Understanding high dynamic range (HDR) displays – enhancing the viewing experience

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These days, we are surrounded by displays all around us – at home, in our cars, at work, at the mall, even in elevators. In many ways, displays have become the primary way that we interact with the world and receive information from it.

During a given day, the average individual spends between six and nine hours staring at a display. With this level of exposure, it's only natural for individuals to put extra emphasis on the quality of their experience with various displays.

The most common way to improve a display is to increase its resolution. 4K TVs and monitors are commonplace today. However, as the race for resolution rages, we will approach a point of diminishing returns. Beyond a certain point, the human eye cannot distinguish the reducing size of pixels on a panel, and the benefit of increasing the resolution begins to plateau. Improving the dynamic contrast range of a display however, brings the user experience to new heights.

SDR displays

A conventional display with a standard dynamic range (SDR) uses a conventional 2.2 gamma electro-optical transfer function (EOTF) curve, as shown in **Figure 1**, typically with 8 bits of color depth. This limits the contrast ratio of the display to roughly 1,200-to-1. In SDR displays, the backlight has no greater function than to simply provide a uniform source of light.

The liquid crystal array is responsible for managing the pixel data, which makes up the color content of the image. Typically, the backlight for the entire display is controlled globally, at one level. This level is defined by building a histogram of the image and analyzing the white point to define the brightness level.

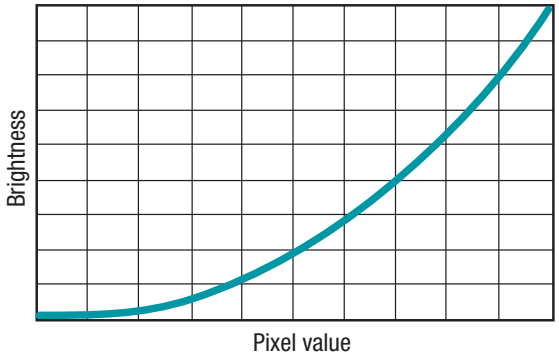

***Figure 1**. 2.2 gamma EOTF.*

The fundamental problem with this scheme is that a brightness level defined by a single white point will cause a contrast washout: the image would be analyzed as a single entity. The whites may be dimmer, while the blacks may lose granularity.

HDR displays

A high dynamic range (HDR) display uses an EOTF curve that is extended on both ends (as shown in **Figure 2**), typically requiring a minimum of 10 bits of color depth. In this scheme, it is fairly easy to obtain contrast ratios well over 200,000-to-1. In HDR displays, the backlight is often divided into smaller zones, controlled individually, called 'local backlight' or 'regional backlight'.

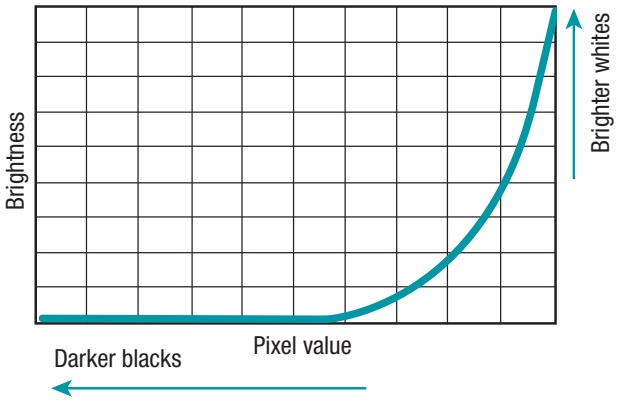

Figure 2. *Extended Society of Motion Picture and Television Engineers (SMPTE) ST2084 EOTF.*

Matching the brightness of these zones to the overlaid pixel data opens up the possibility of creating much brighter white areas and significantly darker black areas. For example, a particular frame that shows an object being lit by the sun on one side and causing a shadow in the other may overemphasize the brightness behind the sun, but a very low brightness level behind the shadow. This will result in a very bright, lifelike representation of the sun, while still preserving the data granularity in the shadows.

