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Four-order temperature protection for high-power 256-step LED current dimming chip☆

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ABSTRACT

This study presents a high-resolution current-mode approach for LED dimming. We propose the 256-level currents to control LED brightness with 8-bit binary code. Based on current mirror theory, a switchable current is controlled by 8-switch current mirror arrays. To prolong the lifespan of LED driver, four order of the temperature sensor is proposed to control LED driving current. The diode is used as temperature sensor. In order to protect over heating of LED driver, the four sensing levels are used to control LED current. The over voltage protection is also designed to avoid to damage power MOS of this chip. With full-costumed design, the chip area included pads is only 1.87 mm^2 using TSMC 0.25 μm high-voltage technology. The single chip can drive 72 W LED devices in maximum when the LED driving current is 1.2 A and the supply voltage is 60 V. The 256-step current levels are used for LED dimming, where the resolution of current to luminance can achieve 1 mA. The maximum driving efficiency can be up to 98%, and our lighting efficiency can be improved by 20% compared with switching modulation.

1. Introduction

Today nearly a quarter of the electrical energy was used for lighting in the world. If energy-effective LED lamps are used, we not only save the Earth's resources but also gaining economic benefits. Since Kyoto Protocol is announced, a strong focus on the global carbon reduction environmental issues caused by the prevalence of energy-efficient lighting. The development of LED lighting applications rapids recently and also lit the surrounding industrial development prospects. The luminous efficiency of LEDs is gradually increasing, where is over 180 Lux/Watt since 2016. It is predictable trend that LED will soon replace traditional lighting solutions.

The conventional lighting tube can directly plug in to AC power. Since LED is a kind of semiconductor device, low DC voltage is used. First, the AC/DC driver is required [1–12]. The driving quality will also affect the level of LED luminous efficiency. The efficiency of LED driver impacts on the system performance, so the driver design is one of the keys for LED lighting. Since LED is DC component, it is easier dimming than AC tube. LED brightness dimming can be applied not only for energy dissipation reducing, but also for color adjustment. LED can produce maze true color lighting for many applications, such as LED display. The LED luminance is proportional to its forward current, so we can control the driving current for dimming purpose. For LED dimming, chip-level or board-level [13–16] were implemented. The typical dimming methods include PWM(Pulse Width Modulation), AMC(amplitude-mode control) and CMC (current-mode control). PWM method is simple and effective method to control the LED brightness by turn-on cycle. However, there are some drawbacks about PWM dimming. The PWM dimming for LED devices not only produces electromagnetic interference (EMI) but also shortens the LED lifespan [19]. We need extra cost to solve EMI problem from PWM switching. The visible flicker disappears when we design PWM frequency being over 400 Hz. Nevertheless, the flickering level is strong by the detection of the optical meter.

AMC(amplitude-mode control) approach likes the DC-DC converter that can control the output voltage to adjust LED brightness. However, the LED lighting is very sensible to voltage changing. The LED lighting is dependent on its driving current. However, the relative-ship of voltage-to-current on LED components is exponential. While the voltage changes little, the driving current changes greatly. LED lighting level is hard to control in high accuracy. Besides, the temperature of high-power LED increases when the driving current increases. With voltage driver, the bad cycle occurs since the temperature successively increases to cause the driving current increasing, and the driving current increase may cause the temperature further increases. LED lifecycle would be shortened because the driving current and temperature is not

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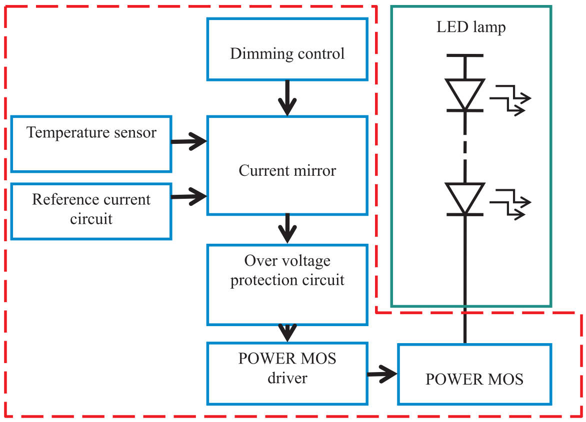

Fig. 1. The system architecture of proposed LED driver.

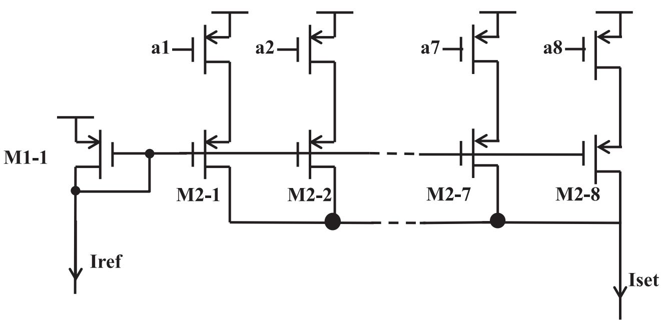

Fig. 2. The reference current generation with current mirror.

