



## **A NEW HIGH-POWER LED DRIVER WITH POWER-EFFICIENT CONSTANT-OUTPUT-CURRENT CONTROL**

**RENBO XU<sup>1,2</sup>, HONGJIAN LI<sup>1,2+</sup>, YONGZHI LI<sup>3</sup> and  
CHANGQIAN ZHANG<sup>4</sup>**

<sup>1</sup>School of Physics Science and Technology  
Central South University  
Changsha 410083, P. R. China  
e-mail: xrb1118@163.com

<sup>2</sup>School of Materials Science and Engineering  
Central South University  
Changsha 410083, P. R. China

<sup>3</sup>College of Physics and Information Science  
Hunan Normal University  
Changsha 410081, P. R. China

### **Abstract**

A new type of drivers for high power light emitting diode is introduced based on Boost-Buck converter that operates in Peak Current Mode. In contrast to conventional LED current drivers, the new driver controls the average current, not the forward peak current. The new control method called as Double-Loop Current-Mode control is proposed through adding a current outer loop that is constituted with an error amplifier and an integrator. Its advantages are that it can regulate the average output current accurately and it is of high power-

Keywords and phrases : LED driver, current outer loop, average output current.

<sup>+</sup>Corresponding author

Received April 28, 2011

efficiency. Besides, the new control technique could be applied to different input voltage cases and it can protect the Metal Oxide Semiconductor switches availably.

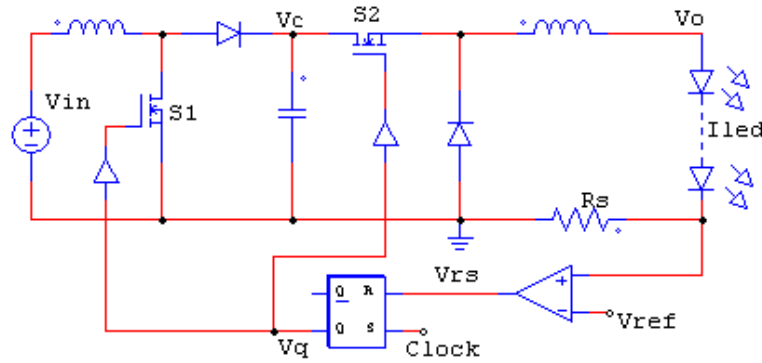
## I. Introduction

In recent years, as the progress of light emitting diode (LED) technology, high-power LED has more and more applications such like cellular phone, pocket pc and LCD (Liquid Crystal Display), TV, etc., which creates a huge market demand for LED driver. However, requirements such as high power factor, long life time, low cost, switch protection, accurate current control and high luminous efficiency pose challenges to the design of LED driver circuit. One of the most commonly used high-power LED is driven at 350mA and LED manufacturers are constantly working on driving LED at higher output current so that it can provide sufficient light output for broader lighting applications [1-2].

This brings about the need for high-power LED driver that can deliver and regulate LED current in a power efficient manner. Among all kinds of LED drivers, switch mode power converters are common choices for high-power LED driver due to its better efficiency [3]. In general, DC-DC PWM (Pulse-Width Modulation) converters for LED have three basic types: Buck, Boost and Buck-Boost. Some other topologies like Flyback, Boost-Buck, Single-End Primary Inductance Converter (SEPIC) etc. are all derived from the three basic topologies above [4]. In order to study the performance of DC-DC PWM converters, we take Boost-Buck type for example, as shown in Figure 1. Unlike conventional LED drivers, it could be applied to both low and high voltage cases. And it is widely used in car applications because the car power supply voltage is changeable.

Considering that the ripple of LED current will impact the luminous flux and consequently the luminous efficiency, the peak current mode (PCM) control is chosen in Figure 1. It can be known from the analysis that PCM control technique of Boost-Buck converter features fast transient response and high stability [5, 6]. But it only control the forward peak current of LED,

not the average current, it cannot satisfy the accurate regulation of luminance. In this paper, a novel high power-efficient PWM controller for average current is proposed.



