

Controlling LEDs

- why various control types are needed
- the existing methodologies used to control LEDs

Technical white paper
January 2011

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1 Controlling LEDs

1.1 Abstract

Ten years ago, many people didn't even know what an LED was. Today, they're the new hot item on the shelves – and everyone wants to use them. Often, designers do not know how to control LEDs or they have had negative experiences working with them. This white paper will provide a brief overview of what an LED is and how to use LEDs for general illumination applications and the advantages and limitations of doing so. It will also go into detail about why you should consider dimming LEDs and what questions need to be answered in order to dim LEDs properly to meet your expectations. The overall goal of this paper is to make you more comfortable with using LEDs on your projects.

1.2 What is an LED?

A Light Emitting Diode (LED) is an electronic device that produces light when an electrical current is passed through it. The wavelength (or color) of light that is emitted is dependent on the materials from which the LED is made. LEDs are available in many colors, including red, blue, amber, green, and near-UV colors, with lumen outputs ranging from 10 lumens to 200 lumens.

The LEDs used predominantly in general illumination applications are “Phosphor Converted Blue” LEDs, which are blue LEDs that have a layer of yellow phosphor placed over the LED. The phosphor absorbs some of the blue light, and emits yellow light. When the unabsorbed blue light mixes with the yellow light it creates what your eye perceives as “white” light.

1.3 Advantages and Limitations of LEDs for General Illumination

Advantages

- High Efficacy (Lumens per Watt) LED-based lighting fixtures can achieve efficacies ranging from 25 LPW to over 80 LPW, compared to an incandescent efficacy of 5-10 LPW.
- Longevity LEDs can achieve useful lifetimes ranging from 25,000 hours to up to 100,000 hours, compared to ~1000 hours for an incandescent.
- LEDs do not contain hazardous materials as compared to mercury vapor in CFLi bulbs.

Limitations

- Higher cost High Brightness LEDs, necessary for general illumination, are expensive. They also require electronic drivers to convert conventional AC voltage to discrete DC voltages for the LED arrays.
- Limited Applications Due to the relatively young technology and timeline for wide acceptance, LED-based lighting fixtures are not always available for every application or aesthetic requirement.
- Controls compatibility Due to the wide range of LED-based lighting product types, not all LED lamps are dimmable, and the ones that can be dimmed may be limited in dimming performance and system compatibility. This white paper will expand on these issues and provide solutions.

2 Why Dim LEDs?

Similar to fluorescent, incandescent and other conventional light sources, dimming LEDs saves energy at a roughly 1:1 ratio. This means that if you dim LEDs down to 50% of their light output you will save nearly 50% of your energy usage. So not only do you save by using a more efficient source, you save even more energy by dimming LEDs.

