A Flyback Driver with Adaptive Switching Frequency Control for Smart Lighting[1]

Chua-Chin Wang[2], *Senior Member, IEEE,* Zong-You Hou, and Teng-Wei Huang
Department of Electrical Engineering,
National Sun Yat-Sen University, 80424, Taiwan
ccwang@ee.nsysu.edu.tw

***Abstract* – A novel flyback light emitting diode (LED) driver with adaptive switching frequency for smart lighting is proposed in this investigation. Switching loss and severe harmonic distortion of conventional flyback LED drivers when the LED is operating in high switching frequency and high voltage are resolved. The proposed flyback LED driver design auto-adjusts the switching frequency by detecting the conduction period and the current of LED. Adaptive switching frequency approach is then applied to enhance efficiency and maintain the color and brightness.**

I. Introduction

LED has been recognized as the future lighting devices, since it is more energy saving, environment kindly, and compact, as compared to the conventional lamp bulbs, including incandescent, fluorescent, and high intensity discharge (HID) devices [1], [2]. Certainly, white LED (WLED) has been to residential lighting, automobile lighting, portable lighting, flash light, street lighting, as shown in Fig. 1.

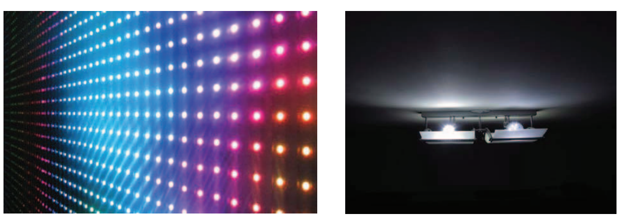

Fig. 1. LED lighting application examples.

Nevertheless, though the driver of the LED plays a key role in lighting, the efficiency of the driver is still not on the same pace with the LED technology advancement. For instance, to achieve higher brightness, WLED needs a high stable current with higher voltage drop compared with conventional LED. Since the flyback LED driver provides energy storage as well as converter isolation, it is commonly used in LED drivers. Referring to a typical driver design [3], an optocoupler isolates secondary side from primary side to generate a stable voltage. This kind of flyback designs are suffered from high voltage stress upon switching components therein. High peak current is another critical problem for the prior flyback LED driver when it is in discontinuous conduction mode (DCM) and boundary conduction mode (BCM). Lin *et al.* proposed a primary-side control IC, including a sampling feedback voltage and a knee point detector, to keep the duty cycle as constant [4]. However, this method encountered a problem when the output voltage of the bridge rectifier (V_{in}) is close to zero, the current of the primary winding and the drain to source voltage of the power MOS will vary quickly. Thus, the controller can not reacted synchronously because the voltage valley signal changes too fast. If the controller overlooks valley signals, it will result in hazards for LED lighting.

II. Flyback LED Driver for Smart Lighting

Fig. 2 shows our flyback LED driver, including an electromagnetic interference (EMI) filter, a bridge rectifier, a snubber, a diode, a transformer, a power MOS switch (S_1), and a flyback control circuit. The EMI filter suppresses the conducted interference of AC voltage (V_{ac}), which is then rectified to be a high DC voltage by the bridge rectifier. The inductor of flyback is split to work as a transformer. Therefore, the flyback LED driver is turned into a buck-boost converter. The flyback control circuit determines the turn-on time of the S_1 generating a varying magnetic field in the primary winding. The energy of the primary winding is transferred to the secondary winding when the S_1 is turned off, thereby charging the output capacitor (C_o). The transformer provides good isolation between primary side and secondary side. The output voltage of auxiliary side is detected by flyback control circuit. As soon as the drain to source voltage of S_1 is sensed and compared with a reference voltage (V_{REF}), the flyback control circuit auto-adjusts the turn-on time of the S_1 to keep a stable output voltage (V_o).

