Product Document

Published by
ams OSRAM Group

OSRAM
Opto Semiconductors

Brilliant Mix and Mix-to-Match — Professional white for general lighting

Application Note

Valid for:
DURIS® S / DURIS® E / DURIS® P
OSLON® Square / OSLON® SSL
OSCONIQ® P

Abstract

Using LEDs, white light can be generated either through phosphorus conversion or color mixing. In this application note, two additional concepts of generating high-quality white light are introduced: Brilliant Mix and Mix-to-Match.

With the Brilliant Mix concept, a mint white LED is combined with a red emitter to generate high-quality white light. The correlated color temperature (CCT) can be varied by selecting an appropriate bin. The main advantage of this approach is a higher luminous efficacy (up to 30 % increase) compared to phosphorus-converted LEDs with similar CCT and power consumption, while not compromising on the color quality.

On the other hand, the Mix-to-Match concept is a proprietary program with which even tight color bin specifications can be ensured over the long term, even in high-volume LED applications. Using a mathematical model, color, voltage, or brightness bins can be mixed and matched to result in tighter bin specifications. This has the advantage that the entire production distribution can be used; it also ensures that the application always has the same properties and appearance.

Author: Retsch Stefanie / Chew Ivan Ken Yoong

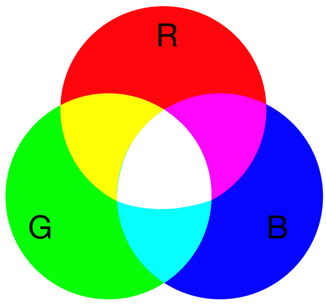
Table of contents

A. Conventional white light generation

Presently, there are two approaches to generate white light with LEDs. The more commonly used method involves utilizing phosphorus-converted white light — a short wavelength light (typically blue or near UV) from a single LED chip is converted to a longer-wavelength light by a yellow phosphorus coating. The second method involves mixing multiple LED emitters to create a spectral power distribution (SPD) that appears white.

These methods follow the principle of additive color synthesis to generate white light. As shown in Figure 1, white light can be generated by mixing the three primary colors of Blue + Green + Red (color-mixed light) or a single primary color with its complementary color, for example Blue + Yellow (phosphorus-converted light).

Figure 1: Principles of color mixing to generate white light

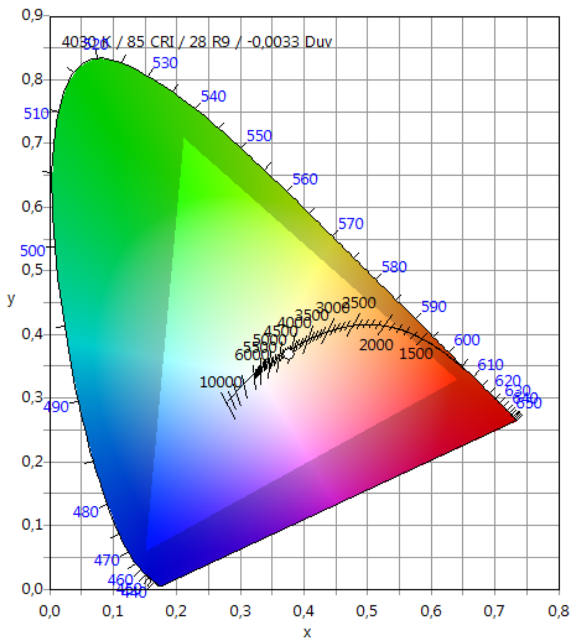


Color-mixed white light

Color-mixed white light is produced by mixing multiple emitters with different primary wavelengths. Thereby, the individually colored chips (typically Red, Green and Blue) are regulated in such way that together they emit white light. The color properties of the resultant spectrum can be tuned by adjusting the wavelengths, driving currents, and number of primary emitters. Typically three emitters are used, but certain applications can require more primary emitters. Increasing the number of emitters improves the light quality and the producible color gamut, but the system's cost and complexity also increases accordingly.

