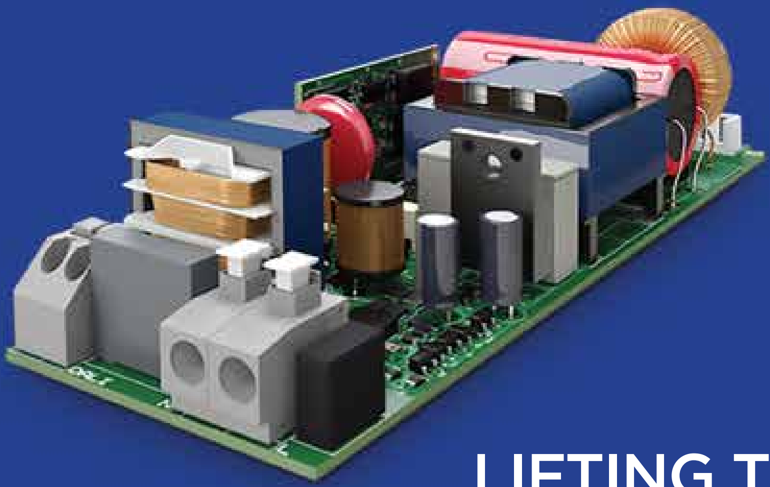


LIFTING THE LID ON LED DRIVERS

Technical white paper by Fulham
for Lumo Series LED drivers
AUGUST 2016

FULHAM
LUMO SERIES

EXECUTIVE SUMMARY

The business case for adopting LED lighting has grown stronger as the technology has become more pervasive.

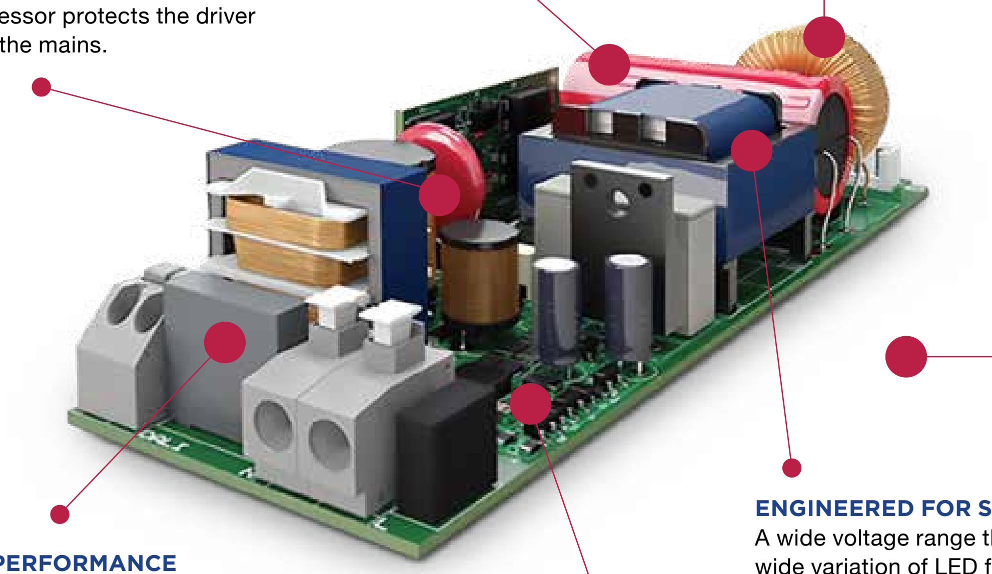
It is becoming increasingly clear that the quality of an LED driver significantly influences the performance, reliability and profitability of lighting fixtures. However, choosing the right driver is not straightforward, because it is a closed unit. The decision is made more difficult by the lack of consistent information from vendors about the performance and specifications of the driver.

The purpose of this white paper is to demystify some of the critical issues about LED drivers and how they influence luminaire performance – allowing fixture designers to ask the right questions of a prospective supplier. In turn, they can make an informed specifying and purchasing decision, ensuring they obtain the right solution that best meets their budgetary and operational requirements.

