LED Backlight: Enhancement of picture quality on LCD screen

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Abstract: *LED backlight for LCD is an emerging technology with vast performance potential compared to CCFL backlight. The key performance which directly impacts the consumer is the image quality on LCD screen. This paper will review some of the performance enhancements in image quality arising from LED backlight.*

Keywords: LED Backlight; LCD screen; image quality; color gamut; motion blur; high dynamic range; adaptive dimming.

Introduction

Light Emitting Diode (LED) backlight for Liquid Crystal Display (LCD) backlighting is gaining momentum to end the domination of Cold Cathode Fluorescent Lamp (CCFL) based backlight. LEDs have better performance parameters than CCFL in terms of voltage of operation, frequency of operation, reliability, low temperature operation and image quality on LCD screen. This paper will focus on the superior image quality on LCD screen stemming from the performance of LED backlight. Image quality under high ambient light and low ambient light are both important. LCDs suffer from 'Motion blur', reduced contrast ratio and color gamut under dull lighting and lack of full color gamut at high brightness on LCD screen. Further, with CCFL backlight the image on LCD screen never exceeds color gamut of 100% NTSC. LED backlight provided impetus to LCD to overcome all these drawbacks. The emergence of LED backlight is a boost [1] to LCD TV.

Color gamut

It is highly desirable to see the color picture on LCD screen to be the same as one sees in nature. The acceptable color gamut is represented by NTSC triangle. LED backlight by virtue of the superior spectrum emitted by red (R) green (G) and blue (B) LEDs is able to provide, in combination with transmission characteristics of color filters of LCD, color gamut exceeding NTSC triangle. Three primary colors emitted by R- G- B white LED backlight are able to give a color gamut represented by 110% NTSC.

Color spectrum of R-G-B white backlight: LED backlight that is obtained by mixing green, red and blue in the correct ratio (64%G, 28%R and 8%B) yields a spectrum as shown in Fig. 1. It can be seen that the color filter transmission has a broad band signifying that each color filter can pass colors in wide range of wavelengths . For example red filter can pass orange and green filter can pass blue green and blue filter can pass blue green. If the backlight emission is of broad band in nature or has secondary peaks then the color purity obtained on LCD screen will not be pleasing.

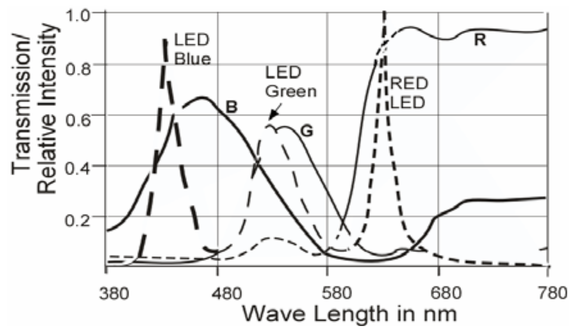

Figure 1. R, G and B LED spectrum superimposed on color filter transmission characteristics

As illustrated in Fig. 1, although the transmission characteristics of color filter is of broad band in nature, the emission spectrum from LEDs are sharp and hence the color purity (and thus color gamut) is enhanced. This is clearly illustrated for red emission from LED. In contrast (not shown here) CCFLs have secondary peak in red and blue emission thus not able to exceed NTSC triangle.

Four primary colors from LEDs: Two green, one blue and one red emitting LEDs are employed in field sequential mode for obtaining high color gamut. A color gamut represented by a triangle that is 122% of NTSC triangle is developed by Ikuo Hiyama et.al [2]. Their LED emission spectrum superimposed on color transmission characteristics is shown in Fig. 2. Once again the LED emission spectrum is sharp and two green LEDs enhances the NTSC triangle area as shown in Fig. 2b. The field sequential mode of driving is possible because of fast response of LEDs being in the range of 100 ns a feature totally absent in CCFL. The LEDs employed had the wavelength peaks at 660 nm (R), 502 nm (G1), 520 nm (G2) and 415 nm (B).

Recently six primary colors have also been employed [3] using two green, two blue and two red emission from LEDs to obtain 145% NTSC. Thus LED backlight for LCD enables seeing the color on LCD screen as we see the colors in nature.

