U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

SSL Flicker Fundamentals and Why We Care

2014 LightFair

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Flicker - Terminology

Flicker, flutter, shimmer

- Repetitive change in magnitude over time, or modulation, of the luminous flux of a light source
- Light source modulation

- Visible, invisible, perceptible, detectable (sensation)
  - Sensation: External conditions are detected; neurons respond
  - Visible flicker = Luminous modulation is sensed and perceived
  - Invisible flicker = Luminous modulation is sensed, but not perceived

Flicker - Terminology

Stroboscopic vs. Phantom array effects

- Stroboscopic effect: Luminous flux modulation made perceptible by the motion of objects, when the observer's eye is still
- Phantom array effect: Luminous flux modulation made perceptible by the motion of the observer's eye, when the light source is still

Potential flicker-induced impairments

- Neurological problems, including epileptic seizure
- Headaches, fatigue, blurred vision, eyestrain
- Migraines
- Reduced visual task performance
- Increased autistic behaviors, especially in children
- Apparent slowing or stopping of motion (stroboscopic effect)
- Distraction

Flicker Factors

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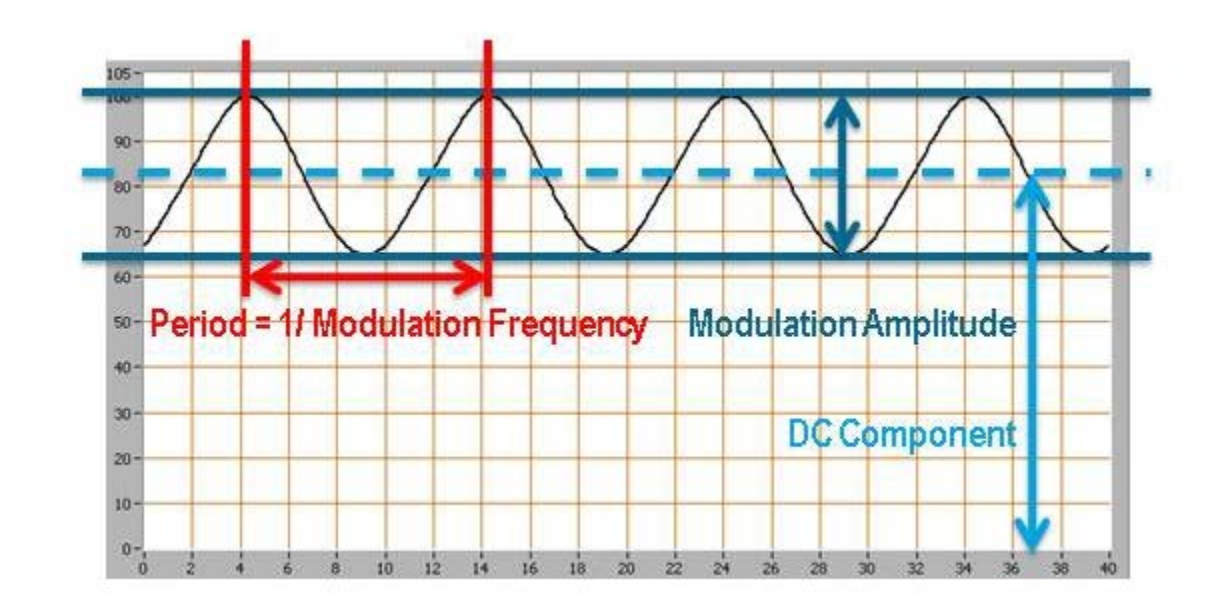
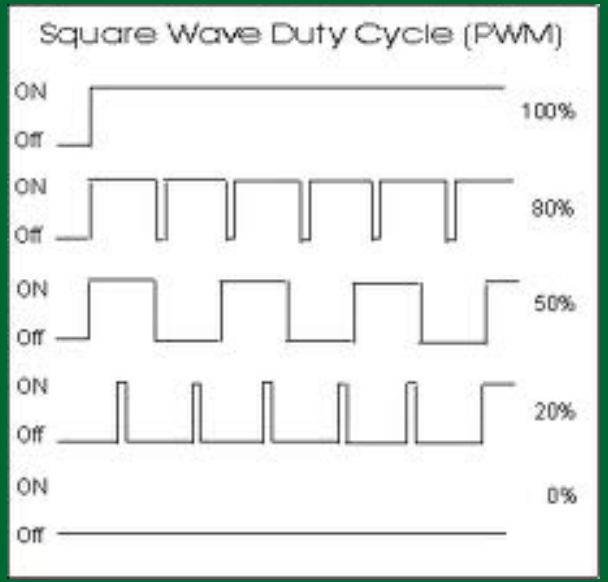
Flicker factors for both Visible and Invisible Flicker

- Modulation Frequency
- Modulation Amplitude
- DC Component
- Duty Cycle



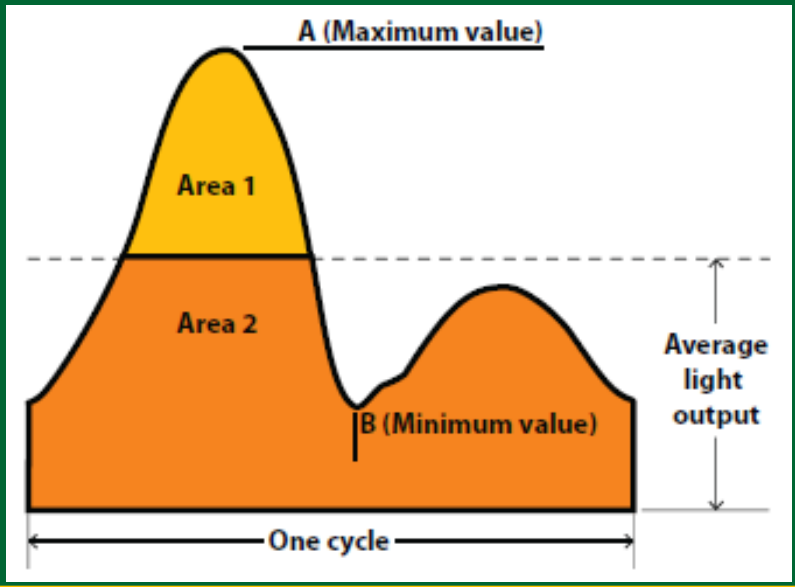


Flicker - Metrics

IESNA has defined two metrics for flicker:

- Percent flicker
  - 0-100% scale
  - Older, but more well-known and more commonly used
  - Accounts for average, peak-to-peak amplitude
  - Does not account for shape, duty cycle, frequency

- Flicker index
  - 0-1.0 scale
  - Newer, but less well-known and rarely used
  - Accounts for average, peak-to-peak amplitude, shape, duty cycle
  - Does not account for frequency

