, where the blue filter has been shifted by 20nm towards the UV compared to conventional LCD filters. This is not the case with the white phosphor LEDs (in which white light is created by using a blue

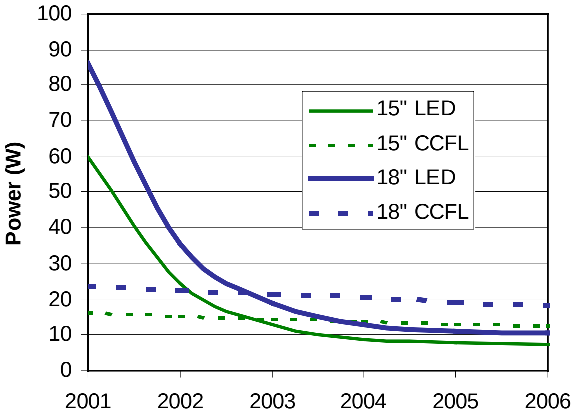

Figure 1: Expected power consumption for LED backlights compared to CCFL backlights (250nits)

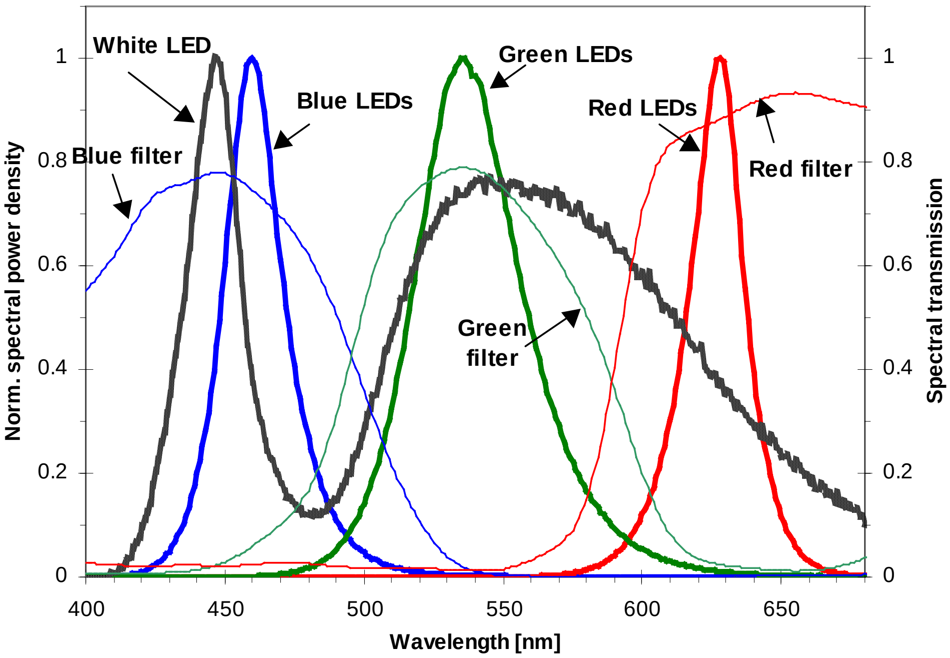

Figure 2: Typical LED backlight emission spectra and LCD color filter spectra

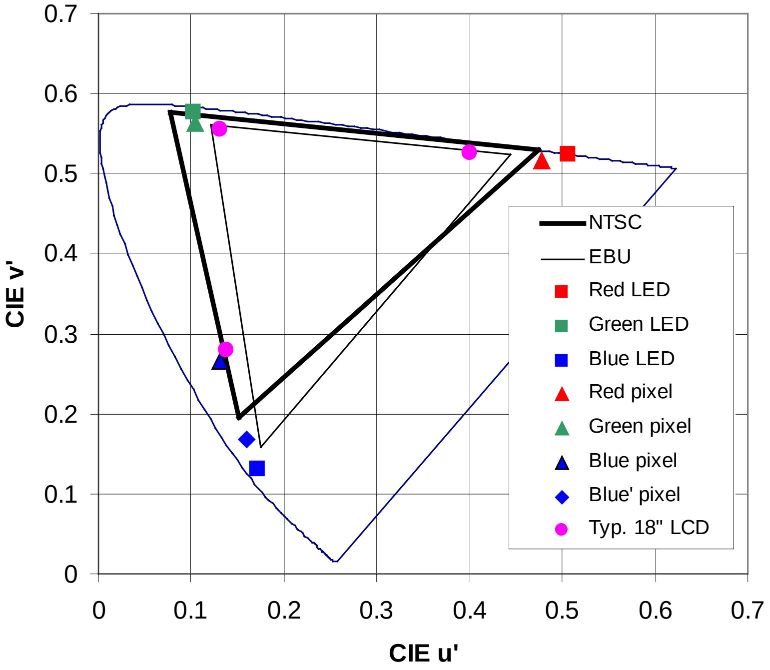

Figure 3: CIE 1976 (u'v') color diagram of the LED backlight primaries, and the resulting primaries through the LCD panel for CCFL and LEDs. The blue' pixel is obtained with a 20 nm shifted blue filter.

emitter coated with a phosphor) where the color filters (especially the red and the green) do not match very well with the phosphor emission spectra. Furthermore, because with RGB-White the R, G and B contributions are controlled separately, user selection of the color temperature of the white pixel can be set by adjusting the backlight rather than by the LCD, which enables optimum dynamic range for all color temperatures selected.

By using RGB White the backlight spans a 130% NTSC color space. Due to overlap of the spectra with more than one color filter in an LCD (e.g. leakage of green though blue pixels) this color space will be reduced, but by proper tuning of the color filters and the LED colors it is possible to obtain approximately a 100% NTSC color performance with at least 28% flux transmission through the color filters. Examples of color