Contrast, gray scale and color gamut under dark environment

An ingenious concept by Shiga and Mikoshiba [4] originally developed for reducing the power

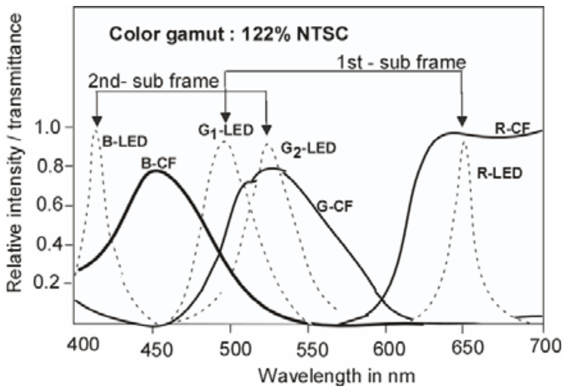

Figure 2a. Four primary color LED emission with superimposed color filter transmission characteristics

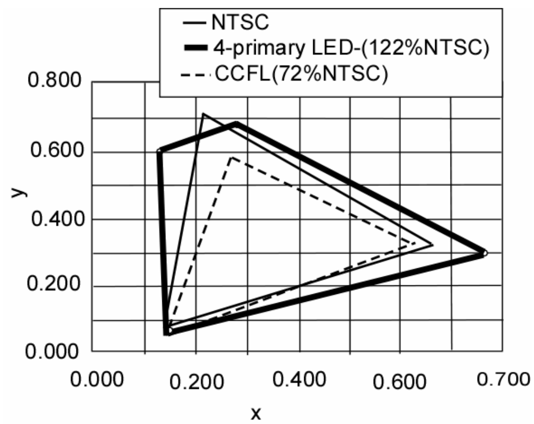

Figure 2b. CIE diagram comparing CCFL backlight with four primary color LED backlight.

consumption of backlight has resulted in enhancement of picture quality. In this concept the backlight luminance is modulated according to the incoming TV signal. When the original incoming signal is small the luminance of the backlight is reduced. The reduced luminance in turn is used to increase the signal to increase the transmittance of LCD so that the luminance on the LCD screen will be the same as would exist if the original signal was not altered and the luminance of the backlight not reduced. With the changes on the backlight luminance and changes in incoming signal, the gray scale capability is enhanced for small incoming signal, otherwise would not have been possible. A practical demonstration of this concept was published [5]. The concept was further extended [6] to evolve 0D, 1D and 2D adaptive dimming. 0D dimming refers to overall dimming of the backlight, 1D dimming refers to line dimming (linear strip of backlight) and 2D refers to individual point light source dimming as in LEDs and this type of dimming is not possible in CCFL of backlight. As this approach emphasizes on power reduction of backlight detailed description, except the dimming related to the picture, is deferred here. Fig. 3 illustrates the dimming of LED backlight, with individual LED control, related to a scene like 'sunset'.

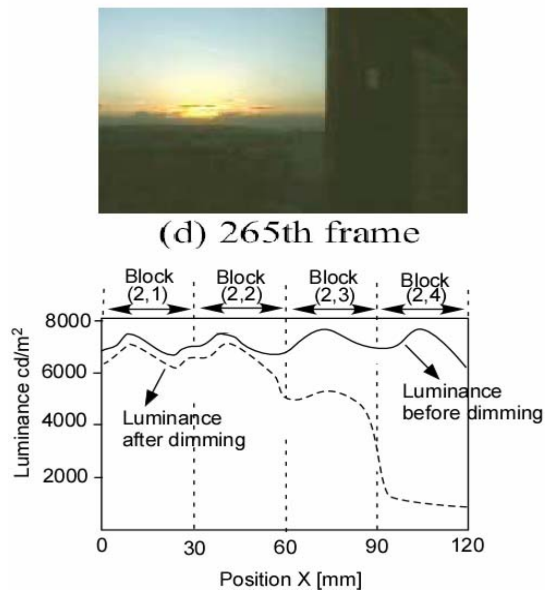

Figure 3. 2D adaptive dimming for 'sunset' scene employing LED backlight with individual LED blocks with block control.

A black & white picture of 'sunset' is shown above. Since the right hand side of the picture is a dull sky, fairly dark, the backlight is clearly seen dimmed with a steep drop in luminance. This automatically improves the gray scale in the picture (not shown in Fig. 3).

Color gamut and contrast improvement of low gray level images: Incoming image data modulating the brightness of individual color LED and the modulated brightness in turn altering the incoming image data to adjust for LCD transmission has been exploited by Konno et.al [7] in enhancing both the contrast ratio and color gamut of LCDs in dark environment. LCDs have low contrast under dark environment due to the leakage of light from backlight through the 'closed' pixels of LCD. Under dark environment the leakage of light through 'closed' pixels of LCD is not negligible as in the case of normal ambient light. This is because the traditional backlight is kept ON to full brightness all the time and thus the leakage of light under dark environment results in low contrast that is absent in the normal ambient light condition. Blue wavelength leaks out more than other colors. Even if the LCD shutter against blue pixel is closed the leakage of blue light is easily seen. This gives rise to low contrast and degradation of color purity that reflects itself in reduced area of NTSC triangle. Fig. 4 illustrates this distinctly.

