Help Combat Flicker

with Properly Designed LED Drivers

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Properly Designed LED Drivers can Help Combat LED Light Flicker

When it comes to LED lighting, one common challenge is light modulation: fluctuations in the output of the light source which can produce so called Temporal Light Artifacts (TLAs). All lighting is subject to light modulation but in some older types of lighting (i.e., incandescent, halogen, etc.) it can be harder to detect due to the afterglow. In this white paper, we will focus on what exactly TLA is, the different types and how it can be addressed through proper LED driver design or selection.

What are TLA's?

Temporal Light Artifacts are defined as an undesired change in visual perception induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for an observer in a certain environment and include flicker, stroboscopic and the phantom array effects. We will focus in this white paper on the first two types.

Overview of TLAs

The light from the sun does not modulate when it illuminates earth. All artificial light sources generate some sort of light modulation. Even the light of incandescent bulbs modulates 100 times (countries with 50 Hz) or 120 times (countries with 60 Hz) per second, but due to the afterglow phenomenon the human eye does not notice this.

The output current of LED drivers is a DC signal; the current is steady and flowing in one direction only. Though, a little AC ripple is superimposed on the DC signal. LED light sources react instantly on each change in drive currents. If the ripple is high, then so is the change in luminous flux. TLAs can contribute to issues like eye strain, seizures, reduction in motivation, distraction, and reduced visual task performance. Also, TLAs can cause interference with imaging devices like video and surveillance cameras (a common effect is black stripes). Another challenging effect caused by TLAs can be observed in factories with spinning machines where it appears as if the machine is standing still. Along with these examples, there are many reasons to keep light modulation low in the applicable frequency range.

Different Types of TLAs and their Impact

Flicker is the perception of visual unsteadiness induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a static environment. On the other hand, stroboscopic effects are changes in motion perception induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a non-static environment (see Table 1). This difference is important. Flicker is per definition visible; invisible *light modulation* is causing other effects, like stroboscopic effects.

TLA Type	Environment	Observer
Flicker (0-80 Hz)	Static	Static
Stroboscopic Effects (80-2000 Hz)	Dynamic	Static

Table 1: Visual Perception and Environment Type

A widely accepted metric for flicker is the parameter 'Pst LM', where 'st' stands for short term and 'LM' for light flicker meter method. The value Pst LM = 1 means that the average observer has a 50 % probability of detecting flicker. A widely accepted metric for the stroboscopic effect used in this Regulation is the Stroboscopic Visibility Measure (SVM) as defined in standards. The value SVM = 1 represents the visibility threshold for an average observer.

Flicker is related with frequencies ≤ 80 Hz. LED drivers typically do not generate significant current ripple peaks at ≤ 80 Hz. In most cases when visible flicker is observed, it is related with poor power quality or a bad power grid, such as mains voltage fluctuations that are visible as light modulation.

Stroboscopic effects are only noticeable in a non-static environment. An easy way to observe this phenomenon is when playing drums under modulated light. It will be perceived like the drumsticks are moving in discrete steps rather than in a continuous way. But when the environment is static, those effects cannot be observed.

Preliminary research suggests that people can no longer detect light modulation once the frequency increases into the kilohertz (kHz) range.

Properly Designed LED Drivers Make a Difference

Most LED drivers are powered by our AC mains that operate at 50 or 60 Hz. Your basic LED driver rectifies the mains and thus doubles the frequency into to 100 or 120 Hz. As we know from above, this might be detectable which can cause discomfort.

LED drivers designed with a so called two-stage topology can greatly reduce output ripple and therefore, flicker. This type of topology adds a second stage behind the active Power Factor Correction (PFC) stage. Although you can achieve the ideal DC and reduce ripple, the addition of the DC/DC converter stage comes with an increase in cost and a reduction in efficiency.

