LED DIMMING

A HELPFUL GUIDE...
INTRODUCTION

There are five types of dimming control interfaces described in this document: 2-Wire Forward Phase, 2-Wire Reverse Phase, 3-Wire (Lutron), 4-Wire (0–10V), and Digital Signal Dimming Interfaces. The following pages will help to explain the uses, benefits and limitations of each dimming technology.

We will start by defining some basic terminology used in describing dimming equipment and solid state lighting.

LED & DIMMING TERMINOLOGY

**Constant Current**
Also known as Constant Current Reduction (CCR). This term is used to refer to a technology used by an LED Driver to provide power and control for an LED Board. The driver sends a continuous current flow to the LED for a given light level. Since the light output is proportional to the current flowing through the LEDs, the current is reduced to reduce the brightness of the LEDs. This term is NOT applicable when discussing the type of dimming control required by an LED fixture. It is used only to describe dimming of an LED Board. Constant Current Drivers are the most common type used for LED general lighting luminaires.

**Constant Voltage**
This term is used to refer to a technology used by an LED Driver to provide power and control for an LED Board. In this case, the driver provides a constant supply of voltage to an LED Board array. Constant Voltage LED Drivers are often used to power LED luminaire arrangements where several luminaires are wired in series to a common power supply (e.g., undercabinet lighting). Constant Voltage LED Drivers always use a PWM technique to provide dimming of the LEDs (see PWM on the next page). This term is NOT applicable when discussing the type of dimming control required by an LED fixture. It is used only to describe dimming of an LED Board.

**Drop Out**
When the voltage at which the luminaire/fixture stops operating is higher than the lowest dimmer setting. As you dim the fixture, it suddenly drops out completely.

**Dead Travel**
The amount of change in control before there is a visible change in the amount of light being produced by the fixture.

**ELV Type Dimmer**
An Electronic Low Voltage Dimmer used with electronic low voltage drivers. Also known as a trailing-edge dimmer.

**MLV Type Dimmer**
A Magnetic Low Voltage Dimmer used with magnetic low voltage drivers. These are generally the same as a leading-edge incandescent style dimmer.

**Ghosting**
When an LED lighting fixture continues to glow in the off position. This can be attributed to two primary reasons. Drivers utilize capacitors to provide smooth and continuous DC power to the LED Board. Some drivers may discharge this power slowly for several seconds directly after main power is turned off to the unit. Additionally, ghosting can occur when a driver and dimming control have been mismatched (e.g., incandescent dimmer paired with an electronic low voltage driver).
**Leading-Edge Dimmer**
A dimmer that was designed to work with Incandescent lamps. Older dimmers of this type were not designed to work with LED lamps/drivers and problems with flicker, pop-on and ghosting due to residual voltage have been observed. Newer designs have been specially designed to eliminate these problems.

**LED Board**
The LED Board within an LED light fixture refers to an electronic circuit board containing the actual LEDs. The LED Board connects to the LED Driver within a fixture.

**LED Driver**
An electrical device that converts line voltage power to a power level that low voltage LEDs can use, much like a low voltage transformer converts line voltage power (120VAC) to low voltage (12VDC) so that it can be used with 12V lamps.

**LED Light Fixture**
The term LED Light Fixture used herein refers to the lighting luminaire that is typically made up of a housing that contains the LED Driver, one or more LED Boards, and associated wiring interconnects.

**LED Dimmable Driver**
An LED Driver that provides the correct power to the LED Board so that it can function and also allows the lumen output to be dimmed to create mood, ambience and to save energy.

**Light Emitting Diode (LED)**
A low voltage semiconductor device that emits light when electrical current is passed through it.

**Pop On**
When a light source requires a higher voltage to begin operating than it does at the dimmers lowest setting. The light fixture behaves well as you lower the brightness, but “pops on” as you raise the brightness from full off.

**Pulse Width Modulation (PWM)**
A method most LED Drivers use to regulate the amount of power to the LED. PWM turns LEDs on and off at high frequency, reducing the total ON time to achieve a desired dimming level without visible flicker. PWM signals are sent from the LED Driver to the LED Board.

**Reverse Phase Dimmers**
Also known as “Trailing-Edge” were designed to work with most electronic (ELV) and 3-wire CFL loads.

**Trailing-Edge Dimmer**
A type of dimmer that was designed for use with most electronic low voltage (ELV) and 3-wire CFL transformers/ballasts.

