Application Note #587
Revision J
February 2024

0-10 V Control Topology

Introduction

0-10 V topology is a common control topology that can be found all across the lighting industry. It was originally developed for control of fluorescent ballasts, but with the growth of LEDs, it has become one of the most common control topologies. While there are some standard details to how 0-10 V works as a topology, there are many details that can affect the quality of the end solution.

0-10 V topology is often looked at as an open standards-based topology. However, there are a number of details not covered by standards that can determine how a 0-10 V solution should be designed and how well a solution will work. This document will provide a summary of these details for Lutron 0-10 V products, as well as provide background and explanation of different 0-10 V topics.

It is important to note that even after all of these details have been collected and examined to determine the compatibility between a 0-10 V driver and a control, there is no guarantee that the dimming performance will meet the expectations of the customer. Dimming performance is directly tied to the driver's capabilities - dimming range, smooth and continuous dimming, and compatibility with the control system.

Finally, it is important to understand that analog 0-10 V dimming usually requires more control circuits than its digital counterparts, such as DALI®, Lutron EcoSystem, and Lutron wireless in-fixture solutions such as the Athena wireless node and Vive in-fixture controller. These digital solutions also provide more flexibility to re-zone spaces that a wired analog 0-10 V solution cannot, as well as helping alleviate many of the performance and compatibility issues discussed in this document.

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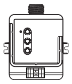
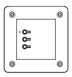
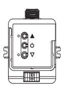
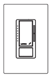
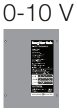
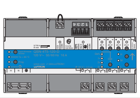
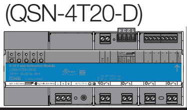
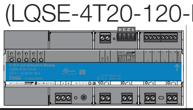
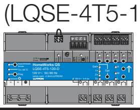
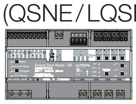
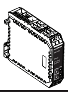
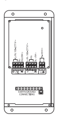
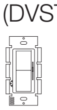
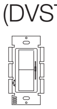
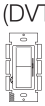
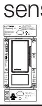
Product Specifications

	Input Signal	Operating Voltage (V∼)	Control Capability	Relay Rating (A)	0-10 V Line Rating (mA)	Sink/ Source	Linear vs Logarithmic	NEMA® 410-2015 Compliant
Vive PowPak dimming module with 0-10 V control (RMJS-8T-DV-B, -8TN-DV-B, and -8T-DV-B-EM) 	Clear Connect Type A[1]	120/277	0-10 V	8	60	Auto sink/ source	Linear	Yes
Vive PowPak dimming module with 0-10 V control (RMJS-5T-347) 	Clear Connect Type A[1]	347	0-10 V	5	60	Sink	Linear	Yes
PowPak wireless fixture controller (FCJS-010) 	Clear Connect Type A[1]	120-277	0-10 V	1	6	Auto sink/ source	Linear	Yes
Vive Maestro RF 0-10 V sensor dimmer (MRF2S-8SD010) 	Clear Connect Type A[1]	120/277	0-10 V	8	50	Sink	Linear	Yes
Energi Savr Node for 0-10 V (QSN-4T16-S) 	QS link[2]	120-277 347	0-10 V	16	50	Sink	Linear	Yes
0-10 V DIN Power Module (QSN-4T5-120-D) 	QS link[2]	120	0-10 V	5 each zone, 16 total module	50 each zone	Auto sink/ source	Linear	Yes
0-10 V DIN Power Module (QSN-4T20-D) 	QS link[2]	100/120/ 277	0-10 V	20[4]	50 each zone	Auto sink/ source	Linear	Yes
0-10 V DIN Power Module (LQSE-4T20-120-D) 	QS link[2]	120	0-10 V	20[4]	50 each zone	Auto sink/ source	Linear	Yes
0-10 V DIN Power Module (LQSE-4T5-120-D) 	QS link[2]	120	0-10 V	5 each zone 16 total module	50 each zone	Auto sink/ source	Linear	Yes
Athena Wireless Node (A-WN-D01) 	Clear Connect Type X[3]	9.5-28.8	0-10 V	N/A[5]	10	Sink	Linear	N/A[5]

See page 4 for footnotes.

Product Specifications *(Continued)*

	Input Signal	Operating Voltage (V~)	Control Capability	Relay Rating (A)	0-10V Line Rating (mA)	Sink/ Source	Linear vs Logarithmic	NEMA® 410-2015 Compliant
International Energi Savr Node for 0-10 V (QSNE/LQSE) 	QS link[2]	220-240	0-10 V, 10-0 V	5 each zone 10 total module	50 each zone	Auto sink/ source	Linear	No[6]
TVM module (GRX-TVM) 	Panel link	24	0-10 V, 10-0 V	16[7]	50/output; maximum 750/24 outputs	Auto sink/ source	Linear	Yes[8]
EcoSystem to 0-10 V interface (TVI-LMF-2A) 	EcoSystem	120, 220/240, 277	0-10 V	2	25	Sink	Linear	Yes
0-10V control interface (GRX-TVI) 	Forward, Reverse, Center, Phase Control[9]	100-277	0-10 V	16	300	Sink	Linear	Yes
Nova T☆ controls (NTSTV) 	—	120-277	0-10 V	8	30	Sink	Logarithmic	Yes
Diva 0-10V controls (DVSTV) 	—	120-277	0-10 V	8	50	Sink	Linear	Yes
Diva 0-10V controls (DVSTV-453) 	—	120-277	0-10 V	450 W 3.75 (120 V~) 1.62 (277 V~)	50	Sink	Linear	Yes
Diva 0-10V controls (DVTV) 	—	24 V⎓[10]	0-10 V	16 (with PP-DV)	30	Sink	Logarithmic	Yes[10]
Maestro 0-10V dimmer sensor (MS-Z101) 	—	120-277	0-10 V	8	50	Sink	Selectable	Yes

1 Clear Connect Type A (CCA) - a wireless low frequency communication protocol used for applications such as Pico and sensor controls.
2 QS Link - the wired control network capable of communication between QS devices.
3 Clear Connect Type X (CCX) - a wireless 2.4 GHz communication protocol used for Athena and Ketra system controls. See Lutron Clear Connect RF Technology Whitepaper for more details.
4 Compatible with ANSI C137.1 fixtures (configurable via software).
5 The Athena wireless node does not contain a line-voltage relay; it requires an ANSI® C137.1-compliant driver that supports electronic off.
6 Rated for resistive, inductive, or capacitive loads as defined by IEC®/EN 60669-2-1.
7 Uses panel modules to switch line voltage. Depending on the panel type, 16 A is the maximum for a single circuit.
8 Both "X" modules and "U" modules are NEMA® 410-2015 rated and capable of controlling 120-277 and 347 V loads.
9 Need either high/low-end trim or 3-wire fluorescent signal.
10 PP-DV or PP-347H is NEMA® 410-2015 compliant and is assumed to be switching the load in this application.

