DISPLAY TECHNOLOGIES & **MULTI-PRIMARY SYSTEMS**

The ultimate goal of any display system is to produce images that approach real life, combining high dynamic range, high contrast, and a gamut of colors as close to possible to those we can see. Yet for decades, electronic displays have fallen short of that goal, limited by tristimulus designs that rely on red, green, and blue primaries to achieve color shading.

While the volume of reproducible colors using RGB color mixing has increased significantly over the past two decades, there are still billions of color shades that cannot be reproduced accurately as they fall outside the color gamut “triangles” that are characteristic of current displays. We can enlarge those triangles by increasing the luminance and saturation of each primary color, but still leave out color shades that lie outside the triangle.

Any display’s color gamut can be increased by adding any or all of three additional primary colors – cyan, magenta, and yellow. In this case, adding cyan changes the color gamut triangle to a more rectangular shape, increasing coverage of the 1931 and 1976 CIE visible color spaces and bringing us closer to photorealism. Adding yellow and magenta would cover even more of the CIE color spaces, although not to the degree offered by adding a cyan primary.

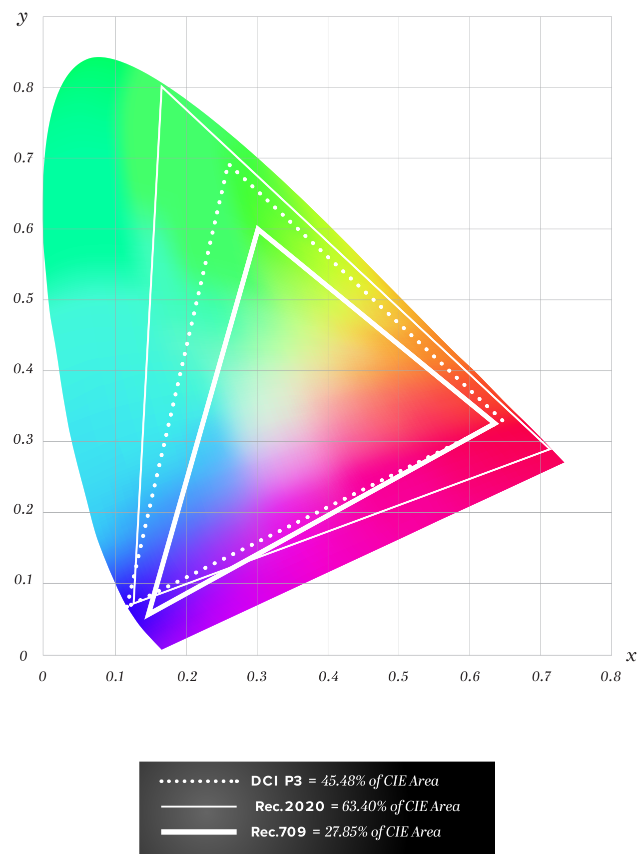

ILLUSTRATION 1: SAMPLE OF EXISTING COLOR GAMUTS

Suggesting the use of additional color primaries to expand the gamut of colors in a display is a simple matter. Implementing it, however, is a vastly different exercise. There are significant design, manufacturing, and cost obstacles to overcome along the way, and some display architectures cannot be easily adapted to add even one primary color.

Which displays are best suited to this task? Let’s take a look at current display offerings to see which direct-view and projection displays can be adapted to a four-primary color imaging process.

Expanding the Triangle with Projection Displays

For **projection displays**, full-color imaging is usually accomplished with individual red, green, and blue imaging chips aligned in precise registration on a combining prism. Expanding a projection display's color gamut requires a fourth imaging chip with a cyan color filter (RGBC) and a redesign of the combining prism. This concept isn't new, as an RGBY high-brightness 4LCD projector was shown by Sanyo in 2008, using an additional yellow imaging chip to maintain color saturation at high brightness (7000 lumens).

