Understanding Color Shift Across Operating Conditions for Standard & Pro9™ COB LEDs

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INTRODUCTION & PURPOSE

The introduction of the Pro9™ phosphor system to XLamp® chip-on-board (COB) LEDs brought a large performance increase at 90 CRI (matching that of conventional 80 CRI) while maintaining high CRI and color quality metrics. Since these Pro9 LEDs employ different materials than the standard 90 CRI COBs, products utilizing Pro9 will have a different color shift response across the operating range.

This technical brief highlights the color shift differences between Cree LED's standard white XLamp COB LEDs and the XLamp Pro9™ COB LEDs as functions of temperature and current relative to data sheet binning conditions. Pertinent plots and information are presented to demonstrate these shifts in color space.

In this technical brief, the color shift and CRI response of these two systems was compared using CXB1830 LED standard and Pro9 phosphor systems.The CXB1830 LED is a COB style package operating at 35 V with a maximum current of 1400 mA and is available across CCT and CRI space in a multitude of bins.

CASE STUDY DEFINITIONS

The following abbreviations and shorthand will be used in this document extensively: standard phosphor (a combination of yellow + green + red emitting phosphors to achieve a particular CRI and CCT color point) and Pro9 phosphor (specific use of a narrow band red phosphor material for enhanced output in high-CRI applications).

SPECTRAL COMPARISON

From a spectral perspective, the standard 90 CRI and Pro9 90 CRI products appear to differ substantially in the 580 nm – 650 nm red wavelength range. Figure 1 and Figure 2 show representative spectra of standard 90 CRI and Pro9 90 CRI CXB1830 LEDs across the color space offerings, respectively. Both systems are pumped by a series of blue emitting diodes (spectral peaks around 450 nm) with yellow, green, and red emitting phosphors converting the blue light to a white output target with appropriate CRI. However, in the Pro9 system the red phosphor has substantially narrower emission lines vs. the very broad emission centered around 615 nm in the standard 90 CRI products.

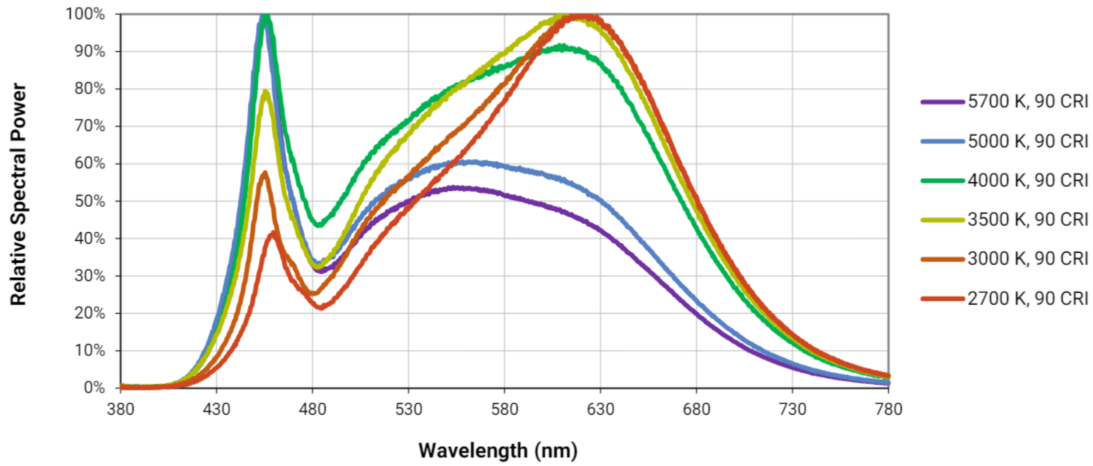

Figure 1: Compilation of representative CXB1830 LED spectra at the binning condition across white color space using standard phosphors and a 90 CRI minimum specification

