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White paper

LED Lighting Quality

Achieving Natural Dimming Performance without Flicker

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1. Abstract

LED lighting has arrived in the mainstream market but challenges with light quality and flicker still remain. LED technology is continually changing and is far superior to that of the traditional sources like incandescent and halogen. This paper will address how to achieve the natural dimming characteristics of traditional light sources using LED technology.

2. Dimming LEDs

The adoption of LED lighting has grown rapidly over the last few years primarily because of the higher efficacy and increased energy efficiency LEDs have over traditional light sources. Lighting control and dimming have always been a part of these traditional sources and must continue to be part of LED technology. A system approach must be understood when implementing LED control, meaning, knowledge of control, driver, LED and luminaire are necessary for success.

Dimming LEDs enables the designer and end user to create an emotion or build an experience within a space all while reducing energy consumption. LED technology enables features beyond what traditional light sources can offer because of inherent digital characteristics. This poses both challenges as well as opportunities and understanding the tools you have to work with (control, driver, and LED) can enable exciting solutions never experienced with traditional light sources (i.e. Visible Light Communication).

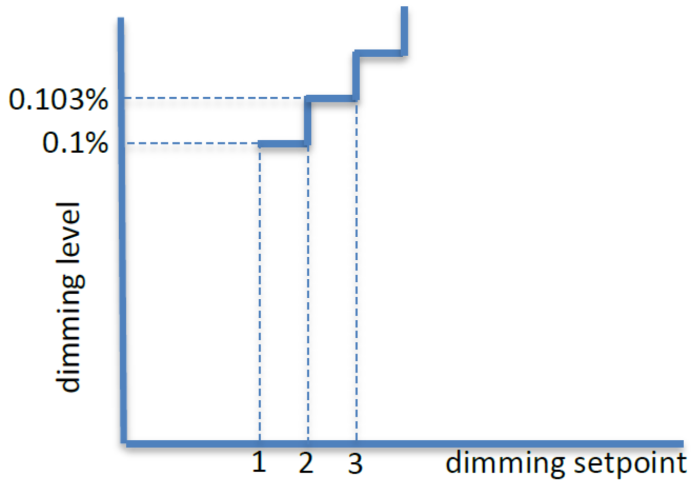
There are certain characteristics of the traditional sources that have been taken for granted with LED technology, and rightfully so. Characteristics such as quick turn on, color stability, and smooth flicker-free dimming from full output to off have taken a back seat to efficacy (lumens per watt) and longer life times in LEDs. But with such advancement in technology, an experience of LED lighting should encompass not just efficiency and lifetime but the natural characteristics of the traditional light sources.

3. Achieving Natural Dimming Performance

The characteristics of LED lighting that need consideration for producing natural dimming performance are the smoothness of the dimming curve, flicker or lack thereof, the capability to produce light without LED color shift and also the capability to mimic the blackbody curve while dimming. Again, we must look at this from a systems approach and understand what each of the components within the system is capable of.

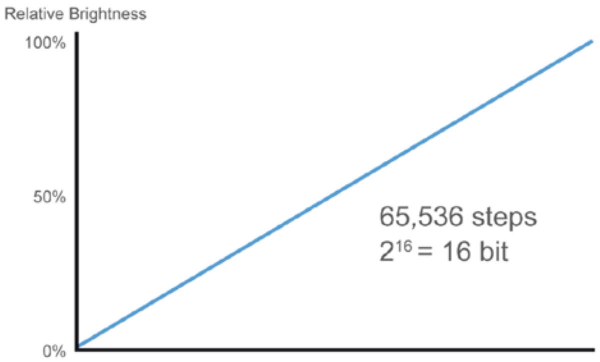
3.1 Smoothness of Light Output

To address dimming smoothness we must understand the digital nature of an LED and LED driver. In order to shift from one light level to another the output must step, and that step size is critical to the visual experience. To ensure natural dimming performance the driver should step the LED from 100% light output to its low end light level without noticeable change. The human eye can detect a change greater than 3% of green wavelength light (most visible to the naked eye, 550 nm), so we must change at a rate of less than 3% (i.e. 0.1% light level to 0.103% will not be noticed as a step but a smooth transition – see graph below).



