VARI*LITE

WHITE PAPER

LED SPECTRUMS AND SMARTCOLOR CONTROL

Lighting is continuing to evolve, and as it evolves, we have more options to create lighting effects than ever. It was not that long ago that we used different types of lamps to create the desired lighting environment and lighting effects. Now, we have even more possibilities with the addition of more LED color options. Using the combination of multicolor LEDs and a unique manner of control, we can easily create more colors today than ever before.

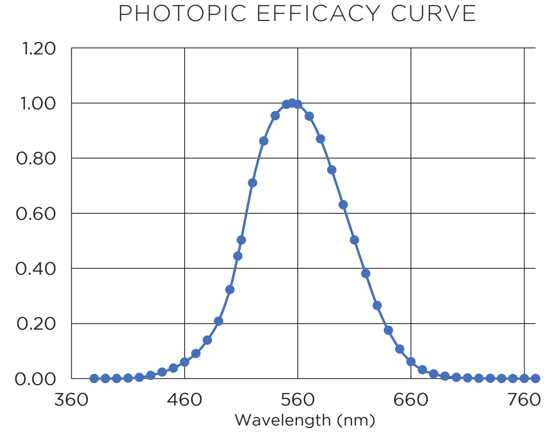

FIGURE 1. EYE SENSITIVITY CURVE ACCORDING TO CIE

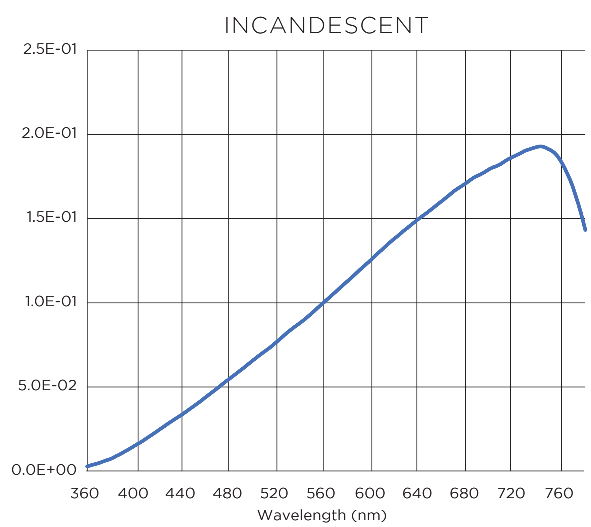

FIGURE 2. INCANDESCENT FIXTURE SPECTRUMS

LIGHTING SPECTRUM BACKGROUND

While there are many ways to explain the different types of lighting sources and measuring colors, for this discussion we will use the color spectrum and the different wavelengths of color. Visible light falls into the electromagnetic range of wavelengths from about 300 nm (violet) to around 800 nm (red). When scientists want to chart color spectrums, they typically use a graph that compares relative irradiated energy versus the wavelength of light. Scientists have studied the human eye and perceived brightness of colors and found that the human eye can see great levels of detail in shades of greens, yellows, and oranges colors, and less details in shades of reds, blues and violets. Referring to **FIGURE 1**, we can note the human eye is sensitive to 420 to 720 nm range of wavelengths, with higher sensitivity to the middle range of wavelengths that include the greens, yellows, and oranges. Many of the calculation we use for light energy, such as lumens and other characteristics, are all based on the sensitivity curve. The overall perceived color is based on the combined wavelengths, and overall brightness is based on the height and width of the overall curve.

On traditional fixtures, light is produced using a lamp (bulb), and lighting designers use color gels, filters, and graduated cyan, magenta, and yellow (CMY) mixing filters to produce different color effects. The gels and filters are placed in front of the light beam and filter out certain spectrums from the light beam, which is why this approach is called subtractive color mixing. Understandably, this results in lower output of light, or brightness, depending on the color, as frequencies are subtracted from the beam.

