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시그마 델타 변조에 의한 LED 드라이버의 입력 콘트롤러 설계

Delta Sigma Modulation of Controller Input Signal for the LED Light Driver

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요 약 우리는 이 논문에서 ADPCM (adaptive differential pulse code modulation)을 적용함으로써 디밍 콘트롤러를 갖는 LED 드라이버의 설계를 제시한다. ADPCM 장비는 고해상도를 가지고 LED 전류를 정확하게 제어하며, 고조파 전류 펄스의 퍼짐으로 인하여 초래되는 RFI 를 감소시켜 준다. 또한 제어 동작의 정밀도를 높여준다. 이 연구에서 LED에 펄스 전류를 인가함으로써 고효율 에너지의 LED를 제어하는 디지털 제어회로의 설계를 제시한다. 우리가 설계한 LED 전류구동시스템은 디지털 제어 부와 아날로그 SMPS (스위치 모드 파워 서플라이)를 별도로 구현한 두개의 시스템이다. 입력레벨이 0.7 인 경우의 시뮬레이션 결과는 시그마 델타 변조를 하여 얻은 D/A 컨버터의 출력을 나타내었다. 개수가 510 개인 펄스신호의 경우 0.15 % 의 정밀도를 얻을 수 있었다.

Abstract In this paper, we present the LED dimming control system by using ADPCM (Adaptive Differential Pulse Code Modulation). This ADPCM apparatus accurately controls the LED current with high resolution reducing the RFI (radio frequency interference) due to the spreading out of the harmonics of current of pulses. Additionally, this makes it easier to increase the accuracy of control operation. This study introduces to make a digitally controlled circuit for controlling LED with high-energy efficient by adopting pulse current to LED. The LED current drive system we designed are two systems, the digitally-controlled unit and analog switching mode power supply unit, can be developed separately. The simulation shows the sigma delta modulation of digital to analog converter's output when the input level is 0.7. From this simulation, the output is approached to accurately 0.15% to target value with 510 pulses.

Key Words : LED, CFL, DC/DC converter, D-S DAC, PWM

Ⅰ. Introduction

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a pn-junction diode, which emits light when activated[1]. When a proper voltage is applied to the leads, electrons recombine with electron 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

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determined by the energy band gap of the semiconductor. The LED light system is commonly used for general-purpose lighting equipments. It is very convenient and efficient product for electric lighting device compared to the fluorescent light. Due to the limited electrical characteristics of charging and discharging processes, the range of fluorescent light is limited. However, the LED light intensity can be controlled by changing the LED terminal current without almost any limitations. We can supply electricity to LED by constant direct current or unidirectional electric current pulse, or the mixture of the two. The only limitation to turn on the LED is the current direction on the terminal[2]. An incandescent light bulb, incandescent lamp or incandescent light globe is a device generating light with a wire filament heated to a high temperature by an electric current passing through.

The heated filament is protected from chemical oxidation reaction by introducing a glass or quartz bulb filled with inert gas or vacuum.

In a halogen lamp, filament evaporation is prevented by a chemical process that redeposits metal vapor onto the filament, extending its life. The light bulb is supplied with electrical current by feed-through terminals or wires embedded in the glass. Most bulbs are used in a socket which provides mechanical support and electrical connections. Incandescent bulbs are gradually being replaced in many applications by other types of electric light, such as fluorescent lamps, compact fluorescent lamps (CFL), cold cathode fluorescent lamps (CCFL), high-intensity discharge lamps, and LED lamps [3].

