# What is Color Gamut?

## How do we see color and why it matters for your PID options?

One of the buzzwords at CES 2017 was “broader color gamut”. In this whitepaper, our experts unwrap this term to help you understand color and its relationship with displays.

This ‘back to basics’ piece will cover the topics of how color is perceived by the human eye, definition of color gamut, and color generation in display solutions. We hope that this material will help you connect the dots and appreciate the progress that innovative display manufacturers are making in the area of color expression and image quality.

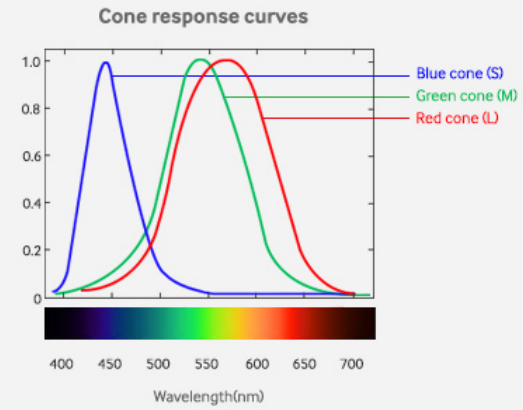
Fascinated by industry developments in the area of color space? Check out the second part of this series, which covers specifics of quantum dot technology and how it functions in displays.

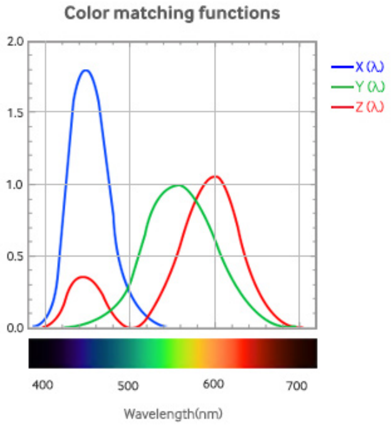
## Color and the human eye - what is color and how do we see it?

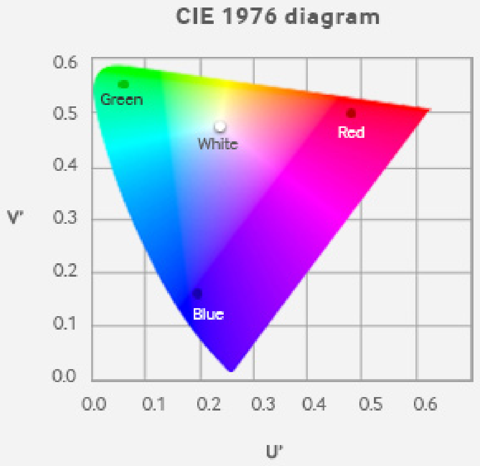
**Color** is a visual perception detected by our eye through interpretation of the light information by our brain. When the light hits an object, the latter absorbs a portion of the light and reflects the rest. Light wavelengths that are absorbed or reflected depend on the object’s properties. As the light bounces back off the object, it hits the light-sensitive retina at the back of the eye. The retina has millions of specialized pigmented cells called **cones**, which in humans come with three different spectra sensitivities – short, medium, and long. The cones are responsible for our **trichromatic color vision**.

The human eye can detect visible light with wavelength ranging from about 380 nm to 780 nm. In a nutshell, each type of cone is specializing on a particular wavelength. Red hues have longer wavelength, green – medium, and blue – short. So as the light reflected off the object hits the cones, it stimulates them to varying degrees. The resulting signal is then transmitted through the optic nerve to the visual cortex of the brain, which is responsible for color interpretation.

All colors are created as a combination of red, green, and blue hues. As the mixed color passes through the human eye, a number of wavelengths in the composition stimulates respective type of cones, which in turn initiate the optic network for recognition and interpretation. Many different combinations of light wavelengths can produce the same perception of color.

