Common LED Functions and LED Driver Design Considerations

Texas Instruments

Kenneth Du
Product Marketing Engineer
Power Switches, Interface & Lighting
Texas Instruments

TI POWER

LEDs offer many advantages over traditional lighting options. Understanding each LED function will enable designs with higher efficiency, better reliability and longer lifetimes.

At a glance

This paper describes four main functions of an LED and how to optimize your design with each.

1 LED indication

Changing market conditions are driving higher standards for safety requirements.

2 LED animation

LED animation drivers include features such as color mixing and brightness control to drive the most widely used RGB LEDs.

3 LED illumination

LED illumination uses high-power LEDs or strings of LEDs to illuminate someone or something.

4 LED backlighting

Backlight LED drivers enhance user experience across many display sizes – extending battery life and reducing board space.

When selecting an LED driver for broad industrial applications, it's easy to get overwhelmed with choices.

Finding an LED and designing the best drivers for your system is like identifying a single star in the night sky. Just as a planisphere can help recognize stars and constellations, understanding the four main functions of an LED can help you select appropriate LEDs and related LED driver circuits.

LEDs are a popular lighting source because they offer many advantages over traditional incandescent and neon lamps including higher efficiency, better reliability, longer lifetimes, smaller sizes and faster switching capabilities. LEDs are not only used to illuminate visible lights for human machine interface (HMI) and lighting purposes, but also for detection, measurement and medical care in the infrared (IR) and ultraviolet (UV) wavelengths.

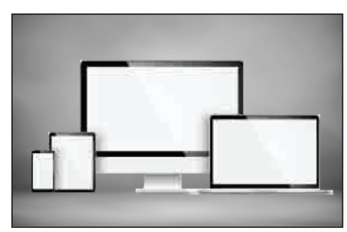
Given such diversified use cases for LEDs, learning how to design the best LED drivers can be complicated for hardware and software engineers. While LEDs are used across a breadth of applications, there are still similarities regarding their functionality within end equipment, and each function has common design considerations.

The four main functions of an LED include indication, animation, illumination and backlighting, as shown below in **Figure 1**.

LED indication

LED animation

LED illumination



LED backlight

Figure 1. *Examples of four typical LED functions.*

LED history and its first applications

In the early 1960s, LEDs were invented and mainly used to replace incandescent or neon indicator lamps and seven-segment displays in expensive equipment, since the power density was low and the cost extremely high. Continuous and intensive research into LED technology led to the production of more efficient LEDs with different colors. In 1994, the invention of ultra-bright blue LEDs expedited the development of cost-effective white LEDs. Meanwhile, invisible wavelength LEDs extended from original IR to UV, and modern LEDs began spanning the visible, UV and IR wavelengths, with high efficient light output.

Applications for modern LEDs range from simple indicators to both visible and invisible lights, with use cases among nearly all types of electronic equipment. For example, in smart homes, smart speakers act as a smart home hub to which other smart devices in the household connect, including smart locks, video doorbells, thermostats, large and small appliances, vacuum robots, and lighting systems; see **Figure 2**. In these applications, different power levels and color LEDs are used to indicate status, or for HMI, LCD backlighting or IR/white illumination.

Figure 2. *LED use cases in a smart home.*

Design considerations

LEDs are diodes, which are easy to turn on if forward-biased, but complex to design with a single method covering so many applications. The traditional design rule is to use the power level of total LEDs in the system as a guide to select different LED drivers. However, as dimming capability becomes a common requirement and the color mixing of RGB and white LEDs improves the user experience, software control on top of LED driving makes it harder to find an appropriate solution. Thus, designers must consider not just the power level but the topology, efficiency, dimming method and control.

LED indication

LED indicators are used in nearly all kinds of electronic devices.

As the most popular function, LED indicators are the easiest to design. The indicators in the system usually just need to turn on or off to indicate status, so applying a forward-biased voltage on the LED and adding a current-limit resistor, as shown in **Figure 3**, is the most straightforward method. A mechanical or electronic switch (a transistor or metal-oxide semiconductor field-effect transistor [MOSFET]) can turn the LED on or off.