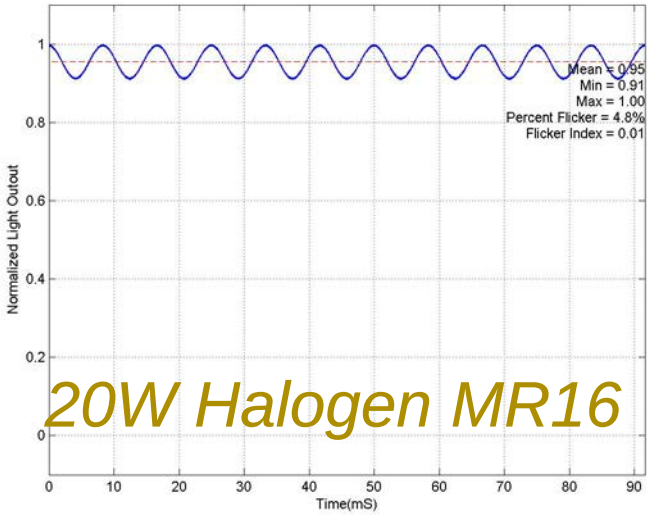


Source: IES Lighting Handbook, 10th Edition

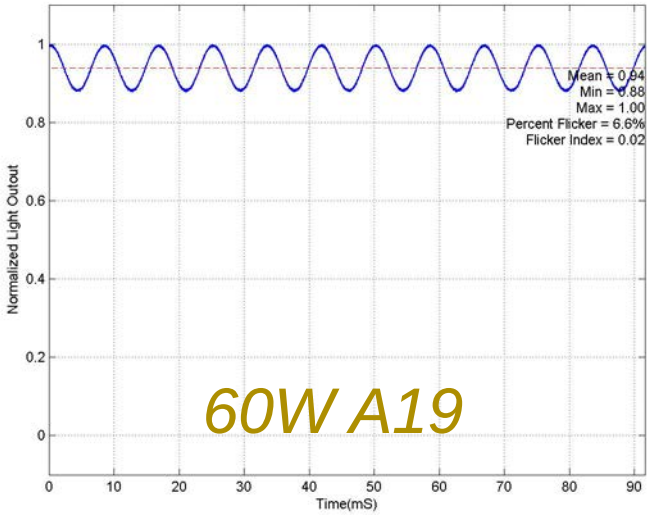
- Percent Flicker = $100\% \times \frac{A - B}{A + B}$

- Flicker Index = $\frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}}$

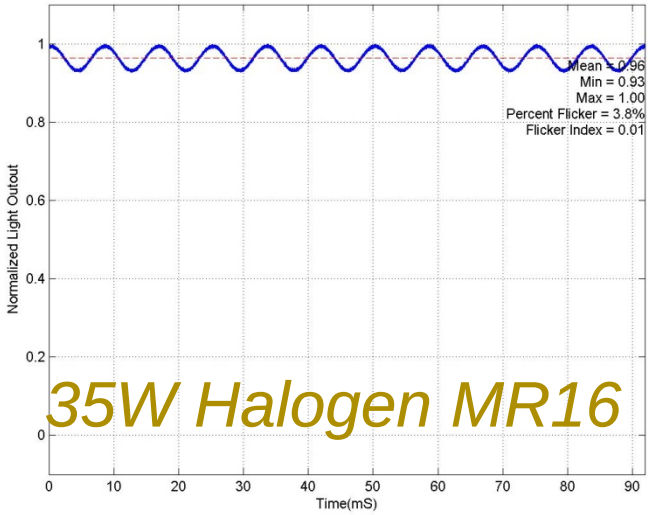
Incandescent, Halogen, Metal Halide



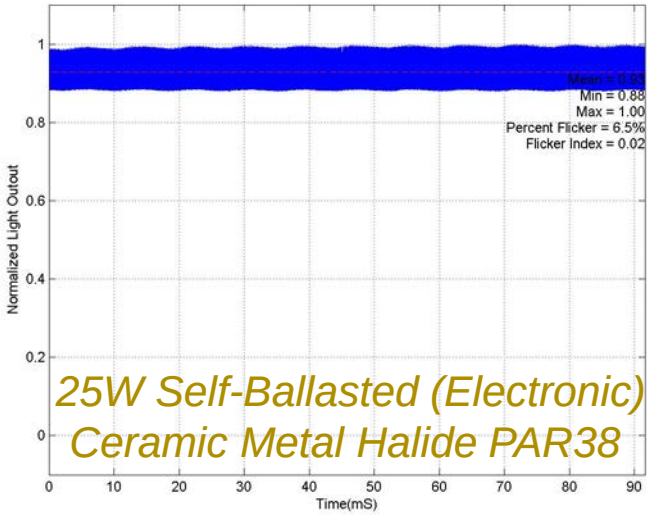
20W Halogen MR16



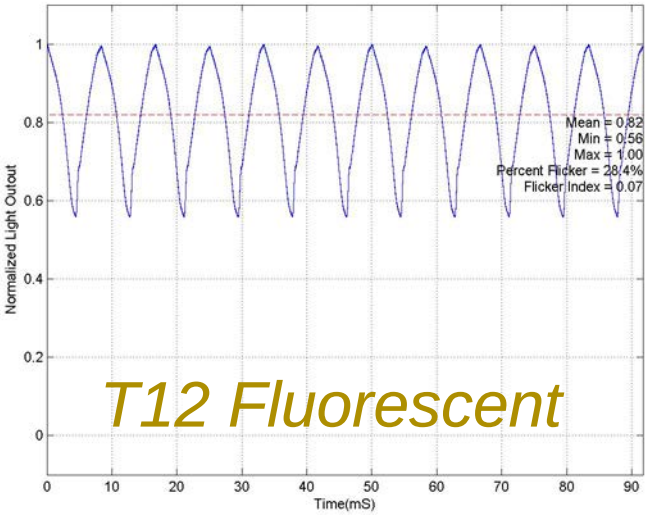
60W A19



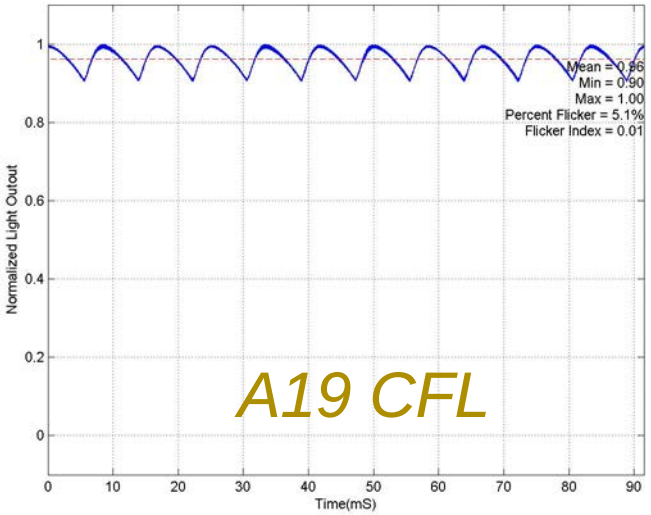
35W Halogen MR16



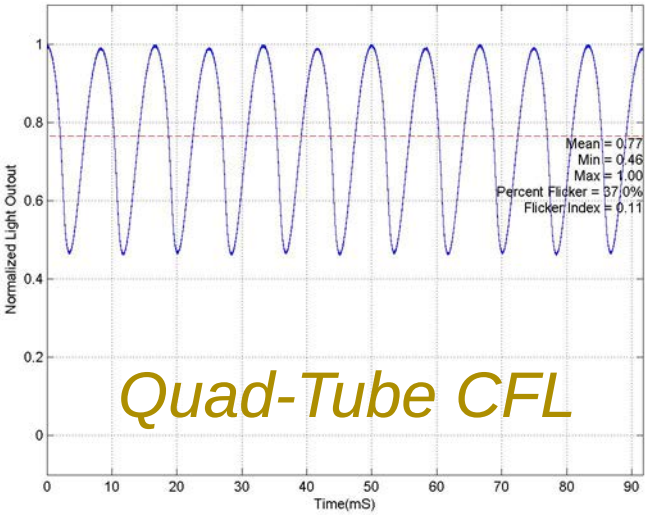
25W Self-Ballasted (Electronic) Ceramic Metal Halide PAR38



