Testing and Verification of Dimmable LED Lighting

The cost of LED lighting has rapidly declined in recent years, driving its widespread adoption. While LED lighting is already the most energy-efficient option compared to incandescent bulbs and fluorescent lamps, one important feature has yet to be fully leveraged—dimming capability. Conventional incandescent bulbs can be dimmed using TRIAC-based dimmers, but due to their high energy consumption, many countries and regions have restricted or banned their production. Fluorescent lamps, though still available on the market, consume more power than LEDs and generally lack dimming capability. Therefore, despite LEDs being more expensive than fluorescent lamps, the ability to dim LED lighting offers additional energy savings that fluorescents simply cannot achieve.

The benefits of dimmable LED lighting have already been demonstrated in numerous applications, and it is now becoming increasingly common. Beyond the cost reduction, dimming capability further enhances energy efficiency.

For example, in indoor lighting, dimmable LEDs can compensate for changes in natural light throughout the day—whether it is sunny, cloudy, rainy, or nighttime—keeping indoor illumination at a stable level. During the day in bright conditions, LED brightness can be reduced, while at night, maximum output can be used; during cloudy or rainy weather, the brightness can be set to a medium level. This avoids unnecessary full-output lighting in daylight, thereby saving energy. Another example can be seen in parking lots: at night, when the area is unoccupied, the lighting can be maintained at a lower brightness level, increasing only when motion is detected. This significantly reduces wasted energy and helps realize the concept of intelligent lighting.

Even in residential settings, legacy TRIAC dimmers originally designed for incandescent bulbs can be used to adjust LED brightness, allowing users to meet different lighting requirements while saving energy.

This article outlines the methods for dimming LED lighting and introduces equipment with dimming control functions that can be used in testing and verification during R&D or production. With these advancements, it is anticipated that dimmable LED lighting will continue to grow in popularity.

Common types of TRIAC dimmers available on the market

How LED Lighting Achieves Dimming Functionality

In the current market, there are two primary types of LED dimming technologies: power-side control and load-side control. The first type, power-side control, includes conventional TRIAC dimmers as well as techniques that utilize the switching time of the wall switch connected to the LED lamp. By toggling the switch on and off in specific time intervals, step-dimming can be achieved (e.g., three-step, four-step, or multi-step dimming). The advantage of this method is that it requires no additional dimming devices-users can control brightness simply by using the existing wall switch and adjusting the duration of the on-off cycles.

The most direct form of dimming control is the analog dimmer (TRIAC-based) originally designed for incandescent lamps. This type of dimmer has been available on the market for more than 20 years and has been widely adopted in luminaires requiring dimming functions. It works by using a TRIAC (triode for alternating current) in combination with a variable resistor to alter the phase angle of the AC voltage supplied to the LED driver. Adjusting the variable resistor changes the cut-off angle of the AC waveform, thereby controlling the amount of power delivered. Dimmable LED drivers are designed to detect the phase-angle variation in the input AC voltage and, based on this information, regulate the current flowing through the LED load. As a result, the brightness of the LED lighting can be adjusted, achieving the desired dimming effect, as illustrated in Figure 1.