This approach can be applied to both LCD projectors (using small high-temperature polysilicon imaging chips) and Digital Light Processing™ (DLP) projectors using digital micromirror devices (DMDs). As before, the greatest increase in color volume results from adding a cyan imaging chip to the existing RGB array. This concept has been demonstrated by 6P Color using two DLP projectors in precise registration. The first projector provides conventional RGB color imaging, while the second projector adds cyan. (Cyan is filtered out from the RGB projector to maintain white balance.)

Expanding The Triangle With LCD Displays

Liquid crystal displays (LCDs) have become the dominant direct-view display type over the past fifteen years, finding use in everything from consumer televisions and computer monitors to digital signs, command and control and process control displays, and medical and scientific imaging. Substantial investments in LCD panel manufacturing, combined with ever-larger LCD fabrication lines ("fabs") and enhancements to color filters and backlights, have resulted in impressive performance at ever-lower prices. But that's also led to intense competition among display manufacturers.

One way to make RGBC DLP projector is to use the existing blue element and multi-flex time for the cyan.

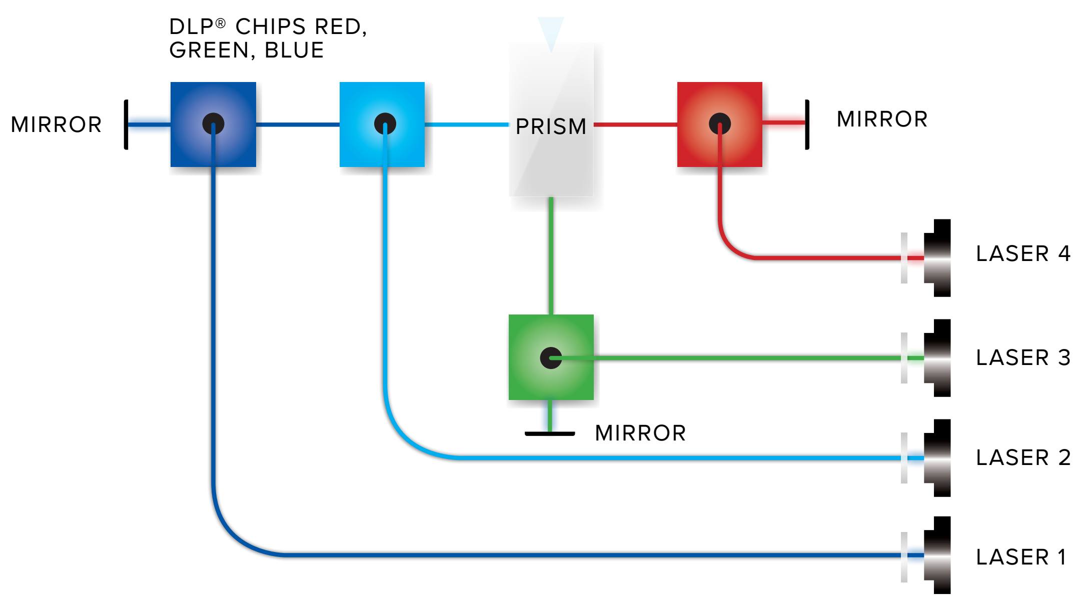

ILLUSTRATION 2: ILLUSTRATION 2 RGB LASER LIGHT PATH, 3X DLP

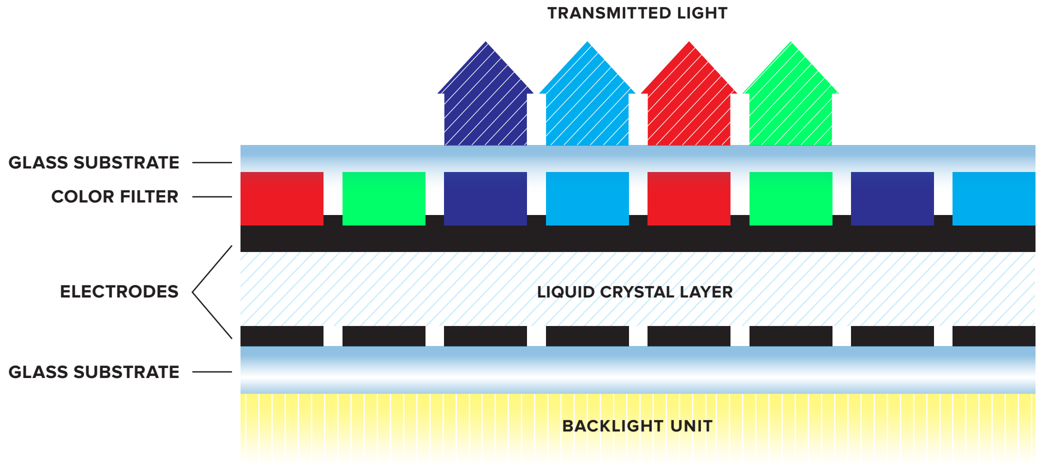

ILLUSTRATION 3 - TYPICAL LCD DISPLAY

In fact, LCD panels with resolutions as high as 3840x2160 pixels (UltraHD) are largely commodities now, leading some television manufacturers to exit the panel manufacturing business due to low or no profit margins and instead shop for panels on the open market. (The majority of LCD panels now come from fabs in China and Taiwan.) Given the highly competitive and price-sensitive LCD television business, manufacturers are understandably reluctant to make additional investments in LCD imaging technology.

Yet LCD panels are a perfect candidate for adding a fourth primary color. They employ high-intensity backlights in combination with color filters or with high-luminance inorganic color materials (quantum dots) to achieve a large color gamut triangle. Presently, only LCD panels using light-emitting diode (LED) backlights with color filters can add a cyan pixel to each red, green, and blue (RGB) pixel to result in a substantially larger gamut of displayed colors. Additionally, the x,y coordinates for the green locus could then be shifted to capture more shades of yellow.

