

# A New Cost-Effective Current-Balancing Multi-Channel LED Driver for a Large Screen LCD Backlight Units

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## Abstract

A new current-balancing multi-channel LED driver is proposed in this paper. The conventional LED driver system consists of three cascaded power conversion stages and its driver stage has the same number of expensive boost converters as those of the LED channels. On the other hand, the proposed LED driver system consists of two cascaded power stages and its driver stage requires only passive devices instead of expensive boost converters. Nevertheless, all of the currents through multi-channel LEDs can be well balanced. Therefore, it features a smaller system size, improved efficiency, and lower cost. To confirm the validity of the proposed driver, its operation and performance are verified on a prototype for a 46" LCD TV.

**Key Words:** Backlight unit, Capacitor charge balance, Current balance, LED driver, Multi-channel LEDs, PWM dimming

## I. INTRODUCTION

In recent years, liquid crystal display (LCD) flat panel displays have become one of the fastest growing markets in large screen displays due to various advantages such as low power consumption, long lifespan, low profile and high contrast ratio [1], [2]. Since LCDs are non-emissive display devices, they usually require a backlight unit (BLU) in monitor or TV applications. In the case of conventional LCD applications, multiple fluorescent lamps such as a cold cathode fluorescent lamp (CCFL), an external electrode fluorescent lamp (EEFL) and a flat fluorescent lamp (FFL) have been used as LCD BLU sources. However, an RoHS directive's limited permission of mercury (Hg) use requires that environmentally friendly lamps be employed as backlight sources.

Recently, light-emitting diodes (LEDs) have become one of the most promising candidates for BLUs and other lighting applications. Although the high cost and low light efficiency of LEDs make it difficult for them to be widely adopted as a backlight source, LEDs satisfy the RoHS directive and have many desirable merits such as a long lifespan, wide color gamut and fast response. Moreover, as the light efficiency of LEDs has improved and the cost reduced, LEDs have become a suitable solution for a BLU source.

To implement sufficient luminance for large sized LCD TVs, series-parallel configured multi-channel LEDs are usually adopted. In driving multi-channel LEDs, it is most important to obtain uniform and sufficient luminance despite the

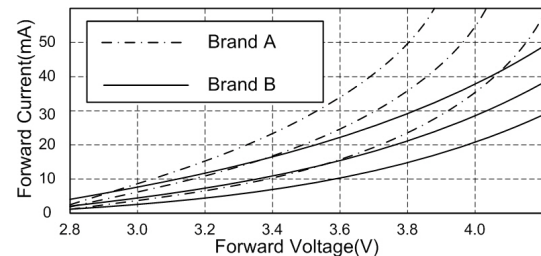


Fig. 1. V-I characteristics of LED.

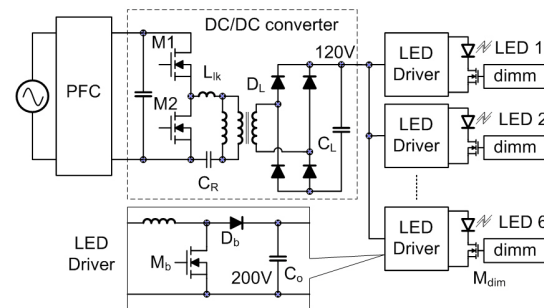


Fig. 2. Schematic of conventional LED driving circuit.

characteristic variations of each LED. Fig. 1 shows the V-I characteristics for each LED array produced by different manufacturers. As shown in this figure, each LED has different properties according to the voltage, current and temperature. Thus, although the same voltage is applied to each LED array, there exists LED current variations caused by the temperature of the p-n junction, the time variation and the performance difference of each array [3]–[5]. The variation of each LED

