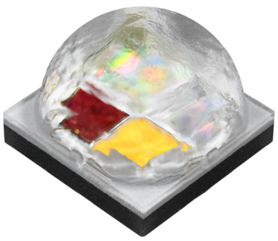
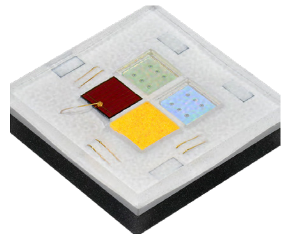
XP-L Color Technical Brief





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INTRODUCTION

With the launch of the XLamp® XP-L Color LED, a 3.5 mm x 3.5 mm multicolor LED component available in both lensed (high density) and flat-lens (high intensity) models, Cree LED has continued to push the boundaries of total output per area, color mixing, and optical source size in a discrete package. The XP-L Color LED was designed for use in architectural, entertainment, and color mixing applications, especially where fixture size is challenging in terms of dimensional size, total weight, or where the tightest emitter grouping is required. This technical brief demonstrates the usage and performance of the XP-L Color LED in several applications, including wall wash and 2x2 spotlight arrays, and provides a performance comparison with Cree LED's XM-L Color LED. Several optics are used throughout this technical brief; these optics are available to be purchased on the open market from the referenced companies in each section.

XP-L COLOR LED LINEAR WALL-WASH APPLICATION

Multicolor wall-wash lighting fixtures are designed to create a smooth, even illumination across vertical surfaces, enhancing the visual appeal of walls by highlighting textures, colors, and architectural features. These fixtures come in various types: track, recessed, cove, linear, and are often used in art galleries, museums, and commercial spaces to enhance the ambiance and draw attention to specific wall features. They can be customized with different beam angles, color temperatures, and dimming options to suit various design needs. From the LED perspective, a wall-wash fixture tends to require a Lambertian emission, tight emitter spacing, and high output candela to maximize coverage while minimizing fixture cost.

A total of four XP-L Color LEDs were built onto a linear MCPCB, either in non-rotated or rotated fashion (Figure 1) with a direct current driver input on one end, then fitted with four Ledil Leila Y-O optics. This particular optic is optimized for 3.5 mm x 3.5 mm LED packages (single color) and has an oval emission pattern with 45° + 15° FWHM, chosen as a good candidate for spreading light horizontally from a small source in a wall-wash type application. The MCPCB was placed at the base of a white painted wall wherein color wall-wash images were taken with a radiant imaging camera. Photometric data was recorded in an integrating sphere with a TEC to keep the board at a controlled temperature.

Two sets of linear boards were built up: one with all of the XP-L Color LEDs in the same orientation (non-rotated) and one with each XP-L Color LED rotated 90° with respect to its neighboring part (rotated). The purpose of both boards is to compare the subjective wall-wash color and coverage quality when the source emitters are modulated in the x-y plane, ideally for more even coverage. These two layouts are shown as cartoons in Figure 1, where the colored squares correspond to each individual color emitter.

