

4.5: Multi-Primary LCD for TV Applications

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Abstract

Multi-primary technology is applied to get wide gamut high efficiency LCD panels, suitable for high quality TV applications. In this paper, we describe four and five primary displays using CCFL backlights, with color gamut between 92% NTSC and 110% NTSC. We will present trade-off analysis, experimental results and comparison to other gamut enhancement technologies.

1. Introduction

Recently, wide color gamut TVs were introduced to the market. Since the invention of color TV nearly 60 years ago, all color information has been based on a unique combination of three primary colors: Red, Green and Blue, known in short as RGB. The historical reason was very simple: all traditional television sets were based on cathode ray tubes (CRTs), and based on the availability of color phosphors and the complexity of the technology, three color primaries were adopted as the building blocks of the color information. However, with the introduction of the current display technologies like LCD, Plasma and Microdisplays, there is an increasing request for wider gamut color TVs.

In the past, we discussed the application of multiprimary technology in projection displays^{1,2,3}. The first company to adopt the Genoa multiprimary technology was Philips in its single panel 5-primary LCoS TV. As of today, several major TV brands offer both front and rear projection TVs employing multiprimary technology.

For LCD TVs, manufacturers are considering several gamut enhancement methodologies. Most of these technologies are backlight related – use of Wide Color Gamut CCFL or LED backlights can increase the gamut^{4,5}. We adopted also for LCD TVs a different approach, similar with the approach we first used in projection TVs - multiprimary technology.

In this paper we will present the adaptation of the multiprimary technology to LCD panels, including both analytical analysis and actual results. The technical discussion will address the physical color gamut, performance trade off (color gamut, number of primaries, brightness, white color temperature), compatibility with LCD technology (color filters, driving electronics), different application possibilities and the ColorPeak signal conversion algorithm. We will then compare the Genoa multiprimary technology with other brightness and color gamut extending technologies.

2. Design and Implementation of Multiprimary Technology

2.1 Color Design Parameters

A multiprimary LCD display will include more than three colored sub-pixels, so that the spectral transmission of the color filter plate

may be significantly different from that of an RGB color filter. The color filters and the backlight have to be optimized for optimal color and brightness. In this paragraph we will describe the basic design considerations.

The spectral intensity of each color primary, P_i , can be described as:

$$P_i = BL * PI * a_i * CF_i$$

Where BL is the spectral intensity of the backlight, PI is the spectral transmission of the LCD panel (including polarizers), a_i is the aperture ratio of the primary P_i and CF_i is the spectral transmission of the relevant color filter. The overall output, B is the sum of all primaries:

$$B = \sum P_i$$

The color points and relative brightness of each primary and the “white” state can be calculated from the spectral distribution of P_i and B.

PI is usually a given parameter for each LCD manufacturer. BL and CF_i can be modified and optimized within certain manufacturability constraints. a_i can be identical or different for each primary, depending on sub-pixels layout.

The color and intensity of the individual primaries is determined mainly by the backlight and color filters spectrum. Presently, different vendors can supply backlight with various spectrums, using so called “normal CCFL” and “wide gamut CCFL” phosphors. Within the available phosphors limitations, it is possible to modify the ratios of the different phosphors during the optimization process.

Regarding color filters, there are two basic requirements, as compared with the conventional RGB filters that are used in the present in the LCD TVs.

For a multiprimary display, new yellow, and cyan filters are required. The yellow filter should be as saturated as possible, so that the resulting yellow color coordinates will be close to the CIE boundary. The cyan color filter should enable significant deviation from the BG connecting line. Also, it is desired to increase the saturation of the RGB colors, and to “fine tune” their color coordinates for optimal gamut coverage. Obviously, the color filters trade off should take into account filter manufacturability and possible influence on display contrast.

In the optimization process, there are several design goals:

(a) Increase color gamut area coverage (% NTSC). The absolute value of the NTSC ratio is not necessarily related to actual image quality, however it is still an industry benchmark and customers may prefer one TV over the other based on the NTSC ratio value.

