Brilliant Mix – Professional White for General Lighting

Application Note

Abstract

At OSRAM Opto Semiconductors, the name "Brilliant Mix" stands for a new, highly efficient concept for generating white light with a high color rendering index for general lighting applications with light-emitting diodes (LEDs).

This paper was prepared to provide a first look at the new concept and the way LED lighting works. In addition to comparing the standard white concepts, it includes two proposals for controlling Brilliant Mix applications.

Introduction

In many lighting applications, conventional light sources are currently being replaced or displaced by more energy and cost-efficient technologies such as compact fluorescent lamps with state-of-the-art LED technology.

In this context, LED lighting for general lighting technology (or SSL - "solid-state lighting") is still in its early development stage and harbors significant potential for increasing brightness and/or efficiency.
Nevertheless, this trendsetting technology already surpasses most light sources in terms of efficiency and meets many application-related requirements such as dimmability, no switch-on delay, outstanding light quality, economy and environmental compatibility.
For general lighting applications as well as for effect and mood lighting, LED-based lights can replace conventional light bulbs of up to 100 watts.

Below we present an innovation in the ongoing development of SSL technology which makes it possible to efficiently generate warm white light with a high color rendering index with LEDs.

Conventional White Technology with LEDs

Most LED technologies use the principle of additive color synthesis to generate white light (Fig. 1).

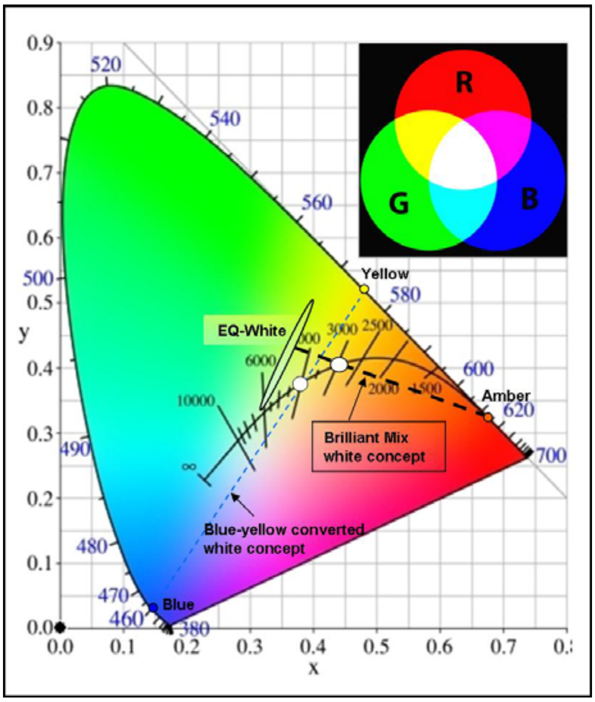

Figure 1: Principles of color mixing

As shown in Fig. 1, white light can be generated by mixing the three primary colors (**B**lue + **G**reen + **R**ed) or a single primary color with its complementary color (for example, **B**lue + **Y**ellow).

Currently, two different methods are used to create white light with LEDs.

- **Combination of multiple colored semiconductor chips (usually RGB) in multi-packages or in LED clusters**

With the multi-chip method, the brightness of the individual colored chips (generally **r**ed, **g**reen and **b**lue) is regulated in such a way that together they emit white light.

The major advantage of this method: since the three colors are controlled separately, almost any color temperature or chromaticity coordinates can be set within the color plane (Fig. 2).

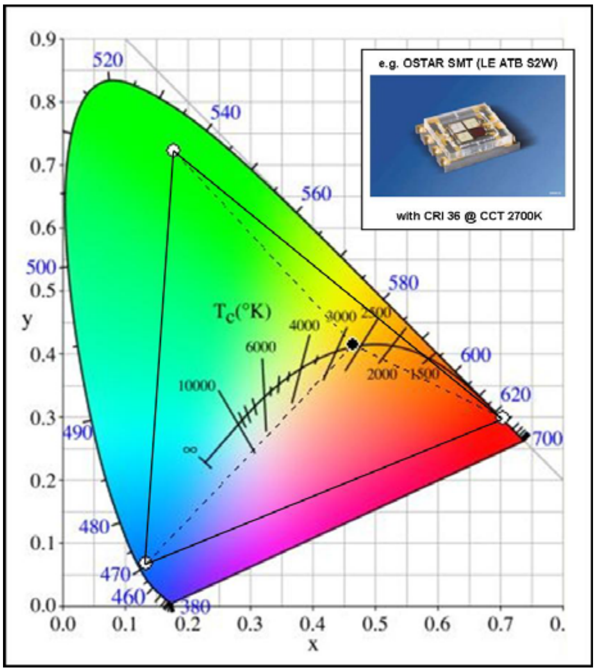

Figure 2: Color range possible with the RGB multi-chip method

This leads however to higher costs, due to the relatively complex electronics.

The most serious disadvantages with regard to general lighting applications, however, are the generally low color rendering index (CRI = 20-60) and the low luminous efficacy at the white point.
Particularly for warm-white light with a low blue component, this method becomes more inefficient (mixing proportion for 2700K: 43%R, 55%G, 2%B).

Since most general lighting applications require only one set of white chromaticity coordinates and no color change, the multi-chip principle is in most cases inappropriate.

- **Combination of a semiconductor chip (blue) with a converter material (= luminescence conversion) in a single package**

With this technology, the light of the blue LED chip excites the luminescent substances in the converter material (yellow phosphor), which causes them to emit yellow light. According to the color model, the human eye perceives the combination of the two as white light.

A significant benefit of this method is its integrated design with a single chip, which makes controlling the LED relatively easy. The optical system is also easy to handle since no color mixing in secondary optics is required.

This system is particular efficient with "cold" light (high color temperature), because the color coordinates are closer to the blue light source, and the phosphor does not have to shift the blue coordinates quite so far.

