High efficiency multi-channel LED driver based on SIMO switch-mode converter

Luchen Yu, Minjie Chen, Xutao Lee, T.Yoshihara
Graduate school of information, production and systems, Waseda University
2-7 Hibikino, Wakamatsu-ku, Kitakyushu-shi, Fukuoka, Japan

Abstract—This paper presents a new method to drive multiple LED strings efficiently. The proposed driver is based on single-inductor multiple-output (SIMO) switch-mode converters. Because the proposed driver gets rid of linear current regulators and maintains desired constant current of each string directly, it maximizes the overall efficiency and handles mismatching problems of the conventional driver. The simulation results show excellent performance on four-string LED with four 1W LEDs in each string including individual dimming. The measured efficiency was improved at least by 15% compared with the conventional driver of linear current regulators.

I. INTRODUCTION

Recently, high-brightness LEDs have become the optimal solutions for display backlighting, decorating lighting, traffic lighting, portable devices. Because they have long life time, low maintenance requirements, and improved luminance. In backlighting application, multi-channel of LED strings is widely used.

This paper presents a method to drive multi-channel LED strings applying SIMO switch-mode converters and offers the maximum efficiency. The circuit directly maintains constant current of each string by sensing resistors and a current-mode pulse width modulator (PWM) controller.

II. PROPOSED LED DRIVER BASED ON SIMO SWITCH-MODE CONVERTERS

The proposed N-channel LED driver based on SIMO switch-mode converter is shown in Fig. 1. It consists of N LED strings. Each string is combined with a sensing resistor Ri (i=a,b,…,n), a current amplifier CAi and an Error amplifier EAi. These three work as current feedback, connected to a PWM controller. Each channel is turned on in respective phase of $\Phi_a$, $\Phi_b$, …, $\Phi_n$ within a whole period T.

The accurate relationship of $V_{IN}$, $V_O$, switching frequency $f_s$, duty cycle $D$, and current through LEDs can be derived by the proposed circuit in Fig. 2.

Stage 1: $\Phi_i$ conducts. PWM processes, and converts the control voltage $V_{EAi}$ to D. M conducts. The inductor is charged by the input voltage during $T_{ON}$, and current through the inductor rises up to $I_{P_i}$.

Stage 2: $\Phi_i$ conducts. Main switch M shuts down because duty cycle D equals zero. The inductor is discharged during $T_{OFF}$, and current through the inductor falls down to zero.

Stage 3: $\Phi_i$ is turned off and prepares for next phase.

To ensure that the inductor works in DCM, $T_{ON} + T_{OFF}$ must be less than $T/N$. The current through each LED string equals to the inductor current in $T/N$ being averaged to the whole period T. It’s obvious that from the known $V_{IN}$, $V_O$ and switching frequency $f_s$, if I want to get constant $I_{LEDi}$, I just need set the sum of inductor charging and discharging time. Then the duty cycle of PWM output voltage is determined. If there is any change in $I_{LEDi}$, the PWM controller change the duty cycle D to change charging and discharging time of the inductor, so that maintain the desired constant current in LEDs.

Dimming can be done respectively. Taking one channel as example, the driver circuit is shown in Fig. 3. PWM dimming can adjust the brightness of each LED string by controlling the average LED string current.

III. PERFORMANCE EVALUATION

The proposed LED driver is builted and verified experimentally with a 400kHz SIMO switch-mode converter operating at a input voltage source of 20V. The desired current through each LED string is 350mA. Four parallel strings of LEDs and with four LEDs series connected in each string were used to evaluate the performance of the designed circuit. The measured current in four LED strings $I_{LEDa}$, $I_{LEDb}$, $I_{LEDc}$, $I_{LEDd}$.
the current waveform of inductor, and the waveform of output voltage of PWM controller are shown in Fig. 4. There are small ripples in LED current, less than 20mA, in the range of LED’s capability. Average voltage drops measured through each LED string are $V_{LED_a}=11.7V$, $V_{LED_b}=11.9V$, $V_{LED_c}=12.25V$, $V_{LED_d}=12.43V$ at 350mA.

The advantage of the proposed LED driver is more apparent when mismatching of the four strings of LEDs appears. Choosing one case to clarify, the middle two of voltage drops are set close to each other, and the first and last voltage drops have ±20% tolerance respectively. When this case comes to the conventional drivers with linear regulator, the efficiency must be poor. Other adjustment methods can reduce power loss on linear regulator only a little, but cannot eliminate such kind of power loss ether. However, the switch-mode converter overcomes the mismatching problem, as shown in Fig. 5. Average voltage drops measured through each LED string are $V_{LED_a}=9.9V$, $V_{LED_b}=11.9V$, $V_{LED_c}=12.25V$, $V_{LED_d}=14.64V$ at 350mA.

By the way, the proposed driver doesn’t have the problem of mismatching of LEDs voltage drops, so that even in the worst case, difference between voltage drops on LEDs as high as 20%, the efficiency isn’t affected. This characteristic improves the stability and applicability of one LED driver.

IV. CONCLUSION

A novel LED driver based on SIMO switch-mode converter is proposed. The driver is consists of four channels of LED string, each string is combined with current sensing resistor and series of amplifier and all channels use a current-mode PWM controller. PWM controller maintains the current through each LED string by controlling the charging and discharging condition of the only inductor. The work period of the inductor is divided into four phase, and each LED string occupies one phase. By setting charging and discharging time of inductor, less than one period of PWM controller, the buck converter is in DCM mode. The DCM mode insures that each channel works respectively and does not disturb with each other, so that dimming signals can be easily attached on each string.

By getting rid of linear regulators, there is no power loss on linear regulators. The proposed driver improves the overall efficiency significantly. The performance of the proposed LED driver was simulated at the case of four-channel LED with four LEDs in each string. The switching frequency of the buck converter is 400kHz, and the input voltage is 20V. Hence, the output voltage is assumed around 12V, so that each LED is supposed to be 1W during lighting at the current of 350mA.

The performance was verified stable and good even when high mismatching of LED string voltages exists. The efficiency was improved by 10-15% under different tolerance of LED string voltages compared to the corresponding conventional driver with linear regulator. This characteristic can be more suitable for applications. The proposed driver is also suitable for PWM dimming, especially more flexible dimming signals. It realizes different dimming requirement on one driver.