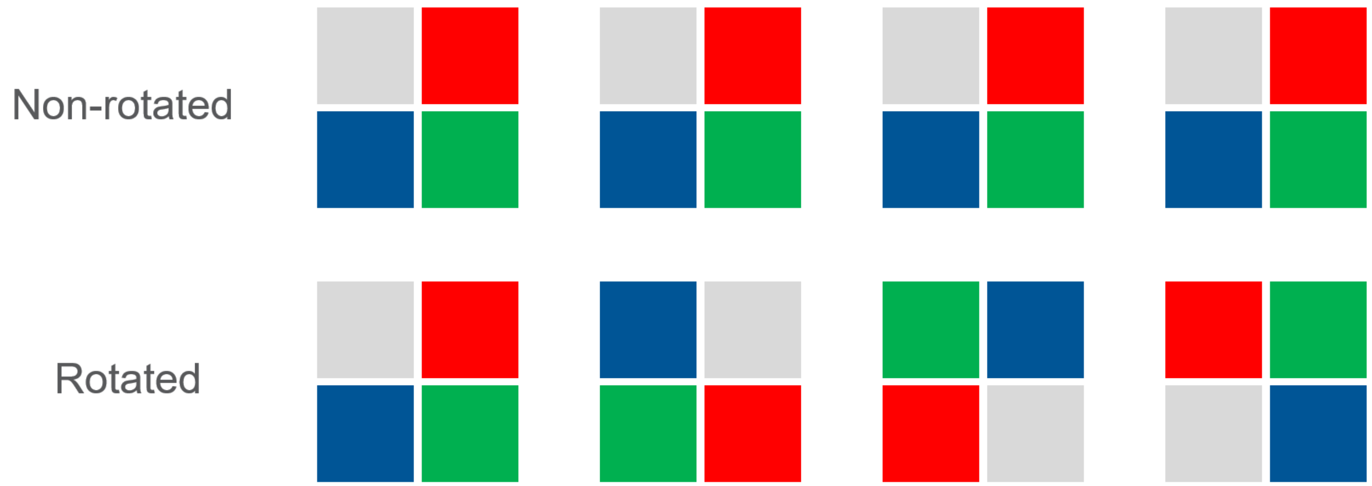

Figure 1: LED RGBW emitter layout showing the non-rotated and rotated cases

Before characterizing the emission profile of the XP-L Color LED with the Leila Y-O optic, the parametric data was recorded and is tabulated in Table 1. The white emitter in the LEDs in this array was a 5200 K device with 82 CRI. Optical efficiency for this optic was advertised at 80% and was measured to be approximately 78% across each of the four individual channels.

Table 1: Parametric performance of the XP-L Color LED RGBW channels in the Leila Y-O optic. All channels were driven at 350 mA.

Channel	Power (W)	Luminous Flux (lm)
Red	3.08	225
Green	4.06	397
Blue	4.20	69
White	4.24	394

Wall-wash emission images were all collected in the same fashion without moving the linear board between each channel testing. Images of each of the four channels (red, green, blue, white) as well as a color-mixed 3000 K white target are shown in Figure 2; non-rotated configurations are represented by the top row of wall-wash images while rotated configurations are represented by the bottom row of images. It is quite clear, both in the captured images as well as viewing each in person, that the rotated LED linear configuration produces a more even and full coverage of the subject wall when everything else is kept static between the two configurations. The impact of orientation is most obvious in the beam edges (the bottom left and right corners of these images) as well as in the mixing quality of the 3000 K color-mixed emission.