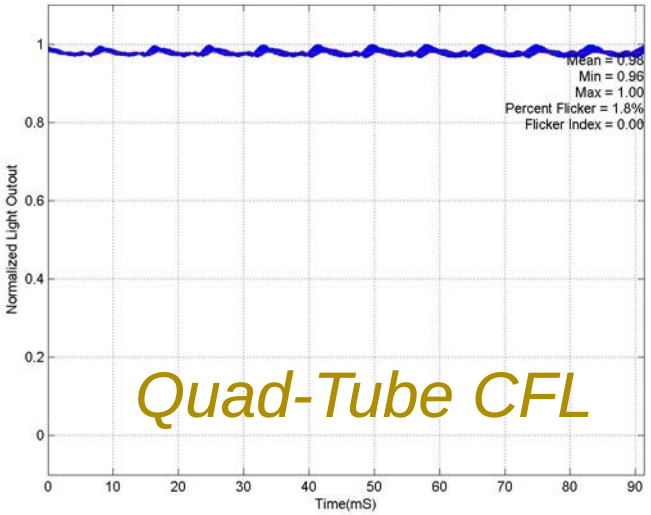
T12 Fluorescent



A19 CFL



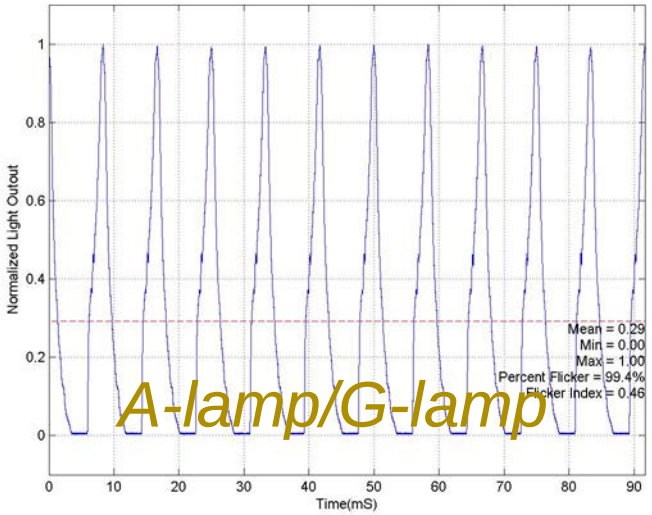
Quad-Tube CFL

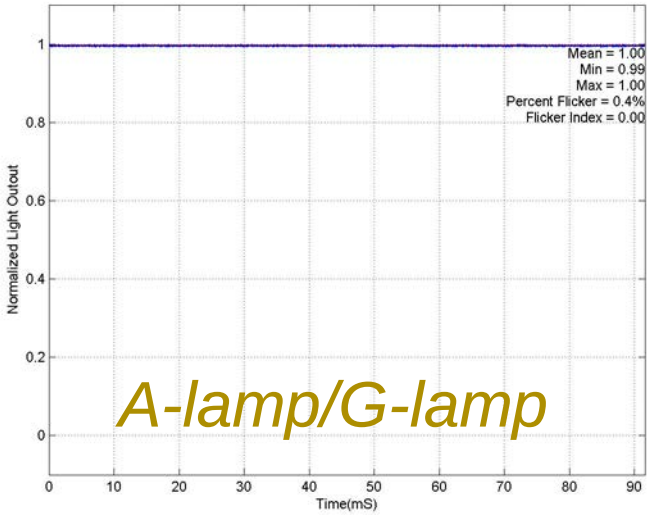


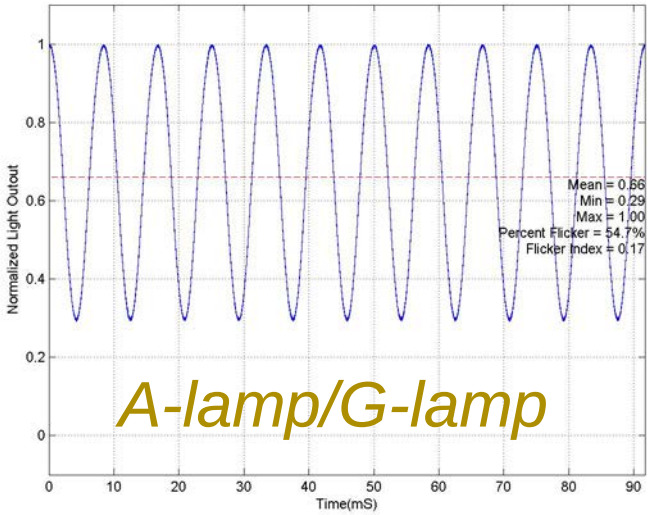
Quad-Tube CFL

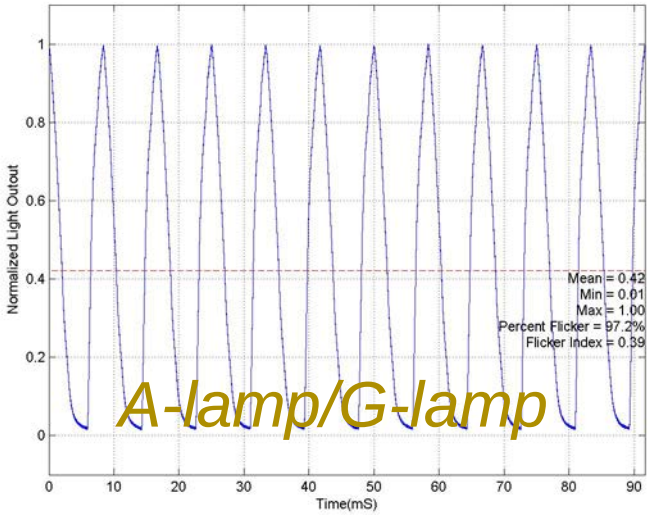
Magnetically-ballasted **Electronically-ballasted**

What about solid-state lighting (SSL)?