**Figure 1.** LED Boost-Buck converter diagram.

The basic circuit description of Figure 1 is described in Section 2. The new high-power LED driver with power-efficient accurate output current control is derived in Section 3. Section 4 presents the simulation and experimental results.

## II. Circuit Description

The DC-DC converters in the open loop usually use Pulse Width Modulation to control the switch to regulate the output voltage [7-9]. The duty ratio is a proportional relation to the input and output voltage. But there are some factors like input voltages disturbances and ripples cause the output voltage unstable. In order to deal with the problem, a feedback loop is added to the system.

The general idea behind it is to adjust voltage or current through closed loop control. And the DC-DC converter under PCM is operated in Continuous Conduction Mode (CCM). A sensing resistor placed in series to the high-power LED is used to sense the current and convert it to a feedback voltage for system control [10-13]. To prevent the sensing resistor to consume too much power and gain high power efficiency, a small resistance

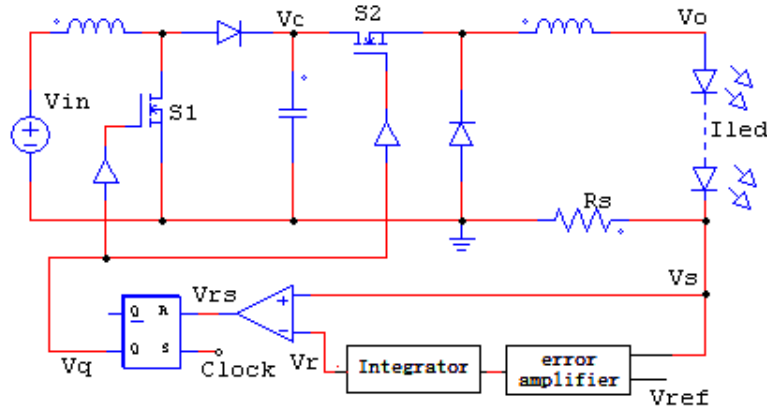
is chosen. After the output current flowed through the sensing resistor, the sensing feedback voltage can be gained. Then the error signal is acquired after the reference voltage compared with the sensing voltage and passed by the RS flip-flop. And the output signal of the driver becomes the control signal of power MOS switches and realizes the peak current control.

The complicated Boost-Buck converter could be considered as a single Boost converter connected with a single Buck converter. From the Boost-Buck converter diagram in Figure 1, we can see that a conductor, MOS switch  $S_1$ , a diode and a capacitor form the Boost part, and the Buck part are constituted with the other components except for the comparator and RS flip-flop. According to the operation of Boost-Buck converter, the relationship between input voltage  $V_{in}$  and output voltage  $V_o$  can be described as [14]:

$$\frac{V_o}{V_{in}} = \frac{D}{1-D}. \quad (1)$$

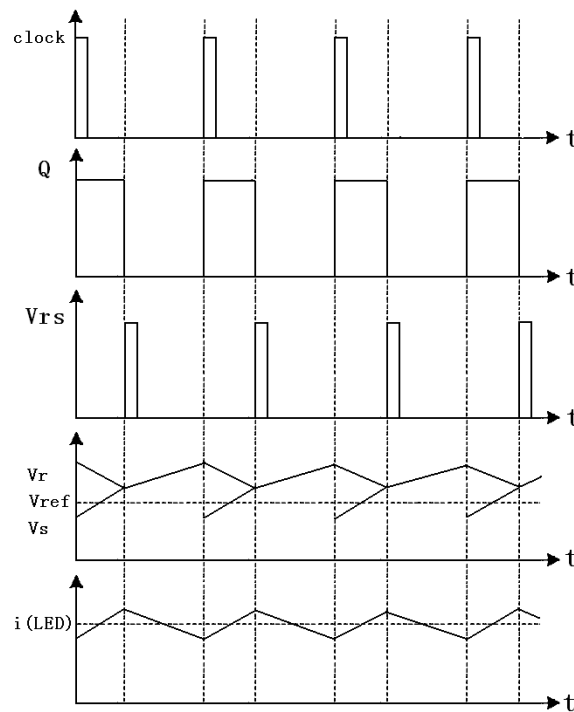
In the equation 1,  $D$  is the steady duty ratio of MOS switch, and we can regulate the output voltage through controlling the duty ratio  $D$ .

