Light Emitting Diode

Design Considerations for Full-color Luminaires Using Discrete Color LEDs

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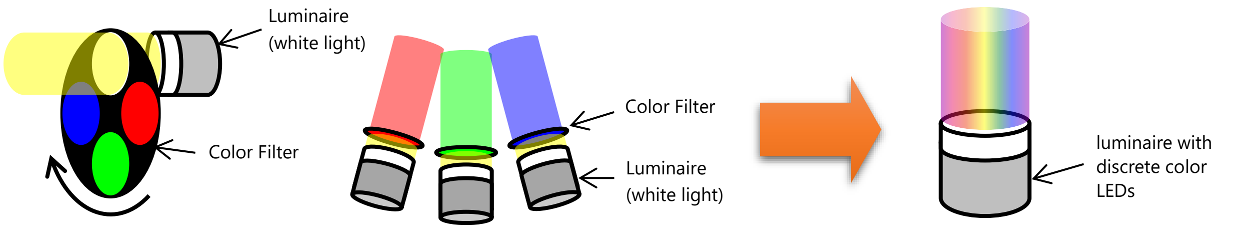
1. Overview

In recent years, discrete color LEDs[1] have started to be used in various types of lighting fixtures for various applications from residential luminaires that are easy for anyone to use, and controllable even with a personal smartphone, to large floodlights designed to decoratively illuminate buildings and landscapes.
Before LEDs, in most cases, colored lights were created with large, white halogen lamps incorporated in a floodlight or a stage lighting luminaire with color filters placed in front of the emitted light, as shown in Figure 1. Now, full-color luminaires using discrete color LEDs are widely available and they have specific advantages: the size of the lighting fixtures can be reduced since the LEDs are very small (i.e. a few mm in width), and since several different color LEDs are incorporated into a single luminaire, many different colors[2] can be created without color filters and/or other external parts. Other advantages include reducing the number of the luminaires required for the intended application, energy saving, and better color reproduction.
This application note provides information on how to create required colors using discrete color LEDs and cautions/suggestions when designing them into luminaires.



White light + color filters (conventional way of producing colored

Full-color luminaires using discrete color LEDs[3]

Figure 1. How to create colors with traditional luminaires vs. luminaires using discrete color LEDs

Note:

[1] "Discrete color LEDs" refers to single-color LEDs that emit high purity colors (e.g. red, green, blue, etc.).

[2] Using red, green, and blue LEDs, each with 256 brightness levels, over 16 million color combinations can be produced (256 * 256 * 256 =16,777,216).

[3] This illustration is only a reference image of a full-color luminaire. How the luminaire operates is different than what is shown here.

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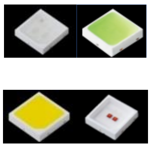
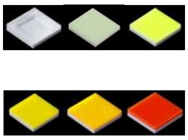
2. LED Product portfolio for full-color luminaires

Table 1 shows the color LEDs that are mainly used for general lighting. Colors other than RGB (i.e. red, green, and blue) are also available. For further information, contact a local Nichia sales representative.

Table 1. Nichia's color LEDs

LED Series (Appearance)	Specifications	
119B-V1 /219B-V1 	Part Number[4]	NCSC119B-V1, NCSB119B-V1, NCSE119B-V1, NCSG119B-V1, NCSA119B-V1, NVSA119B-V1, NCSR119B-V1 NCSC219B-V1, NCSB219B-V1, NCSE219B-V1, NCSG219B-V1, NCSA219B-V1, NVSA219B-V1, NCSR219B-V1
	Outline Dimensions	3.5×3.5×2.0mm
	Rater Power Consumption	1.0W
	Suitable applications /Advantages	Since this LED is high power and has high luminance, it is used mostly for floodlights. It also has high color purity and can create vivid colors.
757G /757H 	Part Number[4]	NE2B757G, NF2E757GR, NF2E757H-F1, NE2G757G, NFSY757G, NE2R757G-P6
	Outline Dimensions	757G: 3.0×3.0×0.65mm 757H: 3.0×3.0×0.8mm
	Rater Power Consumption	0.3W
	Suitable applications /Advantages	This LED is more suitable for low luminance applications such as sign boards and indoor lighting including indirect lighting.
E17A 	Part Number[4]	NCSCE17A, NCSBE17A, NCSEE17A, NCSGE17A, NCSGE17A, NCSAE17A, NCSRE17A, NCSRE17A
	Outline Dimensions	1.7×1.7×0.35mm
	Rater Power Consumption	1.0W
	Suitable applications /Advantages	Since this LED series is very small, the luminaire size can be reduced. All the LEDs in this series have the same forward voltage (VF), regardless of the color.

