

Addendum A for LEM-7-13: Lighting Controls for Energy Management

If you, as a user of IES LEM-7-13, believe you have located an error not covered by the following revisions, you should e-mail your information to Pat McGillicuddy, pmcgillicuddy@ies.org, or send a letter to Pat McGillicuddy, Manager of Standards Development, IES, 120 Wall St., 17th Floor, New York, NY 10005. Additions will be posted to this list online as they become available.

Revisions to IES LEM-7-13 Section 3.2 – Economic Considerations

In the last paragraph, after the first sentence, which reads:

“Additional variables impacting the economic performance of lighting control systems include energy rates, peak demand charges, installation and commissioning costs, and any available financial incentive such as utility rebates rewarding users for power or energy reductions or installations of specific lighting control devices.”

Add the following sentence:

“It should be noted that reducing lighting energy reduces heat load, which may provide a reduction in energy needed for cooling.

Add the following text at the end of the last paragraph:

“It should be noted that control features for color change (CCT and color rendering) in support of biologic applications (circadian rhythms, performance and alertness, healing, horticultural applications, animal husbandry, or unity with exterior environment) can result in increased energy consumption if not implemented properly.”

New Annex:

Annex B – LED On-Off Control and Dimming**INTRODUCTION**

LED technology is capable of smooth, flicker-free dimming over a wide range—typically down to 10% or less, and even down to 1% or less on premium commercial dimming systems—which is why LED dimming is an effective means of reducing the overall energy consumption of lighting systems. All the lighting control strategies described in **Section 2** are applicable to LED technology.

This annex supplements IES LEM-7-13 to update and augment the information specific to LED dimming in **Section 5.5 Solid State Lighting** and **Section 7 Control Protocols**.

B.1.0 LED DRIVER-CONTROLLED DIMMING IMPLEMENTATION**B.1.1 LED Driver Outputs**

LED drivers are designed to be either *constant current* or *constant voltage* output devices, and these two types of drivers are not interchangeable. It is typically the luminaire manufacturer's responsibility to select the driver type and configuration to meet the electrical requirements of the LED module(s) used in the luminaire.

Constant voltage drivers provide a fixed voltage to multiple LED arrays, LED modules, LED tape, or LED luminaires that are connected in parallel, e.g., cove or under-cabinet lighting. Constant voltage drivers are typically electronic, but some magnetic low voltage (MLV) and electronic low voltage (ELV) transformers used for halogen strip lights in a cove or with MR16 lamps or luminaires can also be used as constant voltage drivers. These drivers commonly provide 12-V or 240-V outputs, although other output voltages are possible. Dimming of LED lighting that uses constant voltage drivers can only be accomplished via a pulse-width modulation (PWM) output method, described later. In addition, MLV or ELV transformers can be used with some types of LED modules. These need to be dimmed using the appropriate dimmer type, also described later.

Constant current drivers provide an unchanging current, e.g., 700 mA, to a dedicated LED module that is designed to operate at that current level. Constant current drivers are commonly used for downlights, sconces or other LED luminaires. While most constant current drivers provide one output current, some can be adjusted to support multiple output currents, which provides design flexibility to accommodate different light outputs. There are two different dimming methods for adjusting the output current for constant current drivers: PWM and constant-current reduction (CCR). Although most drivers use one method or the other, some dimming drivers use a combination of the two methods.

PWM is accomplished through current switching between 0 amps and the rated output current at a specific modulation frequency, meaning that the LED load is either on (at rated current) or off. The ratio of on-time to off-time determines the perceived brightness of the LED source. **Figure B1** shows an example of the current for an LED source dimmed to approximately 25% of full perceived brightness as a result of current flowing for 25% of the each cycle.

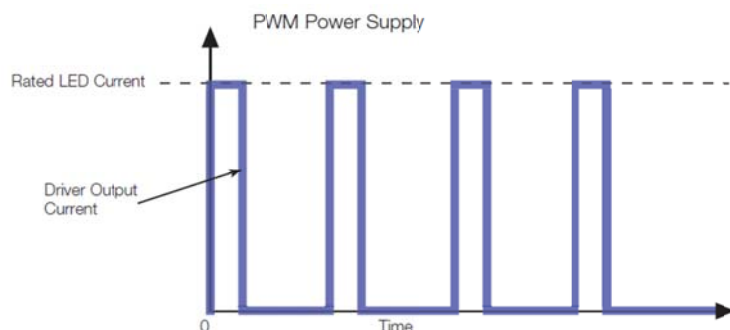


Figure B1. Dimming using pulse width modulation (PWM) (Image courtesy of Lutron, Inc.)

