BY MIKE WOOD

Color rendering enhancers

THOSE OF YOU who have read this column in the past will know that I consider the current trend of using white LEDs with dichroic subtractive color mixing to be a transient anomaly. It just seems crazy to me that we don't use the strength of LEDs as excellent additive mixing sources, but instead use them to make a mediocre white light source, then throw away most of the light by using subtractive color mixing. Yes, I know there are good reasons for this, particularly for those users to whom white light output is king, but you can't convince me it's a sustainable or lasting technology. We must, one day, switch over to additive mixing.

However, that's not what this column is about. What I do find interesting is that the use of powerful white LED sources has stimulated the development of a new kind of filter, a color rendering enhancement filter. Quite a number of automated light manufacturers now offer a drop-in filter (either as a separate filter or on the color wheel), which improves the color rendering. How do these filters work, and what are the advantages and disadvantages of using them?

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Theory

The first thing to realize is that these are filters: they take light away. There's nothing we can do to add wavelengths of light we don't have, but we can adjust the ratios of those that are already present in the light beam. **Figure 1** shows the whole story from a theoretical point of view.

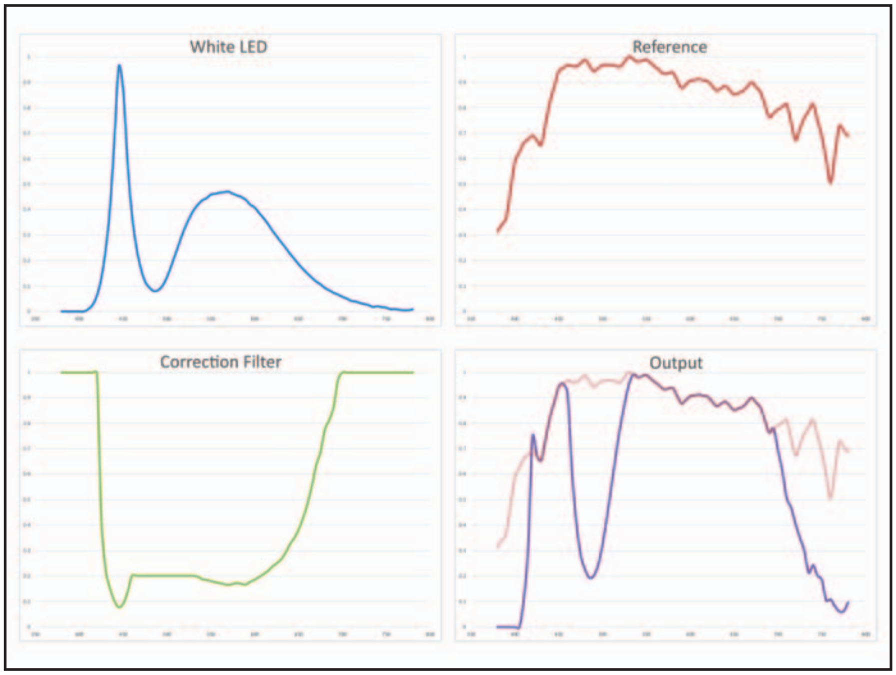

Figure 1 – Color rendering enhancer theory

The four curves shown here represent the spectral power distributions (SPDs) of the light as it goes through the system. Each chart shows the output of the system at different wavelengths, blue wavelengths on the left and red on the right of each graph. Top-left (the blue curve) is the white LED itself. This is a typical phosphor-converted 7,000 K white LED with a blue pump LED topped with a translucent broad-yellow phosphor. The net result is as seen here, a narrow blue spike from the LED along with a broad yellow/green hump. Taken together the eye sees this as a white. The lack of reds and the valley of missing energy in the cyan means that the color rendering is not as good as it might be. Next, at top-right (the red curve), we have our perfect reference source, in this case a daylight of the same color temperature, 7,000 K and, by definition, perfect color rendering. How do we get from one to the other? We need a filter that converts the white LED to a curve more like the daylight. Mathematically

> "… there's no magic here."

the process is straightforward: filters act on spectra as multiplying factors. So, we can essentially divide the result we want to achieve by the light we have and the result will be the filter that's required. However, there's a problem. We know we can't add wavelengths we don't have. That would be mathematically equivalent to dividing a number by zero, and that is a bad thing. Instead we need to pick the lowest value that we are going to try and correct, and still let some light through. In this case I chose to limit the filter to 20%. That filter is shown at the bottom-left (green curve). It cuts out some of the blue spike, reshapes the green/yellow hump, and allows through as much red as is available. The final result is shown bottom-right (purple curve). The output is now much broader. Still missing the cyan and red, but the curve in the center matches the reference (pale red curve) pretty well. This results in a much better color rendering. So, job done.