ENGINEERED FOR DURABILITY
Large highest commercial grade electrolytic capacitors on the output side, specified for 10,000 hours at 105 degrees. Within the driver we have a self-regulating temperature design ensuring our confident 5 year warranty.

ENGINEERED FOR PERFORMANCE
The Lumo Series' low ripple design creates a very stable power output for flicker-free lighting and smooth dimming. Making your LED lighting perform to the highest possible standards.

ENGINEERED FOR RELIABILITY
An active surge suppressor protects the driver from disturbances on the mains.



ENGINEERED FOR SIMPLICITY
A wide voltage range that can power a wide variation of LED fixtures. Taking out the complexity of your Supply chain.

ENGINEERED FOR PERFORMANCE
No use of electrolytic capacitors on the input side, creating a low inrush current with guaranteed minimal circuit breaker loading.

ENGINEERED FOR EFFICIENCY
Active flyback leakage energy recovery circuit bringing the driver efficiency up to 92% or higher, minimizing temperature increase.

see **www.fulham.com** for more unique aspects of our latest LED drivers >

ENGINEERED FOR BEST FIXTURE PERFORMANCE.

Reliability. Performance. Simplicity.

Lumo Series drivers are all built on core engineering design principles for exceptional standards of performance and reliability in LED systems. Highest-grade critical components together with design features for thermal derating and low inrush ensure excellent reliability. Low ripple design creates flicker-free lighting and perfectly smooth dimming. Simplicity of specification and installation is also a key aim of the Lumo Series, hence the wide voltage range which is a characteristic of all drivers in the portfolio.

THE POWER INSIDE.

5 YEAR WARRANTY

CONTENTS

1. Introduction

The LED driver plays a crucial role not only in operating LED fixtures but in controlling their performance. To date, however, little is understood about how this unit works or its importance. A lack of established standards and a lack of awareness about the exact role and functions of an LED driver have also made it difficult to compare products easily.

A further complicating factor is the considerable variety in the quality and depth of information that manufacturers provide. Products that at first appear to be similar can often perform very differently under a particular set of conditions and engineers must know the right questions to ask in order to dig beyond the manufacturer's literature.

The time has come for fixture makers to learn how to specify and choose LED drivers more accurately, given that these units are the primary influencer of fixture reliability. This is a pressing need for the industry: the United States Department of Energy has called for testing protocols to define driver performance and reliability, as well as a standard reporting format which would facilitate analysis, simulation and design tools for luminaire manufacturers.

Another important consideration is the European Union's Eco-Design Directive (2009/125/EC) which aims to establish mandatory ecological requirements for energy-using and energy-related products that are sold in EU Member States. As of 2016, LED fixtures and lamps being supplied in the EU must comply with stage 3 of the Directive's requirements, which are stricter than previous iterations.

This white paper "lifts the lid" on driver technology, outlining the design and performance issues that engineers must be aware of in order to select the optimum driver for each application. These issues are discussed in the coming pages under three key heading:

Performance
Reliability
Flexibility

LED drivers that at first appear similar can perform very differently under a particular set of conditions, engineers must know the right questions to ask in order to go "under the hood".

Source: 'Manufacturing Roadmap' report, prepared for the US Department of Energy, August 2014.

2. Performance

2.1 The importance of driver efficiency and its effect on total cost of ownership

An LED driver's efficiency depends on several external factors: the dimming level, output voltage, operating temperature and output loading.

Depending on where the fixture is to be placed, it may not need to run at a 100 per cent load and dimming can then significantly reduce power consumption, creating a stronger business case for the LED investment, but only if the driver retains its efficiency when the fixture is dimmed.

To give one example: in large spaces such as an airport check-in area, it may be possible to run the fixture at a 20 per cent load during off-peak times with minimal perceptible difference in light output. Using LEDs in such an environment, there-fore, is an excellent opportunity to achieve energy savings. However, will the driver you chose maintain a reasonable efficiency even at lower dimming levels?