Note:

[4] Nichia part numbers. The 4th character refers to the color of the light as follows: R: red, G: green, B: blue, C: blue (royal blue), E: bluish green, A: amber, Y: yellow.

3. Color gamut specifications compared with the color gamut of LEDs

Figure 2 shows the color gamut ranges of LEDs and the following color gamut specifications for color televisions, PC monitors, etc.

1. NTSC (National Television System Committee) Specification

   A specification established to standardize the composite video signals and broadcasting systems for analog televisions. The gamut range that can be depicted under this specification is wide. However, at the time it was established, it was difficult for analog TVs to cover the whole range; most of the analog TVs at that time listed the color reproducibility as "XX % of the NTSC gamut".

2. sRGB Specification

   An international specification established by International Electrotechnical Commission (IEC). Many computer monitors, printers, and digital devices such as digital cameras follow this specification. Color differences may occur when two or more devices are connected; those differences can be reduced when all the devices connected to each other comply with this specification. Though the gamut range that can be depicted under this specification is not wide (i.e. 72% of the NTSC gamut), it is approximately the same as that of the BT.709 specification. The BT.709 specification is widely used for high-definition television (HDTV) and Blu-ray disc (BD).

3. Adobe RGB Specification

   While the gamut range that can be depicted under this specification is close to that of the NTSC specification, the coverage is slightly different. This is not an international specification. However, it is accepted as a de facto standard in the printing and publishing industries. Many computer monitors, printers, and digital devices such as digital cameras also follow this specification.

4. BT.2020 Specification

   A specification for a high dynamic range (HDR) for the next generation 4K/8K broadcasting and Ultra HD Blu-ray disc (UHD BD). The gamut range that can be depicted under this specification is very wide. While the conventional HDTV specification, BT.709, can only reproduce 74.4% of all the surface colors seen in nature, this specification can reproduce 99.9%.

As shown in Figure 2, the color gamut range that can be depicted using LEDs is wider than the range covered by the NTSC specification or the Adobe RGB specification. This means that when compared to familiar personal full color display devices (i.e. color televisions and computer monitors) LEDs have a comparable or even better color reproduction.

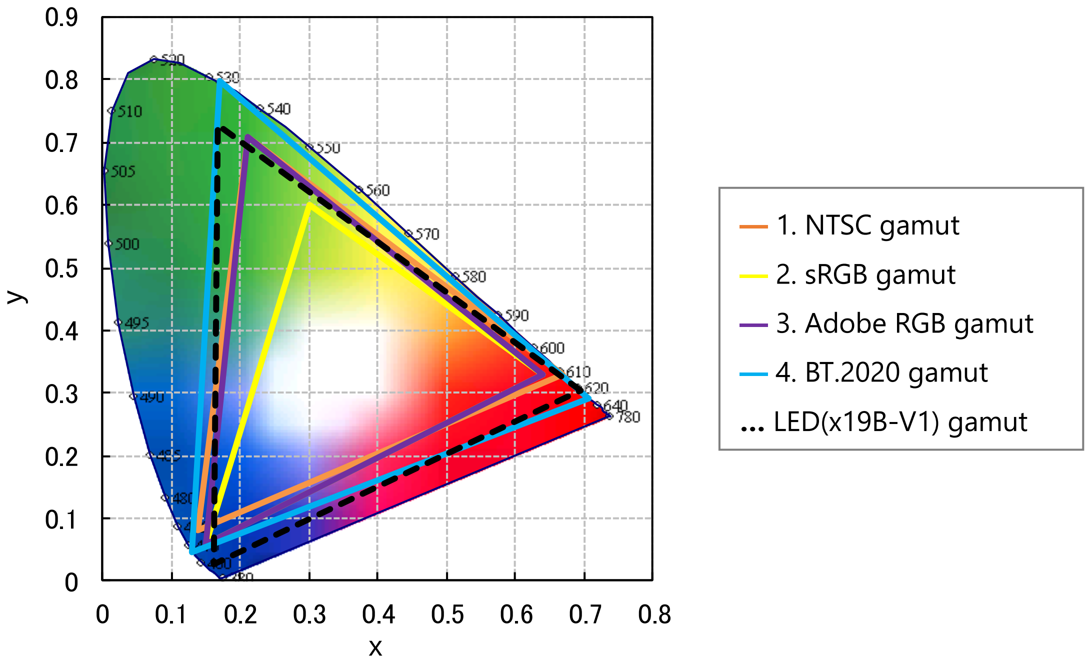


Figure 2. Comparison of the gamut ranges of LEDs and major color gamut specifications

4. Additive color mixing vs. subtractive color mixing

The process of combining two or more primary colors to produce another color is called color mixing. Different colors can be created by changing combinations of the colors and their mixing ratio. There are two types of color mixing: additive and subtractive as described below.