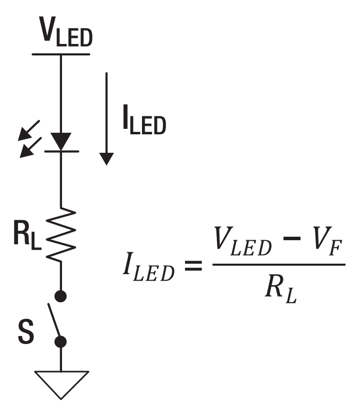
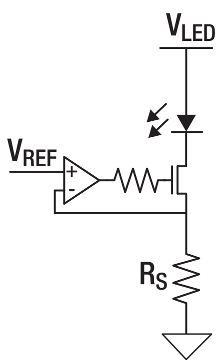


Figure 3. *An LED driving circuit with a current-limiting resistor.*

Some types of equipment, like appliances, use several indicators or seven-segment and dot-matrix displays to show information like time or battery power level. Designers usually implement universal shift registers like 74HC164 or 74HC595. However, because the LED current-voltage curve is exponential, the LED current shifts easily, due to variations of LED supply voltage (V_{LED}) and current limit resistor (R_L). These current shifts result in bad uniformity and shorter life spans, especially for battery-based applications where V_{LED} varies a lot. A constant-current LED driving circuit, as shown in **Figure 4**, generates a more accurate current through all LEDs. The reference voltage (V_{REF}) usually comes from accurate voltage sources, making the LED current constant regardless of the V_{LED} variation.



$$I_{LED} = \frac{V_{REF}}{R_S}$$

Figure 4. *An LED driving circuit with constant current.*

LED drivers integrating these kinds of constant-current circuits are used widely. High current accuracy for multiple channels assures better brightness uniformity, while driving many LEDs with a single chip also reduces the system size. An internal ghosting elimination circuit, if added in the driver, simplifies the design to drive dot-matrix displays. After huge semiconductor process improvements, the cost of LED drivers for indication is now comparable with transistor arrays.

LED animation

LED animation became more common with the invention of colorful LEDs. Animation helps improve the HMI experience by generating millions of colors and changing the brightness to form visually pleasing lighting patterns. In devices like those in a smart home, LED animation facilitates vivid interactions between "cold" electronic equipment and humans, making the equipment "talk with" or "listen to" the consumer. That's the magic of LED animation.

An LED animation driver is an upgrade from an LED indicator driver; its additional features include color mixing and brightness control to drive the most widely used RGB LEDs.

According to the RGB color model, adding RGB light in various ways can produce a broad array of colors, as shown in **Figure 5**. For example, if each color (red, green and blue) has 8-bit depth, all of the different combinations possible can create 16.8 million colors. After generating a certain color, applying a gradient change of the brightness can achieve a "breathing" effect.

Figure 5*. A color ring produced by RGB color model.*

Color mixing and brightness control are usually accomplished with an LED driver that has analog dimming or pulse-width modulation (PWM) dimming to control each RGB LED independently. Analog dimming adjusts the DC forward current through the LED, which can be used for color calibration to achieve a certain color temperature, such as a 6500K white. PWM dimming modulates the average current with a different duty cycle, which makes it easy to get resolution as high as 16 bits for better effects.

Since perceived brightness is not linear with luminance of LEDs, and the human eye is more sensitive at low luminance, exponential dimming of the LED driver is necessary to achieve a smooth breathing effect.

Figure 6 shows a typical block diagram for an LED animation driver. Some applications require automatic control, which means that the LED driver can realize the lighting patterns without continuously communicating with the controller, which needs static random access memory and a corresponding algorithm.