A major advantage of this method is its tunability. Since all emitters are controlled separately, any color coordinate inside the area defined by the intersection of the emitters' chromaticities on a CIE color chart can be produced (Figure 2). This area is also known as the color gamut of the light source. It can be seen that a greater variance in the emitters enlarges the color gamut.

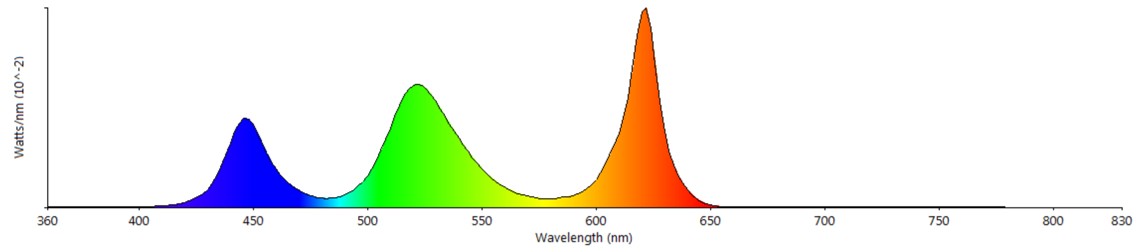
Figure 2: Color gamut produced by RGB emitters



Theoretically, color-mixed white light can achieve a higher luminous efficacy than phosphorus-converted white light. Furthermore, color mixing allows greater flexibility and control over the light spectral composition and allows very fast modulation as the phosphorescence radiative lifetime is in the millisecond range.

However, this white light generation method suffers from generally low CRI values and low luminous efficacy at white color coordinates, particularly for warm-white light as the blue chip content (the most efficient LED at the moment) is decreased. The color quality can be improved by adding more emitters to broaden the spectral power distribution, but this will lead to higher costs and more complex driving electronics.

Figure 3: Typical spectral power distribution of a white RGB LED

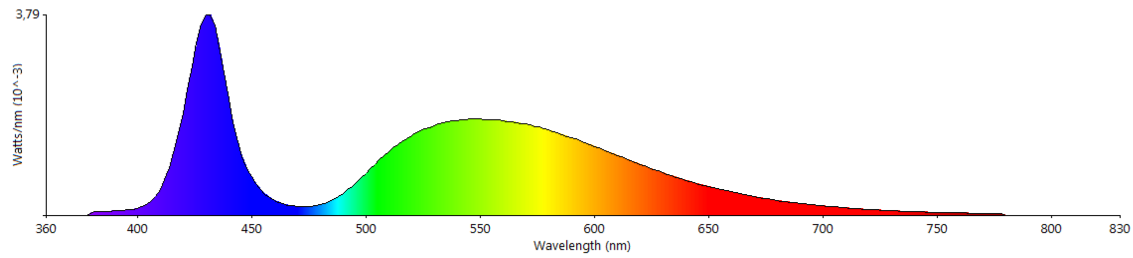


Since most general lighting applications require only one set of white color coordinates and no color change, this method is generally not used. The advantages of this method are more suited for specialized lighting applications where a high degree of light tunability is valued, such as stage lighting, smart lighting, horticulture lighting applications, and display lighting.

Phosphorus-converted white light

In a phosphorus-converted white LED, a blue LED chip (~ 450 nm) excites the luminescent substances in the converter material (yellow phosphorus), causing a change in the visible light spectrum produced. According to the color model mentioned previously, the human eye perceives the combination of the two contrary colors blue and yellow as white light. Relevant light properties such as the correlated color temperature (CCT), color rendering index (CRI), and R_9 content can be varied by changing the phosphorus composition.