Specification Descriptions

0-10 V vs. 10-0 V vs. 1-10 V

0-10 V is a topology defined by the International Electrotechnical Commission (IEC®) 60929 Annex E standard and uses a varying DC voltage between 1 and 10 V to determine the lighting level. The fixture outputs a minimum light level when the 0-10 V signal is 1 V or less. It is not defined whether this is off or low-end, which means you can get differing functionality depending on the manufacturer. Between 1 and 10 V, the signal corresponds to levels between the minimum and maximum output level. A signal above 10 V corresponds to the maximum light level. Sometimes it is referred to as 1-10 V, as that is the actual range in which the light levels will vary.

10-0 V is a topology that is not defined in the IEC® standard, but it also makes use of a varying DC voltage. The levels are inverse of a 0-10 V topology, with 10 V being low-end and 1 V being high-end. This topology was made popular in certain metal halide dimming systems, but has almost disappeared as a result of the decline of metal halide as a high output light source.

Wire Colors

Prior to 2021, the 0-10 V control wires were traditionally purple and gray. A change effective January 1, 2022 made to the 2020 edition of the NEC® prohibits field-connected control wires from being gray to avoid confusion with gray 277 V∼ neutral wires. To accommodate this change, 0-10 V signal wires use purple and pink insulation starting in 2021. Depending on the date of manufacture of the devices (control and/or driver), the 0-10 V wires may be purple/pink or purple / gray.

Sink vs. Source

The concept of sink vs. source in 0-10 V topology relates to the small amount of current being provided on the 0-10 V wires that is used to create the DC voltage difference. When looking at the control and the driver(s) being used in a particular application, one side will always be providing the current (source), and one will be dissipating it (sink).

In order for the control and the driver to be able to work together, you must have one device that can source and one that can sink, allowing for a complete circuit to exist between the devices. There are some devices that are capable of being sink or source (often by auto sink / source detection) which allow them to take either role. As a note, there can sometimes be issues if connecting two auto sink / source devices together. Depending on how the devices perform their auto-detect, they might continue to misread each other and create issues with interoperability.

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Specification Descriptions *(Continued)*

Sink vs. Source *(Continued)*

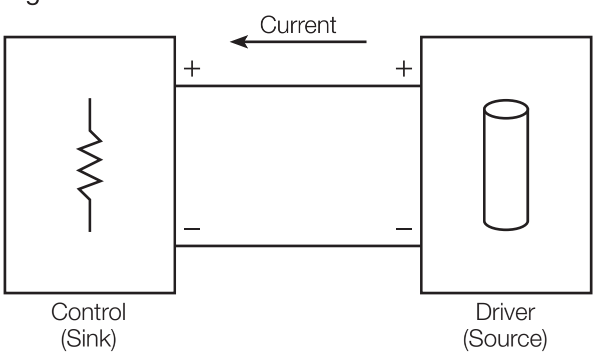
IEC® 60929 Control Standard

This standard dictates that the load (driver) shall be the source of the current and the control should sink that current. Not all drivers use this standard, so it is important to determine whether the driver is sink or source so that a matching control can be selected. The IEC® 60929 standard is the one most commonly applied in commercial and residential applications.

American National Standards Institute (ANSI®) C82.11 Driver Control Standard

This standard is very similar to the IEC® 60929 standard in that the driver is called out as the source and the control as the sink.

Figure 1: Driver as Source



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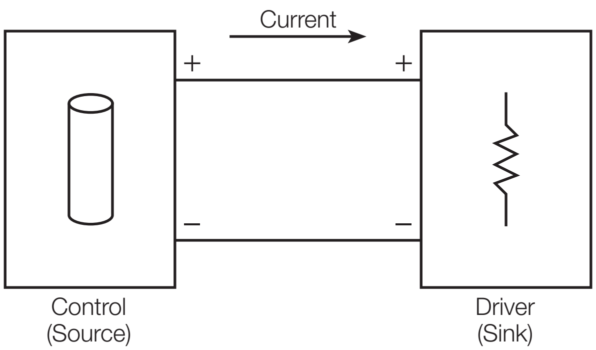
Specification Descriptions *(Continued)*

Sink vs. Source *(Continued)*

ANSI® E1.3 Entertainment Lighting Control Standard

Written by the Entertainment Services and Technology Association (ESTA), this standard was specifically designed around theatrical lighting control. In this standard, the control is the source and the driver is the sink. This standard is usually only used with legacy devices because the DMX standard has become the most commonly used control standard within the theatrical world.

Figure 2: Control as Source



ANSI® C137.1: 0-10 V Control with Electronic Off

ANSI® C137.1 is an optional standard that controls and drivers can follow which defines the interface and performance requirements for 0-10 V controls and drivers where output power is adjustable between minimum/off and maximum via a control input signal. Unlike previous standards, it also defines an optional 0-10 V voltage level which the control can go to in order to indicate to the driver that it should be in an "electronic off" state, meaning the lights are off even though constant-hot (unswitched) power is still applied to the driver. This is sometimes referred to as "dim to off" Both the control and the driver need to follow the standard for the system to support the electronic off functionality. Long wire runs may be a concern in these applications due to the potential for voltage drop along the 0-10 V wires; see the section on "How far can I run a low-voltage 0-10 V circuit" for details.

Refer to the control and driver product spec sheets to determine if they are ANSI® C137.1 compliant. Lutron controls that meet ANSI® C137.1 requirements will include this detail in their product spec sheets. Unless ANSI® 137.1 or "Electronic Off" compatibility is stated by both the control and driver being used, Lutron recommends using the control to switch off line voltage to the fixture to ensure they turn off.

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Specification Descriptions *(Continued)*

0-10 V mA Rating

Directly related to the previous notes on sink vs. source, every 0-10 V device has a rating for how much current (in mA) that it sources or sinks. In addition to stating that the load shall source the current, the IEC® 60929 standard dictates a minimum load source current of 10 µA and a maximum of 2 mA. Not all drivers follow the 2 mA maximum set by the standard, but it can be used as an approximation if no information can be determined about the driver being used.

Knowing the sinking / sourcing capabilities of the control and the driver are necessary to determine the maximum number of drivers that can be controlled by a single control circuit. The maximum number of drivers can be found by taking the sink capability of the control and dividing by the source current of each driver.

The 0-10 V mA rating and the relay rating are two of the limiting factors for how many drivers can be used with a control. With the low wattage of most LED loads, it is very common for the 0-10 V mA rating to be the limiting factor. Inrush current may also limit how many can be used with a control; see page 9 for more details.

Relay Rating

The rating of the relay is the traditional load current rating that is discussed with regards to switching controls (e.g., 16 A relay). It represents the total amount of current that can be run through the control to power the total load of the connected fixtures. It is very common to see a rating of 16 A because that is the maximum allowable current that a 20 A lighting circuit can have (the NEC® mandates derating the circuit to 80% for lighting circuits).

The 0-10 V mA rating and the relay rating are the two limiting factors for how many ballasts / drivers can used with a control. In contrast to LEDs with fluorescent loads, it ~~is~~ was very common for the relay rating to be the limiting factor.

