BY MIKE WOOD

CRI and the Color Quality Scale, Part 2

CQS offers discerning users a metric to allow direct comparison of luminaires with different light source technology

IN THE WINTER 2010 ISSUE of *Protocol* I wrote about the Color Rendering Index (CRI) and how it is calculated. That article finished with a brief discussion on how the CRI value and measurement is perhaps a poor one for assessing arrays of colored LEDs.

The problems with CRI

To recap, the normal CRI value is based on the calculated ability of a light source to render eight standard colors. The eight colors are all relatively unsaturated, which works well for broad band light sources with continuous spectra, but can be problematic for narrow band LED sources with large peaks and valleys in their spectra. An RGB light source can produce good rendering of the unsaturated test colors, resulting in a high CRI, even when its rendering of saturated colors is poor. Another problem is that the CRI is calculated as a simple average of the rendering of the eight colors. This makes it possible for a light source to obtain a high CRI even though it renders one or two of the colors very poorly. This is often the case with RGB LEDs where the precise selection of wavelengths chosen for the three colors and how they match up with the eight test colors can be critical. A change of a few nanometers in color of an emitter can swing the CRI from 70 to 90. This is a purely artificial swing related to inadequacies in the measuring technique and the results are misleading. LED RGB triads may look similar to the eye but give wildly varying CRI results. This problem also opens the possibility of a manufacturer gaming the CRI of a product by carefully picking LED wavelengths that result in a high CRI.

Let's look at an example of this. **Figures 1** and **2** show the spectra and color rendering of an RGB LED source, let's call it RGB 1, with LED wavelengths centered at 460 nm, 540 nm and 605 nm. At a nominal CCT of 3300 K this source has a calculated CRI of 81 which is quite high and normally would be considered very respectable. However, if you look at **Figure 2** you can see that this source would render saturated reds and purples very poorly while over emphasizing saturated blues. (The blue line in **Figure 2** is the reference while the red is the calculated result under the test light source. If the light source were perfect the red and blue lines would coincide.)

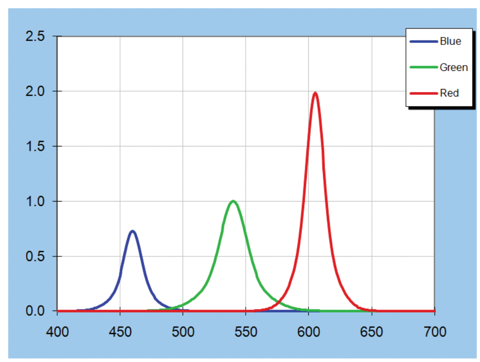


Figure 1 - Spectra of RGB LED with CRI of 81

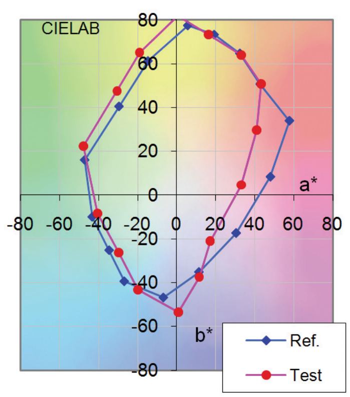


Figure 2 - Color Rendering of RGB LED with CRI of 81

Now let's just move those LED wavelengths very slightly to 455 nm, 534 nm and 616 nm (RGB 2) as shown in **Figures 3** and **4**. The result of this small change is a huge drop in CRI down to 67, which is a level most people would say was unacceptable. However a careful look at **Figure 4** reveals that, in fact, most colors are better rendered than in the sample with a CRI of 81, the biggest errors are in the green and red where colors are over emphasized, and that nowhere in the gamut are any colors under-rendered. Most people would prefer this light source even though it has a low CRI.

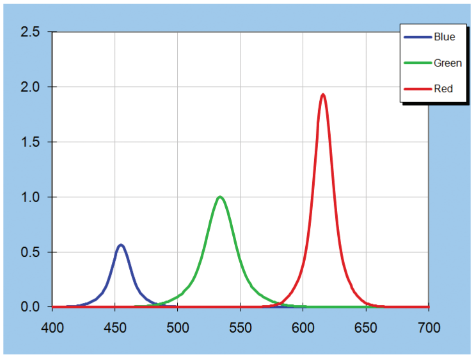


Figure 3 - Spectra of RGB LED with CRI of 67

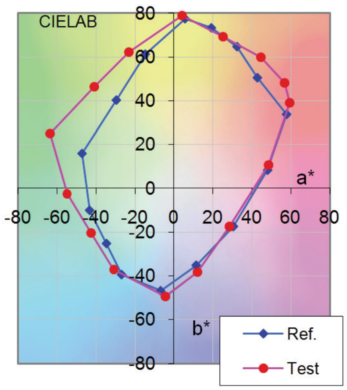


Figure 4 - Color Rendering of RGB LED with CRI of 67

Note: This overemphasizing of some colors is common with narrow band light sources like LEDs and can lend a cartoon like or hyper-real appearance to colored objects. Personally I don't like this, as even though it is less overtly objectionable than under-rendering, it is actually just as much of a problem as under rendering for entertainment lighting where color fidelity is often the goal.

