Evolving LED Color Standards

See how TriGain® Technology surpasses TM30 standards

EVOLVING COLOR
STANDARDS IN LED

LED products have revolutionized the lighting industry of today, replacing existing technologies and enabling new applications through the combination of energy efficiency and spectral tunability. Never before has a manufacturer had so much control over the emission spectrum of their products. However, with the evolving technology comes evolving color standards to better quantify the capability of LED products. This can often present a challenge to the customer, as they try to ensure they select the right product to align with current and future color standards.

Historically, the color rendering index (CRI) has been used to quantify color quality, however, CRI is a simplified measure of how a light source compares to an incandescent or daylight source. With LEDs, the color quality of traditional sources can easily be surpassed, and many applications can benefit from a more optimized appearance. As a result, CRI is no longer sufficient and can often be misleading. Additional color metrics are required, and industry has begun shifting to the more detailed TM-30 system.

A new metric system, however, is not enough on its own. It provides a toolset to take a deeper look at color quality, but there is no definition of what makes a "high quality" light source. Recent color studies are now starting to hone in on preferred ranges of performance, using the TM-30 system. While these ranges have not yet been standardized, industry is trending in that direction.

Another key LED benefit, efficiency, can also complicate the color quality decision. Efficiency and color quality are typically opposed; to get better quality, you must sacrifice efficiency. This can be a tough decision for customers to navigate as efficiency has a more quantifiable cost benefit compared to higher quality light. Current's TriGain® phosphor, however, can deliver the best of both worlds with a unique capability.

This white paper reviews the basis of color metrics and evolving trends in color, explaining the benefits of TriGain® products over the rest of the market to future-proof against rising color standards in industry, without sacrificing energy efficiency

COLOR METRIC

Before comparing different LED sources on color quality, a background on color science and metrics needs to be established. There are numerous color metrics that have been developed over the years for characterizing the color quality of light, with varying degrees of industry use. In general, they can all be broken down into three categories, depending on how they're calculated – fidelity, gamut, and preference.

Fidelity metrics attempt to quantify the "naturalness" of a light source. A reference blackbody source (e.g. incandescent, daylight) is used to represent the target performance, and thereby receives the maximum score of 100. A set of color samples is selected and compared under both the test source and the reference source. Each color sample may shift in saturation, hue, or brightness under the test source. Any color shifts in the samples are penalized, regardless of whether they are perceived as better or worse. The CRI metric averages the color shift of 8 pastel colors, while a popular supplemental metric, R9, uses only a single, saturated red color. **Figure 1** below is an exaggerated example for R9 to illustrate the fidelity concept.

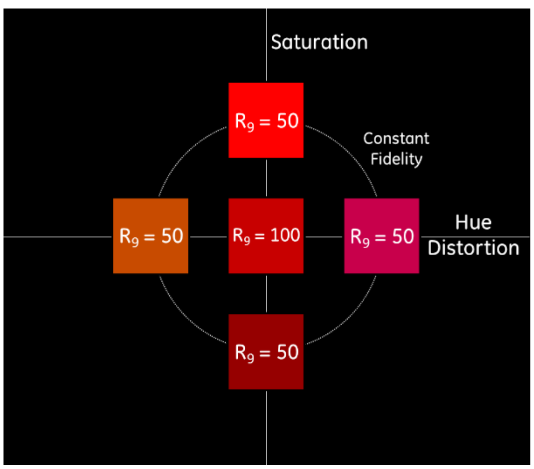

Figure 1: Illustration of the impact of saturation and hue distortion on fidelity metrics.

Gamut metrics attempt to quantify the saturation of a light source. A blackbody source is again used as a reference, and typically scores 100, however the test source can have a gamut value above or below the reference. A set of test color samples is selected, and the area of color space encompassed by the samples is calculated and compared to the reference source. If the colors appear more saturated, then they will shift outwards in color space and the encompassed gamut area will increase, resulting in a metric value above 100.

Preference metrics attempt to quantify the expected user preference of a light source. While fidelity and gamut metrics are strictly objective metrics, preference metrics can be highly subjective depending on the user and application. As a result, preference metrics are difficult to define to an absolute value. However, general trends have been found through studies, leading to target preference regions balancing both naturalness and saturation.

