Developing LED Luminaire System for Generating White Light by Multiple LED Emitters

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Abstract

White is the color the human eye realizes when it looks at light containing all the wavelengths of the visible spectrum. In this paper, we propose an LED system to realize the white light by combining multiple LEDs used in emitting spectra of multiple colors to improve color renderings. When a light-emitting diode is switched on, electrons recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. The color of an LED is determined by the semiconductor material. The proposed system is composed of voltage generator, LED emitter, and LED luminaire. The sensor for detecting the color is well adopted in order to detect the light colors received from the LED emitter, with steady-current controller designed using operational amplifier and transistor. We took advantage of steady-current through the LED emitter in order that several forms of light composed of different wavelengths or frequencies could be adopted producing white color of all frequencies.

Keywords: *Visible light, LED luminaire, Color rendering index (CRI), LED emitter, Delta-sigma converter*

1. Introduction

The visible spectrum is part of the electromagnetic spectrum that can be detected by the human eye. Electromagnetic radiation (or EM radiation) in this range of wavelengths is called visible light. The wavelengths of visible light can be categorized from about 390 to 700 nm

[1]. A light-emitting diode (LED) is a semiconductor light source [2]. LEDs emit light when an electric current passes through them. LEDs are widely used as indicator lamps in many devices and are increasingly used for other lighting. The most popular type of tri-color LED has a red and a green LED combined in one package with three leads. A LED is often small in area (less than 1 mm^2), and integrated optical components may be used to shape its radiation pattern [3]. These are called tri-color because mixed red and green light appears to be yellow and this is produced when both the red and green LEDs are on. Appearing as one of practical electronic components in 1962, early LEDs emitted low-intensity red light, but modern versions are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness [4].

We propose a LED lighting system by adopting more than two kinds of LEDs emitting different visible colors. With many advantages, LED is used in the back light of liquid crystal display (LCD), cell phones, mobile digital device or independent lighting apparatus.

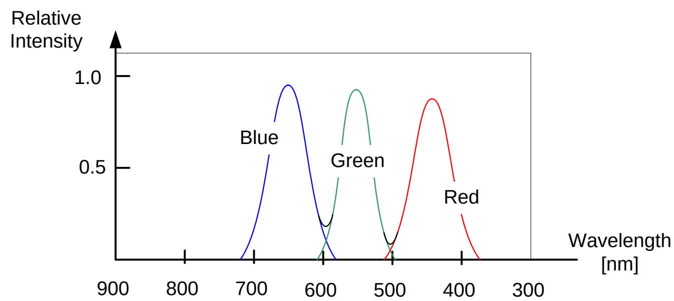

Figure 1. Spectra of LED composed of red, green, and blue colors

Compared to the conventional lighting systems, LED luminaire dissipates less power. Figure 1 shows optical spectra composed of red, green, and blue colors. The common colors of red, green, and blue LEDs and the compound of white spectra is expressed. Compared to the white light from the conventional incandescent lamp or fluorescent lamp, the lights from the LEDs show a superior characteristic of color rendering index (CRI). However, as shown in the figure, the relative intensity of spectrum is lower in the wavelengths of 480nm (the border of red and green color) and 600nm (the border of green and blue color). Therefore, compared to the region of visible light generated from the solar lights, the value of CRI is low due the lower intensity of spectra.

2. Color Rendering Index (CRI)

The color rendering index (CRI), sometimes called color rendition index, is a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. The CRI is currently the only internationally agreed metric for color rendering evaluation. Light sources with a high CRI are desirable in color-critical applications such as photography and cinematography [5]. It is defined by the International Commission on Illumination as the effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant [6]. The procedure for the calculation is, first, to calculate the color differences ΔEi 14 selected Munsell color system when illuminated by a reference illuminant and when illuminated by a given illumination [7].

The first eight samples are medium saturated colors, and the last six are highly saturated colors (red, yellow, green, and blue), complexion, and leaf green. The CRI of a light source does not indicate the apparent color of the light source; that information is under the rubric of the correlated color temperature (CCT) [8]. The reference illuminant is the Planckian radiation for test sources having a correlated color temperature (CCT) < 5000 K, or a phase of daylight for test sources having CCT ≥5000 K. The process shows the von Kries chromatic adaptation transformation. The special color rendering indices, R_i , for each color sample is given by

$$R_i = 100 - 4.6 \, \Delta E_i \; (i = 1, \ldots, 14) \tag{1}$$

Equation (1) expresses the evaluation of color rendering for each particular color [9]. The general color rendering Index, *Ra*, is given as the average of the first eight color samples:

$$R_a = \frac{1}{8} \sum_{i=1}^{8} R_i \tag{2}$$

In Equation (2), the score for perfect color rendering (zero color differences) is 100. The CRI is often used to refer to *Ra*, but the CRI actually consists of 15 numbers ; R_a and R_i [9] .

3. Technical Solution

In this work, we propose the LED lighting luminaire, controlling the implementation of accurate white light through the improved CRI by composing the multiple LEDs, emitting the multiple colors as shown in Figure 2.