To achieve a low color temperature (warm-white light) with this technology, several luminescent substances must be combined, mostly by adding red phosphor to the yellow. This reduces the LED's efficacy, however, because the converter's efficiency is lower.
As a result, the following rule applies to all white LEDs with luminescence conversion which are available on the market: the lower their correlated color temperature, the less efficient they are (Fig. 3).

In terms of its color rendering index, the single-chip technology features significantly better properties relative to the RGB multi-chip concept.

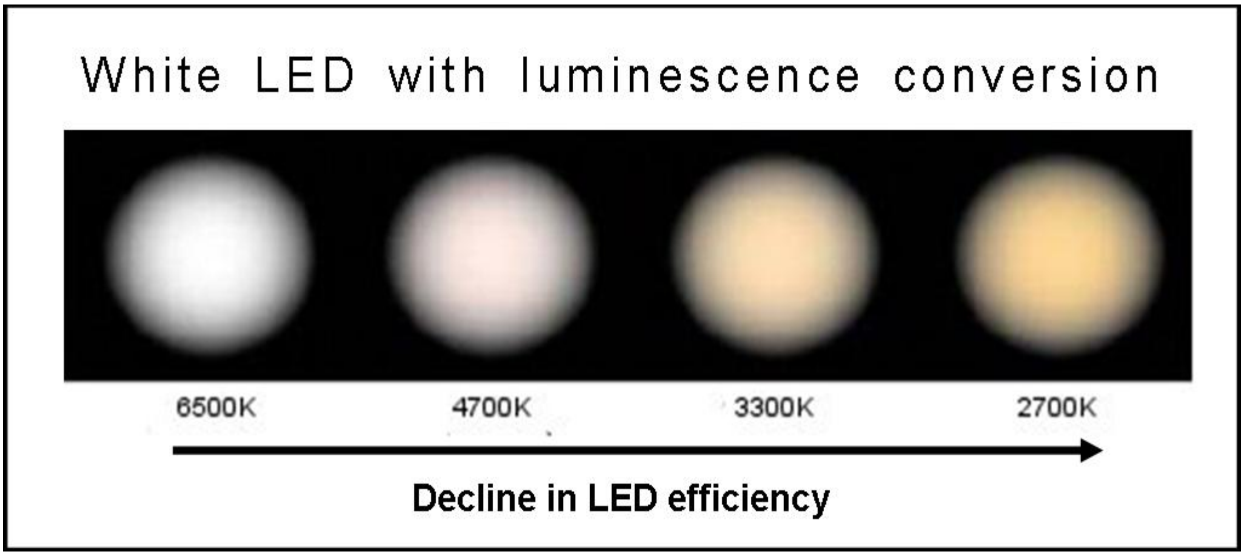

Figure 3: Decline in LED efficiency based on the color temperature

When we compare the spectra of single-chip techniques (Fig. 4), we can see that their curves are broader and more homogeneous than that of the RGB system.

Besides the local minimum between 480 nm and 490 nm, the weak red range of the single-chip techniques in particular (which is important for general lighting applications) turns out to be a major disadvantage, because it prevents a good CRI value.

The color rendering index of white converted LEDs typically lies in the 70-80 range. The latest developments achieve a CRI value around 95, but with a lower efficacy.

Currently, the white converted concept has become the accepted standard for general lighting applications.

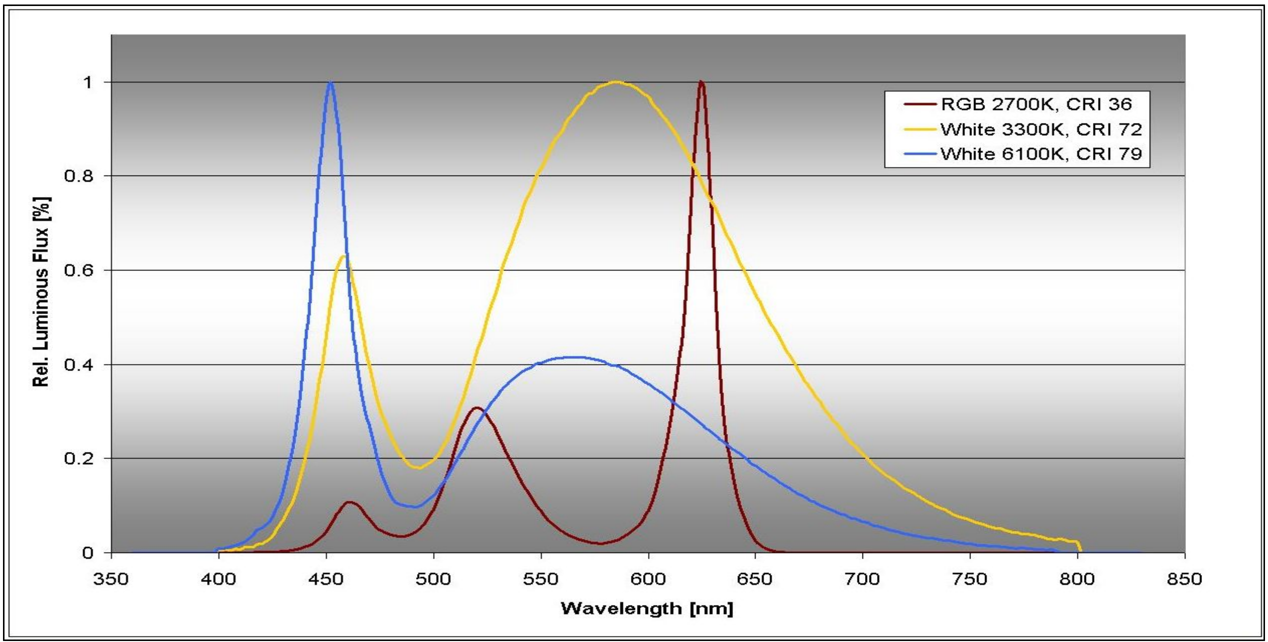

Figure 4: Sample spectra of different white-light methods

Brilliant Mix

A new approach developed by OSRAM Opto Semiconductors, named "Brilliant Mix", combines the two existing methods to create a "warm-white" LED light source with a high color rendering index (CRI > 90) and a high luminous efficacy.