SSL: (almost) anything is possible …

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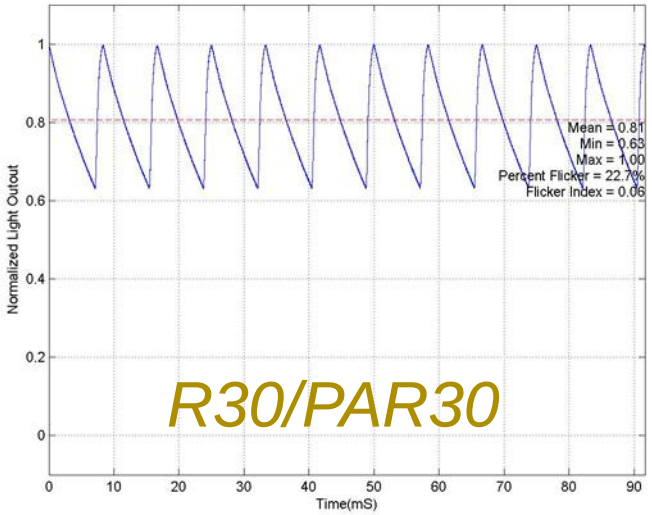

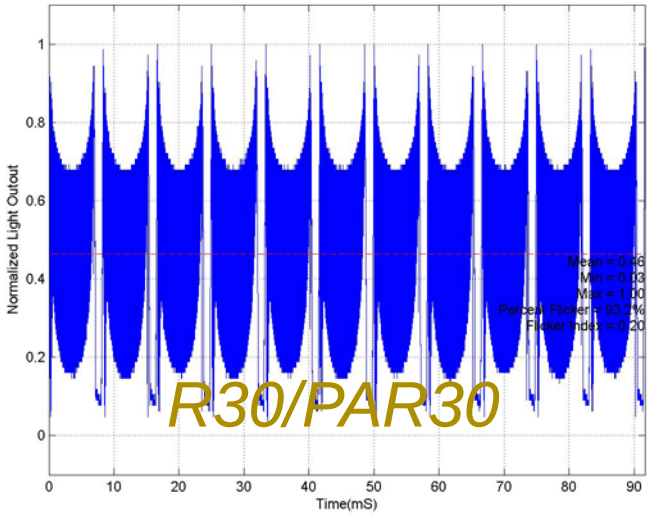

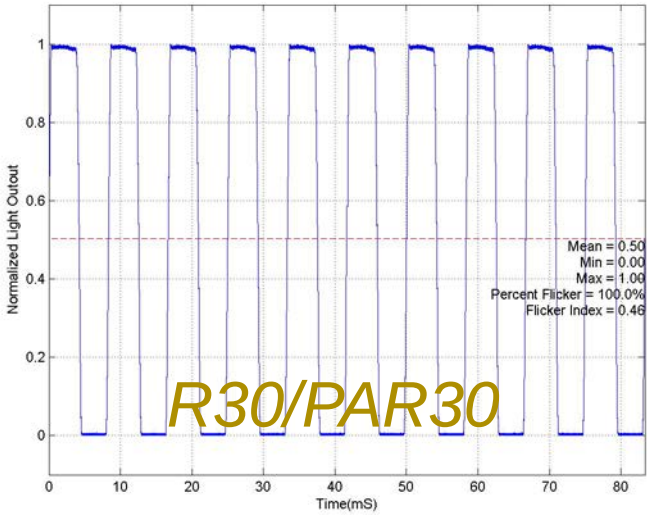

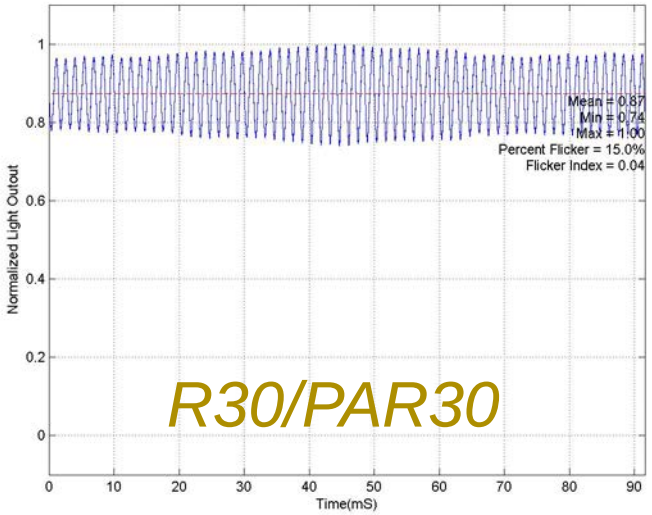

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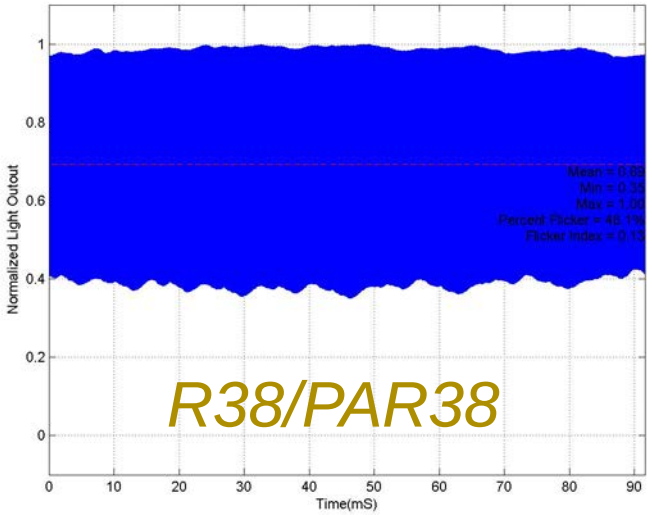