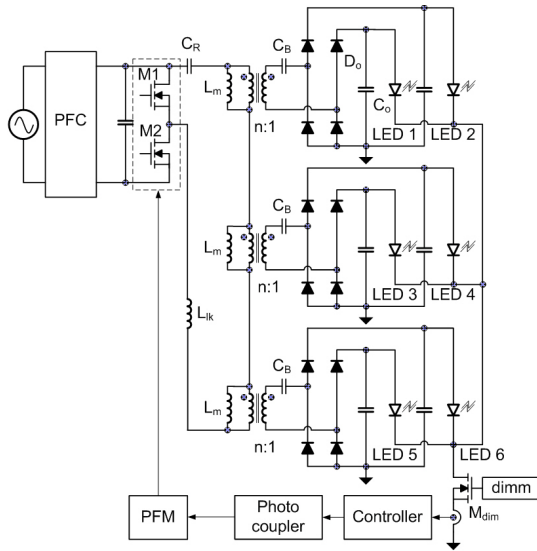


Fig. 3. Schematic of proposed LED driver.

current, proportional to its luminance, could deteriorate its brightness quality, lifespan, and reliability. To overcome the above-mentioned problems, each LED array should be controlled to be balanced by a constant current instead of a constant voltage.

Fig. 2 shows a schematic of a conventional LED driving circuit for a large screen LCD TV. Each LED channel consists of a large number of serially connected LEDs and its operating voltage is about 200V in the case of 46" LCD TV. As shown in this figure, the overall system consists of three cascaded power conversion stages, that include a power factor corrector (PFC), an isolated DC/DC converter and a LED driver. The PFC stage produces a constant voltage from the AC input voltage source and then the isolated DC/DC converter converts the PFC output voltage into the voltage required to drive the LEDs, where the LLC resonant converter has usually been adopted as an isolated DC/DC converter due to its favorable advantages such as high efficiency and low EMI [6]–[8]. Then, to maintain the currents through the multi-channel LED arrays constant and balanced, one boost converter per LED channel is required to control the current through each LED. Although this driving circuit can tightly control the LED current, it has several disadvantages such as a high cost of production, a low power conversion efficiency, and a bulky system. Moreover, the many active devices and driver ICs used in each boost converter might deteriorate system reliability. This is because the overall system does not consist of three power conversion stages but also the same number of boost converters as those of LED channels.

To overcome above-mentioned drawbacks, a new cost effective current-balancing multi-channel LED driver is proposed as shown in Fig. 3. Since the proposed LED driver requires only passive devices such as transformers and capacitors instead of a boost converter, the cost of production can be considerably reduced and the system reliability can be much improved. At the same time, since the isolated DC/DC converter and LED drivers are integrated into one power stage, the proposed driver system features a high power conversion efficiency and a small

size.

## II. A NEW CURRENT BALANCING MULTI-CHANNEL LED DRIVER

### A. Operational principles of the proposed LED driver

Fig. 3 shows the proposed LED driver, where a LLC resonant inverter is adopted. As can be seen, 3 transformers, 3 capacitors, and 12 diodes are required to drive 6 channel LED arrays. Each transformer's primary side is serially connected with each other and each transformer's secondary side is connected to a DC blocking capacitor ( $C_B$ ) and a full bridge rectifier. The detailed principles of the current balancing for each LED array are described as follows. For the convenience of the analysis, the following assumptions are made.

- 1) All parasitic components are discarded except for those specified in Fig. 3.
- 2) All transformer magnetizing inductors are same as  $L_m$ .
- 3) The total of the leakage inductors for all of the transformers is  $L_{lk}$ .
- 4) The voltage across each LED is the same as  $V_{LED}$ .
- 5) From the above assumptions, all the transformer magnetizing currents during each half switching period are equal to  $i_{Lm\_P}$  and  $i_{Lm\_N}$ , respectively.
- 6) The dimming switch is continuously conducting.