The primary obstacle here is cost. Filter patterning designs would need to be changed to accommodate the cyan pixels, which would add to the cost of manufacturing – a major consideration in today's profit- challenged marketplace for wholesale LCD panels. Technically speaking, adding a cyan pixel is not a problem. Multi-primary LCD displays have been mass produced in the past; most recently, Sharp's Quattron LCD televisions used an RGBY color stripe to achieve a slightly larger color gamut.

Expanding The Triangle With Oled Displays

Organic light-emitting diode (OLED) displays have gained significant traction in recent years. OLED displays are manufactured using two different processes. The first process uses separate red, green, and blue (RGB) emitters, and display panels made this way are limited to use in small consumer displays (smartphones and tablets) along with desktop monitors used for critical evaluation of color images, such as grading monitors for film and television post-production.

The second process employs arrays of white OLED emitters (WOLED) in combination with red, green, and blue color filter stripes (RGBW). The white pixel is added to boost overall luminance. WOLEDs scale economically to larger display sizes, finding their way into televisions, computer monitors, and digital signage. Although their peak luminance does not equal that of LCDs equipped with quantum dots, they are still sufficiently bright for indoor and controlled lighting environments.

Both OLED types have a significant advantage over LCDs in viewing angles (much wider) and black levels (deeper). OLED displays also have fewer layers than LCDs, enabling the manufacture of flexible displays. While OLED panels carry a premium over LCD panels on the wholesale market, manufacturing efficiencies have substantially reduced the cost of finished displays in recent years, resulting in greater adoption of the technology.

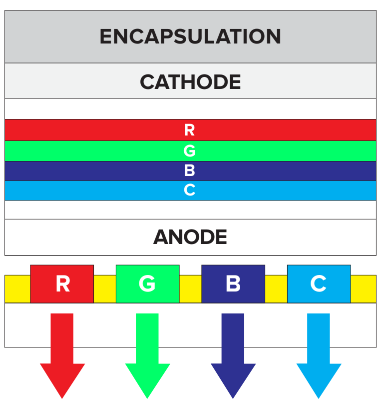

ILLUSTRATION 4: C-OLED TANDEM (MULTI-LAYER)

At the present time, no one has developed a cyan OLED compound. Given the substantial financial investment required, that's not likely to happen with RGB OLED displays. However, the color strip design used in WOLED panels can be easily adapted to add cyan to each pixel. The color coordinates for the green pixel can then be shifted to capture more shades of yellow. But altering the color filter stripe this way would sacrifice some luminance to gain a wider color gamut.