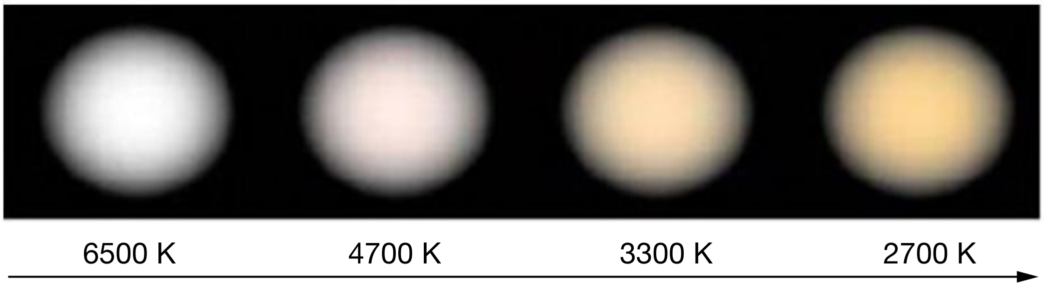
Figure 4: Typical spectral power distribution of a phosphorus-converted LED



White light produced by this method is particularly efficient at higher CCTs as the target color coordinates are closer to the blue light source. To produce lower CCTs, several luminescent substances must be combined, mostly by adding red phosphorus to yellow. However, this increases the unavoidable effect of Stokes energy loss, which is the energy lost due to the conversion of short wavelength photons into long wavelength photons, reducing the overall efficiency by 10 - 30 %. Generally, the lower the CCT, the less efficient these LEDs are (Figure 5).

In terms of lighting quality, phosphorus-converted white light features a broader and more homogeneous spectral power distribution compared to color-mixed white light. Today, a CRI in excess of 95 can be produced by phosphorus steering. However, there is an inherent trade-off with the luminous efficacy.

Figure 5: Decline in LED efficiency based on the color temperature



One benefit of this method is the integrated design with a single chip. This simplifies the control of the LEDs. Furthermore, the optical system is easy to handle since no color mixing in the secondary optics is required.

When comparing the spectrum of the single-chip technique (Figure 4), we can see that the curve is broader and more homogeneous than the one of the RGB system (Figure 3). Besides the local minimum between 480 nm and 490 nm, the weak red range of the single-chip technique in particular turns out to be a major disadvantage, because it prevents a good CRI value, which is important for general lighting applications.

The color rendering index of white converted LEDs typically lies in the range of 70 – 80. The latest developments achieve a CRI value of around 95, but with a lower efficacy. Currently, the white converted concept has become the accepted standard for general lighting applications.

B. Brilliant Mix

The Brilliant Mix concept is an approach developed by OSRAM Opto Semiconductors, which combines the two existing white light generation methods to create a warm-white LED light source with a high color rendering index (CRI > 90) and high luminous efficacy. This method eliminates the less efficient red phosphorus, traditionally used to produce lower CCTs, by including a discrete Amber or Red LED.

The Amber or Red LED is combined with a White LED (EQ White) to generate warm-white CCTs within the 2700 – 4000 K range. The “EQ White” LED is a special phosphorus-converted LED with a blue chip and a green phosphorus which has the advantage of a very low conversion loss rate. This results in an efficient light source when used in combination with the blue emitter. Thanks to the discrete Red LED, the proportion of red light (needed for the warm-white chromaticity coordinates and the high CRI) does not have to be generated by the phosphorus.

If the color coordinates of the two emitters are plotted on a CIE color chart (Figure 6), all possible combinations along the straight line between both points can be achieved by adjusting the mixing ratios. It can immediately be seen that color coordinates along the Planckian locus can also be generated. The CCT produced can be varied by changing the chromaticity of either emitter.

The main advantages of this new approach is a higher luminous efficacy (up to 30 % increase) compared to phosphorus-converted LEDs with similar CCT and power consumption. Furthermore, the Brilliant Mix concept features very good color quality values (Table 1).

