Concerns in the Age of the LED: Temporal Light Artifacts

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Flicker and stroboscopic effect are presently hot topics in lighting, along with other subjects like blue light (subject of a recent FIRES article [1]). A National Electrical Manufacturers Association (NEMA) standard, NEMA 77[1], addresses measures for temporal light artifacts (TLA), which is an umbrella term covering both flicker and stroboscopic effect (as well as phantom arrays; see **Comment** at the end). The NEMA metrics for flicker (short-term flicker indicator, P_{st}) and stroboscopic effect (Stroboscopic Visibility Measure, SVM) are both based on experiments done with many human observers, to measure average human sensitivity to flicker and stroboscopic effects.

The strict definitions of *flicker*, *stroboscopic effect*, and *temporal light artifact* are given in CIE TN 006[2]. **Flicker** is the perception that a light source is varying in intensity with time, when neither the viewer's eyes, nor the light source, nor the objects in the lit space are moving. It may be observed at light modulation frequencies up to about 80 Hz. **Stroboscopic effect** is the perception that the brightness of a moving object is changing in intensity as it moves through the lit space **(Figure 1)**, when the eye is not moving. If the light source is modulated by a square wave, for instance, then a moving object will appear as an array of objects, instead of a streak, because the object is in different locations when the light is on than when it is off. Stroboscopic effect plays a role from frequencies near 80 Hz, up to about 2,000 Hz, in typical office environments.

The word *flicker* has often been used imprecisely to mean both flicker, as described above, as well as stroboscopic effect. These are two separate physical effects and deserve precise definitions. (Flicker creates an image in one spot on the retina, and the change in light must be slow enough that that spot can react to the change in light sufficiently to yield detection of flicker. Stroboscopic effect creates a series of images, each in a different spot on the retina, which is detectable to much higher frequencies.) Another confusing term sometimes used is *invisible flicker*, which is apparently used to describe stroboscopic effect, even though it is not invisible (although many people are not able to describe it without demonstrations and instruction).

