Novel Flicker Migration and EMI Noise Reduction Circuit for AC Direct LED Lightings

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Abstract – A novel AC direct light emitting diode (LED) driver circuit that uses flicker mitigation and the electromagnetic interference (EMI) noise reduction method is proposed in this study. This method is based on the current controls of the flicker mitigation capacitor using MOSFET. The core block of the proposed circuit is fabricated as an IC chip. LED lightings are fabricated with the IC chip. The lightings show a flicker index of 0.15, and a 20dBμV peak value and 35dBμV average value of conduction noise margin for EMI regulation. It can be applied to the low power and low cost single chip LED lightings.

Keywords: LED lighting, LED EMI noise, AC direct LED driver, Flicker of lightings

1. Introduction

In recent years, light emitting diode (LED) lights have emerged as replacements for incandescent light bulbs, cold cathode fluorescent lamps, and high intensity discharge (HID) lamps. Such a trend is due to their high light efficiencies, long operating lifetimes, environmental friendliness, and improved luminance. These advantages could gradually make LED lights a general light solution [1, 2, and 3].

The brightness of the LEDs depends on the power supplied on them. Based on a classification by the power source type, AC–DC converter type and AC direct methods have been developed [4, 5, 6, and 7]. The AC–DC converter types such as the flyback [8] and buck converters need the input EMI filters, transformers, and electrolytic capacitors, which require a large volume and are expensive. Specifically, the electrolytic capacitor has a short lifetime and determines the overall lifetime of a switching converter for LEDs [2, 3, and 9].

The AC direct drive method uses switching transistors to produce a staircase voltage for tracking the applied AC voltage. These switches create EMI noise and cause the flickering of LED lightings.

Many solutions have been developed for flicker mitigation using capacitors and inductors. A large number of power inductors and capacitors are required for the same. These make the driver circuits bulky and expensive [1, 2, 3, and 9].

To overcome these kinds of weaknesses, we have developed a new AC direct driver that uses a new method of flicker mitigation and EMI noise reduction. The developed AC direct driver also has several protection functions such as soft-start, over-voltage protection (OVP) and over-temperature protection (OTP) to enable a stable operation in commercial applications.

2. Proposed LED Driver

The former flicker mitigation method adds the electrolytic capacitor in parallel with LED strings. To reduce flicker and EMI noise voltage, a large value of the bulky electrolytic capacitor is needed. For instance, a 470µF and 450V capacitor is usually required for 10w LED lightings.

To reduce EMI noise and to mitigate flicker, we propose a new circuit that is implemented as an IC chip. The proposed circuit schematic is shown in Fig. 1. The proposed method is based on the current controls of the flicker mitigation capacitor \(C_{\text{flk}}\) that uses a MOSFET.

In our method, the charging and discharging current for the capacitor \(C_{\text{flk}}\) is controlled by LDMOSs. This controlled current makes lower EMI noise and has better flicker characteristics. The LDMOS LD1 is operated as the regulated current source for charging time, and LDMOS LD4 is operated as the regulated current source for discharging time.

2.1 System configuration

The overall system configuration of the proposed AC LED driver is shown in Fig. 1. The LED driver circuit is composed of resistors \(R_{\text{flk}}, R_{\text{bottom}}, R_{\text{upper}}, \) and \(R_{\text{set}}\), a 450V electrolytic capacitor \(C_{\text{flk}}\), LED strings, a single bridge diode (BD), a transient voltage suppression diode (TVS), and several functional blocks. The pre-regulator block in Fig. 1 is for generating a pre-
regulated stable low voltage (15 V and 5.5 V at typical operation conditions) for most of the internal blocks. The adaptive reference generation block detects the supplied AC voltage and creates an adaptive reference voltage to generate the regulated currents.

The driver block has the power FETs (LDMOSs) and OP amplifiers. This block generates the regulated current according to the power setting of the external resistor.

The OTP and OVP blocks in Fig. 1 generate the signal for over-temperature and over-voltage protection, respectively. The dimming control block is for the dimmer function.

### 2.2 Operational principle

Fig. 2 shows the simplified schematics for the conventional method and the proposed method. Flicker index is improved by flattening the input voltage. The conventional method uses a large value of capacitance $C_{flk}$ to flatten the input voltage. The conduction EMI noise increases with the abrupt inrush current from the input line. The input line current is the sum of the current through $C_{flk}$ and the LED branch ($I = C_{flk} \frac{dV}{dt} + I_{LED}$). The input abrupt inrush current is proportional to the value of $C_{flk}$. The effect of $C_{flk}$ on the flicker index and on the conduction noise is contrasting. Increasing the $C_{flk}$ improves the flicker index but deteriorates the EMI noise, and decreasing the $C_{flk}$ deteriorates the flicker index but improves the EMI noise. The conventional method is to select an appropriate value of $C_{flk}$ to meet the target power factor and flicker index.

