TLC5940 PWM dimming provides superior color quality in LED video displays

By Michael Day (Email: m-day@ti.com)
Applications Manager, Portable Power Products

A design technique called dot correction was discussed in Reference 1. This technique is used to calibrate each individual pixel in large form-factor displays. Once calibrated, or dot corrected, each pixel provides the same brightness level when commanded to a specific brightness. This technique calibrates the analog current supplied through individual LEDs in an array. While dot correction offers an excellent solution that compensates for the variation of lumen output between pixels, this analog brightness adjustment is only the first step in developing a high-quality LED display. This article presents a technique called pulse width modulation (PWM) dimming that can be used to adjust LED brightness while maintaining superior color quality. This technique is also referred to as PWM grayscaling.

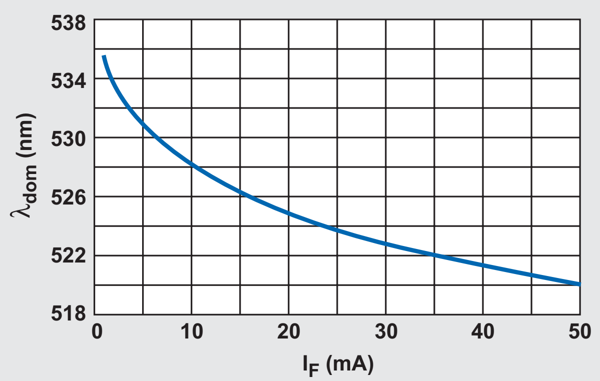
Low-end displays typically require only monochromatic LEDs. Applications include simple sporting scoreboards, single-line scrolling displays, and transportation road signs. A newer and growing market requires high-quality video displays capable of full-motion video shown in millions of colors. These applications include ever-expanding advertising markets encompassing convenience stores, shops, gas stations, and stadiums. An emerging market for LEDs is in DLP- and LCD-based televisions. Accurate color reproduction in these televisions is dependent on the available colors in the backlight. Proper control of the red, green, and blue (RGB) LEDs produces a color spectrum that is larger than the NTSC color space for television broadcasts. By contrast, cold cathode fluorescent lamp (CCFL) backlighting only produces about 85% of the NTSC color spectrum.

These displays require sophisticated LED drivers capable of providing multiple brightness levels. The number of colors available in the display is proportional to the number of brightness levels available for each of the RGB LEDs that make up a single pixel in the overall display. Competition between display manufacturers is driving designers toward high-end LED drivers with integrated PWM functionality capable of delivering thousands of brightness levels. These brightness levels result in enhanced color shading and improved video quality. The TLC5940 is designed to meet these needs.

High-quality, full-color video requires hundreds or thousands of brightness levels between 0% and 100%. Older LED drivers use analog dimming to provide these brightness levels. Analog dimming changes brightness by changing the LED's forward current. For example, if an LED is at full brightness with 20 mA of forward current, then 25% brightness is achieved by driving the LED with 5 mA of forward current. While this dimming scheme is simple and works well for lower-end displays, the drawback with analog dimming is that an LED's color shifts with changes in forward current. Figure 1 shows a true green LED's color variation with changes in forward current. This LED's full brightness is specified at 20 mA. Analog dimming to 25% brightness shifts the color spectrum from 525 nm to 531 nm. This color shift becomes unacceptable in displays requiring a true color representation.

PWM dimming provides reduced brightness by modulating the LED's forward current between 0% and 100%. The LED brightness is controlled by adjusting the relative ratios

Figure 1. Color shift caused by analog dimming



of the on time and off time. A 25% brightness level is achieved by turning the LED on at full current for 25% of each period. Figure 2 shows a comparison between analog and PWM dimming for a 20-mA LED being dimmed to 25% brightness. To keep the user from seeing the LED turn on and off, the switching speed must be greater than 100 Hz. Above 100 Hz, the human eye averages the on and off times, seeing only an effective brightness that is proportional to the LED's on-time duty cycle. The advantage of PWM dimming is that the forward current is always constant, so LED color does not vary with brightness like it does with analog dimming. Pulsing the current provides precise brightness control while preserving the color purity.