The incandescent light is very excellent for the lightening device. The high CRI (color rendering index) and wide range of dimming performance are the most superior characteristics of the incandescent light. This excellent incandescent light performance makes the incandescent lighting systems widely used on world today. Incandescent bulbs typically have short lifetimes compared with other types of lighting; around 1,000 hours for home light bulbs versus typically 10,000 hours for compact fluorescences and 30,000 hours for lighting LEDs. As a substitute device of incandescent light, LED is one of the challenging devices to replace the incandescent light. For the light characteristic difference between two is that the incandescent light changes its color temperature widely as well as intensity while dimming. Compared to the incandescent light, LED has little difference its light spectrum while dimming[4]. In terms of the efficiency of electric energy, LED is a more effective better device compared to incandescent light or fluorescent light. It is known that the LED can save about 50% of electric energy than that of fluorescent light and 80% than that of incandescent light bulbs. In the field of applications, the LED is also called solid state light. This means that the LED has limitation on its operating temperature; i. e., the typical operation temperature to turn on LED is -40oC~125oC, which is very limited range compared to the incandescent light bulb.

II. Overall System Configuration of LED Light

Figure 1 shows a block diagram we propose for LED lighting system. Since an AC voltage supply is applied to the input terminal, AD to DC (not ahown in the figure) and DC to DC converter is used.

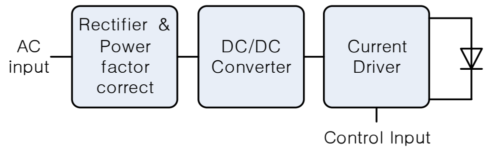

그림 1. 디밍 콘트롤러를 갖는 LED 조명 시스템
Fig. 1. LED Lighting system with dimming control

The efficiency of system is related not only LED current driver, but also rectifier, power factor correct circuit and DC/DC converter. Hence, in this study, system adapted high efficient units for them; such as resonant power converter for DC/DC converter and PFC with transient mode[5]. The overall system efficiency is reduced if the units are inserted, from AC input power to LED terminal DC current power. To obtain a high efficiency, we separated the system two sections; one is analog power converter unit and the other is digital LED current driver unit. The analog section is widely studied by researchers[6].

(1) DC/DC converter

In the proposed system, DC/DC converter works very efficiently for the SMPS (switched mode power supply) compared to the other method, due to the soft switching operation. The combination of two inductors and one capacitor ("L-L-C"), offers a relatively narrow range of switching frequencies, which are much easier to design a standard EMI filter for, combined with the capability of producing zero-voltage switching (soft-switching) through careful design which can significantly improve EMI and efficiency over a wide load range[7]. Therefore, the LED driver adopted the resonant LLC converter to be able to improve the performance of front end DC/DC converter significantly for high efficieny over wide range of output voltage and power[5]. This analog AC/DC converter have high efficient conversion rate up to 90% or higher for 10% to 100% varying power range.

(2) LED Current Drivers

With better efficiency and performance, The LED had been widely studied by the researchers for the source of light. For that purpose LED drivers are being developed to satisfy requirement of LED luminance (or light), which is almost proportional to the average current of LED[8]. Various kinds of control method have been developed in order to control LED. The typical methods are classified as follow.

(1) Resistors are connected in series with LED.
(2) Constant current is connected to LED.
(3) Width or number of Current pulses are controlled.

The first two methods are very simple ones to implement, but those control methods are hard to make accurate one. On the other hand, the third method, however, need to adopt a electronic circuit, which is very complex but accurate results and energy-efficient operation. In this paper, this study focused to make a digitally controlled LED current control circuit with high-energy efficient circuit with pulse current drive to LED.

(3) Delta Sigma Digital-Analog Converter

The delta sigma digital to analog converter(D-S DAC) is widely used for the digital to analog interface such as audio, measurement, control, and etc. This method is very convenient to implement and its circuit is little affected the components accuracy. User can design high order DAC by change high order digital filter in H1 block of figure 2 and get better result than zero order or first order[6]. But in this LED driver, the delta sigma converter is composed by software for lower cost and simple hardware circuit. After several times of implementations, the first order structure can reduce the number of microprocessors machine code and fast operation.

