

LED Light Flicker

Most lighting companies today are migrating to LED and there is one common problem that most of them struggle to figure out and that is flicker. This white paper focuses on understanding what is flicker, different types of flicker, ways of quantifying flicker and different factors that may introduce flicker.

So, what is flicker?

The Illuminating Engineering Society of North America (IESNA) defines flicker as “variations of luminance in time”. Others define flicker in different ways such as:

- Quick, repeated changes in light intensity
- Light that appears to flutter and be unsteady
- Amplitude modulation of light at frequencies.

Flicker is present in lighting regardless of the lighting technology in use. Both fluorescent and incandescent lights have flicker. In early days when fluorescent lights used inductive ballasts, flicker was already a problem. To mitigate this problem, fluorescent bulbs were typically used in pairs or even quads.

Flicker is not noticeable in legacy lighting because of the resistive nature of the light sources. Resistive light sources such as incandescent lamps are slow to respond to change in current. When the power is switched off it takes a while before the lamp stops glowing. Due to this slow response, flicker is less apparent. This is not the case in LEDs, an LED stops emitting light instantly after the power is switched off. That is why flicker is more noticeable.

Types of Flicker

There are two main types of flickering with lights – **visible flicker** and **invisible flicker**.

Visible flicker is commonly observed by the naked eye and is typically considered objectionable. This is when the light output from a given source changes rapidly. The rapid change in light output, which is generally anything



below a frequency of 100Hz (cycles per second), is believed in some cases to have health implications.

Some studies show that short-term exposure to frequencies in the range of 3Hz to 70Hz are associated with epileptic seizures, with the greatest likelihood occurring in the range of 15Hz to 20 Hz. It is said that around one in 4000 people are identified as suffering photosensitive epilepsy and there may be just as many who have not been diagnosed, so this is a serious issue for lighting in large public spaces. This explains why TV programs warn us that ‘the following program contains flashing lights’.

Flicker can also cause problems that are not health related such as:

- Reduced visual task performance
- Apparent slowing or stopping of motion (stroboscopic effect)
- Distraction
- Eye strain
- Reduction in motivation

Invisible flicker is flicker that we can’t see, but which we all experience. This is also a real problem. The symptoms of invisible flicker are familiar to us because they are the symptoms associated with

- sick-building syndrome (SBS) – SBS is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified.
- headaches, migraine, dizziness, general malaise, eyestrain

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- impaired intellectual and/or visual performance.

Although studies suggested that frequencies above 200Hz may have negligible biological effect, the upper frequency limit is not really known. An upper limit of 5.4kHz has been noted, but the jury is still out on that as more evidence needs to be collected.

Shimmer is low frequency and random variations in light output that are typically less noticeable than flicker. Fig. 1 below shows an example of a waveform of the output current taken from an LED light fixture that had shimmer issue. As you can see the amplitude of the current changes randomly over time.

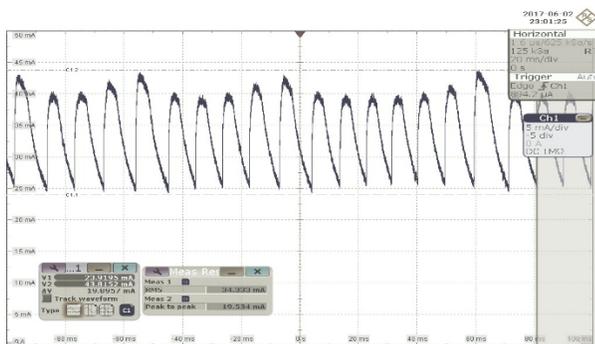


Figure 1. Output current waveform of shimmering fixture

Why do LEDs Flicker?

Flicker is caused when the current flowing through the LED changes in amplitude. In present days we power our LEDs using an LED driver especially designed to supply a constant current. Flicker is not solely caused by the power supply but can be due to incompatibility of the different components that make up the lighting system namely dimming control, LED driver and LED load. Since LED power supply companies do not know which LEDs they will be used with, they characterize the supplies by measuring their output current ripple at nominal voltage load.

Quantifying Flicker

The photometric flicker found in electric light sources is typically **periodic**, with its waveforms characterized by variations in amplitude, average level, periodic frequency

(cycles per unit time), shape, and, in some cases, duty cycle.

Percent Flicker and **Flicker Index** are metrics historically used to quantify flicker. Percent Flicker is better known and easier to calculate, but Flicker Index has the advantage of being able to account for differences in waveform shape (or duty cycle, for square waveforms). Both metrics account for amplitude variation and average level, but since both are based on the analysis of a single waveform period, neither can account for differences in periodic frequency. An example of a periodic waveform is shown in Figure 2, along with equations for both flicker metrics.