Since this type of PWM dimming is microprocessor-driven, it is limited to a maximum number of discrete brightness levels, commonly referred to as grayscale steps, for each LED. The total available number of discrete steps during any one period determines the LED's brightness resolution. High-quality displays require hundreds to thousands of brightness steps to accurately reproduce the full color spectrum necessary for full-motion video. The TLC5940 provides 12 bits of PWM dimming to meet this need. These 12 bits of resolution provide $2^{12} = 4096$ shades for each LED. Each pixel in a color display is composed of three LEDs—red, green, and blue. Individually driving each of these LEDs to one of 4096 brightness levels renders the RGB cluster capable of 68.7 billion colors.

The following example illustrates the TLC5940 PWM dimming capabilities. For simplicity, the example assumes there are only 3 bits of PWM dimming. Since 3 bits is equivalent to $2^3 = 8$ shades, each LED can be programmed to stay on anywhere from 0 to 7 PWM grayscale steps. Each video frame starts with all LEDs turned off. At the rising edge of the first PWM clock, all LEDs turn on except ones that are programmed with grayscale values of zero. The IC increments a grayscale counter at the beginning of each PWM clock cycle. Each LED stays on until the PWM grayscale counter goes above the LED's programmed PWM value. This is better explained by Figure 3, which shows waveforms and a block diagram for a simplified 3-bit PWM dimming controller. Programming the grayscale value of the red, green, and blue