A lower-cost, but still effective method to reduce the output ripple is through a single-stage topology with a built-in ripple suppressor circuit. This circuit design can sense when the ripple of the current is too large, and it can adjust the voltage to make the ripple smaller (see Table 2).

Single-Stage Topology	Two-Stage Topology
High light modulation	Low light modulation
Mainly 100/120 Hz (low frequencies)	Complex signal with both low* (100/120 Hz) and high frequencies (up to hundreds of kHz)

(*) the amplitude of the low frequency part is very low.

Table 2: Single-Stage vs. Two-Stage Topology

LED drivers frequently specify output ripple current as it can be specified independent of light engine. Although related to ripple current, light modulation may vary at the luminaire level. The light modulation can be influenced at the system level based on light engine design, driver selection and temperature amongst other factors. Often, the light modulation will be lower than the current ripple, due to the lower luminous flux when the forward current is oscillating. Therefore, it is often helpful to measure light modulation at the luminaire level.

Over time, the definition of ripple current has evolved as a result of LED driver improvements and market requirements. Single stage designs most commonly specify ripple current as Peak to Average while two stage designs use Peak to Peak. Furthermore, for two-stage designs we mention the total output current ripple and in addition, the low frequency part (see Table 3). The 200 Hz limit derives from a CA Title 24 limit; you could replace < 200 Hz in fact by ≤ 100/120 Hz.

Single-Stage Topology			
Total Output Current Ripple (pk-avg)	-	50%lo	75%lo
Two-Stage Topology			
Total Output Current Ripple (pk-pk)	-	5%lomax	10%lomax
Output Current Ripple at <200 Hz (pk-pk)	-	2%lomax	-

Table 3: Example of an Inventronics datasheet.

How to measure TLAs? Which metrics?

Common measures for TLAs are Percent Flicker (also called Modulation Depth) and Flicker Index, but they are very outdated and incomplete. These measures are limited because they don't take the human eye sensitivity into account; furthermore, they do not take into account frequency, wave shape and duty cycle (see Images 1 and 2).

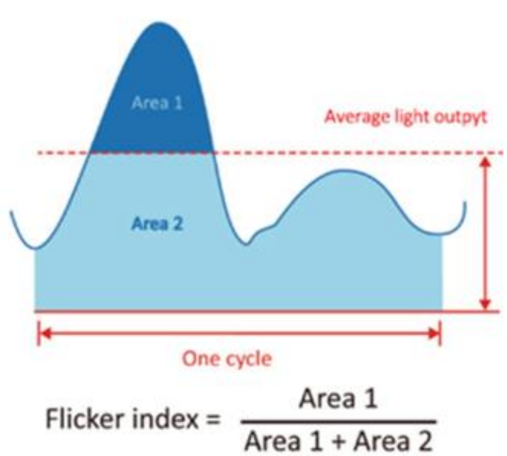


Image 1: Flicker Index Measurement

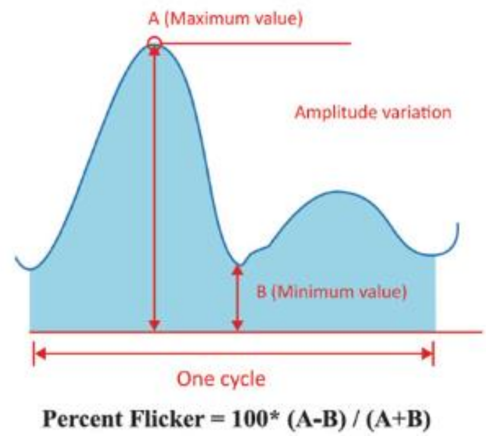


Image 2: Percent Flicker Measurement

In fact, Percent Flicker (See Image 2) is depicting the difference between the maximum peak and the amplitude. More complex ways of measuring are Pst LM for flicker and SVM for stroboscopic effects. The SVM method filters frequencies up to 2000 Hz, a Fourier analysis is executed and incorporates the eye sensitive curve (see Image 3).