### III. The Proposed Constant Output Current Circuit



**Figure 2.** The proposed LED driver with double-loop current-mode control.

From the analysis of Boost-Buck converter features under peak current mode it can be known that the converter has high stability, fast transient response and high efficiency. But it cannot satisfy the accurate regulation of luminance, because the converter only controls the forward peak current, not the average current [15]. In order to control the average current of LED precisely, a new driver called as double-loop current-mode control technique is proposed through adding a current outer loop into the peak current mode control technique, as shown in Figure 2. The error amplifier block and the integrator block constitute an outer loop, and the voltage comparator, the RS flip-flop and the driver form inner loop.



**Figure 3.** The working waveforms of the proposed driver.

From the system block diagram in Figure 2, we can see that there is a sensing resistor  $R_s$  to sense the output current. The operation of the circuit is as follows. Metal Oxide Semiconductor switches  $S_1$  and  $S_2$  are controlled

by the basic RS flip-flop. There are two repeated phases. During phase 1, the input  $S$  of RS flip-flop is high level, and the output  $Q$  is high level, then the switch  $S_1$  and  $S_2$  are turned on. After the output current flowed through the high power LEDs and  $R_s$ , the sensing feedback voltage  $V_s$  can be acquired. The control voltage signal  $V_r$  between the integral voltage  $V_r$  of error value and the sensing feedback voltage  $V_s$  is obtained to control the RS flip-flop. Then the output of RS flip-flop control the MOS switches  $S_1$ ,  $S_2$  and regulate the output current accurately. When the sensing feedback voltage  $V_s$  moves upward and surpasses integral voltage  $V_r$ , the circuit enters phase 2. The input  $R$  of RS flip-flop changes to high level, and the output  $Q$  is low level. Then the MOS switches  $S_1$  and  $S_2$  turn off. The sensing feedback voltage  $V_s$  moves down quickly until the next clock in input  $S$  comes and the circuit enters phase 1 again. Then the two phases are repeated continuously and the working waveforms are shown in Figure 3.

Different with the Boost-Buck converter the new reference voltage in the double-loop current-mode control  $V_r$  is

$$V_r = -\frac{1}{RC} \int (V_{ref} - V_s) dt. \quad (2)$$

By using the integral value of error value between reference voltage and sense voltage it regulates the control voltage to eliminate the steady error of the average current. Besides, the new driver could be applied in wide frequency and the minimum and maximum frequency could be described in equation 3 and 4.

$$f_{\min} = \frac{1 - \frac{1}{1 + \eta_{\min} \times (V_{in, \min} - V_d)/V_o}}{T_{off}} \quad (3)$$

$$f_{\max} = \frac{1 - \frac{1}{1 + \eta_{\max} \times (V_{in, \max} - V_d)/V_o}}{T_{off}}. \quad (4)$$

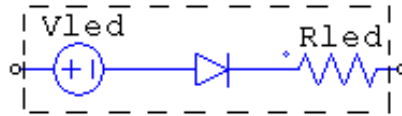
In the equation 3 and 4,  $V_d$  is the diode conduction voltage drop,  $T_{off}$  is the actual turn-off time,  $\eta_{min}$  and  $\eta_{max}$  are the minimum and maximum efficiency respectively.

As a result of double-loop current-mode control technique, the driver provides a precise constant average output current for the LEDs and gets high power efficiency. Moreover, the proposed converter operating in CCM has many better performances such as variable input voltages, wide frequency bandwidth and high stability.

#### IV. Simulation and Experimental Results

In the section, to study the proposed controller without losing generality, the control performance of Double-Loop Current-Mode control technique is verified by time-domain simulation, and based on that, the proposed LED driving system has been developed to implement a serial of comparative experiments. The results show the advantages and validity of the new driver, such as excellent dynamic performance and good robustness.