Figure 2. Analog dimming vs. PWM dimming

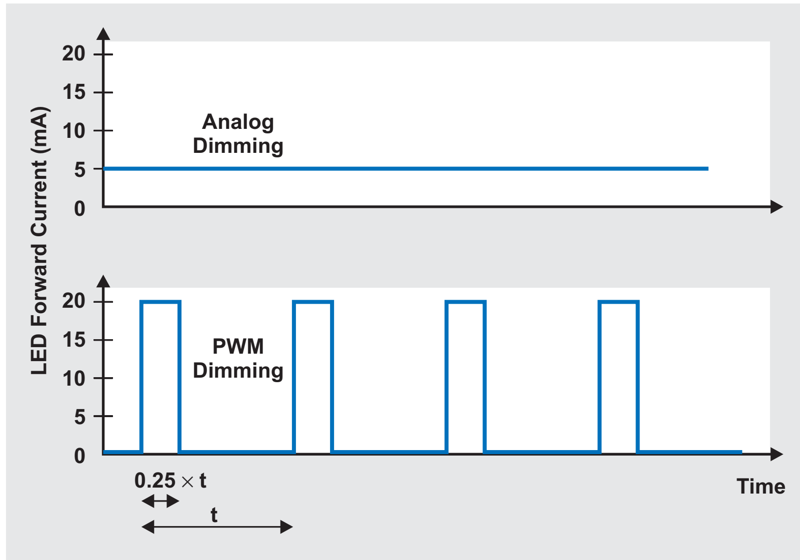


Figure 3. Orange pixel generated with 3-bit PWM dimming

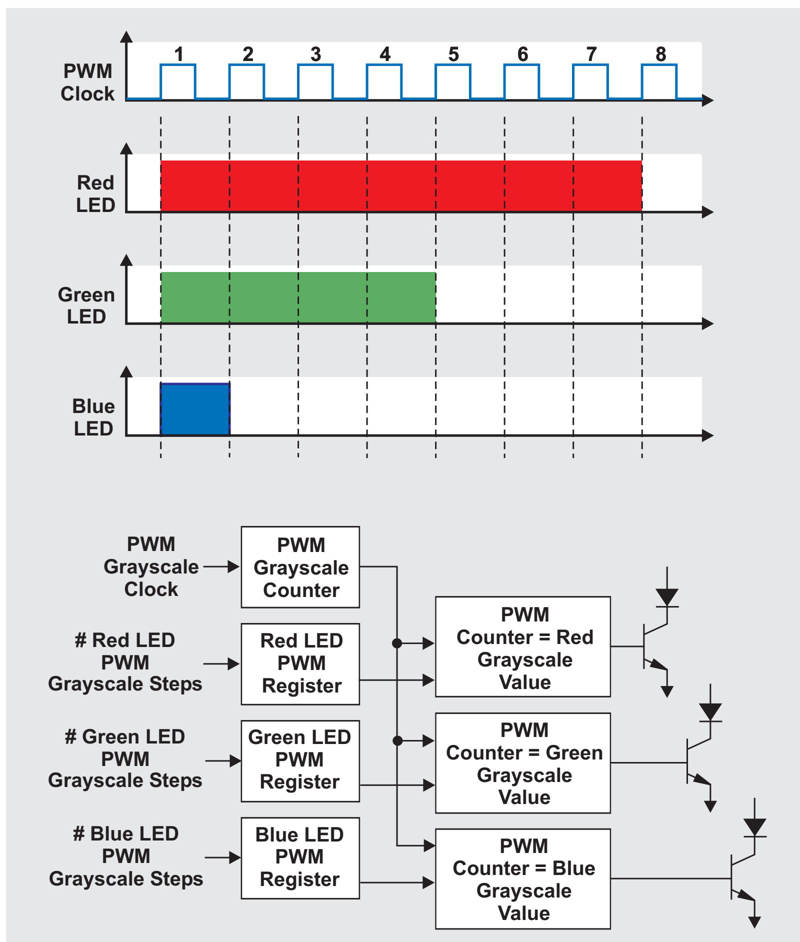
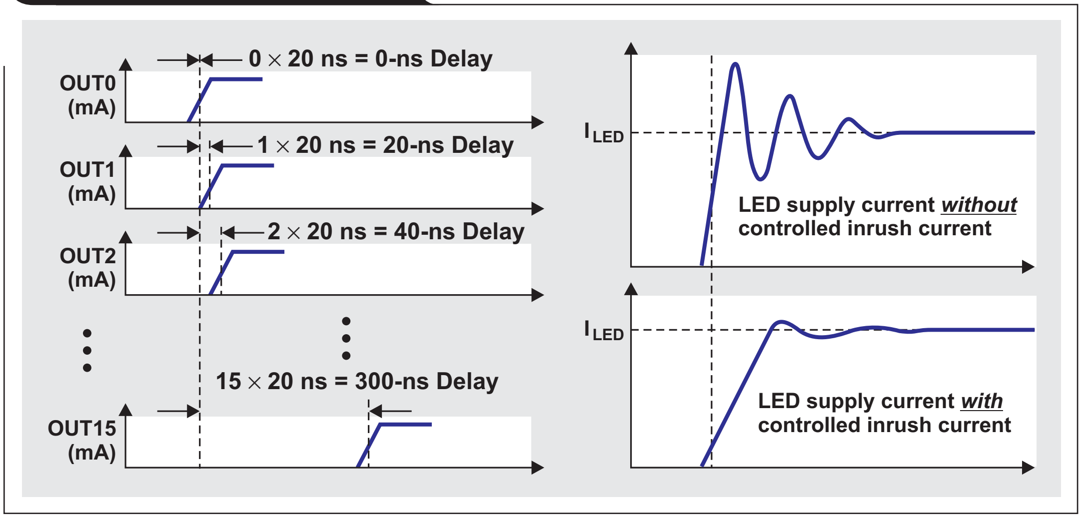


Figure 4. Inrush current control



LEDs to 7, 4, and 1, respectively, produces an orange pixel on the screen. The green LED is programmed to a grayscale value of 4. It turns on at the rising edge of the first PWM clock cycle and stays on for four full PWM clock cycles. This 3-bit PWM dimming example is capable of producing $2^3 \times 2^3 \times 2^3 = 512$ colors for each RGB pixel. Expanding this math to the TLC5940's 12-bit PWM dimming shows that this part is capable of providing a palette of $2^{12} \times 2^{12} \times 2^{12} = 68.7$ billion colors.