Notably, the flyback control circuit is composed of a comparator, a valley detector, a diode conduction period detector, a LED current estimator, a PWM circuit & oscillator, and a high voltage (HV) buffer. The S_1 and a resistor (R_{sen}) generates a sensing voltage (V_{sen}) coupled to the LED current estimator.

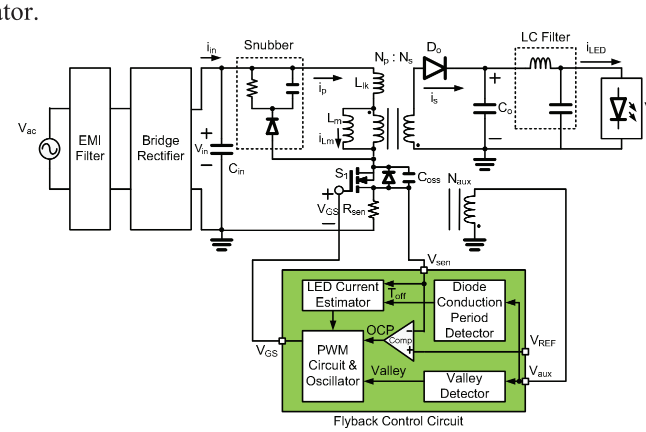

Fig. 2. Block diagram of the proposed flyback LED driver

1 This research was partially supported by Ministry of Science and Technology under grant NSC102-2221-E-110-081-MY3, NSC102-2221-E-110-083-MY3, and MOST104-ET-E-110-002-ET.
2 Prof. Chua-Chin Wang is the contact author.

978-1-4673-8364-6/16/$31.00 ©2016 IEEE

The LED current estimator generates a voltage proportional to the current of the S_1 when it is turned on. The diode conduction period detector is in charge of estimating correct conducting period. When the resonance between inductor (L_m) and capacitor of the S_1 when exciting current (i_{Lm}) is close to zero is quite small, the signal (T_{off}) needs to keep the voltage drop constantly to prevent misjudgment of the period. Because the LED current estimator and the diode conduction period detector clamp the current and the period to PWM circuit & oscillator, PWM circuit & oscillator will generate a gate drive of S_1. A turn-on signal, Valley, is generated from the valley detector. By contrast, a turn-off signal is generated by the output of the LED current estimator compared with the sawtooth wave of the PWM circuit & oscillator. Thus, the brightness of the LED can be adjusted by tuning the period of the PWM circuit & oscillator. Finally, the HV buffer provides a large driving current and HV electrostatic discharge (ESD) protection.

In summary, to avoid missing valley signals when the S_1 isn't turned on, the S_1 turn-on time is constrained in the range of (T_{sys_min}, $T_{sys\_min} + T_r$) by the flyback control circuit, where T_{sys_min} is the period of the maximum switching frequency of the S_1, T_r is the resonant period between L_m and the capacitor of the S_1. Therefore, the power efficiency is enhanced and switching loss is reduced.

III. Experiment and Measurement

An experiment of the proposed flyback LED driver is carried to justify the functionality. A LED string consisting of cascaded XMLEZW-02-0000-0B00U440F LEDs is used as the load. Referring to Fig. 3, a prototype control system based on Fig. 2 is used to drive the LED string load. Regardless of the number of LEDs, the brightness of each one is ensured provided the input AC voltage is the same, where the load current of 700 mA is the same in every scenario.

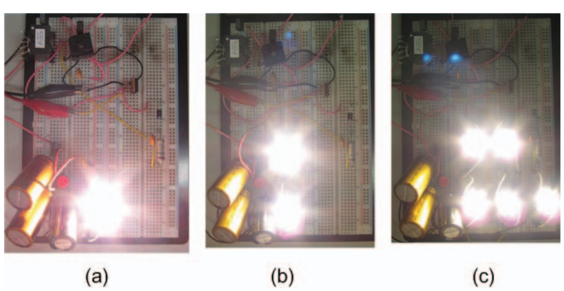

Fig. 3. No. of LEDs are turned on : (a) 1 ; (b) 2 ; (c) 5.

