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.

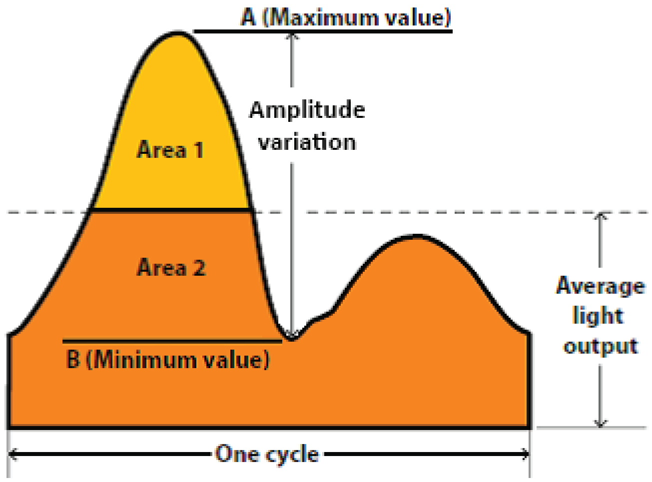
Why Flicker Matters

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



$$\text{Percent Flicker} = 100\% \times \frac{A - B}{A + B} \qquad \text{Flicker Index} = \frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}}$$

Figure 1. Periodic waveform characteristics used in the calculation of flicker metrics. *Modified from IES Lighting Handbook, 10th Edition.*

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 is able to account for differences in periodic frequency. An example of a periodic waveform is shown in Figure 1, 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 affect, 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.

Flicker in Commercially Available Light Sources

Evaluating the performance of any new technology should start with an understanding of how the incumbents perform. Figure 2 illustrates the luminous flux variation over time and flicker metrics (Percent Flicker and Flicker Index) of six conventional lamps, including incandescent, electronically ballasted metal halide, and both magnetically and electronically ballasted fluorescent products, as measured by the DOE CALiPER program. For conventional sources (including magnetically ballasted fluorescent), the maximum Percent Flicker is on the order of 40% and the maximum Flicker Index is roughly 0.15.

LED products, by contrast, exhibit a wide variation in characteristics, as shown in Figure 3. These examples were chosen to demonstrate—to some degree—the extent of variation seen in commercially available products, and do not represent a statistical sample of all products on the market or even all products measured by DOE. Note that LED sources exhibit variation across all the flicker waveform attributes, exceeding the ranges exhibited by conventional lighting. Some LED sources produce little to no discernible flicker, while others exhibit large variation in amplitude (as evidenced by waveforms with a Percent Flicker value of 100%) and shape. Perhaps most significantly, some of the periodic frequencies measured by CALiPER are not seen in typical conventional sources, and flicker characteristics do not appear to correlate well with any LED source characteristics (e.g., product type, driver type, or input power). Flicker frequency is not captured by the existing flicker metrics, even though flicker may be less noticeable when the modulation is at a higher frequency.

Recommendations

Flicker can be a significant detriment to lighting quality, but it is rarely considered in the design or specification process. The flicker characteristics seen in some products pose a concern for anyone responsible for human health, well-being, or performance in spaces with electric lighting. Standardized flicker measurement procedures are not yet in place, and existing flicker metrics have inadequacies that may be exposed by LED products. Further, there are no well-defined thresholds that would enable those metrics to be used to identify problematic flicker for specific applications or populations. Nevertheless, flicker metrics can be a first step to compare two sources—lower values are better. If flicker waveforms are available, the specifier can identify better products by looking for less amplitude modulation, a higher average level (relative to the maximum and minimum values), and a higher periodic frequency.

In the absence of flicker metrics and waveforms, specifiers can pursue qualitative means for evaluating flicker. Specifiers should consider how the risk of flicker-related problems is heightened or reduced by a given light source, the type of space, its occupants, and the tasks being performed. LED systems should always be visually evaluated, ideally with flicker-sensitive clients. Waving a finger or pencil rapidly under the LED source, or spinning a flicker wheel, can expose the presence of flicker through the stroboscopic effect, even for those who are not naturally sensitive. Low flicker sources should always be used for both ambient lighting and task lighting in offices, classrooms, laboratories, corridors, and industrial spaces. Minimizing flicker is especially important where susceptible populations spend considerable time, such as hospitals, clinics, medical offices, classrooms, and daycare centers. In contrast, flicker may be less of a concern for parking lots, roadways, or other exterior lighting where light levels are lower and people spend less time. Indoors, sources with more flicker may be acceptable when used for accent lighting of objects, or when mixed with low-flicker lighting systems or daylight. A number of task dependent factors can be considered when evaluating flicker risks, including the duration of direct exposure (longer is worse), the retinal area being stimulated (greater is worse), the contrast with surround luminance (more