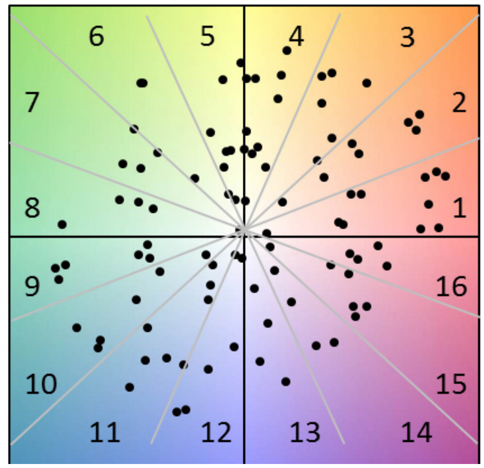

Figure 2: Illustration of the 99 test color samples and 16 hues of the TM-30 system.

The recent TM-30 system provides a series of metrics for improved evaluation of color quality. It uses 99 test color samples, broken down into 16 hues, for a more accurate depiction of color performance, as illustrated in **Figure 2** above. The system provides two main metrics – Rf for fidelity, and Rg for gamut – averaged over all 99 test color samples. The TM-30 system also breaks down the color quality by hue for fidelity, saturation, and hue shift (e.g. Rcs,h1 represents the chroma shift, or saturation, of the red colors in the first hue segment). When plotted together, Rf and Rg map to a triangular application space, as can be seen in **Figure 3**. The reference blackbody source sits at the apex of the triangle (Rf = 100, Rg = 100).

Since the introduction of TM-30, numerous studies have been performed to determine a target preferred region, with many of the results trending in the same direction. In general, users prefer a reasonable fidelity for a natural appearance, an increased gamut for saturated colors, and in particular, an increased red saturation. One publication that appears to be gaining the most traction for premium color standards provides the following guidelines: Rf ≥ 75, Rg ≥ 98, and -7% ≤ Rcs,h1 ≤ 15%, but more preferably 0% ≤ Rcs,h1 ≤ 8%.[1] These guidelines are highlighted in **Figure 3** to illustrate this target region for optimal color performance. Light sources within these areas can be expected to be more preferred than those outside.

(1) Royer, Michael. "Emerging Specification Guidance for TM-30." LD+A Magazine, June 2018, pp. 24-28.

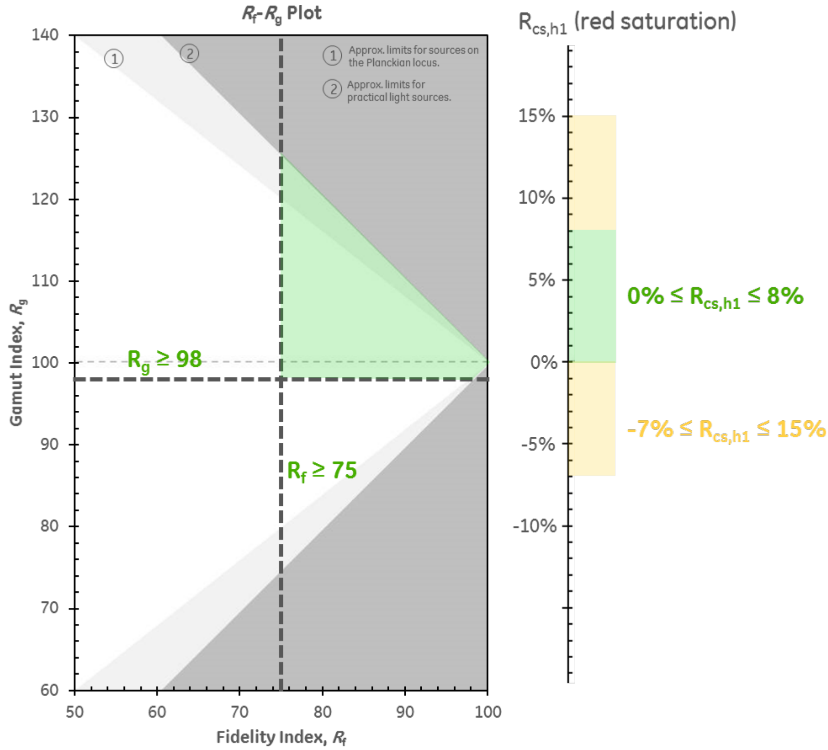

Figure 3: Illustration of the target region for optimal color performance in the TM-30