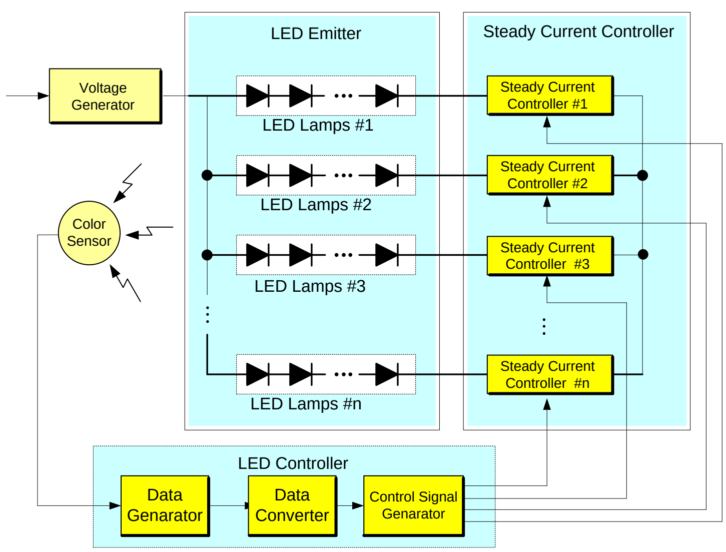

Fig. 2. Schematics of LED system with an emitter and a controller

The proposed system is composed of voltage generator, LED emitter, and LED lighting device. The sensor for detecting the color is well adopted in order to detect the light colors received from the LED emitter. The system has sensor used in detecting the colors of lights generated from the emitter. The system generates the control signal so that the incoming signal should be a pre-determined white color. The system in Fig. 2 has subsystems given below.

1. Voltage generator: supplies the voltage signal to the LED emitter.
2. LED Emitter: contains multiple LED lamps representing used to accepts signals from voltage generator
3. LED Controller: used in order to control the LED emitter. The controller generate data used to control LED lamps. The controller regulates the LED lamps by quantized control signal after delta sigma modulation.
4. Data converter: generate the quantized data by way of delta-sigma conversion.
5. Control signal generator: produces the control signal used to regulate LED lamps by applying the quantized data.
6. Steady current controller: keeps constant the current through the LED lamps. It is composed of transistors with collector, base, and emitter. The collector is connected to the LED lamp, the base is connected to the ground earth, and the emitter is used for receiving the control signal.

This implementation of LEDs is important because functionality can be added to designs with only minor modifications, usually at little or no cost [10]. An LED can be used as a photodiode used for light detection as well as emission. This capability has been demonstrated and used in a variety of applications including ambient light detection and bidirectional communications [11]. The LED controller is composed of data generator, data transformer, and control signal generator. The controller for a steady current is made up of transistors with collector, base, and emitter [12]. The collector is connected to the *n* numbers of LED lighting lamps, the emitter is connected to the ground terminal, while the base is the input terminal for the controlling signal.

The control signal generator is pulse generator that produces the pulse of width adjusted to accept the quantized data. It is operating as D/A converter producing the voltage signal depending on the quantized data. The LED emitter is composed of more than 4 LED lamps, emitting each of the corresponding colors. In the system we propose, the CRI can be improved by the combined construction of multiple LEDs emitting the multiple colors of lights. In Figure 2, the configuration of LED luminaire, as device composed of voltage generator, LED emitter, LED controller, color sensor, and steady-current controller. The LED luminaire is so designed that it encloses LED emitter in order to produce white lights similar to solar lights.

4. System of Operational Amplifier and Transistors

Figure 3 shows an example of designing a configuration of steady-current controller included in the system of Figure 2. It can vary the voltage signal across an LED circuit in order to maintain a steady electric current through emitter. When a component is indicated to be driven by a steady current, the driver circuit is a current regulator and must appear to the component as a current source. It is designed by an operational amplifier of non-inverting input terminal and a transistor [13].

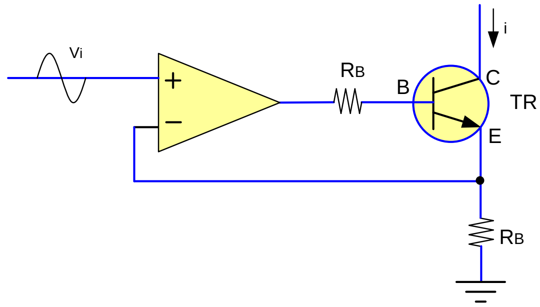

Figure 3. Configuration of steady-current controller

5. System of Delta-sigma Converter

Figure 4 shows the delta –sigma convertor designed to implement the data converter. The convertor is comprised of register, low-pass filter, and quantizer. The register temporarily stores the control data applied [14]. The filter passes bands of frequencies in the range of for the operation of quantizer. The detailed operation of the convertor is expressed. Given the value of control data 5.5, the output value of the converter is any value from 0 to 9. If the control data is 5.5, the output signal for the pulse width modulation is 5 or 6 due to the limitation of hardware resolution. If the incoming control data is 5.5, the output signal shows the value 5 due to the quantization [15]. Therefore, the value to the low pass filter is -0.5, the value to the quantizer is 5.5-(-0.5)= 6. The output from the quantizer is the value of 6.

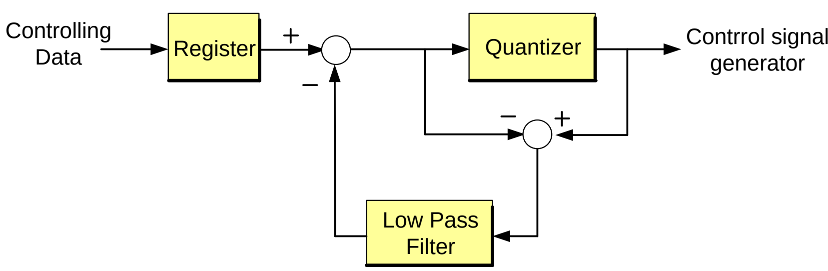

Figure 4. Configuration of delta-sigma data converter

6. Conclusions

In this paper, we have developed an LED luminaire system for generating white light by multiple LED emitter. We took advantage of operational amplifier, transistors, and delta-sigma converter in order that several forms of light composed of different wavelengths or frequencies could be adopted producing white color of all frequencies. Systems based on the proposal will be discussed in the following papers.

Remark: This work is the extended and modified version of presentation at the conference of IST 2013 (Bali, Indonesia).

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