However, these graphs are very misleading! I rescaled all four SPDs to be zero to one on the vertical axis to make comparison easier, whereas, in actual fact, the filter removes a lot of the light and our output light is much dimmer than the original LED. How much dimmer? In this extreme example the filter reduces the light output to 23% of the original value, a 77% loss. That's too much to be acceptable. Instead, the manufacturers take an intermediate approach, decide what level of light loss is acceptable, and then design the filter accordingly. It will always be a trade-off between how much improvement in color rendering is achieved versus the light lost to achieve it. Most manufacturers seem to be working with around 25% loss and which gives them around five or more extra points of color rendering.

What do these filters look like, what color are they? Looking at the Correction Filter curve in **Figure 1** we can take a pretty good guess. It's a filter which allows through red and blue but attenuates greens and yellows. It's going to be a pink or magenta filter. Reduce the filter losses by reducing the saturation and letting a bit more light through and we'll get a pale magenta, likely very close to a standard minus-green filter. Okay, if a minus green filter could do this, let's test the theory!

Practice

My test set-up was very simple, a white LED light source was a work light in my workshop, the detector was a Sekonic C-800 meter, which can measure SPDs and TM-30-15 color rendering index, and my filter was a Rosco swatch book with the filters placed across the meter sensor. **Figures 2** and **3** show the starting point, an approximately 6,100 K white light source with a typical SPD. The cyan valley was less than my theoretical source, but there is still very little long-wavelength red light. The color rendering measured as having a TM-30-15 Rf of 82, and Rg of 94 and a CRI Ra of 82.5. Not a horrible light source, but let's see if we can do better. (*Note: I'm including CRI Ra values here as a link to the past, you should not be using CRI as a measure of color rendering for LED sources, it just doesn't work. Nevertheless, I know there's a lot of history to forget here. Take the CRI values in this article with a large pinch of salt and just look at the TM-30.*)