**Standard Phase Dimmers**
Also known as “Leading-Edge” were designed for use with Incandescent and MLV lighting loads.
NOMENCLATURE CLARIFICATIONS REGARDING LED DIMMING

Much of the confusion surrounding LED dimming is regarding the nomenclature involved and the “point of reference” within the dimming system chain where the dimming mechanism is defined. Please refer to Figure 1.0 on page 11 for a simplified diagram showing the components involved when dimming an LED lighting fixture. As shown in the Figure, the primary components are the dimmer (which might be a wall box style dimmer or a dimming module within a panel-based dimming system), the LED Driver, and the LED Board. Physical wiring connections are made between the dimmer and the driver and between the driver and the LED Board.

For the purpose of this discussion, we will refer to the point where the dimmer connects to the driver as the “Primary Side” or “input” of the driver. The point at which the driver connects to the LED Board will be referred to as the “Secondary Side” of the driver or the driver “output.” Technically speaking, the mechanism of dimming occurs at the dimmer to fixture interface (primary side of the driver) and at the Driver to LED Board interface (secondary side of the driver). The primary side of the driver is the point at which a dimming control device is connected (e.g., wall box dimmer, dimming system module, etc.). This dimming control device is the primary topic of this document. The primary side connection involves the line voltage AC power connection. The secondary side of the driver provides the DC dimming connection to the actual LED Board. This interface is internal to the light fixture and is typically specified and designed by the lighting fixture manufacturer. Detailed discussion of the interface between the driver and the LED Board is beyond the scope of this document and will only be summarized herein.

As shown in Figure 1.0, there are different types of nomenclature used depending upon whether one is discussing the input to the driver or the output of the driver. Often times, people will refer to an LED light fixture (consisting of a driver and an LED Board) as being PWM dimming or requiring constant current or constant voltage. This is misleading because these terms refer to the dimming mechanisms occurring between the driver and the LED Board, NOT at the input to the fixture (e.g., the input to the driver).

When designing and specifying lighting fixtures and the controls (e.g., dimming control equipment) that are compatible with each fixture type it is critical that the “dimmer to fixture interface” be defined and specified correctly. To accomplish this, the dimming control device must be compatible with the dimming technology associated with the input (or primary side) of the LED Driver.

The primary purpose of this document is to clarify the difference between the dimming technologies used on the primary and secondary side of LED Drivers and to clearly define the dimming technologies/nomenclature used to describe the control devices used to connect to the input (primary side) of LED Drivers (e.g., the input to the light fixture). A discussion of dimming technologies used between the LED Driver and LED Board (e.g., PWM, Constant Voltage, and Constant Current) is beyond the scope of this document.

The following pages describe the technologies used for dimming control of LED Drivers. These technologies are also used for dimming of conventional lighting loads including: incandescent, fluorescent, magnetic low voltage, and electronic low voltage. The five dimming control technologies described are:

- 2-Wire Forward Phase
- 2-Wire Reverse Phase
- 3-Wire (Lutron)
- 4-Wire (0–10V)
- Digital Signal Dimming Interfaces

Refer to Table 1.0 on pages 9 and 10 for a summary of each control technology listed above. This table defines the key characteristics of each type of dimming. The following descriptions provide further explanations and typical wiring diagrams for each type of interface.
2-WIRE FORWARD PHASE DIMMING

History
2-Wire Forward Phase Dimmers were originally designed for use with Incandescent (120V) lighting fixtures that use A19 lamps and PAR type lamps. They have evolved for use with other types of lighting loads including magnetic low voltage (MLV) and some types of LED Drivers. They are the least expensive and most widely installed dimmers in the marketplace. They are also known as Leading Edge Dimmers or Triac Dimmers. These dimmers use a silicon device, usually an SCR or a Triac, to turn the AC waveform on part way through its cycle. By varying the point at which the waveform turns on, we can alter the amount of power delivered to the lamp.

Synonymous Terms

Benefits
• Incandescent compatible LED Drivers/lamps work with most 2-wire forward phase dimmers making them perfect for many retrofit applications.
• Some LED Drivers are specially designed to eliminate the problems associated with using 2-wire forward phase dimmers with LED fixtures including flicker, ghosting, pop on, drop out, etc.
• 2-wire forward phase dimmers are the least expensive and have the most installations in the marketplace. In many cases, these dimmers are less expensive than electronic low voltage dimmers or 0–10V dimmers.
• Generally provide smooth dimming down to 10% depending upon the dimmer’s limitations.

Limitations
• 2-wire forward phase dimmers should not be used with ELV drivers because doing so could cause any of the following malfunctions: dimmer buzz, lamp flicker, interaction between circuits or radio frequency interference (RFI).

