NXP Semiconductors – Article on 2-D dimming LED backlighting
Dated 25 January 2008

Solid-state backlighting boosts the TV viewing experience

Advanced backlighting technology using LED-based light sources and segmented control can create a vibrant viewing experience, while also reducing power consumption in LCD TVs

Authors: Pierre de Greef, Hendriek Groot Hulze and Harm van der Heijden, NXP Semiconductors

Solid-state backlighting using LEDs has a number of distinct advantages in LCD TV applications. Compared to the Cold Cathode Fluorescent Lamps (CCFL) and Hot Cathode Fluorescent Lamps (HCFL) that currently dominate the market in large-area LCD backlighting, LEDs can offer significantly better power efficiency. This is not inherently a result of their optical efficiency (lumens per watt), which currently only matches that of CCFL, but is due to the fact that LEDs can be dimmed much more flexibly and efficiently to match the required picture brightness. Two-dimensional backlight dimming using an addressable array of LEDs creates a more vibrant viewing experience, with much better contrast ratios, wider color gamut and better color saturation.

Various dimming techniques have been introduced for CCFL and HCFL back-lighting over the past few years. For example, in some cases the entire backlight is dimmed, matching the required picture brightness – a technique called 0-D dimming. When dimming is performed along a single axis (for example, by controlling the intensity of a single HCFL lamp or a group of CCFL lamps in parallel) it's called 1-D dimming.

Recent cost and performance improvements in LEDs, that now make LED backlighting a much more practical proposition, open up the possibility of new and more effective backlight dimming techniques. The fact that LEDs can easily be arranged in a two-dimensional array and individually controlled now makes it possible to perform 2-D (horizontal and vertical) dimming – something that is not possible with conventional CCFL or HCFL lamps. This allows the backlight to locally produce more light behind bright areas of the displayed picture and less light behind dark areas of the displayed picture.

In practice, an array of 10 x 18 high-efficiency white LEDs is sufficient to locally optimize the backlight intensity for typical picture content, leading to much better contrast ratios and significantly reduced average power consumption in the backlight. This localized control of backlight output based on picture content can save on average about 50% of power consumption for typical TV picture content.

From white to RGB

If RGB triplets of colored LEDs are used instead of white LEDs, then 2-D LED backlighting offers even greater advantages. The color gamut achievable by controlling the intensity of the red, green and blue LEDs in an RGB triplet is significantly wider than that of a conventionally backlit LCD panel. As a result, an RGB LED backlight can create brighter, deeper, more saturated colors. Intelligent saturation control can therefore be applied to map the color space of the video content (sRGB) to the LED backlight's color space. Such mapping algorithms should leave whites, skin tones and soft colors untouched, but can expand saturated colors to vibrancy levels that can only be generated by the LEDs.

Arranging the RGB LEDs in a two-dimensional array and individually controlling them on a per color basis (2-D color dimming) reduces power dissipation as well as improving color gamut and contrast ratio. This is because the individual backlight segments only need to generate that part of the visible spectrum that will be transmitted by the LCD pixels in front of them – see figure 1. A conventional white backlight generates a visible spectrum with a fixed color white-point, only to have much of its spectrum energy blocked and dissipated as heat in the LCD panel's color filters. Localized color control of backlight output based on picture content can save on average about 80% of power consumption for typical TV picture content.

Despite its benefits, backlight dimming is not without complications. This is because it introduces two different ways of adjusting picture brightness. To achieve a low brightness image, such as a night scene, you can block more of the backlight output using the LCD's pixels or alternatively dim the backlight. Optimum front-of-screen performance in terms of spatial and temporal contrast ratios and color gamut, together with optimized backlight power dissipation, is achieved by compensating a reduction in backlight luminance by gaining the pixel drive signals. Adaptive backlight dimming therefore requires a significant amount of image processing to be performed on the video stream in order to analyze picture content. The acquired information then needs to be intelligently combined with the characteristics of the backlight in order to derive optimum backlight and pixel drive signals.