The tungsten lamp used in traditional stage lighting produces a warm glow that has deep reds and yellows. To demonstrate this, we can refer to **FIGURE 2**, which shows the spectrums of an example incandescent bulb fixture producing a warm (2700K) white beam. The tungsten lamp produces a spectrum that is deep in red and yellow wavelengths, but lacks depth in the blue wavelengths. You can also see that there is also excessive infrared energy generated in the longer wavelengths (> 720 nm) that we do not see but experience as heat. Generating light wavelengths that are not visible wastes energy and makes the fixture less efficient. To address the need for deeper blue colors, popular moving head fixtures in the entertainment industry included arc lamps in addition to tungsten lamps. Arc lamps produce deeper blues but lack some of the orange and red. The combination of the two lamp types could produce a wide variety of colors, and luminaire manufacturers would often add a CTO or CTB mixing flag to help with mixing these colors.

LED TECHNOLOGY

Just over a decade ago, LED technology was introduced to lighting, and many fixtures today use a white LED module with subtractive color mixing. To further illustrate subtractive color mixing, refer to **FIGURE 3**.

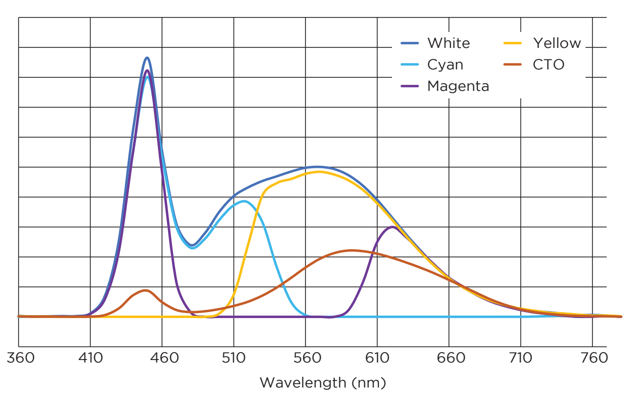

FIGURE 3. WHITE LED FIXTURE WITH FILTERS

The white LED is shown as the overall curve. When the cyan, magenta, or yellow filters are in the beam, the resulting curve has a portion of the curve removed based on the respective wavelengths. Each filter blocks roughly a third of the wavelengths, so if all three are in the beam, then the resulting light beam will be very dim. When the CTO filter is in the beam, the resulting light is filtered gradually to block more of the lower wavelengths, so the resulting beam resembles the mix between the original white source and the incandescent curve shown in **FIGURE 2**.

Over the past few years, many of the LED fixtures started using multiple color LED chips to produce colors using additive color mixing. With additive color mixing, each LED generates a different color spectrum of light, and mixing the colors together involves adding the color spectrum of that LED to the overall output of the light, usually red, green, and blue LEDs. This often results in a color mixed light beam that is higher in output, or brighter, than a color mixed light beam from a comparable traditional lamp using subtractive mixing.

When using different colors together to mix to a new color, the additive color mixing nature of color LEDs is very similar to the subtractive color mixing using the CMY filters. For instance, when using subtractive color mixing to make blue, we would combine cyan and magenta to mix a blue tone. Likewise, when using additive colors, we would combine red and blue to mix a magenta tone. Refer to **FIGURE 4** to see an illustration of the spectrums produced by these different LED colors.

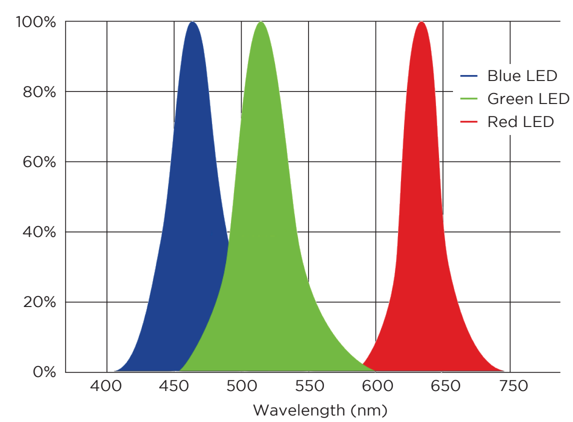

FIGURE 4. ILLUSTRATION OF RGB LEDS[1]

The human eye can infer and integrate the energy to see the yellows, oranges and other colors that emerge between the other wavelengths. When mixing LED colors, the eye must interpret the colors, and we often refer to the CIE 1931 chart to see the color coordinates mixed by the different LED colors. Refer to **FIGURE 5**, where the colors produced by the RGB LEDs are converted to x, y coordinates on this chart. The triangle shown on the chart represents the mix colors possible from the three colors.