Customer Concerns
• At times, noticeable noise in a forward phase dimming system can be observed as the filaments of the lamps are being dimmed. When the power is turned on to the lamp part way through the waveform cycle, the filament expands very rapidly, and then as the voltage ramps back down again the filament cools. This rapid cycle of expansion and contraction leads to “Lamp Sing” (an audible hum that can be objectionable).

2-Wire Forward Phase Dimmer Wiring Diagram

![2-Wire Forward Phase Dimmer Wiring Diagram](image)
2-WIRE REVERSE PHASE DIMMING

History
2-Wire Reverse Phase Dimmers were originally designed to control Electronic Low Voltage (ELV) Transformers used in low voltage (12V) MR16 type fixtures. 2-wire reverse phase dimmers and ELV transformers are more expensive but offer quieter operation, better control and tend to last longer than many 2-wire forward phase incandescent style dimmers.

Synonymous Terms
Electronic Low Voltage, ELV, Trailing Edge and Reverse Phase

Benefits
- ELV dimming drivers are generally widely tested and approved by dimmer manufacturers for LED loads.
- Generally, 2-wire reverse phase dimmers work better on LED Drivers than most 2-wire forward phase dimmers. This is due to the fact that most LED Drivers use Electronic Low Voltage (ELV) Transformers. These transformers are generally capacitive type loads which work much better when controlled by Reverse Phase dimmers.
- Allows smooth dimming down to 5% depending upon the dimmer’s limitations.

Limitations
- 2-wire reverse phase dimmers can be more expensive than forward phase incandescent or magnetic low voltage style dimmers.
- Smaller install base could mean replacing incompatible dimmers on retrofit projects.
- 2-wire reverse phase drivers should not be used with forward phase dimmers because doing so could cause any of the following malfunctions: dimmer buzz, lamp flicker, interaction between circuits or radio frequency interference (RFI).
- 2-wire reverse phase dimmers require a neutral wire. This can result in having to pull additional wire on remodel projects.

Customer Concerns
- Some architectural loads (e.g., linear fluorescent) perform better when dimmed with ELV dimmers. However, it is very important to refer to the luminaire manufacturer’s datasheet to verify compatibility of forward or reverse phase dimming.

2-Wire Reverse Phase Dimmer Wiring Diagram
3-WIRE (LUTRON) DIMMING

History
Lutron originally developed its Hi-Lume 1% Dimming ballast for use with fluorescent and compact fluorescent dimmer controls. It is a 3-wire system that has a separate line voltage wire that carries the phase control dimming signal separate from the power wires. Hi-Lume 3-wire drivers/ballasts dim down to 1% of initial lumens, are more precise and more immune to electrical noise.

Synonymous Terms
Hi-Lume, 3-wire

Benefits
• Allows smooth, continuous dimming down to 1% of initial lumens depending on dimming control limitations.
• Lutron’s Hi-Lume LED Driver is compatible with more Lutron dimmers than any other brand and also compatible with their EcoSystem control system.
• Backed by Lutron’s 5-year Limited Warranty.

Limitations
• Compatible Lutron wall dimmers can be more expensive than electronic low voltage, incandescent or magnetic low voltage style dimmers.
• All Lutron Hi-Lume drivers and compatible dimmers are 3-wire, requiring a dimmed hot and a switched hot. This necessitates pulling an additional wire and, depending on the dimming control equipment used, may require additional dimming hardware and resulting in potentially significant cost increase for the dimming system/equipment.

3-Wire Dimmer (Lutron) Wiring Diagram
4-WIRE (0–10V) DIMMING

History
4-Wire (0–10V) Dimmers have been used in commercial applications for fluorescent lighting and occupancy and daylight sensor systems for years and are now becoming popular with LED products. One reason this standard is widely established is that it is defined in the IEC standard number 60929 Annex E, making it acceptable to most engineers. However, many manufacturers of dimming equipment and 0–10V ballasts/drivers do not always adhere to the standard resulting in unexpected incompatibilities between dimming control equipment and fixtures that employ 0–10V ballasts/drivers.

Synonymous Terms
0–10V, Fluorescent Dimming, 4-wire dimming, low voltage dimming

Benefits
• Use existing 0–10V systems in retrofit applications.
• Large 0–10V install base in commercial applications due to IEC standards.
• Allows smooth dimming down to 5% depending upon the dimmer’s limitations.
• Compatible with many daylight harvesting controls, occupancy sensors, and building automation.

