Color Temperature Control of LED Floodlight Using RGB Light Color Mixing Theory

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Abstract

A number of R, G and B LEDs for reference color temperature mixing ratio of RGB was determined by the theory of RGB mixing as a baseline. Once the number of LEDs was determined the objective color temperature from baseline has been achieved by the control the RGB duty ratio. And a practical prototype of 50W floodlighting adjusted by the above algorithm. The micro controller was developed with control algorithm for RGB duty ratio to obtain the objective color temperature. Detailed experiments to optimize algorithm of duty ratio and color temperature will be discussed in this paper as well.

1. Introduction

A color temperature of 50W floodlighting was controlled by well known color mixing theory. The objective color temperature was determined from color coordinate of black body radiation for KSA 0075. Once one knows color coordinate a RGB mixing ratio would be determined by tri-stimulus value. From this color mixing ratio the number of RGB and duty ratio were calculated and adopted at prototype of 50W flood lighting. The control algorithm of duty ratio for RGB LED was developed as well. A color temperature was measured by variation of duty ratio from developed control algorithm and compared to theoretical value. There were minor discrepancies due to several parameters including thermal control problem of LED module. However those values were calibrated with duty ratio and objective color temperature with several iterations. Detailed algorithm for control of color temperature due to optimized duty ratio and prototype of 50W floodlighting were discussed in this paper.

2. The Theory of RGB Mixing and Tri-Stimulus Value

A relationship between RGB mixing and tri-stimulus was defined by equation (1)

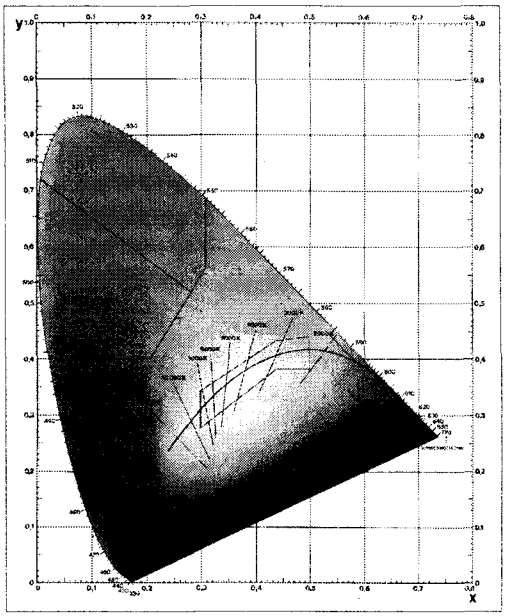

Figure 1. CIE Chromaticity Diagram

$$x_{total} = \frac{X_{total}}{X_{total} + Y_{total} + Z_{total}} \qquad (1)$$

$$y_{total} = \frac{Y_{total}}{X_{total} + Y_{total} + Z_{total}}$$

where,

x_{total}, y_{total} : color coordinate of color mixing
X_{total}, Y_{total}, Z_{total} : tri-stimulus value of color Mixing

$$\begin{pmatrix} X_{total} \\ Y_{total} \\ Z_{total} \end{pmatrix} = \begin{bmatrix} x_r & x_g & x_b \\ y_r & y_g & y_b \\ z_r & z_g & z_b \end{bmatrix} \begin{pmatrix} \frac{Y_r}{y_r} \\ \frac{Y_g}{y_g} \\ \frac{Y_b}{y_b} \end{pmatrix} \quad (2)$$

where,
x_r, y_r, z_r : color coordinate of R,
x_g, y_g, z_g : color coordinate of G
x_b, y_b, z_b : color coordinate of B
Y_r, Y_g, Y_b : brightness of R, G,, B [lm]

$$n_r : n_g : n_b = \frac{Y_r}{Y_{1r}} : \frac{Y_g}{Y_{1g}} : \frac{Y_b}{Y_{1b}} \quad (3)$$

where,
n_r : n_g : n_b , color mixing ratio of RGB LED
Y_{1r}:Y_{1g}:Y_{1b} , contrast ratio of one RGB LED

3. Color Coordinate of Objective Color Temperature

Color coordinate of black body radiation of KSA 0075 and color coordinate due to variation of color temperature were plotted simultaneously in Figure 2. The temperature of 10,000K was extrapolated from the coordinate of KSA 0075.

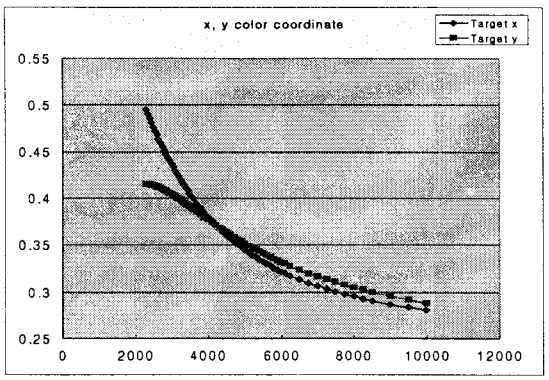

Figure 2. Variation of color coordinate due to color temperature

For each objective color temperature the number of LED was determined by this color mixing algorithm and it was integrated on control circuit for LED module.