**Mode 1** : When  $M_2$  is on and  $M_1$  is off during a half switching period of the driver, the current through each transformer's primary side is the same as  $i_{pri\_N}$  as shown in Fig.4 (b). This is because each transformer's primary side is connected in series. Therefore, since all of the transformer magnetizing currents are same as  $i_{Lm\_P}$  from assumption (5) and all of the transformer turn ratios are equal to one another, all of the transformer's secondary side currents are identical as follows:

$$\langle i_{sec\ P1} \rangle = \langle i_{sec\ P2} \rangle = \langle i_{sec\ P3} \rangle = n \langle i_{pri\ P} - i_{LM\ P} \rangle \quad (1)$$

where  $\langle \bullet \rangle$  is the average value of ' $\bullet$ '.

**Mode 2** : Similarly, when  $M_1$  is on and  $M_2$  is off during the other half switching period of the driver, the current through each transformer's primary side is also same as  $i_{pri\_P}$  as shown in Fig.4 (c). This is because each transformer's primary side is connected in series. Therefore, since all transformer magnetizing currents are the same as  $i_{Lm\_N}$  from assumption (5) and all the transformer turn ratios are equal to one another, all of the transformer's secondary side currents are identical to the same manner of mode 1 as follows:

$$\langle i_{sec\ N1} \rangle = \langle i_{sec\ N2} \rangle = \langle i_{sec\ N3} \rangle = n \langle i_{pri\ N} - i_{LM\ N} \rangle \quad (2)$$

At this point, since the blocking capacitor ( $C_B$ ) is serially connected to the transformer's secondary side, the DC offset current of the transformer's secondary side can be eliminated. Namely, the average current through the transformer's secondary side during each half switching period are equal to one another as follows:

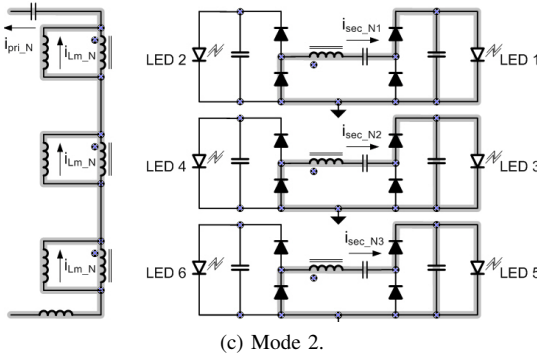
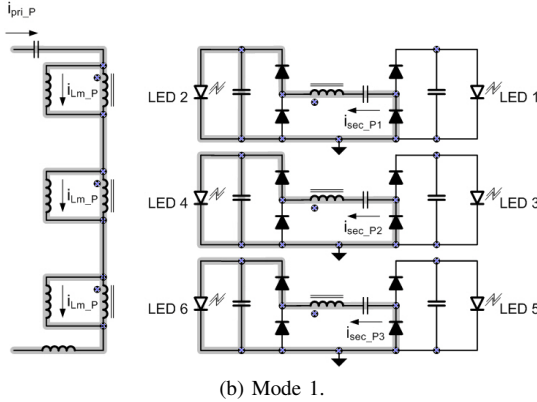
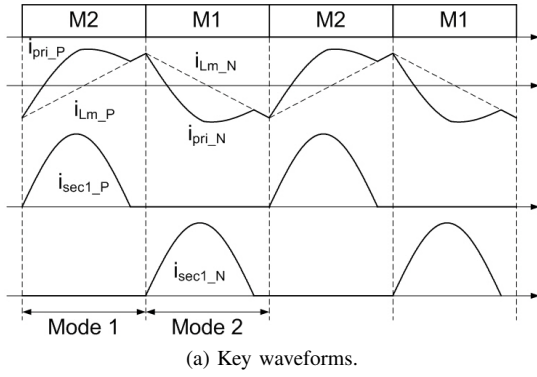


Fig. 4. Operational mode diagrams.

$$\begin{aligned} \langle i_{sec\ P1} \rangle &= \langle i_{sec\ N1} \rangle, \\ \langle i_{sec\ P2} \rangle &= \langle i_{sec\ N2} \rangle, \\ \langle i_{sec\ P3} \rangle &= \langle i_{sec\ N3} \rangle. \end{aligned} \quad (3)$$