Here, too, the basic principle is based on mixing two colors in order to generate warm-white correlated color temperatures (CCT: 2700 K - 4000 K).
As the basic colors, however, this approach uses red or amber LEDs combined with special white LEDs which have been shifted into the green range (called “EQ-White").

The "EQ-White" LED is produced – similar to a "normal converted white LED" - with a blue chip and green phosphor. This has the advantage that – in addition to adequate chromaticity coordinates and a balanced basic spectrum – the green phosphor has a very low conversion loss rate and makes for a very efficient light source in combination with the blue chip.

Thanks to the discrete red LED, the proportion of red light (needed for the warm-white chromaticitc coordinates and the high CRI) does not have to be generated by the phosphor.

Translated into the CIE color plane (Fig. 5), it becomes apparent that with these LEDs all chromaticity coordinates on a straight line (blue) between EQ-White and amber can be generated by adjusting the luminous flux ratios of the two light sources relative to each other. Thereby the straight line produces also an intersection point with the Planckian locus.

Since the luminous efficacies of the two light sources are maintained, the new approach makes total luminous efficacies of over 110 lm/W possible.
This means that the new Brilliant Mix concept produces up to 30 percent more light than exclusively phosphor-converted warm-white LEDs with a comparable color rendering index at the same power consumption.
In addition to its high luminous efficacy, the Brilliant Mix concept also features a very good color rendering index.

