INTRODUCTION

This application note provides an example of obtaining custom colors by combining the spectra of the four dies available on an RGBW LED. The custom color is transmitted using the Digitally Addressable Lighting Interface (DALI) protocol to a customized control gear while retaining full DALI compatibility. The stored color can be read back from the control gear for analysis or can be copied over to another compatible control gear. An example PC application provides the interface to pick the custom color, compute its associated parameters for the particular LED dies and send the colors using the DALI protocol to the control gear.

HARDWARE

The present application targets the following hardware devices:

- Microchip Lighting Communications Main Board which acts as the custom color DALI control gear.
- CREE® MCE4CT-A2-0000-00A4AAAB1 RGBW LED, included on the Lighting Communications Main Board.
- Microchip DALI adapter which provides the DALI circuitry to the Lighting Communications Main Board.
- Microchip USB to DALI Interface which is required by the PC application to communicate using the DALI protocol.

COLOR MIXING USING RED, GREEN, BLUE AND WHITE LEDs

A particular color can be obtained by configuring different currents through each of the four LED dies. Figure 1, obtained from the data sheet of the CREE LED, shows the relative luminous flux each die provides as a function of the current through it. Note that in the case of the Microchip Lighting Communications Main Board, the maximum current through each die is on the order of 200 mA such that the LED luminous flux has been approximated to be proportional to the associated current.

FIGURE 1: LED RELATIVE LUMINOUS FLUX vs. DIE CURRENT FOR EACH DIE
Colorimetry

In order to perform color mixing, a parametric way of defining colors is required. A natural approach would be to select a target color from this space and obtain the necessary parameters that will yield that color. The 1931 CIE xy color space, depicted in Figure 2, has been chosen for this application.

FIGURE 2: CIE 1931 XY CHROMATICITY DIAGRAM.

EQUATION 1: COORDINATES IN THE 1931 XY PLANE

\[
\begin{align*}
    x &= \frac{X}{X + Y + Z} \\
    y &= \frac{Y}{X + Y + Z}
\end{align*}
\]

A color is defined in this plane with coordinates \(x, y\) that are shown in Equation 1. The tristimulus values \(X, Y\) and \(Z\) can be computed using Equation 2.

EQUATION 2: TRISTIMULUS VALUES FOR A GIVEN SPECTRAL POWER DISTRIBUTION, \(I(\lambda)\)

\[
\begin{align*}
    X &= \int_{380}^{780} I(\lambda) \tilde{x}(\lambda) d\lambda \\
    Y &= \int_{380}^{780} I(\lambda) \tilde{y}(\lambda) d\lambda \\
    Z &= \int_{380}^{780} I(\lambda) \tilde{z}(\lambda) d\lambda
\end{align*}
\]

In Equation 2, \(I(\lambda)\) represents the spectral power distribution of the source and \(\tilde{x}(\lambda), \tilde{y}(\lambda), \tilde{z}(\lambda)\) are the CIE color matching functions. The spectral locus (curved boundary of the plot) can be obtained by plugging into Equation 2 the spectral power distributions for monochromatic sources, setting \(I_s(\lambda) = \delta(\lambda - \lambda_s)\) and letting \(\lambda_s\) run from 380 nm to 700 nm.

EQUATION 3: TRISTIMULUS VALUES FOR A MONOCHROMATIC LIGHT SOURCE OF WAVELENGTH \(\lambda_s\)

\[
\begin{align*}
    X(\lambda_s) &= \tilde{x}(\lambda_s) \\
    Y(\lambda_s) &= \tilde{y}(\lambda_s) \\
    Z(\lambda_s) &= \tilde{z}(\lambda_s)
\end{align*}
\]
RGBW LED

The spectral power distributions of the LED dies are obtained from the LED’s data sheet and reproduced in Figure 3 for completeness. Please note that only one white die is present in the LED on the Microchip Lighting Communications Main Board, namely the 4000K. These spectra are obtained at 350 mA for each die. Mixing colors becomes simple within the approximation that the shape of the spectrum of each LED die does not depend on its current, since this allows the computation of a single color coordinate for each LED die. Using these color coordinates together with the flux outputs of each LED die, one can control the overall lamp color using the individual die currents.