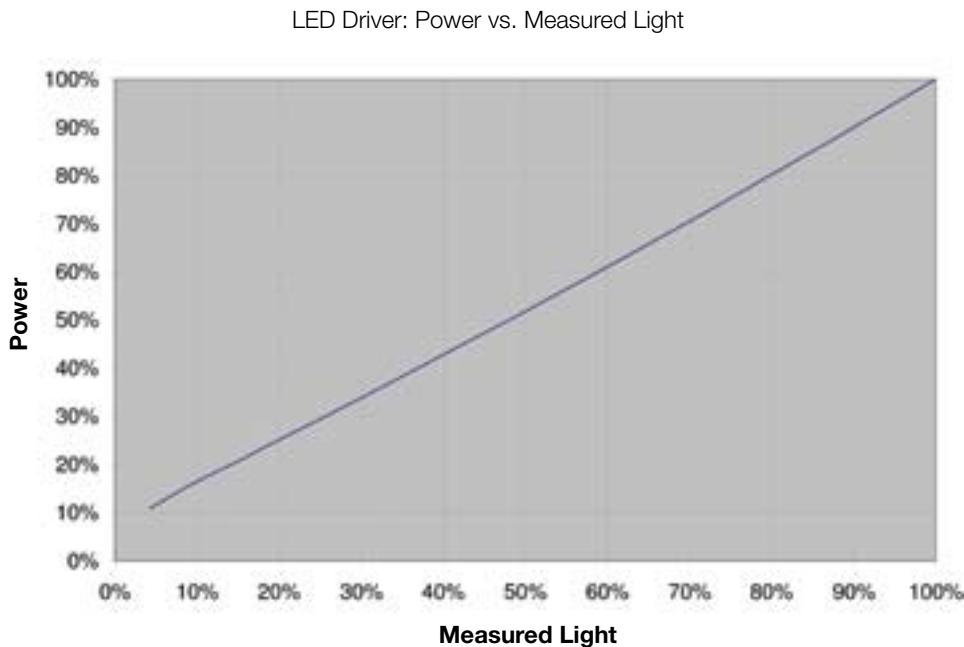


FIGURE 1:
Power vs. Measured Light for a Typical LED Driver

Dimming LEDs also makes them run cooler, which should extend the life of the electronic components of the driver, as well as the phosphor on the LEDs. This will extend their life, doubling or tripling the LEDs lumen maintenance. Research is ongoing to better quantify the relationship of dimming LEDs and lifetime extension.

Dimming any lamp, be it incandescent, CFL or LED enhances ambiance, so whether you are in a restaurant, theater or presentation space, you can create the environment that the lighting designer intended.

Dimming offers many other benefits, including:

- *Space Flexibility* Dimming control systems provide for space flexibility so that what may be an office space today could easily be converted into a call center tomorrow, or a gymnasium can be used as a theater or cafeteria just by adjusting the control of your lighting. Your home and your workplace should be designed to complement your needs. As your needs change throughout the day, your lighting should adapt as well; bright to read a book, but dim for computer use. Whether you are at home or at work, lighting control can create a comfortable atmosphere to support your activities throughout the day.
- *Enhanced Safety* Lighting controls can enhance the safety and security of your home. You can control both interior and exterior lights from the car as you approach your driveway to ensure optimal visibility and can even connect to security systems to turn on lights in case of an emergency.
- *Increased Productivity* Lighting control also increases productivity allowing the user to select the level he/she needs to reduce eye strain and fatigue so that they can work at peak performance for more of the day, or so students can concentrate better and learn more at home or at school.

3 What questions do you need to ask when trying to dim an LED product?

Before you commit yourself or your customer to investing in LED technology you need to understand its limitations, especially when it comes to dimming control compatibility. Many LED luminaire manufacturers are new to the lighting industry and are not familiar with the multitude of control types and the corresponding product design requirements that accompany them. This has resulted in “dimmable” products that do not work as claimed, that never turn off completely, or that flicker. These are major problems that need to be addressed so that consumers do not associate all LEDs with poor performance and become averse to using them. High-performing LED products do exist, but you need to ask the right questions to make sure you have chosen one of those products appropriately.

Answering the following five questions will allow you to align your expectations with the potential performance of your selected LED dimming system.

1. What type of LED product am I using: an LED lamp or LED fixture?
2. What is the dimming range of the product?
3. What is the dimming performance of the product?
4. What is the minimum or maximum number of fixtures/lamps that can be connected to one dimmer?
5. On what type of control does the LED product operate?

The following sections detail what you need to know to answer these questions.

If you need help determining any of these items, you can contact the

LED Control Center of Excellence

- Phone: 1.877.DIM.LED8
- Email: LEDs@lutron.com
- Web: www.lutron.com/LED

3.1 What type of LED product am I using: an LED lamp or LED fixture?

LEDs are low-voltage devices. Therefore, additional electronic components are typically required to convert the line-voltage power to a low voltage for the LEDs. These electronics may also interpret control signals, and dim the LEDs accordingly. These devices are referred to as LED drivers.