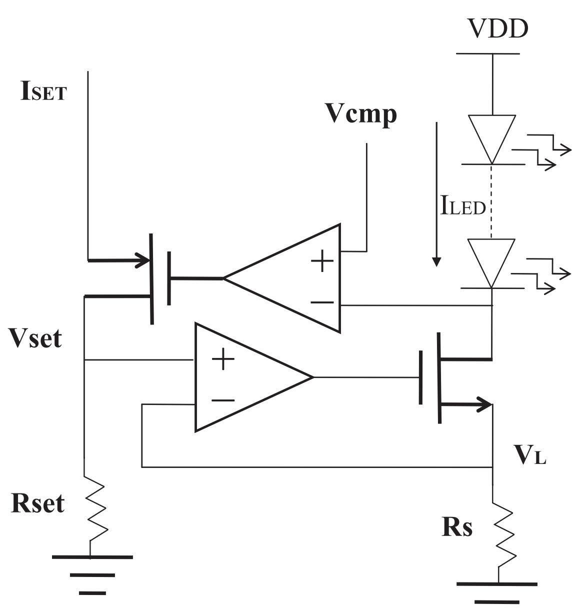

Fig. 3. The regulated current control with over-voltage protection for LED driver.

easily controlled under specifications. With these reasons, the present LED driver mostly used constant current driving rather than voltage because the driving current is independent of the voltage drift and temperature change.

CMC (current-mode control) controls the driving current to change LED brightness. Recently, a bilevel LED driver is proposed to improve PWM drawback [13], which adds a DC offset of PWM dimming to reduce the switching energy. The current dimming method is without PWM switching, which is no flicker and EMI problem. The lighting efficiency can be improved by about 20% compared with PWM dimming [13]. Clearly, the current dimming method has better performance than the conventional method.

However, the bilevel current approach only can adjust two-step currents for LED dimming, which is no enough for practical LED dimming requirements. To solve this drawback, we proposed a multi-level CMC method that is designed at the last stage of LED driver after AC/DC converter. We design a high-resolution current mode control for true-color LED dimming. The dimming step can be up to 256 current levels, which the resolution achieves 1 mA to control LED brightness meticulously. The constant current driver can produce stable lighting without any flickering, which is health for human eyes. In order to protect the driver, four-order over-heating protection is proposed using semi-conductor material as temperature sensor. This approach can avoid that the LED lighting suddenly turns off when the temperature is over the specification. Besides, over voltage protection had been built-in to this chip. This can avoid damage the driver under the cases of high transited voltage and abnormal supporting voltage. The rest of this paper is organized as follows. The chip architecture is proposed in Section 2. The implementation and experiments are described in Section 3. The conclusions are marked in Section 4.

2. System architecture of LED driver

In this study, we proposed a high-resolution current-mode LED driver by 256-step digital control. Fig. 1 shows the system architecture of our proposed LED driver. The reference current is generated from the band-gap reference voltage to against various temperatures and input voltage drift. For LED dimming, the current switch is used to control driving current by current mirror of the reference current. The temperature sensor is used to control driving current. When the temperature is over the specification, the driving current decreases to avoid damage the driver. The over voltage protection is used to sense the voltage of supporting LED. When the sensing voltage is over one threshold, the driving current shuts down to zero to protect LED devices.

2.1. Current mirror dimming control

Fig. 2 shows the circuit of current mirror control using current switch. The MOS M1-1 is used to produce the reference current Iref. The M2-1 to M2-8 is current mirror of M1-1. This consists of weighting current mirror array that is controlled by current switch. The ratio of channel length (L) and width (W) of M1 and M2 is defined by

$$M_1^{W/L} = \frac{W1}{L1}, \quad M_2^{W/L} = \frac{W2}{L2}, \tag{1}$$

respectively. If $M_2^{W/L}$ is M times of $M_1^{W/L}$, the mirroring current can be achieved by M factor of the reference current as

$$I_2 = M \times I_1 = M \times I_{REF}. \tag{2}$$

We defined M factor of M2-1, M2-2 to M2-8 by 1,2,4...128. The weighting current Iset is from summation of all mirror currents by

$$I_{set} = (a1 + 2a2 + 4a3 + 8a4 + 16a5 + 32a6 + 64a7 + 128a8)I_{ref} \tag{3}$$

where a1,a2,..,a8 are current switch of mirror current M2-1, M2-2 to M2-8.

In Fig. 3, the circuit of current control for LED dimming is controlled by virtual ground of OPA. The current dimming control is a closed-loop system. The LED driving current is through to the sensing resistor R3. The sensing voltage (Vs) is feedback to control power MOS for closed-loop control. As the driving current is increased or decreased in unprediction condition, for example, input voltage is suddenly changed, the LED driving current can be controlled to a constant value by the closed-loop control.

The reference current can be generated by