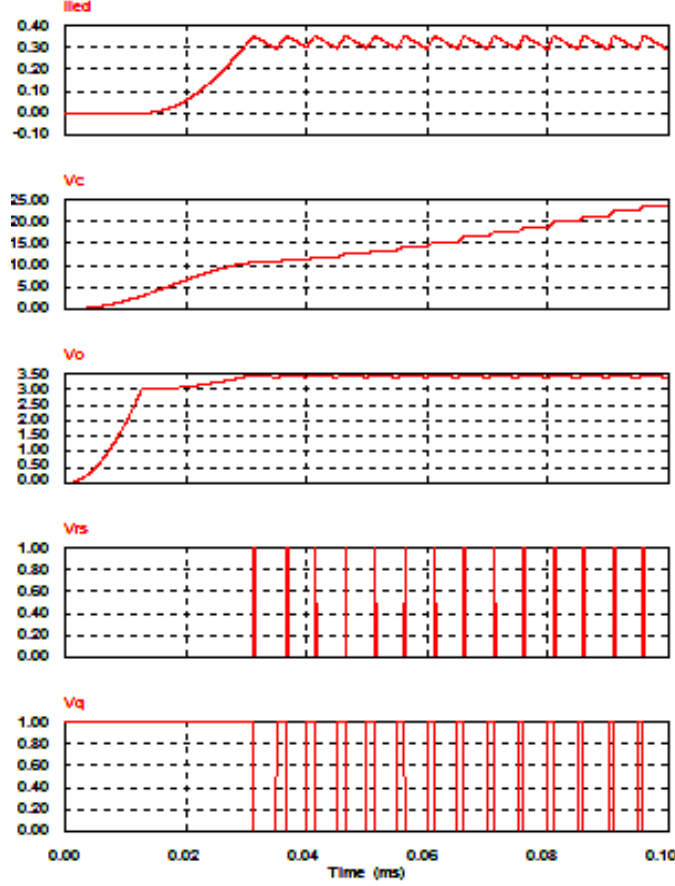
In the driving simulation, the input voltage  $V_{in}$  is commonly used 12V, the reference voltage  $V_{ref}$  is 0.035V and the sensing resistor is 0.1 $\Omega$ . The clock signal is amplitude of 1V, frequency of 200 kHz. The LED component is replaced by a voltage of 3V and a resistor of 1.2 $\Omega$ , as shown in Figure 4.



**Figure 4.** LED equivalent circuit.

Figure 5 is the waveforms of Boost-Buck converter. The output voltage  $V_o$ , LED current  $I_{led}$ , power MOSFET gate driving signal  $V_q$  and boost output voltage  $V_c$  etc. are shown in the figure. The curves showed that the ideal CCM operation is well realized. From the simulated waveforms, we can see that the LED current  $I_{led}$  is changed with the driving signal  $V_q$ . When

$V_q$  is high level,  $I_{led}$  moves up to 350mA. Then  $V_q$  converses to low level,  $I_{led}$  moves down to 300mA until  $V_q$  is changed to high level and  $I_{led}$  moves up again. The feedback signal  $V_{rs}$  is also consistent with the theory well. Moreover, the boost output  $V_c$  approaching 24V surpasses the input  $V_{in}$  much and the output  $V_o$  is 3.50V below  $V_{in}$ , which realizes the operation of the boost-buck converter.