points and spaces are given in Fig. 3, where a CIE 1976 uniform chromaticity scale chart is presented with the color primaries of the backlight, the NTSC standard primaries, and the primaries of an LCD display with a CCFL lamp, and of an LCD display with RGB-LEDs. The well defined and narrow color bands of an LED backlight will relax requirements on color filter design or will enable new filter types which may have higher transmissions.

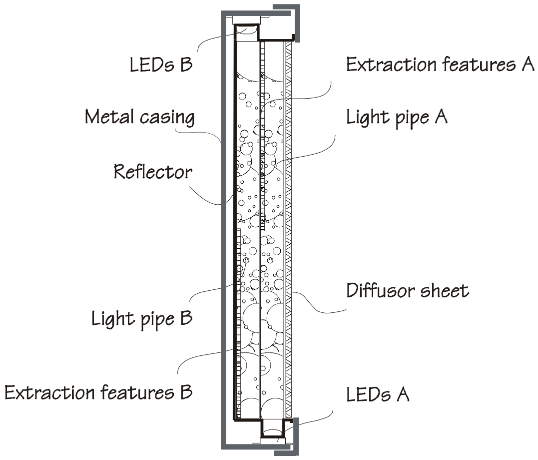

Figure 4: Schematic drawing of the double light guide used in the 18" demonstrators to achieve excellent color mixing and insensitivity for LED fluctuations.

To obtain good color uniformity with separate red, green and blue LEDs a careful design of the light pipe and LED collecting optics is required. Light, entering the light pipe from the edge, is distributed over the light pipe. By using silk screen printed dots or micro structures on the rear surface of the light pipe, light is extracted to create an even illumination of the LCD panel. With RGB-LEDs as light source, such an extraction feature should receive light from at least one red, one green and one blue LED, but preferably as many LEDs as possible.

This can be realized by creating a distance (mixing cavity) between the LEDs and the extraction features. A solution where a large mixing cavity is created in the light pipe by using two light pipes is shown in Fig. 4. With this type of solution we have obtained color uniformities of about $\Delta u'v' \sim 0.01$ over the full surface of an 18" backlight.