Fig. 4 has a small triangular area for gray level of 32 and 64 portraying reduced color gamut at these gray levels in a dark environment. The dynamic contrast ratio is 498:1 which is half that of plasma display and

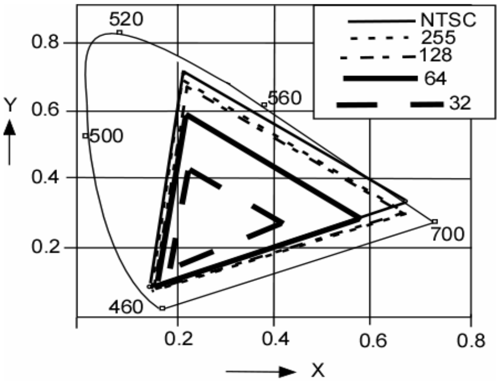

Figure 4. Color gamut on gray level obtained in a dark room on Advanced Super In-plane-switching (AS-IPS) LCD.

nearly 80 times less than CRT. light is to reduce the brightness of backlight. But this will reduce the luminance of relatively bright portions of the picture. This is where the color control system comes in to play with three basic process steps:

1. Analysis of received image data histogram and obtaining maximum level data (MLD) of each color image.
2. Maximum level data is substituted for the backlight gray level for modulating the brightness of backlight.
3. Original image data conversion by the modulated brightness of backlight so as to alter the transmission of LCD to obtain the same luminance as would have been obtained were the whole image processing not done and backlight brightness not altered.

These processes are schematically shown in Fig. 5. Dynamic modulation of brightness of individual colors is possible because of the fast response of LED that emits red blue and green colors as individual light sources.

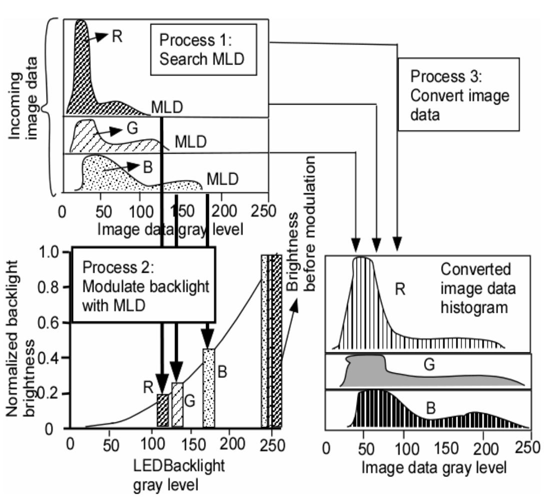

Figure 5. RGB Color control system employing LED backlight

By implementing this RGB color control system on a 32" AS-IPS LCD TV, A. Konno et.al enhanced the dynamic contrast ratio of the display under dark environment from 498:1 to 20,000:1, exceeding plasma display, and obtained a color gamut of 100% NTSC for a gray level of 32 and 120% NTSC for gray levels from 50 to 250.

Motion blur

Active Matrix LCD (AM-LCD) is well known to have motion blur defect which is absent in CRT. This defect stems from two basic factors that relate to the LC response time and 'write and hold' (or 'sample and hold') nature of AM-LCD driving with LC response time contributing 30% and 'write and hold' contributing 70% to the defect [8]. Because of this, even if the response time of LCD is zero, the motion blur still remains and clearly seen at both the leading and trailing edge of the images. For the entire frame time the image is stationery and is shifted to the next frame suddenly in step rather than in a continuous motion. But the human visual system tracks the image in a smooth and continuous fashion. This results in the perception of 'smeared-out' image called 'motion blur.' A clear description of this is given in ref [9].