4. Development of 50W LED Floodlighting Module and Control Circuit

LED Module has total 57EA of LEDs, Red 22EA, Green 21EA, Blue 14EA, and size of LED module is D340×W130×T0.5mm and was used double faced of a PCB. And luminous flux is 800lm, Efficacy is 18.3lm/W, variation of color temperature is 2,500~10,000K, Driving voltage of Red LEDs is 23.1V, Driving voltage of Green and Blue LEDs is 22.4V respectively, Therefore, V_{total}=24V, I_{total}=2.45A, P_{total}=58.8W

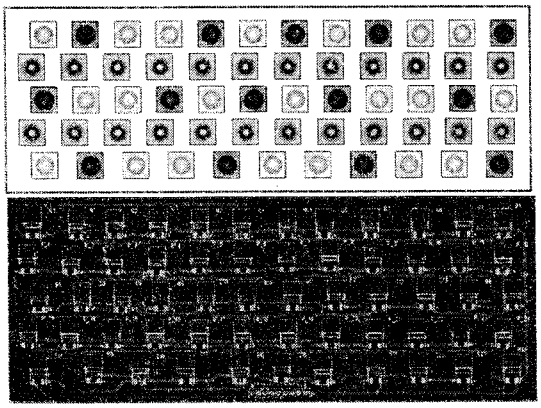

Figure 3. RGB LED Array for Color Mixing and PCB layout

The Control circuit in order to control LED module has micro controller is called AT89C4051. The AT89C4051 is 8 bit micro controller with 4K bytes flash. Size of the Control circuit for color temperature is D120×W 60×T1.6mm.

And the control circuit contain RS232 communication part, LED switching part, mode control part, micro controller part, voltage regulator part for input voltage of micro controller, etc

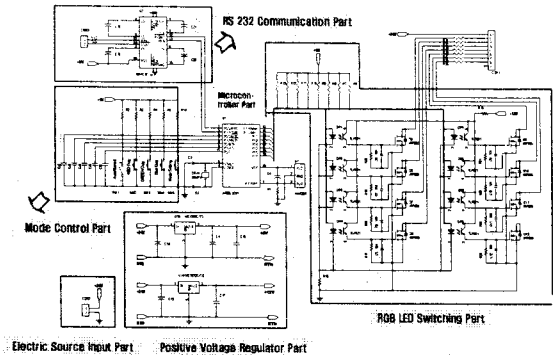

Figure 4. Layout of Control Circuit

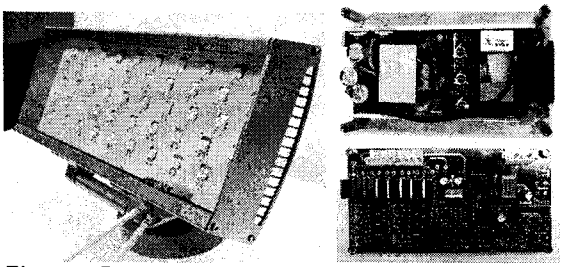

Figure 5. Production of LED Floodlighting /Control Circuit/Driving Circuit

The driving circuit in order to drive LED module convert AC into DC, so as to supply voltage and current to be suitable to LED module in the source of electric power and have over current protection and over voltage protection with additional performance

5. Algorithm of Color Temperature Control and Measurement Results

Figure 6 shows procedure and construction of color temperature for LED floodlighting. And color temperature control of LED floodlighting module was developed was carried by procedure as Figure 6.

Figure 7 shows operating waveform of LED duty ratio. And Table 1 shows measurement color temperature and x, y coordinates of LED floodlighting module by R, G, B duty ratio

Table 1 shows measurement color temperature and x, y coordinates of LED Floodlighting module by R, G, B Duty Ratio

Figure 8 shows color temperature variation of blackbody and LED floodlighting module. In the Figure 8 color temperature variation of blackbody and LED floodlighting module are very correspond. The black curve represent color temperature variation of blackbody and the red curve represent it of LED floodlighting module in the Figure 8.