LED luminaires come in two distinct types: the LED bulb (also called an LEDi or retrofit lamp) and the LED fixture.

LED bulbs have Edison-base sockets and are meant to replace standard incandescent or screw-in CFL bulbs. The bases of these bulbs have integral drivers that determine if they are dimmable, and if so, what the dimming performance is.

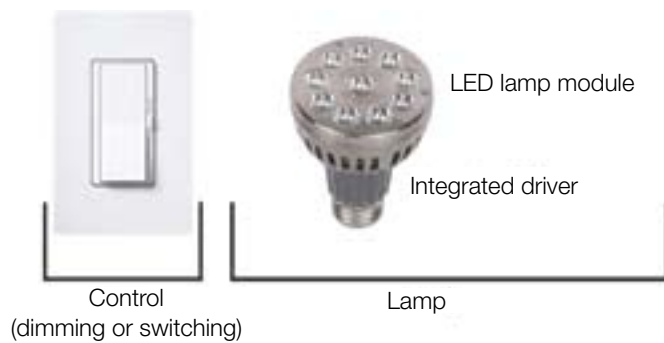


FIGURE 2: LEDi (LED retrofit lamp) and control must be compatible

LED fixtures can vary from cove lights to down lights and usually have an external driver. Some fixture manufacturers offer different driver options on the same fixture to support different control technologies or applications (such as dimmable vs. non-dimmable).

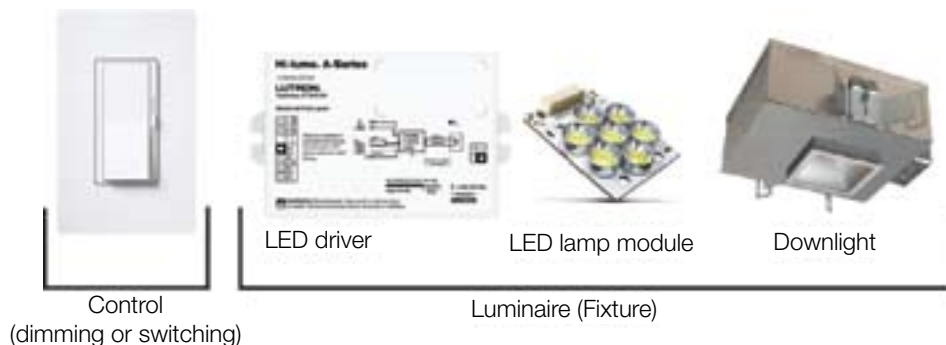


FIGURE 3: LED fixture (with driver and LED lamp module) and control must be compatible

There are two different types of drivers. LED drivers may be constant voltage types (usually 10V, 12V and 24V) or constant current types (350mA, 700mA and 1A).

Just as their names would suggest, a constant current driver provides a constant current, such as 700mA, to a pre-made LED array that is designed to operate at or below that current level. This is great for a down light, sconce or other LED fixtures that use only one light source per driver (much like a fluorescent lamp with its associated ballast). Note that some drivers support multiple currents, making them more flexible when designing a fixture.



FIGURE 4: Constant current driver example

A constant voltage driver provides a constant voltage to one or more LED arrays connected in parallel. A constant voltage driver is used in areas where you may have a variable amount of fixtures, such as a cove or under-cabinet light. These are similar, or sometimes identical, to electronic or magnetic low voltage power supplies (such as those used with MR16 lamps) and often have 12V and 24V outputs.



FIGURE 5: Constant voltage driver example

These two types of drivers are NOT interchangeable, and it is the design of the LED array that determines which driver is appropriate. Often this is application-based, but it is still the configuration of the LEDs that determines if a constant current or a constant voltage driver is needed. Some drivers are manufactured to operate specific LED devices or arrays, while others can operate most commonly available LEDs. Additionally, the long-life benefits of LEDs would be reduced if the driver was not designed for an equally long life.