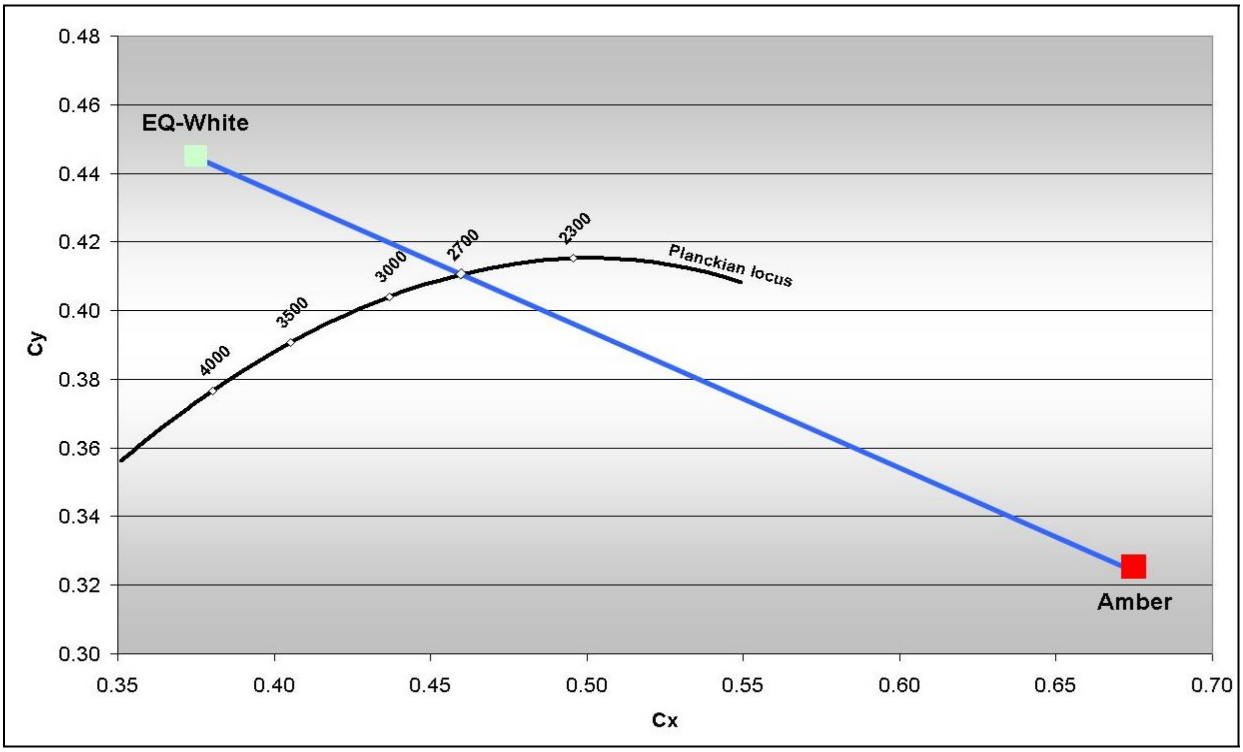

Figure 5: The Brilliant Mix concept in the CIE color space

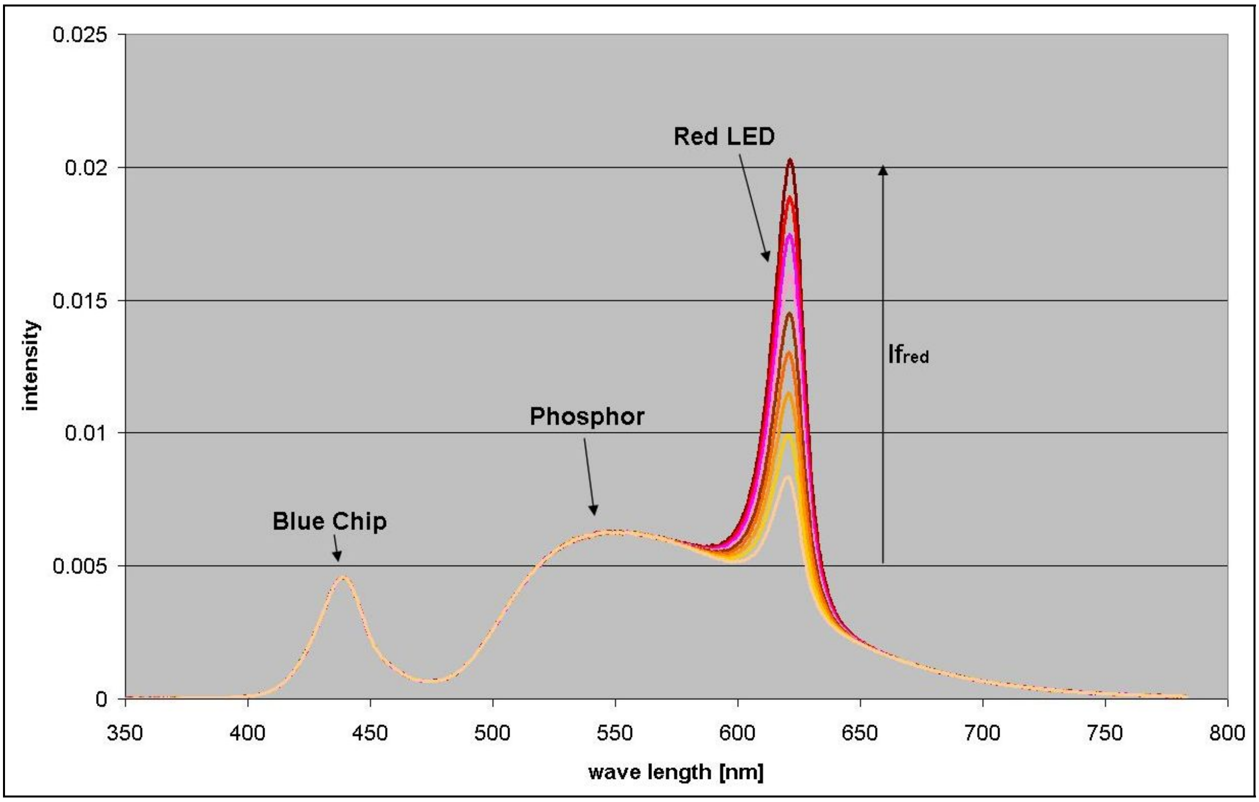

Figure 6: Total spectrum of Brilliant Mix

The overlay of EQ-White and red creates a wide spectrum which can be modified by changing the luminous flux-current-ratio. Fig. 6 shows this effect by varying the forward current on the amber LED.
Despite having a minimum in the wavelength range of 475 nm, Brilliant Mix achieves excellent CRI values of R_a = 90 (typical).

Beyond that Brilliant Mix shows by comparison of the extended CRI values R9 and R13, which are very important for general lighting, clearly improved values than other conventional light sources or typical white LEDs.

CCT	Ra	R9	R13
Brilliant Mix 2700K	92	83	97
Brilliant Mix 3000K	91	78	98
Brilliant Mix 4000K	83	48	85
Compact metal halide (typ.)	82	27	93
Compact fluorescent lamp (typ.)	87	17	93

Figure 7: Comparison of significant CRI values of different light sources

Uses for Brilliant Mix

The following section covers the practical application and the concept-specific features of Brilliant Mix in more detail.

LED Design

One of the most important aspects in implementing the Brilliant Mix concept involves selecting a suitable system design.
It must make a homogeneous color mix possible while meeting typical general lighting requirements such as high luminous efficacy, long life time, etc.

The OSLON SSL (Lx CxDP) in OSRAM Opto Semiconductors' product portfolio is particularly well-suited for the Brilliant Mix concept and optimally meets the application requirements. The OSLON SSL is a single-chip LED with primary optics; it is a member of the group of 1-watt packages (Fig. 8).
The single-chip design has the advantage for Brilliant Mix applications that the LEDs can be arranged in a cluster, which means

that the luminous flux is freely selectable. The color temperature can also be easily adjusted thanks to the LED selection.

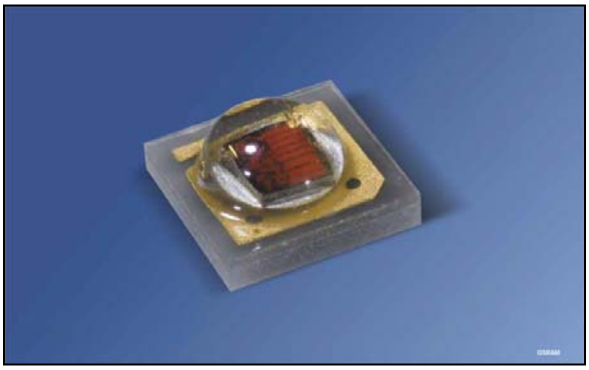

Figure 8: OSLON SSL from OSRAM Opto Semiconductors (LA CPDP)

The small size of the LED (3 mm x 3 mm) is a further advantage, because it permits the creation of tight clusters. In combination with the primary lens' wide angle of 150°, this also ensures a good color mix.

Built with the latest chip technology, the ceramics-based LED features a very good luminous efficacy and a lifecycle of over 100,000 hours, depending on the application conditions.

The LED features a typical thermal resistance of 7 K/W, which is beneficial for a good thermal management.

The data sheets of those LEDs which are suitable for Brilliant Mix applications (LUW CQDP.EQW and LA CPDP (amber)) contain more detailed information.

Luminous Flux Requirements – Minimum Number of LEDs

Typical luminous flux values for general lighting applications range from 400 lm to 1200 lm. This corresponds approximately to the luminous flux values of incandescent lamps ranging from 40 watts to 100 watts.

To achieve equivalent light outputs with LED technology, multiple LEDs must be com-bined into clusters.
The required number of LEDs depends on several factors, such as:

- Luminous flux of the individual LEDs
- Color temperature
- Operating parameters (temperature T_S, current I_F)
- etc.