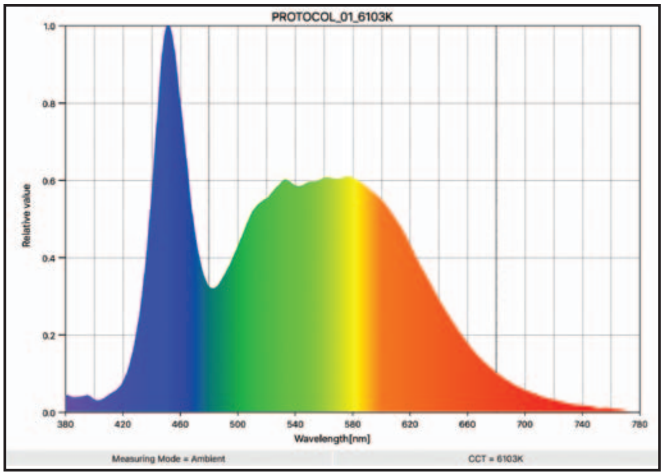

Figure 2 – LED source SPD

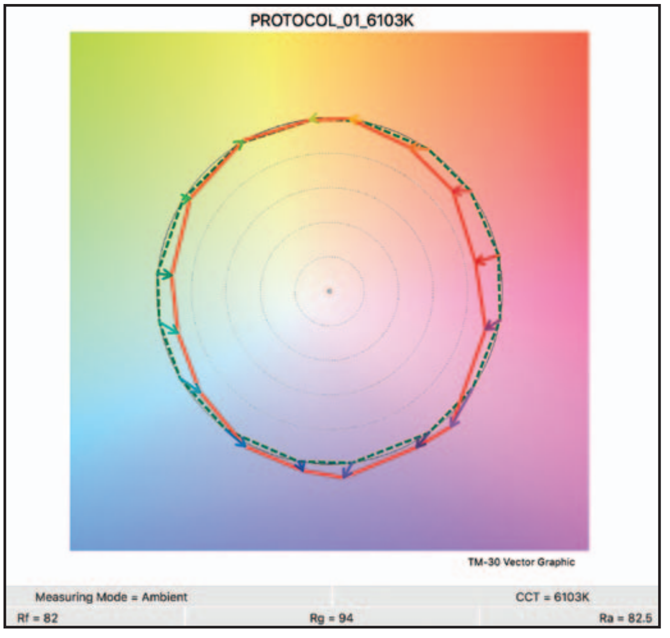

Figure 3 – LED source color rendering

Figures 4 and **5** show the same source with a #3308 Minus Green filter in place. The SPD curve has been flattened as expected, and the color rendering has gone up. Now we have a TM-30-15 Rf of 85, Rg of 104, and CRI Ra of 89.5. Quite a noticeable improvement. Light output has dropped down to about 63% of the original. What's immediately noticeable is that we still have a large blue spike, can we do better still by reducing that? The way to reduce a blue spike is with a filter of the complementary color, a yellow.