Measuring and reporting flicker is not a standard practice for commercial light sources. Although industry bodies have developed flicker metrics, they have not produced complementary standardized measurement procedures to ensure appropriate comparisons of reported values. Conventional lighting technologies exhibit little variation in flicker for a given source type; for example, all incandescent A19 lamps behave similarly. However, the type of ballast has a substantial effect, although just knowing whether it is magnetic or electronic has usually been sufficient for flicker characterization. As a result, there has historically been little need for measuring and reporting the flicker performance of a specific product. The Illuminating Engineering Society of North America (IESNA) released the definition of "percent flicker" and "flicker index" in the ninth edition of The IESNA Lighting Handbook. Fig. 2 shows how the metrics are defined.

Two common ways of measuring Flicker

- Percent Amplitude Modulation (PAM)** or Percent Flicker
 - AKA Peak-to-Peak or Michelson Contrast
 - Most research is based on this metric
 - Easy to measure
- Flicker Index**
 - Older research used this metric
 - More difficult to measure

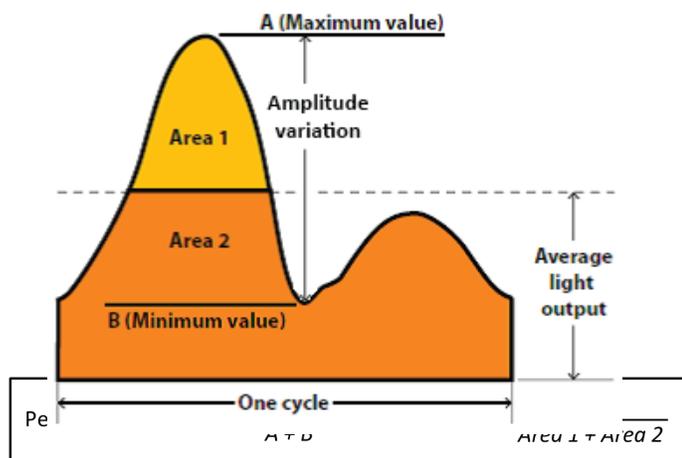


Figure 2. Source: IESNA Lighting Handbook, 10th Edition

California Title-24 “reduced flicker operation”

Light source in combination with specified control shall provide “reduced flicker operation” when tested at 100 percent and 20 percent of full light output, where reduced flicker operation is defined as having percent amplitude modulation (percent flicker) of less than 30 percent at frequencies less than 200Hz, tested according to the requirements in Joint Appendix JA-10 a combination of percent amplitude modulation (<30%) and cut-off frequency (for frequencies less than 200 Hz) Below is a summary of the test equipment needed and test conditions required to comply to CA Title 24.

Reference:

(CEC) California Energy Commission. 2016 Title 24, Part 6. Building Energy Efficiency Standards for Residential and Nonresidential Buildings. <http://www.energy.ca.gov/title24/2016standards/>

- 2016 Reference Appendices. (Including Joint Appendix JA10 Test Method for Measuring Flicker of Lighting Systems)

Appendix JA10 – Test Method for Measuring Flicker of Lighting Systems

Results specific to a light source and its dimmer.

Test Equipment

1. Light tight enclosure (does not have to be an integrating sphere)
2. Photodetector with rise time < 10 microsec

3. Transimpedance amplifier
4. A-D conversion (digital oscilloscope, data acquisition card etc)

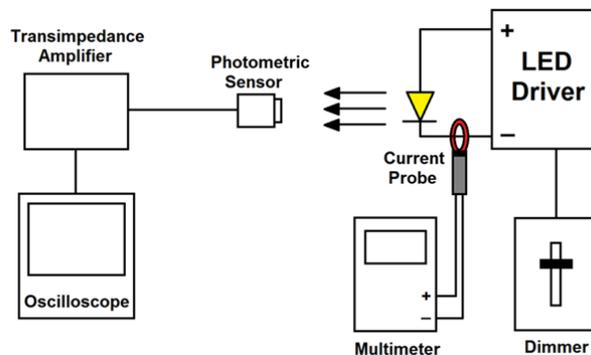


Figure 3. Percent Amplitude Modulation (PAM) Test setup

Test Conditions

1. Test should be done in an enclosure that will prevent stray light to ensure that measurements come from LED load under test only.
2. Input power should be within 0.5% of the rated input voltage and frequency.
3. Drivers, LED load and test equipment should be warmed up at least 30 minutes prior to taking measurements.
4. Temperature should be maintained at a constant temperature of 25°C ± 5°C during the entire measurement period.
5. Measurements should be taken within 2% of the required dimmed output level.
6. Data recording interval ≤ 50 microseconds (equipment measurement rate ≥ 20 kHz)
7. Data capture duration ≥ 1 second

Processing of Data

1. Conduct a Fourier analysis to transform data for each dimming level into the frequency domain.
2. Filter frequency data for cut-off frequencies
3. Vector multiplication with cut-off vector
4. Cut-off vector: 1's below cut-off frequency and 0's for higher frequencies
5. Perform inverse Fourier transform to place data back in time domain.