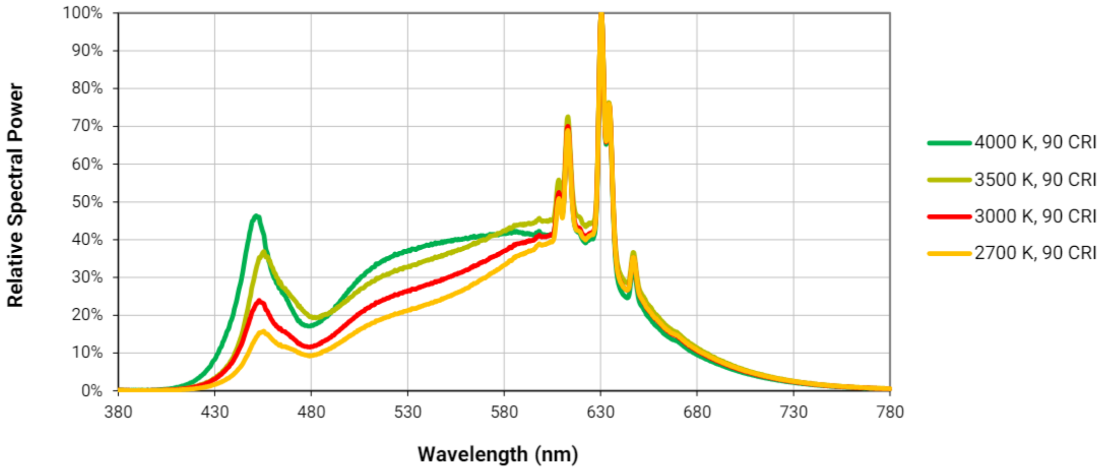

Figure 2: Compilation of representative CXB1830 LED spectra at the binning conditions across white color space using Pro9 phosphors and a 90 CRI minimum specification

Another important spectral feature, related to the color temperature of the product, is the total amount of blue emission (also called the red / blue ratio in high-CRI products). As the color temperature moves from 4000 K to the warmer CCTs, the total red phosphor content of the product increases and a larger percentage of the spectra output is weighted in the 580 nm+ wavelength range.

It is important to understand these spectral features considering that both the primary emission diodes – 450 nm in these products – as well as the secondary emission phosphors directly affect how the color point and color temperature shift at a given operating condition as compared to the binning condition presented on the data sheet. In both the standard and Pro9 90 CRI targets, the blue emitting diodes have similar wavelength responses to changes in current and temperature; therefore, this brief will primarily focus on the effect of current and temperature on the two phosphor systems.

COLOR SHIFT WITH TEMPERATURE

All phosphor-converted white LED systems demonstrate a shift in CCx and CCy as a function of temperature, with the shift direction and magnitude dependent on the phosphor materials used. The CXB1830 LED (3000 K color point) standard and Pro9 temperature-dependent phosphor shifts are shown in Figure 3, with peach lines representing the standard phosphor and red lines representing the Pro9 phosphor combinations. The color shift in CCx space differs between the two phosphor systems, with the Pro9 system exhibiting a larger shift on both sides of the 85 °C binning temperature. However, the CCy dependance on temperature is similar between the two systems.

It is important to note that the color shift with temperature is also dependent on the relative amounts of phosphor material in the LED package. For example, a 2700 K device will show a different color shift response compared to a 4000 K device. This will be detailed later in the brief.