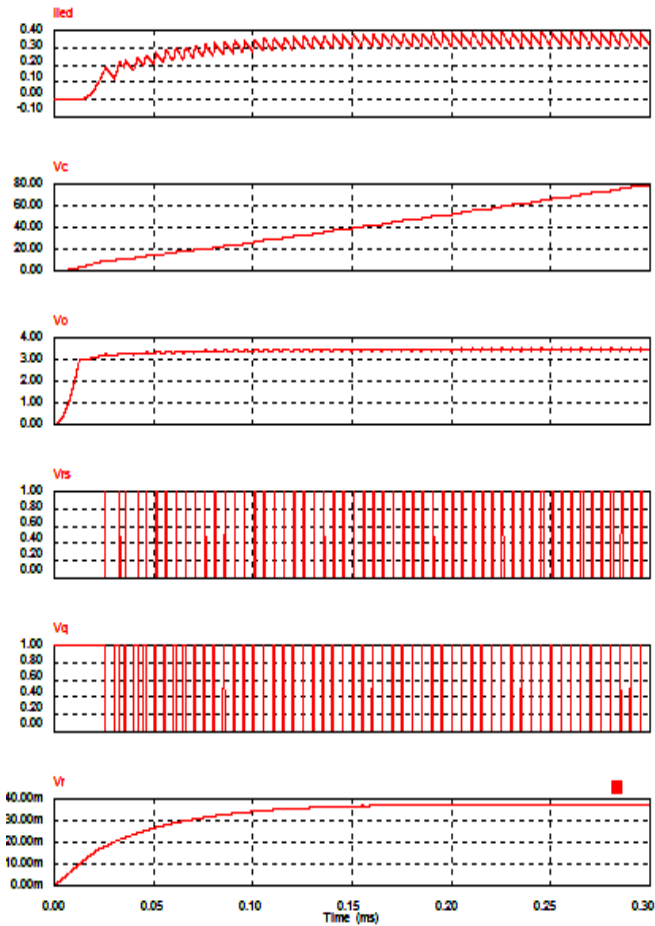


**Figure 5.** Simulated waveforms in Boost-Buck converter.

Figure 6 is the waveforms of the proposed Double-Loop Current-Mode driver in CCM. From the figure, we can see that boost output  $V_c$  is also much higher than the input voltage  $V_{in}$ , which makes the operation of boost-buck converter well verified again. The output voltage  $V_o$  is more stable than



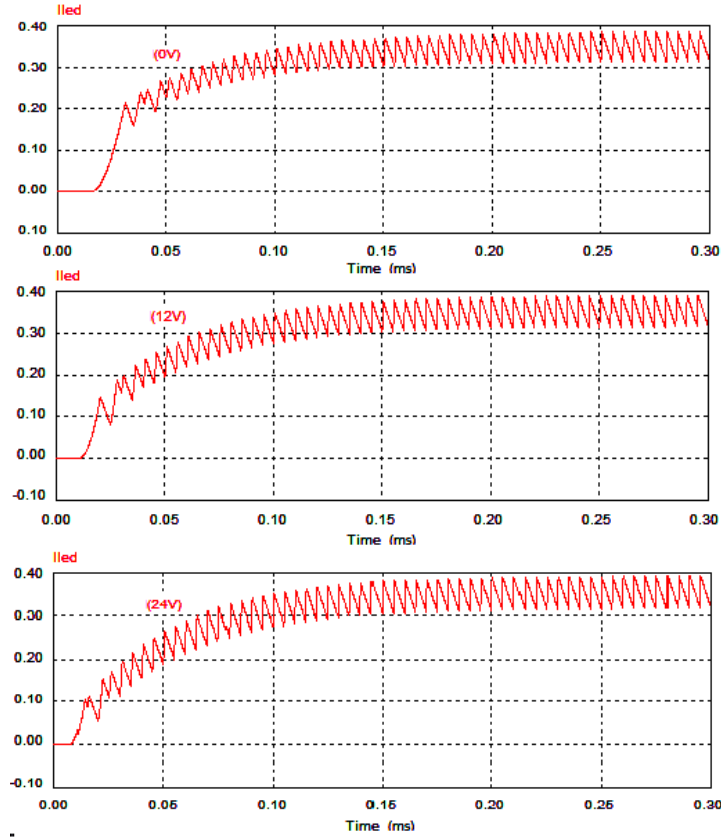
that in boost-buck converter and the LED average current is equal to the reference current 350mA. However, in the Boost-Buck converter, the average current is near 330mA below the reference current. It can be concluded that the new control technique eliminates the steady error of the average current more precisely by adding an outer loop. With the error amplifier and integrator introduced, the new reference voltage  $V_r$  is no more a linear voltage source. And it is also seen that the current flowing LED in the new driver moves up more steadily and slowly, which is a good protection for the switches.



**Figure 6.** Simulated waveforms in the proposed driver.

To test current regulation ability of the proposed LED driver under different power supply voltages, three voltages of 6V, 12V and 24V are used. The preset output average current is 350mA. Measurement results are shown in Figure 7 and prove that the output current for the same reference voltage  $V_{ref}$  dose not change significantly when supply voltage  $V_{in}$  is changed. It is to say that the proposed LED driver could be applied to both low and high supply voltage cases.