The instantaneous response of LEDs to changing current makes them highly susceptible to flicker, especially compared to incandescent sources. One of the most important LED driver features to understand is the quality of the DC output voltage of the driver. Finally, be cautioned that remote mounting of the driver could result in potential voltage drops, power losses, or noise susceptibility on the DC wiring that must be properly accounted for.

The Lutron Hi-lume® A-Series LED Driver has the capability to dim the LED light output from 100% to 1%. It offers smooth and continuous dimming for both constant-current and constant-voltage sources, as well as providing pulse width modulation (PWM) and constant current reduction (CCR).

Dimming drivers can dim LEDs by CCR or PWM. Most dimming drivers operate using the PWM method. With this method, the frequency could range from a hundred modulations per second to thousands of modulations per second, so that the LED appears to be continuously lit without flicker. See Lutron® Application Note 360 for further information on dimming LEDs with PWM versus CCR.

3.2 What is the dimming range of the product?

Incandescent lamps dim to below one percent perceived light, which looks like an orange filament glow. The dimming range of an LED lamp or fixture can vary greatly from one device to another. Some may dim to a minimum level of only 50 percent, while a different product may dim to one percent. Additionally, manufacturers will quote measured light numbers, but consumers are familiar with perceived light. What is the difference?

Measured light output is the quantifiable value of light measured by a light meter or similar device. This is the dimming percentage indicated on LED product specification sheets.

Perceived light is the amount of light that your eye interprets because of pupil dilation. The eye's pupil dilates at lower light levels, causing the amount of light to be perceived higher than measured (e.g., 20 percent measured light equals 45 percent perceived light). The equation for determining perceived light is to take the square root of the measured light percentage (e.g. $\sqrt{0.2} = 0.45$).

You need to select the dimming range of your fixture or lamp that will be suitable for your application. A product that dims to 20 percent measured light (45 percent perceived) wouldn't make sense in a media room, but may be the energy-saving solution necessary for an office. If an LED fixture or lamp spec sheet does not state the dimming range, you should contact the manufacturer for that important piece of information. The Lutron testing report cards (found at www.lutron.com/LEDTool) includes perceived light as well as measured light, to align customer expectations. It is important to know that the dimming range of a product is based solely on the driver. The integral driver will determine the dimmability of a screw-in LED retrofit lamp and an external driver will determine the dimmability of an LED fixture. Each dimmer may have varying features that will affect your ability to trim out flicker if it exists and minimum load requirements, but it will not affect the dimmability of a product. The driver will determine the low-end light level and the performance. Finally, be aware that the dimming range of a single product may vary based on what control is used.