Figure 6: The Brilliant Mix concept in the CIE color space. All color coordinates along the line between the two emitters can be created

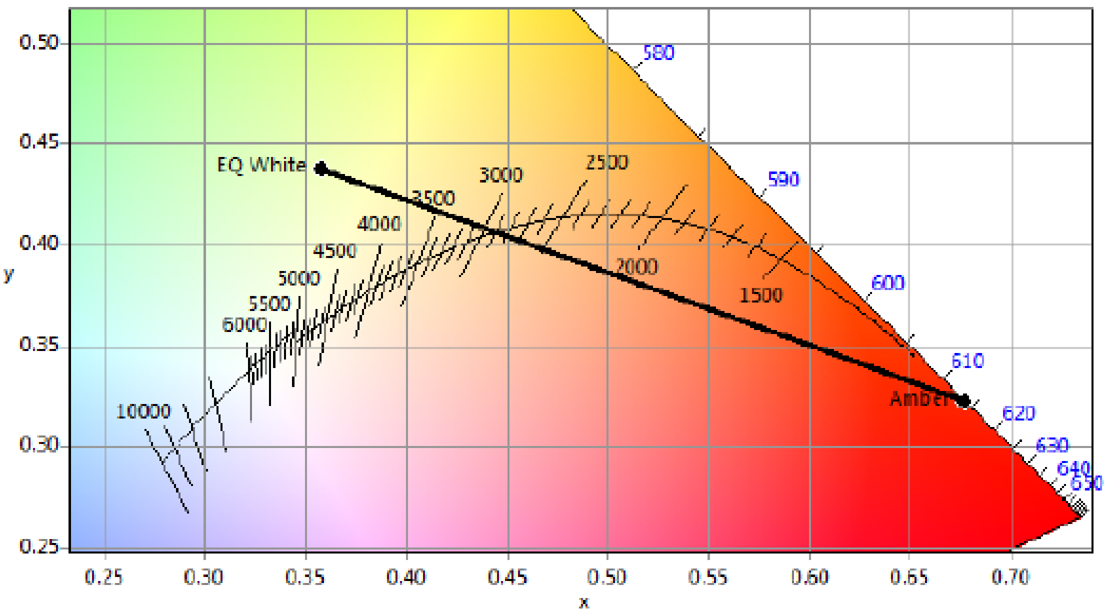
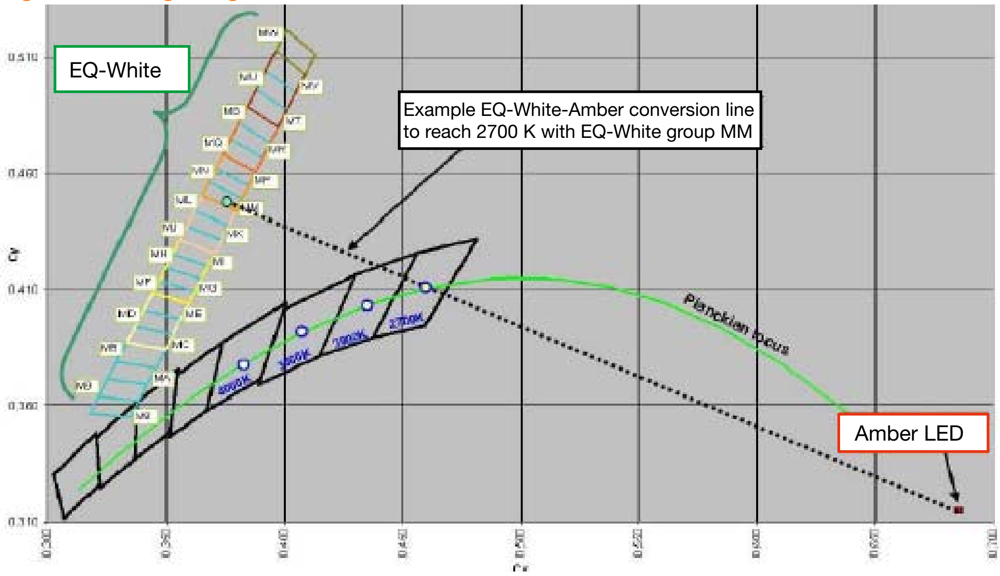