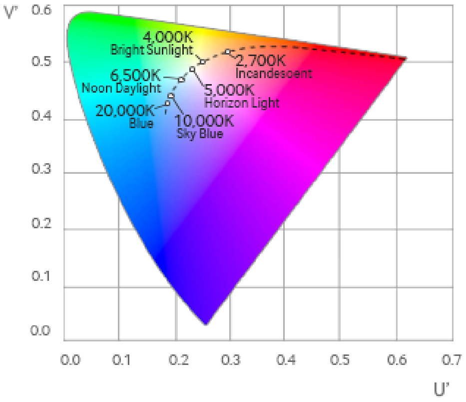

Cone response curves


Color matching functions

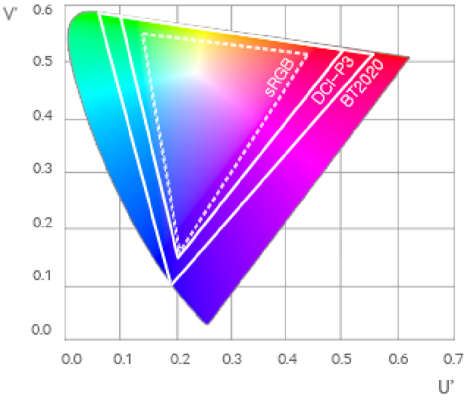

CIE 1976 diagram

Light intensity is another important characteristic that affects how we perceive color. Color temperature is an expression of relative intensities of the various wavelengths that make up light. Color temperature is expressed in units of Kelvin (K) – and lower temperatures mean redder light, while higher temperatures produce bluer light. In this case, color is expressed as temperature because objects will radiate different light frequencies when heated to high temperature.

CIE chromaticity diagram



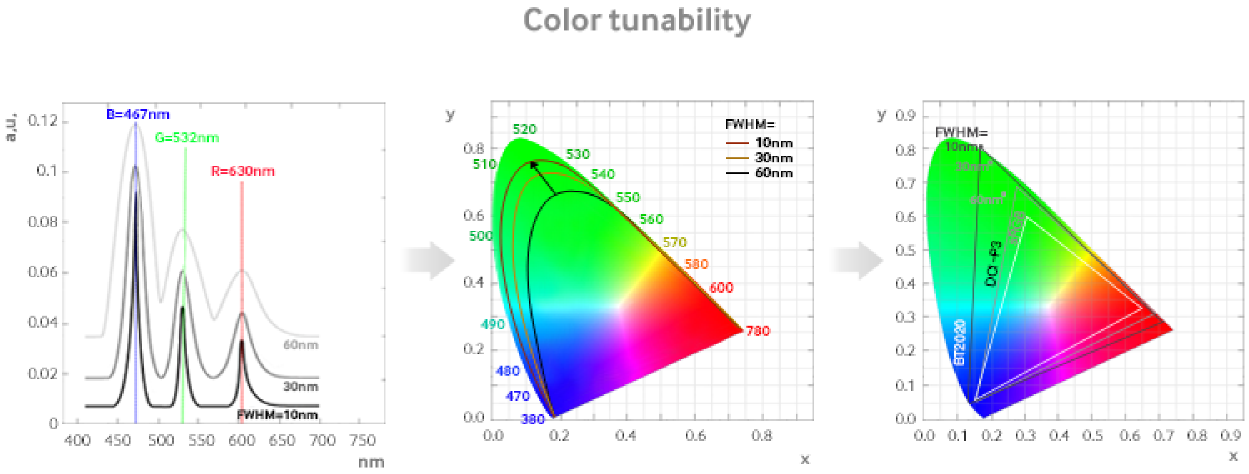
(CCT : IT 6, 500K / TV 10,000K)