Finally, from equations (1), (2) and (3), all of the LED currents can be exactly balanced as follows:

$$\begin{aligned} \langle i_{sec\ P1} \rangle &= \langle i_{sec\ N1} \rangle = \langle i_{sec\ P2} \rangle \\ &= \langle i_{sec\ N2} \rangle = \langle i_{sec\ P3} \rangle = \langle i_{sec\ N3} \rangle. \end{aligned} \quad (4)$$

Accordingly, the proposed driver can keep the currents through all of the LED arrays constant and balanced using only passive devices such as transformers and capacitors.

Moreover, if only the current through one LED array is controlled, all of the currents can be controlled by the above-mentioned principles. Therefore, only one controller is required regardless of the number of LED arrays.

Meanwhile, since the exact same magnetizing inductors and LED voltages can not be obtained, there actually exists a few current of unbalance among each of the LEDs. If the blocking capacitor CB is large enough to be considered as a constant voltage source (0V), the peak current  $i_{LM\_peak}$  through the transformer magnetizing inductor can be determined by:

$$i_{LM\_peak} = \frac{V_{LED} T_s}{nL_m} \quad (5)$$

where  $T_s$  and  $V_{LED}$  are the switching period and the LED voltage, respectively.

Generally, a larger peak current through the magnetizing inductor produces a larger resonant current and transfers a larger energy to the output side in the LLC resonant converter [6]–[8]. Therefore, if a magnetizing inductor or LED voltage mismatch exists, differences among the peak magnetizing currents of each transformer arise, which cause a secondary current unbalanced from transformer to transformer and equations (1) and (2) not satisfied anymore. Finally, the LED currents can not be exactly balanced. To mitigate the current unbalance problem caused by the transformer and the LED voltage mismatches, the magnetizing inductor must be designed to be maximized as much as possible, which can minimize the effect of the  $V_{LED}$  variations and the peak current differences among each magnetizing inductor. Moreover, a transformer with a similar magnetizing inductance must be employed.

TABLE I  
COMPARISONS BETWEEN CONVENTIONAL AND PROPOSED LED DRIVERS IN THE ASPECT OF THE NUMBER OF DEVICES

Items		conventional driver	Proposed driver
transformer		1EA (EEM4344)	3EA (EFD2025)
Power switch	M1 & M2	2EA (2SK3561)	2EA (2SK3561)
	$M_{dim}$	6EA(FDU3N40)	1EA(FDU3N40)
	$M_b$	6EA(FDU3N40)	0EA
Diode	$D_{LLC}$	4EA (1N5408)	0EA
	$D_b$	6EA (UF4007)	0EA
	$D_o$	0EA	12EA (UF4007)
	Inductor	6EA (500uH)	0EA
Film capacitor	$C_R$	1EA(1kV)	1EA(1kV)
	$C_B$	0EA	3EA(100V)
Electrolytic capacitor	$C_L$	1EA(68uF/200V)	
	$C_o$	6EA(10uF/350V)	6EA (10uF/350V)
Control IC	LLC	1EA (MC33067) fsw=60kHz	1EA (MC33067) fsw=60kHz
	Boost	6EA (HV9911) fsw=100kHz	0EA (HV9911)

Table I shows a comparison between the conventional and the proposed LED drivers in terms of the number of devices. As shown in this table, since the proposed LED driver can remove many of the expensive devices such as power switches, inductors and control ICs of the conventional inverter, its production cost can be considerably reduced. On the other hand, the increased number of devices such as transformers, diodes and DC blocking capacitors are not dominant in the production cost when compared with the effect of cost reduction.