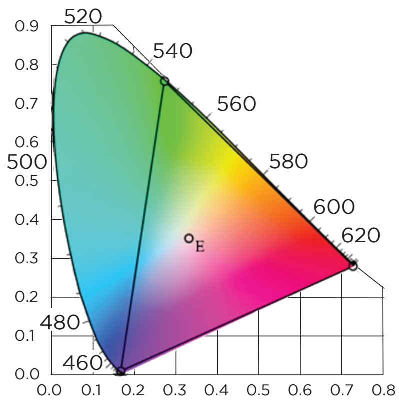

FIGURE 5. CIE 1931 COLOR SPACE

The colors within the triangle are all possible with the three colors of LEDs. The challenge is producing a quality white light for general illumination with mixing with just 3 colors due to the lack of wavelengths in the middle range of frequencies. So, many LED manufacturers offer RGBW LED modules that contain a white LED as well, so they are 4-in-1 modules. A white LED creates white light by using a blue LED with a phosphor coating that converts the blue light to white. The color temperature of the white light depends on the amount and type of phosphor use. **FIGURE 6** shows the output spectrums of the white LED. Please note the wide range of energy in the green, yellow, and orange wavelengths where the eye is most sensitive. This produces a good quality white light at one particular color temperature.

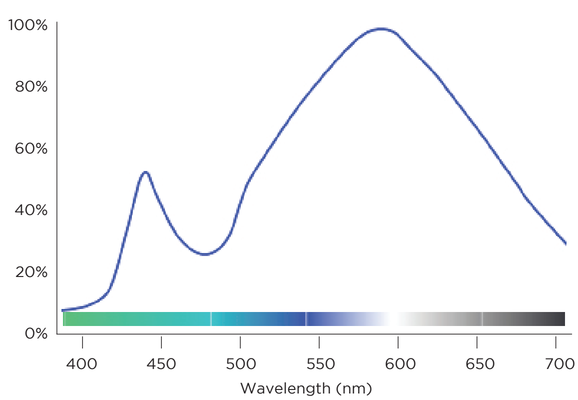

FIGURE 6. SPECTRUMS OF TYPICAL WHITE PHOSPHOR LED[2]

The challenge comes when you want to reproduce other color temperature white light. White light is often referenced by the color temperature and the color rendering index. The color temperature is based on the "black body" curve, which range from warm white to cool white and are given in K Kelvin. The Color Rendering Index is one of many methods used to describe the quality of the white light, pertaining to how objects appear illuminated in this light versus how they appear in sunlight. The higher the CRI, the closer the light will appear like the sun, at least in theory.

When mixing LED colors with more than a few LEDs, we look at the amount of energy produced by each LED with respect to the sensitivity of the eye in **FIGURE 1**. So, the greens contribute more to the perceived brightness than the blue and red. As an example, in **FIGURE 7** we can look at the data from an RGBW fixture set at the recommended RGBW settings to product a warm white at 3000K.