TriGain® Phosphor

To generate light, LEDs typically convert blue or violet light to other colors in the spectrum, such as red and green, using phosphors. The blue or violet light and the various phosphor emissions combine to form white light. The selection of phosphors determines the color quality and efficiency of the spectrum, and the red phosphor, in particular, drives the inverse relationship between the two. Standard red phosphors are very broad, and a significant amount of their emission is wasted in the inefficient deep-red and near-infrared regions (650nm and beyond). For enhanced color quality, the red phosphor is typically shifted further out into these inefficient wavelengths. For this reason, Current spent considerable time and effort developing a narrow red phosphor. The discovery of TriGain®, a potassium fluorosilicate (PFS) phosphor, after numerous years of research and development marked a significant breakthrough in phosphor technology in the LED market, providing an efficient solution to premium color quality. **Figure 4** provides a spectral comparison between TriGain® phosphor and standard red phosphors, against the photopic curve, or the luminous efficiency by wavelength.

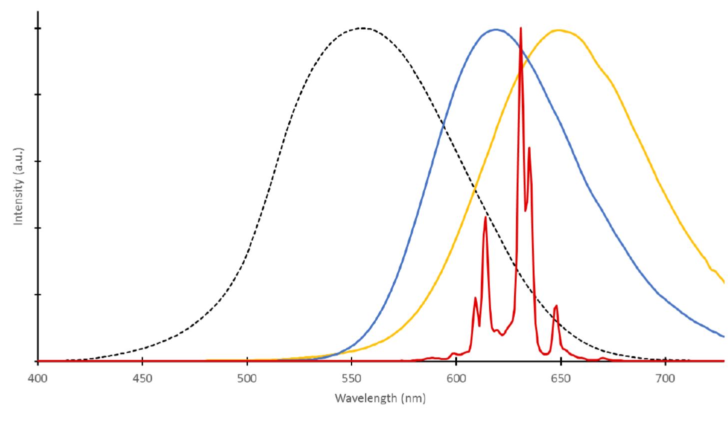

Figure 4: Spectral comparison of Current TriGain® phosphor with industry standard re phosphors, and the photopic curve.

Performance Comparisons

Performance comparisons of a variety of LED solutions help to illustrate the differentiation of TriGain® products with the rest of the market. The target regions identified in the TM-30 system (**Figure 3**) are used to compare color quality, while the luminous efficacy of radiation (LER) is used to compare efficiency. LER is a measure of how efficient the spectrum inherently is at producing light, using the photopic curve in **Figure 4**, and helps to remove variations from electronics and optical design when comparing different sources.

Five LED sources have been chosen as representative of industry capability, including both standard and premium offerings. A nominal color temperature of 3500K is used for this analysis, however a similar comparison would result at other CCTs. The plots in **Figure 5** illustrate the selected spectra, including (a) industry standard 80 CRI, (b) industry standard 90 CRI, (c) premium "full-spectrum", (d) premium enhanced saturation, and (e) TriGain®.

One apparent difference in **Figure 5** is the red phosphor emission component. From the industry standard 80 CRI spectrum (a) through the premium enhanced saturation spectrum (d), the red phosphor emission is seen shifting further and further right to longer, less efficient wavelengths, while the TriGain® spectrum (e) has very little energy lost in the longer wavelengths. Another key factor of color quality is the distinction between the red (above ~600nm) and green (~500-550nm) components of the spectrum. There is little distinction in the standard 80 CRI spectrum (a), but that distinction grows in the more premium offerings. With TriGain® being so narrow, there is a natural distinction between the green and red emission peaks.