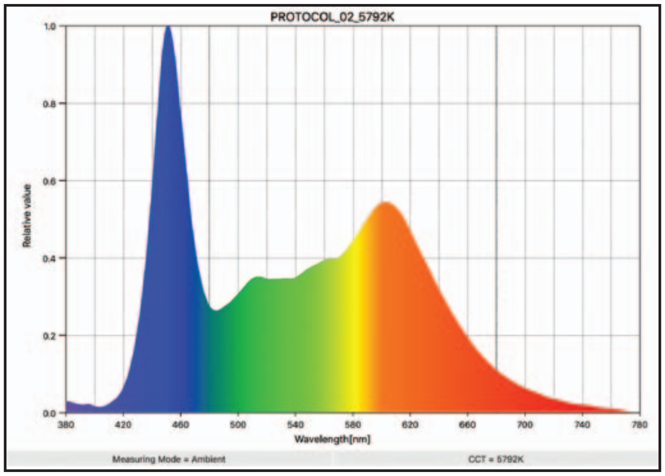

Figure 4 – LED source + Minus Green SPD

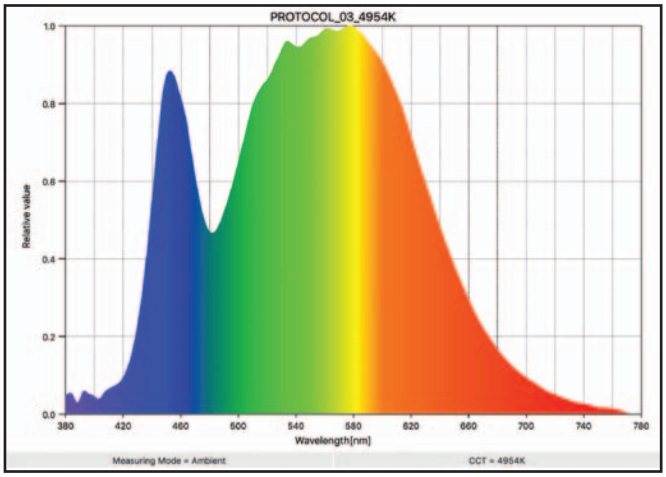

Figure 6 – LED Source + No Color Straw SPD

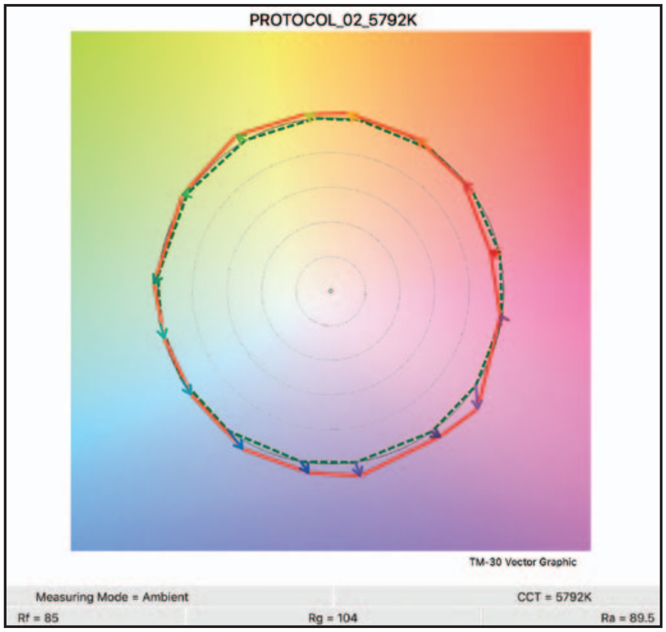

Figure 5 – LED source + Minus Green color rendering

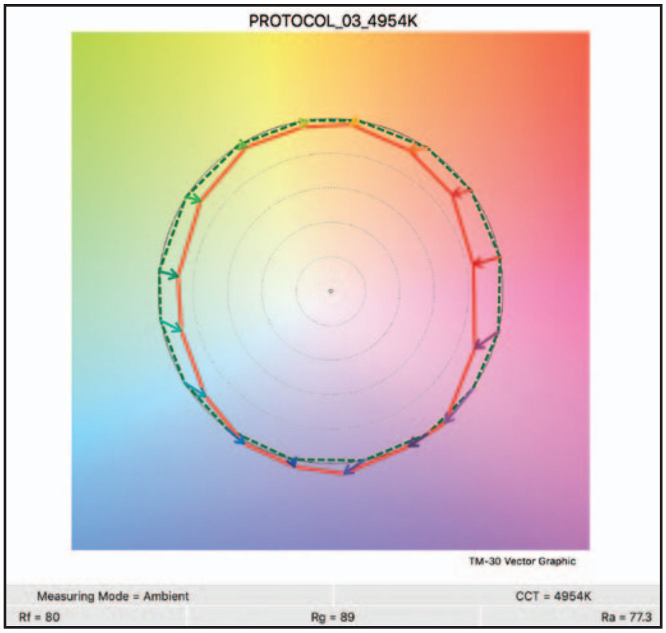

Figure 7 – LED Source + No Color Straw Color Rendering

Let's try yellow on its own to see the effect. **Figures 6** and **7** show the result with just a #06 No Color Straw pale yellow filter in the beam. The blue spike is considerably reduced relative to the yellow hump as we expected. Unfortunately, color rendering is actually reduced down to an Rf of 80 and CRI Ra of 77. However, we don't intend to use this on its own. Let's see what we get with both the Minus Green and the No Straw Yellow in at the same time. That's **Figures 8** and **9**.

This seems to be working pretty well! TM-30 Rf is up another couple of points to 87, Rg is 98, and CRI Ra is 89.8. All very acceptable. Downside is that the output is now down at 58% of the original, but perhaps that's acceptable in some use cases. Note also that, primarily because of the blue reduction from the No Color Straw, our CCT is reduced to 4,172 K.

I experimented for a while longer, trying different combinations of magentas/minus green gels with pale yellows and straws and the very best result I achieved with this very empirical approach was a TM-30 Ra of 88, Rf of 99, and CRI Ra of 91 using a #06 No Color Straw along with #4930 Lavender as shown in **Figures 10** and **11**. CCT is also pretty good at 5,636 K. I'm sure if I'd played longer and tried other manufacturer's gel books as well I could have done a little better, but I suspect that's just about as far as it's reasonably practical to go because of the missing cyan and lack of deep reds and blues. You can never add missing wavelengths with filters, just take them away. With the two filters in place I was down to 42% light output, which is probably going too far. Compare **Figure 10** with