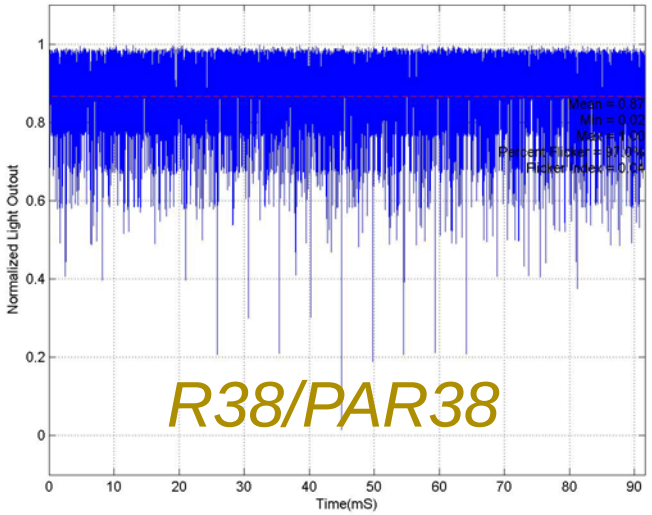

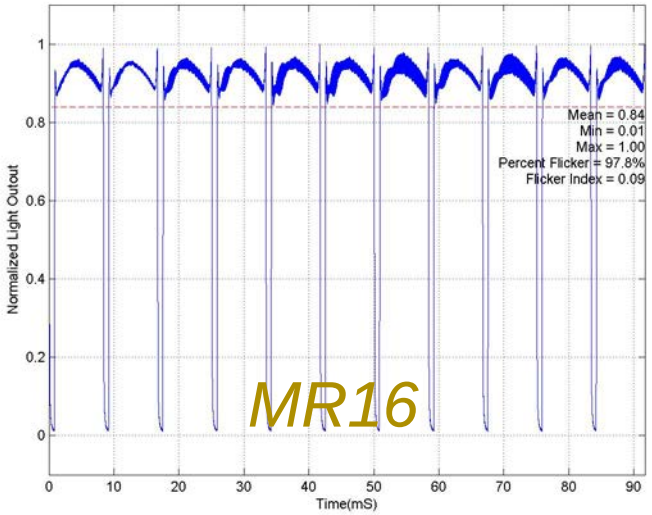

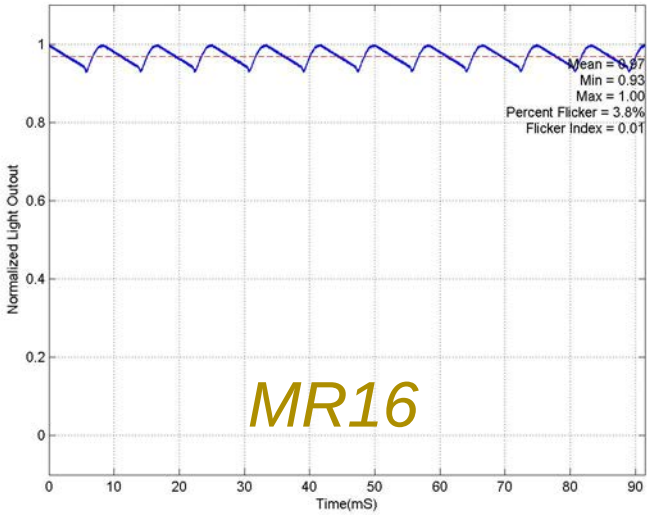

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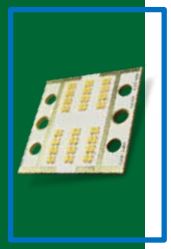
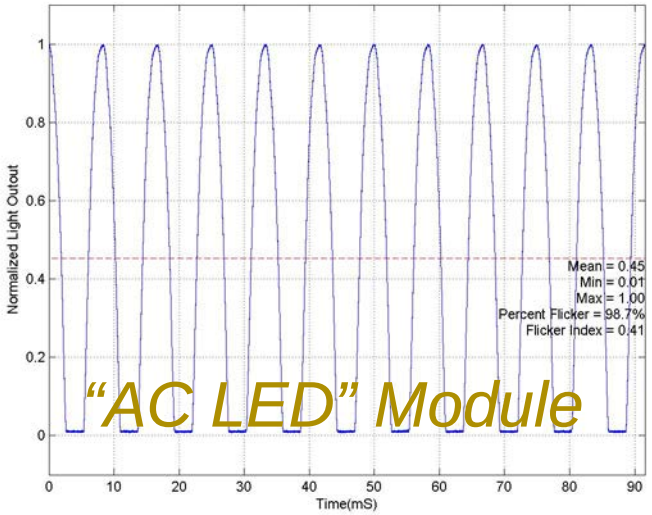
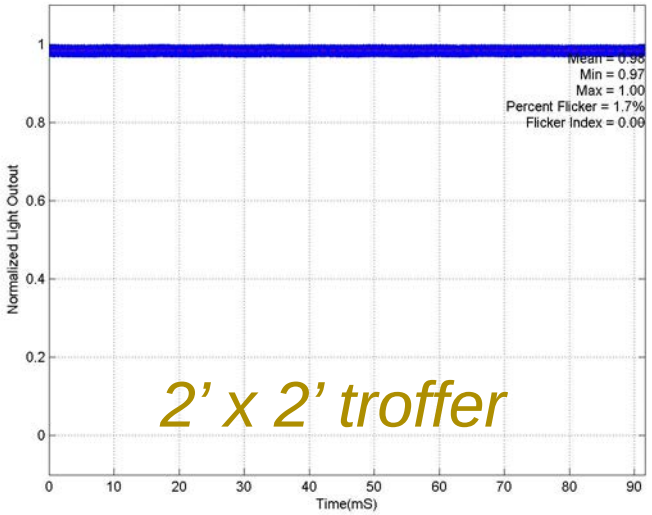
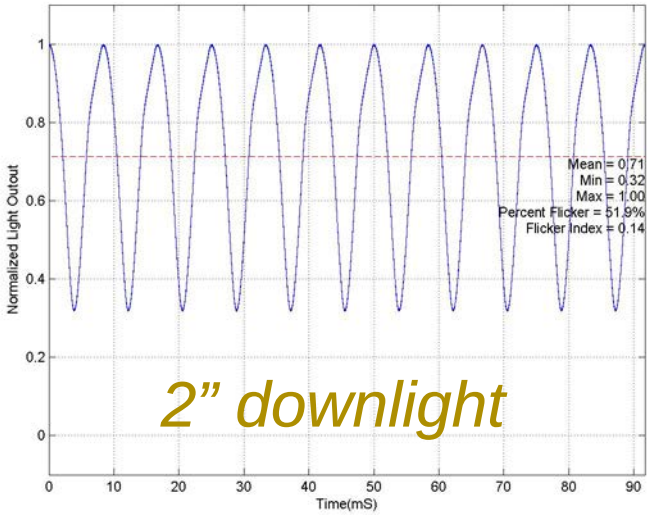