(b) Increase brightness at the desired white point;

(c) Get good color coverage and color intensity distribution for the best viewing experience. One possible approach is to design the

three dimensional color gamut of the display to as close as possible to cinema gamut.

2.2 Aperture Ratio and Sub-pixels Layout

There are two basic possibilities for the aperture ratio of the sub-pixels: all sub-pixels with the same size, or different sizes for the different colors. Both methodologies can be realized in different sub-pixels layouts. See figure 1 for some examples of possible sub-pixels layout.

Using different sub-pixels sizes may enable easy white point balance; however, from the standpoint of LCD TFT manufacture, identical sub-pixels sizes are definitely preferred. Thus, it is preferred to use identical sub-pixel sizes, and balance white point by further color filters optimization and change of mix of the phosphors in the CCFL backlight.

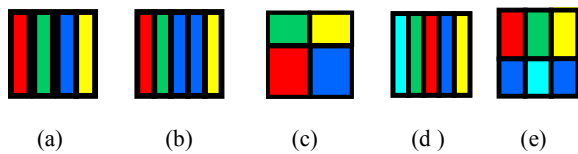


Figure 1. Example of possible sub-pixels layout

In a straightforward configuration, each primary color will occupy one or two sub-pixels for each individual pixel. Thus, since the number sub-pixels will increase, aperture ratio will decrease as compared with the RGB display. This aperture ratio decrease is taken into account in the overall brightness calculation.

In the configurations that were discussed above, each pixel was treated and balanced individually. If the basic size of the pixel is identical to that of a corresponding RGB panel, this approach allows full spatial resolution. However, using this approach it is essential to design new TFT panel with different sub-pixels layout new panel driving electronics.

As an alternative approach with a shorter time to market, we developed an advanced multiprimary scaling algorithm – Pixcale. This algorithm enables realization of the multiprimary technology using the same TFT backplane and drive electronics for a multiprimary panel as for an RGB panel. The color filters are applied to the original sub-pixels, so that the effective pixel size is increased, as illustrated in figure 2. This approach has been demonstrated successfully for both four- and five-primary panels.

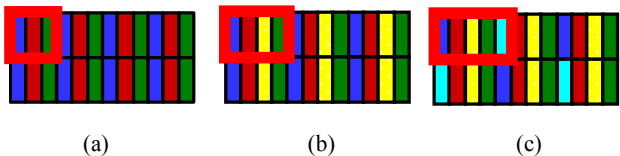


Figure 2. Example of Pixcale multiprimary layout. a- RGB. b- Four primaries, RGBY, "stripes" configuration. c- Five primaries, RGBCY, "staggered" configuration.

Although the real pixel size is increased, the apparent resolution is only marginally affected. Spatial resolution is determined mainly by the bright sub-pixels (in RGB displays mainly the G sub-pixel). In multiprimary displays we have more bright sub-pixels: G, Y and sometimes also C. By an optimized choice of sub-pixels order, an even increased spatial resolution can be obtained. The Pixcale algorithm uses both the intensity and color information of

neighboring sub-pixels to optimally present the image. Although spatial algorithm for most images is preserved, for "pure" RGB colors, there will be some resolution loss, and at close distance this resolution loss is visible. By using a "staggered" sub-pixels pattern, as in figure 2 (c), this visible resolution loss is minimized.

2.3 Color Conversion Algorithm

The color conversion algorithm for projection TVs was discussed in the past¹. We use a basically identical algorithm for the LCD TV application. For a Pixcale type display, we add a dedicated multiprimary spatial scaling algorithm that takes into account the location, color and intensity of each sub-pixel to get a smooth image.