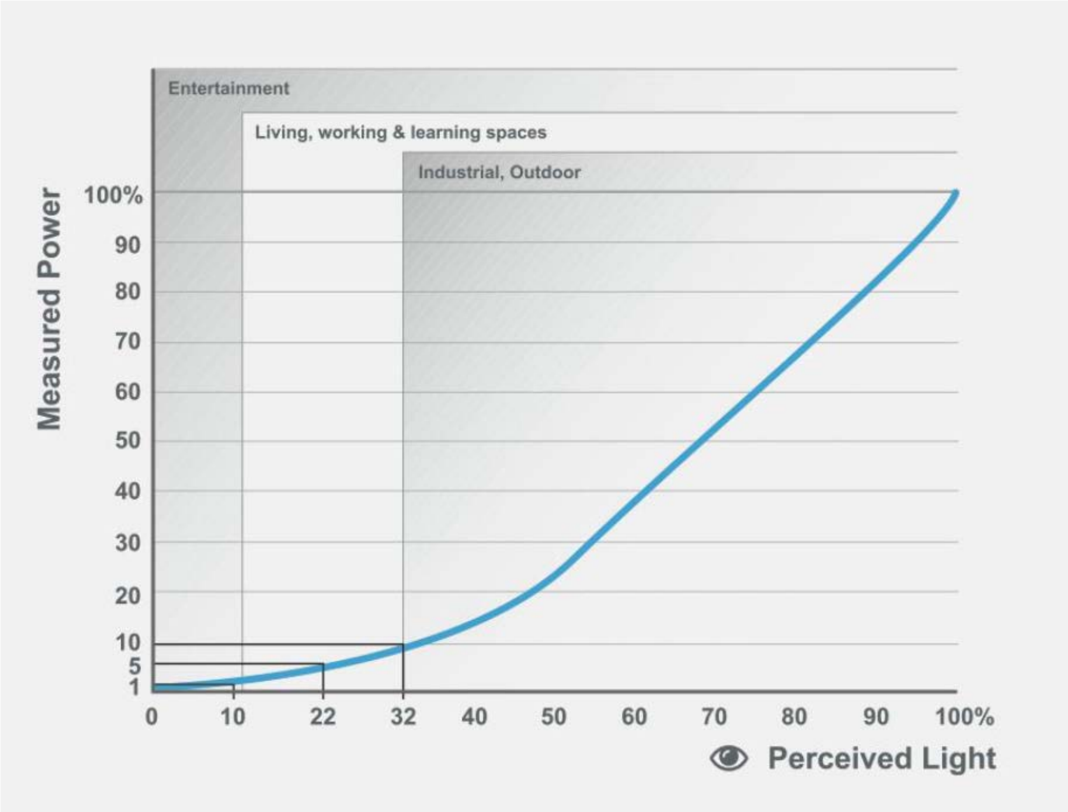
The next consideration is the resolution at which the LED dims, since the LED responds instantaneously to current changes and doesn't receive a dampening effect that an incandescent filament provides. In order for the light level to transition smoothly, the control and driver must have enough steps so the eye does not perceive the change. The minimum amount of steps from 100% light output to low end is 65,536, which is 16 bit resolution. Notice the difference in the graphs below indicating what may be perceived when different resolutions are implemented (2 bit vs 16 bit).

Resolution is the number of steps between 0% and 100% brightness:



3.2 Light Level

Below is a chart that shows the relationship of measured power (similar to measured light) versus perceived light (blue line). This is an important distinction to make with LEDs since achieving low stable light levels is often a challenge. With traditional incandescent and halogen sources this was not an issue because they were able to dim smoothly to very low perceived light levels. Again, LEDs are much more advanced than incandescent lamps and they should be able to perform as well, if not better. To ensure natural performance and high quality dimming occurs within the luminaire, an appropriate LED driver must be selected. We will describe what considerations should be made when choosing the right LED driver.