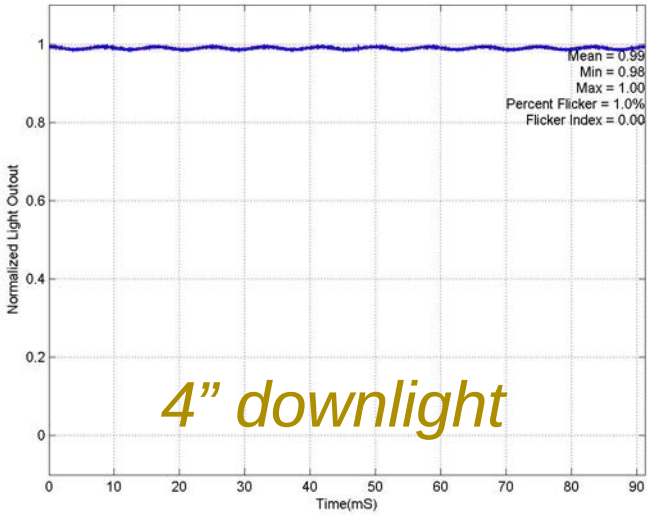
"AC LED" Module



2' x 2' troffer

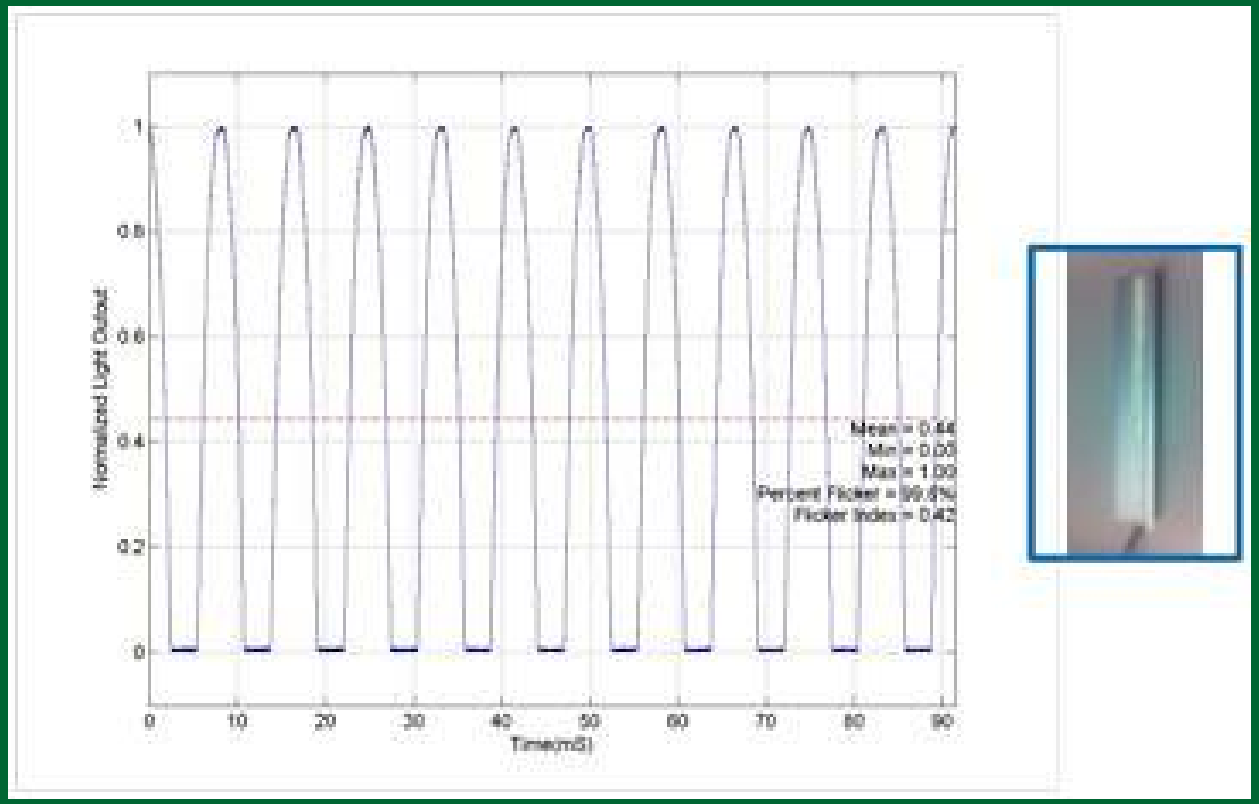


2" downlight



4" downlight

SSL Examples



Flicker typical of all tested SSL modules marketed as containing “AC LEDs”

Frame of Reference for All Products

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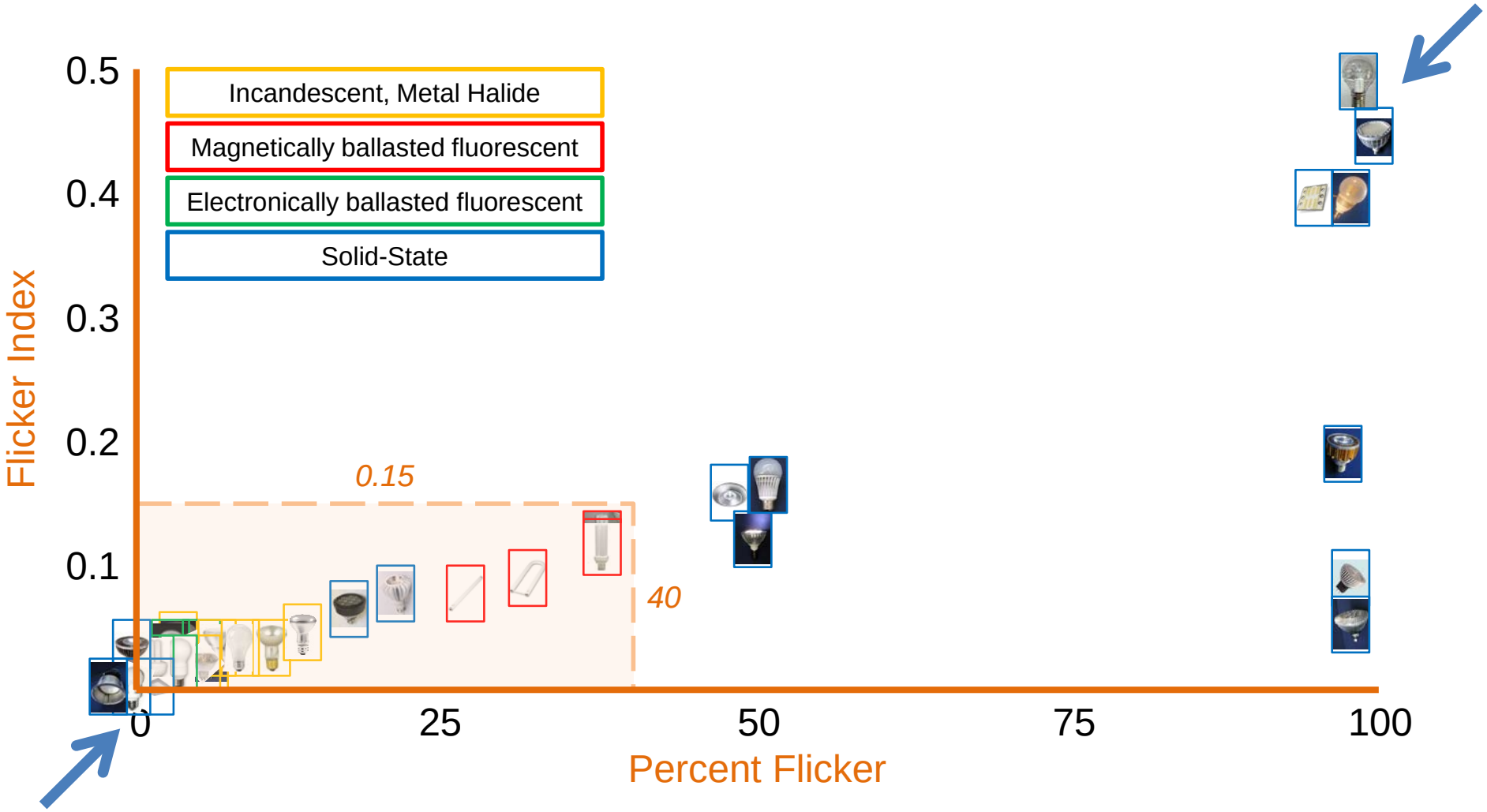
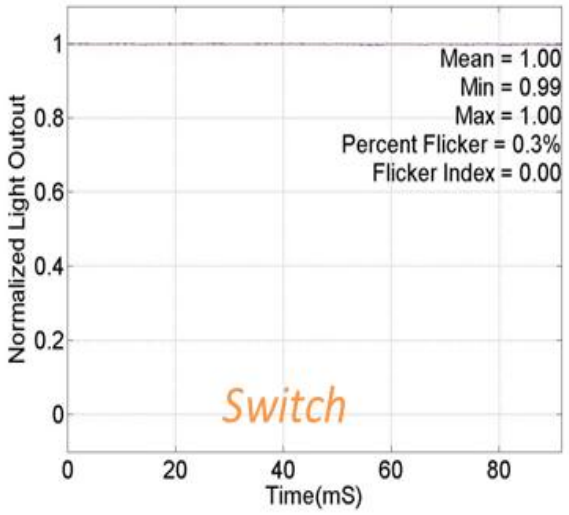
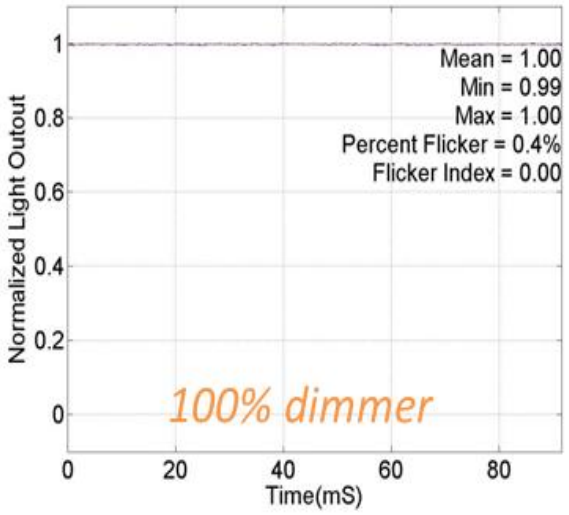
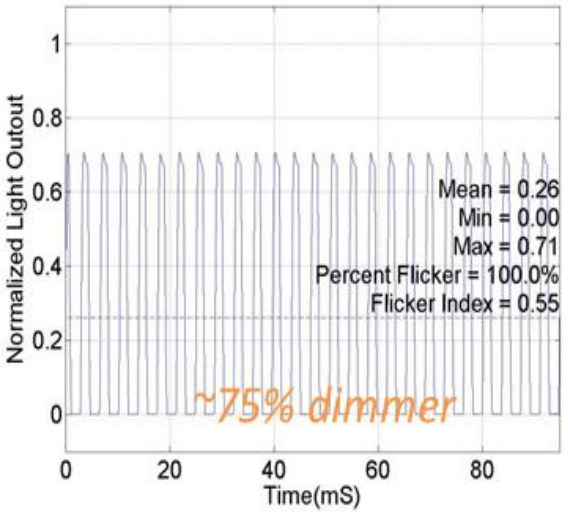