### B. Dimming of the proposed LED driver

Dimming is one of the most important functions, along with current-balancing, in a LED BLU for LCD TVs [9]–[11]. Dimming is used to regulate the luminance and contrast

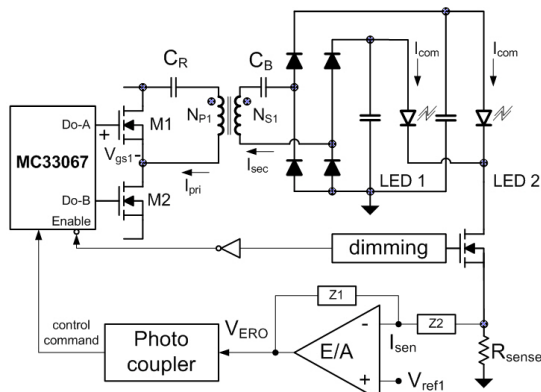


Fig. 5. Block diagram of proposed inverter with PWM dimming circuit.

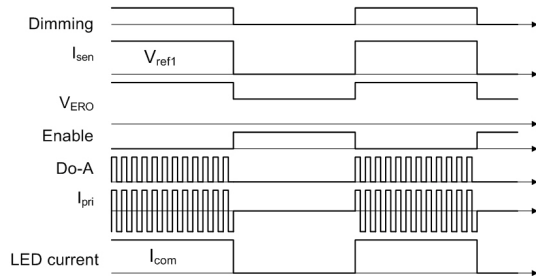


Fig. 6. Key waveforms of PWM dimming.

ratio of a LED BLU according to a user's command or video signal. Its methods can be classified into analog and pulse width modulation (PWM). Firstly, analog dimming is used to regulate the luminance of a BLU by varying the amplitude of the LED current. However, this scheme could generate a color shift in accordance with the amplitude of the LED current and deteriorate the color gamut. On the other hand, PWM dimming is accomplished by regulating the pulse width of the LED current with a current amplitude constant. This dimming scheme allows for a large range of dimming levels. Also, compared with analog dimming, the LED brightness intensity of PWM dimming is independent of color, which makes it suitable for many applications [12], [13]. Therefore, the proposed inverter adopts PWM dimming to regulate the brightness as shown in Fig. 5. Fig. 6 shows the key waveforms of PWM dimming. As can be seen in this figure, when the dimming signal is high, the switch  $M_{dim}$  is conducting and the LED current sensed from the sensing resistor ( $R_{sense}$ ) is applied to the inverting input of the error amplifier. Thus, the LED current is controlled to be  $I_{com}$  at the steady state. On the other hand, when the dimming signal is Low,  $M_{dim}$  is turned off and the inverting input of the error amplifier becomes zero, which is because the LED current is blocked. At the same time, since a high signal is applied to the disable input of the control IC, the inverter is shut down.

### III. EXPERIMENTAL RESULTS

To confirm the validity of the proposed LED driver, a prototype of a 180W rated LED driver for a 46" LCD TV is implemented with following specifications:

- Inverter input voltage (PFC output voltage) : 385V

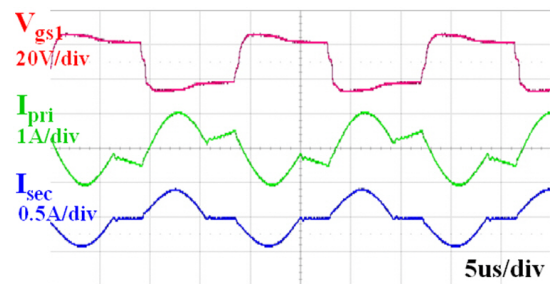


Fig. 7. Key waveforms of proposed LED driver.

- Amplitude of the LED current at the steady state : 100mA
- The number of LED channels : 6 channels
- Transformer : Core - EFD2025
- Number of turns  $N_p : N_s = 29 : 74$
- Resonant tank :  $L_m = 700\mu H, L_r = 50\mu H, C_r = 44nF$
- Output capacitor :  $10\mu F$
- LED voltage: about 200V

Fig. 7 shows the key waveforms of the proposed LED driver. As shown in this figure, the current  $I_{pri1}$  through the transformer's primary side is large enough to ensure ZVS of the main switch ( $M_1, M_2$ ) at the switching instant. Moreover, since the serially connected capacitors  $C_R$  and  $C_B$  with the transformer completely block the DC offset current through the transformer magnetizing inductor, the transformer magnetic core can be fully utilized, which can reduce the transformer size and increase the power density.