Fig. 9 shows the number of LEDs required for a light source with a luminous flux of 400 lm in accordance with the Brilliant Mix concept.
This calculation is based on the typical average luminous flux values of the EQ-White (LUW CQDP.EQW) and amber LED (LA CPDP) at their grouping current, and their change in luminous flux depending on the temperature (Fig. 10):

- LUW EQ-White: 130 lm @ 350 mA
- Amber: 71 lm @ 400 mA

As the table shows, this results in a number of LEDs for each color temperature which are affected by the resulting solder point temperature T_S.

LED Number							
CCT	4000K		CCT	3000K		2700K	
LED Color	EQ-White	Amber	LED Color	EQ-White	Amber	EQ-White	Amber
T_S = 65-75°C	3	1	T_S = 65-85°C	3	3	3	3
T_S = 75-95°C	3	2	T_S = 85-95°C	3	3	3	3
with T_J = T_S + 10°C (by rule of thumb)							

Figure 9: Number of LEDs for a 400 lm light source depending on the color temperature and the junction temperature

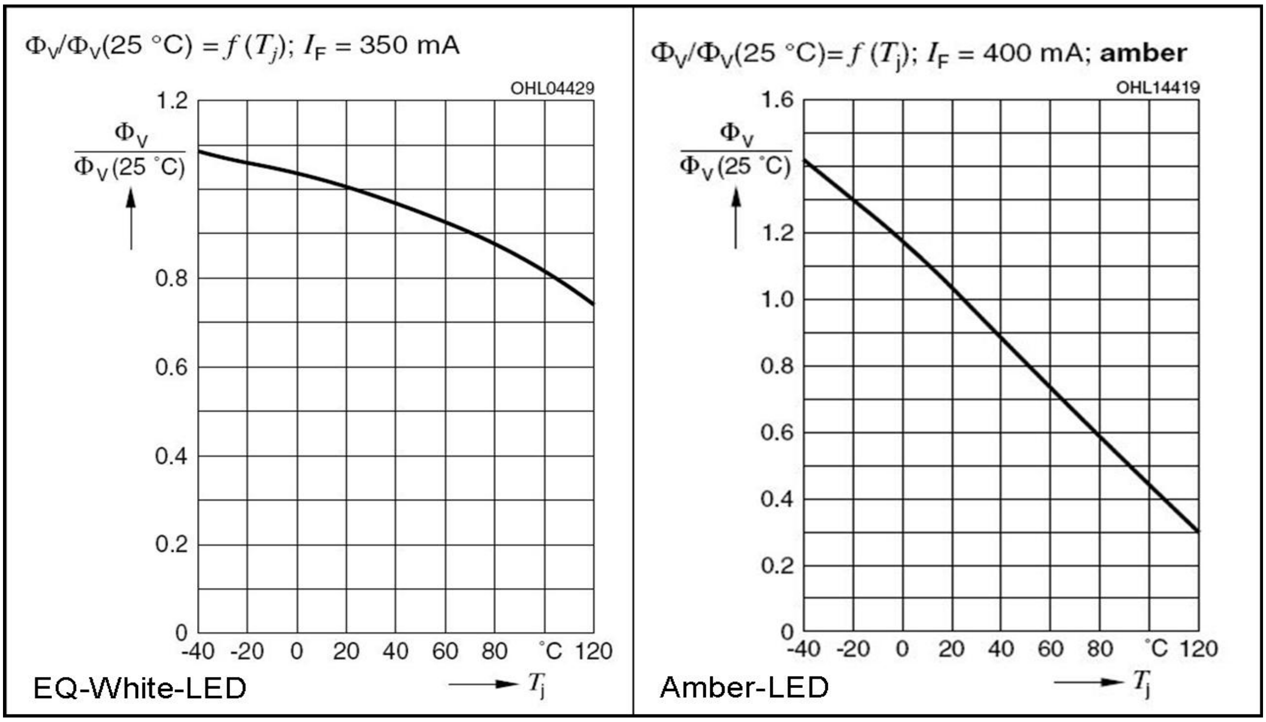

Figure 10: Relative luminous flux depending on the junction temperature T_j

In practice, this means that to create a light source with a color temperature of 4000 K, for example, 4 LEDs (3 x EQ-White and 1 x amber) are needed in order to get a luminous flux of 400 lm. If the light source is to be designed for a solder joint temperature of up to 95°C, the minimum number must be increased to five LEDs (3 x EQ-White plus 2 x amber).

For lower color temperatures (-> 2700 K), i.e. warmer light, the number of amber LEDs must be higher due to the larger required red luminous flaux share. Here, three amber LEDs are needed.
To realize higher luminous flux values, the number of LEDs has to be multiplied accordingly.

This can also be achieved by increasing the forward current, which results inevitable in a decrease of luminous efficacy.
Generally the driving currents are around the grouping current, but the exact values should be individually determined for each application.

Optical Design

With regards to luminaire design, the wide beam angle of the LEDs (Fig. 11) gives preference to designs which incorporate reflectors.

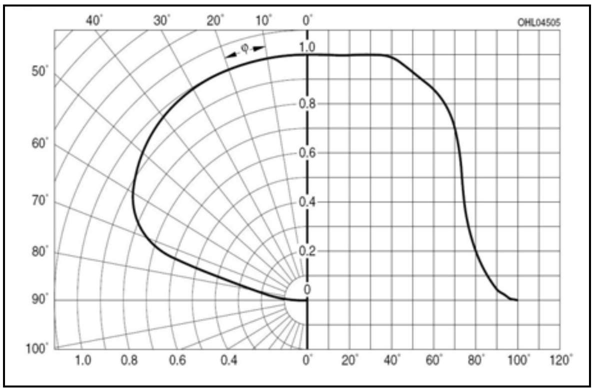

Figure 11: Directional characteristics of the OSLON SSL 150° (e.g., LA CPDP)

So-called "multi-faceted" reflectors are especially recommended, because their shape supports the color mixing necessary with the Brilliant Mix concept.
To attain a good color mixing it is recommended to place the amber and EQW LEDs evenly distributed and point symmetrically with respect to the center.