Color Quality Scale

In recognition of these problems NIST (the National Institute of Standards and Technology) has been working on a new means for measuring and reporting color rendition called the Color Quality Scale (CQS). The goal was to keep the good points of CRI with its use of standard color chips and direct relation to the real-world, while addressing the shortcomings arising from the choice of standard colors and the math used to combine the results.

A major decision in the new metric was to continue to report results as a single number. Although this inevitably results in some compromises in the resolution of the results, it was felt important to keep that link to the well known and understood CRI. The purpose of a metric like CQS is to condense an immense amount of information into something manageable and useful. In order to be useful for the greatest number of users, most of whom have very limited knowledge of colorimetry, a one-number output continues to be desirable. Throughout our personal and professional lives we use many measurement scales whose precise meanings and measurement methodologies are unknown to us without concern. Examples of such scales include shoe sizes, octane ratings of gasoline, and radio station frequencies. Though most people don't know precisely how those numbers are determined, they find the scales useful and have a general understanding of how different outputs relate to each other (a larger shoe size means a bigger foot!).

The CQS, like the CRI, is a test sample method. That is, color differences are calculated for a standard set of colored samples when illuminated by the test source and a reference illuminant. As mentioned above the CRI samples are all relatively unsaturated colors and this can hide problems a source may have rendering more saturated tones. NIST has established through extensive computational testing that, although light sources can perform poorly with saturated samples even when performing well with unsaturated ones, the inverse is never true. That is, there is no light source spectrum that would render saturated colors well, and render unsaturated colors poorly. This important result shows that nothing is lost and everything is gained by only using saturated colors as our new sample set. Therefore, CQS uses fifteen saturated colors chosen to be evenly spaced across the entire visible spectrum.