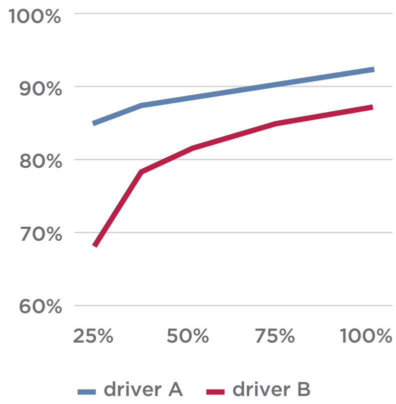
Ordinarily, we might assume that dimming reduces the power consumption significantly, but in fact, the efficiency also drops considerably. What's more, this drop may not be consistent between two different LED drivers. To test this, we compared two 40W LED drivers at different dimming levels. When operating at 100%, driver A required effective power of 43.48w, whereas driver B consumed 45.98 w: a difference of 6%. However, when tested in a dimmed-down state (25% load), driver A was shown to be 25% more efficient than driver B (see graph).

This is also very relevant for scenarios where a lighting manufacturer makes a decision to use one LED driver for multiple lighting fixtures, each with different numbers of LEDs. In this scenario, the driver will run at a lower load for the smaller fixtures and then there is a risk that the luminare will have a lower efficiency than expected as shown in the graph above.

This shows the importance of properly specifying and testing whether the driver maintains an acceptable performance in all likely operating scenarios and at a range of different loads. This is the only way to ensure the most accurate calculation of the total cost of ownership. You will see that not all drivers are created equal!

Some drivers lose efficiency when dimmed, the only way to verify this is by testing the various drivers that are under consideration.

Driver efficiency at % load
Typical 40W LED Drivers



2.2 Input voltage and its effects

Nowadays, most LED drivers are optimised to work with the mains supply in a specific geography, such as 120 VAC in the United States and 230 VAC in Europe and Asia. There has been a trend in the industry towards using separate product series for both markets, as it allows for most cost effective high-performance driver designs.

However, it is possible to build universal inputs, which might be easier from a supply chain point of view. This typically comes at a cost premium because the driver requires both high voltage as well as high current components.

2.3 On/off behaviour: testing guidelines to determine behaviour and ensure compliance with ECO design directive

The LED driver is the single determining factor in the starting speed of an LED fixture A fixture's starting time from the off position should be less than 0.5 seconds, [as stated in the ECO design directive], both for functional reasons and in some cases, health and safety (such as in emergency lighting). However, not all LED drivers perform to this level. and therefore are not eligible to carry the EC mark.

To add to this issue, flickering is common in many LED drivers when starting up or at lower dimming levels. Start-up performance is also dependent on the load of power coming to the unit.

To ensure optimal on/off performance, fixture makers are advised to test for multiple scenarios at high and low dimming settings or different loads on the driver. It's not always possible to know these elements from the manufacturer's datasheet, which makes drivers difficult to specify unseen. Drivers should be thoroughly tested to determine:

- How long does it take for the driver to start?
- How long does it take for the driver to switch off?
- Does the driver start without flicker?
- Does the driver switch off without flicker?
- Does the driver start at the original dimming level?

2.4 The impact of LED driver technology on dimming

With both PWM and linear dimming, drivers must be tested at deep dimming levels to ensure that flickering is not a problem.