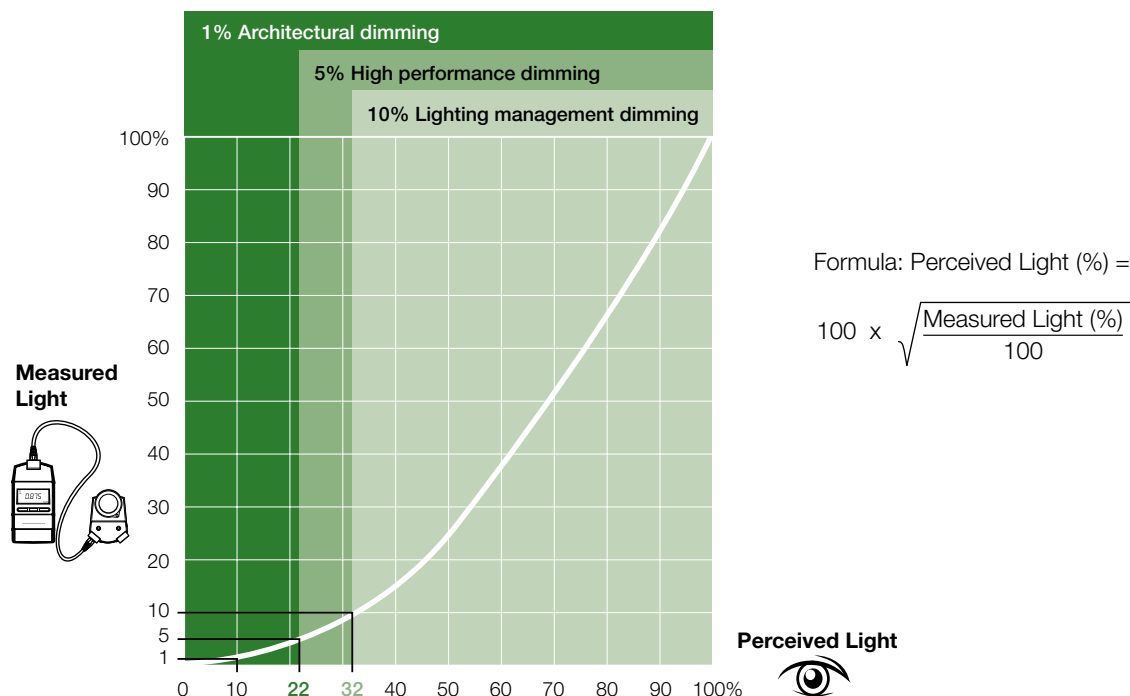


FIGURE 6: Measured vs. Perceived Light

Source: IESNA Lighting Handbook, 9th Edition. (New York: IESNA, 2000), 27-4.

3.3 What is the dimming performance of the product?

Each manufacturer defines dimming in a different way, but what you need to know is whether the dimming will be distracting or have noticeable, unexpected drops in light. The public's experience with incandescent dimming is that it is smooth and continuous. Specifically, a change in the control (dimmer) position should be reflected by an equal change in light level. There should be no abrupt change in light level as the light source is being dimmed.

Even more important is ensuring that there are no points of flicker in the dimming range. Flicker is the unexpected modulation of light level that is visible to the human eye. Flicker can come from many sources, including line noise, control noise, component tolerance, and LED driver circuit design. Flicker can be continuous (happening all of the time), or intermittent (only happening some of the time or at certain light levels). A good driver should account for all of these factors and still provide flicker-free, smooth, and continuous dimming.

Other undesired behavior can occur when dimming an LED. A properly designed driver should not have any of the following problems:

- *Pop-on*: After being dimmed to a low light level and switched off, sometimes LED bulbs will not turn on until the dimmer's slider is moved up. This is referred to as "pop-on," which is especially challenging in 3-way situations where lights can be turned on/off from different locations, not just using the dimmer.
- *Drop-out*: There should be no drop-out, so the light should only turn off when the switch is turned off. This can be achieved by utilizing the low end trim settings available on many wallbox and system level dimmers to ensure that the lights remain on at their lowest light level at the bottom of the dimmer's travel.
- *Dead-travel*: Adjusting the control without a corresponding change in light level is undesirable
- *Audible Noise*: Buzzing from the lamp, or from the dimmer due to the lamp.
- *Shimmer*: Small changes in light intensity. This can usually only be noticed at medium to low light levels, and often only at the periphery of vision.

3.4 What is the minimum or maximum number of LED fixtures/lamps that can be connected to one dimmer?

A common problem with LED system operation involves overloading the driver. LED drivers are rated for a maximum load (in volts, amps, and/or watts) that must not be exceeded. Similarly, some LED drivers may not perform well if too little load is put on them.

The number of lamps able to be installed on a single phase control dimmer may seem like an easy question to answer. However, it is not as simple as looking at your 600-watt dimmer and dividing 600 by the 15-watt LED lamp you have selected to determine that 60 lamps can be used on a circuit. You may only be able to use 100 watts of the LED load on a dimmer rated for 600 watts. While the LED lamp may only draw 10 watts continuously, it may have a start-up inrush current or repetitive current during every half-cycle that makes it appear much worse. That 15 watt LED lamp will appear to the dimmer as a 100 watt incandescent load, so if you use more than 90 watts of that LED, you will overload the dimmer.