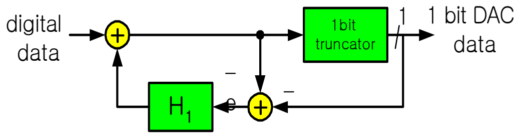

그림 2. 델타 시그마 DAC 에 대한 오류 궤환 시스템
Fig. 2. Error Feedback system for delta-sigma DAC

For this circuit, the number of bits compare to bit depth of PWM is hard to compare directly. Refer to the previous study; the bit increase rate is about 10 times than bits depth of PWM[6]. This one bit D-S DAC circuit need only add and invert functions to implement and, the output is '0 ; off' and '1 ; on' signal. The operation is very similar to that of PWM generator's. It is not necessary for the users to introduce a new interface circuit for D-S DAC for LED driver sibce it can be implemented by software. Hence, this delta-sigma DAC output pulses are not periodic than PWM generator, the pulse spectrum of D-S DAC output pulse spectrum is widely spread over frequency than PWM.

III. Overall system Configuration Reults

After considering above condition, the developed LED driver system is shown in figure 3. The LED current drive system ells the digital unit and analog switch mode power supply unit can be developed separately. After developed each part, those are combined. After minor correction for tuning, its maximum performance can archive.

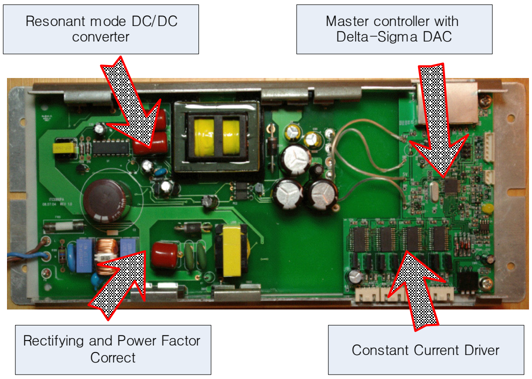

그림 3. 제작한 LED 드라이버 회로
Fig. 3. Manufactured LED driver circuit

The system performance measurement is based electric measurement and human emotional test. These are as following terms.

(a) Electric specifications are match to KS standard.
(b) The efficiency of system is above the 90% at full load.
(c) The system dimming archives 10~100% without flickering.
(d) In dimming range, the electric efficiency is 80% or above

The LED light drive system with D-S DAC dimming control system have good performance. Its performance can compare to higher bit resolution of PWM controlled system. The PWM control system is very hard to measure the terminal voltage of constant current source because of it independent operation. But software controlled D-S DAC can sample the terminal voltage of constant current source by software also. Hence the overall system performance can keep maximum efficiency without flickering and low RFI.

The RFI performance is another achievement of the dimming control system. With PWM controlled LED circuit, its current is periodic and its harmonic frequency also appeared on fixed frequency. But this D-S DAC pulses spectrum is spread out except the single frequency, because its pulse train look irregular. Figure 4 shows the generated D-S pulse waveform output when the input level is 0.7. From this simulation, the output is approached to accurately 0.15% to target value with 510 pulses.

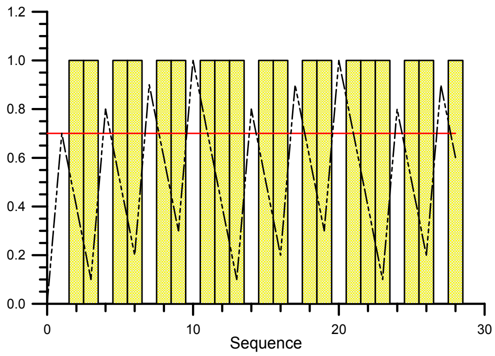

그림 4. 생성된 D-S 펄스 파형
Fig. 4. Generated D-S pulse waveform

IV. Conclusions

In this paper we present a highly efficient LED light driver with dimming control using delta sigma modulation. For the well-known current control of PWM, digital circuit is hard to make a higher resolution, such as 12-bit resolution of circuit with 25 kHz. Hence, we implemented the alternator method of digital system to control the current to LED instead of PWM generator for novel operation. For the alternator method, the D-S DAC (delta sigma digital to analog converter) brings remarkable result for the result for dimming resolution and RFI. The studies on the D-S modulation and D-S digital to analog converter tell it can reduce the number of switches of digital circuit and it brings higher resolution than PWM circuit with same frequency of digital circuit.

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