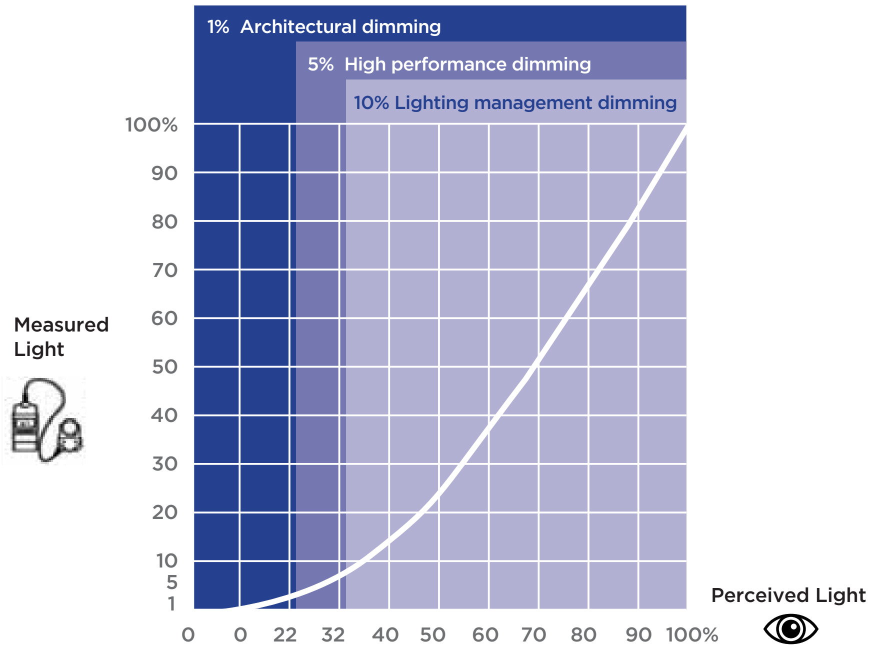
As we have already seen, dimming is a key way to reduce a fixture's running costs. Dimming at ranges between 20% and 50% can enable significant cost savings with negligible loss in levels of comfort and safety (see graph below). Given the effect of dimming levels on efficiency, it is worth emphasising again the importance of testing dimming at various levels with your specific LED load.

LED drivers can use several different dimming technologies, such as linear analog dimming and PWM dimming. Pulse-width modulation [PWM] switches the LED current very rapidly to achieve an average light level. With PWM, the switching frequency needs to be far beyond what is perceptible, or else the driver will produce noticeable flickering, especially at lower dimming levels. Linear analog dimming doesn't have this drawback, however in this situation the dimming level of the driver must go very deep (less than 2%) in order to achieve smooth dimming. This must be tested, because some LED drivers exhibit flickering at deep dimming levels even when dimmed linearly.

Design example

At full brightness, the measured light in a space is 60 foot-candles.
At the lowest dimmed level, 10% perceived light is desired.

1% measured light (0.6 fod) is perceived as 10% (desired result)	5% measured light (3 fod) is perceived as 22% (2x brighter than desired)	10% measured light (6 fod) is perceived as 32% (3x brighter than desired)



Formula: Perceived Light (%) = $100 \times \sqrt{\dfrac{\text{Measured Light \%}}{100}}$

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

2.5 Ripple & flicker: Why it's important to test LED drivers thoroughly in a range of use cases, and what you will learn

Ripple & flicker effects occur when any power supply – in this case we are focusing on an LED driver – converts mains electricity from AC to DC. By their nature, these products will always have some disturbances on the output; more commonly known as ripple. This sends either more or less current to the LEDs and is what causes the fixture to start flickering.

A ripple level of 100Hz or less is highly visible and can cause visual discomfort. For task or office lighting, ripple must be 10% or less.

A ripple level of 100Hz or less is highly visible and can cause visual discomfort to people. If the LED driver is powering task or office lighting, flicker must be less than 10% to be deemed acceptable.
As explained before flicker issues also result from dimming, which makes it important for lighting designers and fixture makers to check drivers with multiple loads and at a range of dimming levels.

It is very important to note that a high current ripple could cause currents beyond the specified maximum of the LED component thereby triggering failures in the LED's. Also, an LED's reliability is increasingly affected at high drive currents and is unlikely to survive its original calculated lifetime

2.6 EU Eco-Design directive – what you need to know

LED lighting fixtures have a very long lifetime and must be designed to comply with future regulations. The European Union's Eco-Design Directive (2009/125/EC) aims to establish mandatory ecological requirements for energy-using and energy-related products that are sold in EU Member States. From 2016 onwards, LED fixtures and lamps being supplied in the EU must comply with stage 3 of the Directive's requirements, which are stricter than previous iterations.