PWM dimming is not without its drawbacks. The discrete switching cycles can cause noise in the system. Simultaneously turning on all LEDs at the start of a video frame requires a large inrush current with a very steep rising edge. Without a method to reduce this inrush current, the higher-end LED drivers capable of driving 16 LEDs with up to 120 mA of current in each channel would require excessive input bypass capacitance. Turning on all 16 LEDs simultaneously requires the input capacitor to deliver 1.92 A within the turn-on time of the IC. The upper right graph in Figure 4 shows the ringing present during the leading edge of the current pulse when all LEDs are turned on simultaneously. Parasitic inductance on the PWM creates this noise and ringing. The TLC5940 significantly reduces the effect by staggering the turn-on of each LED. The left side of Figure 4 shows this staggered turn-on. The lower right graph in Figure 4 shows how the staggered turn-on reduces the rise time of the inrush current, which in turn reduces the ringing, the noise in the system, and the input capacitor requirement. The TLC5940 staggers LED turn-off as well; however, this is not typically needed in most systems. Figure 2 shows that turn-off is inherently staggered when the LEDs are programmed to different dimming levels.

The TLC5940 combines both PWM dimming and dot correction to produce extremely high-quality video. Dot correction produces an accurate LED color by adjusting for changes in an LED's wavelength caused by temperature variations or aging. PWM dimming then provides the shading necessary to provide thousands or millions of individual colors from three individual LEDs. PWM dimming coupled with dot correction is clearly the choice for both existing and future markets requiring high-quality color control in LED-based lighting applications.

Reference

For more information related to this article, you can download an Acrobat Reader file at www-s.ti.com/sc/techlit/*litnumber* and replace *"litnumber"* with the **TI Lit. #** for the materials listed below.

Document Title	TI Lit. #
1. Michael Day and Tarek Saab, "TLC5940 dot correction compensates for variations in LED brightness"	slyt225

Related Web sites

power.ti.com

www.ti.com/sc/device/TLC5940

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products	
Amplifiers	**amplifier.ti.com**
Data Converters	**dataconverter.ti.com**
DSP	**dsp.ti.com**
Interface	**interface.ti.com**
Logic	**logic.ti.com**
Power Management	**power.ti.com**
Microcontrollers	**microcontroller.ti.com**

Applications	
Audio	**www.ti.com/audio**
Automotive	**www.ti.com/automotive**
Broadband	**www.ti.com/broadband**
Digital control	**www.ti.com/digitalcontrol**
Military	**www.ti.com/military**
Optical Networking	**www.ti.com/opticalnetwork**
Security	**www.ti.com/security**
Telephony	**www.ti.com/telephony**
Video & Imaging	**www.ti.com/video**
Wireless	**www.ti.com/wireless**

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page
support.ti.com

TI Semiconductor KnowledgeBase Home Page
support.ti.com/sc/knowledgebase

Product Information Centers

Americas

Phone	+1(972) 644-5580	Fax	+1(972) 927-6377
Internet/Email	support.ti.com/sc/pic/americas.htm		

Europe, Middle East, and Africa

Phone			
Belgium (English)	+32 (0) 27 45 54 32	Netherlands (English)	+31 (0) 546 87 95 45
Finland (English)	+358 (0) 9 25173948	Russia	+7 (0) 95 363 4824
France	+33 (0) 1 30 70 11 64	Spain	+34 902 35 40 28
Germany	+49 (0) 8161 80 33 11	Sweden (English)	+46 (0) 8587 555 22
Israel (English)	180 949 0107	United Kingdom	+44 (0) 1604 66 33 99
Italy	800 79 11 37		
Fax	+(49) (0) 8161 80 2045		
Internet	support.ti.com/sc/pic/euro.htm		

Japan

Fax			
International	+81-3-3344-5317	Domestic	0120-81-0036
Internet/Email			
International	support.ti.com/sc/pic/japan.htm		
Domestic	www.tij.co.jp/pic		

Asia

Phone			
International	+886-2-23786800		
Domestic	Toll-Free Number		Toll-Free Number
Australia	1-800-999-084	Malaysia	1-800-80-3973
China	800-820-8682	New Zealand	0800-446-934
Hong Kong	800-96-5941	Philippines	1-800-765-7404
India	+91-80-51381665 (Toll)	Singapore	800-886-1028
Indonesia	001-803-8861-1006	Taiwan	0800-006800
Korea	080-551-2804	Thailand	001-800-886-0010
Fax	+886-2-2378-6808	Email	tiasia@ti.com
Internet	support.ti.com/sc/pic/asia.htm		ti-china@ti.com

C120905

Mailing Address: Texas Instruments
Post Office Box 655303
Dallas, Texas 75265