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Specification Descriptions *(Continued)*

NEMA® (National Electrical Manufacturers Association) 410-2015 Rating and Inrush Current

When lighting loads are turned on, there is a momentary spike in the current running through the load that is much higher than the steady state current. For incandescent loads, that inrush current was fairly standard for various wattages and bulb sizes and is accounted for in controls based on the steady state power rating. This means that any control that is rated for 600 W of incandescent load is designed to handle the 10× inrush current that is known to come along with 600 W of the incandescent load.

Due to the capacitive nature of LED loads and drivers, the inrush current is not necessarily the same for each steady state power rating. The initial charging of the capacitors, which depends on the LED driver design, can require a huge amount of current, sometimes 100-300× the steady state current. This is drastically different than the inrush current of incandescent lamps which many of the controls may have been previously designed to handle. If this is not accounted for properly when adding loads to a circuit, the huge inrush current has the potential to cause damage to relays and cause them to fail quicker than their designated life-cycle. This issue can also cause nuisance tripping of circuit breakers.

NEMA® 410-2015 is a voluntary testing standard that defines a limit to inrush current, which is the spike of current that occurs when many types of electronic loads, including ballasts and drivers, turn on. It was developed soon after fluorescent dimming ballasts were introduced to the market. The lamp and dimmer manufacturers agreed to create the testing standard to quantify and properly account for inrush currents.

High inrush current is also a concern for LED lamps and can sometimes be the limiting factor over steady state current of how many LED lamps can be part of a control circuit. The NEMA® 410-2015 standard dictates a defined level of acceptable inrush current for different levels of steady state current. Therefore, when using NEMA® 410-2015 compliant loads and controls, only the steady-state current needs to be used to determine how much load can be put on a circuit. NEMA® 410-2015 specifically applies to loads that are switched on and off (as opposed to phase-control dimming or electronic off features) because it specifically examines peak inrush at turn on.

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Specification Descriptions *(Continued)*

NEMA® (National Electrical Manufacturers Association) 410-2015 Rating and Inrush Current *(Continued)*

Table 1 is an excerpt from the NEMA® 410-2015 standard which outlines the acceptable inrush current for different steady state currents at 120 V~ and 277 V~. Based on the steady state current of the load, you can look up the acceptable peak current, pulse width, and the I^2t value. A driver manufacturer would have to ensure that when the driver is set up under the prescribed test conditions it does not exceed the peak current and I^2t value for the steady state current. A control manufacturer would need to ensure that their controls rated for the given steady state current must be capable of reliably handling the peak current during repeated turn-on cycling.

Table 1: NEMA® 410-2015 Peak Current Specifications for 120 V~ and 277 V~

Steady State Current (A)	Peak Current (A) 120 V~	Pulse Width 120 V~ (ms)*	I^2t (A^2 sec) 120 V~**	Peak Current (A) 277 V~	Pulse Width 277 V~ (ms)*	I^2t (A^2 sec) 277 V~**
0.5	75	0.34	11	77	0.50	11
1	107	0.48	24	131	0.71	27
2	144	0.70	41	205	0.85	76
3	166	0.89	55	258	0.98	111
5	192	1.20	74	320	1.20	205
8	221	1.25	98	370	1.25	274
10	230	1.50	106	430	1.50	370
12	235	1.80	110	440	1.80	387
15	239	2.00	114	458	2.00	420
16	242	2.10	117	480	2.10	461

* Pulse widths shown in the table above are shown in Figures 3-14 of the NEMA® 410-2015 **Performance Testing for Lighting Controls and Switching Devices with Electronic Drivers and Discharge Ballasts** document and will provide adequate performance with electronic devices having pulse widths up to 2 ms, in accordance with ANSIR C82.11 or ANSIR C82.14 standards.

** The values used to calculate I^2t are the peak current shown in the table above and a pulse duration of 2 ms (t).

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Specification Descriptions *(Continued)*

NEMA® (National Electrical Manufacturers Association) 410-2015 Rating and Inrush Current *(Continued)*

Table 2 is an excerpt from the NEMA® 410-2015 standard which outlines the acceptable inrush current for different steady state currents at 347 V~. Based on the steady state current of the load, you can look up the acceptable peak current, pulse width, and the I^2t value. A driver manufacturer would have to ensure that when the driver is set up under the prescribed test conditions it does not exceed the peak current and I^2t value for the steady state current. A control manufacturer would need to ensure that their controls rated for the given steady state current must be capable of reliably handling the peak current during repeated turn-on cycling.

Table 2: NEMA® 410-2015 Peak Current Specifications for 347 V~

Steady State Current (A)	Peak Current (A) 347 V~	Pulse Width 347 V~ (ms)	I^2t (A^2 sec) 347 V~
0.5	198	0.34	92
1	270	0.47	173
2	354	0.70	294
3	396	0.86	369
5	450	1.15	476
8	492	1.50	569
10	508	1.67	606
12	529	1.86	658
15	550	2.05	711
16	552	2.10	716

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Specification Descriptions *(Continued)*

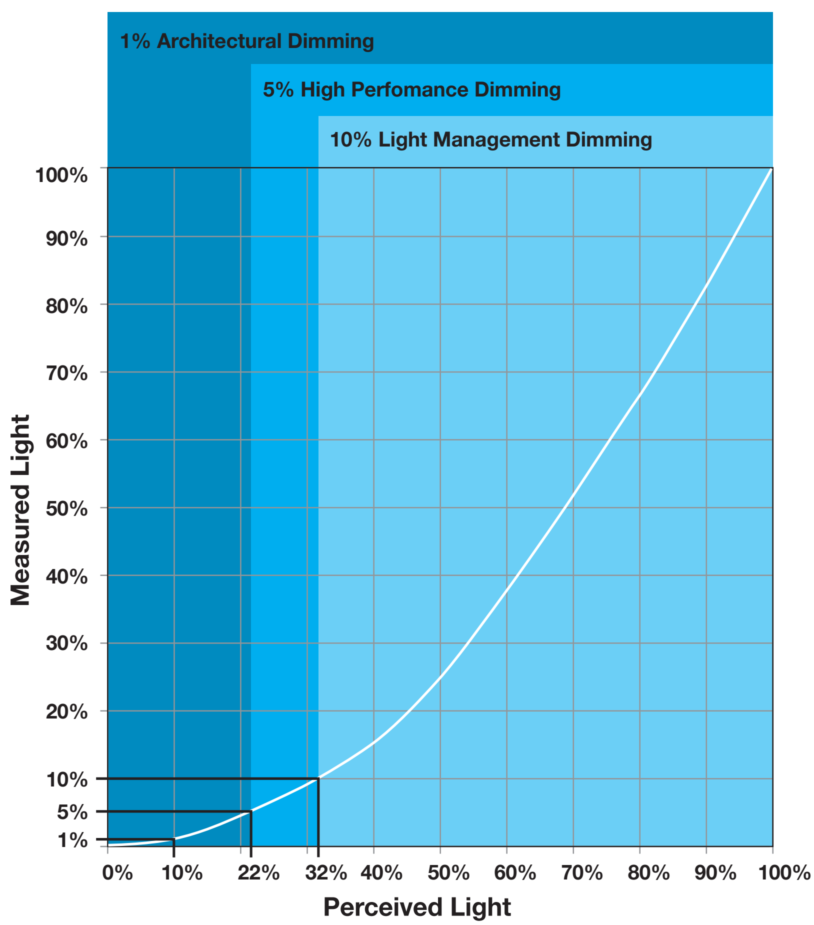
Linear vs. Logarithmic Dimming Curves

A "dimming curve" represents the relationship between the input and the output of the various devices in a lighting installation. This relationship determines how the light level changes based on changes to the input, such as a slider. There are two dimming curves that are present in any 0-10 V lighting installation:

1. For the control, it is the shape of the curve plotted using the commanded % of light from the system (for example, the dimmer's slider position) against the output voltage on the 0-10 V line.
2. For the driver, it is the shape of the curve plotted by 0-10 V input voltage vs. measured light output.

