Stepless Tunable Four-Chip LED Lighting Control on the Black Body Radiation Curve with Generalized Reduced Gradient Method

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***Abstract*— In this paper, the algorithm for the stepless tunable four-chip LED on the black body radiation curve, using the Generalized Reduced Gradient method, is proposed. The lumen outputs of four-chip LED, for color temperatures between 2500K and 6500K, are then calculated in real-time, without using a lookup table, and for high quality lighting design.**

Keywords—RGBA, LED, Black Body Curve, Optimization

I. INTRODUCTION

According to the Illuminating Engineering Society (IES) Lighting Hand Book, the Color Rendering Index (CRI) of the three-chip RGB (Red Green Blue) LED at 3300K is equal to 80. However, the CRI of the four-chip RGBA (Red Green Blue Amber) LED at 3300K can reach 90 [1]. Based on the International Commission on Illumination (CIE) 1931 chart, the color gamut of the four-chip, Red, Green, Blue, and Amber (RGBA) LED is also higher than the RGB LED. Therefore, the RGBA LED can be used for a wide range of applications such as stage lighting. The Generalized Reduced Gradient (GRG) method is a generalization of the reduced gradient methods. It allows nonlinear constraints and arbitrary boundaries on the variables during the calculation process [2], [3]. The GRG method can be used for the LED spectrum calculation [4], [5] or the LED package application [6], [7]. The black body radiation curve, based on Planck's Law, consists of an electromagnetic radiation emitted by a black body in thermal equilibrium at a defined temperature. For the solid-state lighting application, the ANSI C78.377 standard determined the color temperature gamut for the bins of the emitted white light LED. The color tunable lighting system design by the RGB LEDs [8] [9] or RGBA LEDs [10] are discussed. However, the output of the multi-channel LED is measured to establish a lookup table by attempting and error correcting the specific chromaticity coordinates or the color temperature. Then, the lookup table is imported into the microcontroller (MCU) of the control system. When the user inputs the targeted color temperature, the MCU checks the lookup table and finds the best solution for the output. For RGBA LEDs, the four variables are adjusted for the specific chromaticity coordinates or the color temperature. For the solved system, no unique solution for the same chromaticity coordinates exists.

In this study, using the four-chip LED measurement results, we construct the calculation model for additive color mixing. The parameters, including four channels' lumen as a function of the current, are controlled by the GRG method in the spreadsheet in order to predict the chromaticity coordinates on the black body radiation curve. Then, the algorithm of the four-chip LED for different color temperature requirements on the black body radiation curve is proposed.

II. MEASUREMENTS AND DISSCUSSION

In the beginning, each channel of the four-chip LED is measured for the color gamut as shown in Fig. 1. According to the datasheet, the lumen limit of each channel is not the same. Therefore, the maximum lumen of each color should be measured as a function of the current. The relationship between the lumen and current can be descripted by the linear regression, which will be calculated later. Then, four chromaticity coordinates and four lumen variables for additive color mixing procedure are defined by the GRG method. The optimization target is the chromaticity coordinates on the black body curve. The maximum Luminous efficacy (Lm/W) is also considered in the calculations. Following the iterations, each lumen of the four-chip LED is calculated. In order to compute the linear regression between the lumen and color temperature, the lumen increments of the color mixing result is controlled for a reasonable standard deviation of the color matching range (SDCM) on the black body curve. After the linear regression of each channel, the only variable, color temperature, is required to predict each lumen output. Finally, the gain factor is determined in cool white and warm white based temperatures on the lumen limit for the dimming requirement (Fig. 2).

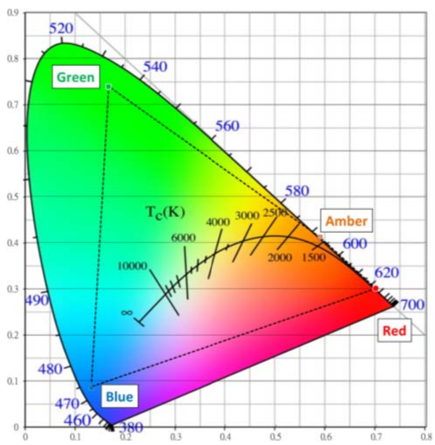

Fig. 1. The color gamut of the four-chip LED.

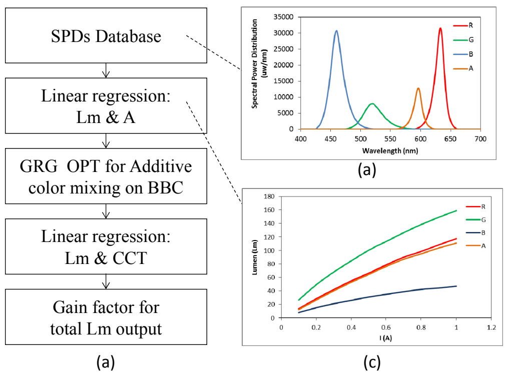

Fig. 2. (a) Flow chart, (b) SPDs of RGBA LED, (c) The Lumen of RGBA as a function of the current

After the optimization process, the lumen of the four-chip LED are indicated to LmR, LmG, LmB, and LmA in Eqs. (1)-(4). The CCT range is changed from 2500K to 6500K. The gain factor (F) is between 0 and 2.48. According to the algorithms, the chromaticity coordinates of the four-chip LED can be controlled on the black body curve while satisfying the ANSI standard (Fig. 3). The CCT devation and the Duv with different CCT input is show in (Fig. 4). The average Duv is about 0.00285.

$$\mathrm{Lm\,R} = F\times[(1E{+}06)\times CCT^{-1.35}] \tag{1}$$

$$\mathrm{Lm\,G} = F\times[\,56.86\,] \tag{2}$$

$$\mathrm{Lm\,B} = F\times[\,-1E{-}07\times CCT^{2} + 0.0022\times CCT - 3.1923] \tag{3}$$

$$\mathrm{Lm\,A} = F\times[151.41\times CCT^{-0.157}] \tag{4}$$

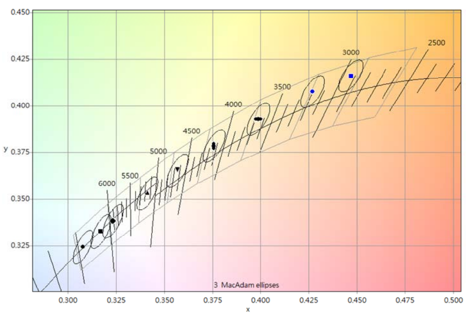

Fig. 3. Tunable range of four-chip LED on the BBC.

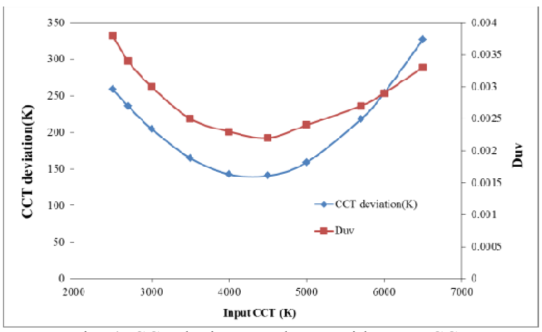

Fig. 4. CCT deviaton and Duv with Input CCT

III. Conclusion

The tunable chromaticity coordinates of the four-chip LED on the black body curve was discussed. The stepless dimming control method for the color temperature and lumen is proposed within average Duv 0.0027 between CCT 2500K to 6500K.

Acknowledgment

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