Multi-channel LED driver with self-optimized active current regulator

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Abstract: A novel multi-channel LED driver is presented, consisting of an active current regulator and a switch-mode voltage regulator for each channel. This driver is implemented using a 0.35 µm 40 V high voltage process. The active current regulator directly controls an LED-current without any current-sensing resistor and its operating voltage is self-optimized by the switch-mode voltage regulator. This self-optimization is successfully achieved and the active current regulators have channel-current deviations of a maximum of ±2%. Its power-conversion efficiency is up to 91% at the load power of 7 W.

Keywords: LED, driver, current-sensing resistor, self-optimization

Classification: Electron devices, circuits, and systems

References


1 Introduction

Recently, light emitting diodes (LEDs) have been dynamically applied to many types of illumination [1, 2, 3, 4, 5]. These LEDs should be driven using a constant current to avoid violating the absolute maximum current rating.
and compromising reliability, and to obtain predictable and matched optical properties which are directly related to their forward current [1, 2, 3]. It is possible that LED drivers provide several solutions for this driving scheme. Such an LED driver can be realized using a linear or switch-mode type [1, 4]. A typical LED driver, either linear or switch-mode driver, is basically a type of output voltage regulator, and thus has to be converted to an output current regulator. This conversion is generally done using a current-sensing resistor, placed in series to LEDs [4, 5]. In a multi-channel application, therefore, a typical driver has current deviations between individual channels as the current-sensing resistors have deviations of generally ±10%. In this letter, we propose a novel integrated LED driver with a current regulator devoid of any current-sensing resistor and optimized by a switch-mode voltage regulator.

2 Design and implementation

The proposed LED driver has four channels, consisting of a constant current circuit with current-sink transistors as output stages, complementary switching transistors for synchronous buck converters, a low dropout regulator, a soft-start circuit, error amplifiers, comparators, and other parts. A block diagram of this LED driver is shown in Fig. 1. This driver is designed and fabricated through a 0.35 \( \mu \)m 2-poly 4-metal 40 V high voltage CMOS process.

In this LED driver, an LED-current is actively regulated using an internal constant current circuit based on a current mirror circuit, named an active current regulator. The operational principle of the proposed driver is as follows: In order to properly regulate the desired LED-current, the current-sink transistor (M\(_{\text{CS}}\)) as an output stage of the current mirror circuit must

![Fig. 1. Block diagram of the proposed LED driver.](image-url)
operate in a saturation region. Namely, the drain-source voltage \((V_{DS})\) of the M\(_{CS}\) should be enough high to saturate the M\(_{CS}\) for normal operation of the active current regulator. On the other hand, the \(V_{DS}\) of the M\(_{CS}\) should be lowered for low power dissipation in the M\(_{CS}\) or for a highly efficient LED driver. Thus, it is desired that the \(V_{DS}\) is set to the minimum saturation voltage \((V_{DS_{sat}})\), regardless of a forward voltage drop across LEDs. Using a feedback of the \(V_{DS}\), the buck converter can regulate the channel-voltage which is equal to a sum of the cumulative forward voltage drop and the \(V_{DS_{sat}}\), when the reference voltage \((V_{REF})\) for the error amplifier is set to the \(V_{DS_{sat}}\). That is, the buck converter self-optimizes the active current regulator.

In the constant current circuit, any current-sensing resistor is not used, but the external biasing resistor \(R_{EXT}\) is used. The \(R_{EXT}\) determines a bias current of the constant current circuit, which is amplified by a current gain of approximately \(10^4\) through the current mirror circuit. All the channel-currents are identically generated by the current mirror circuit which has four current-sink transistors for each channel. Because of this process, the proposed driver has no current deviation between individual channels if there is no transistor mismatches, especially between the current-sink transistors. The current mirror circuit can be on-off controlled by an internal pulse width modulation (PWM) generator, so-called digital dimming. It can control the average channel currents and the average brightness of the LEDs. In addition, the current mirror circuit also can be priorly disabled by an over temperature protection circuit when the driver is overheated. The channel currents cannot be generated until the driver is cooled down.

The other external resistor \(R_{DCF}\) determines a switching frequency for DC-DC conversion, which is controlled by an R-C time constant with an internal capacitor. The switching frequency can be adjusted between several tens of kHz and a few hundred kHz.

3 Result and discussions

Self-optimization of the proposed LED driver has been verified by driving a different number of LEDs, such as three, four, five, and six, in series at each channel and measuring the channel voltages. Other conditions are the supply voltage (PVDD) of 24 V, the external inductor of 470 \(\mu\)H, the external capacitor of 10 \(\mu\)F, and the \(R_{EXT}\) of 15 k\(\Omega\) for a channel-current of 50 mA. Fig. 2 shows the driving result of the verification system and the voltage waveforms at the outputs of the buck converters which have a different number of LEDs as loads. Each channel has a voltage difference which corresponds to the different forward voltage drop across the serially connected LEDs. It is confirmed that the buck converter automatically adjusts the output voltage to the sum of the voltage drop across the serially-connected LEDs and the \(V_{DS_{sat}}\).

In order to test the current deviations between each channel, the channel-currents are measured using five sampled drivers, and the result is shown in
Fig. 3. The maximum deviation from the average is within ±2% for each LED driver. This result can be obtained regardless of the number of LEDs serially connected at each channel. The number of LEDs, however, is restricted by the PVDD of which maximum value is fixed to 40 V. This deviation may be occurred by transistor mismatches and channel asymmetry, such as different current paths. This result is effective until the $V_{\text{REF}}$ or $V_{DS,sat}$ is lowered by about 0.5 V. The $V_{DS,sat}$ of 0.5 V, however, is a little high because the 40 V high voltage process used in this research is not optimized for the proposed method. It is obvious that advance and optimization of the high voltage process can lower both the $V_{DS,sat}$ and power loss at the $M_{CS}$.

To obtain a high luminous-efficient LED lighting, it is an important for an LED driver to achieve a high power-conversion efficiency. The power-conversion efficiency of this driver is about 91% at the PVDD of 38 V and the channel current of 50 mA with twelve LEDs for all channels. Compared to other multi-channel driver [1], power-conversion efficiency of this proposed LED driver is improved because voltage optimization has been done independently for each channel. In other words, even though LEDs at each channel have different forward voltage, there is no excess voltage at the individual constant current source.

4 Conclusion

We propose a multi-channel LED driver with self-optimized active current regulators, realized via a 0.35 µm 40 V high voltage process. It is verified that this proposed LED driver is suitable for a paralleled multi-channel LED application within about ±2% current deviations between the individual channels. Its power-conversion efficiency is up to 91% at the LED-load power of about 7 W. In the future, we will lower the drain-source saturation voltage of the current-sink transistors to obtain enhanced power efficiency.
Fig. 3. Measured channel-currents of the five sampled drivers.

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