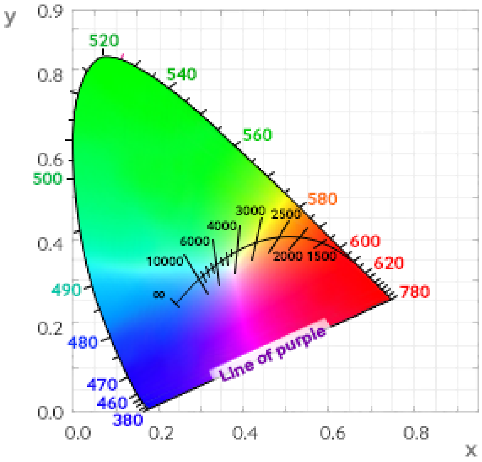
(Color Gamut Trend : sRGB → DCI-P3 → BT2020)

## Color space – how do we measure the color?

In the display world, there are a number of standards for mapping color, with CIE 1976 [1] being recommended as an authoritative display measurement standard by Society for Information Displays (SID). Chromaticity diagrams are a preferred way to map a color space as they only measure color quality, isolating other factors such as luminance. A color space is defined as uniform representation of visible light perceived by human eye. It maps all of the colors to a grid, assigning them measurable values of spectral absorbance, allowing for comparison between colors and description of color gamut standards.



A CIE chromaticity diagram maps the spectral distribution of light by brightness parameter and two chromaticity coordinates representing hue and saturation. All hues visible to an average person are contained inside the 'horseshoe' diagram. The edge of the 'horseshoe' – the **spectral locus** – represents the maximum saturation for the spectral colors that are measured by the light's wavelength in nanometers. **Line of purples** is the straight line connecting both ends of the spectral locus and it represents fully saturated colors that are combination of violet (360nm) and red (780nm). Desaturated colors are located in the center, emanating from the white. The curved line in the white region of the diagram shows absolute color temperatures in Kelvins.



The CIE diagram presented above is a visualization of the set of colors achieved using additive color mixing. When additive trichromatic system is used, a new color can be created by mixing a light of different wavelengths and varying brightness. This diagram represents the complete subset of colors visible to a normal human eye. To describe a range of colors available on a devise though, the industry uses the notion of color gamut.

**Color gamut** is a measure of the range of colors that a display can produce. While the gamut of the normal human vision covers the entire CIE diagram, achieving it via display technology is only possible in theory. Hence, color standards are represented as a triangle within the diagram defining the subset of colors that can be achieved by combining colors at its corners. In recent years, display color space standards have been continuously evolving with color gamut becoming progressively larger.

## Color gamut standards evolution

Understanding color gamut coverage is crucial for evaluating display technology and its ability to generate true-to-life colors. The majority of display devices use the RGB color model to define the color of every pixel. The chromaticity diagram above illustrates that using these three primaries we can cover most of the color space.

### RGB and sRGB

RGB standard, referred to as ITU-R Recommendation BT 709 or Rec 709 [2], was approved in 1990. RGB only covers 33.2% of the chromaticities of the CIE 1976 u’v’ diagram. sRGB standard was created in 1996 and uses the same primaries and white point as Rec 709. This is the most common color gamut used for consumer electronics products. This color gamut is still quite narrow and only covers **38.7% of the CIE 1976** u’v’ chromaticities.

### DCI-P3

The DCI-P3 [3] color space released in 2007 uses the same blue primary as the Rec 709 and sRGB color spaces, but it employs different green and red primaries. The red primary of DCI-P3 is monochromatic 615 nm and green primary is a slightly more yellowish hue of green, but more saturated. DCI-P3 is 26% larger than sRGB gamut and it covers **41.7% of CIE 1976** chromaticity diagram.

### BT 2020

ITU-R Recommendation BT 2020, or Rec 2020 for short, establishes the widest display color gamut, requiring monochromatic RGB primaries (467 nm, 532 nm, and 630 nm). This color gamut is extremely wide – it is 72% larger than sRGB and 37% larger than DCI-P3. The resulting color space **covers 57.2% of CIE 1976** chromaticity diagram.