Measured power vs perceived light

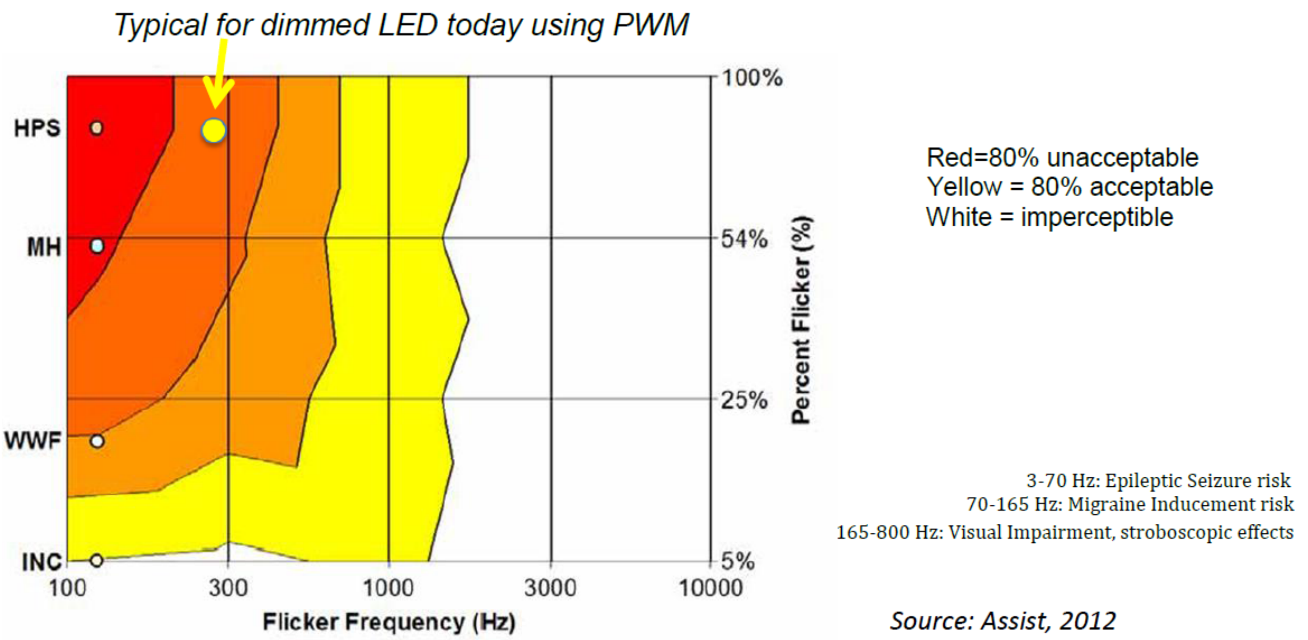
3.2 Flicker

A major issue plaguing the LED lighting industry today is flicker but not simply flicker that is easily perceived. The Illuminating Engineering Society of North America (IESNA) Lighting Handbook defines it as the “rapid variation in light source intensity” (Rea, 2000). Virtually every light source powered from an AC line will have some type of modulated signal.

The flicker that is presented in this document is photometric flicker. Flicker generated from line noise or transients may be considered flicker but not photometric and not covered in-depth in this paper.

There are two primary types of photometric flicker: visible and stroboscopic. Visible flicker is consciously perceivable by the human viewer and objectionable to all. Stroboscopic flicker is not consciously perceived and may have biological effects on the human person. Stroboscopic flicker has a greater impact on children, migraine headache sufferers, and individuals with epilepsy and autism.

Stroboscopic flicker is primarily generated by an LED dimming method called Pulse-Width Modulation (PWM). PWM cycles the LED from maximum current to zero current and repeats it at a rate, ideally, higher than what is typically perceived, about 800 Hz. This PWM signal is generated by the LED driver. Knowing what technology a driver uses to dim the LED will help to understand if flicker will be present in a luminaire. The image below plots where light sources fall in terms percent flicker and flicker frequency and how that corresponds to the risks associated with flicker.



A luminaire should be in compliance with the characteristics below to be considered flicker free.

Light Level	100%-10%	10%-5%	1%	0.1%
Percent Flicker	<25%	<100%	100%	100%
Minimum Modulation Frequency	>10kHz	>10kHz	>1000Hz	>1000Hz

There are a few ways to identify if flicker may be present but the easiest way is with a pencil. If you wave a pencil in front of the LED source and it doesn’t appear as a complete blur then chances are flicker is present.

The IES has provided guidelines to quantify how much flicker is present within a luminaire. While manufacturers are not yet required to provide this information it is incumbent upon the designer or user to request it.

IESNA has defined two metrics for flicker:

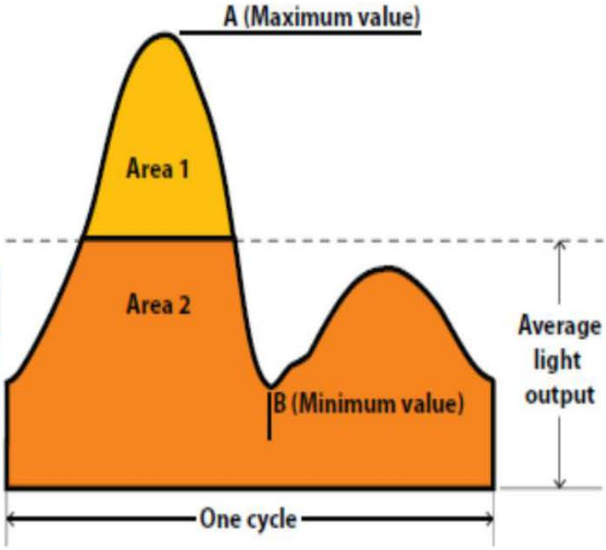
- Percent flicker (0 – 100%), lower is better
- Flicker index (0 – 1.0), lower is better