From 2016, all drivers must comply with more stringent EU legislation in terms of no-load power consumption, start-up time and power factor. Not all current drivers in the marketplace will comply.

Given the LED driver's key role in defining performance, power factor and starting time in a fixture, the drivers themselves must comply with the regulations – a fact that is not yet widely known. Not all current LED drivers will comply with the latest version of the Directive.

2.6.1 Standby and no-load power consumption

Under the Directive's previous energy efficiency requirements (from September 2014), fixtures had to consume less than 1.0w with no load. As of September 2016, stage 3 reduces this baseline further. Fixtures and lamps must consume less than 0.5w either with no load or in standby mode.

2.6.2 Start-up time

Stage 3 of the EU Directive includes a functional requirement for a 0.5 seconds starting time in certain types of lighting. Although LED technology is still evolving, this should be borne in mind when specifying drivers.

2.6.3 Power factor

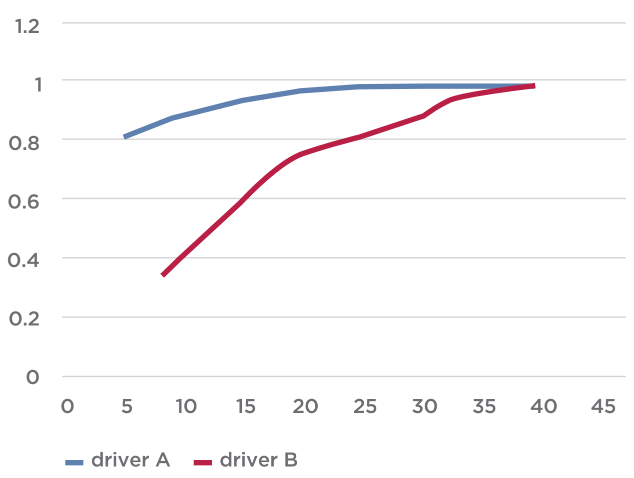
Stage 3 of the EU Directive also make the following specifications for the power factor:

- $P \leq 2$ W: no requirement
- 2 W $< P \leq 5$ W: PF > 0.4
- 5 W $< P \leq 25$ W: PF > 0.5
- $P > 25$ W: PF > 0.9.

Be aware that a luminaire must fulfill these power factor requirements, whatever LED load is on the driver used inside the fixture. Some luminaire manufacturers use the same driver with for example 30W and 40W LED fixtures. In this case, it is mandatory that the 40W driver fulfills the regulations with a load of only 30W. Which is not the case with driver B on the graph.

In addition, meeting those power factor limits when dimming the luminaire could be an extra sales argument for luminaire performance and quality.

Example of Driver Power Factor versus Load



3. Reliability

3.1 Operating temperature

The temperature at which the LED driver is running plays a key role in defining its lifetime. Temperature management is an essential skill in fixture design, and customers need to know what the LED driver's critical parameters are.

The hottest point of an LED driver is the maximum case temperature, or TC (max). This point will be indicated on the driver casing. At this point, manufacturers define a limit not to be exceeded (TC max), but in practice many manufacturers define the standard lifetime of their driver (often referred to as 50,000 hours) at a lower operational temperature than the TC max.

Although LED drivers have a temperature protection mechanism, in many units this is triggered only when the maximum case temperature is far exceeded. If we take a driver with a lifetime of 50,000 hours at 70°, we see that when it reaches its TC max of 85°, its lifetime decreases considerably to just 18,000 hours (see chart below). What's more, for this specific driver the temperature protection is only triggered when the unit runs at 110° – at which point its lifetime falls further to under 3,000 hours.