There are many methods that have been successfully employed for minimizing motion blur. The simplest method among them relates to backlight. A simple fact needs to be remembered prior to the description of a solution to motion blur through backlight. That is, no image on LCD screen can be seen if the backlight is 'off'. Assuming that the motion blur at the edges of an image is a gradation of light intensity (unwanted gray level), it is possible to get rid of it if the backlight is turned 'off' in a timely fashion with respect to the image writing and writing-over during frame sequence. This is precisely what was done by N. Fisekovic et.al [10] on their 18" TN SXGA AMLD employing 8 segmented (band) LED backlight in edge-lit configuration. In this case, the LCD screen faces from behind 8 segments of backlight. The light from these segments are turned ON sequentially so that the pixels are exposed to light only when they attain the desired maximum gray level transmission set for the pixels in the image. As the panel is addressed line by line in a frame, LC cells in different line will take different time to attain desired maximum transmission and this difference is negligible for ¼ of a frame. The backlight is synchronized with pixel addressing i.e., video signal. Every segment of the backlight is turned ON only when the gray level transmission reaches maximum value for the pixels in the segment and then turned OFF as soon as the gray level transmission starts to fall. This means the backlight is not exposed to the pixels when the pixel transmission starts increasing or starts decreasing. From the top of the panel to the bottom of the panel the band of backlight is scanning in synchronization with video signal. This is termed as 'scanning backlight'. In this mode no light intensity is seen when the pixels are changing their transmission and hence motion blur is not visible. The sequence of light exposure through 8 segments is depicted in Fig. 6.

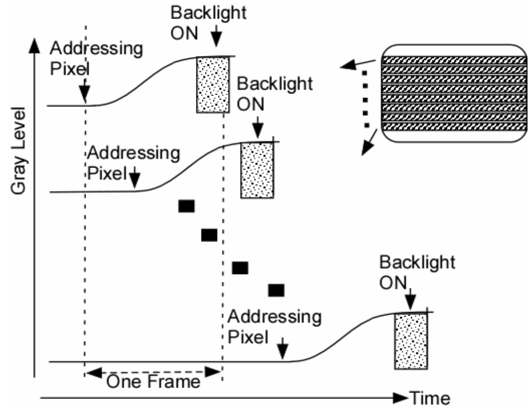

Figure 6. Scanning LED backlight to reduce Motion Blur

In a way it is a crude approximation to CRT in terms of image generation and movement. Color purity, contrast and motion picture quality are all improved with this scheme. As LEDs are fast in response to yield instantaneous brightness and darkness, the degree of motion blur is expected to be less compared to 'scanning fluorescent lamps'.

Imaging backlight enhances image quality

On a sunny day when objects are seen in nature the luminance can exceed 10,000 cd/m^2 and most of flat panel displays have a luminance in the range of 300-500 cd/m$^{2.}$ To enhance the brightness on LCD if the backlight brightness is increased, in addition to degrading the life performance of backlight, the color purity suffers. An ingenious concept has been developed [11] by Helge Seetzen and Lorne Whitehead for achieving high brightness but preserving the color purity through the use of 'imaging backlight'. In this approach LED backlight is used more as a display of low resolution than as a traditional backlight. LED generates a low resolution image and projects the image on LCD screen that generates the same image with high resolution. White LEDs employed can yield luminance as high as 25,000 cd/m^2 and at the same time yields no emission in the 'off' state thus giving 8-bit resolution between these states. LCD is known to possess 8-bit resolution and hence these two modulators in combination can yield 16-bit resolution.

A simple basic schematic of white LED backlight with traditional LCD is shown in Fig. 7.

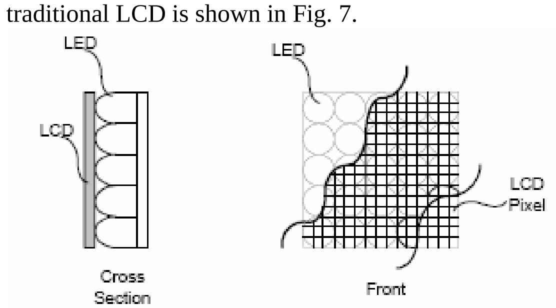

Figure 7. Low resolution LED imaging backlight

A simple illustration of low resolution image of LED and its image backlighting traditional LCD (with adaptive correction) resulting in the final image of 'Memorial Church' through high dynamic range (HDR) display is shown in Fig. 8.

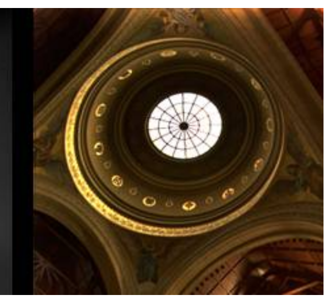

Fig. 8a. LED image **Fig.8b.** LCD Corrected Image.

Fig. 8c. Final HDR display

By employing RGB LEDs good color gamut has been obtained at high (>1000 cd/m^2) as well as low (1 cd/m^2) luminance levels. HDR display is the only known display to achieve this feature.

Conclusion

It should be emphasized that without fast response (100 ns) and good color spectrum of LEDs, LCDs that display hitherto unheard of high image quality in terms of contrast, gray level, motion blur and color gamut are not possible.

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