By definition, PWM dimming is accomplished at frequencies high enough to be imperceptible to the human eye. Frequencies lower than 200 Hz are potentially observable in peripheral vision, with the likelihood of discernible flicker decreasing as frequency increases. Higher frequencies are also required in order to eliminate stroboscopic effects in fast motion environments or interference with other electronic equipment, including video systems. In addition, IEEE has published a recommended practice (IEEE 1789) that specifies the minimum frequency at which drivers need to operate to avoid potential health risks to viewers.

In CCR dimming, the current flows continuously at a set value for a given light level. Since the amount of light output is proportional to the current flowing through the LED, a reduction in current will reduce the brightness of the LED. **Figure B2** shows an example of the current for an LED source that is reduced to approximately 25% of full light output using CCR.

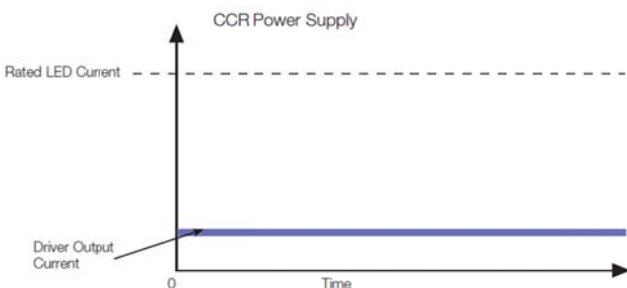


Figure B2. Dimming using constant current reduction (CCR) (Image courtesy of Lutron, Inc.)

CCR dimming has several advantages over PWM dimming for certain applications. CCR dimming is used in applications with strict EMI requirements, including videoconference applications, medical suites and MRI rooms, and for applications with high motion activity or rotating machinery.

B.1.2 On-Off Control of LEDs

The growing interest in the use of LED lighting for many general illumination applications means the LED products need to be compatible with switching controls, which provide on-off control of the LED light source. Due to the nature of LEDs, there are specific technical considerations and product requirements to ensure successful switching.

The most basic form of LED lighting on-off control is line-voltage switching. Switching is accomplished manually with wall switches or relay control systems. Automatic switching using occupancy sensors or

daylight sensors can provide cost effective control to meet minimum building code requirements. The instant-on and zero warm-up time of LED sources provide superior functionality in warehouses, sports facilities and exterior switching applications. Luminaires that include multiple switched circuits can also utilize multi-level switching, in which portions of the luminaire can be turned off or on based on the needs of the occupants of the space. Since luminaires are turned on or off instantly, switching control is primarily utilized in applications where adjustability of the overall lighting level is needed but the aesthetics associated with dimming are not required.

B.1.3 Dimming Controls for LED Lighting

In general, dimming controls for LED lighting can be implemented via either of two methods:

- Direct dimming of the line voltage feeding the LED lamp or luminaire
- Providing a separate control input to the driver that is typically a low-voltage analog or digital signal (referred to as *directly controlled* because the signal acts directly as the method of level control, as opposed to control of line voltage or current)

Because the control input type is independent of the driver output type (constant current or constant voltage), ensuring the compatibility of a control with a particular LED lamp or luminaire begins with verifying that both use the same control method, whether it's a simple standalone wall box dimmer or a more complex lighting control system.

Dimming of the line voltage is implemented via either of two methods. These methods are commonly referred to as *forward phase control* (FPC), also known as *leading edge* (LE), and *reverse phase control* (RPC), also known as *trailing edge* (TE).

B.1.3.1 Forward Phase Control Dimming

Forward phase control dimming is also sometimes referred to as *triac dimming* because of the bidirectional triode thyristors (commonly called triacs), components that can only be used in FPC circuit designs. Historically used for incandescent and MLV transformers, this is the most common method of line voltage dimming control. The U.S. National Electrical Manufacturers Association (NEMA) estimates that there are over 150 million FPC dimmers installed, and many of these are likely to be used for control of LED lamps as incandescent lamps are replaced. Unfortunately, these dimmers were never designed for LED loads and typically do not have safety certification for this application. Performance may be inadequate in many cases, with LED flicker, drop-out, pop-on, or failure to dim at low levels commonly occurring. **Figure B3** shows and example of an FPC dimming diagram.

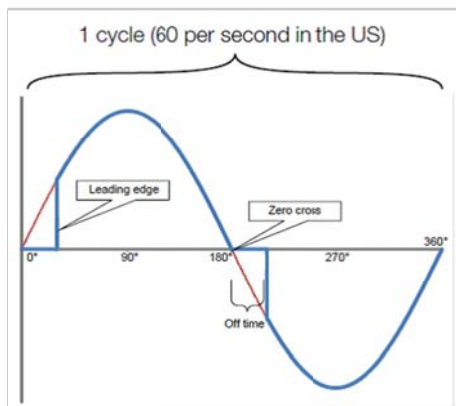


Figure B3. Forward phase control (FPC) dimming. (Image courtesy of Lutron, Inc.)