Neglecting this transient current can put significant stress on the dimmer and can cause premature product failure or undesired system performance (such as excessive acoustic noise). This transient electrical stress may limit the maximum number of lamps you can install on one dimmer. The average stress Lutron has observed is the equivalent of a 100W incandescent, even for LED loads that are less than 20W.

A minimum number of fixtures may be required to operate a dimmer because of the 25-watt to 40-watt minimum load that most incandescent dimmers require to operate correctly under all conditions. When using incandescent bulbs, the minimum load requirement was easily met with usually only a single bulb. However, with LEDs, four or more loads may be needed on a dimmer in order to meet the required minimum load.

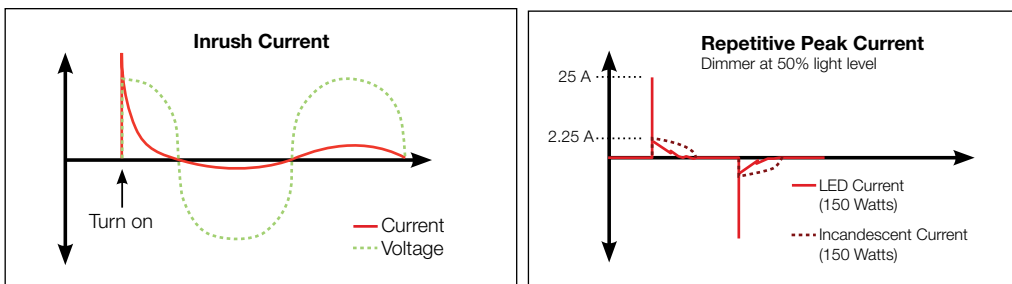


FIGURE 7: Inrush Current and Repetitive Peak Current

3.5 On what type of control does the LED product operate?

The following control technologies refer to the signal and wiring between the control on the wall and the fixture or lamp. LED retrofit lamps generally only use forward or reverse phase control technologies. LED fixtures may use any method, and it is independent of the driver type (constant current or constant voltage).

The compatibility of a dimmer with a particular LED fixture begins with making sure they both use the same control method. These control technologies are used in standalone applications and control systems as well as in wired and wireless lighting control systems. Controls that use phase control to control a lamp may also use a wireless technology to communicate between loads or within an entire home lighting control system.

Forward Phase Control: Typically used for incandescent and magnetic low-voltage (MLV) light sources, this is the most common method of dimming control. The National Electrical Manufacturers Association (NEMA) estimates that there are approximately 150 million forward phase control dimmers installed residentially, and many of these are likely to control LED replacement lamps in the future.

Working well with forward phase control is critical to the success of LED bulbs because of the huge existing installed base. Unfortunately, these controls were never designed for LED lights and are not UL listed to operate LED lights, so the performance is hit or miss and in many cases will cause LEDs to flicker, drop out, pop on or not dim very low. These dimming controls may also require multiple lamps per control in order to meet the minimum load requirements of the control.

Note that new forward phase control dimmers have recently entered the market that have been specially designed to reduce or eliminate the problems seen with controlling LED loads on existing incandescent dimmers. These dimmers are UL listed with specific LED loads, ensuring an acceptable application.

Reverse Phase Control: Typically used to control electronic low-voltage (ELV) light sources, reverse phase control is best for capacitive loads such as LED drivers. While it does not have the installed base that incandescent dimmers have, this control type is often more successful at high performance LED dimming without flicker.

Reverse phase dimmers were designed for the lower power “electronic loads” of electronic low-voltage transformers, so they tend to work better with the drivers required for LED loads. Unfortunately, these controls nearly always require a neutral wire to power the internal electronics, and not every electrical back box has a neutral present. Installing reverse phase dimmers in older buildings may require that a neutral wire is pulled to the box. Furthermore, these types of controls are not as widely available in the marketplace and are generally more costly.