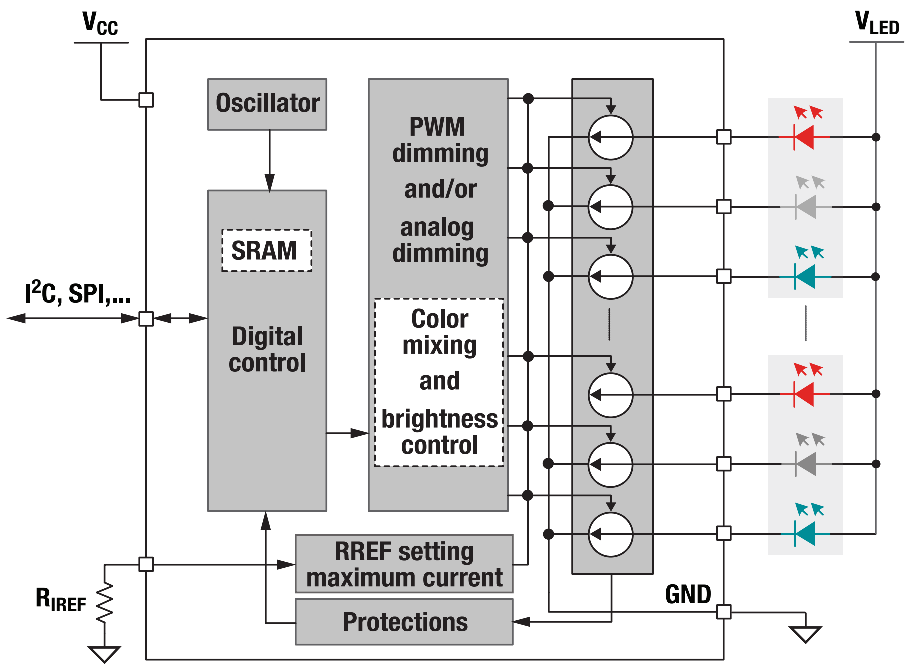


Figure 6. *Typical block diagram of an LED animation driver.*

LED illumination

LED illumination uses high-power LEDs or strings of LEDs to illuminate someone or something. White LED illumination is pervasive and one of the most efficient lighting sources, while IR LED illumination working with cameras makes the subject visible in the dark. UV LED illumination plays an important role in the medical and chemical industries.

A constant-current power regulator is a must for LED illumination because a high-power LED's current may double with a voltage increase of only 10% – meaning that there is a high possibility of damage to the LED. The power stage's topology and flexible dimming control are two main considerations for choosing LED illumination drivers, as shown in **Figure 7**.

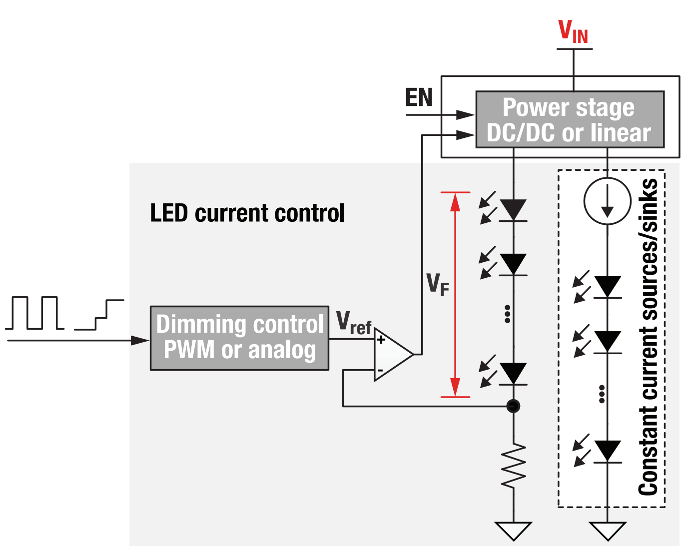


Figure 7. *Typical block diagram for LED illumination.*

For the power stage, LED illumination usually uses LED strings, so it's necessary to compare the total forward voltage (V_F) of the LED string and the input voltage (V_{IN}) to choose the right topology. If the V_F is higher than the V_{IN}, you will need a boost topology to generate enough voltage to forward-bias the LED string. If the V_F is lower than the V_{IN}, you will need a buck topology to increase the total efficiency. Linear constant-current sources or sinks may also fit if V_F is close to, but slightly lower than, V_{IN}.