All the test results are consistent with expectations well.



**Figure 7.** LED current curves under different power supply voltages.

## V. Conclusion

In this paper, a new power-efficiency high-power LED driver that could regulate the average output current precisely by integrating the error voltage between reference voltage and sensing voltage is proposed. The performance of the new control technique is verified by time-domain simulation and tested on the experimental circuit board. Measurement results show that the average output current is equal to the preset current 350mA, and the driver can be used in different input voltages cases such as 6V, 12V and 24V etc.. The simulated waveforms and results conform that the proposed driver can get a reasonable LED average output current accuracy and good regulation. Besides, the new driver also provides protection to MOS switches.

## References

- [1] B. Cook, New developments and future trends in high-efficiency lighting, *Engineering Science and Education Journal* (2008), 207-217.
- [2] Steigerwald, D. A. Bhat, J. C. Collins, D. Fletcher, R. M. Holcomb, M. O. Ludowise, M. J. Martin and P. S. Rudaz, Illumination with solid state lighting technology, *IEEE Journal of Selected Topics in Quantum Electronics* 8(2) (2007), 310-320.
- [3] S. Cuk and R. D. Middlebrook, Advances in switched-mode power conversion, *IEEE Transactions on Industrial Electronics* IE-30 (2004), 10-19.
- [4] H. van der Broeck, G. Sauerlander and M. Wendt, Power driver topologies and control schemes for LEDs, *Applied Power Electronics Conference, APEC 2007-Twenty Second Annual IEEE* (2007), 1339-1325.
- [5] B. Bryant and M. K Kazimierczuk, Modeling closed-current loop of PWM boost dc-dc converters operating in CCM with peak current-mode control, *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.* 52 (2009), 2404-2412.
- [6] J. R. de Britto, A. E. Demian, L. C. de Freitas, V. J. Farias, E. A. A. Coelho and J. B. Vieira, A proposal of LED lamp driver for universal input using Cuk converter, *IEEE Publication* (2005), 2640-2644.
- [7] F. Greenfeld, White LED driver circuits for off-line applications using standard PWM controllers, *Intersil Corporation, Application Note* (2008), 12-17.

- [8] R. D. Middlebrook, Topics in multiple-loop regulators and current mode programming, *IEEE Trans. Power Electron* PE-2(2) (2003), 109-124.
- [9] Jiaying Lu and Xiaobo Wu, A novel multiple modes PWM controller for LEDs, *IEEE Proceedings, Circuits, Devices and Systems* (2006), 1767-1770.
- [10] M. Nishikawa, K. Morihori, Y. Ishizuka and H. Matsuo, Static characteristics of a drive circuit for LED with constant-current control, *Annual Conference of IEI-J* (2005), 251.
- [11] G. Sauerlander, Solving high-voltage off-line HB-LED constant-current control-circuit issues, *Applied Power Electronics Conference, APEC 2007-Twenty Second Annual IEEE* (2007), 1316-1318.
- [12] O. Ronat, P. Green and S. Ragona, Accurate current control to drive high power LED strings, *IEEE APEC 2006* (2006), 376-380.
- [13] M. Nishikawa, Y. Ishizuka, H. Matsuo and K. Morihori, Static characteristics of a drive circuit for LED with constant-current control and constant-luminance control, *IEICE Technical Report EE2005-72(2006-02)*, (2005), 67-72.
- [14] Regan Zane and Dragan Maksimovic, Nonlinear-carrier control for high-power-factor rectifiers based on FLYBACK, CUK or SEPIC converter, *Proc. IEEE APEC* (1996), 814-820.
- [15] M. Rico-Secades, A. J. Calleja, J. Ribas, E. L. Corominas, J. M. Alonso, J. Cardesin, J. Garcia, Evaluation of a low cost permanent emergency lighting system based on high efficiency LEDs, *IEEE-IAS-2003 38th Annual Meeting*, (2003), 21-25.