HDR display architecture

A standard SDR liquid-crystal display (LCD) subsystem typically consists of some sort of a graphics engine, timing controller (TCON), light-emitting diode (LED) driver, lighting module and the LCD panel itself. From an architectural standpoint, HDR panels are inherently no different than typical SDR panels – they use the same building blocks, but the requirements of the devices in the system are significantly different.

Figure 3 shows a typical HDR display architecture led by the graphics processing unit (GPU). A GPU or system on chip (SoC) on an HDR display is responsible for generating the image content. Since it has intimate knowledge of the content, the SoC must construct a histogram of the content, identify the white point and define a brightness level for the image.

For a locally dimmed panel, the problem is even more complex. For example, if the display is divided into 128 zones, the SoC has to generate 128 histograms, analyze them and define a brightness level for each zone. For a typical display with a 60Hz refresh rate, the SoC has to conduct this analysis 60 times every second. As you can imagine, that is a lot of computation, and requires dedicated high-end engines. Once the SoC has generated the image pixel data and its matching zonal backlight brightness data, it passes this information over to the TCON and backlight driver, respectively.

The TCON receives the pixel data from the image generator and does whatever is necessary to drive the individual pixel components of the LCD array. Its core function is to rearrange the image data, organize it into rows and columns, and send this information to the relevant row and column driver integrated circuits (ICs). A frame buffer embedded into the TCON accounts for the staggering amount of data that has to be processed per screen.

There are some limitations of a GPU-led HDR display architecture. Imagine an application where the image was generated on a different system

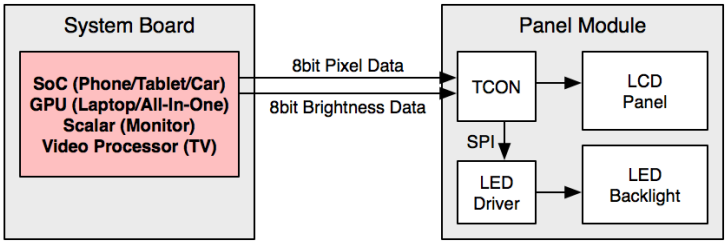

Figure 3. *GPU-led HDR display architecture.*

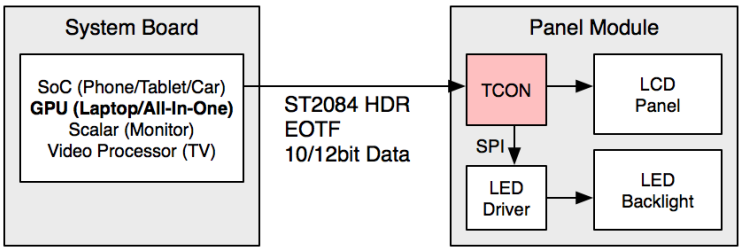

Figure 4. *TCON-led HDR display architecture.*

than the display – like a computer with a remote HDR display. In this case, the monitor manufacturer would want the display to function well with any computer.

You could also design an HDR display so that the SoC or GPU is responsible for providing the pixel data and extended EOTF data to the TCON. The TCON would conduct the computation of histogram analysis followed by brightness definition and provide this information to the follow-on blocks. **Figure 4** represents such a display architecture.

The next building block is the backlight driver. When you look at backlight drivers for locally dimmed HDR displays, the requirements are drastically different than they are for edge-lit displays. But you can group them into three broad categories. **Figure 5** shows a simple comparison between edge-lit and direct-lit backlight driver displays.

In an HDR display, you want to control smaller sections of the backlight individually. Accordingly, an HDR backlight driver has significantly more channels compared to a traditional high-current backlight driver. Since you are controlling multiple zones for the same screen size, the average power level per zone is also significantly lower. Furthermore, since the different channels control adjacent sections of the backlight, the current sinks have to be matched accurately, which requires a very high dimming resolution. 12 to 14 bits of dimming control is typical; it enables better calibration and smoother brightness transitions for a better user experience.