The challenge is to match the very low spatial resolution of the backlight (typically 10 x 18 segments) with the very high resolution of the LCD panel (up to 1920 x 1080 pixels for a high-definition TV). The situation is further complicated by the existence of optical crosstalk between adjacent backlight segments – the fact that each segment spills some of its light into neighboring segments.

Achieving a balance

The optimum backlight level needs to be determined from a separate statistical analysis of the R, G and B values of the picture pixels so that appropriate drive levels can be determined for the corresponding segment of the backlight. If all the pixel levels are high, they will match to the backlight at the nominal backlight level. When the RGB pixel values are low, the backlight levels are dimmed to minimize light leakage through the panel. At the same time, the RGB gain for the LCD pixels need to be increased to preserve the required picture brightness. Contrast (especially for dark levels) will be improved, but clipping for bright pixels is introduced. Adaptive backlight algorithms therefore need to find an optimal compromise. The red, green and blue gains also need to be adjusted to compensate for mixing of the varying RGB-light levels from the backlight in the LCD panel's color filters.

Interaction between the backlight segments due to optical crosstalk also has a large impact on overall picture performance. This crosstalk limits the effective spatial backlight modulation, and the achievable picture quality improvement is therefore very much dependent on the properties and construction of the backlight.

Another important aspect of crosstalk compensation is the ability to dynamically drive the backlight LEDs above their nominal levels – a process known as adaptive boosting. In this way, a lack of light in one segment due to dimming in neighboring segments can be compensated.

Crosstalk compensation helps to reduce the error between the predicted light level in the center of a segment and the requested light level. As a result, the spatial modulation of the backlight profile is amplified. However, straightforward linear error compensation leads to a lack of light at the borders of bright segments. Asymmetrical compensation can prevent this – see figure 2.

Where the number of LEDs in the backlight is low, the opportunity for backlight boosting is limited. This is because with a small number of LEDs, each LED must be driven close to its maximum level to achieve the required picture brightness. However, as the number of LEDs in the backlight increases, boosting can be used to greater effect, not only to compensate for crosstalk but also to increase the vibrancy of bright picture content. A larger number of LEDs, and consequently smaller backlight segments, will allow the backlight luminance to be modulated over a larger range, providing even more temporal and spatial contrast. On typical picture content, a power reduction beyond 50% can be achieved using dimming and boosting, without introducing visible image artifacts.

A vibrant future

Unfortunately, the higher cost of high-efficiency LEDs compared to conventional CCFL or HCFL lamps currently limits the number of LEDs to a few hundred. However, as LED-based backlighting becomes more mature, these cost differentials are likely to come down. LED backlighting has already become commonplace in mobile devices and is now appearing in notebook computers (due to its better power efficiency). For TV sets, it is likely to be introduced first for screen sizes of 50-inch or above, before working its way down to smaller screen sizes as production costs fall.

To facilitate the introduction and encourage the use of LED-based adaptive backlighting, NXP Semiconductors has implemented all the required algorithms for 2-D white LED dimming, and 2-D RGB LED dimming plus color-gamut mapping, on its PNX5100 LCD TV platform. Located at the back-end of the video pipe, the PNX5100 controls both motion-compensated up-conversion to 120 Hz and 2-D backlight driving using on-chip hardware pixel-based accelerators – see figure 3. Its software-driven backlight control is highly flexible and can be tuned to specific customer requirements and display panels.

Diagrams and figures:

Figure 1

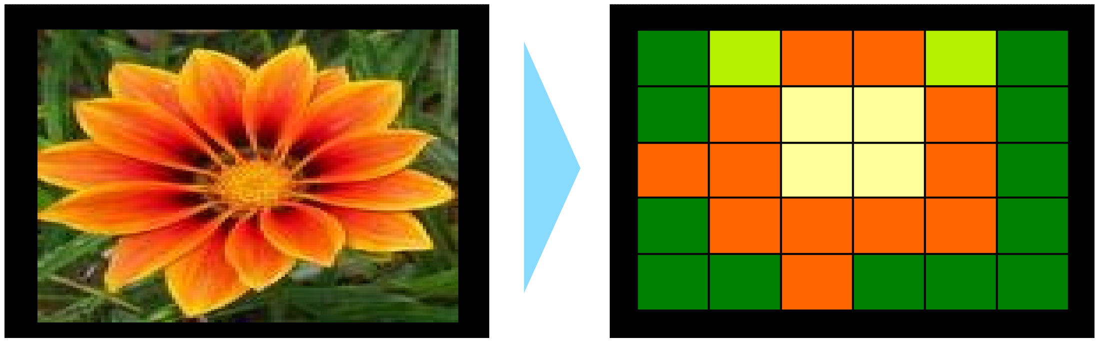

Figure 1 – 2D color dimming

Figure 2

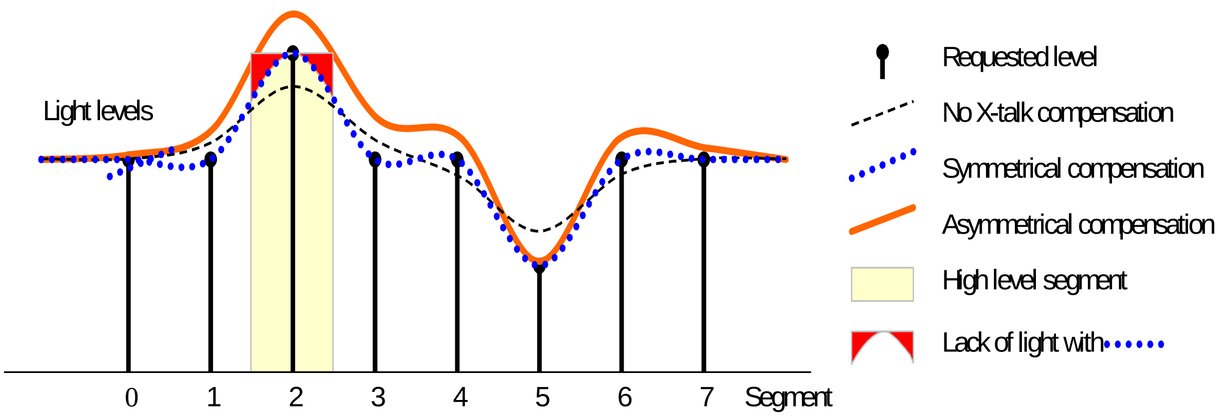

Figure 2 – Symmetrical and asymmetrical crosstalk compensation

Figure 3

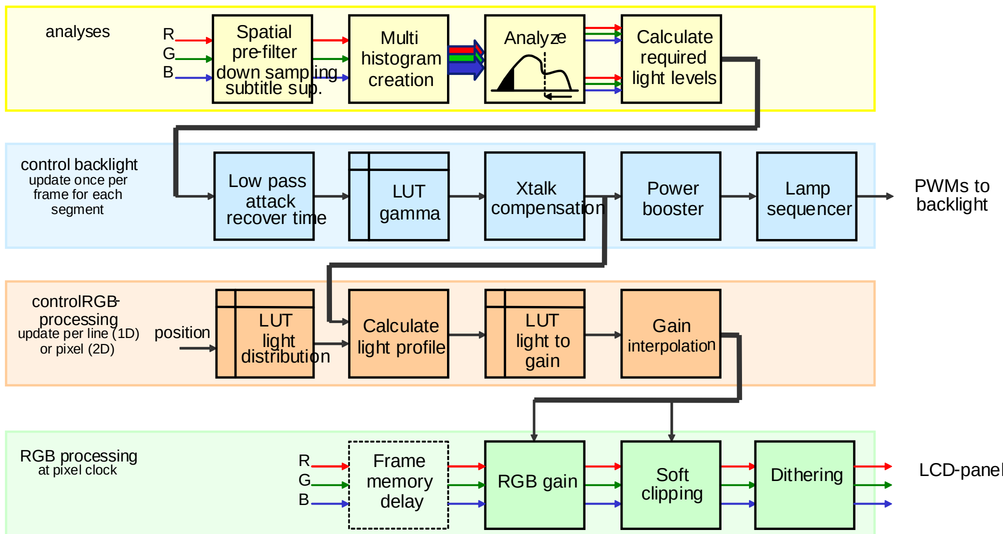

Figure 3 – Adaptive dimming block diagram