4.1. Additive color mixing

In additive color mixing, a new color is created by adding different colors together. The three primary colors used in additive color mixing are red, green, and blue. This method applies to computer monitors, color tunable lighting, etc. to produce colored light. The more colors that are mixed, the brighter the produced color becomes; when all three primary colors are added together, white light is produced. Figure 3 shows a reference image of additive color mixing.

Example: As shown in Figure 4, adding red and blue light produces magenta light. The magenta light has a wavelength that contains both red and blue light.

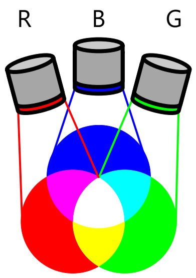


Figure 3. Reference image of additive color mixing

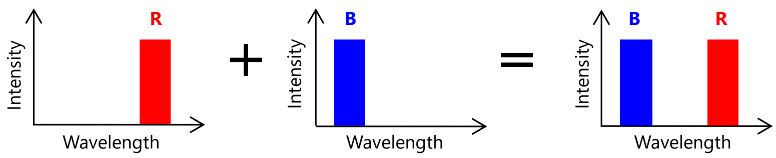


Figure 4. An example of additive color mixing

4.2. Subtractive color mixing

In subtractive color mixing, a new color is created by adding differently colored materials that reflect certain colors (i.e. printer inks, color filters, etc.). The three primary colors in subtractive color mixing are cyan, magenta, and yellow. Contrary to additive color mixing system, in subtractive color mixing the more colors that are mixed, the darker the produced color becomes. Figure 5 shows a reference image of subtractive color mixing.

Example: As shown in Figure 6, when a cyan and yellow color filter are used together, the cyan filter absorbs the wavelength in the red region and the yellow filter absorbs the wavelength in the blue region; only the green wavelength is transmitted to produce green light.

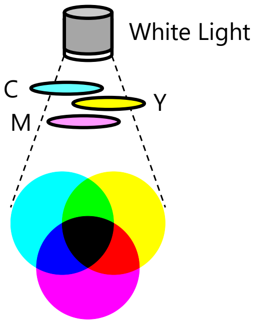


Figure 5. Reference image of subtractive color mixing

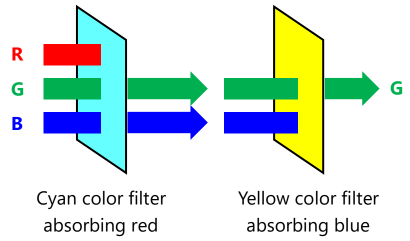


Figure 6. An example of subtractive color mixing

5. Color mixing designs using LEDs (i.e. additive color mixing)

5.1. Method of color mixing

The method used for color mixing with LEDs is additive color mixing. For additive color mixing with tristimulus values X, Y, and Z in the CIE 1931 XYZ color space[5], the mixed color light can be expressed as the sum of the tristimulus values for the component of each primary color light.

The tristimulus values of the mixed color light are derived using the equations below equation 1; where the tristimulus values for the nth LED (i.e. LED_n) are expressed as X_n, Y_n, and Z_n respectively. For example, the tristimulus values for the 1st LED (i.e. LED_1) are expressed as X_1, Y_1, and Z_1, those for the 2nd LED (i.e. LED_2) as X_2, Y_2, and Z_2, those for the 3rd LED (i.e. LED_3) as X_3, Y_3, and Z_3, etc.

$$\begin{cases} X = X_1 + X_2 + X_3 + \cdots + X_n \\ Y = Y_1 + Y_2 + Y_3 + \cdots + Y_n \\ Z = Z_1 + Z_2 + Z_3 + \cdots + Z_n \end{cases} \qquad \text{Equation 1}$$

Note:

[5] See the XYZ color space in the CIE 1931 Standard for details.

Equation 2 shows the relationships among the tristimulus values, the chromaticity coordinates (x, y), and the brightness (i.e. luminous flux or luminance).

$$\begin{cases} X = \frac{Y}{y}x \\ Y = Y \quad \text{Brightness (i.e. luminous flux or luminance)} \\ Z = \frac{Y}{y}(1-x-y) \end{cases} \qquad \text{Equation 2}$$

Using equations 1 and 2 above, the chromaticity and brightness of the mixed color light can be calculated if the chromaticity and brightness of the primary color light are known, and vice versa. That means that the brightness required for each color LED will be known once the required chromaticity and brightness for the mixed color light are specified.