For dimming control, analog dimming and PWM dimming are still the main control methods.

Analog dimming has a continuous output current and is popular in camera-related applications such as video surveillance because it can diminish flicker. There are two types of input sources to consider for analog dimming: DC voltage input and PWM input, as shown in **Figure 8**. Analog dimming with a DC voltage input adjusts the output current by applying a DC voltage signal. The dimming ratio of this method is usually low due to the voltage accuracy. A PWM input can achieve a high dimming ratio with a scale from 0% to ~100%, and usually needs a high-frequency PWM input for the internal filter.

For PWM dimming, the output current is not continuous, as **Figure 9** shows. In the LED current waveform, tr and tf are the rise and fall times in response to the PWM command, which affects the dimming ratio and minimum pulse width. The rise and fall time varies for different PWM dimming methods, as shown in **Figure 10**, including main FET dimming, series FET dimming and shunt FET dimming.

Main FET dimming has the highest rise and fall times, making it hard to achieve fast dimming and a high dimming ratio. Series FET dimming can improve the dimming speed and ratio, while a shunt FET is the fastest solution for PWM dimming with the highest dimming ratio. **Table 1** compares the dimming methods described so far.

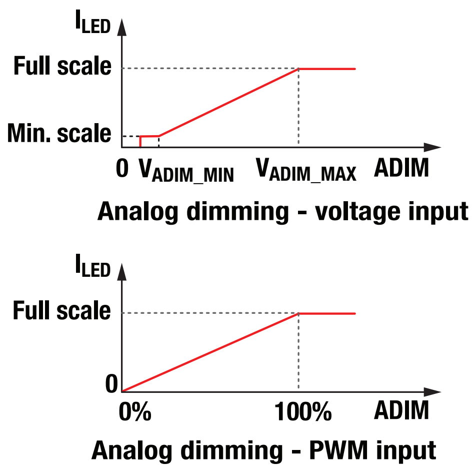


Figure 8. LED illumination with analog dimming.

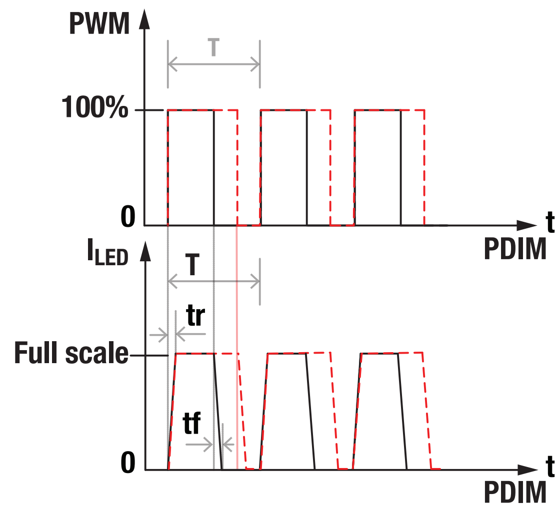


Figure 9. LED illumination with PWM dimming.