Table 1: R_x performance of Brilliant Mixing LEDs compared to other sources

Source	**R_a**	**R_9**	**R_{13}**
Brilliant Mix 2700 K	92	83	97
Brilliant Mix 3000 K	91	78	98
Brilliant Mix 4000 K	83	48	85
Compact metal halide (typ.)	82	27	93
Compact fluorescent lamp (typ.)	87	17	93

As can be seen from Figure 6, only one set of color coordinates can be achieved based on the color coordinates of the two emitters. To be able to implement color temperatures in the 2700 – 4000 K range, the LEDs used must feature slightly different color coordinates. This is achieved through the bin distribution (variance that occurs during production) of the EQ-White LED. In addition to being binned by their luminous flux, the LEDs are grouped according to their color coordinates (Figure 7). Different bins can then be selected during the design stage to achieve target color temperatures.

Figure 7: Targeting different CCTs via EQ-White bin selection



For example, the OSLON® SSL product portfolio is particularly well suited to the Brilliant Mix concept. The single-chip LEDs with primary optics are housed in a compact 1-watt package. The compact package size (3 mm x 3 mm) is advantageous as it allows the creation of tight clusters, ensuring a good color mix in conjunction with the wide primary lens angle of 150°. Moreover, these ceramic-based LEDs also feature a very good luminous efficacy, a thermal resistance of 7 K/W, and a life cycle of over 100,000 hours, subject to application conditions.

C. Mix-to-Match

Under the Mix-to-Match name, OSRAM Opto Semiconductors has developed a proprietary program with which even tight color bin specifications can be satisfied and ensured over the long term, even in high-volume LED applications. Generally, the program works for systems with two or more LEDs wherein the individual LEDs themselves should not be visible or a sufficient mixture of the two LEDs is available. Using mathematical algorithms, the process parameters luminous flux, wavelength, color coordinates and voltage are set for application-specific requirements individually or in combinations. This has the advantage that the entire production distribution can be used; it also ensures that the application always has the same properties and appearance.

Parameters that can be mixed and matched:

- Color
- Luminous flux
- Voltage

Figure 8 shows an example for a color mix-and-match. Two 5-step color bins are combined to create a 3-step color appearance at system level. A mixture of an LED from the top left bin and an LED from the bottom right bin will result in a system-level appearance with color coordinates within the bin of the center point intersected by them. This allows taking advantage of the higher yield, while maintaining tight color regulation.