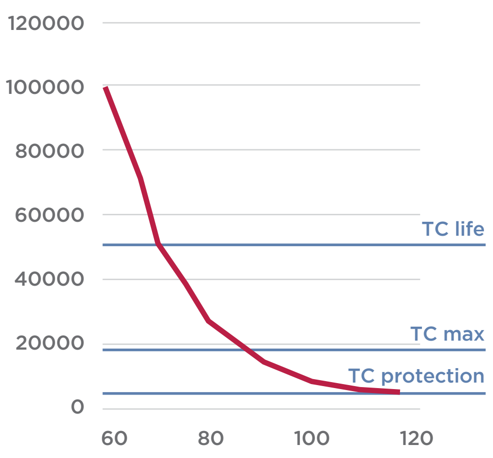
If you don't have alternative temperature protection in your fixture, expecting a lifetime of 50,000 hours could be a risky assumption; the actual lifetime could be closer to 5,000 hours. This issue requires close attention by fixture makers and lighting specifiers. Running a fixture too hot will greatly impact the longevity of the LEDs too.

This issue is also related to supplier warranties. Customers should check under what conditions the driver warranty has been set. In some cases, there are discrepancies between the information provided in a data sheet and the actual warranty's terms and conditions.

Equally, the specifier needs to think about where the fixture will be used as the housing of the unit or the ambient climate could affect the driver's operating temperature.

Driver lifetime is closely linked to operating temperature. In many driver units temperature protection is only triggered when maximum case temperature (TC max) is far exceeded. This can seriously affect the lifetime of the driver. Be sure to fully understand the temperature protection mechanism of the driver you are selecting.

Driver lifetime (hrs) vs temp. (ºC)

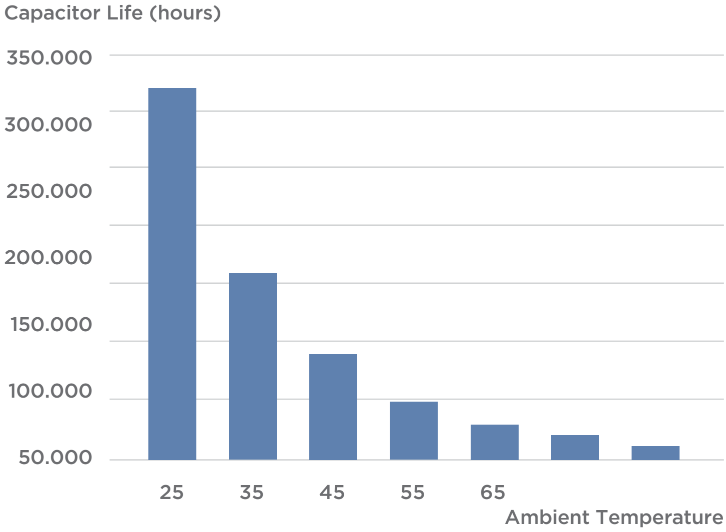


3.2 Electrolytic capacitor quality

Electrolytic capacitors (elcos) are the primary cause of failure in LED drivers. This component uses a gel which gradually evaporates over time. The rate of evaporation depends on the quality of the component and the temperature at which it is used. For every 10 degree increase in temperature, the lifetime halves (see chart).

There are significant differences in quality between elcos. Be sure to ask the driver manufacturer for:
- Manufacturer of the elcos (is it a recognised quality supplier?)
- Specification of the elcos (temperature grade)

Elcos are the primary cause of failure in LED drivers. For every 10 degree rise in temperature, the elco lifetime halves. High-quality elcos are critical for driver reliability.



3.3 Solder joint reliability

Solder joint reliability is another issue that can trigger failure in LED drivers. Factors influencing this include temperature cycling, heavy components, or mechanical stress due to potting. As it is a metal bond, the different materials comprising the solder joint may also have different thermal expansion properties. The most important contributor to solder joint reliability is temperature cycling. The higher the operating temperature of the driver, the higher the risk of cracks forming in the solder joint.

4. Flexibility

4.1 The importance of driver efficiency

As we hope this white paper has shown, LED driver efficiency is directly linked to the flexibility of the lighting fixture. Unlike traditional light sources, LED is not limited by the amount of times it can be switched on and off; the ability to control or shut off a luminaire goes a long way to determining the cost saving obtained from using LED technology.