The proposed method uses a small value of $C_{flk}$ for a lower EMI noise. The small value of $C_{flk}$ makes the flicker index worse. To solve this problem, we use an active switch $S$ as shown in Fig. 2 (b) to improve the flicker index. The brief operation of the active switch flattens the voltage waveform by clipping the charge in the high voltage time ($I_{cha}$), keeping the charge in the medium voltage time, and pushing the charge in the low voltage time ($I_{dis}$). The active switch $S$ and a smaller $C_{flk}$ value are key principles of our method for both the EMI noise reduction and the flicker index improvement.

Fig. 3 is the behavioral switching waveform of the LED string current. The current flow through the LED string is regulated by the reference node voltage of the LDMOSs (REF2–REF4) and the feedback voltage on $R_{set}$. The
charging current to the capacitor \( C_{flk} \) is controlled by the reference voltage of node REF1. The LED current mitigation is made by the current \( I_{dis} \). The switching behavior for the current \( I_{LED} \), including \( I_{dis} \), are as follows.

1) Time \( t_0 \)–\( t_1 \): During this time, the current \( I_{dis} \) from the charged capacitor \( (C_{flk}) \) in Fig. 1 flows through LED1–LED3 and LD4. Discharging current at \( t_0 \) depends on the capacitor size of \( C_{flk} \). It is continued until the charge of the \( C_{flk} \) is vacant. In this time, the LDMOS LD1, LD2, and LD3 are switched off and only LDMOS LD4 is switched on. The discharging current \( (I_{dis}) \) can be controlled LDMOS (LD4).

2) Time \( t_1 \)–\( t_2 \): The LDMOS LD1 and LD2 are turned on. The capacitor \( (C_{flk}) \) is charged through LD1. The device LD2 is turned on for LED current \( I_1 \). The current flows through the LDMOS LD2 and LD3 at the same time. During this time, the current through LD2 decreases gradually as the AC supplied voltage increases. In addition, as the current through LD3 increases linearly, the total LED current also increases linearly.

3) Time \( t_2 \)–\( t_3 \): The LDMOS LD1 and LD2 are still turned on, while LD3 is slightly turned on too. The LED current flow through LD3 is regulated like it was during \( t_1 \)–\( t_2 \). The current through LD3 decreases gradually according to the increase in supplied voltage. On the contrary, the current through LD4 increases linearly and the total current through LD3 and LD4 increases linearly.

4) Time \( t_3 \)–\( t_4 \): LD1 and LD3 are switched off. LD2 is switched. LED current flow through LD3 is regulated like it was during \( t_1 \)–\( t_2 \).

5) Time \( t_4 \)–\( t_5 \): The LDMOS LD1 and LD3 are still turned on. LD4 is slightly turned on. The LED string current flows through LDMOS LD3 and LD4 at the same time. The current through LD3 decreases gradually according to the increase in supplied voltage. On the contrary, the current through LD4 increases linearly and the total current through LD3 and LD4 increases linearly.

6) Time \( t_5 \)–\( t_6 \): LD1 and LD4 are switched on. LD3 is switched off. Current flow through LD4 is regulated like the case of time \( t_1 \)–\( t_2 \).

7) Time \( t_6 \)–\( t_7 \): LDMOS LD1 is switched off and the operation of the other LDMOS (LD2–LD4) is similar to the operation during the \( t_1 \)–\( t_6 \) time.

The MOSFET LD1 is operated as the current regulator for the reduction of the spike type charging current through the capacitor \( (C_{flk}) \), which creates a high EMI noise. The discharging current \( (I_{dis}) \) is controlled by the LDMOS (LD4).

In order to use the current controlled charging and discharging operations, a small value of the capacitor is sufficient. In the proposed circuit, the electrolytic capacitor value can be reduced to 10 \( \mu \)F.

4. Fabrication and Measurement Result

4.1 Chip

The proposed LED driver circuit is designed and fabricated using a 0.8\( \mu \)m BCDMOS process manufactured by CSMC. Fig. 5 is the photo of the fabricated IC for the ‘IC chip block’ in Fig. 1. The die size is 2000 \( \mu \)m \( \times \) 1950 \( \mu \)m including the sealing PAD. This chip contains four LDMOSs with a 550V breakdown and a single JFET for pre-regulation circuits.

4.2 Design of the Capacitor \( C_{flk} \)

In actual design, the \( C_{flk} \) should be predetermined and optimized. The value of \( C_{flk} \) is initially selected by a rough estimation equation \( C_{flk} = I_{flk} \frac{dt}{dv} \). \( I_{flk}, dt, \) and \( dv \) are roughly estimated values of the average LED current, one cycle time, and average input voltage, respectively. The roughly estimated \( C_{flk} \) is expressed as \( C_{flk} = \frac{(k_I I_{av})(k_T)}{(k V_{av})} \). The average LED current \( I_{av} \) is the target LED output power/average voltage (in our case 23 W/(311 V/2)). One cycle time \( T \) is 1/60. The average voltage \( V_{av} \) is 311 V/2. The factors \( k_I, k_T, \) and \( k \) are initially set as 0.5. This value for the factors mean 50% of the current, period, and voltage affect the \( C_{flk} \) using the active controlled switch. The initially estimated \( C_{flk} \) is \( 0.5 \times 23/(311/2) \times 0.5 \times (1/60)/(0.5 \times (311/2)) = 7.92 \) \( \mu \)F. This initial value is optimized experimentally and set as a commercially available capacitor value, in our case 10 \( \mu \)F.

