BY MIKE WOOD

Color prejudice, or how bright is that LED really?

You're invited to help solve the quandary

A YEAR OR SO AGO IN THE SUMMER 2007 issue of this journal I described the normal techniques and the underlying theory behind measuring the light output of luminaires in lumens. We talked about field lumens and ANSI lumens and how and where each one might be useful. That article represented techniques I've been using for nearly thirty years and that have been in normal use for very much longer than that. The figures you get from these tests on normal theatrical luminaires are well understood and provide the starting point for many a lighting design.

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A fundamental of these tests and our use of them is that the results are for white light. That's historically not been a problem—all the light sources we have used are white, or close to it. Incandescent lamps, discharge lamps and fluorescents may differ in the color temperature of the white and in how good they are in rendering colored objects but they all start out in white. We then take those white light sources and, through the use of filters, tune them to the color we want. Those filters, whether gel, colored glass or dichroics, are readily available in a huge range of colors and we are completely familiar with their use. We also know that this means of coloring a light source is known as subtractive because we are subtracting wavelengths of light. The familiar consequence of subtractive coloring is that the result is always dimmer than where we started—that's what subtractive means after all, we are taking light away.

We do use additive color mixing occasionally, a four color cyc light is an obvious example, but I don't think we use them enough to be as intuitively familiar with the results as we are with subtractive. Now along come LEDs. Yes—I'm talking about LEDs again and I make no apology for that. LED based luminaires seem to be here to stay. LED based light sources are inherently additive—they use natively narrow band emitters and you need to combine a number of devices of differing wavelengths together to make the resultant output appear white. This addition can be achieved either by using multiple LEDs of discrete and differing wavelengths such as the ubiquitous Red, Green, Blue (RGB) mix or through a wavelength shifting phosphor which adds in the missing wavelengths. Any way you slice it, it's additive mixing.

Why does being additive matter? Well, as long as you only ever use a luminaire in white it doesn't—whether we achieve that white through a native black body emitter such as an incandescent lamp or through the addition of multiple wavelengths as we do with an RGB LED array really doesn't matter as far as measurement goes. The difference comes when we get into colors. Through long experience of using them we are all very familiar with the behavior of incandescent light sources with gel filters in front of them—we know how much light we are going to lose by adding the filter and we compensate with our design and color choice to make it work in the overall design. Adding in a deep blue filter might lose us 90% or more of the light for example. Applying that same thinking to an additive LED array just doesn't work—this time when we want to make that same deep blue we can do it very efficiently using primarily the blue LED with perhaps some of the other colors to adjust the hue. In this case the loss of output is likely to be very much lower—we are using that blue LED in its most efficient mode in fact.

Thus the dilemma—our usual techniques for measuring white light based units still apply when we are talking about white light from LED based sources but perhaps don't fairly represent what those same sources can do in deeper colors. If your lighting design calls for Brechtian white and the deepest colors you use are steel tint and straw then the current methodology works perfectly for you. (This is very likely the case if you are lighting a news broadcast for television). If, on the other hand, you are looking for some mid or saturated colors then how bright is that LED based unit going to be in a mid blue?

There have been attempts to deal with this by the marketing departments of some LED fixture manufacturers however, to my mind, many of these attempts have been somewhat biased and misleading so far. Some manufacturers refer to their LED unit having the "equivalent" output of a much higher wattage incandescent unit while others try and refer to output in saturated colors. In one recent case the manufacturer's wild claims related more to the inefficiencies of the colored filters used in conventional source luminaires than they did to the efficiency of his own LED based unit.

Although I might decry the abuse of photometrics that more than one of these manufacturers are resorting to, I have a great deal of sympathy with their plight and their intended goals. The basis on which 99% of their customers judge luminaires is their performance in white light, however they are now trying to sell something to those same customers that performs less well in white and much better in deep colors. How do they tell people that in a logical, justifiable and honest manner? There are new standards for measuring the output of LED luminaires however, again, they concentrate on performance in white light primarily for architectural or home use and don't address the issues we face in entertainment lighting with colored lighting.