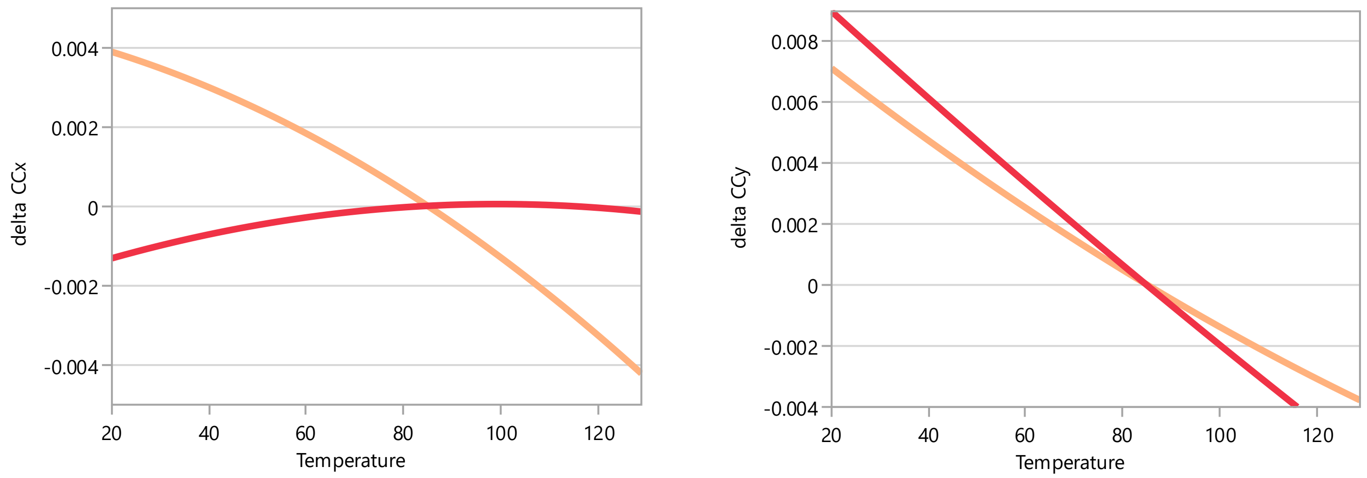

Figure 3: Color shift traces of a 3000 K CXB1830 LED with standard phosphors (peach lines) and Pro9 phosphors (red lines) as a function of case temperature at 800 mA

COLOR SHIFT WITH CURRENT

Similar to the color shift dependence on temperature, drive current also plays a role in the final color point of an LED device. The CCx and CCy color shifts vs. drive current at a fixed 85 °C case temperature are plotted in Figure 4. (The CXB1830 LED binning current, the reference point for the graphs in Figure 4, is 800 mA). The CCx shifts between the two phosphor systems are similar across the current range while the magnitude of the CCy shift for the Pro9 phosphor system is larger than the standard system both above and below the data sheet binning current of 800 mA.

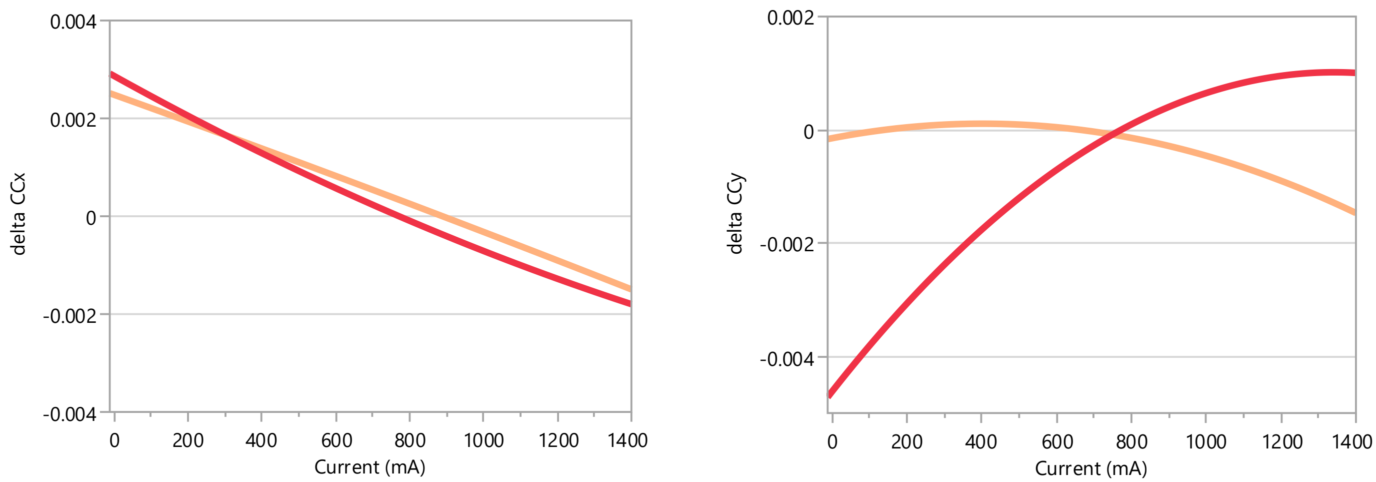

Figure 4: Color shift traces of a CXB1830 LED with standard phosphors (peach lines) and Pro9 phosphors (red lines) as a function of drive current at Tc = 85 °C

COMBINED COLOR SHIFT ACROSS THE OPERATING WINDOW

Understanding the individual dependence of color shift on temperature and current is critical for the lighting designer when understanding and designing for fixtures with varying ambient temperatures or dimming profiles. However, equally as important is understanding the shift in color point between the binning condition on the data sheet for a given LED (standard or Pro9) and the operating condition of the fixture.