A typical backlight driver takes a single pulse-width modulation (PWM) input signal and controls the brightness of the entire display accordingly. On an HDR display, you are trying to control hundreds (possibly thousands) of brightness levels and

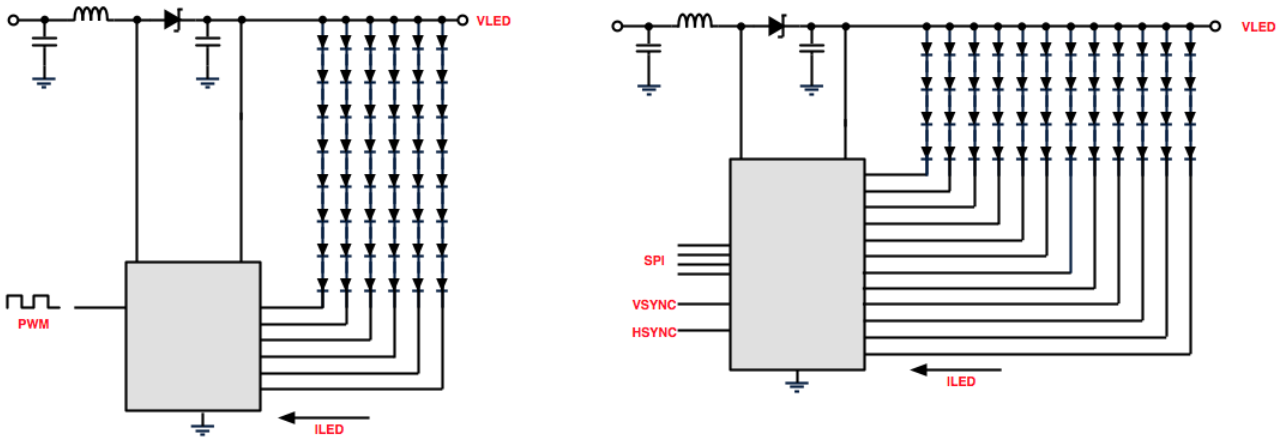

Figure 5. *Edge-lit vs. direct-lit LED backlight drivers.*

refresh them fast enough so that the transitions are seamless to the human eye. As you may imagine, the communication interface has to be significantly faster. Typically, you may see a +10MHz Serial Peripheral Interface (SPI) or similar protocol on an HDR backlight driver.

Previously, I talked about the TCON managing the timing of the row and column drivers so that the pixel data refreshes correctly from image to image, without any visual artifacts. For HDR displays, the goal is to vary the backlight for each zone, as applicable per the image, for each refresh of the screen. In this case, it is very important to ensure that the backlight brightness is updated in synchronization with the pixel data. To manage this, use the HSYNC and VSYNC signals from the TCON as the trigger to push brightness data from the buffer to the LEDs. These signals are usually unnecessary for traditional backlight drivers.

The final building block in the architecture would be the lighting module itself. In traditional displays with a global backlight, the lighting module would consist of a very thin printed circuit board (PCB) strip with LEDs mounted directly on it, a reflector, a series of diffusers stacked up to smoothen out any lighting artifacts, and in some cases light guides. For HDR displays, you would have similar components but set up differently. Instead of a light bar along one of the edges, you have a thin flat mat, in the form factor of the display, with LEDs mounted on it. The spacing of the LEDs would depend on the required zone size. The higher the zone count, the higher the LED count. Since the LEDs in a direct-lit panel are directly behind the liquid crystal array, and the light transmission distance is reduced, you wouldn't typically need a reflector or a stack of diffusers. You may need one or two diffuser films per zone, but mainly to reduce any light bleeding from one zone to another. This makes the mechanical design much easier.

If you'd like to get more tips and tricks for HDR display design, please visit ti.com/display_training.

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