As discussed at the beginning of Section “Color Mixing using Red, Green, Blue and White LEDs”, the flux is approximated to be proportional to the LED die current.

The color coordinates of each LED die can be computed using the mechanism described in the previous section, plugging the spectral power distribution of each LED into Equation 2 and Equation 1. While these spectral power distributions shown in Figure 3 are arbitrarily scaled, it is easy to see that any scaling does not affect the x, y coordinates of the LED die.

FIGURE 3: LED DIES SPECTRA

These computed parameters are given in Table 1, along with the maximum luminous flux specified in the LED data sheet.

TABLE 1: LED COORDINATES IN THE 1931 CIE COLOR SPACE AND THEIR MAXIMUM SPECIFIED LUMINOUS FLUX

<table>
<thead>
<tr>
<th>LED die</th>
<th>x</th>
<th>y</th>
<th>Y Max. Luminous Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>RED die</td>
<td>0.6857</td>
<td>0.3143</td>
<td>30.6 lm</td>
</tr>
<tr>
<td>GREEN die</td>
<td>0.2002</td>
<td>0.6976</td>
<td>67.2 lm</td>
</tr>
<tr>
<td>BLUE die</td>
<td>0.14176</td>
<td>0.06175</td>
<td>8.2 lm</td>
</tr>
<tr>
<td>WHITE die</td>
<td>0.38158</td>
<td>0.3678</td>
<td>80 lm</td>
</tr>
</tbody>
</table>
By mixing three given colors, the accessible gamut is the triangle defined by the coordinates of these colors. Using the provided LED dies yields the gamut depicted in Figure 4. Since the triangles overlap, there are two solutions to mix three of the available colors to yield each color in the gamut. Thus, the application requires one extra input to define which of the die’s output shall be maximized.

**FIGURE 4: ACCESSIBLE GAMUT USING THE GIVEN LED**

Mixing Colors

Starting with a desired color defined by its coordinates in the 1931 CIE color space, the LED contributions are computed using the following mechanism:

- Checking if the point lies within any of the triangles
- For all triangles that contain the point, compute the individual die contributions, as described below.
- Select the configuration that yields the maximum output for the chosen LED die.

Having selected the three dies that will be used, the required flux for each die can be obtained starting from the equations given in AN1542. This mixing is given in **Equation 4**, which yields the needed flux outputs for each die.

**EQUATION 4: RELATIVE FLUX VALUES REQUIRED FOR YIELDING THE DESIRED OUTPUT COLOR**

\[
\begin{align*}
\frac{Flux_0}{Flux_1} &= \begin{pmatrix}
\frac{x_0}{y_0} & \frac{x_1}{y_1} & \frac{x_2}{y_2} \\
1 & 1 & 1 \\
\frac{1-x_0-y_0}{y_0} & \frac{1-x_1-y_1}{y_1} & \frac{1-x_2-y_2}{y_2}
\end{pmatrix}^{-1} \begin{pmatrix}
x \\
y \\
1-x-y
\end{pmatrix} \\
\frac{Flux_1}{Flux_2} &= \begin{pmatrix}
\frac{x_0}{y_0} & \frac{x_1}{y_1} & \frac{x_2}{y_2} \\
1 & 1 & 1 \\
\frac{1-x_0-y_0}{y_0} & \frac{1-x_1-y_1}{y_1} & \frac{1-x_2-y_2}{y_2}
\end{pmatrix} \begin{pmatrix}
\frac{x}{y} \\
1 \\
1-x-y
\end{pmatrix}
\end{align*}
\]

**EQUATION 5: LED DIMMING VALUES**

\[
k_i = \frac{Flux_i}{Y_i}
\]

The last step is to scale these dimming values such that they lie between 0 and the maximum value usable for the LED PWM.
DALI CONTROL GEAR

The DALI standard does not specify color information for device type 6 (LED) control gears. However, the standard does define user-accessible memory banks that can be programmed remotely, leaving their implementation and usage free to the application developer. This application makes use of this fact and defines the memory map for memory bank 2 described in Table 2.