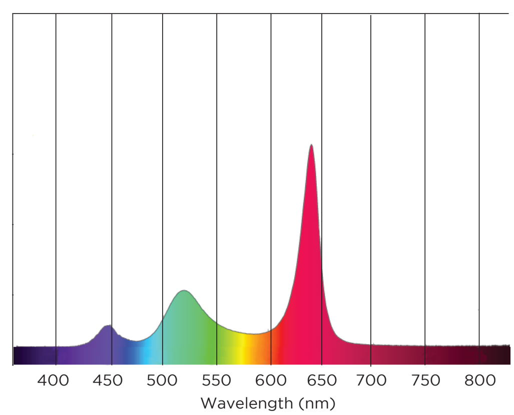

FIGURE 7. RGBW FIXTURE AT 3000K WHITE

When set to this color, the output brightness drops to below 50% of the maximum output possible due to color we are trying to meet. Since we are reproducing a color temperature that requires more red than green, we must turn down the other LEDs to mix the overall color, and thus turn down the overall brightness. The typical maximum power distribution on these RGBW fixture is such that the RGB add up to roughly the same lumen output brightness as the white when all the LEDs are at full power, but it only be at a particular white color temperature. We can see the white LED on the fixture does not contribute much for this color temperature based on the distribution of the spectrum produced when mixing a warm white color. The color produced by the fixture matches the color representation required, however it doesn't have much depth and has a lower color rendering index of 34, mainly because its relying on red, the cool white, green, and blue LEDs to produce much of the color. The lack of spectrum in the orange and yellows will be evident when shining on the subject and is what has often been the complaint of LED fixtures. Taking the same fixture, we can see how well the RGBW fixture reproduces a cool white in **FIGURE 8** For this color, there is not as much red needed, and it matches closer to the required color, and has a CRI of 73.

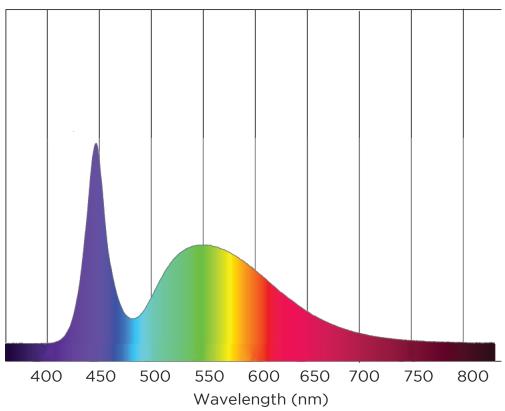

FIGURE 8. RGBW FIXTURE AT 6500K WHITE

INTRODUCING MORE COLORS

As the LED lighting as evolved, we now have much more LED colors to use, and can fill in these gaps with more LED color options. With these new options, we can produce many more colors and deeper representations of the complex cool and warm whites. New fixtures such as the Vari-Lite VL5LED WASH and Strand Leko® LED Profile employ more LED colors to help fill in these gaps on the colors, adding in cyan, lime and amber LED colors to the red, green and blue. **FIGURE 9** shows the new VL5LED producing a warm white at 3200K.

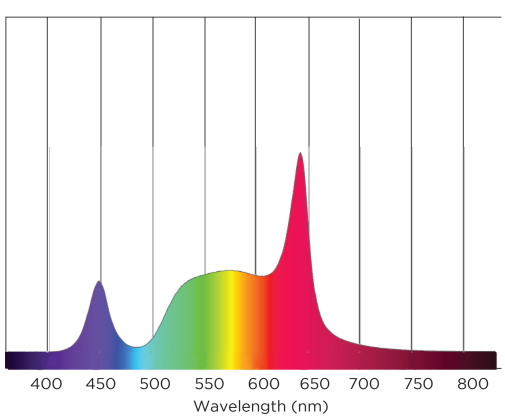

FIGURE 9. VL5LED AT 3200K WHITE

Note the levels of amber color filling in between the green and red colors, and the lime and cyan filling in between the green and blue. This greatly increased the number of colors we can mix using this system, and at this level has a relatively high CRI of 85 and lumen output of 10,000 lumens. Likewise, we can look how these same LED colors can help create colors on the other side of the black body curve by looking at **FIGURE 10** below. Note again the depth of the colors between the blues and greens. You can see the improvements the cyan and lime colors are providing. At this color temperature, the VL5LED is almost 90 CRI and 13,000 lumens.