Fig. 8 shows the experimental waveforms at 20%, 50% and 80% of the dimming ratios. As shown in this figure, the LED current becomes zero at the low dimming signal and it is controlled to be 100mA at the high dimming signal. Furthermore, when the dimming signal becomes high, the output voltage and the LED current are slowly increased by soft start, which can reduce the overshoot of the LED current and the acoustic noise.

Table II shows the current balancing performance of each LED array measured using a multi-meter after 30min. of aging. As shown in this table, the currents through each LED array are almost the same according to the dimming ratios. Fig. 9 shows the linearity of the LED1 current according to the dimming ratio. As shown in this figure, the LED current is linearly increased according to the dimming ratio.

Based on Table I, the power consumption dissipated in the key components averaged over one switching period is shown in fig. 10. Assuming the other components, those not specified in this figure, have similar power consumption and the turn on switching loss of the boost converter is small enough to be discarded due to the DCM (Discontinuous Conduction Mode) operation, the proposed driver shows a lower power loss than the conventional one by about 1.32W.

Table III shows the comparative results of the measured input power consumption. As shown in this table, the proposed driver system has a smaller power consumption than the conventional system by 1.5W under the same conditions. As mentioned above, the conventional LED driver system consists of three cascaded power conversion stages. On the other hand, since the isolated DC/DC converter and the LED drivers are

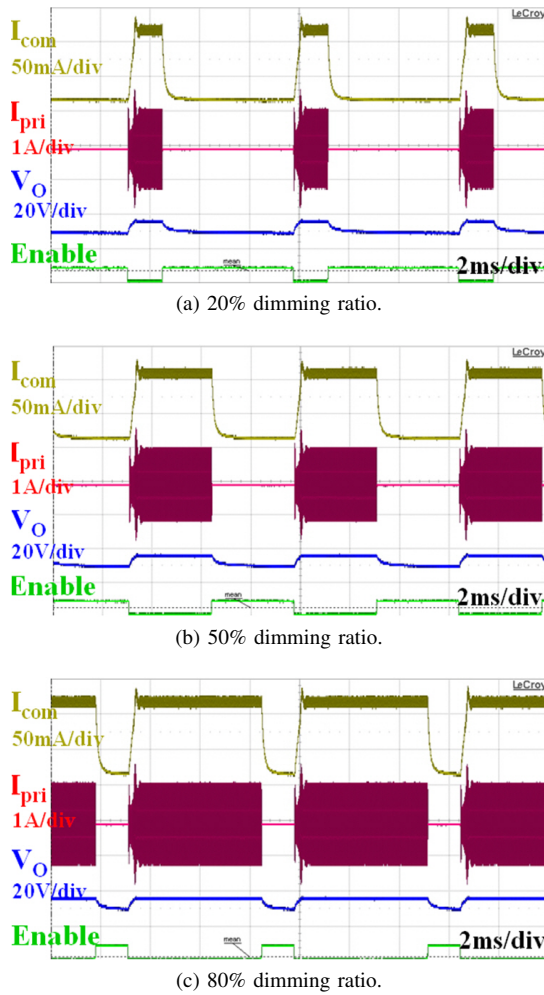


Fig. 8. Experimental waveforms according to dimming ratios.

integrated into one power stage, the proposed LED driver system consists of two cascaded power stages. Therefore, the proposed driver system features better efficiency than the conventional system.

From the above-mentioned experimental results, although the proposed LED driver is composed of several passive devices instead of six expensive boost converters, the current through each LED array can be well controlled to be balanced according to all of the dimming ratios. Therefore, the production cost can be considerably reduced and at the same time, the proposed driver system features higher power conversion efficiency and similar dimming and control performances when compared to the conventional system.