There are a number of caveats associated with the use standard forward phase control dimmers with LED lighting. LED lamp wattages are generally lower than the wattage of the incandescent lamps they replace and may not meet the minimum load requirement of the dimmer, resulting in improper or inadequate operation of the LED lamp. In addition, the maximum rating of the FPC dimmer must also be considered. For example, a 600-watt incandescent dimmer will not necessarily operate satisfactorily when connected to 40 15-watt LED lamps. While the LED lamp may draw only 15 W continuously, it will exhibit a *repetitive peak current* during every half-cycle of AC power that causes the same demand on the dimmer as a 60-watt incandescent load (see **Figure B4**). This transient current puts significant stress on the dimmer, exceeds the dimmer's design limits, and may cause premature product failure or improper system performance, such as excessive acoustic noise. LED loads as low as 20 W can result in the same electrical demands of up to a 100-watt incandescent lamp.

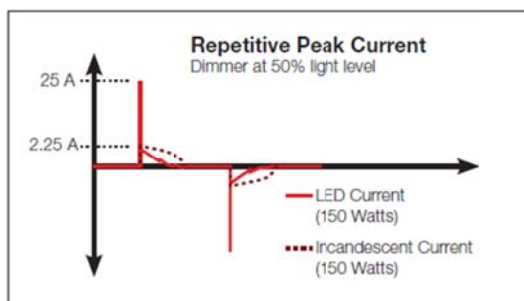


Figure B4. Repetitive peak current comparison. (Image courtesy of Lutron, Inc.)

Finally, because LEDs are very sensitive to small changes in current, the stability of an LED lamp at low light levels will be dependent on the power quality of the AC source and the design of the driver circuitry. Even minute fluctuations in line voltage may result in visible flicker in the lamp.

Newer FPC dimmers are designed to reduce or eliminate the problems with controlling LED lamps, including the ability to drive small-wattage loads. Some dimmer manufacturers and many lamp manufactures provide compatibility lists for specific LED lamps and luminaires to help ensure acceptable dimming performance.

B.1.3.2 Reverse Phase Control (RPC) Dimming

Reverse phase control is sometimes referred to as *ELV dimming* because it is traditionally used to control electronic low voltage (ELV) transformers. (Note, however, that not all ELV dimmers require reverse phase control.) RPC dimming is often more effective with LED drivers than other control methods are due to the similarity to transformer loads. While they do not have nearly the installed numbers of incandescent dimmers, RPC is often the control type supported by LED lamp and luminaire manufacturers. RPC dimmers typically require a neutral wire connection for internal electronics. Not every electrical switch box has a neutral wire available, particularly in older buildings, which limits the applicability of RPC. **Figure B5** shows an example of an RPC dimming diagram.

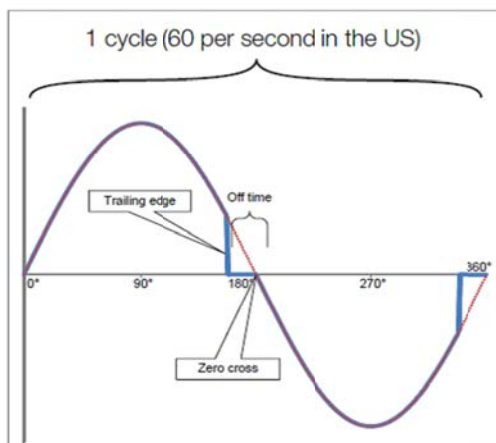


Figure B5. Reverse phase control (RPC) dimming. (Image courtesy of Lutron, Inc.)

B.1.3.3 Compatibility

Standards are being developed that address compatibility between drivers and LED loads. The NEMA SSL-7A¹ standard specifies basic interoperability between LED lamps and phase-control dimmers and addresses compatibility and reliability. However, SSL-7A compliance alone does not ensure that dimming performance will meet the needs and expectations of customers. A follow-up standard, NEMA SSL-7B, is under development, with the intent of providing criteria for a level of dimming performance that will be acceptable to consumers.

Additionally, some LED lamp manufacturers and dimmer manufacturers perform in-house testing and provide results on their respective websites.

B.1.3.4 LED Dimming Using Existing 3-wire Fluorescent Controls

This control type is a form of forward phase control typically used for fluorescent dimming. The three-wire line voltage connections consist of a dimmed hot (forward phase) wire, a switched hot wire and a neutral wire. Providing a third wire for control allows for more-precise dimming than 2-wire control, with reduced susceptibility to electrical noise. Three-wire controls have been used for over thirty years to dim fluorescent ballasts to 1% without flicker, drop-out, or pop-on. The substantial existing base of 3-wire dimming installations can be used with LED drivers designed with a 3-wire control input with minimal or no modification.