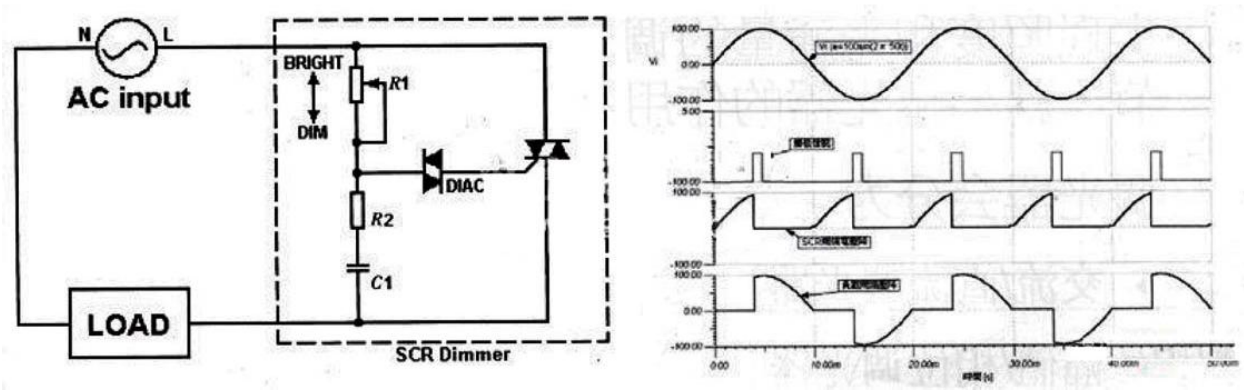


Figure 1. Conventional analog dimmer

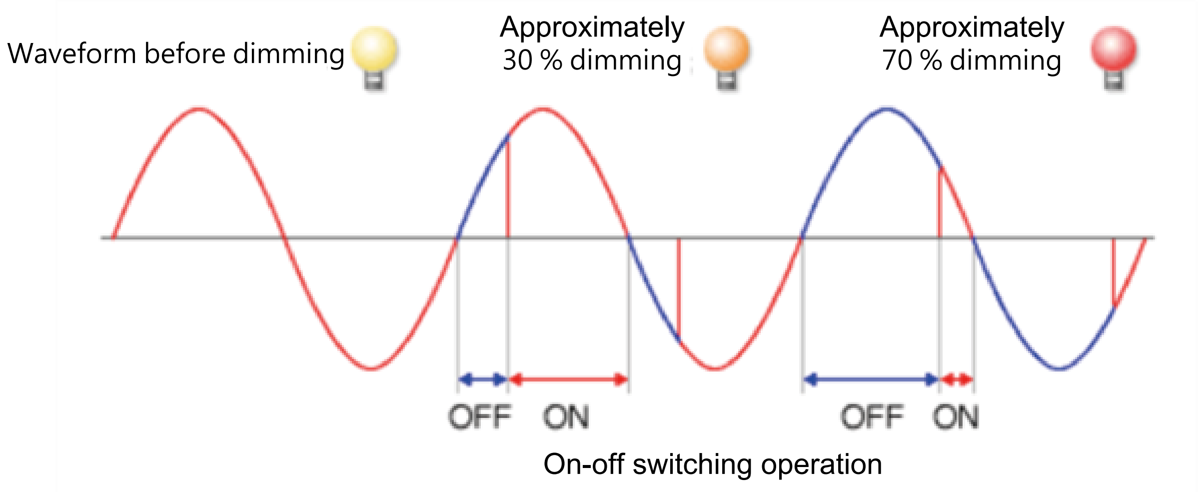


Figure 2. Dimming control by TRIAC dimmer through phase angle modulation

The second dimming technology is LED load-side control, which regulates the brightness by directly controlling the current flowing through the LED. This can be achieved either by continuously adjusting the LED current from 0 % to 100 % or by using digital Pulse Width Modulation (PWM). In PWM dimming, a pulse signal in the range of several hundred hertz is applied, and the duty cycle of the pulse is varied from 0% to 100%. This effectively changes the average current delivered to the LED, thereby controlling its brightness. Load-side control typically requires a remote controller to send dimming commands.

The dimming control signal for the LED driver can take the form of either a 0 V to 10 V analog voltage corresponding to 0%–100% LED current, or a PWM signal with a duty cycle ranging from 0 % to 100 % at frequencies typically between 100 Hz and 1 kHz. Because of the human eye’s persistence of vision, flicker is not perceived at modulation frequencies in the hundreds of hertz range. As shown in Figure 3, this technique is widely used in applications such as TV or LCD monitor backlighting, where PWM is employed to adjust display brightness. One key advantage is that while conserving energy, PWM dimming maintains consistent color characteristics of the display, making it one of the most suitable technologies for LED dimming.

Wireless remote control LED lights

If the lighting application requires optimal linearity and color accuracy, a driver capable of true PWM dimming would be the most suitable choice. Conversely, for applications that are highly sensitive to noise or demand maximum efficiency, an analog dimming driver should be employed.