Figure 8: Example of color mix-and-match

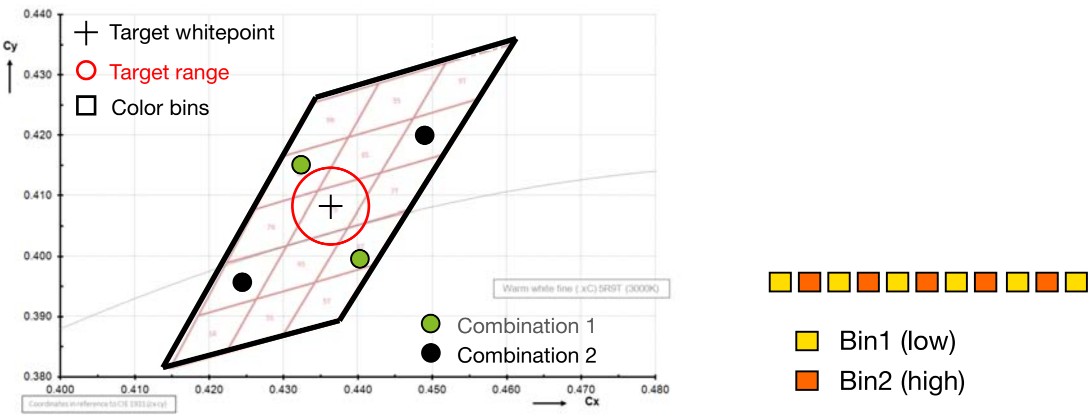
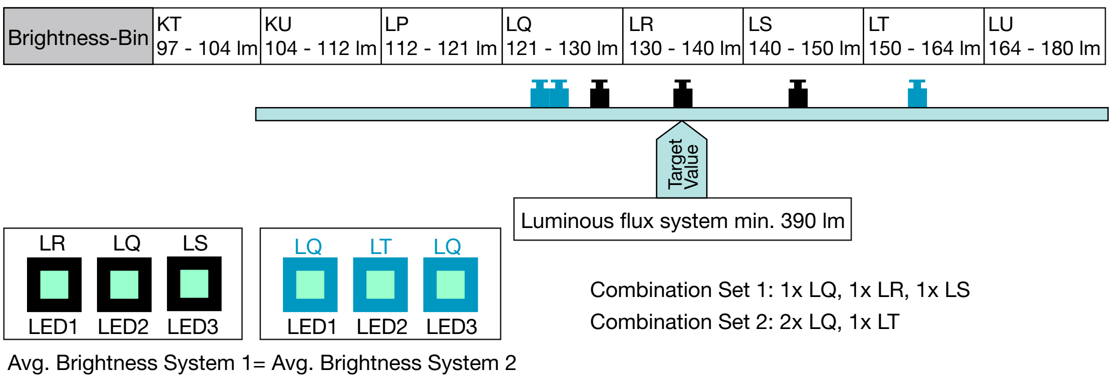


Figure 9 illustrates the general principle of Mix-to-Match by taking the luminous flux parameter as an example. It shows a system with three LEDs for which a minimum total luminous flux of 390 lm is required. Ideally, this can be achieved by installing three LEDs from the "LR" luminous flux bin. Since the production line does not turn out only "LR" LEDs, however, suitable combinations from the various bins are defined which also meet the specification.

In this example, the combinations 1x LQ + 1x LR + 1x LS or 2x LQ + 1x LT can be defined, because both meet the total luminous flux requirement of at least 390 lm.

Figure 9: Mix-to-Match principle using the luminous flux parameter for a three-LED system