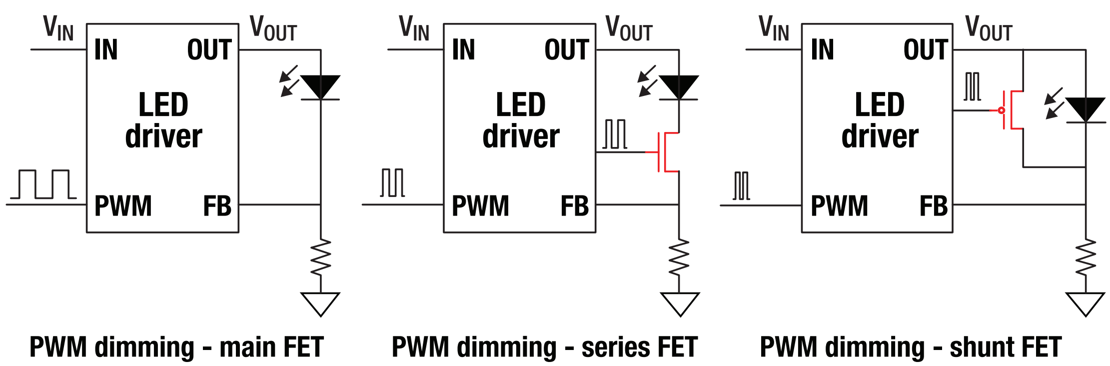


Figure 10. LED illumination PWM dimming methods.

Item	Analog dimming		PWM dimming		
	Voltage input	PWM input	Main FET	Series FET	Shunt FET
Input signal	DC voltage	PWM	PWM	PWM	PWM
Dimming ratio	Low	High	Low	Medium	High
Dimming speed	Low	Medium	Low	Medium	High
Flicker under camera	No	No	Commonly	Rarely	Rarely

Table 1. LED illumination dimming comparison.

LED backlighting

LED backlighting is used for illumination purposes. It is common for several white LED strings to backlight LCD displays, since LCDs are not self-luminous. While applications such as mobile phones, notebooks, monitors and TVs all use different sized LCDs, design considerations for LED backlighting remain the same, focusing on efficiency and the dimming or contrast ratio.

A boost LED driver is usually applied to drive the LED strings. To generate the maximum luminance required, a larger LCD panel needs more LED strings and a higher LED count in series. Adding constant-current sinks will achieve higher accuracy between different LED strings.

High efficiency is very important for the backlight driver, which means the product can achieve lower power consumption and better thermal performance. High efficiency also extends battery life for battery-powered applications. To achieve high efficiency, the LED backlight driver needs a highly efficient power stage, low quiescent current, a low headroom voltage for the constant-current sinks and optimized external components.

The contrast ratio is another key consideration in backlighting, especially for displays covering both indoor and outdoor use. A thermostat with a 7-inch LCD display may only need a 300-nit maximum luminance, with a dimming ratio less than 500-to-1, but a fish finder that's a similar size may need up to 3000-nit luminance and a dimming ratio of more than 10,000-to-1. Analog dimming can achieve a low dimming ratio, such as 500-to-1, while a dimming ratio over 10,000-to-1 requires high-resolution PWM dimming or hybrid dimming, which is a combination of PWM and analog dimming.

Depending on the LED architecture, LED backlighting has two configurations: global dimming and local dimming.

Global dimming enables the placement of one or several LED strings at the edge of the LCD panels and uses a light guide to disperse the light uniformly. This scheme is easy to accomplish and is the most widely used solution today.

Local dimming uses a full LED array to increase the contrast ratio by applying more individually-controlled zones behind the panel. With the breakthroughs in mini LEDs and corresponding matrix drivers, local dimming is on its way to a prosperous future in applications that require an ultra-high contrast ratio.

Looking to the future

Higher power density, higher efficiency and smaller package sizes are enabling the implementation of LEDs in more use cases. At the same time, LED drivers are also optimized to meet different requirements based on the four LED functions:

- LED indicator drivers are becoming more integrated, with a cost comparable to discrete transistor arrays.
- LED animation drivers face higher channel-count challenges, while matrix drivers continue to be released to market, driving hundreds of LEDs with a single chip.
- LED illumination drivers need faster dimming capabilities for applications like machine vision, along with higher power density and low electromagnetic interference.
- LED backlight drivers are facing breakthroughs at the multilevel boost stage for extremely high efficiency in global dimming, while local dimming with matrix drivers provides a higher contrast ratio.

Advanced LED drivers for the four main functions of an LED will help resolve today's challenges and bring LED applications to a new level.

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