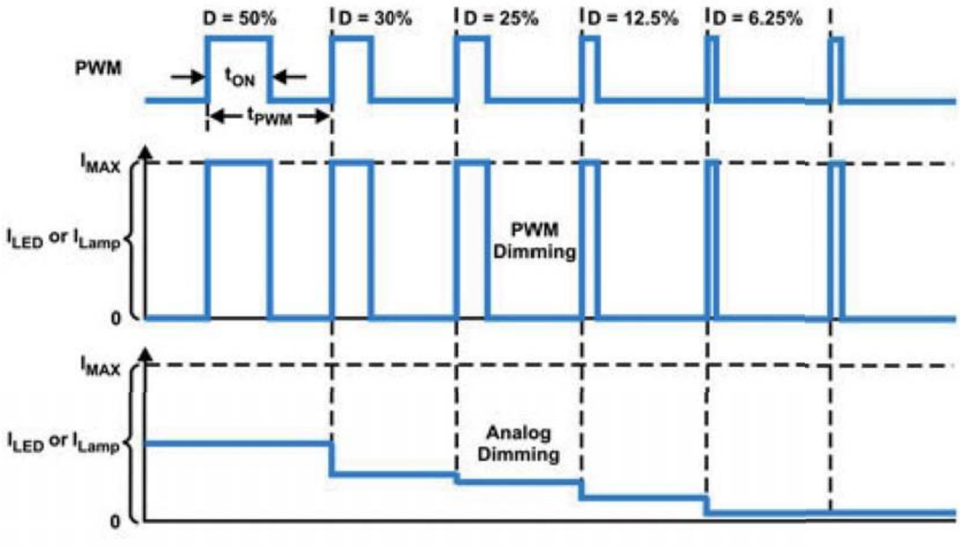


Figure 3. Light output or LED current under analog dimming and PWM dimming

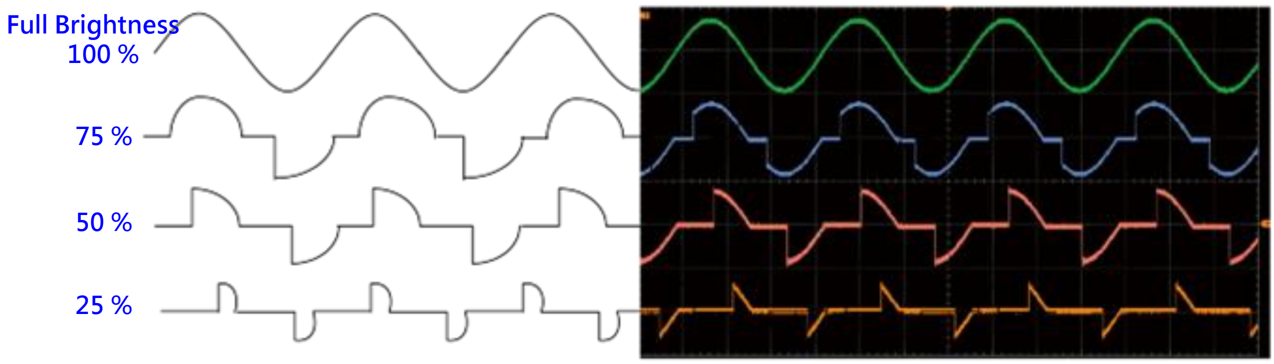
Prodigit Dimmable LED Lighting Test Solutions

1. The ASR Series AC/DC power supplies from GW Instek can simulate TRIAC dimmers.
2. The 3340G Series LED electronic loads from Prodigit are equipped with built-in, independently isolated output signals, providing both 0 V to 12 V analog control and PWM dimming control.

For testing and verifying LED lighting in combination with conventional dimmers (TRIAC), it is certainly possible to use actual dimmers. However, during the R&D stage or in mass production testing, the need for consistency, automation, and fast verification becomes essential.

Conventional TRIAC dimmers rely on manual adjustment of a knob, which alters the internal resistance and thereby shifts the output phase angle. This manual setup and adjustment process does not meet the requirements of rapid, automated testing. To address this, the GW Instek ASR Series AC/DC power supplies provide a dimmer simulation function, capable of emulating phase-angle changes from 0° to 180°. In addition to manual adjustments via the front panel, the power supply can also be computer-controlled through an interface, enabling fully automated testing and verification, as illustrated in Figure 4.

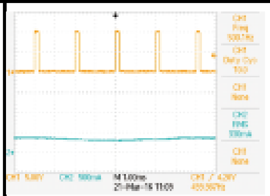
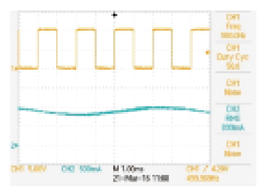
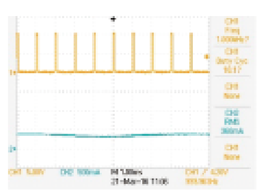
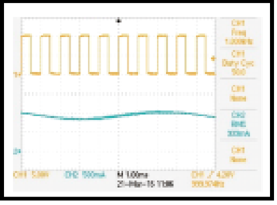
Figure 4. ASR series AC/DC power supply simulating a conventional TRIAC dimmer