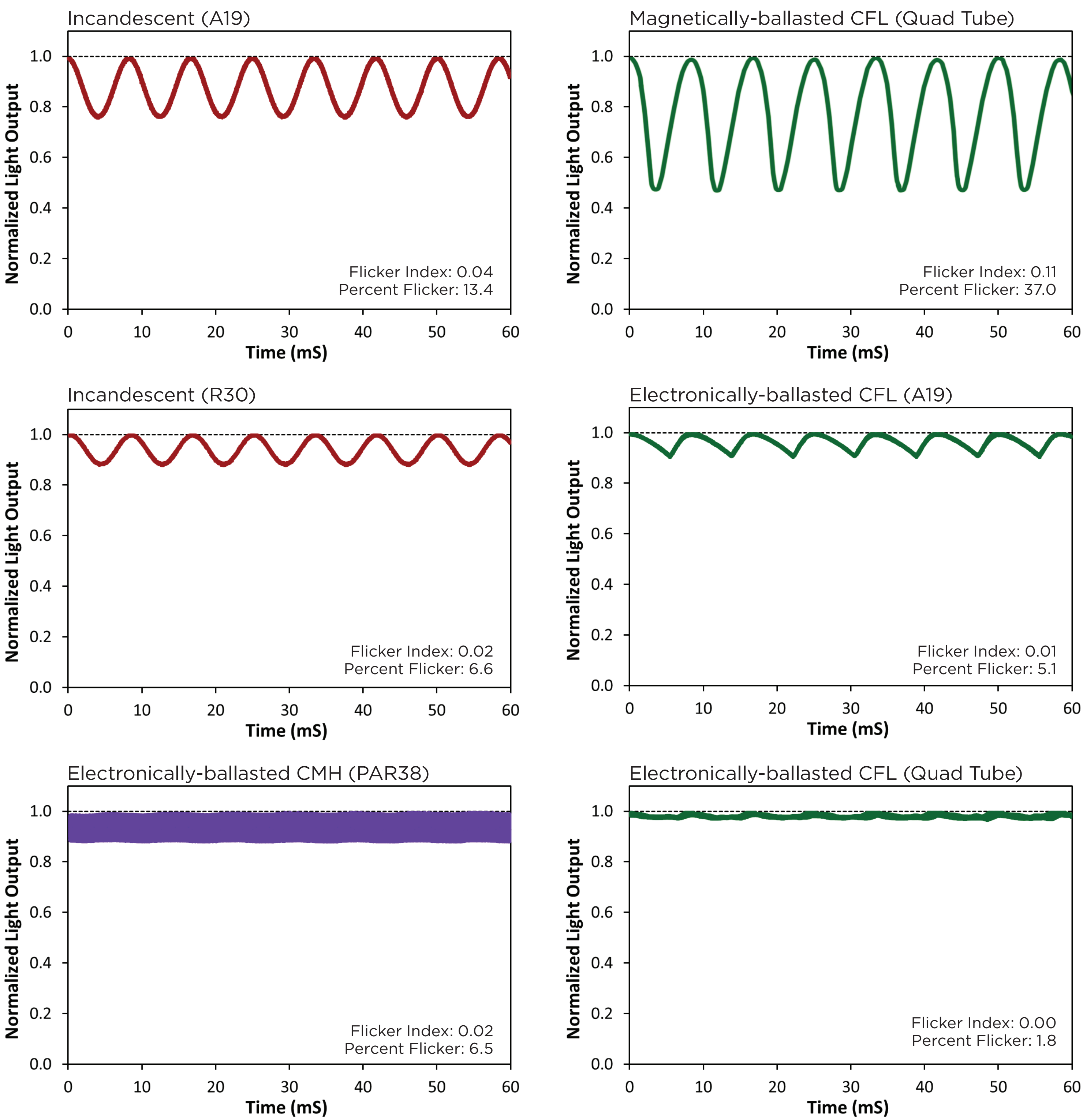


Figure 2. Examples of modulating light output for conventional lamps. The modulation of incandescent sources does not typically lead to perceptible flicker, but magnetically-ballasted fluorescent lamps are known to cause issues for some people.

is worse), the amount of color contrast (more is worse), and the amount of eye or object motion (more is worse).

