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A single chip for 4-channel LED dimming driver of 240 W true color display with SPI control☆

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ABSTRACT

LED (Light Emitting Diode) lighting can provide rich colors for many applications such as stage lights and LED display panels. This paper presents a 4-channel LED dimming chip based on SPI(serial parallel interface) and multi-level current control for true color lighting. This chip includes four channels, each of which can drive a current of about 1 A. For four-channel LED dimming, a control of 8-bit PWM is proposed with SPI protocol. To meet any type LED power, the maximum driving current can be easily adjusted by digital switches rather than by changing the sensing resistors. The prototyping chip was designed using TSMC 0.25 μm process, which is the second generator of high-voltage technology, and the resulting chip area with pads is only $1.9 \times 2.419\ mm^2$. Each channel can drive up to 60 W LED devices with supplying voltage 60 V and driving current 1A. The total driving power can achieve 240 W in maximum. With SPI control, the number of I/O pins can be reduced for multi channels driving. For practical tests, this chip can be controlled by a microprocessor through SPI protocol to adjust the PWM duty of each channel. Experimental results show that the chip can drive a 4-channel COB LED array for true color display.

1. Introduction

Since 1994, blue LED is successfully implemented by S. Nakamura. This has encouraged the fast development of true color LED lighting and display systems. For LED display panels, the color of each pixel is formed with Red, Green, Blue (RGB) LED components. Since LED lighting provides greater brightness than a conventional LCD display, LED panel is preferred for large area outdoor display. For stage lighting system, rich colors are needed to support impressive playing performances so LED lighting is applied to the productions of drama, dance, opera and other performance arts. For such applications, a power LED driver is required since the lighting range must cover the entire stage. A conventional lamp requires 1000-W for the applications of stage lighting. Recently, for the purpose of energy saving, LED light fixture is more popular than conventional lamps. Besides, LEDs provide an environmentally friendly light source, featuring high brightness, small size, light weight, and rapid response. Rich choices of light colors can be obtained by mixing red, green, blue, and in some cases amber LED lights at different intensities to enhance the displaying effect with various colors.

A multi channel LED driver is required for true color LED lighting or display systems [1–22]. LED driver for RGB components is used for LCD backlight module to enhance color saturation for LCD display [1]. A multi-channel constant current driver [2] is proposed to promote output power. However, each channel is not independent for dimming so the driver cannot be used as for true color display. A single inductor multiple-output (SIMO) switch-mode converter is proposed in Ref. [3], however, the driving current is low due to the use of only one inductor. A resonant DC/DC LED driver for four LED strings is constructed in Ref. [4], which can provide high efficiency, but the cost is high because a resonant circuit is required for each channel. A dimmable multi-channel Red--Green-Blue (RGB) LED Driver for backlighting and display is proposed in Ref. [5]. However, the driving current is only 25 mA for each channel so that the proposal cannot be applied to high power systems such as stage lights. Guo et al. [21]. presented ac/dc LED driver with a single-stage for multiple-channel LED driver with N + 1 active power switches (N being the number of LED strings). Its peak efficiency can achieve 89% at 30-W rated output power. Li et al. [22]. presented a single-inductor multiple-output (SIMO) LED driver with precise dimming with the coordination of a string-level scheme and a system-level dimming scheme. This SIMO LED driver can achieve widely dimming range with digital methods.

In this study, we develop a single chip for a true-color LED driver,

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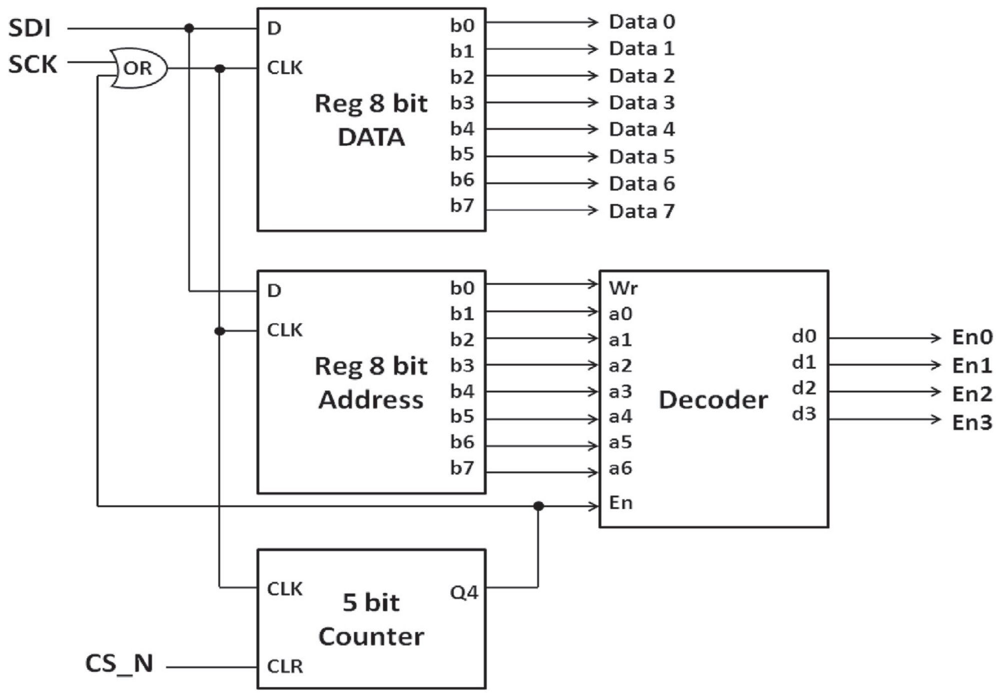