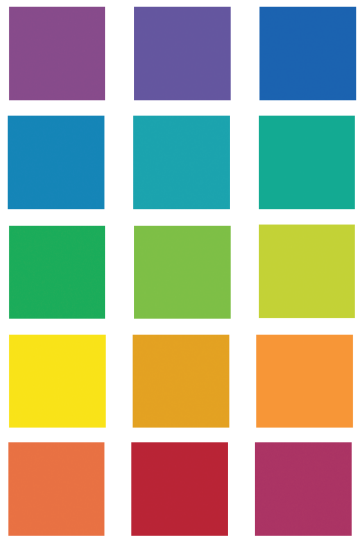


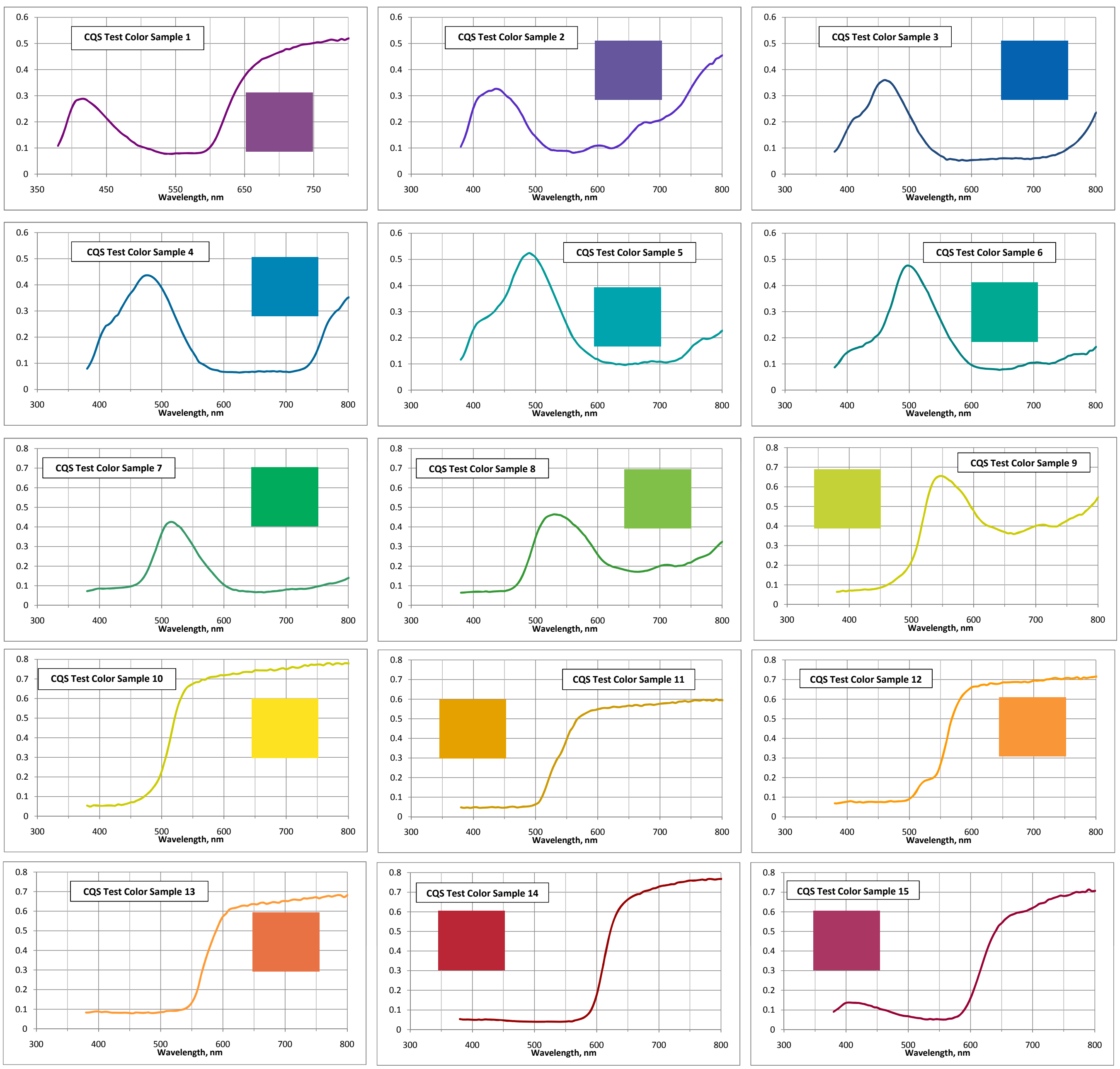
Figure 5 - CQS Standard Colors

Compare **Figure 5** with the sample set used for CRI (**Figure 1** in the Winter 2010 issue of *Protocol)* and you can see how much more saturated these are than the TCS01 - TCS08 samples typically used for CRI. **Figure 6** shows the full set of CQS test colors and their spectra. *(Note: These colors are unlikely to appear accurately in this journal. The limitations of the printing process will render them as less saturated and with different tonal values than the originals.)*

All fifteen CQS colors are available as real samples with standard Munsell numbers but, as with CRI, there is no need to ever use them! Everything you need to calculate CQS can be derived from the source spectrum and knowledge of the color properties of the samples. Although the initial calculation of the errors in the rendering of each of the fifteen colors is very similar to that used for CRI, there are a number of important differences between how those values are used to calculate the final metric.

I wrote earlier that the simple averaging of the color difference values, as happens with CRI, can result in assigning a source a high CRI value even though one or two samples show significant color differences. The CQS avoids this by combining the 15 values by an RMS (root-mean-square) calculation. By squaring every value before averaging them we emphasize any errors and ensure that poor rendering of even a few of the samples will have a significant impact on the result. There are other changes in the math for CQS that further improve the result over that of CRI, but these are out of the scope of this article. However the result, I believe, is something that will suit the entertainment business very well and will give us a true metric for how good a light source's color rendering is, both to the human eye and to the TV or film camera.

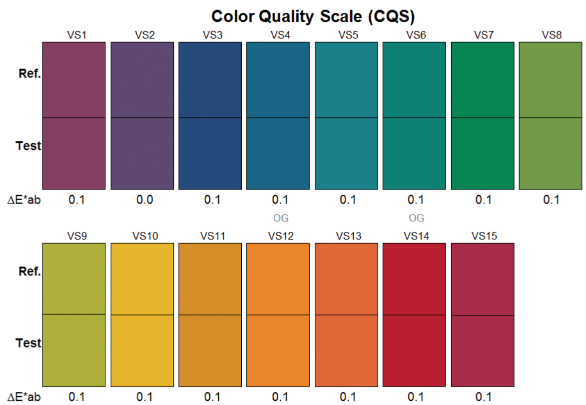
Figure 6 - CQS Test Color Spectra



Example results

Let's take a look at the CQS results for some real light sources to see how they stack up. **Figure 7** shows an incandescent lamp.