Rec 2020 colorimetry adoption continues to grow, however, compliance needs more clear definition as 100% of this color space is not physically achievable. At this point, only few displays have come close to providing Rec 2020 color space.

In LCD panels, only quantum dot (QD) technology offers tunable primaries making optimizing for BT 2020 color gamut possible. The unique properties of quantum dots enable us to generate spectrally narrow primaries with full width at half maximum (FWHM) [4] of 30-54 nm based on quantum dots type, resulting in the widest color gamut coverage possible.

*As we discussed how color is perceived and measured, let's move forward to explore how displays generate color.*

## Color and LCD solutions

Wide color gamut yields most true-to-life image quality and most vibrant colors. Let's discover how LCDs function and where the industry is headed in terms of color reproduction.

### LCD color generation principles

Traditional LCD displays have a backlight system comprised of a number of **light emitting diodes** (LEDs). These LEDs are blue but they are covered in green and red phosphor to create a white light. Phosphor is also used to change and control the color temperature of the LED by altering phosphor concentration.

As the light is shone from the LED through a polarizing filter, it hits **liquid crystals** (LCs) that either block the light or let it pass through the layer of red, green, and blue **color filters** (CF). These are called **subpixels**.  Because red, green, and blue can be mixed to create any color, each color pixel formed by the three subpixels creates distinct colors that then form an image. Through control and variation of the voltage applied, the intensity of each subpixel can be adjusted to make it brighter or dimmer and hence determine what color is produced on the display. Millions of colors can be generated by different combinations of sub-pixels.

This mechanism along with white LEDs is simple and inexpensive – that is why it is widely employed in the display industry in products ranging from commercial displays to TVs, monitors, notebooks, tablets, and smartphones.

If you want to learn how LCDs are built, explore our blog on LCD manufacturing process to see how these color generation principles are realized though the hardware.

## The future of color expression

To achieve wider color space, display manufacturers are coming up with a number of solutions that enhance LCD performance. One of the most promising and realistic technologies that allow us to get closer to BT 2020 coverage requirements is **quantum dot displays**.

Underlying principles of how QD-enabled LCDs function are similar to those with traditional configuration. The main difference is that QD displays use blue LEDs instead of white light, which in addition to shining through to the subpixels also illuminate quantum dots that have been tuned to give off red and green light.  Because QD colors are so pure, they can shine RGB colors with less wasted light making for more colorful picture.

There are various types of QD display designs, which we are covering in the second part of this series on color. Read on to learn more about the quantum dot technology, QD display types, and the future of color expression.

**References:**

[1] CIE (International Commission on Illumination) defined the original CIE standard in 1931. In its 1976 revision the standard adopted a more linear color space, minimizing variations in perceived color and making color comparisons more accurate.

[2] ITU-R Recommendations constitute a set of international technical standards developed by the Radiocommunication Sector (formerly CCIR) of the International Telecommunication Union (ITU).

[3] DCI stands for Digital Cinema Initiatives, LLC – which is a joint venture consisting of the major motion picture studios.

[4] Full width at half maximum (FWHM) is the method of specifying spectral width calculated as a difference between points on the spectrum curve at which the function reaches half its maximum value.

**Key terms glossary:**

- **Color** is a visual perception detected by our eye through interpretation of the light information by our brain.
- **Human eye wavelength sensitivity**: human eye can detect visible light with wavelength ranging from about 380nm to 780nm.
- **Color temperature** is an expression of relative intensities of the various wavelengths that make up light.
- **Color space** is defined as uniform representation of visible light perceived by human eye.
- **Color gamut** is a measure of the range of colors that a display can produce.
- **Spectral locus** – represents the maximum saturation for the spectral colors that are measured by the light’s wavelength in nanometers.
- **Line of purples** is the straight line connecting both ends of the spectral locus and it represents fully saturated colors that are combination of violet (360nm) and red (780nm).