For each device, the dimming curve is likely to be linear or logarithmic (also often called "square law"). Linear curves mean there is a linearly-proportional relationship between the input and the output. For example, a linear control would put out approximately 5 V when the slider is at the 50% mark, and the driver would output approximately 50% measured light when it gets a 5 V signal. Logarithmic curves have a non-linear relationship between the input and output, which are used to allow for compensation between measured and perceived light (Figure 3). This relationship is due to the changes in the human eye as the light level decreases. The dilation of the pupil allows more light to enter the eye at low light levels, meaning lower light levels are not *perceived* to be as low as the *measurement* would indicate. For example, the measured light level could be 10%, but the light level perceived by the eye would be around 32%.

Figure 3: Measured vs. Perceived Light Levels



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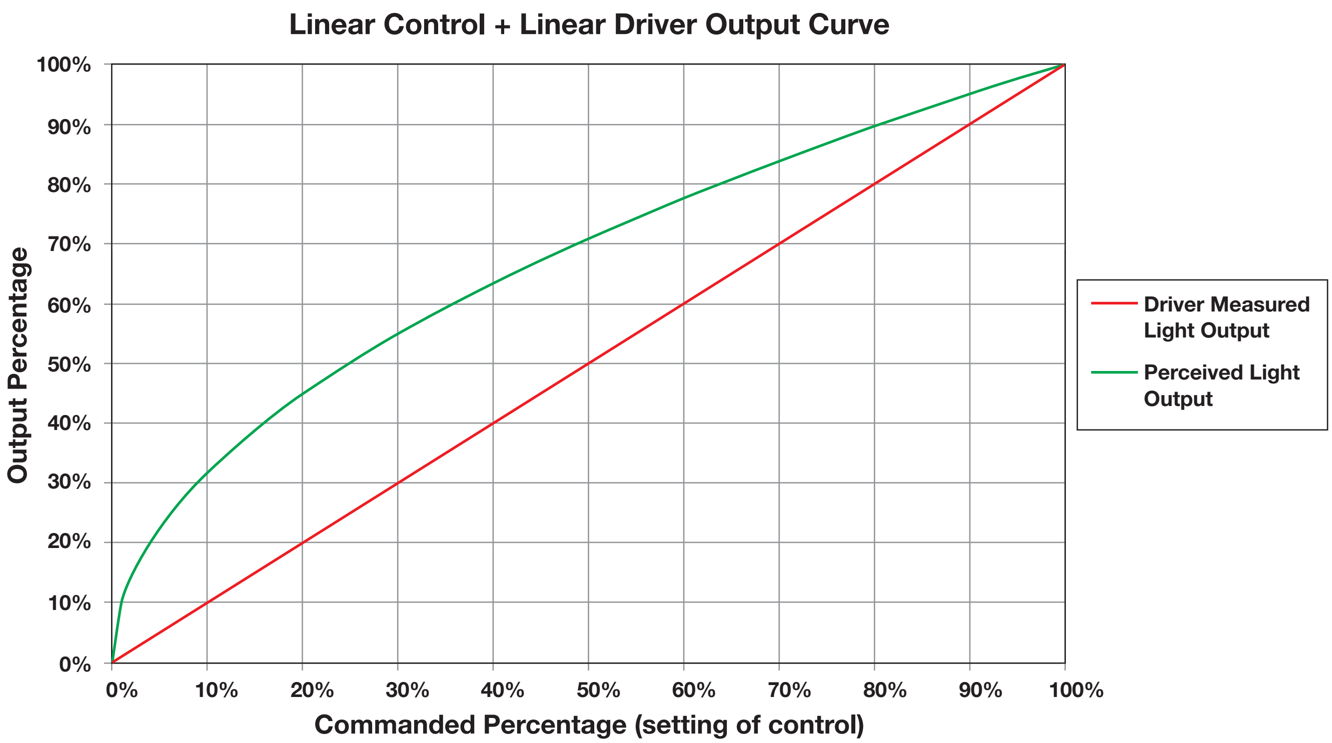
Specification Descriptions *(Continued)*

Linear vs. Logarithmic Dimming Curves *(Continued)*

When pairing two controls together, it is important to ensure that the right combination is selected. There are three different scenarios.

Scenario 1. **The control and the driver are both linear.** The result is that you get an overall linear dimming curve between the control system input (e.g., slider position) and the measured light output. Because the overall dimming curve is linear, the perceived dimming curve is non-linear, and is perceived to the human eye as more of an inverted logarithmic curve. This means that light level changes will be similar at high-end, and more rapid at low-end. Figure 4 shows the perceived light output and driver ~~power~~ measured light output based on commanded % when both the control and the driver are linear.