3-wire Control: This standard fluorescent control type is used by dimmers that were created for fluorescent dimming. Three-wire controls have a separate line voltage wire that carries the phase control signal separate from the power wires.

Three-wire is more precise than forward or reverse and the control signal is much more immune to electrical noise. There are over 30 years of history in the industry of using 3-wire controls to dim fluorescent ballasts to 1% without flicker, drop out, or pop on. Of course, to get this performance, a third line voltage control wire must be pulled to the fixture.

0-10V Control: This analog control standard has been used in energy management controls such as occupancy and daylight sensors and is now becoming popular with many LED products. This control type is isolated and considered low voltage class 2, enabling it to be safe to the touch and allowing for simplified wiring.

One of the benefits of 0-10V controls is that it is defined in the IEC standard number 60929 Annex E. Unfortunately, some manufacturers don't follow this standard. This leads to drivers and lamps that claim to be 0-10V compatible but drop out or pop on, or that dim backwards with the lowest light at the top of the control and the brightest light at the bottom. Some 0-10V products do not work at all with controls designed for 0-10V ballasts, which are the majority of installed 0-10V controls. Since the control signal is a small analog voltage, long wire runs can produce a significant drop in the signal level resulting in different light levels from different drivers controlled by the same control device. Note also that the IEC standard referred to above only defines the electrical performance of the protocol. It does not define the aesthetic performance (ie, lack of flicker) or low-end light level.

DALI/EcoSystem: The DALI digital standard originated in Europe for control of fluorescent ballasts, but is now commonplace in commercial buildings in the United States. DALI is also defined in IEC standard 60929 Annex E. It allows for digital control of individual fixtures, maximizing the user's control and productivity. EcoSystem incorporates Lutron proprietary enhancements to the DALI protocol.

EcoSystem and DALI provide addressing of individual fixtures and status feedback from the drivers. This makes it easy to digitally assign occupancy sensors, daylight sensors, time clocks, manual controls and other controls to one or many fixtures without complicated wiring. This opens up an entire suite of energy-saving and system-monitoring control schemes where the design and setup is all done within software, making designing with them simple. EcoSystem simplifies the programming process by allowing you to use a hand-held device in the space and not have to know details of the system, such as addresses. Again, the IEC standard referred to above only defines electrical performance, not aesthetic performance.

DMX: Typically used in theatrical applications, DMX remains popular with RGB LED applications where multiple channels are necessary for individual color control. Some manufacturers are using DMX as the control type for white light in general illumination applications, which can often be complicated in terms of wiring, addressing, and interacting with other controls in the space. Contact the manufacturer for more information about how DMX controls can be integrated with control systems. Integrating between general lighting control systems and DMX fixtures can often be complicated, but it is possible.

4 Conclusion

Note that just because a fixture and the desired control use the same control technology (ex: 0-10V) that does not mean they will perform well together. This is especially true with forward and reverse phase control, due to their lack of a formal standard. However, even control technologies that have a standard do not indicate anything about performance, they only pertain to compatibility.

The only way to know for sure if a particular LED lamp or fixture will work with a particular dimmer is to test it. Whether that testing is a mock up or testing by the manufacturer, it is necessary to determine if negative behavior, such as flicker, pop-on, dead travel, etc. will occur. Keep in mind that you will not be able to visually determine what the inrush current of an LED product is so you must find out from the manufacturer or limit the number of lamps you are using to avoid overloading the dimmer. The Lutron LED Control Center of Excellence (COE) can assist in determining compatibility. The COE tests many fixture/driver/control combinations and posts the results online. All of these results are captured in the LED Product Selection Tool (www.lutron.com/LEDTool), which allows you to search by several different criteria.

Many manufacturers (both LED luminaire manufacturers and control manufacturers) conduct compatibility testing of their products. It is up to you to determine if that manufacturer's assessment of "good dimming" will meet your customer's needs.

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