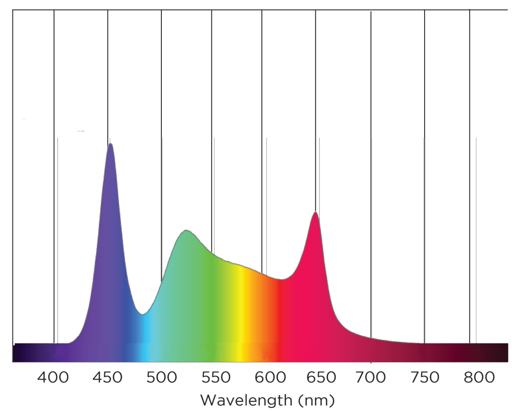

FIGURE 10.VL5LED AT 6500K WHITE

While the additional colors are a welcomed addition to the lighting fixture, each color brings in an additional channel for control and an additional layer of complex math. For years, the color mixing involved either subtractive CMY or the additive RGB, but now we have added new colors to control.

Using the VL5LED, we have six color LEDs which can be add at different levels to create any color temperature white on the black body curve at a CRI of 84 or better, as well as a wide range of colors on the color gamut. When trying to match a color, the individual levels of each color can be calculated using a complex series of calculations that consider each LED coordinates as well as total flux that color contributes. For six colors, it involves over six variables that depend on each other, so can get complicated quickly. Alternatively, we could experiment and use trial and error. We call this approach the individual color control approach. This has been the primary approach available until recently.

SMARTCOLOR CONTROL

Rather than determining by trial and error the exact combination of 6 LEDs that is required to achieve a particular color, SmartColor Control from Vari-Lite and Strand allows programmers to set the color mix and temperature they need, just as they would select the color filters and lamp type in a traditional lighting application. **FIGURE 11** shows the NEO Console window for color control using the familiar CMY+CTO control.

With SmartColor Control, programmers set the color temperature (CTO) channel by dialing up or down the color temperature, which ranges from 1,800K to 10,000K on the fixture.

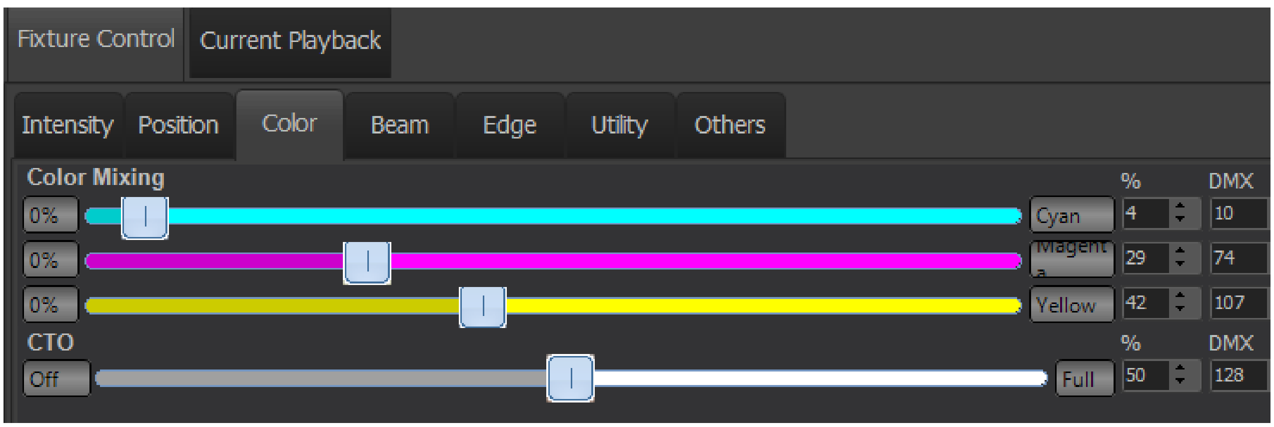

FIGURE 11. NEO CONSOLE COLOR MIX CONTROL USING CMY

FIGURE 12, FIGURE 13, FIGURE 14, and **FIGURE 15** demonstrate the spectrum ranges for just a few of the different color temperatures, all of which are 85 CRI or better. You can see how the six LED colors can work together to build a full spectrum of colors.