Figure 4: Linear Control + Linear Driver Output Curve



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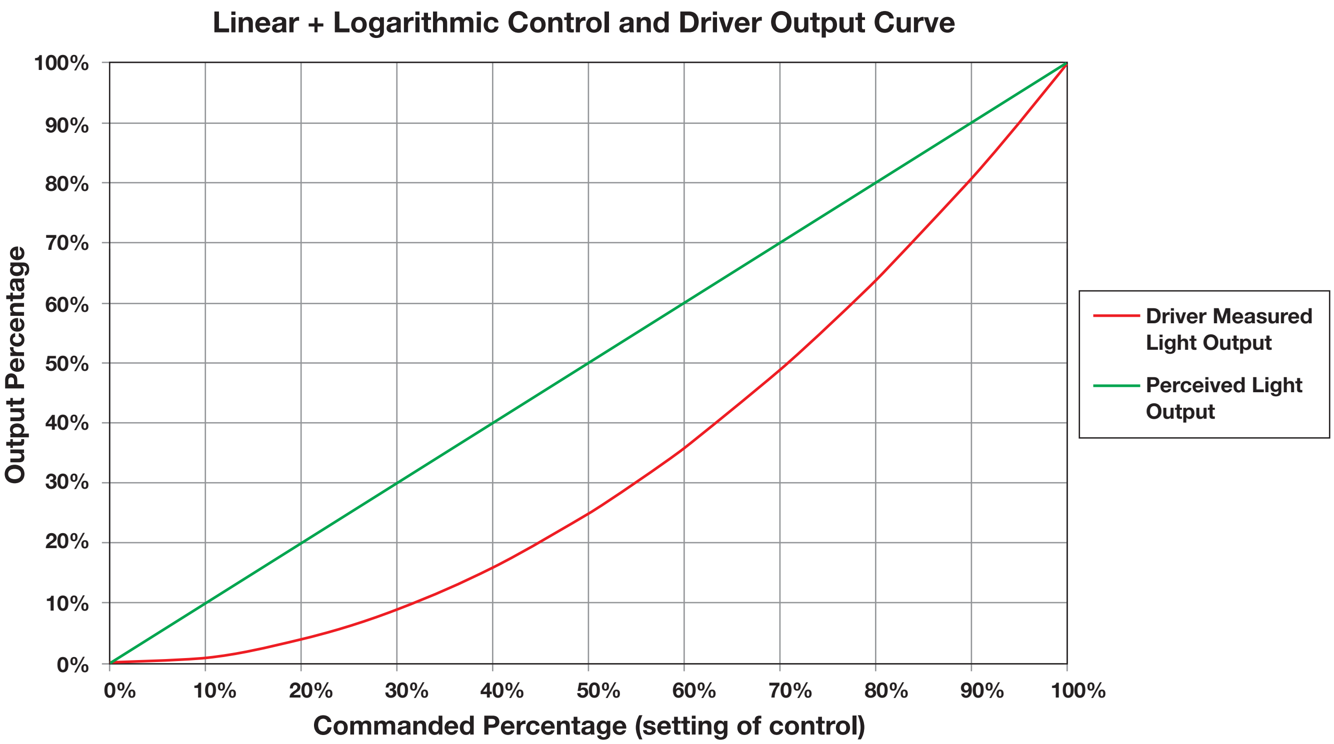
Specification Descriptions *(Continued)*

Linear vs. Logarithmic Dimming Curves *(Continued)*

Scenario 2. **Either the control or the driver is logarithmic (only one of them).** The resulting measured light curve becomes logarithmic, which leads to a linear perceived dimming curve to the human eye. Figure 5 shows what the perceived light output and measured light would be based on commanded % for cases in which either the control or the driver is logarithmic. This is the preferred case for most applications, since the user perception of the dimming performance is that the % of perceived light is a direct linear relationship with the % of the dimming level.

Figure 5: Linear + Logarithmic Control and Driver Output Curve



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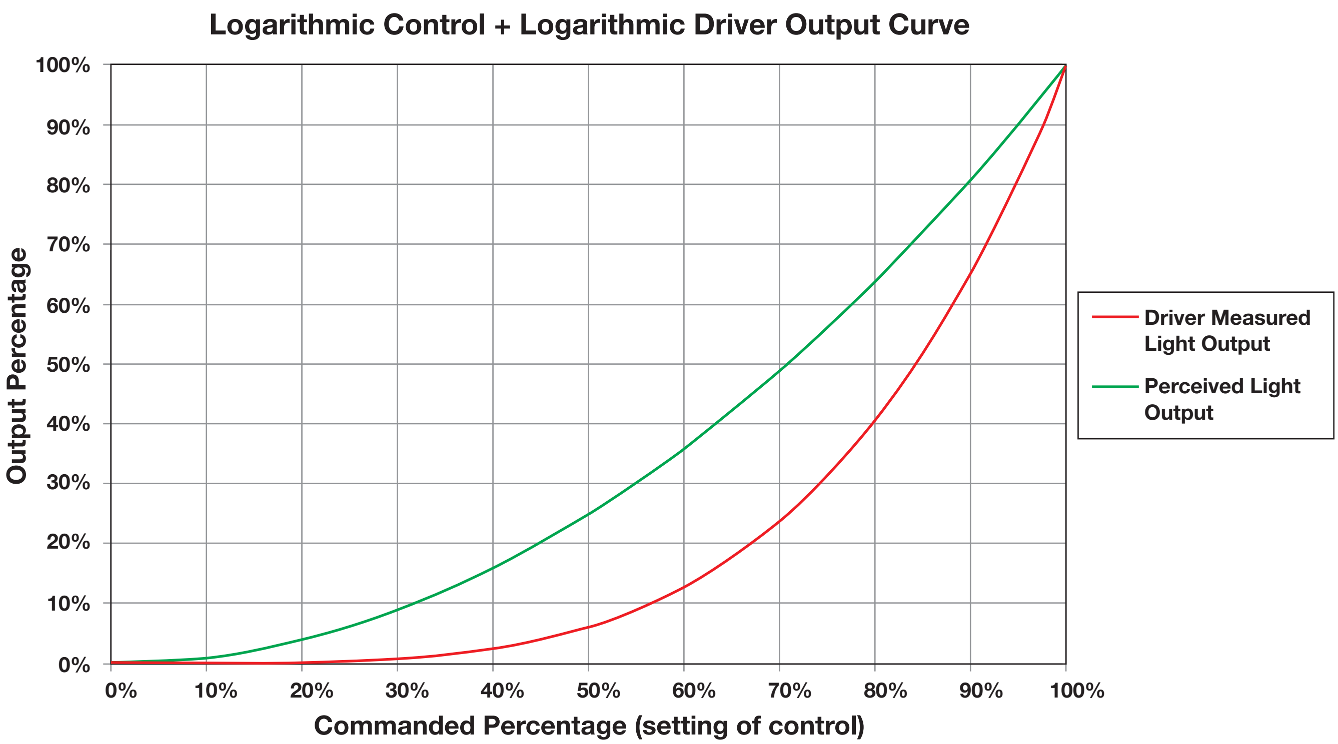
Specification Descriptions *(Continued)*

Linear vs. Logarithmic Dimming Curves *(Continued)*

Scenario 3. **Both the control and the driver are logarithmic.** The measured light and perceived light are both non-linear. This is undesirable because linear dimming would no longer be perceived in the space, ~~at~~ especially near low-end. Figure 6 shows the perceived light and measured light output based on commanded % for cases in which both the control and the driver are logarithmic. This is the least preferred case, as it causes high rates of change at high output levels, and unacceptably low rates of change at low light levels.