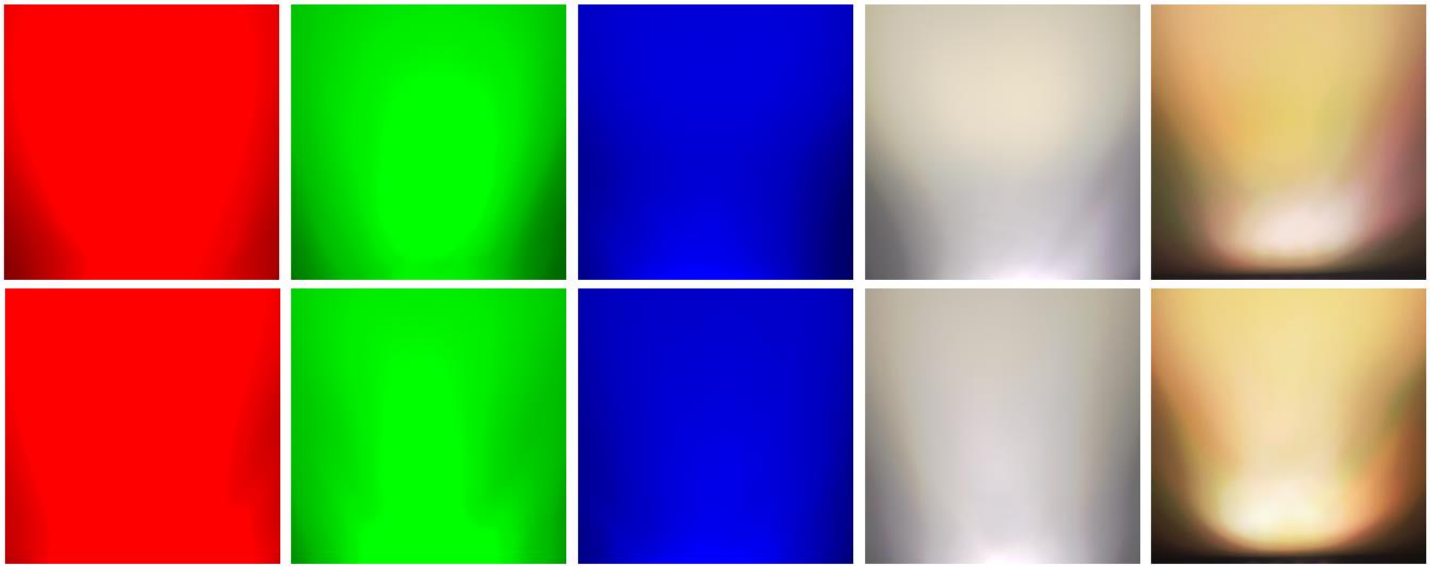

Figure 2: Wall-wash emission color images of non-rotated XP-L Color LED (top row) and rotated XP-L Color LED (bottom row) in the RGBW and "boosted white" 3000 K conditions.

Further color-mixing experiments were performed to understand the capability for this setup to produce white colors spanning the CCT space from 3000 K to 5000 K. A 1000-lm output target was chosen as a baseline in an attempt to normalize approximate power and thermals, as well as to simulate a wall-wash output appropriate for a 15-20-ft tall wall and this type of oval emission. Since the system is locked to four channels and an initial white CRI of 82, there is little head room to increase the CRI as the mixed color target moves toward warmer CCT temperature. The tabulated results of the three target white colors are shown in Table 2 below, including LPW that are in-line with an optical loss of approximately 78%.

Table 2: Comparison of the optical performance of three color-mixed white targets in the Leila Y-O optic

Target CCT	Power (W)	Luminous Flux (lm)	CCT	CRI	LPW
5000 K	12.6	998	4975	82	78.7
4000 K	12.3	1020	3945	68	82.7
3000 K	12.7	1008	3039	53	79.5

In a real application, a CRI of 53 in warm white is likely to be too low to be considered acceptable; however, there are two paths to increase the CRI as the color temperature of the mixed-color target moves warmer: use an XP-L Color LED with a white emitter that has 90+ CRI or is a warmer color point to start, and/or move to a six-channel system that includes emitters in the cyan and lime color spaces. These are outside the scope of this technical brief, but more information can be found in the respective Cree LED application notes.

XP-L COLOR LED 2X2 ARRAY

Designing LED fixtures for stage and entertainment lighting involves a blend of creativity and technical precision. Key elements in their design include the ability to produce a wide spectrum of colors, often through four-channel RGBW or six-channel RGBWWW (with cool, neutral, warm whites) / RGBWCL (with cyan and lime) configurations, allowing for dynamic and mood-setting lighting effects. Advanced LED fixtures also incorporate features like programmable movement and dimming capabilities, which enable intricate lighting designs that can enhance the performance as well as audience engagement. Entertainment and more specifically stage lighting fixtures generally push the envelope on power density and total output, often sacrificing long lifetimes for higher operating temperatures and input powers. The most common entertainment-related fixtures fall into two categories: spotlights (movable or static) and flood lights (of many different beam widths and shapes). In this section, we explore a 2x2 array of XP-L Color LED components with a spotlight optic.

The experimental parameters for this spotlight application evaluation using the XP-L Color LED are as follows: a MCPCB design for four XP-L Color LEDs in a 2x2 grid with 90° rotation to each neighboring part (Figure 3), a CP13939_RGBX2-M lens mounted at each LED position, individual direct current drivers for each of the four channels, an integrating sphere to collect parametric data, and a radiant imaging camera to capture the spotlight shape. The CP13939 optic is manufactured by Ledil and was originally designed and optimized for the larger XM-L Color LED component (a 5.0 mm x 5.0 mm footprint with approximately 50% larger individual emitters) and has an optical efficiency in the 75% range. This RGBX-M optic is designed for applications requiring a round beam pattern with a medium spotlight of approximately 30°, which was maintained with the smaller XP-L Color LED. The white emitter is centered on the black body at 5200 K and has a color rendering index of 82.