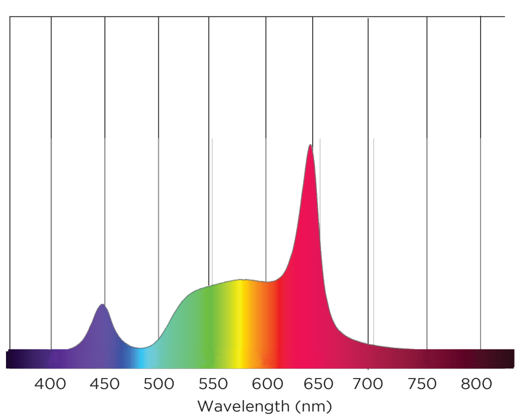

FIGURE 12. VL5LED PRODUCING 2700K WHITE

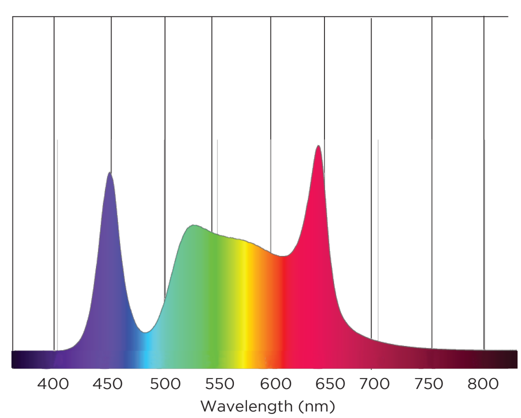

FIGURE 13. VL5LED PRODUCING 4500K WHITE

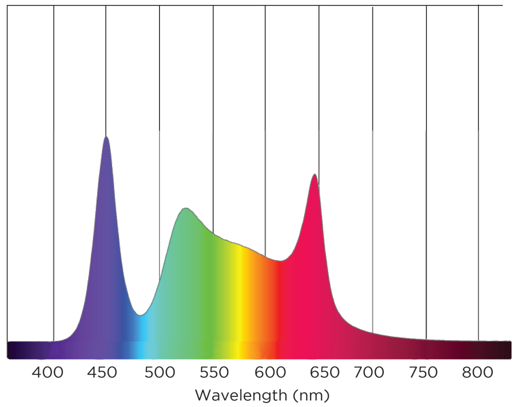

FIGURE 14. VL5LED PRODUCING 5600K WHITE

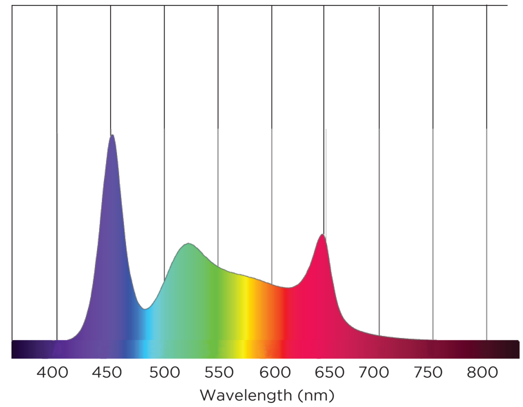

FIGURE 15. VL5LED PRODUCING 8000K WHITE

Once we have selected a starting color temperature range, we have the basis of the LED levels for that color white. Then, we can use the subtractive-style color mixing control, bringing in the Cyan, Magenta and Yellow control channels to adjust the color mix, which the lighting fixture will automatically decrease the appropriate levels for the different LEDs to meet the color we're trying to mix. So, as the Cyan channel increases, the fixture will lower the appropriate LED colors to produce the right Cyan color at that color temperature. If we need to adjust the tone of the Cyan from the fixture to something slightly different, we can raise and lower the color temperature to produce slightly different variation of the Cyan.

We can perform this same approach with all the CMY controls. This provides the user tremendous control of the color without having to remember what the LED colors are in the fixture and how to set them. With the flexibility and ease of the fixture control, and the wide range of color possibilities, we see tremendous potential in this new LED technology provided in new fixtures from Vari-Lite and Strand.

1 Von Bommel, Wout and Rouhana, Abdo. The Science of Lighting. Signify Lighting Academy, 2019. www.signify.com/global/lighting-academy.

2 Wikipedia. "CIE 1931 color space." https://en.wikipedia.org/wiki/CIE_1931_color_space