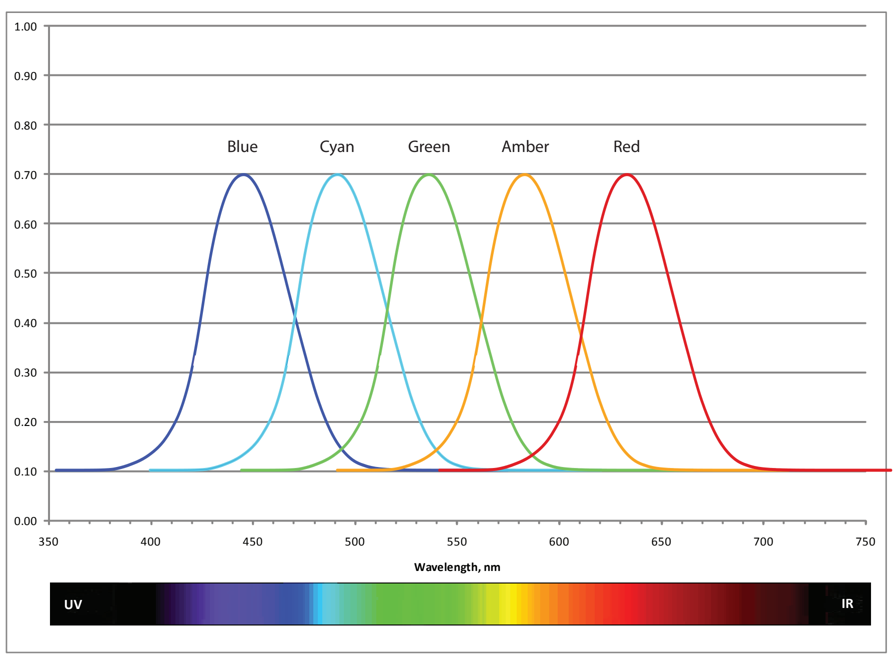
The new standards for LED measurement also mandate a move from relative to absolute photometrics. The entertainment industry has been using absolute photometrics almost exclusively for many years so this was a bit of a non-event for us. Our use of focused, directed light where spill light is useless and wasted has forced us to use measurement systems that measure the actual output of luminaires when used in real situations. We have to measure the light that the audience or camera sees directly and not include what might bounce around the room and end up on the subject eventually. If theatres had small rooms with white walls things might be different but wide open spaces and black walls, not to mention black wrap, pretty much kill that spill light!

It's time, I believe, to put some science and technology behind this and lay down a framework that avoids the hyperbole. Let me try and state the core of problem in a few bullet points:

- The output of a black-body white light luminaire is well defined and measurements of that output are simple, comparable and repeatable.
- Additive mixing fixtures are often more efficient in saturated colors than they are in white.
- The performance of luminaires when producing saturated colors is not well defined and there is currently no agreed methodology for measuring it.

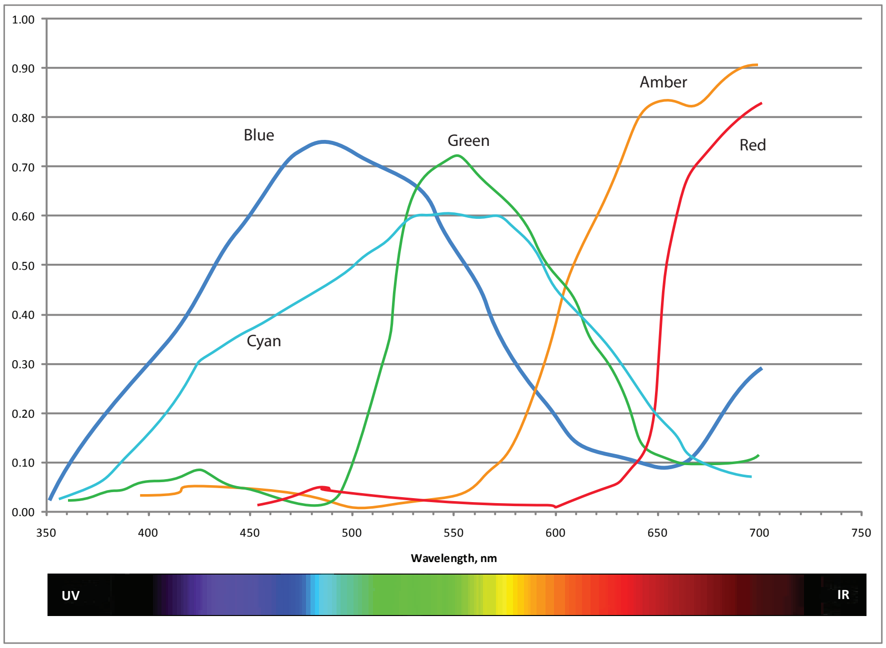
I don't have a magic bullet for solving this question. However a method where the output in a range of specific, well defined colors is quoted as well as the output in white might be a possible route. This still has problems—if the defined colors are too narrow and saturated then a manufacturer who happens to use (deliberately or serendipitously) an LED with an emission band that matches those colors precisely might get an unfairly high rating. Conversely if the colors have a very broad pass band then the results might be too close to that of white light to be useful. It needs some experimentation but perhaps we could come up with a small number, five or six, well defined color bands, perhaps with a mid-level saturation, which give a result that is acceptably representative of the luminaire's performance. **Figure 1** shows an idealized example of what those colors might look like—these are clearly not real spectra and are used here purely for illustrative purposes to show how colors might be selected across the visible spectrum. The level of color saturation (i.e. how much white is also present) would also have to be defined and agreed. One way of making this selection might be to select representative filters from the very wide range of gel colors that are already readily available and that are manufactured to a high degree of accuracy and consistency. In an ideal world we might choose filters such as those depicted in **Figure 1**.