2.4 Electronic Implementation

We developed in the past an MPC (Multi Primary Conversion) ASIC named Keshet^{1,3} that performs the multi primary conversion algorithm. For Pixcale systems, the spatial scaling function have to be added in front of the panel. This can be realized on the panel itself or at the front end of the TV side. The interface between the Pixcale part and the panel is exactly the same as the panel interface in a regular RGB system. The color conversion algorithm and the Pixcale algorithm can be realized both by an additional chip coming right after the Keshet or by a single chip integrating both functionalities.

For full resolution LCD panels we propose the Keshet-LCD as an interim solution. The Keshet-LCD is an evolution of the Keshet chip fitted to the LCD environment. The interfaces, for example, are modified from LVTTTL to LVDS supporting 10bit input per channel and 10 bit per channel output. Like the Keshet, the Keshet-LCD supports 1920x1080 at 60Hz (1080p) resolution.

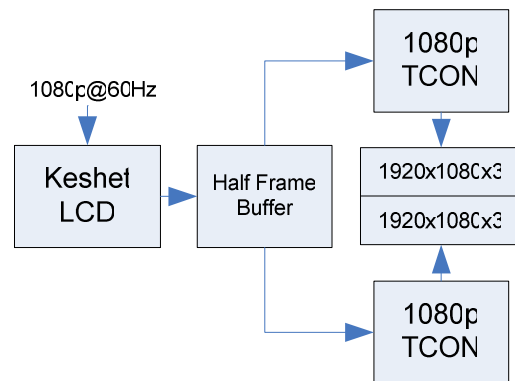


Figure 3. An example of implementation of Keshet-LCD in a 1920x1080 resolution panel. The Keshet-LCD is added to the dual frame rate architecture based on doubling the electronic system and using two TCON chips for the upper and lower half of the panel.

The Keshet-LCD allows panel makers to implement a full HD resolution (1920x1080) full resolution multi primary LCD panel using current electronic architectures. 1920x1080 resolution panels supporting dual frame rate (120Hz) operation can be realized using more column drivers architecture or by doubling the electronic system to support each half of the panel (upper and lower).The Keshet-LCD can fit into both architectures allowing

the realization of a 1920x1080 dual frame rate multi primary panel. Figures 3 and 4 are examples of configurations supporting such panels.

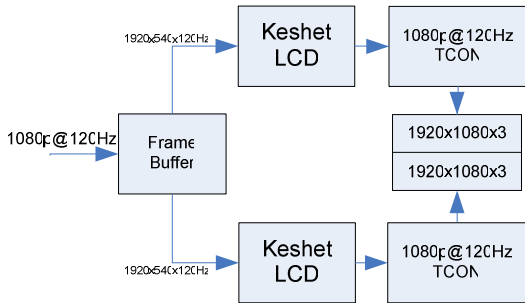


Figure 4. Second example of implementation of Keshet-LCD in a 1920x1080 resolution panel. Video signal entering the system is already at 120Hz.

The Multi Primary Panel Controller (MPPC) chip, as shown in figure 5, is the next step after the Keshet-LCD. This chip embeds the TCON and overdrive functions internally achieving a more cost effective solution.

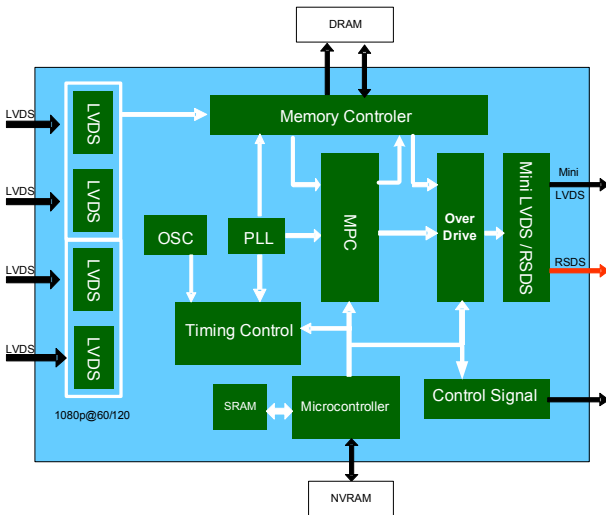


Figure 5. A block diagram of the Multi Primary Panel Controller (MPPC) chip.