Figure 5 presents the color point as a function of temperature and current, within the operating conditions of the data sheet, for CXB1830 Pro9 90 CRI products in 4000 K – 2700 K color points. The baseline 3-step ANSI bin was chosen for ease of illustration. Each of the corners of the polygon are represented by key shapes: circle (25 °C/200 mA), square (25 °C/1400 mA), pentagon (105°C/1400 mA), and triangle (105°C/200 mA). Empirically, as the current increases the color point generally moves up and to the left and as the temperature increases the color point moves down and to the left in CCx/CCy space. Knowing these boundary conditions and the operating conditions (plus any changes in emission color from external optics or films) of the fixture allows for precise knowledge of which color bins to purchase to net a desired final fixture color point.

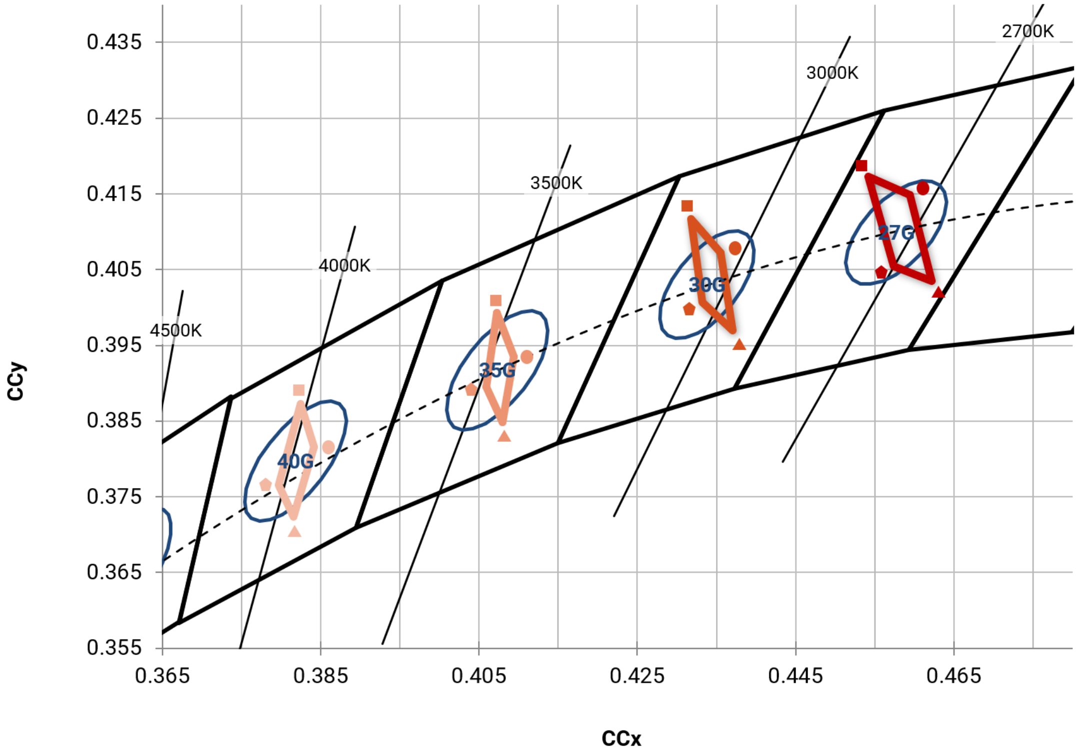

Figure 5: Plot demonstrating the color shift of a CXB1830 Pro9 LED device across color space and the bookends of the data sheet operating conditions. For each color space (4000 K, 3500 K, 3000 K, 2700 K) represented, the symbols correspond to the following conditions: circle (25 °C/200 mA), square (25 °C/1400 mA), pentagon (105 °C/1400 mA), and triangle (105 °C/200 mA).