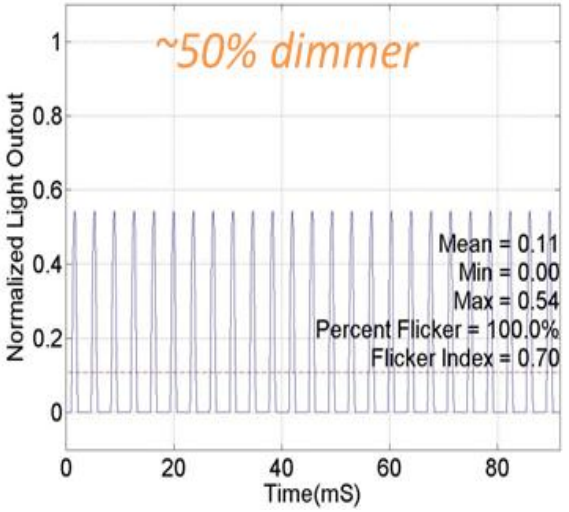
SSL products can be in the same range as conventional products, but can also be wildly different

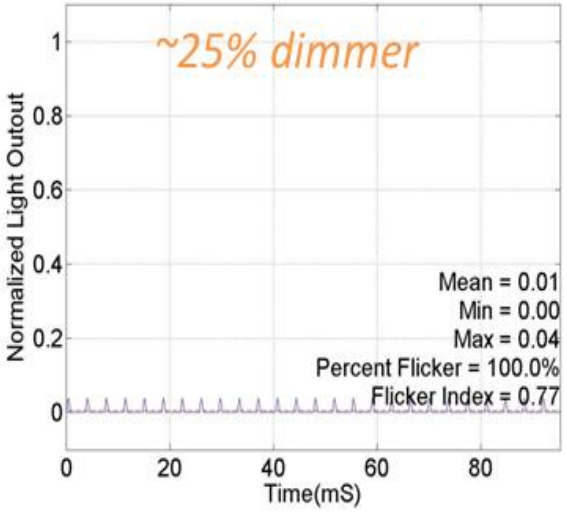
What do PWM dimming drivers do?

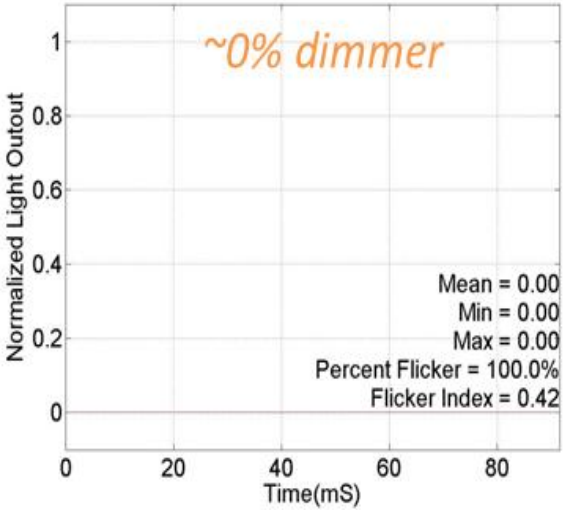












Example of flicker waveforms from a recessed LED troffer with 0-10V PWM dimming driver, exhibiting a flicker frequency around 250 Hz

Application – What makes flicker worse

- Duration of exposure (longer is worse)
- Area of the retina receiving stimulation (greater is worse)
- Location in visual field (central is worse because it projects to a greater area of the visual cortex, even though flicker is less noticeable)
- Brightness of the flash (higher luminances are worse; scotopic luminances produce low risk, high mesopic and photopic luminances produce higher risk)
- Contrast of the flash with the surround luminance (higher is worse)
- Color contrast of flash (deep red is worse)

How can you tell if a product flickers?

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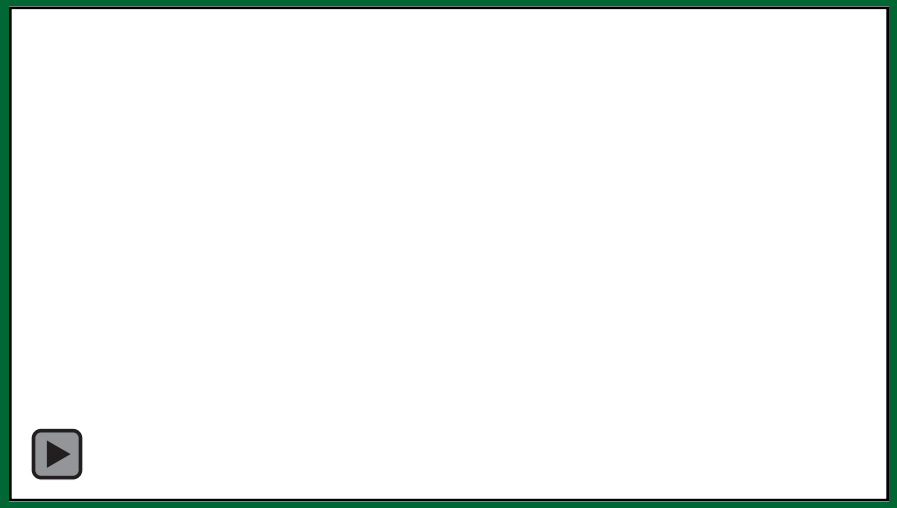
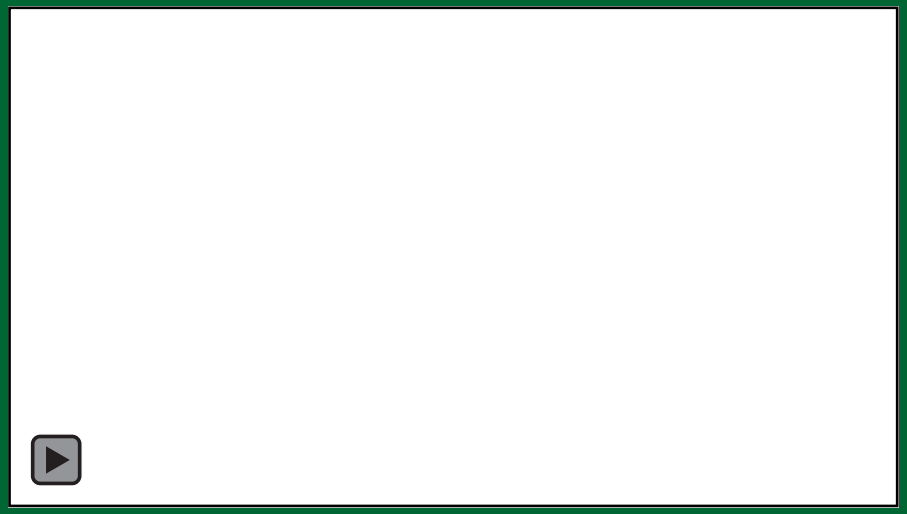
- No reliable metric is reported by manufacturers
- See the product in person, with the same driver/transformer/dimming setting of final installation
- Try a flicker wheel or a spinning top
- Sometimes a digital camera will pick up flicker
- Wave your fingers in the light; look for strobe effect