Figure 3: XP-L Color LED 2x2 MCPCB experimental setup with three of four optics present (left) and component layout cartoon showing RGBW emitter location (right)

After mounting the XP-L Color LEDs to the MCPCB, parametric performance data was collected using a 2-m integrating sphere and associated hardware at 25 °C. This data is tabulated in Table 3 and represents typical performance with the CP13939_RGBX2-M optic attached.

Table 3: Parametric performance of the XP-L Color LED RGBW channels in the Ledil CP13939_RGBX2-M. All channels were driven at 350 mA.

Channel	Power (W)	Luminous Flux (lm)
Red	3.08	201
Green	4.06	351
Blue	4.20	61
White	4.24	354

The optical efficiency was empirically found to be 70.8%, slightly lower than the typical 75% as advertised for the XM-L Color LED likely due to the changes in package size and emission size when using the XP-L Color LED. Additionally, data for a “boosted white” color mix was collected to highlight the capability of using this array to color mix for white; the resultant color was centered on the black body at 3000 K. We chose 3000 K as a test target due to the generally accepted indoor usage of this CCT; however, a large range of white colors can be created using four channel mixing, from 6500 K – 2200 K, with adequate color quality metrics. The “boosted white” channel parameters and output total can be found in Table 4 below.

Table 4: String power details for achieving the "boosted white" target using the XP-L Color LED

Channel	Voltage (V)	Current (mA)	Power (W)	Luminous Flux (lm)	System Efficacy (LPW)
Red	8.80	370	3.22	-	-
Green	10.8	210	2.27	-	-
Blue	10.2	5	0.05	-	-
White	11.7	260	3.04	-	-
Boosted	-	-	8.58	711.1	82.9

Color images of the resultant spotlight when the individual red, green, blue, white as well as the mixed "boosted white" 3000 K channel are shown below in Figure 4.