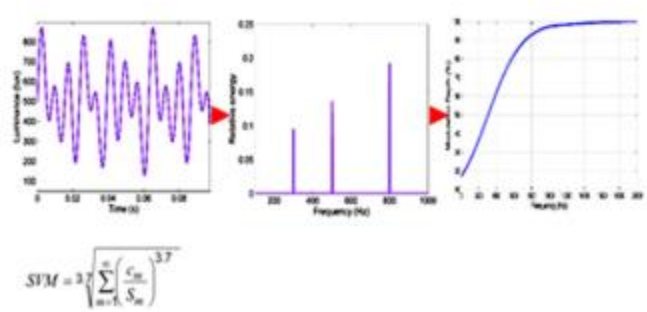


Image 3: Depiction of SVM using the Fourier Analysis and the sensitivity of the human eye.

A handheld spectral flicker meter is designed to show flicker index, percentage flicker and SVM readings. Image 4 shows the result of a handheld spectral flicker meter with Inventronics' EUD-480S140DV (tested at about 93.5% load).

Image 4: Inventronics' EUD-480S140DV readings from a handheld spectral flicker meter.

Another common test measurement is provided by the IEEE1789 diagram (see Image 5). This graph is essentially showing Percent Flicker in function of frequency. It defines three regions: the no-effect region shown in green, the low-risk region in orange and in white the not recommended region. Since it is important to consider frequency, wave shape and duty cycle when assessing TLAs, the IEEE 1789 Diagram also has limitations. For example, the Modulation Depth of a traditional incandescent bulb is typically about 10% at 100/120 Hz falling into the not-recommended area.

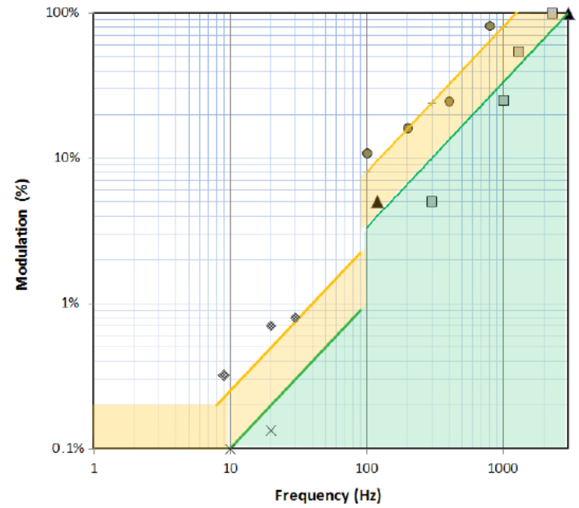
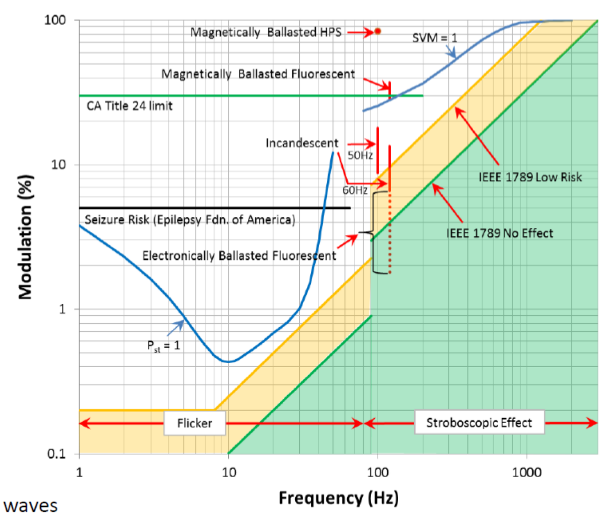


Image 5: IEEE 1789 Diagram

Please also find a comparison of different TLA specifications (Image 6) plotted over the same graph. It is important to understand that Pst LM=1 means the average observer has a 50% probability of detecting flicker while SMV=1 represents the visibility threshold for an average observer.



