DIMMING 101
The unofficial guide for the technically challenged.

Dimming Technologies for Solid State Lighting.

A straightforward look at the technology that confuses us all.
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 Digitally Addressable 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 is how the driver dims the LEDs on a fixture, and occurs based on the dimming input (discussed in this article) to the driver. This term is NOT applicable when discussing the type of dimming control required by an LED fixture. 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
Drop out occurs when the lights are being dimmed down and the light cuts before the bottom of the dimming range provided by the dimmer. In other words, the lights will turn off before the dimmer slider reaches the bottom.

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 or reverse phase dimmer.

MLV Type Dimmer
A Magnetic Low Voltage Dimmer used with magnetic low voltage drivers. These are generally the same as a leading-edge or forward phase 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 and/or electronic in-rush current 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 the lowest dimmed level.

**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” dimmers, these are designed to work with most electronic (ELV) and 3-wire CFL or LED loads.

**Trailing-Edge Dimmers**
A type of dimmer that is designed for use with most electronic low voltage (ELV) and 3-wire CFL and LED loads.

**Standard Phase Dimmers**
Also known as “Leading-Edge” dimmers, these are 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 or others), 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 controls (e.g., dimming control equipment) that are compatible, 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 clearly define the dimming technologies/nomenclature used to describe the dimming type on the primary side of the driver. Understanding of these dimming types and proper coordination between fixtures and controls is essential for a successful lighting installation. 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)
- Digitally Addressable 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 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 low levels, depending on the dimming range of the driver.

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 dimming compatibility.

2-Wire Reverse Phase Dimmer Wiring Diagram

![Wiring Diagram](image-url)
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 are more immune to electrical noise.

Synonymous Terms
Hi-Lume, 3-wire

Benefits
- Allows smooth, continuous dimming down to low light levels based on the performance of the driver.
- Tested compatibility between Lutron dimmers and drivers.

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 manufactures 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
- 0-10V dimming is reliable due to the dimming occurring in the driver, and not due to power cuts in the line voltage to the fixture.
- Large 0–10V install base in commercial applications due to IEC standards.
- Allows smooth dimming down to low light levels, depending on the performance of the driver.
- Control devices are often less expensive and can control larger loads due to not having to dissipate the heat associated with the line voltage dimming.

Limitations
- 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.
- Low voltage conductors are required in addition to the line voltage wiring. The added conductors will increase installation cost.

0–10V Dimmer Wiring Diagram

DIGITALLY ADDRESSABLE 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 Types

<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>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 when using only line voltage wiring.</td>
</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>High level of compatibility between Lutron dimmers and drivers.</td>
<td>The actual dimming mechanism and heat dissipation occurs at the ballast/driver.</td>
</tr>
</tbody>
</table>

- **Description**: 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.

- **Examples**: Incandescent, Magnetic Low Voltage, Lutron Tu-Wire, Advance Mark 10, Lutron A-Series LED Driver

- **Other Terms**: Leading-Edge Dimming, Phase Cut Dimming, Forward Phase, Triac Dimming

- **Benefits**: Common 2-Wire Line Voltage interface/wiring.

- **Notes**: Most common type of dimming. The actual dimming mechanism and heat dissipation occurs at the dimmer.
<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>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 Various LED Drivers</td>
<td>0–10V Low Voltage Dimming Current Sinking</td>
<td>Compatible with many different devices, including photocells, and many different dimming modules. The most reliable and widely accepted form of dimming for electronic loads.</td>
<td>The actual dimming mechanism and heat dissipation occurs at the ballast/driver. The low voltage wires are polarity sensitive. Defined by IEC standard 60929.</td>
</tr>
<tr>
<td>Digitally Addressable 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 Non-Dim On/Off</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Dimming technologies today can be confusing, and incompatibilities between dimmers and drivers can be very problematic for installations of new fixtures and controls. Researching the control type required by the fixture, and providing compatible controls, is essential for successful projects. Two-wire dimming can be challenging, as it is not always clear if triac or ELV dimmers will be most compatible with the fixture. Additionally, having the dimming occur in the dimmer for two-wire systems causes heat, and reduces the wattage that the dimmer can control. To overcome these issues and ensure reliability, 0–10V dimming is quickly emerging as the standard and most reliable way to dim electronic loads. Most LED fixtures on the market today are available with 0–10V dimming.