TABLE II  
AVERAGE CURRENTS THROUGH LEDS ACCORDING TO DIMMING RATIOS (mA)

Dimming	LED1	LED2	LED3	LED4	LED5	LED6
100%	100.81	101.10	100.91	100.9	101.09	101.04
80%	80.86	80.89	80.47	80.45	80.77	80.86
60%	60.44	60.51	60.3	60.28	60.51	60.41
50%	49.94	50.06	49.96	50.03	50.06	50.03
40%	39.92	40.05	40.02	40.03	40.04	39.98
20%	19.98	20.01	20.01	20.02	20.03	19.97

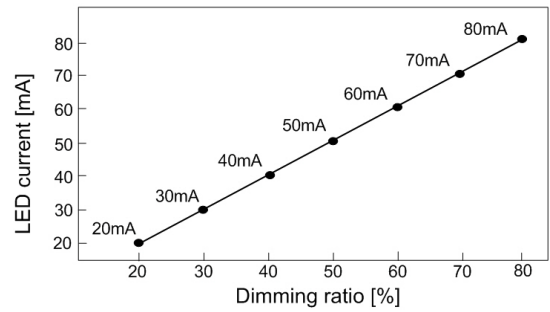


Fig. 9. Linearity of LED1 current according to dimming ratios.

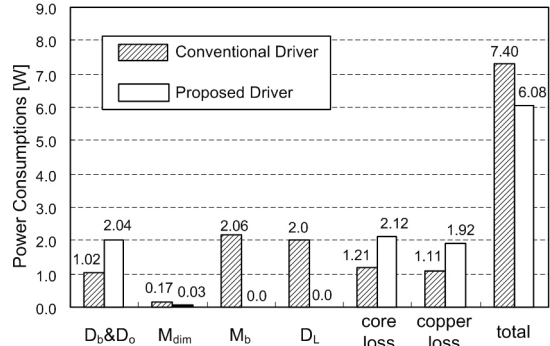


Fig. 10. Calculated power losses dissipated in key components.

#### IV. CONCLUSIONS

A new current-balancing multi-channel LED driver is proposed in this paper. The conventional LED driver system consists of three cascaded power conversion stages and its driver stage is composed of the same number of expensive boost converters as those of the LED channels. Therefore, it has several drawbacks such as poor system efficiency, a bulky system, and high cost. On the other hand, since the isolated DC/DC converter and LED drivers are integrated into one power stage, the proposed LED driver system consists of two cascaded power stages and its driver stage requires only passive devices such as transformers and capacitors instead of the expensive boost converters. As a result, the cost of production can be considerably reduced and the system reliability can be greatly improved.

Meanwhile, although the proposed LED driver is composed of only several passive devices, the current through each LED array is well controlled to be balanced according to all of the dimming ratios. Therefore, the proposed driver system features higher power conversion efficiency and similar dimming and control performances to those of a conventional system.

The summarized merits of the proposed LED driver are as follows:

- Reduced product cost and higher power conversion efficiency with the aid of a 2 stage configuration.
- Higher power density and smaller size.
- Improved reliability through the removal of the control ICs and active devices.
- Ensured current balancing, dimming and control performances.

As a result of these favorable advantages the proposed LED driver is expected to be well suited to various LED applications

TABLE III  
COMPARISONS OF MEASURED INPUT POWER CONSUMPTION

Item	Conventional driver system	Proposed driver system
Input Power	185.5 W	184.0 W

(Test conditions:  $V_{in} = 230V_{rms}(AC60Hz)$ ,  $I_{LED} = 100mA$ , dimming ratio=100%, measured after 30min. aging)

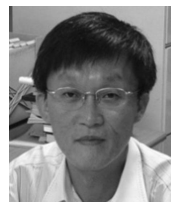
such as digital displays, lighting and so on.

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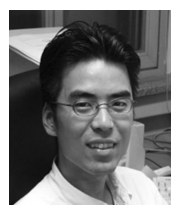
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