$$Percent\ flicker = 100\% \times \frac{A - B}{A + B}$$

$$Flicker\ index = \frac{Area\ 1}{Area\ 1 + Area\ 2}$$

IES Metric	Average	Peak-to Peak Amplitude	Shape	Duty Cycle	Frequency
Percent Flicker	Yes	Yes	**No**	**No**	**No**
Flicker Index	Yes	Yes	Yes	Yes	No

Source: IES Lighting Handbook, 10th Edition

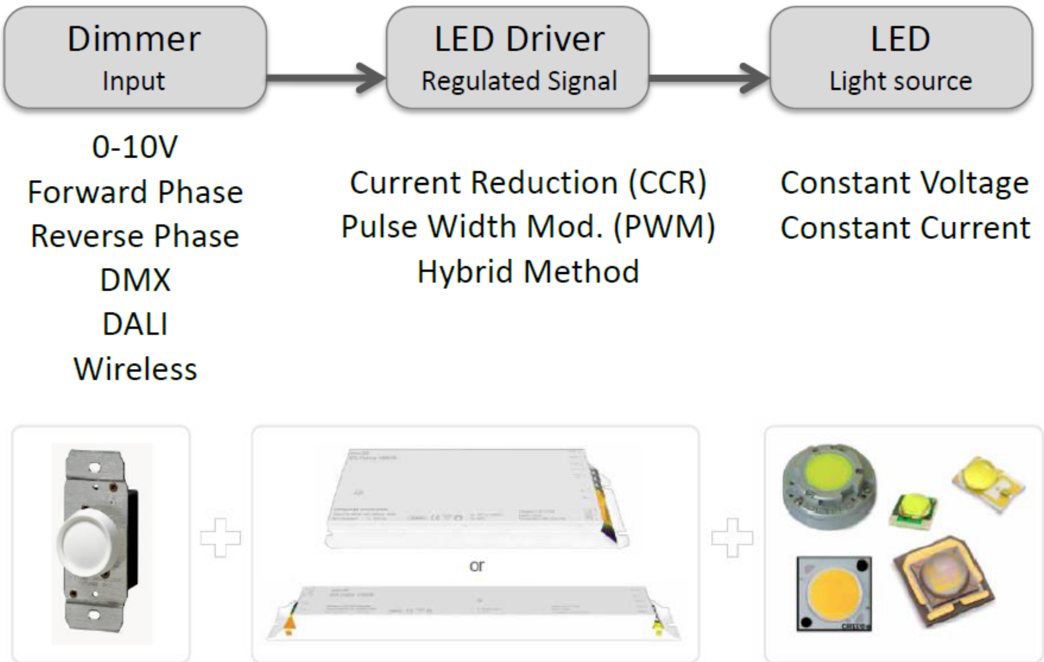


4. LED Systems

Again, the LED system is made up of the control/dimmer, the LED driver, the LED chips or module and the luminaire. To achieve natural flicker-free control of the LED, it is important to ensure those four components are compatible and especially that the right LED driver is selected.

Some controls may only have a few hundred to one thousand set points, which will affect the dimming performance of the LED. Some LED drivers can perform a function of interpolation, which digitally adds steps from one set point of the dimmer to another, assuring a smooth transition from one output level to the next.

The LED driver is typically connected to a power source and also to a control but when a phase controlled driver is used then the power and signal are coincident. Drivers may support a variety of controls: 0-10V, Forward/Reverse Phase, DALI, DMX/RDM. The driver produces a regulated control signal to the LED. This regulated signal from the output of the driver determines the level of performance you will see.



The images below describe the pros and cons of different LED dimming methods. Their usage is dependent on manufacturers' preference if not specified. PWM is typically most cost-effective so it is most often used.