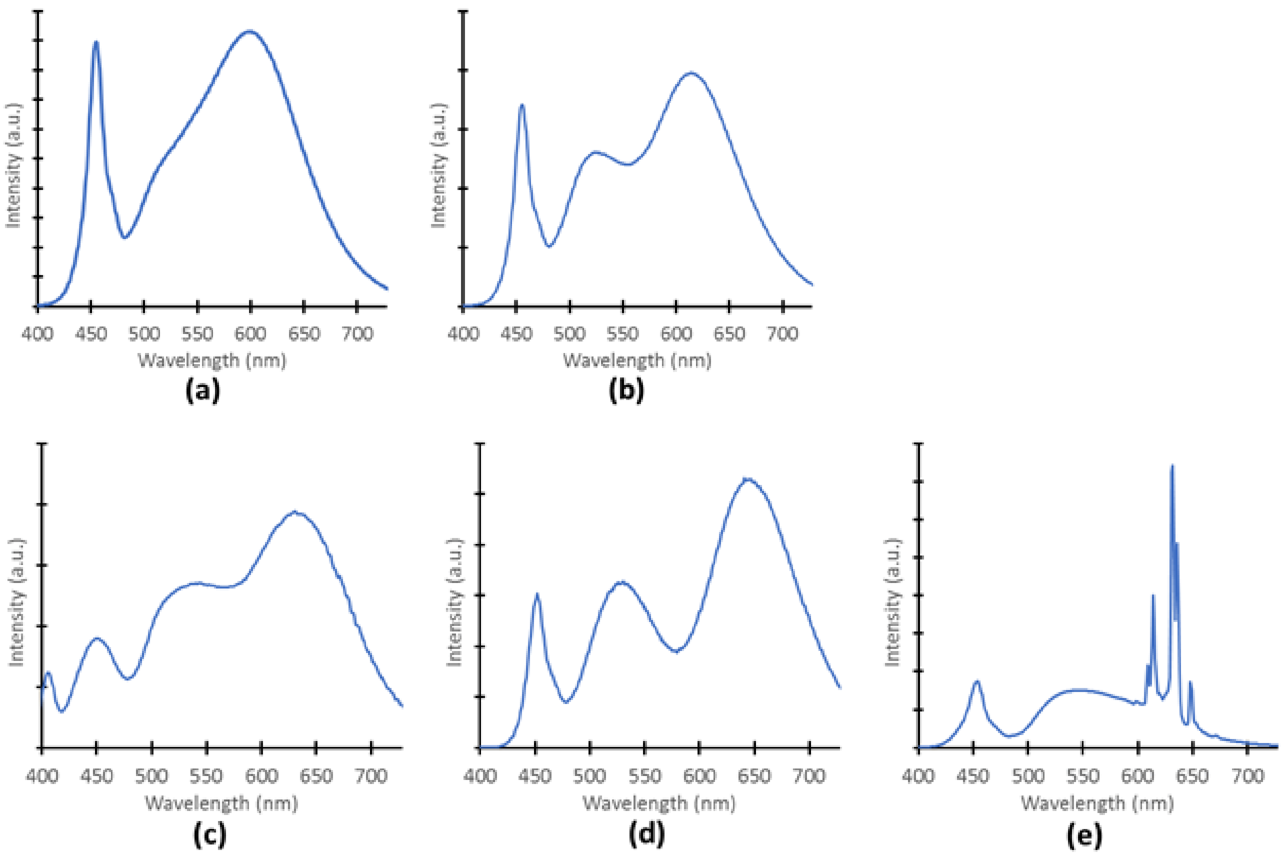

Figure 5: Spectral plots of five selected LED sources at 3500K for performance comparison including
(a) industry standard 80 CRI, (b) industry standard 90 CRI, (c) premium "full-spectrum", (d) premium enhanced saturation, and (e) TriGain®.

PERFORMANCE COMPARISONS

Each of the five spectra was analyzed for color quality and spectral efficiency. **Figure 6** plots the results for Rf, Rg, Rcs,h1, and LER, along with the target TM-30 regions from \Figure 3. In terms of color quality, the standard 80 CRI source is outside both the target areas on Rf-Rg and Rcs,h1, while the other four sources are in the general target areas, with only the full-spectrum and TriGain® sources achieving the most preferred Rcs,h1 area. The LER values clearly show the inverse relationship between efficiency and color quality. For the four non-TriGain® sources (a)-(d), the gamut index, Rg, and red saturation, Rcs,h1, values increase respectively, while the spectral efficiency, LER, decreases with each one. On the other hand, the rTriGain® source sits atop the LER chart, while still meeting the optimum color quality regions. Compared to the full-spectrum source (the only other source to hit the most preferred area), the TriGain® source is about 25% more efficient (330 LER vs. 265 LER).

To further illustrate the unique advantage of TriGain® products, **Figure 7** plots spectral efficiency (LER) against gamut index (Rg), or color saturation. The plot includes 13 LED sources without TriGain® between 3000K and 4000K (blue), along with TriGain® sources at 3500K and 4000K (red). For sources without TriGain®, the relationship between efficiency and saturation is linear with a strong fit (R2 = 0.95), while the TriGain® sources break the mold and enable performance unachievable by the rest of the market.