Figure 12: Example of a multi-faceted reflector

As a rule, luminaires or lamp designs with diffusor materials are also possible, for example as LED retrofits (Fig. 13).
In such cases, however, the color coordinates shift which may be caused by the diffusor material should be taken into account. They also make the system less efficient, because a diffusor always absorbs some light depending on its transmission characteristics.

Figure 13: Example of an LED light source with diffuse bulb material

Secondary lenses are imaging optics. They can be used in combination with the OSLON SSL Brilliant Mix if color shadows in the near-field are acceptable. As a rule of thumb the distance of the illuminated object should be at least ten times larger than the distance of two neighboring amber and EQW LEDs. In many applications this is easily attainable.

Driving

Another important topic with the Brilliant Mix approach is a proper driving concept of the LEDs.
The main decision criterion is the different luminous flux behavior of the two LED types (EQ-White and Amber) along the temperature curve due to their different semiconductor technologies (Fig. 10).
In practice, this means that the specified luminous flux ratio does not remain constant as the temperature increases, resulting in a color temperature drift until thermal equilibrium has been reached.
Depending on the application and its requirements, a choice must therefore be made whether or not color adjustment or temperature compensation are to be considered and implemented.
As a result, the complexity of the driving electronics for Brilliant Mix systems varies from simple driver circuits to sophisticated IC and sensor-supported closed-loop concepts.
Two examples for Brilliant Mix light sources are shown below.

Fig. 14 shows the schematic of simple circuit via dual channel constant current with no color or temperature adjustment.

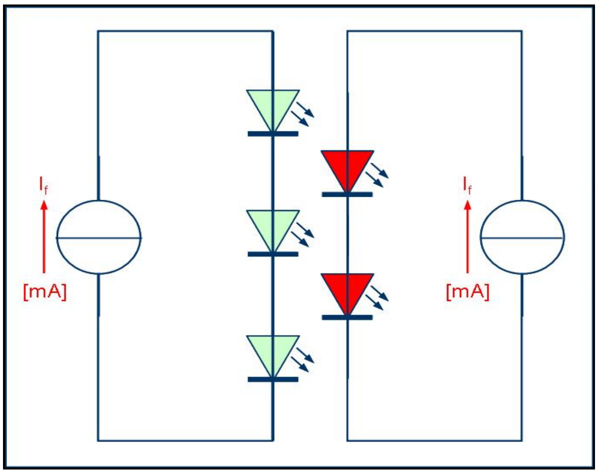

Figure 14: Simple circuit: Dual channel constant current driving

In practice, a certain drift in the color coordinates can be observed after the light source has been switched on. The chromaticity coordinates stabilize only after the operating temperature has been reached, which means that they also vary with the ambient temperature.

Fig. 15 shows a much more complex circuit using a micro controller or an ASIC to control each current source individually with respect to the LED PCB temperature. Thermal compensation, plus additional functions such as dimming and protection against overheating is also given.

In summary Fig. 16 presents an overview of possible circuitries for Brilliant Mix light sources with their respective advantages and disadvantages.

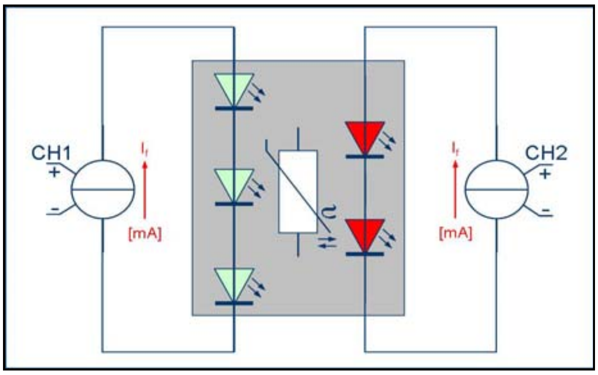

Figure 15: Complex control - CCT-adjustable dimmable temperature-compensated dual-channel constant current driving

Driving Concepts	Advantages	Disadvantages
Single Channel Constant Current	-Low complexity -Low BOM costs -Long LED strings → higher V_f -High efficiency	-CCT and chromaticity change during the heat up time -CCT and chromaticity always depends to the ambient temperature -Steady state CCT is only achievable by determining the ratio btw. amber and EQW LEDs at a certain current level
Dual Channel Constant Current	-Two independent LED strings -Adjustable string current (CCT fine-tuning) -Brightness calibration -Better champing possibilities -High efficiency	-CCT and chromaticity change during the heat up time -CCT and chromaticity always depends to the ambient temperature
Temperature Compensated Single Channel Constant Current	-Temperature compensation -Better CCT stability during heat up time -Better CCT behavior vs. ambient temperature -Low BOM costs -Easy to build up modules	-Customized thermistor is needed -Variation of LED V_f -Possible Efficiency loss at the thermistor
CCT Adjustable Temperature Compensated Single Channel Constant Current	-Temperature compensation -Better CCT stability during heat up time -Better CCT behavior vs. ambient temperature -Low BOM costs -Easy to build up modules	-Customized thermistor is needed -Variation of LED V_f -Possible Efficiency loss at the thermistor
CCT Adjustable Dimmable Temperature Compensated Dual Channel Constant Current	-Temperature compensation and protection -Good CCT stability during heat up time -Good CCT behavior vs. ambient temperature -Constant brightness level -Dimmable (PWM or ANALOG) -Communication interface is possible	-Operation point calibration -Aging predictability of LEDs -Higher complexity

Figure 16: Overview of possible circuitries for Brilliant Mix systems

Color Coordinates

As shown in Fig. 5, with the Brilliant Mix concept only one set of color coordinates on the Planckian locus can be achieved by combining EQ-White and amber LEDs.

To be able to implement color temperatures from the entire range between 2700 K and 4000 K, on the other hand, the LEDs used must feature slightly different color coordinates.
In practice, this is implemented via the EQ-White LED, because on the one hand its chromaticity coordinates are preset by the phosphor concentration, while on the other hand a certain variance occurs during production (due to processes).