The measurement of the experiment is shown in Fig. 4. When the number of the LED is 5, V_o is 28.509 V with a load current (i_{LED}) of 739.5 mA. A peak power efficiency of 91.14 % is attained. The performance comparison of the proposed flyback LED driver and several prior works is tabulated in Table I, where our design demonstrates the best power efficiency and controllability. Fig. 5 shows an application scenario of the proposed design in the street lamp smart lighting control.

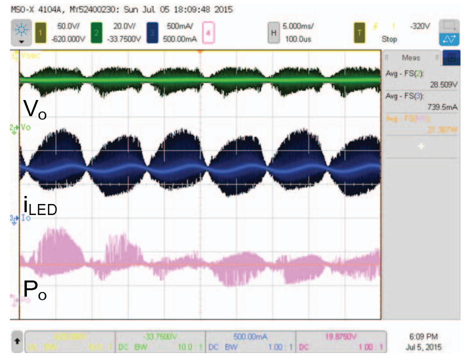

Fig. 4. Measurement of the proposed flyback LED driver.

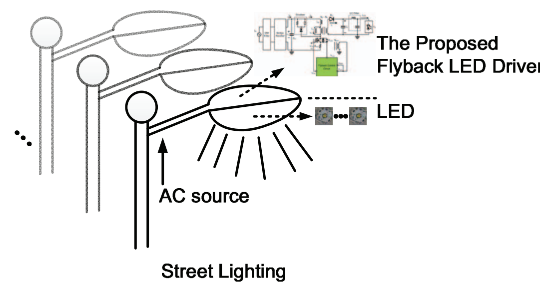

Fig. 5. The application scenario of the proposed design.

TABLE I
Performance Comparison of LED Drive

	[5]	[6]	This work
Year	2013	2014	2015
Input Voltage	12 V**	90 ~ 264 Vrms*	110 Vrms*
Output Current (mA)	920	700	739.5
Rated Power (W)	18.952	5	21.367
Power Efficiency (%)	84.34	83 ~ 85	91.14

Note* : AC Voltage Input
Note** : DC Voltage Input

References

[1] Y.-L. Lai, and W.-K. Lin, "3D high-brightness autosetereoscopic display systems with LED backlight," in *Proc. 2012 IEEE Inter. Conf. on Consumer Electronics (ICCE)*, pp. 614-615, Jan. 2012.

[2] H.-J. Suk, "A color scenario of eco & healthy driving for the RGB LED based interface display of a climate control device," in *Proc. 2013 IEEE Inter. Conf. on Consumer Electronics (ICCE)*, pp. 616-619, Jan. 2013.

[3] W. Kleebchampee and C. Bunlaksananusorn, "Modeling and control design of a current-mode controlled flyback converter with optocoupler feedback," in *Proc. International Conference on Power Electronics and Drives Systems (PEDS),* pp. 787-792, Nov. 2005.

[4] Y.-T. Lin, T.-J. Liang, and K.-H. Chen, "IC design of primary-side control for flyback converter," in *Proc. 2013 1st International Future Energy Electronics Conference (IFEEC),* pp. 449-453, Nov. 2013.

[5] M.I.M. Rashid, S.A. Ghani, and M.F.S. Mustahim, "Development of high power LED driver using LTspice software," in *Proc. 2013 IEEE 7th International Power Engineering and Optimization Conference (PEOCO)*, pp. 92-97, Jun. 2013.

[6] W.-M. Lin, Q.-L. Zheng, Y.-Z. Xu, and Q. Zhang, " Temperature effect on performance and reliability of QR tapped-inductor buck LED driver," in *Proc. 2014 International Electronics and Application Conference and Exposition (PEAC)*, pp. 1397-1400, Nov. 2014.

978-1-4673-8364-6/16/$31.00 ©2016 IEEE