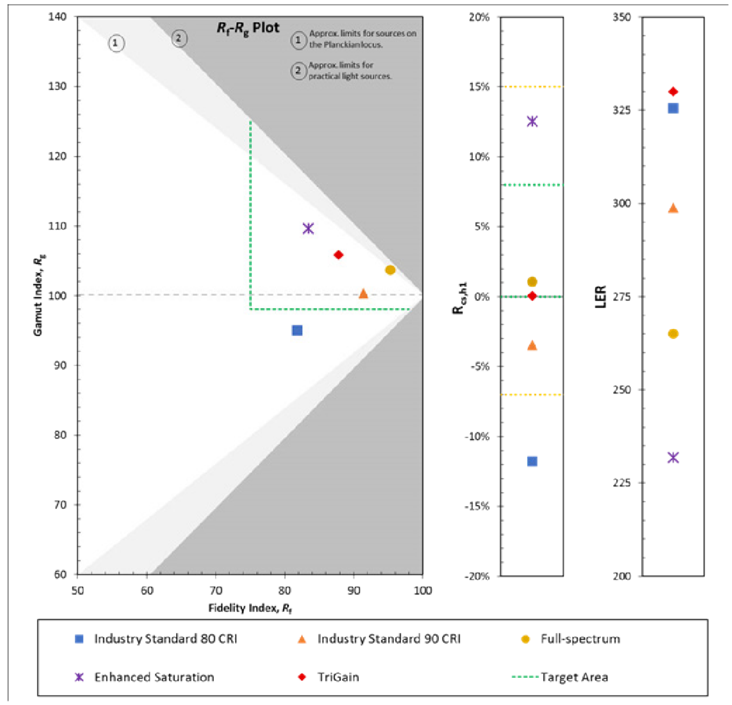

Figure 6: Plot of TM-30 values and targets for R_f, R_g, and $R_{cs,h1}$, along with spectral efficiency LER, for the five LED sources selected.

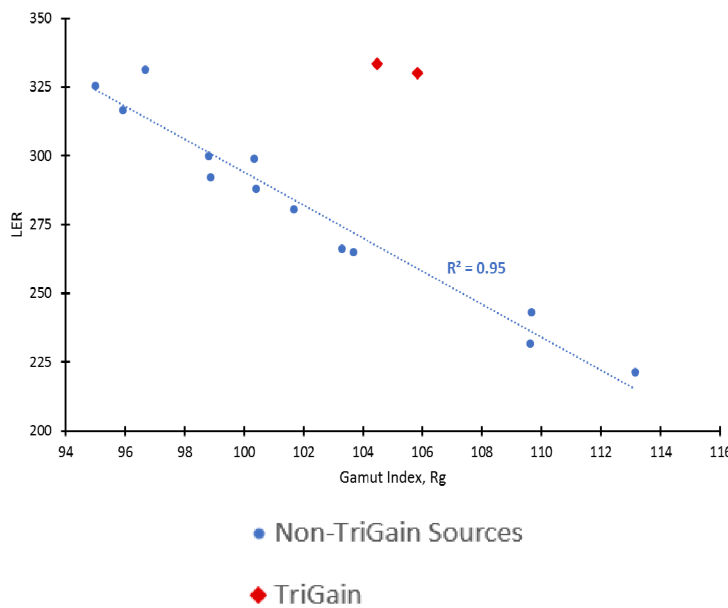

Figure 7: Plot of spectral efficiency (LER) vs gamut index (Rg) for LED sources from 3000K to 4000K without TriGain® (blue) and with TriGain® (red).

The TriGain® Advantage

Color metrics are evolving to match the capability of LED technology, with simplified values like CRI and R9 giving way to more detailed methods in TM-30. Meanwhile, color preference studies are trending towards a high fidelity, enhanced saturation light source for optimal color performance. The unique nature of Current's TriGain® phosphor, with its patented narrow emission, presents a technological leap beyond the rest of the market for both color and efficiency. Only a few light sources can meet the recommended color performance requirements for the TM-30 system, but TriGain® stands alone as the only one to do so with high efficiency. With the rising industry trends in color quality towards a more preferred performance range in fidelity and saturation, TriGain® products provide best-in-class color and efficiency, now and into the future.

Current

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