5.2. Example of color mixing calculation

Using Nichia E17A series LEDs, Nichia provides an example calculation of how bright each discrete color LED should be to produce a required chromaticity and brightness.
The LEDs used for this calculation are as follows: one piece of NCSRE17A LED (red), one piece of NCSGE17A LED (green), and one piece of NCSCE17A LED (royal blue).
The required chromaticity coordinate for the mixed color light is (x, y) = (0.345, 0.355).
The required brightness for the mixed color light is 100 lm.
Figure 7 shows the concept for the example calculation.

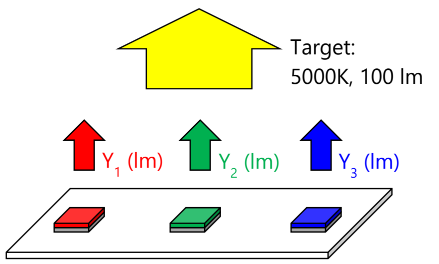


Figure 7. Concept for the calculation

Table 2 shows the typical chromaticity coordinates (x, y) for the E17A series LEDs. In this table, the brightness of the LEDs are variables and expressed as Y_1, Y_2, and Y_3.

Table 2. Chromaticity coordinates for the E17A and target

	Chromaticity coordinates		Brightness
	x	y	Y
NCSRE17A (Red)	0.683	0.313	Y_1
NCSGE17A (Green)	0.252	0.651	Y_2
NCSCE17A (Royal Blue)	0.157	0.021	Y_3
Target: 5000K	0.345	0.355	100 lm

To find the tristimulus values (X, Y, and Z) for each LED, those values from Table 2 are substituted into the equations 2; see Table 3.

Table 3. Calculated tristimulus values

	Tristimulus Values		
	X	Y	Z
NCSRE17A (Red)	2.182 Y_1	Y_1	0.013 Y_1
NCSGE17A (Green)	0.387 Y_2	Y_2	0.149 Y_2
NCSCE17A (Royal Blue)	7.476 Y_3	Y_3	39.143 Y_3
Target: 5000K	97.183	100	84.507

Substituting the calculated tristimulus values from Table 3 into the equations 1 derives the system of equations 3 as below.

$$\begin{cases} 97.183 = 2.182Y_1 + 0.387Y_2 + 7.476Y_3 \\ 100 = Y_1 + Y_2 + Y_3 \\ 84.507 = 0.013Y_1 + 0.149Y_2 + 39.143Y_3 \end{cases} \qquad \text{Equation 3}$$

By solving these equations 3 it is possible to determine the brightness required for each LED: Y_1, Y_2, and Y_3. In this example, the values are Y_1 (red) =25.2 lm, Y_2 (green) = 72.9 lm, and Y_3 (royal blue) = 1.9 lm. This example shows how to create a new color with three different colors; the same method applies when creating a mixed color with two colors (i.e. two white LEDs: one with a high color temperature and the other with a low color temperature). When using this calculation method for color mixing with four or more colors, ensure that the brightness for one or more color(s) is specified in equation 1 so that there are not more than three variables. Note that when mixing four or more colors, there will be more than one combination of brightness for each color to create a certain color.

6. General cautions/suggestions for using the LEDs

When designing full-color luminaires using discrete color LEDs, the following must be considered:

- The absolute maximum rated forward current must not be exceeded for any of the LEDs in the luminaire under any circumstances.
- The absolute maximum rated junction temperature must not be exceeded for any of the LEDs in the luminaire under any circumstances.
- Each LED has its own current and temperature characteristics; the measured values of luminous flux/chromaticity may be different from the designed values when the LEDs are operated in luminaires.
- When designing the power supply circuit and LED circuit, note that for some LED series, there may be significant difference in forward voltage (V_F) among the different color LEDs; ensure that there are no issues.
- Depending on the design of the luminaire, the color of the light may not be uniform on the illuminated surface (i.e. the emitted colors from the LEDs are not mixed and there are different color patches on the illuminated surface). Perform sufficient verification to ensure that there are no issues with the chosen luminaire before use.
- Refer to the technical information related to the selected LED series for the assembly precautions.

7. Summary

This application note has provided an example of designing with color mixing for reference purposes only and Nichia makes no guarantee that customers will see the same results for their chosen application. Sufficient verification must be done prior to use to ensure there are no issues for the chosen application.

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