A new display that combines a blue OLED emitter with red and green quantum dots was recently introduced. The **QD-OLED display** has a very simple display stack with four layers, presumably minimizing manufacturing costs. Blue light from the OLED emitter is used to stimulate high-intensity red and green emission and mixes with those colors to once again create a triangular color gamut, albeit one with a larger volume than can be achieved with LCD panels using color filters, WOLEDs, and RGB OLEDs.

While the peak luminance of a QD-OLED display approaches that of a quantum dot-equipped LCD, the current design architecture would not permit adding a cyan color element. And as stated earlier, no one manufactures cyan OLED materials. As for quantum dot color conversion, a cyan quantum dot does not exist, nor would it be very efficient if it did. Cyan and blue are too close in the color spectrum, so if a cyan QD were to be developed, it would require an ultraviolet light source to achieve any conversion efficiency. And presently, UV light is not suitable for displays as it is hazardous to human eyesight.

Expanding The Triangle With iLED Displays

Another direct-view display technology holds great promise and could eventually replace all existing DV displays. **Inorganic LEDs (iLEDs)** manufactured in small sizes (miniLED and microLED) offer wide viewing angles, high dynamic range, deep blacks, and peak luminance levels exceeding 1,500 candelas per square meter (cd/m2). iLED displays use discrete red, green, and blue LED emitters, creating yet another triangular gamut of colors. The combination of high luminance and color saturation offered by iLEDs exceeds that of all other display systems, save for laser-based displays.

Advances in iLED manufacturing have brought their cost down considerably in the past five years. Pixel pitches have dropped as low as .8mm, creating very large displays (> 89 inches) for eventual use in the home. And iLEDs do not exhibit differential aging between colors over time, a problem that has never been overcome with RGB OLEDs and WOLEDs. The latter technology uses a combination of blue and yellow emitters to produce white light, but the blue compound can still age faster than the yellow compound.

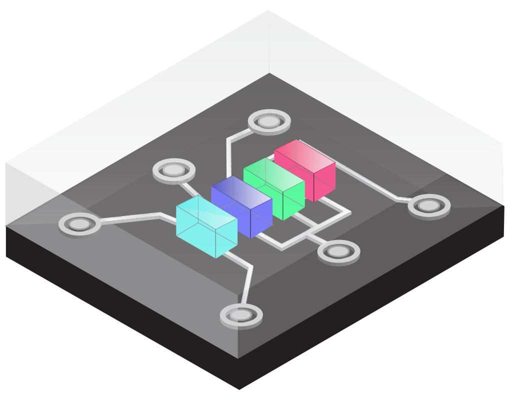

ILLUSTRATION 5: RGB AND CYAN DVLED

Implementing an RGBC pixel stripe for an iLED display requires only that a cyan LED be added to existing red, green, and blue iLEDs. 6P Color has developed and tested such an LED chip, and their prototype iLED videowall has subsequently been demonstrated with a noticeable increase in color accuracy, adding roughly 20% in color volume by using brightness ratios of 29% red, 42% green, 5% blue, and 24% cyan.

ILLUSTRATION 1.4A: RGBC DVLED

Conclusion

Multi-primary color imaging to expand the conventional RGB display color triangle is possible and practical with certain display architectures. Some displays would require minimal modifications to achieve it, while others would require major redesigns. The overriding question is the financial investment required for each type of display. In the current economic climate of little or no profit in display panel manufacturing, there would have to be some certainty for a return on investment (ROI) before proceeding.

Strong display candidates for four-primary (RGBC) color imaging include LCD and DLP projectors, LCD panels with LED backlights and color filters, WOLEDs, and iLED displays. All of these architectures can support a fourth primary with some modification by adding color filters or LED chips. In contrast, RGB OLED panels, QD-OLED displays, and LCD panels that use quantum dots in conjunction with blue LED backlights are not suitable for four-primary imaging as they would present significant technical obstacles to overcome, requiring major redesigns.