In addition for being grouped by luminous flux, the LEDs are also selected in accordance with their color coordinates.

Fig. 17 shows the bin distribution (binning schematic, @ T_S = 25°C) of the EQ-white LEDs from OSRAM Opto Semiconductors with which color temperatures for general lighting applications can be realized.

For example, to achieve a color temperature of 2700 K, ideally EQ-white LEDs from the MM bin group are combined with amber LEDs.
The appropriate chromaticity coordinates will then be set via the current ratio between EQ-white and Amber.

Two important factors need to be taken into account in this context:

Factor 1: The color coordinates or the LEDs' wavelength is affected by temperature variations.
This means that, the chromaticity coordinates shift must be taken into consideration depending on the thermal design of the system.
Fig. 18 shows the target color bins of EQ-White LEDs for certain temperatures.

Steering target color bin for EQ-White				
CCT	4000K	CCT	3000K	2700K
T_S = 65-75°C	MD	T_S = 65-85°C	MK	MN
T_S = 75-95°C	ME	T_S = 85-95°C	ML	MP
with $T_J = T_S + 10°C$ (by rule of thumb)				

Figure 18: CCT-specific target color bins depending on the solder point temperature T_S

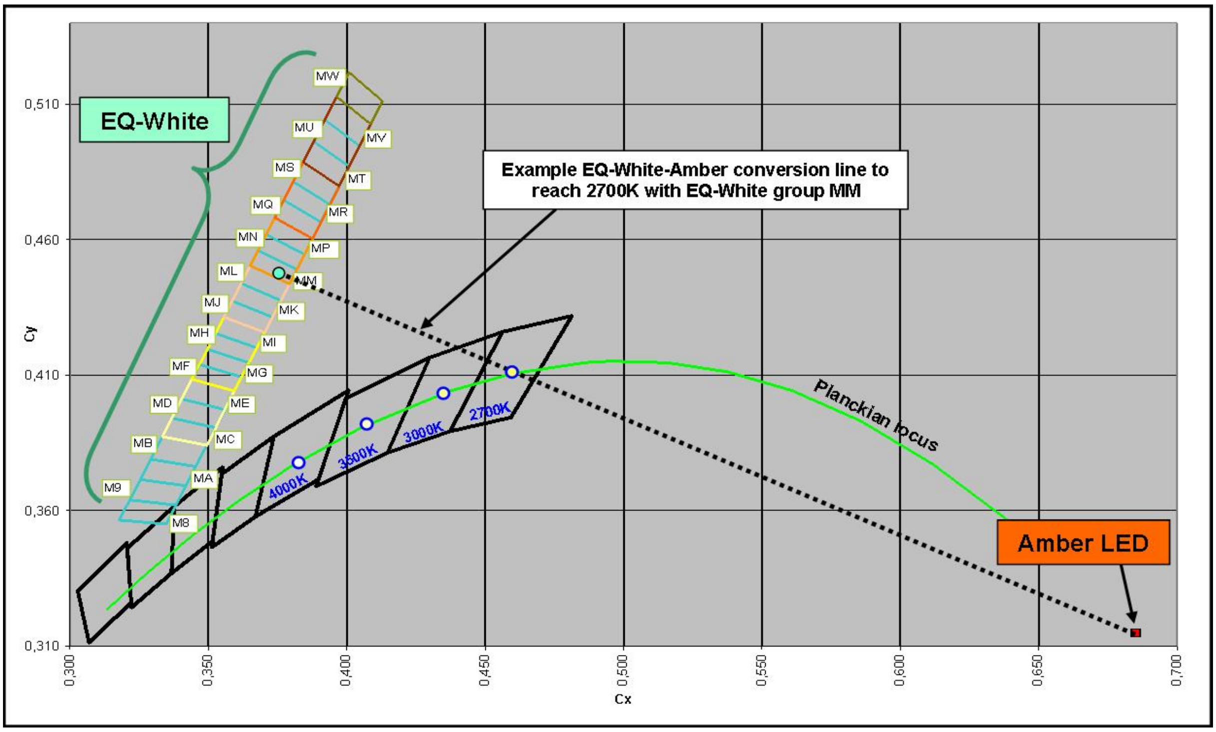

Figure 17: Brilliant Mix in practice – EQ-White principle and binning scheme (@ T_S = 25°C)

Factor 2: Despite the desire to have only one color bin for accurate color control, delivery of a single bin is not an option because of process variation during the production.
In order to obtain a single bin for color control, the principle of color mixing is once again utilized. Within the application and depending on the number of LEDs, various color groups are combined and delivered in such a manner that together they yield the required chromaticity coordinates (see also Mix to Match).
This makes the luminaire manufacturer independent of individual bins and enables the use of almost the entire available color spectrum depending on the target color coordinates and the customer-specific deviation.

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.
The program generally 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.
On the other hand, Mix to Match requires increased care in terms of LED logistics and assembly, because a single order may include different combination sets.

Fig. 19 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 goal could 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.

In practice, however, the customer does not have to worry about the combination of bins. To place an order, the customer needs only a specific order number (Q-number) for which all project-related and relevant information (specifications, list of combinations, etc.) is stored in the logistics system of OSRAM Opto Semiconductors.