Figure 6: Logarithmic Control + Logarithmic Driver Output Curve

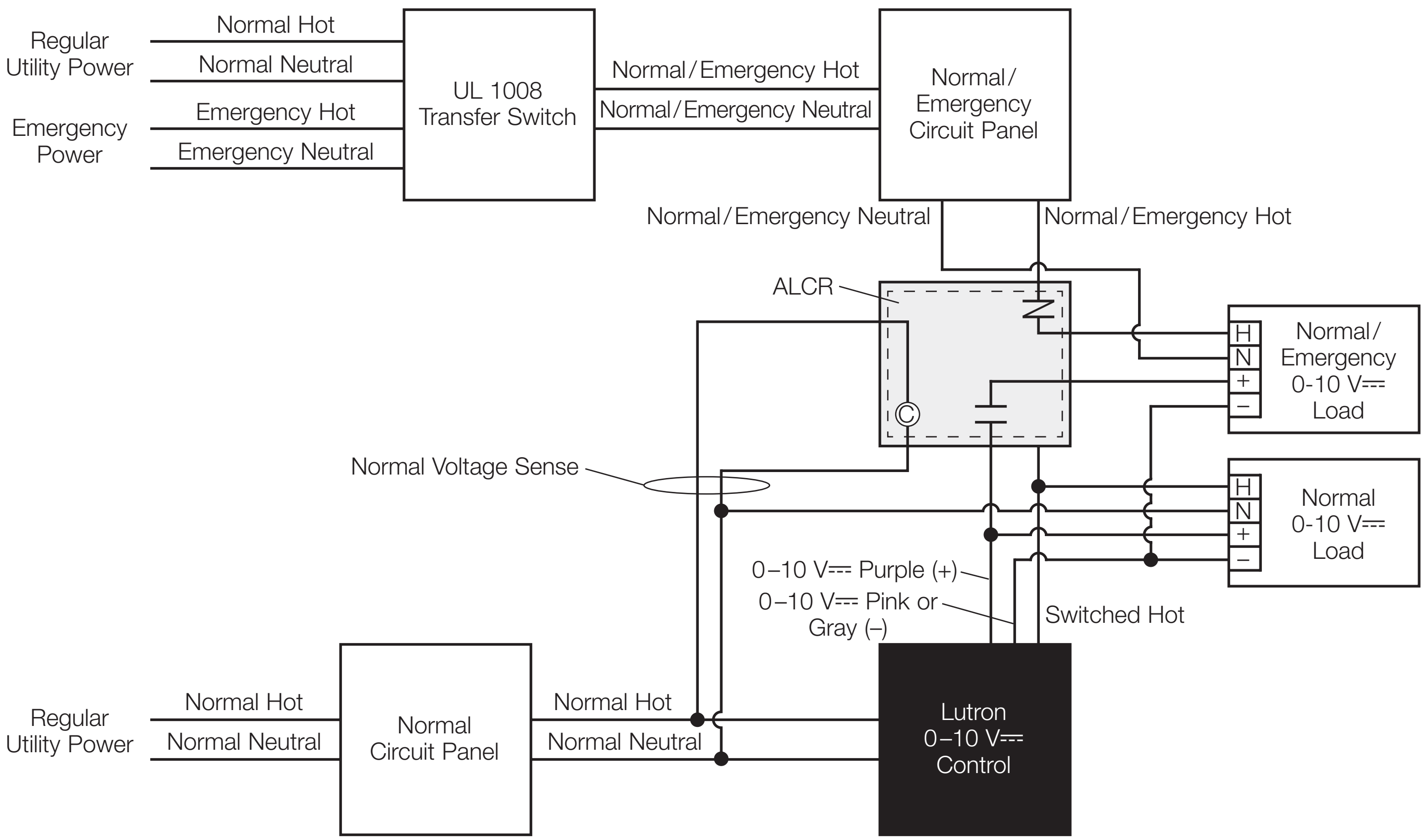


Other Technology Considerations

Emergency Lighting

Emergency lighting defines performance expectations of lights during a power outage and how those required performance expectations are achieved. 0-10 V loads provide an additional challenge over traditional emergency applications. In addition to ensuring that emergency power is supplied to the lights, the 0-10 V signal also needs to be overridden or bypassed. If power is lost to the 0-10 V controller and the 0-10 V signal is not overridden or bypassed, then the fixture may remain at the last dimmed level prior to the power loss. To address these requirements, an Automatic Load Control Relay (ALCR) may be used that is specifically designed for 0-10 V applications to handle emergency power and be able to bypass the 0-10 V signal. An example of this can be seen in Figure 7. For more details, see Lutron Emergency Lighting Application Note #106 (P/N 048106) at www.lutron.com

Figure 7: 0-10 V Emergency Wiring Example



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Other Technology Considerations *(Continued)*

Polarity of Low-Voltage Wiring

0-10 V topology is an analog technology based on referencing the voltage difference between the two wires. The result is that the low-voltage control wires are polarity sensitive, meaning if the wires are switched, the driver and the entire 0-10 V link will not function properly. For example, wire 1 (pink) must tie to connection 1 on every device and wire 2 (purple) must tie to connection 2 on every device.

UL®/NEC® Class 1 and Class 2 Wiring

The issue of UL®/NEC® Class 1 (line voltage) and UL®/NEC® Class 2 (low-voltage) wiring has to do with whether or not the low-voltage 0-10 V signal can be run in the same conduit as the line voltage wiring. This requires knowledge of local codes and the capabilities of the driver and control. Both the control and the driver should list whether their 0-10 V link is rated as Class 1 UL®/NEC® or Class 2. Local codes that allow UL®/NEC® Class 2 wiring to be run as Class 1 will call out requirements for re-classification. These requirements often include adding "Class 1" labels over the "Class 2" markings on devices, larger wire gauges, and different insulation requirements. Some jurisdictions do not allow for re-classification.

Issues may arise if the manufacturer-provided rating (Class 1 UL®/NEC® or Class 2) varies between the control and the fixture. For example, if the control's 0-10 V wires are rated "UL®/NEC® Class 1", and the fixture's 0-10 V wires are rated "Class 2", then it is unclear which wiring practice to follow. Before reclassifying any product, check with the manufacturer first. For example, it may not be possible to reclassify a fixture's 0-10 V wires from UL®/NEC® Class 2 to Class 1, as that may affect the classification of other aspects of the fixture that are electrically connected (for example, other control links or exposed electrical elements, such as the LED module).

Running the 0-10 V signal as Class 1 wiring does introduce some other concerns, including noise/interference caused by coupling between the line voltage and low-voltage wires. This noise/interference can cause a voltage fluctuation on the 0-10 V wires leading to flicker or other undesirable light level changes.

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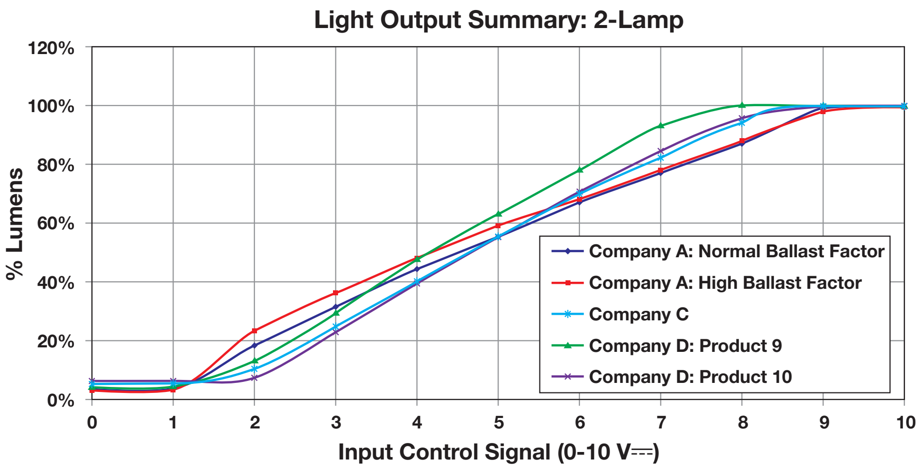
Other Technology Considerations *(Continued)*