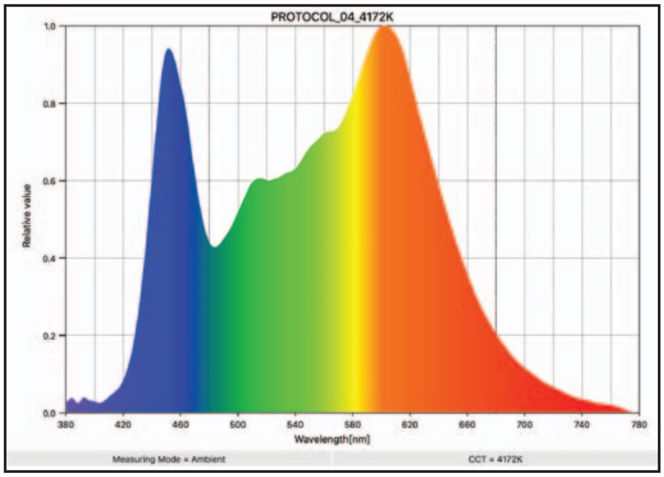

Figure 8 – LED source + Minus Green + No Color Straw SPD

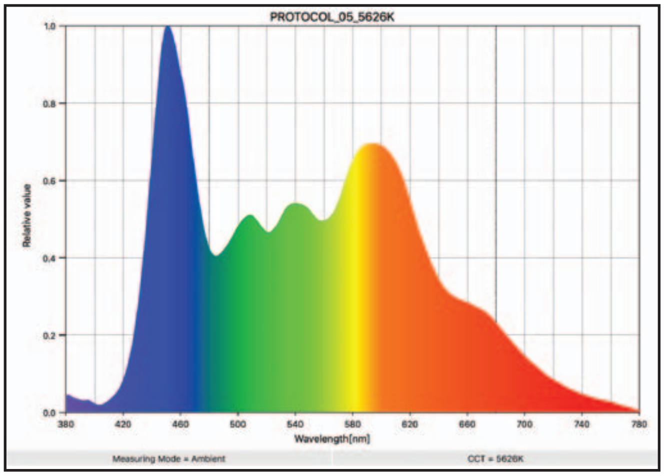

Figure 10 – LED source + Lavender + No Color Straw SPD

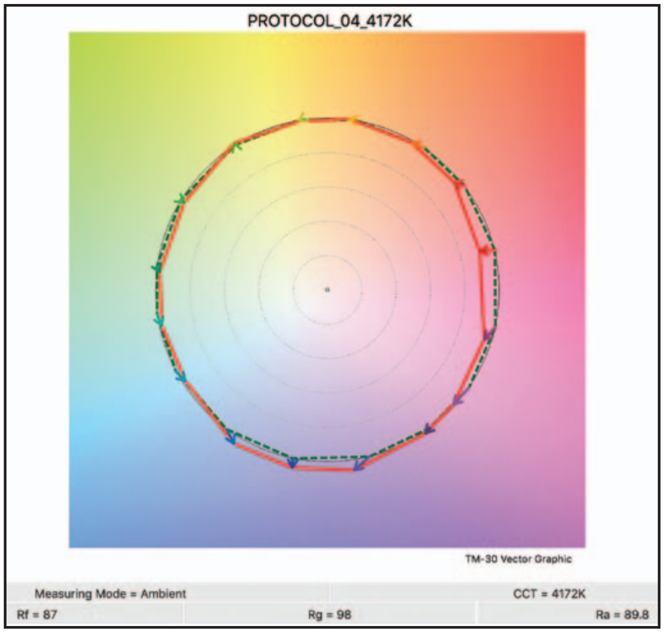

Figure 9 – LED source + Minus Green + No Color Straw color rendering

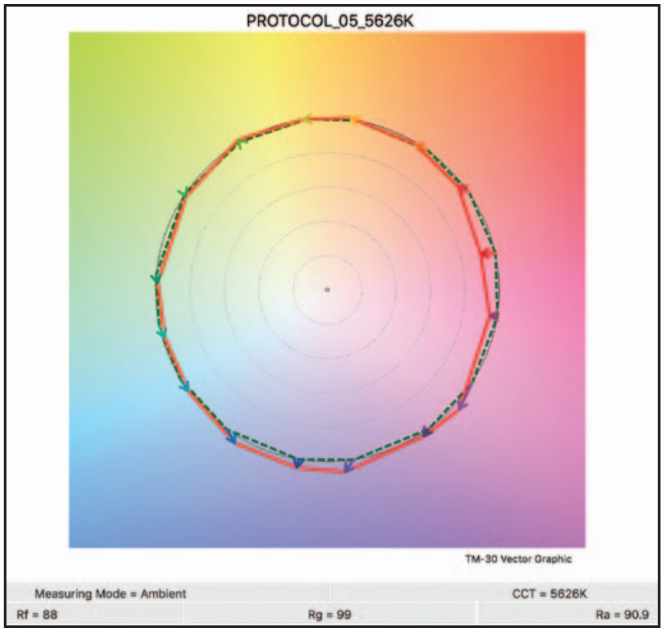

Figure 11 – LED Source + Lavender + No Color Straw color rendering

where we started, **Figure 2**, and you can see what an improvement we've made in continuity of the spectrum.

So what?

There's no real conclusion to be drawn here. This was an interesting exercise, at least for me, in seeing what could be done using standard off-the-shelf filters to improve the color rendering of white LEDs. If I'd been able to manufacture a custom filter tailored to the source, then it would have been possible to get better results: good color rendering, with less reduction in output. This is the approach taken by many of the automated light manufacturers. They are using dichroic filters, likely based on minus green, with tweaks to suit their specific light engines.

As to the point of the article? Just to show that there's no magic here and we are able to trade off light output for color rendering to suit the need by suitable filtering. In the same way you could design filters to maximize TLCI, spectral matching, or other measurable parameters. Never forgetting that these are subtractive filters and we will always lose light. ■

Mike Wood runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 40-year veteran of the entertainment technology industry, Mike is a past President of ESTA and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.