For sine waves

Image 6: Multiple TLA criteria plotted over the same graph for comparison.

What does Inventronics recommend for measuring TLAs?

For North America, Inventronics suggests using the NEMA 77 guidance (See Table 3).

NEMA Recommends as Acceptance Criteria:		
Application Area	**Pst Limit**	**SVM Limit**
Outdoor	≤ 1.0	None
Indoor	≤ 1.0	≤ 1.6

Table 3: NEMA 77 Guidance

For Europe, Inventronics suggests using the new Single Lighting Regulation (SLR), which is referenced in Commission Regulation (EU) 2019/2020 that goes into effect September 1st, 2021. Luminaires and light sources need to comply with:

- Pst LM ≤ 1.0 at full load
- SVM ≤ 0.9 at full load (and SVM $\leq$ 0.4 at full load starting September 1, 2024)

It is important to mention that intended application is also considered in evaluating SVM results. Products with SVM > 0.4 are accepted when the light sources are intended for use in outdoor applications, industrial applications or other applications where lighting standards allow a CRI< 80. Below is a table of Inventronics drivers for reference (Table 4). If you focus on the SVM data, you can see two-stage designs by Inventronics pass the European eco directive (SLR) with a large margin.

LED driver P/N	Load	Findex	Fpercent (%)	SVM
EUC-026S070PS (single stage)	36 Vdc 700 mA	0.075	24.6	0.926
EBS-080S150BT2 (two stage)	48 Vdc 1050 mA	0.001	0.6	0.002
EUD-480S140DV (two stage)	379 Vdc 1200 mA	0.001	0.1	0.019
EUD-150S105BVA (two stage)	135 Vdc 1050 mA	0.002	0.9	0.025

Table 4: Inventronics single-stage and two-stage LED driver design data

The results with single-stage designs have a higher SVM while still meeting proposed limit (≤ 0.9 until 2024). Also, as noted above, there is no limit when application is designated for use in industrial and outdoor products.

Why Compatibility Matters

Of course, TLAs are not entirely caused by the LED driver alone but more the result of incompatible components and even interference from external noise sources. TLAs can also change depending on the different voltage and current characteristics that is specific to each LED load. Therefore, it is important to test the compatibility for your entire lighting system- controls, dimmers and LED drivers and how these components perform with the LED load. Be sure to work closely with the LED driver manufacturer to identify and test the system under the settings expected in the final installation.

Summary:

All types of lighting are subject to TLAs to some degree and there are many factors encompassing the cause- modulation depth, frequency, duty cycle and waveform. All TLA metrics have limitations, in part because a large amount is related to human perception and individuals’ responses can vary greatly.

The most common cause of TLAs is utilizing incompatible components in the luminaire design. Ensure you are using the correct LED driver so the current and/or incoming AC power supplied to the LED remains constant regardless of any fluctuations in the power grid.

It is important to understand which applications require careful attention to TLAs to avoid discomfort and ensure proper safety for those using it as much as possible.

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Dimitri is the European Technical Support Manager at Inventronics and has been with the company for 5 years. He has over 19 years of experience in lighting industry including Philips, Delta Light and Massive. Dimitri earned a Master of Science in Electromechanical Engineering Technology at KAHO Sint-Lieven (currently known as KU Leuven Technology Campus Ghent). He has been published in various lighting trade publications and has presented at numerous industry events.

Resources:

https://en.wikipedia.org/wiki/Flicker_(light)

https://en.wikipedia.org/wiki/Stroboscopic_effect_(lighting)

https://www.energy.gov/sites/prod/files/2015/05/f22/miller%2Blehman_flicker_lightfair2015.pdf

https://www.ccohs.ca/oshanswers/ergonomics/lighting_flicker.html

https://www.ledsmagazine.com/leds-ssl-design/driver-ics/article/16695240/proper-driver-design-eliminates-led-light-strobe-flicker-magazine