A more detailed discussion of the electronic realization of multi primary LCD panels is beyond the scope of this publication and will be discussed in further publications.

3. Results

Genoa is working with several LCD, backlight and color filter companies on the implementation of multi-primary technology in LCD displays. In some cases, a new TFT backplane and sub-pixel arrangement was developed. In other cases, the TFT was not modified, and we used the Pixcale algorithm to accommodate the resolution loss. In this paper we present the performance of three types of 32" panels that were developed by QDI, now part of

AUO. In figure 6, we present the color gamut achieved for three different cases: four primaries (RGBY), "wide color gamut" CCFL, five primaries (RGBCY), "normal color gamut" CCFL and five primaries (RGBCY), "wide color gamut" CCFL. In all cases, we show also the relative brightness, as compared with a reference RGB "conventional" panel, manufactured by the same fab and using the same input power.

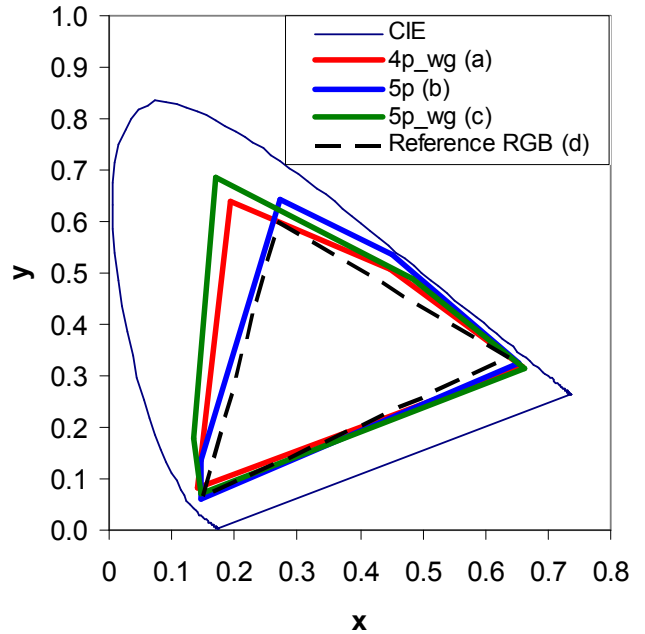


Figure 6. Color gamut of a- four primaries display with wide color gamut CCFL (94% NTSC, 85% relative brightness), b- five primaries display with normal color gamut CCFL (92% NTSC, 115% relative brightness), c- five primaries display with wide color gamut CCFL (110% NTSC, 80% relative brightness), and d- reference RGB display (72% NTSC, 100% relative brightness).

The cost increase caused by multiprimary technology is due mainly to the color filters cost increase. In mass production, the overall cost increase may be in the order of magnitude of 5-10%. With the future ink-jet printing technologies for color filter manufacturing the color filters cost increase will be negligible, so that the overall cost increase of a multiprimary panel over that of a conventional RGB panel will be minimal.

4. Competing Technologies

4.1 General

In the last years, many new technologies emerged to improve the color gamut and brightness of LCD displays⁵. We shall consider here the two leading new technologies: RGB displays with LED backlight, and RGB displays with wide color gamut CCFL backlight.

4.2 RGB Displays with LED Backlight

Changing the backlight from CCFL to LEDs, it is possible to increase color gamut to >100% NTSC. In figure 7 we present the color gamut of a typical LED backlight display, as compared with the color gamut of cinema. LED backlight RGB displays have

excellent color saturation in the red and cyan regions of the gamut. However, the green color extension to the very saturated "metallic green" produces colors that are very far from being natural. Also, as the yellow color is produced by green and red, LED backlights can not reproduce highly saturated bright yellow colors that contribute significantly to image quality. A very careful color processing algorithm is required to get a good appealing image.