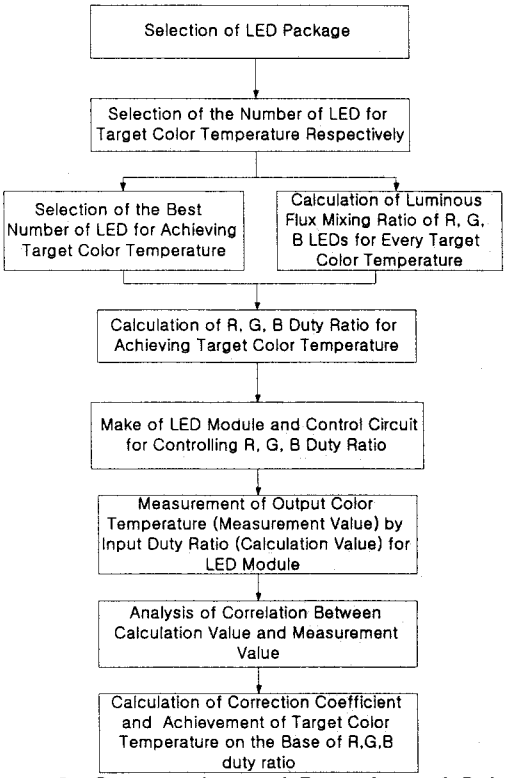

Figure 6. Construction and Procedure of Color Temperature Control

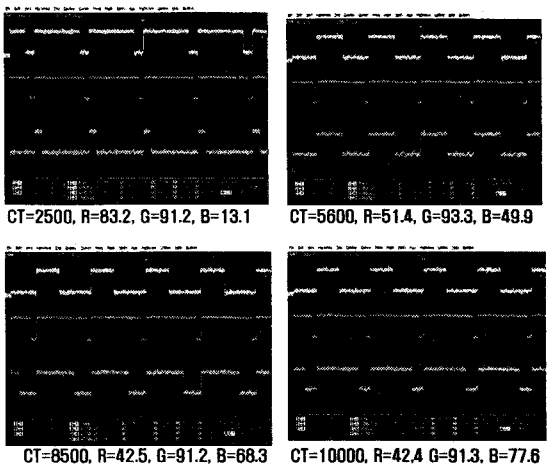

Figure 7. Operating Waveform of LED Duty Ratio

Table 1. Measurement Color Temperature and x, y coordinates of LED Floodlighting Module by R, G, B Duty Ratio

Meas C.T	R	G	B	x	y
2499	83%	91%	13%	0.4782	0.4149
2784	80%	95%	17%	0.4522	0.4072
3410	69%	95%	25%	0.4107	0.3924
3960	63%	95%	34%	0.3800	0.3720
4640	57%	95%	40%	0.3560	0.3610
5600	51%	93%	50%	0.3300	0.3410
5940	40%	91%	52%	0.3230	0.3320
6845	48%	91%	61%	0.3090	0.3150
8526	42%	91%	68%	0.2890	0.3039
10004	42%	91%	77%	0.2800	0.2882

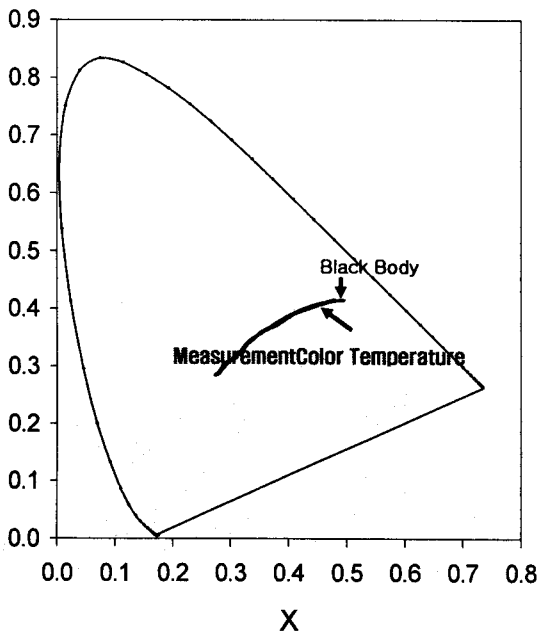

Figure 8. Color Temperature Variation of Blackbody and LED Floodlighting Module

Figure 9 shows patterns of color temperature variation of LED floodlighting which color temperature is controlled for the last time.

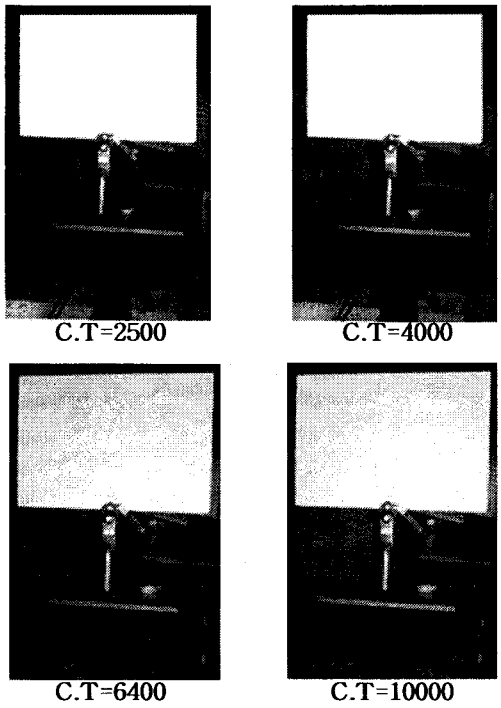

Figure 9. Patterns of Color Temperature Variation of LED Floodlighting Module

6. Conclusion

LED floodlighting module of about 50 W and driv-ing circuit, control circuit were developed for color temperature control. And R, G, B duty ratio of LED floodlighting module very corresponded with blackbody' trace was obtained. In the Future, Control circuit could be applied various application should be developed and development of technique for improvement of confidence should be progress

REFERENCES

[1] J. B. Murdoch, "Illumination Engineering", Macmillan Publishing Company, 1985

[2] A. Zukauskas, M. S. Shur, R. Gaska, "Introduction to Solid State Lighting", John Wiley & Sons Inc., 2002