Limitations
• Some manufacturers do not follow the IES standard. This leads to LED Drivers and lamps that claim 0–10V compatibility but drop out or pop on, or dim backwards with the lowest output at the top and the highest output at the bottom. Also a function of correct pairing of LED Driver and LED load.
• The control signal is a small analog voltage and long wire runs can cause a signal level drop that can produce different light levels from different drivers on the same control circuit.

0–10V Dimmer Wiring Diagram

Digital Signal Dimming Interfaces

History
Digital Interfaces have evolved from a variety of specialized applications throughout the history of lighting control systems. One of the most common digital lighting interfaces is DMX. This standard was established as a result of the more sophisticated needs of theatrical lighting. DALI (Digital Addressable Lighting Interface) is an International Standard (IEC 62386) for the control of electronic ballasts, transformers, LED’s, emergency lights and exit signs. This standard was created to allow the design of lighting systems with individually addressable fixtures among other applications.

These digital lighting interface standards are highly specialized requiring specific control equipment and luminaires that employ unique communication protocols. A full description of these interfaces are beyond the scope of this document.
### Table 1.0
**Dimming Control Interfaces**

<table>
<thead>
<tr>
<th>Load Type Designation</th>
<th>Description</th>
<th>Lamp/Ballast/Driver Examples</th>
<th>Other Terms Used To Describe</th>
<th>Benefits</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The dimmer connects to the fixture using 2 wires (a Hot and a Neutral). The dimmer controls the amount of voltage delivered to the fixture by turning off part of the leading edge of the sine wave for a preset amount of time resulting in reduced lamp output.</td>
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<td>2-Wire (RP)</td>
<td>2-Wire Reverse Phase</td>
<td>Electronic Low Voltage, Various LED Drivers</td>
<td>Trailing Edge Dimming, Reverse Phase</td>
<td>Provides flicker-free dimming of ELV Transformers and many LED Drivers.</td>
<td>The actual dimming mechanism and heat dissipation occurs at the dimmer. Typically best method for LED dimming.</td>
</tr>
<tr>
<td></td>
<td>The dimmer connects to the fixture using 2 wires (a Hot and a Neutral). The dimmer controls the amount of voltage delivered to the fixture by turning off part of the trailing edge of the sine wave for a preset amount of time resulting in reduced lamp output.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3-Wire</td>
<td>3-Wire (Lutron)</td>
<td>Lutron Hi-Lume, Lutron Hi-Lume 3D, Lutron EcoSystem, Lutron A-Series LED Driver</td>
<td>Lutron 3-Wire</td>
<td>Provides very precise dimming level control (down to 1%).</td>
<td>The actual dimming mechanism and heat dissipation occurs at the ballast/driver.</td>
</tr>
<tr>
<td></td>
<td>The dimmer connects to the fixture using 3 wires (a “switched hot,” a “dimmed hot,” and a neutral). The switched hot is turned on or off to power up the fixture (this line voltage connection is what is used to provide all of the power to the fixture). The dimmed hot connection uses either Forward Phase or Reverse Phase dimming as described above to control the dimming of the ballast/driver. The vast majority of all 3-wire ballasts are from Lutron and the dimmed hot requires a Reverse Phase dimming signal.</td>
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<tr>
<td>4-Wire (0–10V)</td>
<td>The dimmer connects to the fixture using 4 wires (a Line Voltage Hot and Neutral and a low voltage pair of wires for a 0–10V analog dimming control signal). The line voltage connection provides power to the fixture and is used to turn the fixture on and off. The low voltage pair of wires are used to control the dimming of the fixture using a DC signal that varies between 0 and 10V.</td>
<td>Advance Mark 7</td>
<td>0–10V</td>
<td>Low Voltage Dimming Current Sinking</td>
<td>Compatible with many different devices including photocells and many different dimming modules.</td>
</tr>
<tr>
<td>Digital Signal Dimming Interface</td>
<td>Digital Signal Dimming Interface (Various)</td>
<td>Various</td>
<td>Various</td>
<td>Various</td>
<td>These specialized interfaces are beyond the scope of this document.</td>
</tr>
<tr>
<td>Non-Dim</td>
<td>Non Dimming or “Switched”</td>
<td>Various</td>
<td>Switched</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
When designing dimming equipment to control fixtures, the primary concern is the electrical interface between the dimming equipment and the driver within the fixture…not the interface between the driver and the LED Board. The terminology used above to describe driver to LED interface types should not be used when defining the type of dimming needed for an LED fixture.