### TABLE 2: DALI BANK 2 MEMORY MAP

<table>
<thead>
<tr>
<th>Address</th>
<th>Description</th>
<th>Default value</th>
<th>Memory access</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>Last accessible memory location</td>
<td>0x20</td>
<td>R</td>
</tr>
<tr>
<td>0x01</td>
<td>Checksum for memory bank</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>0x02</td>
<td>Memory bank lock byte (read-only if not 0x55)</td>
<td>0x00</td>
<td>R/W</td>
</tr>
<tr>
<td>0x03</td>
<td>Red channel scaling value</td>
<td>0x00</td>
<td>R/W lockable</td>
</tr>
<tr>
<td>0x04</td>
<td>Green channel scaling value</td>
<td>0x00</td>
<td>R/W lockable</td>
</tr>
<tr>
<td>0x05</td>
<td>Blue channel scaling value</td>
<td>0x00</td>
<td>R/W lockable</td>
</tr>
<tr>
<td>0x06</td>
<td>White channel scaling value</td>
<td>0xFF</td>
<td>R/W lockable</td>
</tr>
<tr>
<td>0x07-0x14</td>
<td>Identification string</td>
<td>'Microchip RGBW'</td>
<td>R/W lockable</td>
</tr>
</tbody>
</table>

The definitions and usage of addresses from 0x00 to 0x02 are dictated by the DALI standard whereas the rest are application-specific. The bytes from 0x07 to 0x14 form an identification string that can be used by the PC application to make sure that the addressed device supports this color information format. Storing the color information in DALI memory banks ensures that full DALI compliance is maintained by not adding extra commands or modifying existing ones. This also allows the Control Device to read out the color information from the control gear (for example, to copy the color into a newly installed device).

The color information is stored in the locations from 0x03 to 0x06 for each of the LED dies. The bytes at these addresses provide multiplicative factors for each of the LED die intensities, leaving very simple computation to be carried out by the DALI control gear. All color mixing is done on the PC and these four values are written to the DALI control gear's memory bank 2.

The control gear firmware is based on the Microchip DALI Control Gear Library demo application. The only changes to this application are in the following files:

- **lamp_hardware.c** – to make the lamp read the requested color from the memory bank when changing the power level.
- **main.c** – removing reference system power logic.
- **dali_cg_config.h** – changing physical minimum level and setting the features byte to ‘0’ to signal that this control gear does not implement any optional functionality.
- **dali_cg_nvmemory.c/h** – setting the default values for memory bank 2 and removing reference system power functionality.
PC APPLICATION

Configuring the RGBW DALI control gear with a specific color can easily be done using the custom PC application built for this purpose by clicking on the desired color. The application computes the individual color multiplicative factors and uses the USB to DALI Interface to send commands to the DALI bus. These commands program the DALI memory bank 2 with the appropriate values that yield the desired color.

The features of the PC application are:

- Computes the color parameters and can configure the RGBW DALI control gear with a single click.
- Since multiple solutions exist to mix each color, the user can select which LED’s output should be maximized.
- Can read the color information from one control gear such that it can be copied over to another control gear.
- Can check the device before programming to make sure it supports color information. This is done checking for the “Microchip RGBW” string that should be in DALI memory bank 2 of compatible control gears.
- Can be used to send “Direct Arc Power Control” commands.

FIGURE 5: PC APPLICATION USER INTERFACE

In order to represent each color as accurately as possible, the color combinations yielded by the application do not try to achieve constant luminous flux throughout the accessible gamut. Additional computation could achieve this but the maximum possible flux would have a smaller value than the lowest maximum flux of each of the LED dies. This would limit the accuracy of the reproduced colors and was considered unacceptable.

References:

1. CLD-DS16 Rev 11B -- CREE® Product family Data Sheet
5. Microchip – AN1562 - High Resolution RGB LED Color Mixing Application Note (DS00001562)
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