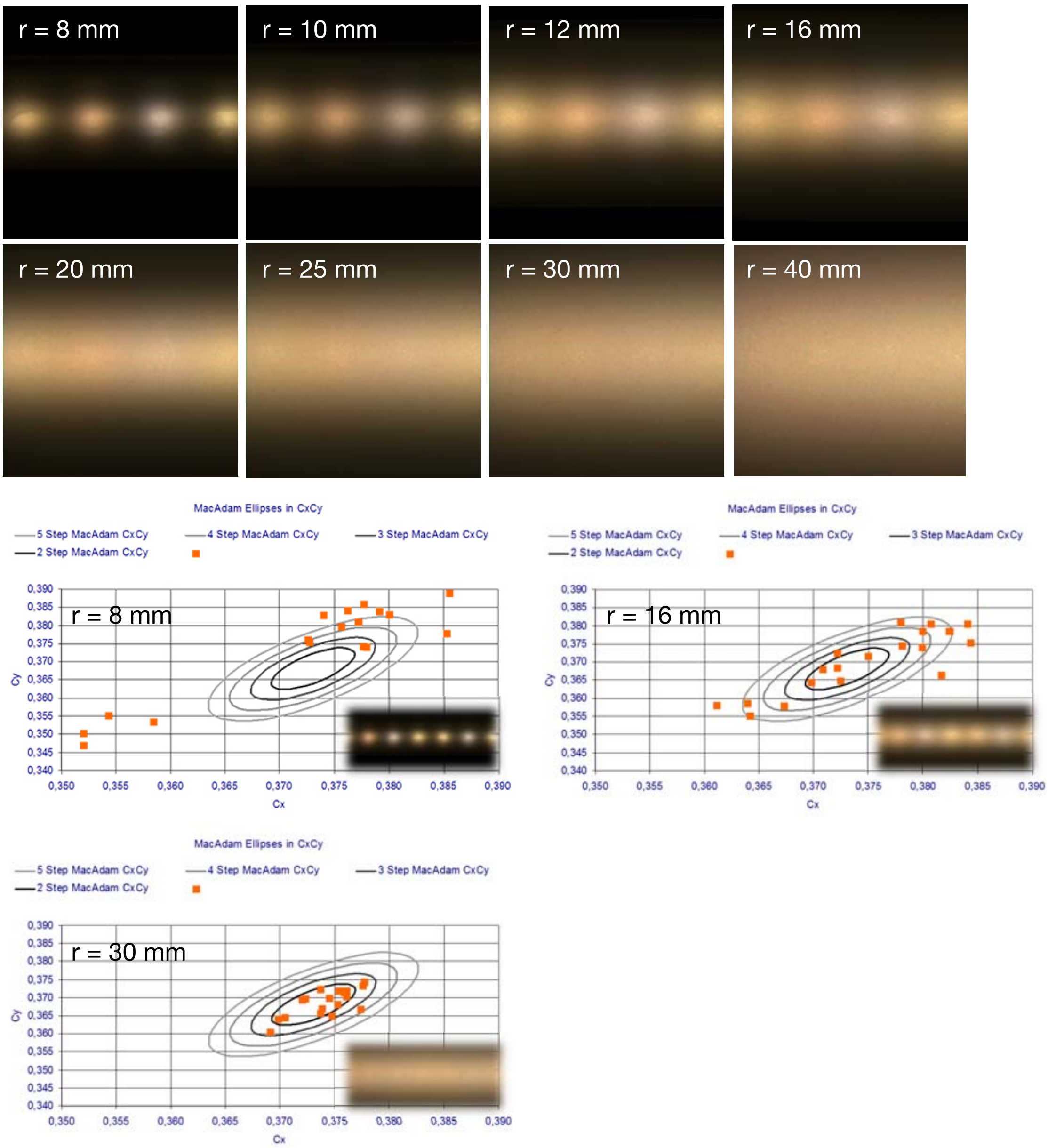


Brightness and color homogeneity

Many applications require a homogeneous white appearance and color mixing, notably linear system setups. For example, wall washer applications require a highly homogeneous illumination on the wall. In this case, the distance between the LEDs and the wall becomes very critical. Figure 10 shows the difference in homogeneity with increasing LED distance from the diffuser. At about 30 mm distance, the LEDs hotspots are almost virtually eliminated and the light appearance becomes indistinguishable from a single, tightly controlled bin.