5. Color Performance in Field Sequential Operation

LED backlights have the potential to accelerate efficiency improvements in LCD technology. Besides continuous operation of the red, green and blue LEDs, they can be switched per color synchronously with the red, green and blue image content to obtain a color sequential display. This has the advantage that no color filters are needed and the system efficiency in principle would be about three times higher. LEDs can be switched with rise and fall times in the range of 20ns. Recently, color sequential

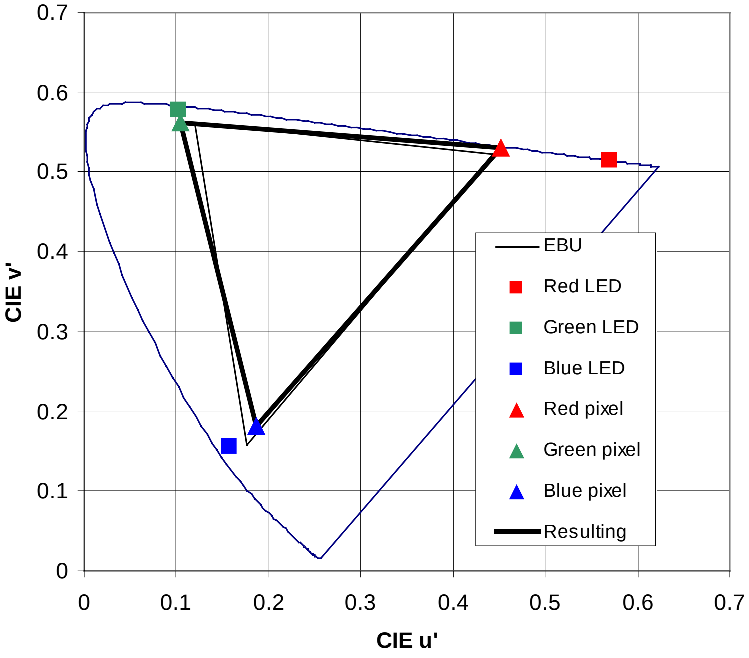

Figure 5: Color gamut obtained with 90% LC switching in color sequential operation using RGB sequence and optimized LED wavelength to match EBU standards.

LCD prototypes have been reported using LEDs [7,8]. Switching speed can be about 2 ms. Together with the pixel addressing time this leaves little time for flashing the backlight and as a consequence the duty cycle is low, typically on the order of about 10%. Especially for the larger panels a very high lamp brightness is required and the lamp-on state should be maximized. However, because the LC has not switched for 100% at the moment of the lamp flash, a color error is introduced, reducing the maximum color gamut considerably. The effect of incomplete switching is shown in Fig. 5 for a red-green-blue sequence. Thanks to the high purity of the primaries and the large dominant wavelength of red that is available, with this sequence it is possible to obtain an effective color gamut that approximates the HDTV standard very closely even when assuming the LC has switched only by 90% at the time the lamps are flashed. Short duty cycles are required with high peak light outputs; an optimized LED design is expected to be able to give the required peak output powers.

6. Conclusions

The results show that using red, green and blue light emitting diodes in edge lit backlighting improves front of screen performance of LCDs considerably, both in brightness as well as in color gamut. It is expected that performance of LEDs will improve even considerably more over the coming years by major improvements in III-V (InGaN) material technology and backlight system efficacy is expected to outperform CCFL solutions within about one year. These advantages together with features as dynamic white point control, dimming, lifetime, ruggedness, switching speed, cold start-up, low voltage (EMC) and the absence of mercury, we expect, will lead to quick adoption of this backlight solution by LCD display industry.

Besides improving performance in existing LCD technology, RGB backlights could accelerate other innovations in this field like color sequential LCDs or the application of non-absorbing color filter solutions.

7. References

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