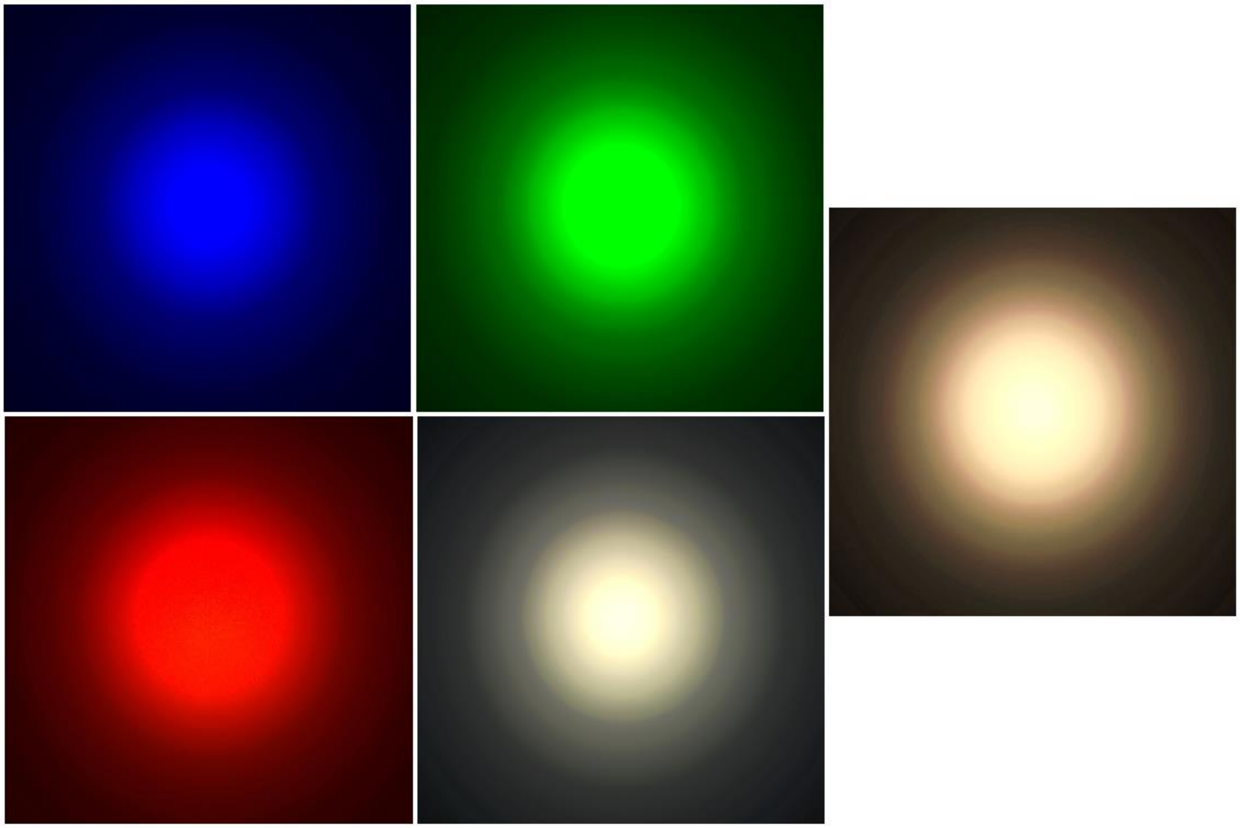

Figure 4: Emission images of single-color RGBW and the "boosted white" spotlights with optic using the 2x2 XP-L Color LED array

The benefit of using a rotated layout in the 2x2 array where each XP-L Color LED component is rotated 90 degrees relative to its neighbor can be seen in Figure 5. A single XP-L Color LED device in-optic shows an asymmetric color shift in the all-on configuration, arising from the inherent spatial asymmetry of the four channels. This asymmetry can be eliminated in the 2x2 array using a rotated device layout, also shown in Figure 5 in the blue trace, and can deliver a more uniform output in the end application.

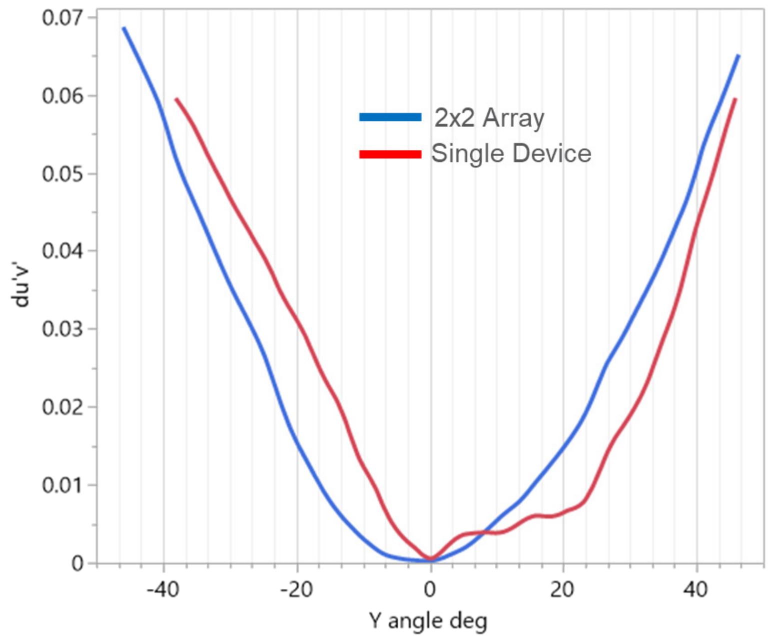

Figure 5: Radiant imaging projection where each channel is set to 350 mA. Overlay of 2x2 versus 1x XP-L Color LED color over angle scans

COMPARISON TO XM-L COLOR LED IN SPOTLIGHT APPLICATIONS

The linear and 2x2 array cases highlighted above showcase the use of the XP-L Color LED as an RGBW emitter for representative architectural and entertainment applications. One aspect of this new product that has not been explored yet is how it compares to the landscape of discrete RGBW components. The XP-L Color LED is the first high-power RGBW discrete component in the 3.5 mm x 3.5 mm footprint, so the most applicable comparison is to the larger XM-L Color LED. To understand the targeted applications and differences between the XP-L Color LED and the XM-L Color LED, an MCPCB was designed to test a single RGBW emitter with the same CP13939_RGBX2-M optic as in the 2x2 array described in the previous section.