4.3 Test board

The conventional circuit mode with a 470\( \mu \)F flicker capacitor (Fig. 4) and the proposed circuit with a 10 \( \mu \)F flicker capacitor of (Fig. 1) are fabricated using the IC chip for the 23W LED lighting. The test board is shown in Fig. 6.

The value and size of off-chip components are \( R_{set} \): 15 \( \Omega \), \( R_{upper} \): 2.2 M\( \Omega \), \( R_{bottom} \): 24 K\( \Omega \), \( R_{in} \): 1 M\( \Omega \), and \( C_{flk} \): 10 \( \mu \)F for Fig. 1 and 470 \( \mu \)F for Fig. 4. Diodes (D block and D flc: 1N4008), LEDs (Samsung LM362A), TVS diode (Model 471), and Bridge Diode (MB6S) are used.

4.4 Test

Radiated light intensity, radiated light pattern, and...
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Fig. 5. Photograph of the fabricated LED Control IC (A: OP. Amps, B: LDMOSFETs (LD1–LD4), and C: RMS Detectors, OTP, OVP, Pre-regulator, Dimming Control, Pre-regulator, Band-Gap, Adaptive Reference Generation Blocks of Fig. 1, respectively)

Fig. 6. Evaluation Board for the normal LED driver mode and the proposed LED driver circuit (A: LEDs, B: Rset, C: Rbottom and Rupper, D: Cflk (to test the conventional circuit mode), E: Cflk (to test the proposed circuit mode), F: TVS and BD, and G: IC Chip of Fig. 1, respectively)

The intensity of the radiated LED light from the test board is captured by the light detector and the digital camera.

Fig. 7 and 8 show the radiated light waveforms of the LED light in (a) and the light patterns of the LED lighting captured by a digital camera in (b), for the conventional circuit mode (topology of the circuit in Fig. 4) for EMI noise reduction and for the proposed circuit mode (topology of the circuit in Fig. 1), respectively.

Light waveform of conventional circuit (Fig. 7 (a)) for EMI noise reduction shows the periodic patterns with the dark period (D) and the white period (W). The light pattern...
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image (Fig. 7 (b)) also shows a wide dark region (D). The light waveform (Fig. 8 (a)) of the proposed circuit is more mitigated compared to the one in Fig. 7 (a). The period “A” in Fig. 8 (a) is due to the controlled discharging current from the electrolytic capacitor to LED1–LED3. The period “B” in Fig. 8 (a) has a mitigated double slope due to the limited amount of charge at the electrolytic capacitor. The light waveform is also mitigated in period “B” because some amount of the current is fed to the capacitor, and not to the LED path.

Fig. 7 and 8 show that the proposed circuit has more mitigated light signals and patterns than the conventional circuit. The flicker index of the conventional circuit mode (Fig. 7(a)) is measured as 0.33 and the index of the proposed circuit (Fig. 8(a)) is 0.15. There is an improvement of 0.18 in the flicker index.

Fig. 9 shows the EMI measurement for the line noise. The measured peak value (blue line), average values (green line) of line noise, and regulation limits (pink and red line) are shown for the conventional circuit for flicker mitigation in (a) and for the proposed circuits in (b). The line noise characteristics of the proposed circuit are improved to about 20 dBμV of peak value and 25 dBμV of the average value, satisfying the EMI regulation. These results show that the new methodology can be applied to the flicker mitigated LED lightings with satisfying EMI regulation.

5. Conclusion

A novel AC direct LED driver with an improved flicker migration performance and satisfying EMI regulation is proposed. The core block of the proposed circuit is fabricated as an IC chip. The 23W power of the LED lighting with an IC chip is fabricated and tested. To test the performance, the conventional circuit mode and the proposed circuit are compared.

The flicker index is improved by 0.18. The value of the electrolytic capacitor is reduced to 1/47 and the conduction noise characteristic for the EMI regulation is improved to approximately 20dBμV of the peak value and 25dBμV of the average values. With this developed driver chip, LED lightings with a lower flicker index and that satisfy the EMI regulation is possible.

It can be applied to LED lightings such as MR6 (near 58 W) and an electronic tube (near 22W). This single driver chip circuit can reduce the cost of the light module and improve the performance in AC direct control lighting applications, thus satisfying the EMI noise regulation.

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References


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