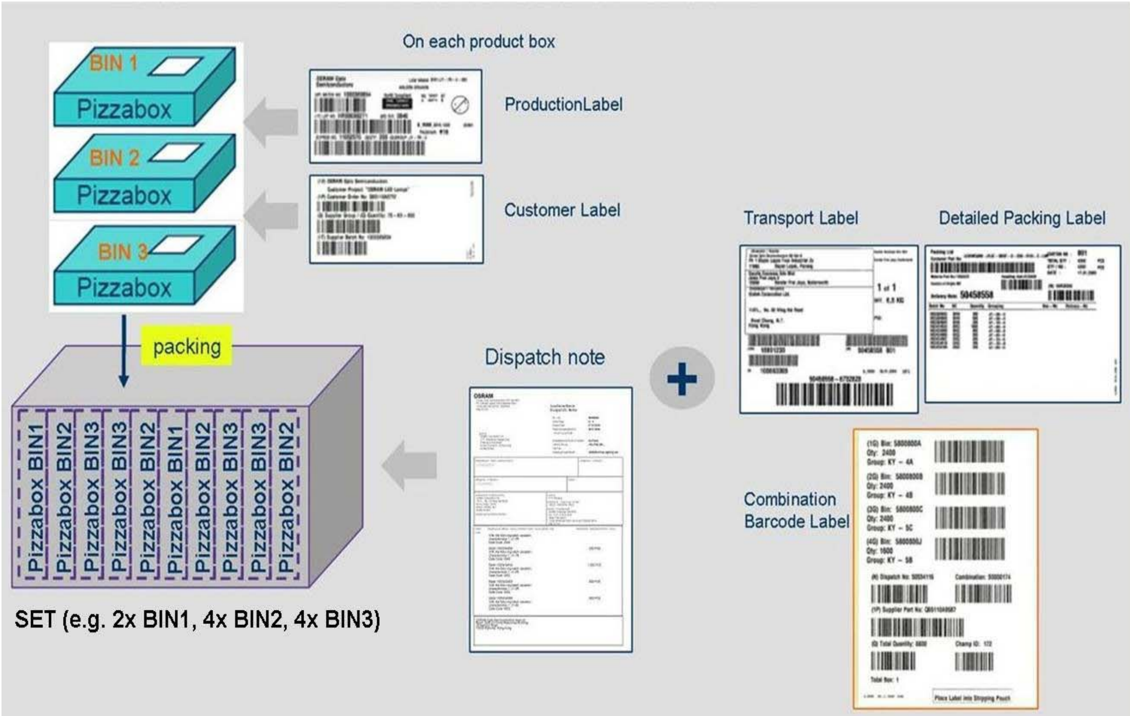
There must be a minimum distance between the diffuser and the LEDs for a homogeneous appearance in a mix-to-match system. If the diffuser distance is not sufficient, the user will be able to observe hot spots of differing color coordinates. Figure 10 shows the appearance and color coordinates as a function of diffuser distance. As can be seen, at about 30 cm distance, the system-level appearance approaches that of a tightly controlled color bin. The distance required also depends on the type of diffuser used.

Figure 10: Appearance of a mix-to-match system in a linear light configuration as a function of distance from the diffuser



To place an order, the customer only needs a specific order number (Q-number) for which all project-related and relevant information (specifications, list of combinations, etc.) are stored in the logistics system of OSRAM Opto Semiconductors. Each combination is supplied as a separate set with all the required bin information (Figure 11).

Figure 11: Delivery combination with detailed information



D. Summary

The Brilliant Mix concept makes it possible to produce highly efficient, warm-white LED light with an excellent color rendering index for general lighting applications. The possible color temperature of the light is in the 2700 K to 4000 K range.

Table 2 summarizes the advantages and disadvantages of the Brilliant Mix concept relative to the current standard method for generating white LED light (phosphorus-converted white). It also shows the challenges which the new concept poses and which should be taken into consideration with regard to logistical requirements and the development of luminaires.

Table 2: Summary of the Brilliant Mix concept

Advantages	**Disadvantages**	**Challenges**
High color rendering index: R_a, typ.= 90	More complicated electronics and optics	Optical mixing of EQ White and Amber LED

Table 2: Summary of the Brilliant Mix concept

Advantages	Disadvantages	Challenges
Very high LED efficacies of > 100 lm/W possible (~ 30 % higher than phosphorus-converted warm white light with comparable CRI)	Higher luminous flux decrease at operational temperatures compared to standard white	Control of LEDs to realize required CCT, luminous flux and color point stability
Covering warm white from 2700 K to 4000 K		Handling the more complicated logistics

OSRAM Opto Semiconductors supports its customers during their development and design process in finding the best solution for a specific application.

For further information or application support, please contact your sales representative or OSRAM Opto Semiconductors.

Don't forget: LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

www.ledlightforyou.com

ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. OSRAM Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. OSRAM Opto Semiconductors also has sales offices throughout the world. For more information go to www.osram-os.com.

DISCLAIMER

OSRAM Opto Semiconductors GmbH

Head office:

Leibnizstr. 4
93055 Regensburg
Germany
www.osram-os.com