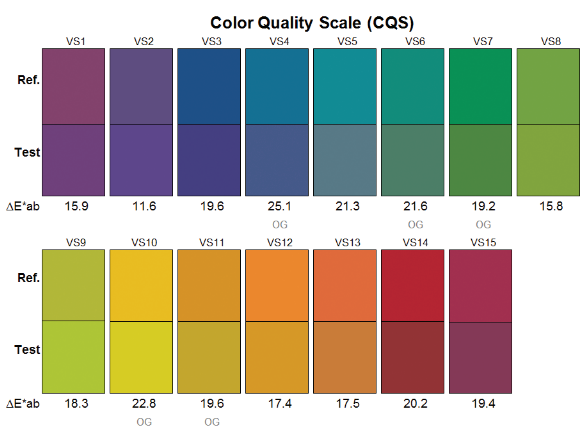
Figure 7 - CQS samples under an incandescent lamp



Perhaps surprisingly an incandescent doesn't have a CQS of 100. Instead, it is 98. A real incandescent lamp is not a perfect black body emitter as incandescent lamps are usually slightly inadequate in the blue, but CQS has the ability to recognize and report that. (The color differences are too small to be rendered in this image—it all looks perfect here!)

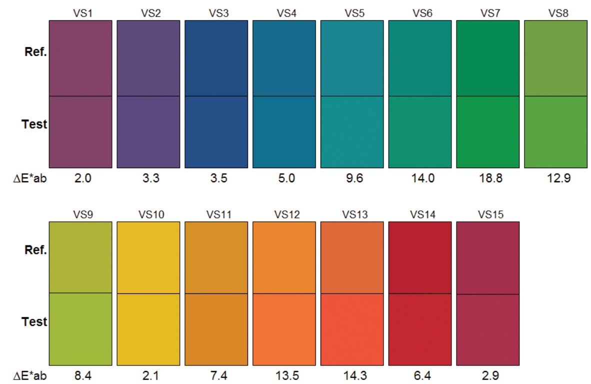
Figure 8 shows a mercury lamp. There are errors throughout the whole spectrum with the largest in the blues and yellows. As expected this lamp has a poor CQS of 46.

Figure 8 - CQS samples under a mercury lamp



But what about those two hypothetical LEDs we talked about earlier? How do they compare when we use the CQS metric instead of CRI? If you recall we had one LED triad, RGB 1, which had a CRI of 81, even though it had very poor color rendering in some areas, and a second triad, RGB 2, which had a poor CRI of 67, but actually did a better job in many areas. Running them through the CQS calculations we get results of 75 for RGB 1 and 79 for RGB 2. **Figure 9** shows the CQS samples when illuminated by RGB 2 where you can see the over-emphasis or chroma-enhancement of the red, amber, and green.

Figure 9 - CQS samples under RGB LEDs at 455nm, 534nm and 616nm



The CQS values for RGB 1 and RGB 2 are now much closer together than the CRI, as one would intuitively expect, and CQS correctly penalizes RGB 1 for poor color rendering in a small area.

This is a much more palatable and representative result. However, it's not perfect. The standard CQS calculation recognizes that over-emphasizing a color is often less objectionable than under-rendering, so it penalizes errors from over-rendering less severely. Sometimes that's true in our industry too, but I suspect that often over-emphasis isn't acceptable, as it always causes associated errors in hue. Thus we want to penalize over-emphasis in the metric. Fortunately, CQS offers a solution.

Although we mentioned earlier that CQS is a one-number metric, NIST acknowledges that certain applications require more specific information about the color rendering properties of light sources, and I would argue that entertainment lighting is one of those applications. We use color extensively in very creative and precise ways and color accuracy is of profound importance to many designers. CQS offers discerning users additional indices, one of which I think is particularly relevant to our industry.

Color Fidelity Scale

This extra metric is the Color Fidelity Scale. It is intended, as its name suggests, to evaluate the fidelity of object color appearances. It removes the leniency accorded to over-emphasis of colors from the main CQS calculation and reports errors of any kind equally strictly. In the case of our hypothetical RGB 1 and RBB 2 LEDs this results in an unchanged Color Fidelity result of 75 for RGB 1 whereas RGB 2 (the over-emphasizer) drops down to 71. Both these values seem to better realistically represent what the eye sees with narrow-band emitters than does CRI and give us a much better idea of what to expect when comparing these narrow-band sources with traditional, broad-band sources.

NIST is still working on testing and developing CQS but I believe it's a metric we should look at adopting for entertainment lighting luminaires. We know CRI does a poor job, and with LEDs is inadequate and often misleading. CQS however should give us a metric that will allow users to directly compare luminaires with different light sources and get results that make sense no matter what the light source technology. ■

Credits: Many thanks to Wendy Davis at NIST for permission to reproduce text and figures from NIST documents.

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.