No flicker



Flicker

Application - Where Flicker Matters

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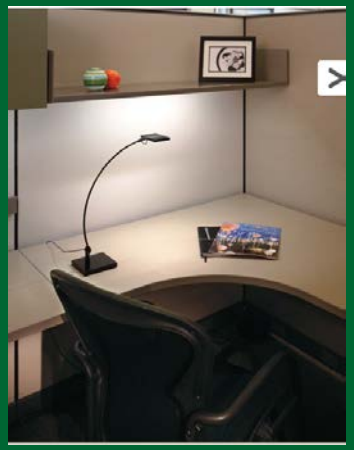
General lighting

Hospitals/clinics

Classrooms



Task lighting

Industrial spaces

Offices

Where flicker is less important

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Roadways/parking lots

Sports and industrial lighting on 3-phase electrical system

Accent lighting on artwork

Very low intensity holiday lighting?

Where flicker might be an advantage

Warning lights

Discotheques

(Just please avoid the epilepsy frequencies and use for very short duration)

Products more likely to Flicker

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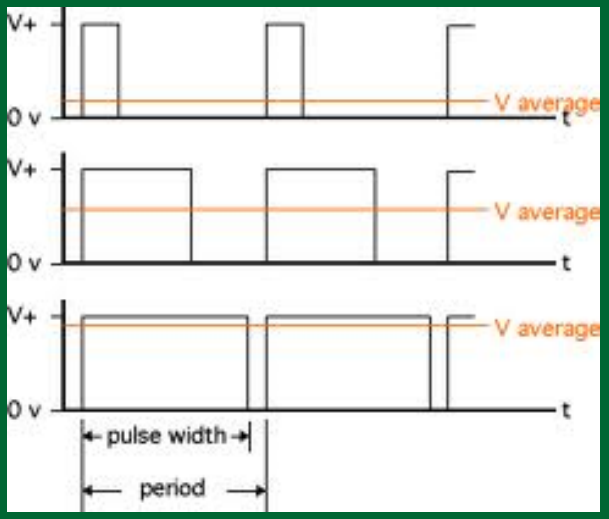
- AC LEDs
- DC LEDs with simple/inexpensive drivers (e.g., inadequate capacitors)
- Integral lamp LEDs on some electronic transformers
- LEDs dimmed with phase cut dimmers (triac, e.g.)
- LEDs dimmed with Pulse Width Modulation (PWM) dimmers



Managing Risk: Recommendations

DOE and other Government agencies:

- Support flicker measurement/flicker standard development

Utilities and energy efficiency organizations

- Require flicker documentation for EE programs

Manufacturers:

- Be proactive now. Test for flicker. Test over dimming range.
- Demand drivers that produce less flicker
- Avoid PWM dimming unless combined with other techniques
- Publish flicker waveforms and flicker metrics

Specifiers

- Avoid products more likely to produce flicker
- See products in person. Learn to test for flicker.
- Use conservative flicker specifications for critical applications

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Building Technologies Office
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

Flicker

The advancement of commercially available LED products is reopening discussions on how the performance of light sources should be evaluated. This includes questions about the necessity of characterizing light sources for flicker, the (potentially visible) temporal variation of emitted light. While conventional light sources operating on alternating current (AC) modulate light output, the variety and severity of modulation seen with LED products—from good to poor—has sparked new interest in quantifying and understanding its impact.

The stroboscopic effect is just one of many potential consequences of flicker. The lamp used for the image on the left does not flicker and thus the moving object is a smooth blur. Because it does flicker, the lamp used for the image on the right appears to create multiple instances of a moving object.

Introduction

All conventional light sources—including incandescent, high intensity discharge (HID), and fluorescent—modulate luminous flux and intensity, whether perceptible or not. Many terms are used when referring to this time-variation, including flicker, flutter, and shimmer. The flicker produced by electric light sources can be a function of how it converts AC electricity to light, or the result of noise or transient events on AC distribution lines. Electrical flicker should not be confused with photometric flicker, which is modulation that is characteristic of the light source itself, rather than disturbances to its electrical input. Light source characteristics that can affect photometric flicker vary by technology; examples include filament thickness for incandescent, phosphor persistence for fluorescent and coated metal halide, and circuit designs for electronically ballasted or driven sources.

LED flicker characteristics are primarily a function of the LED driver. Different circuit architectures present different sets of performance trade-offs for a driver designer, with cost and form factor restrictions further limiting the choices available. For example, a low cost requirement for a small integral lamp may force a fundamental trade-off between flicker and power factor. Dimming an LED source can increase or induce flicker, most notably when phase-cut controls are used and/or pulse-width modulation (PWM) is employed within the driver to reduce the average light output from the LED source.

Why Flicker Matters

Photometric flicker from magnetically-ballasted fluorescent, metal halide, and high-pressure sodium lamps has been a concern of the lighting community because of its potential human impacts, which range from distraction or mild annoyance to neurological problems. The effects of flicker are dependent on the light modulation characteristics of the given source, the ambient light conditions, the sensitivity of the individuals using the space, and the tasks performed. Low-frequency flicker can induce seizures in people with photosensitive epilepsy, and the flicker in magnetically-ballasted fluorescent lamps used for office lighting has been linked to headaches, fatigue, blurred vision, eyestrain, and reduced visual task performance for certain populations. Flicker can also produce hazardous phantom array effects—which may lead to distraction when driving at night, for example—or stroboscopic effects, which may result in the apparent slowing or stopping of moving machinery in an industrial setting.

When discussing the potential human impacts of flicker, it is important to understand the difference between sensation and perception. Sensation is the physiological detection of external conditions that can lead to a nervous system response, while perception is the process by which the brain interprets sensory information. Some sensory information is not perceived, and some perceptions do not accurately reflect the external conditions. As a result, some people who suffer from flicker sensitivity may not be aware that flicker is the reason they are suffering, or even that the light source responsible for their suffering is flickering. Furthermore, not all human observers are equally sensitive to the potential effects of flicker. Populations that tend to be more susceptible to the effects of flicker include children, people with autism, and migraineurs. While the sizes of some specific at-risk populations have been characterized—approximately 1 in 4,000 humans suffer from photosensitive epilepsy, for example—most have not.

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

Want more? Try the Flicker Fact Sheet

And now for questions!

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And

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