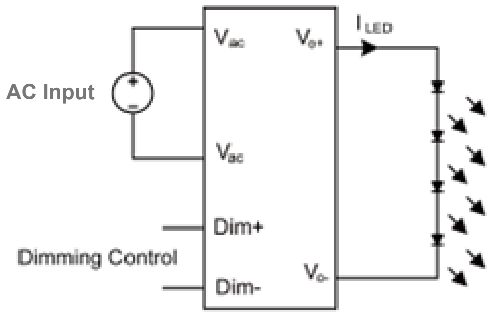


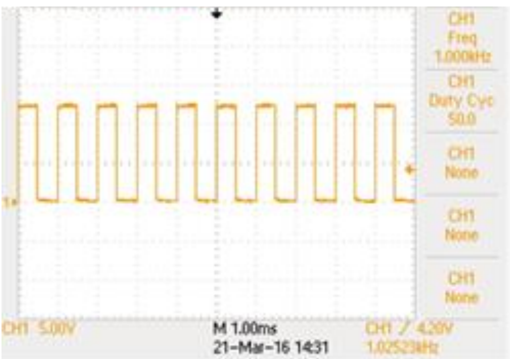
Expected dimming power waveform

ASR-2050 simulated dimming power waveform

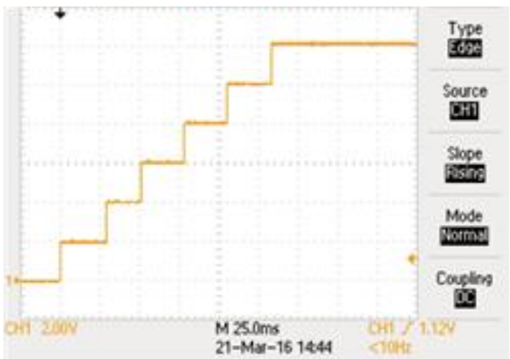
In addition, the ASR Series AC/DC power supplies are equipped with a high-precision power meter. By referencing the readings from the load-side power meter, the conversion efficiency of the LED driver can be calculated, enabling precise measurement of power consumption during dimming. When combined with the 3340G Series LED electronic load (as shown in Figure 5), the built-in high-precision power meter of the ASR Series together with the load-side power meter readings can be used to accurately determine the LED driver's conversion efficiency. For LED drivers utilizing digital PWM dimming, if the dimming control signal is an analog voltage ranging from 0 V to 10 V, a 0 V to 10 V power source can be used as the dimming control signal. Similarly, if the control signal is a PWM waveform at 500 Hz with a duty cycle from 0 % to 100 %, a signal generator may serve as the dimming control source. However, these approaches require additional external equipment. The 3340G Series LED electronic load simplifies this process by providing built-in, independently isolated dimming control signals. These signals eliminate the need for external equipment and can be operated either directly from the front panel or remotely via computer interface, making dimming control both convenient and efficient.

Input and output testing of dimmable LED driver				
Dimming control signal	10 V, 500 Hz, 10 %	10 V, 500 Hz, 50 %	10 V, 1 kHz, 10 %	10 V, 1 kHz, 50 %
Output waveform				





Digital PWM dimming signal



Analog 2 V to 12 V dimming signal

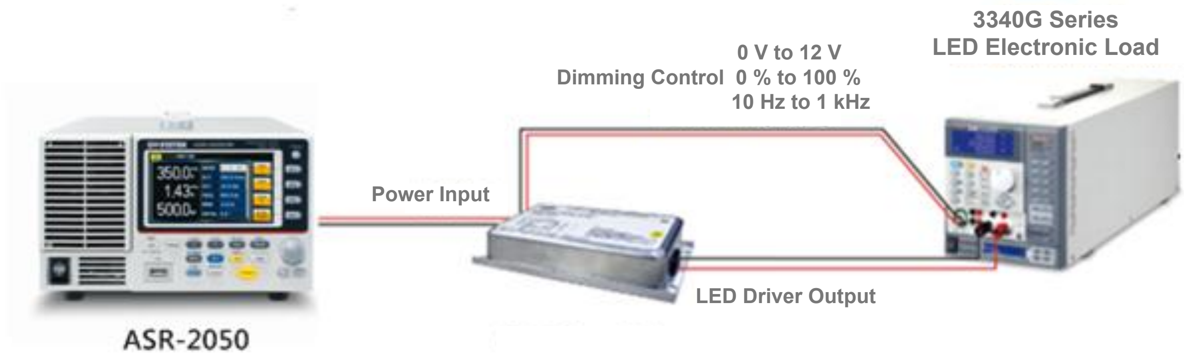


Figure 5. Wiring diagram for LED driver efficiency measurement