The resulting beam patterns are qualitatively matching for both the individual channels and the all-on condition (each of the four emitters driven at 350 mA concurrently). The spotlights appear similar in size and quality by the naked eye across the colors, with slight high-angle banding seen in both components in the all-on condition. Depending on the application and uniformity necessity, this banding could be mitigated with a simple diffuser sheet.

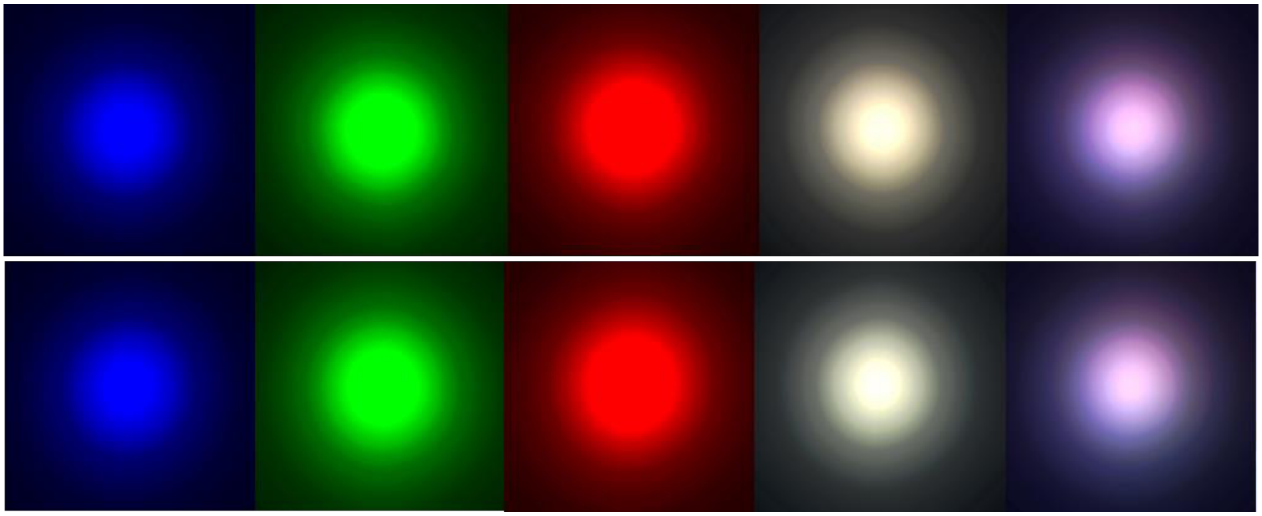

Figure 6: True color beam pattern of the individual channels for thr XP-L Color LED (top row) versus the XM-L Color LED (bottom row) in the CP13939_RGBX2-M optic.

The luminance plot comparisons of the red, green, and blue channels of the XP-L Color LED and the XM-L Color LED are compared in Figure 7. While the absolute luminance values of this comparison are unique to the measurement set up, relative comparisons can be extracted from the data. Luminance performance is both a function of total lumen output and source size, with smaller source sizes delivering higher luminance at equal lumen output. Despite the XP-L Color LED's approximately 50% reduction in source size, the luminance performance is matching the XM-L Color LED in optic.