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- Calculate percent amplitude modulation on resulting time domain data for each filtered dataset over the full sampling duration.

$$PAM = \frac{(Max - Min)}{(Max + Min)} \times 100$$

How compatibility affects flicker

Single stage drivers developed before the California Title 24 specification was ratified, are known to have 2 common characteristics:

- High ripple current
- PAM (Percent Amplitude Modulation) performance to be widely dependent on the load.

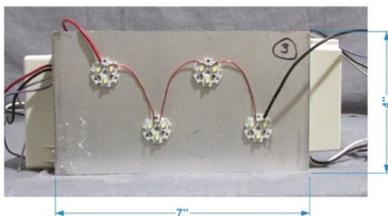
The new generation of LED drivers such as the ERP DRACO family uses a two-stage topology. This approach greatly reduces output ripple and therefore percent flicker.

Below are the results of three experiments we conducted that show how percent flicker changes depending on the LED load characteristics. Therefore, it is important to make sure that the lighting system components (dimmer, driver and LED load) are compatible. This can be accomplished by using compatible dimmers (compatibility lists are available for ERP drivers) and by testing and verifying performance of the dimmer/driver pair with the LED load.

Experiment number 1

Test using different LED loads with the same single stage driver and dimmer.

Setup 1:



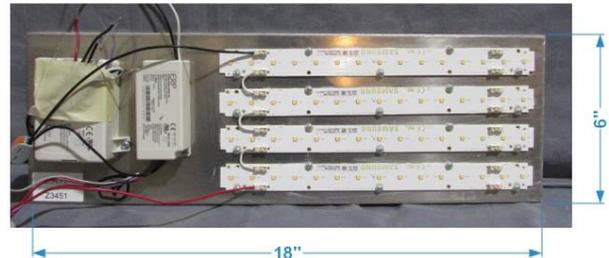
Driver: ESS030W-0700-42
LED: ESS_XPG2
Dimmer: LUTRON NOVA NTFTV

Percent Amplitude Modulation(PAM, %) at each dimming level

Filtering	Dimming level		
	100%	20%	10%
Unfiltered	21.105	19.350	16.896
40 Hz cut off	0.0087	0.0168	0.0275
90 Hz cut off	0.0224	0.0433	0.0806
200 Hz cut off	20.2780	14.2020	8.5440
400 Hz cut off	20.5890	16.4390	11.7490
1,000 Hz cut off	20.5800	16.7930	11.6660

Figure 4a. Flicker test with ESS030W-0700-42 driver and Cree XPG2

Setup 2:



Driver: ESS030W-0700-42
LED: Samsung mid-power
Dimmer: LUTRON NOVA NTFTV

Percent Amplitude Modulation(PAM, %) at each dimming level

Filtering	Dimming level		
	100%	20%	10%
Unfiltered	35.733	31.984	24.938
40 Hz cut off	0.0072	0.0159	0.0310
90 Hz cut off	0.0263	0.0409	0.0757
200 Hz cut off	34.7590	24.6890	14.5180
400 Hz cut off	35.6370	28.6720	19.9390
1,000 Hz cut off	35.5420	29.5680	20.2030

Figure 4b. Flicker test with ESS030W-0700-42 driver and Samsung mid-power LEDs

Experiment number 1 results:

Test results in figures 4a and 4b show different Percent Amplitude Modulation (PAM) readings with the same dimmer/driver pair but with different LED loads. By just changing the LED load we obtained different flicker performance. So, flicker performance is dependent on all the components in the lighting system and not just the driver. That is why it is essential to do full system testing where possible before final installation.

Experiment number 2:

Test using LED loads (with same LED chips) at different Vf with the same single stage driver and dimmer.

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Percent Amplitude Modulation results at:

LED	Driver	Serial Number	Dimmer	Load	Vf = 30 V			Vf = 36 V			Vf = 42 V		
					PAM			PAM			PAM		
Cree XPG2	ESS015W-0350-42	REW035042CB0717A01284	Lutron NTSTV (0-10 V)	100%	23.61%	19.20%	16.57%	23.61%	19.20%	16.57%	23.61%	19.20%	16.57%
				20%	18.78%	16.74%	13.00%	18.78%	16.74%	13.00%			
				10%	17.28%	14.61%	10.10%	17.28%	14.61%	10.10%			
			Lutron DVCL-153P	100%	32.40%	26.87%	22.82%	32.40%	26.87%	22.82%			
				20%	34.74%	29.85%	25.41%	34.74%	29.85%	25.41%			
				10%	29.28%	26.33%	22.01%	29.28%	26.33%	22.01%			
	ESS030W-0700-42	REW070042CF0217A03543	Lutron NTSTV (0-10 V)	100%	25.30%	20.54%	17.32%	25.30%	20.54%	17.32%			
				20%	21.68%	16.49%	13.87%	21.68%	16.49%	13.87%			
				10%	14.84%	11.88%	11.40%	14.84%	11.88%	11.40%			
			Lutron DVCL-153P	100%	34.50%	27.71%	22.72%	34.50%	27.71%	22.72%			
				20%	37.48%	28.60%	25.12%	37.48%	28.60%	25.12%			
				10%	31.61%	23.25%	21.33%	31.61%	23.25%	21.33%			
ESPO50W-1050-42	PEW105042D90117A00483	Lutron NTSTV (0-10 V)	100%	17.62%	15.26%	13.28%	17.62%	15.26%	13.28%				
			20%	15.98%	11.99%	11.04%	15.98%	11.99%	11.04%				
			10%	13.36%	10.40%	10.07%	13.36%	10.40%	10.07%				
		Lutron DVCL-153P	100%	24.30%	19.90%	17.66%	24.30%	19.90%	17.66%				
			20%	27.43%	22.40%	20.19%	27.43%	22.40%	20.19%				
			10%	23.37%	19.05%	17.23%	23.37%	19.05%	17.23%				

Figure 5a. Percent flicker results with Driver, Dimmer and LED load at different Vf's.

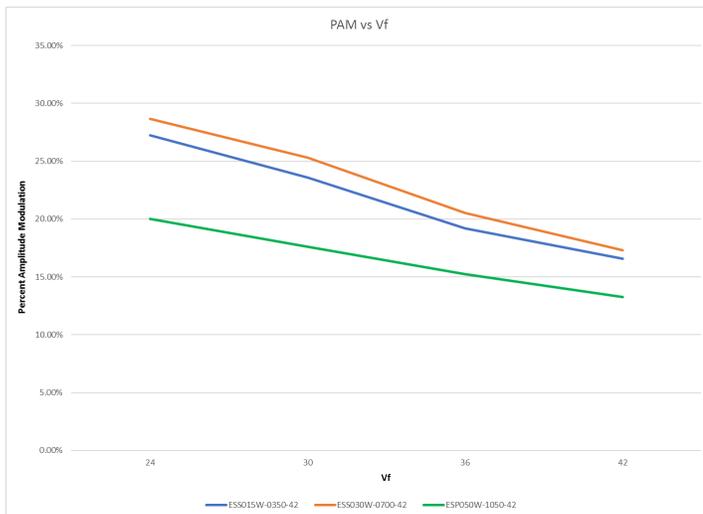


Figure 5b. shows the relationship between the total forward voltage and PAM using the same LEDs.

Experiment number 2 results:

1. The PAM (Percent Amplitude Modulation) changes as the Vf of the LED load changes even using the same type of LEDs.
2. With everything being the same, using a different dimmer the PAM (Percent Amplitude Modulation) changes.

Experiment number 3:

Test using LED loads (with same LED chips) at different Vf, with ERP's DRACO 2- stage driver.

Driver: PDB260-1700-210 (Draco1)

LED: Cree CXA2540

Dimmer: Lutron Nova NTFTV

Load Vf= 187.6 volts			
Filtering	Dimming level		
	100%	20%	min
Unfiltered	12.955	6.988	0.259
40 Hz cut off	0.207	0.199	0.193
90 Hz cut off	0.323	0.302	0.325
200 Hz cut off	12.666	7.351	0.140
400 Hz cut off	12.879	7.145	0.162
1000 Hz cut off	12.917	6.988	0.181

Figure 6a

Load Vf= 152.2 volts			
Filtering	Dimming level		
	100%	20%	min
Unfiltered	10.662	7.471	0.302
40 Hz cut off	0.192	0.253	0.200
90 Hz cut off	0.355	0.364	0.320
200 Hz cut off	10.523	6.905	0.153
400 Hz cut off	10.629	7.332	0.196
1000 Hz cut off	10.611	7.463	0.236

Figure 6b

Experiment number 3 results:

Notice that with a two-stage driver, changing the number of LED loads in series has very little effect on the Percent Amplitude Modulation.

Conclusion:

In order for LEDs to be adopted as a new lighting technology it must emulate as close as possible the performance of traditional lighting system. Flicker is one issue that must be minimized to offer a good user experience.

Testing the complete lighting system with all of its components is one way to insure the lowest possible flicker is obtained.

Another approach would be to use newer drivers with 2-stage topologies that are designed to have very little ripple which greatly reduce flicker. ERP's Draco series offers such drivers that have output ripple in the 10%

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range or lower as can be seen in figures 6a and 6b above.

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