Dimming Curves

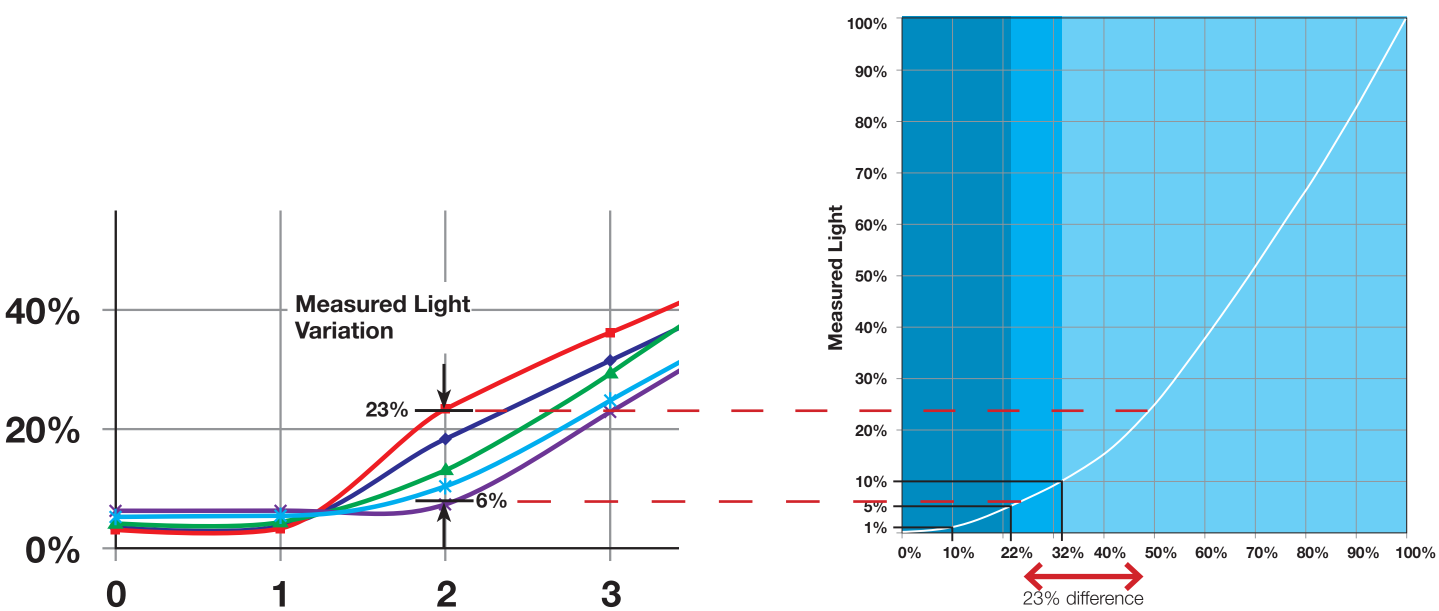
Of the few 0-10 V standards that exist, there is little detail describing the allowable dimming curves. Therefore, different 0-10 V drivers may have different dimming curves. This difference can even exist between drivers made by the same manufacturer. This can create issues when mixing different drivers in the same zone/area. Also, it can be troublesome when replacing a ballast or upgrading to a driver because the new one might have a different dimming curve than the original one. If an exact replacement of the original driver is unavailable, it is possible that all of the drivers in that zone or area may need to be replaced. As an example, Figure 8 shows a comparison between different manufacturers and ballasts. Figure 9 shows the difference in perceived light from the data in Figure 8. At 2 V in this example, there is 23% difference in perceived light between the different ballasts.

Figure 8: Dimming Curve Comparison



Note: The data in the graphs on this page are from the Fluorescent Dimming Ballast Study Report prepared by ADM Associates, Inc. and submitted to the Sacramento Municipal Utility District.

Figure 9: Impact of Variation Between Drivers on Perceived Light



FAQs

How can I guarantee compatibility between the 0-10 V control and load?

Compatibility between a 0-10 V control and load cannot be guaranteed. Using controls and drivers that follow the same standards (e.g., NEMA® 410-2015, IEC® 60929, ANSI® C137.1) can make it easier to ensure acceptable performance. Once all of the necessary specifications are understood and the control is chosen to match the driver, then there is a good chance that they will work together. Unfortunately, there is no way to guarantee the performance because the 0-10 V standard does not define performance. For performance-sensitive applications, it is recommended to do a live mock-up of the control and load to visually inspect the final performance, or to use an alternate control type that offers performance and capability guarantees.

How far can I run a low-voltage 0-10 V circuit?

There are a number of variables that affect how long a 0-10 V circuit can be run. Some of these variables include: the number of drivers, the source rating of each driver, the gauge of the wire, any noise that might be experienced by the wire run, and what voltage drop will allow the control to maintain a minimum light level. If the 0-10 V circuit is going to be run as UL®/NEC® Class 2 wiring (assuming no significant noise), a standard voltage drop equation can be calculated to find out the voltage drop for a given distance. Due to the number of variables that exist, Lutron cannot provide a number that can be used in all applications. The IEC® 60929 Annex E standard states that at 1 V, the driver should be at a minimum light level. Since the driver is the source, that means the voltage will drop along the wire and be lower at the control. For example, if the control is capable of pulling the voltage down to 0.7 V and the voltage drop along the wire is 0.3 V, the voltage at the driver will be 1 V. As a general rule, keeping the voltage drop to 0.3 V or lower is a good practice.

The total voltage drop for a wire run can be calculated using the following equation:

$$V_D = R \times 2 \times d \times n \times I$$

- "V_D" is the voltage drop in volts (V).
- "R" is the resistance of the wire per foot in ohms (Ω),
- "d" is the distance of the wire run in feet (ft), total wire length is the distance out and back, "2d".
- "n" is the number of drivers, and
- "I" is the 0-10 V current (A) sourced by each driver.

If the equation is re-arranged to solve for distance, it becomes:

$$d = \frac{V_D}{R \times 2 \times n \times I}$$

This equation provides the maximum distance based on known information. "V_D" is the maximum allowable voltage drop that will maintain the minimum (1 V) and maximum (10 V) light levels as defined in IEC® 60929 Annex E. Unfortunately, the maximum output voltage of the driver and the minimum voltage of the control are usually unknown. Therefore, minimizing the voltage drop as much as possible provides the best opportunity to achieve both the minimum and maximum light levels. Using 0.3 V for "V_D" is good practice in the absence of additional information. Taking into account the resistance of the wire, the total number of drivers, the current sourced by each driver, and the allowable voltage drop, the maximum distance run of a given circuit can be approximated.

Continued on next page...