Fig. 1. The system architecture of SPI interface.

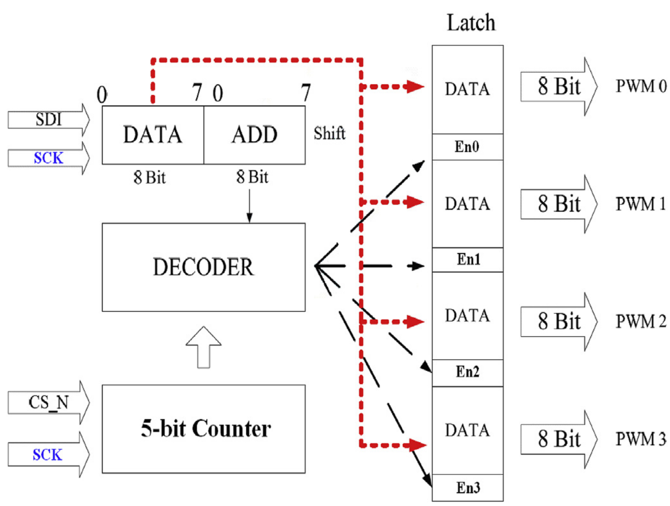

Fig. 2. The PWM control by SPI protocol.

where the driving power is up to 240 W. Four channels are designed to drive various LED devices for color mixing. To reduce the number of I/O pins, 8-bit PWM dimming is done with SPI protocol by a microprocessor. Besides, a 4-bit switch is embedded to adjust the maximum current level to meet the requirement of LED driving current. The advantage is to drive LED components of various powers without changing the sensing resistor. The rest of this paper is organized as follows. The chip architecture is proposed in Section 2. The implementation and experiments are described in Section 3. Conclusions are drawn in Section 4.

2. Proposed chip design

This chip is designed for a single chip of four-channel LED drivers. Each channel employs an independent 8-bit PWM dimming for true color control. In order to reduce the number of I/O pins on the chip, an SPI protocol is employed for PWM dimming of each channel. Fig. 1 shows the architecture of SPI, which includes only three pins of SDI, SCK and CS_N for data/address input, clock and chip selection respectively. The data and address inputs to an 8-bit data register for PWM duty and an address register to decide which channel is being selected. For serial to parallel shifting control, the counter counts the number of shifted bits of the input. When the counter reaches 16, a 16-bit input number had been loaded. Then the encoder decides which one channel active, and then sends the PWM data to the corresponding register. Fig. 2 shows the detailed circuit of 4-channel PWM control with SPI protocol.

The detailed SPI control procedure is as follows:

a. First, a CS_N pulse is sent to reset the 5-bit counter.
b. An SCK pulse synchronizes with an SDI pulse. When sending one SCK pulse, one bit data inputs with SDI port per cycle, and is then saved to a latch. The address latch and data latch are both 8-bit. Hence 16 SCK pulses are needed to transmit the address and data of PWM.
c. After 16 clock pulses, the 5-bit counter reaches 16. Then an enable pulse is sent to the decoder via the Q4 pin of the counter. The encoder encodes the address latch to decide which channel should be loaded by the data latch. This data is the duty cycle of the corresponding PWM signals to be generated. The other channels are not active.
d. To keep system stable, the SCK input is held by an OR gate to avoid data overflow when the counter reaches 16.
e. After 4×16 SCK clock cycles, the PWM signals of the four channels should be latched by the 4x8-bit registers。

Fig. 3(a) shows the 4-channel LED driver with SPI control, where the four channels are used in parallel. The 8-bit PWM duty can produce 256 steps for LED dimming to do true color displaying. In a conventional driver, the driving current is adjusted by the external resistors or voltage. The LED devices of various powers require changing the sensing resistors to meet the power specifications. However, it is difficult to trim the resistors with sufficient precision. Recently, the advanced design can adjust the current with digital interface [22]. In this study, a multi-level current control with a digital code is proposed. An n-bit binary digital code is used to control 2^n switches to determine the level of current. A digital decoder is used to control n-to-2^n current switching. The current source can be controlled to drive the gate of power MOSs based on the value of a binary digital code.