4.2 Inrush current: a selling point for fixture installers

In order to provide a stable output power an LED driver uses energy buffering. The energy is usually stored in the electrolytic capacitors, which many LED driver manufacturers place on the input side of the driver. When the buffer is empty (at start-up) it can demand a lot of energy in a very short time. Without any additional control mechanisms, the driver has a very high control peak, which is known as the inrush current.

A low inrush current is attractive to installers because it allows more drivers to be connected to a typical circuit breaker, simplifying cabling requirements particularly in retrofits. Look for circuit breaker-related specifications in the driver datasheet.

Lighting fixtures are normally connected to a circuit breaker that may be mechanical or electronic. If a certain circuit draws too much current, the entire circuit switches off because if there is a high peak, it assumes there is something wrong. Historically, installers limited the number of LED drivers in order to avoid the circuit breakers to trigger at start-up.

A low inrush current is a very attractive feature for a lighting installer, because it allows more drivers to be connected to a typical circuit breaker. This reduces the amount of cabling that an installer needs to put in place when planning an installation. When retrofitting an installation, installers can simply replace incandescent lighting with LEDs without the need for rewiring. Look for circuit breaker-related specifications in the driver data sheet to assist your buying decision.

4.3 Output voltage & current: the pros and cons of variability

LED drivers are generally provided as fixed or variable current models; fixed current sets one light output; variable current allows fixture makers to adapt the product's light level to suit their specific needs. Most LED drivers now available on the market are fixed-current products.

Fixed-current drivers are the most cost-effective option, while variable-current products make it easy to manage future ranges of products with limited SKUs.

Advancements in LED technology mean that every year, the amount of light that comes from a typical LED family typically increases by as much as 10% or more. This is a positive development because it is now potentially cheaper to produce consistent levels of light from your product.

Using a variable-current LED driver in your fixture allows manufacturers to reap the benefits of improved performance from future generations of more efficient LED technology, and to combine both current and future generations of LED emitters in a fixture. Now that LED technology is much more established, backward compatibility is becoming as important as getting more light from a fixture.

The voltage range defines the variety of LED emitter structures that can be supported by a single driver. This directly influences the amount of driver SKUs required in a manufacturer's supply chain. Fixed-current products are the most cost-effective option and they don't require configuration, however they can increase the number of driver SKUs that a lighting manufacturer must carry. Variable-current LED drivers with a wide voltage range make it easy for fixture makers to manage generations of products or projects with a limited range of SKU's.

5. Checklist for testing LED Drivers

The inherent flexibility that LED technology provides is a good thing, because it provides fixture designers and lighting specifiers with a wide range of options when designing projects. By the same token, the variety in driver types and uses means there are many variables to consider. Every driver is different, so it is essential to test in advance of deployment in order to make the right choice of LED driver for your needs.

The three main considerations are:

- Identify the performance requirements of your fixture
- Recreate the environment where your fixture will be used
- Test close to the use limits – how does the driver behave at minimum and maximum power, not just your ideal scenario?

Testing criteria, as suggested by the US Department of Energy:

- Operating temperature range
- Efficiency with respect to power, load, and temperature
- Input voltage and output voltage variation
- Off-state power
- Power to light time
- Power overshoot
- Transient and overvoltage protection specifications
- Compatibility with specific dimming protocols
- Compatibility with ambient light sensors
- Harmonic distortion in power supply
- Output current variation with temperature, voltage, etc.
- Maximum output power
- Power factor correction

6. Conclusion

As we hope this white paper has shown, LED drivers have a significant influence on lighting fixtures, from their overall cost to quality and performance. Until now, a lack of knowledge about their function has not been made easier by the difficulty in comparing driver specifications between manufacturers. What should be clear is that specifying a driver on cost alone is not advisable, because it eliminates too many critical factors from the decision – ones that could play a significant role in the true performance of a luminaire in the field.

It is essential to ask the right questions of your potential supplier, to test driver performance in a wide range of test conditions – even up to and beyond the limits at which you plan to use it in a fixture. Know in advance the application, and ideally the location where the fixture will be used. Ask manufacturers for their documents, and read any specifications in their data sheets carefully.

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