In Figure 5, it quickly becomes apparent that a CXB1830 Pro9 90 CRI COB that is centered in the 30G 3-step ellipse (3000 K 3-step ellipse) can vary in color across a large fraction of that same 3-step ellipse depending on the operating condition of the fixture.

COMPARISON TO STANDARD PHOSPHOR COBS

Relative color shift is also an important criterion to understand when evaluating the Pro9 COBs as a direct replacement for standard 90 CRI COBs with higher lumen output and efficacy. Figure 6 shows the Pro9 and standard color shift in the same notation as Figure 5. The color shift along both the temperature and current lines between these two product types are orthogonal, respectively, meaning a COB that is binned at the center of the 3 step bin and operating at the edge of the allowed operating range will differ in color point across the 3000 K ANSI quadrangle when dropped into the same fixture. Depending on the operating condition of the end fixture, when a design is migrated to the Pro9 LED solution, a different color bin may need to be ordered to achieve the same final color point of the fixture. Cree LED now has Below Black-Body Line (BBL) color bins available for Pro9 COBs that aid in matching the standard phosphor color point when the Pro9 LED is used in low-temperature, high-current applications, represented by the square in Figure 6. Please see the Pro9 COB LED data sheets for more details, since they have been updated with comprehensive color shift graphs for the most common CCT & CRI configurations.

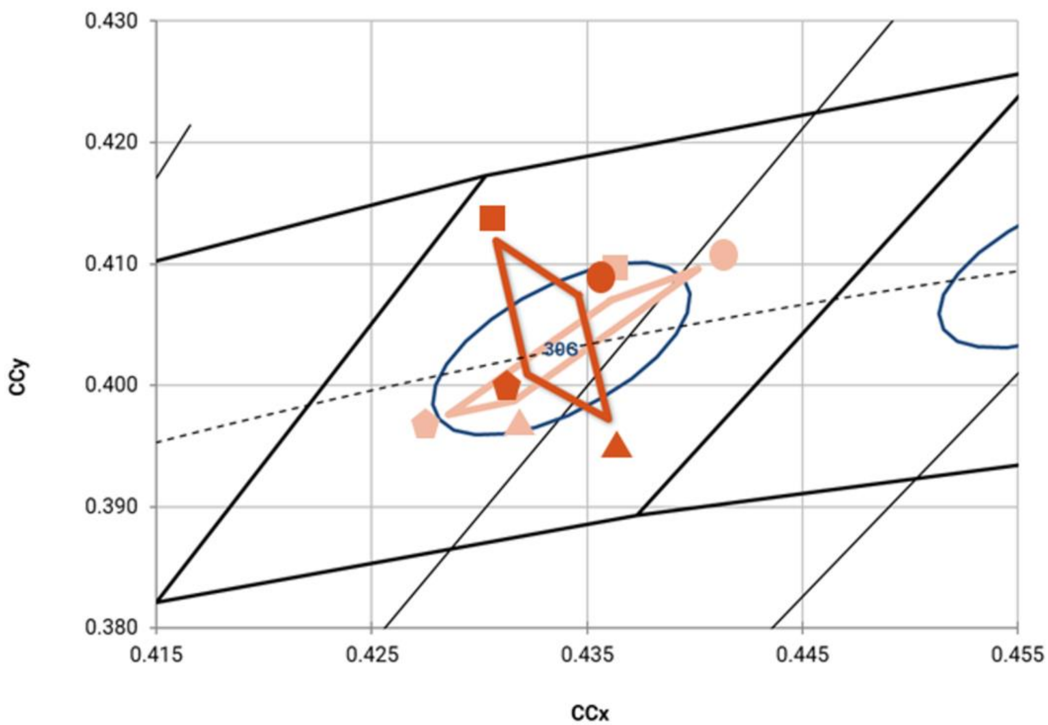

Figure 6: Plot demonstrating the color shift of a CXB1830 Pro9 LED device (red lines and symbols) and a CXB1830 standard phosphor LED device (peach lines and symbols) in 3000 K color space across the limits of the data sheet operating conditions. The symbols correspond to the following conditions: circle (25 °C/200 mA), square (25 °C/1400 mA), pentagon (105°C/1400 mA), and triangle (105°C/200 mA).