FAQs *(Continued)*

How far can I run a low-voltage 0-10 V circuit? *(Continued)*

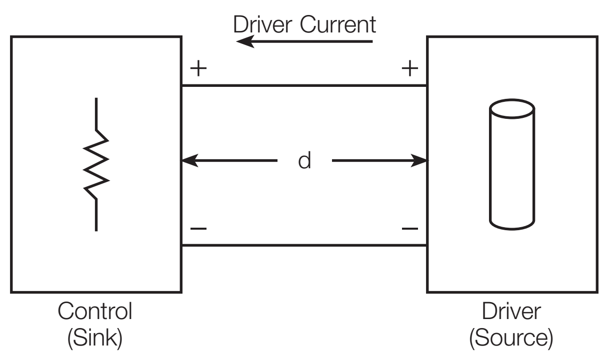
However, this equation only accounts for voltage drop due to the resistance of the wire. Other influences (e.g., noise, inductance, line voltage coupling) can cause additional voltage fluctuations that cannot be accounted for. Due to these other influences, this calculation should be used as a guide and a factor of safety should be included if site conditions are unknown.

Calculation Example:

The following is an example calculation for support of an ANSI C137.1 fixture using standby mode calculation:

- "V_D" is the voltage drop in volts (V): with a voltage at the DIN power module of 0.3 V and voltage at the LED driver for standby mode of 0.5 V, the maximum wire voltage drop to support ANSI C137.1 Standby mode is "V_D" = 0.2 V.
- "R" is the resistance of the wire per foot in ohms (Ω): 14 AWG wire is 0.00326 ohms per foot (from NEC 2014: Chapter 9 Table 8, confirm resistance with wire supplier)
- "d" is the length of the wire in feet (ft), total wire length is the distance out and back, "2d".
- "n" is the number of ballasts / drivers: 50 drivers
- "I" is the current (A) sourced by each ballast/driver: 0.001 A per driver (confirm current with the driver manufacturer's specification, ANSI C137.1 control current supplied by the driver is 0.002 A)

$$d = \frac{V_D}{R*2*n*I} = \frac{0.2\ V}{0.00326\,\frac{Ohms}{foot}*2*50*0.001\ A} = 613\ feet$$



How many fixtures can I put on a 0-10 V control circuit?

There are three limiting factors that come into play when determining how many ballasts/drivers you can have on a 0-10 V circuit.

1. Steady state load current
2. Inrush current
3. The mA sink/source on the 0-10 V circuit

The application needs to be within the wattage rating of the 0-10 V control, within the 0-10 V current sink/source capability, and the control must be able to handle the inrush of the loads to be connected. If the capabilities of the control (found in indivudial product specification sheets or the Lutron Product Specifications table on pages 3 and 4 of this document) and the specs of the driver are known, the maximum number of loads on a circuit can be determined.

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FAQs *(Continued)*

What do I do if the load is not specified as NEMA® 410-2015 compliant?

If a load is not specified as NEMA® 410-2015 compliant on the load specification sheet, that information should be requested from the load manufacturer. The NEMA® 410-2015 standard specifies peak current, pulse duration, and I^2t. Knowing the peak in-rush current of the driver is not enough to ensure NEMA® 410-2015 compliance.

Can I run 0-10 V wires with line voltage wires?

This question relates directly to the Class 1 UL®/NEC® vs. Class 2 wiring discussion that can be found in the **Class 1 vs. Class 2 Wiring** section. Whether or not Class 2 wiring can be re-classified as Class 1 wiring depends on the local codes and if the driver allows for re-classification.

Can I control a 0-10 V circuit without a relay?

The IEC® 60929 version of the 0-10 V standard specifies that when a low-end signal (between 0 V and 1 V) is present, the load will go to “minimum light output”. This is typically interpreted that the fixture will go to low end, and that a line voltage relay is required to switch off power to the fixture in order for it to turn off. Unless described otherwise in the driver’s spec sheet, this relay-based default behavior is the appropriate way to design a 0-10 V lighting system, and is the way most Lutron controls operate.

In contrast, the the ANSI® C137.1 standard introduced the concept of “electronic off”, allowing driver manufacturers a way to turn off by receiving a signal less than 1 V. This requires a control (and appropriate wiring) that can create a sufficiently low voltage at the driver to enable the electronic-off functionality. Controls and drivers that support the ANSI® C137.1 specifications for electronic off usually state that on their respective spec sheets. One example of a Lutron control that supports ANSI® C137.1 electronic off is the Athena wireless node.

What voltage do the 0-10 V controls sit at in the “off” position?

Lutron 0-10 V controls hold below 1 V when “off” (although the exact voltage varies based on product). Diva 0-10 V controls are an exception because the 0-10 V output is determined by the slider position which is controlled separately from the switch.

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FAQs *(Continued)*

What happens to the 0-10 V signal if the controller loses power but the driver does not?

If the driver is sourcing the current, the 0-10 V signal will still be active when the control loses power. The state of the 0-10 V controller will affect the 0-10 V signal and cause the driver to go to some light level. Every control is different so consult Lutron for detailed application concerns. If the desired functionality is for the light to go to high-end, a low-voltage relay or ALCR will have to be used to open the 0-10 V circuit which will send the driver to high-end.

If the dimmer is sourcing the current, which is typically NOT the case, the driver will go to low-end or off (depending on the driver manufacturer) because it will read 0 V. As a safety measure, some manufacturers design the driver so that it goes to high-end if no current is present on the 0-10 V circuit.

What other technologies can help alleviate the issues that exist with 0-10 V topology?

Wired Digital Topologies

EcoSystem – Lutron's EcoSystem controls and drivers are specifically designed to work with each other, which negates many of the compatibility and performance issues common with 0-10 V controls. All EcoSystem controls and loads are guaranteed compatible with one another, and guaranteed to meet their published specifications. EcoSystem utilizes digital communication, allowing polarity-free wiring, and zoning independent of wiring runs. Digital communication eliminates the noise and voltage drop concerns, allowing wire runs up to 64 drivers over 2000 ft (609.6 m). Because EcoSystem fixtures use electronic off, there is no concern with inrush currents during turn-on. Finally, EcoSystem has a default emergency lighting functionality which typically eliminates the need for extra wiring and emergency bypass devices to meet emergency requirements.

DALI-2® – Similar to Lutron's EcoSystem protocol, using DALI-2® controls avoids some of the issues common with 0-10 V controls in regards to performance, inrush current, and noise immunity. To ensure interoperability, DALI-2® requires that all connected devices are DALI-2® certified. Much like EcoSystem, DALI-2® loops may not require special emergency bypass relays, therefore reducing the wiring needed.

Wireless Digital Devices

Athena wireless node – Lutron's Athena wireless node is a radio frequency (RF) device that enables simple, digital control of individual light fixtures in an Athena control system. The Athena wireless node is fixture mounted, OEM installed, and is compliant with DALI-2® compliant drivers and 0–10 V drivers that meet ANSI® C137.1 requirements. Like EcoSystem and DALI®, the Athena wireless node is digitally addressable, accommodating zone and control changes without rewiring.

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P/N 048587 Rev. J February 2024