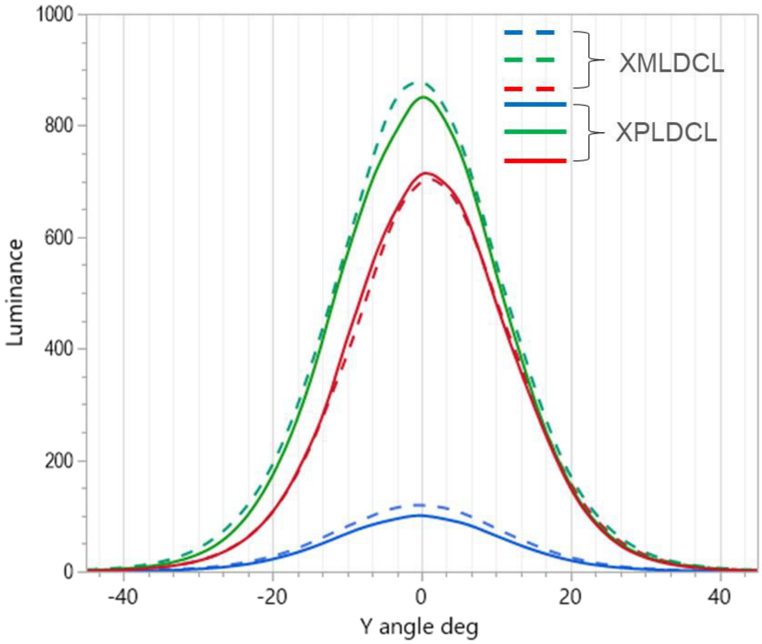

Figure 7: Luminance plots comparing red, green, blue channels of the XM-L Color LED versus the XP-L Color LED in CP13939_RGBX2-M optic at Y=90° slice. Individual channels are set to 350 mA. Dashed lines correspond to the XM-L Color LED and solid lines to the XP-L Color LED. Channel color corresponds to graph color.

Tabulated performance data for all four of the channels and the all-on mode for both the XP-L Color LED and the XM-L Color LED in the 1x array with the CP13939_RGBX2-M optic is presented in Table 5 for reference.

Table 5: Power and flux tabulation for the XP-L Color LED and the XM-L Color LED RGBW/all-on channels in the CP13939_RGBX2-M optic

Component	Channel	Current (mA)	Power (W)	Luminous Flux (lm)
XP-L Color	Red	350	0.77	53
	Green	350	1.03	93
	Blue	350	1.04	16
	White	350	1.06	88
	RGBW	350	3.92	246
XM-L Color	Red	350	0.75	56
	Green	350	0.99	110
	Blue	350	1.00	19
	White	350	1.05	106
	RGBW	350	3.78	289

In terms of total system efficacy, the XM-L Color LED is approximately 10-25% more efficient across the different colors at the 1-W and 4-W (all-on) nominal conditions. Considering the larger emitter size, lower operating temperature, and larger dome, the XM-L Color LED component outperforming the smaller XP-L Color LED is logical; however, when the application requires miniaturization with strong candela and good color mixing, the parametric output and intensity of the XP-L Color LED outshines the XM-L Color LED.

Table 6: System-level LPW comparison of the XP-L Color LED and the XM-L Color LED in the all-on condition with the XP13939-RGBX2-M optic

Channel	XP-L Color LPW	XM-L Color LPW	Delta
Red	68.8	74.7	8.6%
Green	90.3	111	23%
Blue	15.4	19.0	23%
White	83.0	101	21%
RGBW	62.7	76.4	22%

CONCLUSION

The XP-L Color LED component was characterized across several general applications in this technical brief: a linear board/optic combination to simulate an architectural wall wash, a 2x2 array emulating a stage spotlight, and a detailed comparison of a single-up XP-L Color LED versus the larger and more powerful XM-L Color LED in several optics. As the optics vendors evaluate and design for the XP-L Color LED, Cree LED expects specific optics for RGBW 3.5 mm x 3.5 mm LED components to become more and more common.

The XP-L Color LED is a high-power component that works well where application requirements define the smallest fixture size while maintaining tight emitter grouping and high color mixing/intensity. Generally, the spacing required when using individual discrete emitters in color mixing applications leads to larger optics, larger overall systems, and an overall increased cost; the XP-L Color LED can help mitigate these issues when used in these types of applications. This component fills a performance envelope that was not previously addressed from the mainstream LED manufacturers.

This information should be employed as a basis for understanding the capabilities of the XP-L Color LED component as well as a simple usage guide. Full fixture design requires optical, thermal, and mechanical simulations to account for many facets of a live system that were kept controlled in this brief. This brief is exemplar in nature; there are no performance warranties or guarantees implied or otherwise.