Flicker is garnering increasing attention from manufacturers, as well as the standards and specification community. Some manufacturers appear to be giving flicker increased design priority, as evidenced by the improved performance of new product generations. The IES and CIE are considering the development of measurement standards, an IEEE group is working on recommended practices for evaluating flicker risks, and the EPA ENERGY STAR® and California Title 20 programs are considering the adoption of flicker criteria. Collectively, these efforts may make it easier for designers and specifiers to minimize the risk of flicker-induced problems for their clients in the near future.

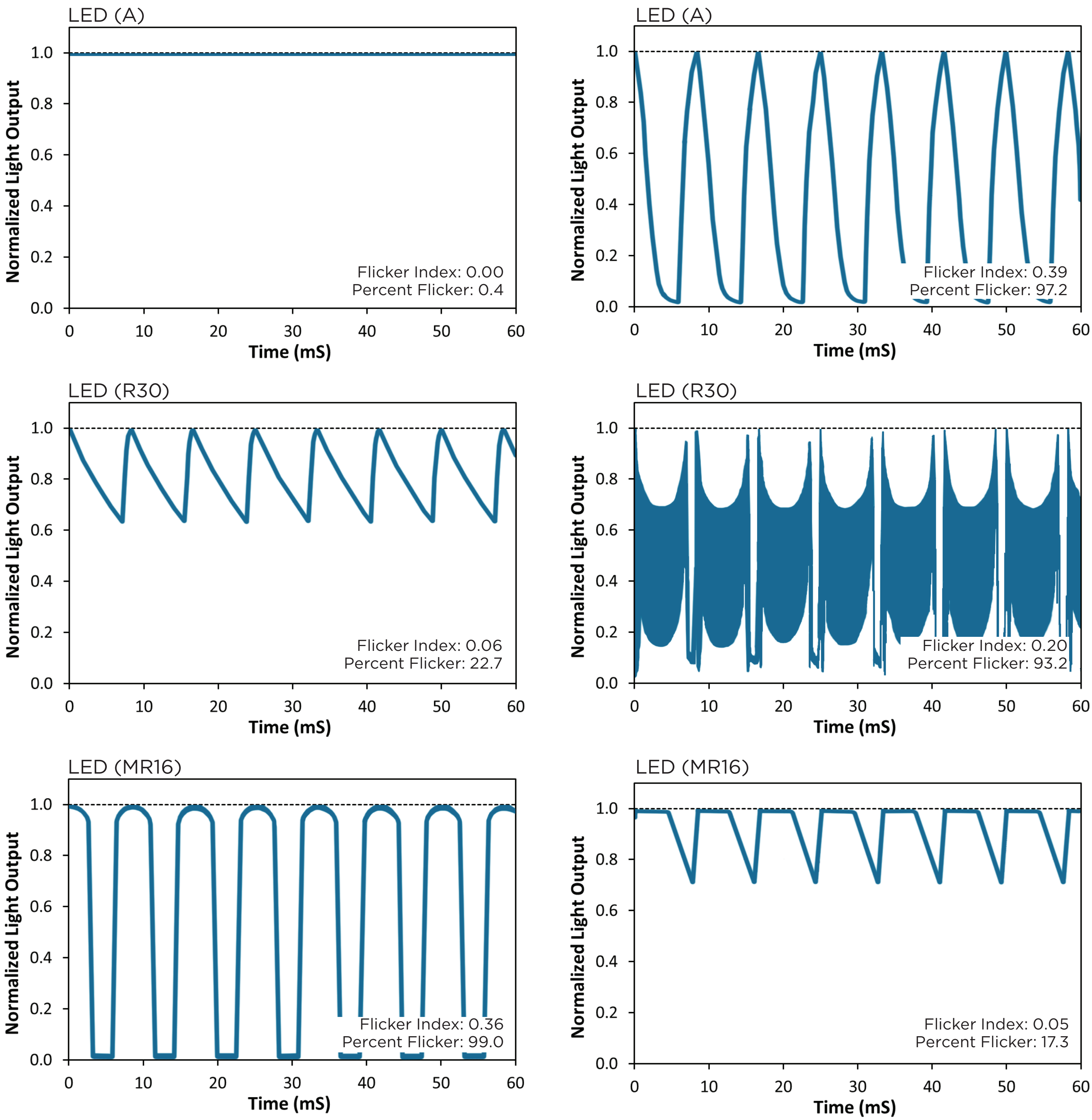


Figure 3. Flicker measurements from LED sources. Examples were chosen to demonstrate some of the observed variation.

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