Figure 1 – Idealized color choices



However unfortunately real filters don't normally look like that with their nice neat curves and well behaved cut-off points. A set of real gel filters would instead look more like **Figure 2**.

Figure 2 – The performance of real gel filters



We could probably do better by using dichroic filters but, in the end, it might not matter what the precise shapes of the color spectra chosen to measure against are—instead what matters is that those spectra are agreed and standardized by everyone so that we all measure using the same yardstick.

Measuring the total lumen output at these wavelength ranges (perhaps through those standard agreed gel filters) you might end up with a result something like that shown in **Figure 3** for our hypothetical fixture:

White	5,000 Lumens
Red	35%
Amber	40%
Green	25%
Cyan	20%
Blue	15%

Figure 3 – Color measurements

The trick here is in defining the pass bands for those colors in a way that's fair and easily measurable.

The percentage figures for the colors could be combined to provide a single "Color Rating" figure for the luminaire that represents how good it is at producing mid to fully saturated colors compared to its performance in white.

Conceivably you could even go a step further and assign a weighting factor to each of the test colors relative to how important/common its use is. You could choose to weight blue at 0.5 because it's an important color but green at only 0.1 because it's only used at Halloween. (Maybe not strictly true—but you get the point). However we agree to do this you would end up with a lumen figure and a color rating for that luminaire. In the case above perhaps this luminaire could be classified as a 5,000 lumen unit with a color rating of 0.3. (All fictitious values purely for illustration).

The lumen value would represent brightness in white light exactly as it does now—the lumen is already well defined and we shouldn't mess with it. The color rating would then represent how good that luminaire is in producing our standard colors. You might expect that an incandescent luminaire using gels for colors would have a high total lumen output and a lower color rating whereas an LED luminaire might be the other way round—a lower total lumen output but a higher color rating.

An alternative way to express the color rating would be to compare the color output with that of a "standard" black body incandescent luminaire. In other words a color rating of two might mean that the rated luminaire is capable of producing colored light output at about twice the level of the incandescent luminaire which has the same output in white light.

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I'm flying a kite here and using the pages of this journal as a means to solicit response—all of the above is totally hypothetical and theoretical and is presented as a means to discuss the problem and attract comment. I've not tried or tested any of these ideas in a practical way yet, although the idea intrigues me enough that I probably will! Does this solution have any merit? Perhaps it does or perhaps it's a waste of time. Maybe somebody has a suggestion for a much better way to do this. There is no point to measurement standards unless they are useful and understandable. One way or another I'd love to hear your opinion. ■

Mike Wood is President of Mike Wood Consulting LLC which provides consulting support to companies within the entertainment industry on technology strategy, R&D, standards, and Intellectual Property. A 30-year veteran of the entertainment technology industry, Mike is the Treasurer and Immediate Past President of ESTA. Mike can be reached at 512.288.4916 or via email at mike@mikewoodconsulting.com.