Pulse Width Modulation (PWM)

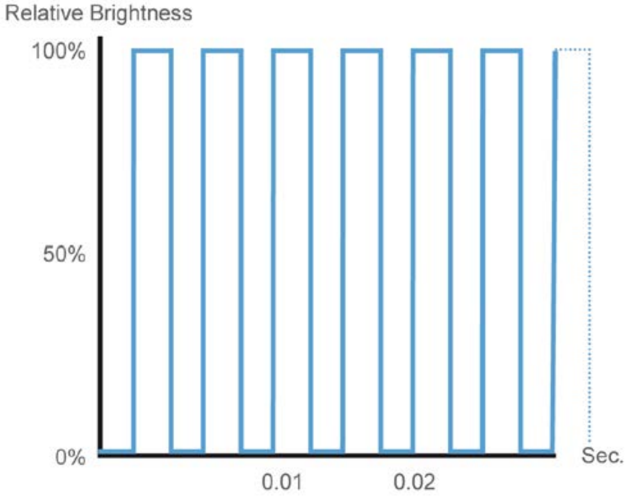
Constant LED current, varying LED on/off times

☑ Good dimming regulation at deep dimming levels

☑ Little color shift when dimming

☒ Potential noise generation

☒ Potentially undesirable flicker, depending on frequency



Constant Current Reduction (CCR)

Varying LED current, varying LED always on

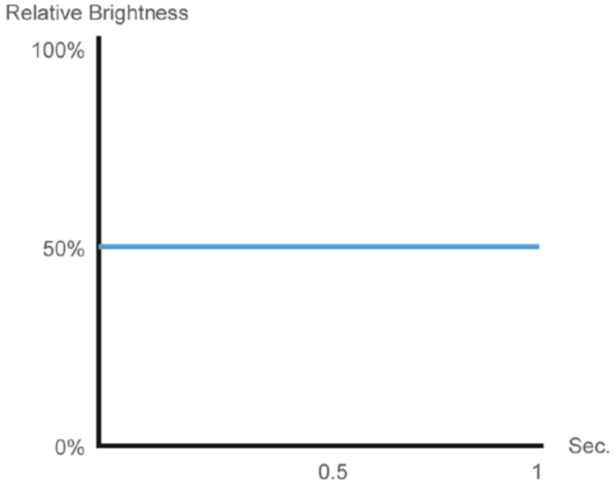
☑ No flicker

☑ Higher LED efficacy at lower dimming levels

☑ No noise generation

☒ Poor dimming regulation at deep dimming levels

☒ Color shift may occur with phosphor converted LEDs



Hybrid Dimming

Varying LED current, duty cycle and frequency on small current range

No LED on/off times

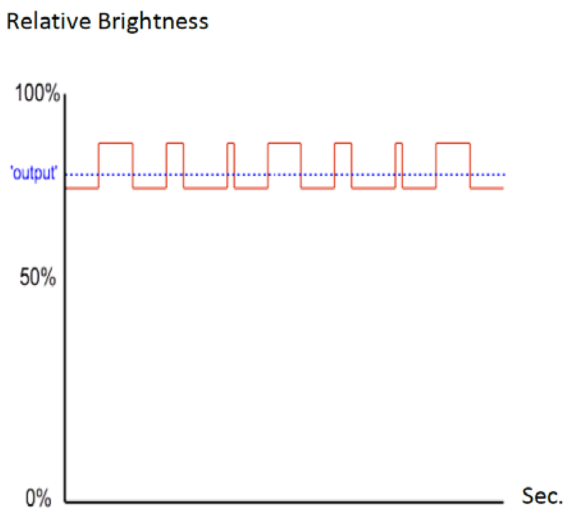
☑ Best dimming regulation at deep dimming levels

☑ High frequency operation
(mixing frequencies between 1KHz and 20KHz)

☑ No flicker

☑ Low noise generation

☑ Little color shift when dimming



5. How to Realize the Full Promise of LED Lighting and Natural Dimming

- Understand the application requirements and set an expectation for the customer, natural dimming is possible if correct technology is implemented

- Know what components will make up your system (control, driver, LED)

- Consider the driver and its capabilities, know which type the fixture manufacturer is using

- Ask about its flicker percentage or index, know what perceived light level it can dim down to and what the dimming resolution is

- Ask the luminaire manufacturer for a driver that meets your requirements

About eldoLED

eldoLED is a world leader in the design and manufacture of intelligent drive solutions for LED based lighting systems. Our technologies empower our customers to deliver the promise of LED lighting: smarter, sleeker and more efficient systems to meet the needs of an ever more energy conscious world. Colour is our nature, Light is our passion, your product our drive.

Products

eldoLED offers a continuously expanding range of programmable, intelligent LED drivers. With in-house R&D and manufacturing, eldoLED is well positioned to deliver leading solutions fast and high quality.

Customer Commitment

Continuous technological innovation and the commitment to help our customers bring solid-state applications to a higher level are two important pillars of our company.

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