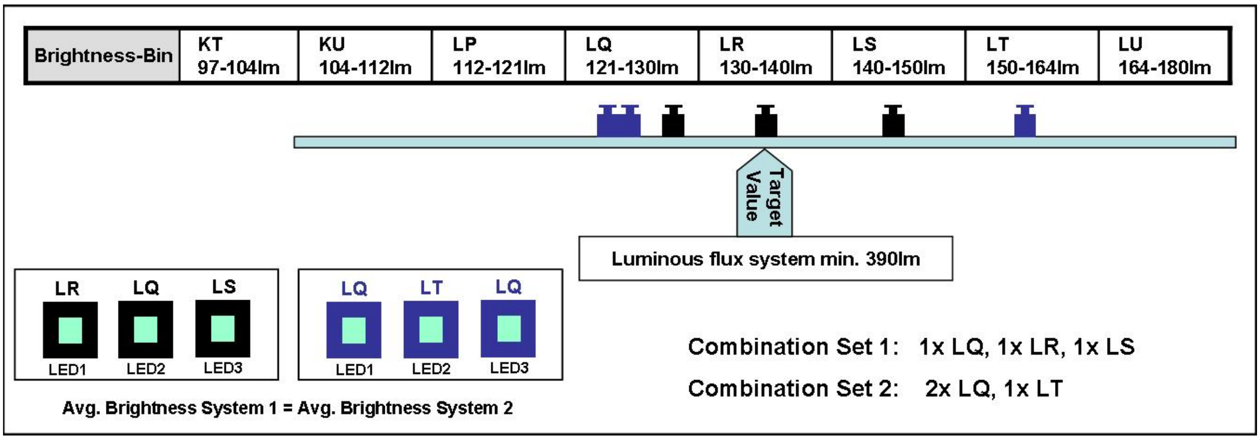

Figure 19: Mix to Match principle using the luminous flux parameter for a three-LED system

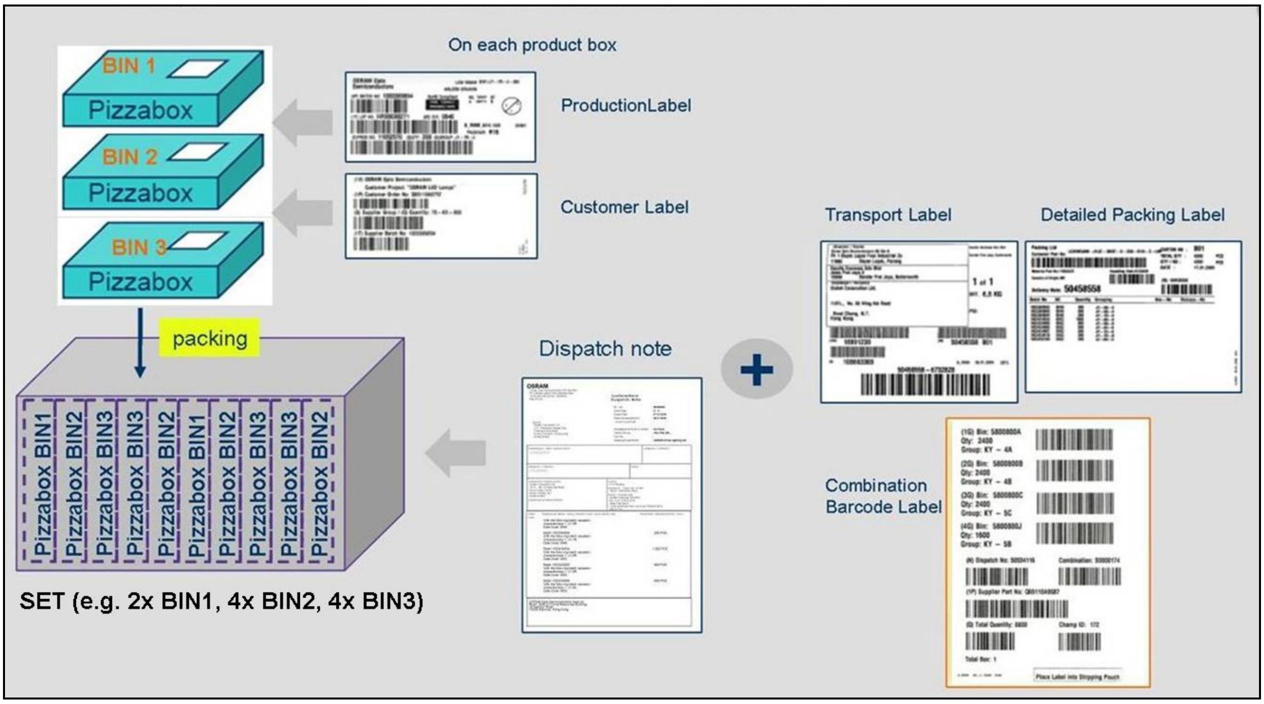

Figure 20: Delivery combination with detailed information

Which bin combination was selected is not important to know, because each combination is supplied as a separate set with all the required bin information (Fig. 20).

Mix to Match with Brilliant Mix

With Brilliant Mix applications, the Mix to Match program is used for the two LED types EQ-White and amber. The combinations are based exclusively on the luminous flux and chromacity coordinate parameters.
Based on a minimum luminous flux of 400 lm at operating temperatures and the most important application parameters shown below, OSRAM Opto Semiconductors has generated a parameter set in the Mix to Match program for each corresponding Q-number, which is available on request:

- Color temperature (2700 K, 3000 K, 4000 K)
- Solder point temperature (65°C-75°C, 75°C-85°C, 85°C-95°C)

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 range of 2700 K to 4000 K.

Fig. 21 summarizes the advantages and disadvantages of the Brilliant Mix concept relative to the current standard method for generating white LED light (phosphor-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.

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.

Advantages	Disadvantages
• High color rendering index: $R_{a,typ}$ **= 90** • Very high LED efficacies of **> 110 lm/W** possible (~30 % higher than phosphor converted warm white with comparable CRI) • Covering warm white from 2700K to 4000K	• Higher luminous flux decrease at operation temperatures compared to standard white. • More complicated electronics and optics
Challenges	
• Optical mixing of EQ White & amber LED • Handling the more complicated logistics • Control of LEDs to realize required CCT, luminous flux and color point stability	

Figure 21: Summary of the Brilliant Mix concept

Appendix

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

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ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM is part of the Industry sector of Siemens and one of the two leading lighting 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) and Penang (Malaysia). 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.

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