LED backlights have some major drawbacks: cost (driven by the cost of the LEDs and the complex driving and feedback electronics) and efficiency. While LED manufacturers are working hard to overcome these drawbacks, there is still very much work to do, and given the trend of very sharp LCD panels cost reduction, LED backlight will probably not become "mainstream" in the next few years.

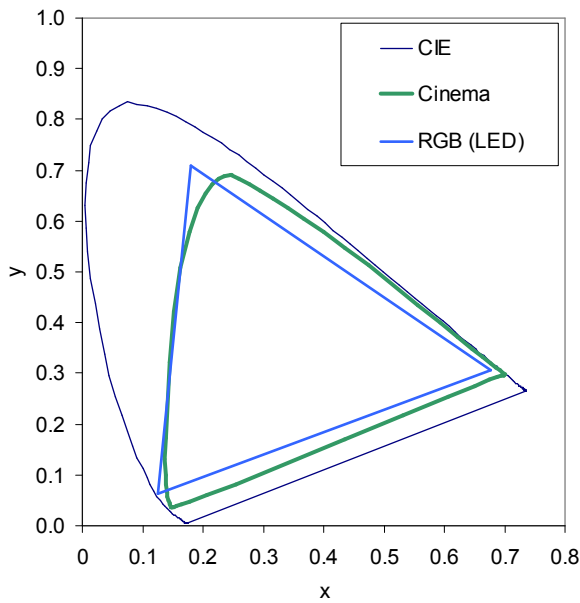


Figure 7. Color gamut of cinema and LED backlight RGB display.

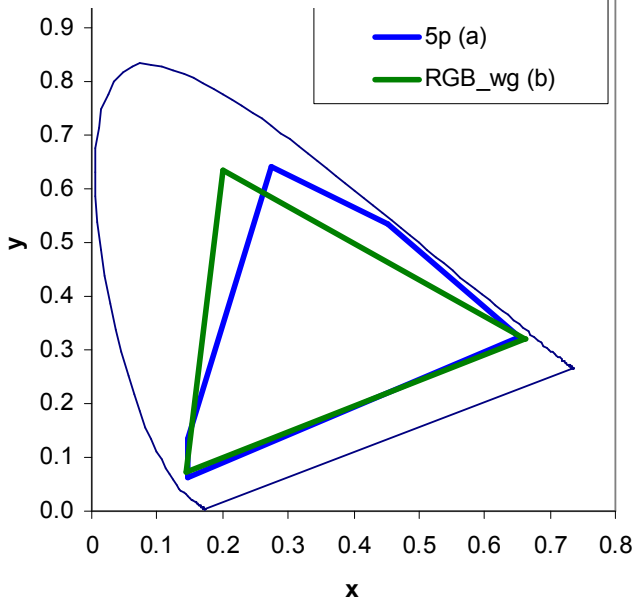


Figure 8. Color gamut of a- five primaries display with normal color gamut CCFL (92% NTSC), and b- wide color gamut CCFL RGB display (90% NTSC)

4.3 Extended Gamut RGB Displays with CCFL Backlight

By using special phosphor (wide color gamut) CCFL backlights, it is possible to get RGB wide color gamut displays. For an example of the measured color gamut of a commercial TV using wide gamut CCFL as compared with the 5 primaries "normal CCFL backlight" display – see figure 8. We can observe that while the NTSC ratio value of both displays is similar (~90% NTSC), the multiprimary display has significantly better and balanced coverage of the color gamut, especially in the very important yellow region.

In addition, while the multiprimary display has a ~15% brightness increase over a reference normal CCFL RGB display, the wide color gamut CCFL RGB display has a reduced brightness by ~20%, so that the multiprimary display offers a ~40% efficiency increase over that of wide color gamut CCFL RGB display with the same NTSC ratio. This brightness efficiency increase may allow the elimination of the high cost DBEF film that is used to enhance brightness, so that the overall cost impact of the multiprimary technology is minimized.

5. Acknowledgements

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6. References

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