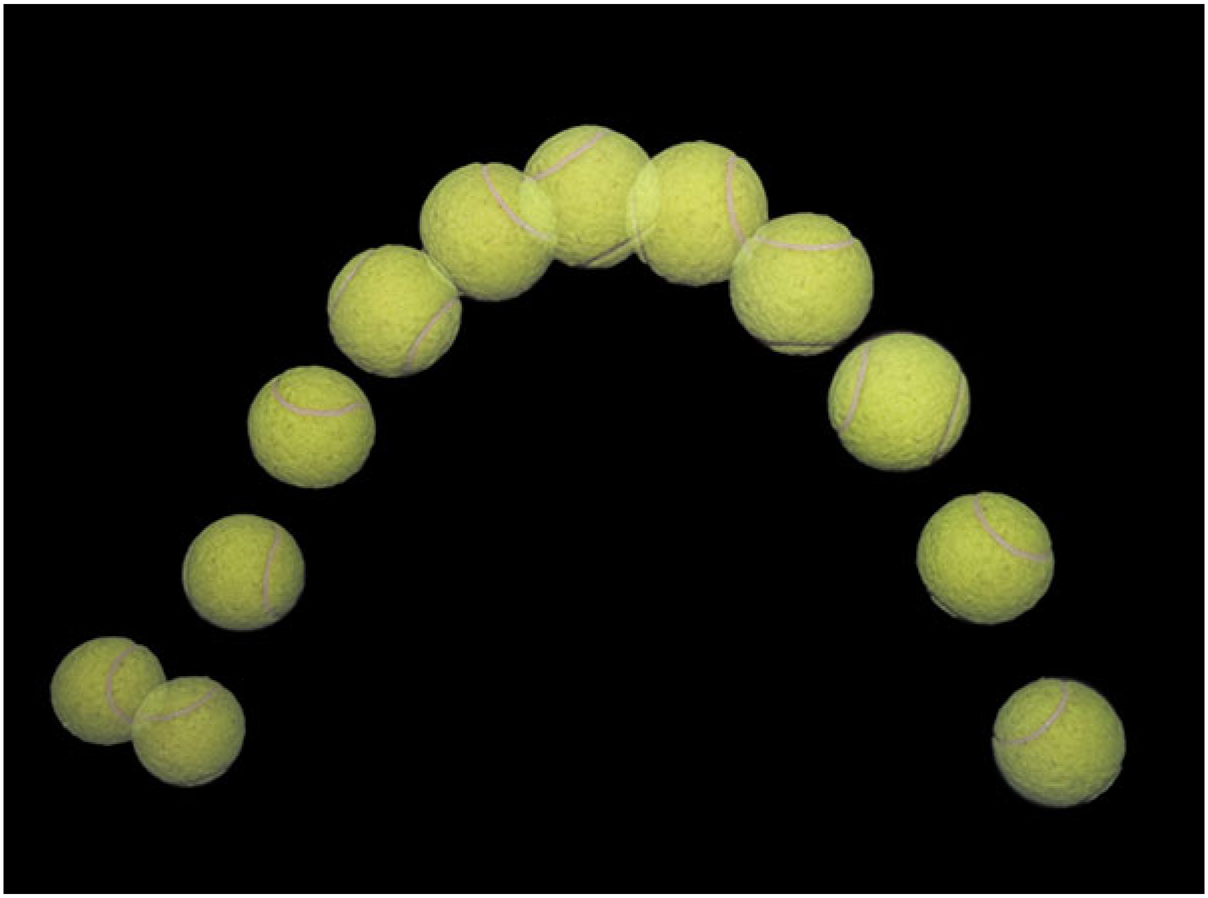

Figure 1: An example of the stroboscopic effect, measured with a short duty cycle and 100% modulation.

At the *detectability threshold*, where P_{st} = 1 or SVM = 1, a hypothetical average observer* can detect flicker or stroboscopic effect, respectively, with probability of 50%. For these metrics, a lower value means the effect is less likely to be noticed, and a higher value means the effect is more likely to be noticed. So isn't it a weak requirement, then, to set limits of P_{st} = 1 or SVM = 1.6 (these are the guidelines given in NEMA 77 [1]), if people will experience flicker or stroboscopic effect 50% (or more) of the time?

To explain P_{st} = 1 in simple terms: Imagine that an observer is given a dial that adjusts the amount of flicker from a light source. The observer is then asked to adjust the dial so that the flicker is just not visible, then asked to turn the knob a tiny bit back to make the flicker just visible. The detectability threshold for a hypothetical average observer, therefore, is the flicker condition where 50% of observers will say that it flickers and 50% will say that it doesn't.

Flicker – P_{st}

The short-term flicker indicator, P_{st}, is defined in the IEC 61000-4-15[3], specification of a flickermeter, which simulates the behavior of an incandescent lamp, perceived by an average observer, when the mains voltage is distorted. IEC 61000-3-3[4] defines the maximum levels of voltage disturbances that electrical equipment (e.g., washing machines, cookers, air conditioners) may generate on the mains voltage. P_{st} = 1 *when the maximum allowed level of distortion is* *applied to the mains voltage waveform*. IEC TR 61547-1[5] adapts IEC 61000-4-15[3] for use with light sources of any technology. The document provides a way to evaluate the immunity of a light source to the effects of disturbances on the mains voltage (which are the most important root cause of flicker).

Any lamp with a full-wave diode bridge at the input will have low flicker (P_{st} approximately 0) when undistorted mains current drives the lamp. No frequencies below 100 or 120 Hz (2 times mains frequency) are present on the mains. Because flicker is only visible to the human eye below approximately 80 Hz, it is impossible for such a lamp to flicker when operated with undistorted mains current.

In most actual conditions, mains distortions will not be present. IEC TR 61547-1[5] has examples of flicker from three typical lamps, when no voltage fluctuations are applied, showing that P_{st} is very small:

EUT	Type	P_{st}^{LM}
1	60 W incandescent lamp	0,025
2	9 W self-ballasted CFL lamp	0,023
3	7 W self-ballasted LED lamp	0,028

When the five voltage fluctuation test conditions defined in IEC TR 61547-1[5] are applied, P_{st} increases for these same lamps to a worst-case P_{st} of 1.0, 0.54 and 0.47, respectively. The incandescent lamp gives the expected behavior (P_{st} = 1). The particular CFL and LED lamps chosen for this study have built-in immunity that gives P_{st} less than 1, and lower flicker than an incandescent lamp, when the specified voltage fluctuations are present. (This is not the case for every CFL and LED lamp! Some have low P_{st} when tested with undisturbed mains voltage, but P_{st} higher than 1 when the voltage fluctuations are applied.) Unlike IEC TR 61547-1[5], NEMA 77[1] does not define specific voltage fluctuations for testing the immunity of light sources, but it does warn the designer that voltage fluctuations should be considered.

The important point is that P_{st} may become large only when there is both 1) a disturbance on the mains voltage, and 2) the light source has insufficient immunity to prevent the disturbance from appearing as a visible light disturbance (flicker). If the mains voltage is not disturbed by lower frequency signals, then P_{st} will be very low. Thus, people will not observe flicker 50% of the time, but only in those rare (and generally temporary[†]) conditions where a sufficiently high fluctuation, caused by other electrical equipment, is present on the mains voltage at a sufficient level to cause the light waveform to have $P_{st} \geq 1$.

Stroboscopic effect – SVM

Similarly, SVM = 1 means that 50% of people will be just able to detect stroboscopic effect under certain circumstances. But these circumstances include motion of objects in the lit space at sufficient speed and with sufficient contrast to make the stroboscopic effect visible. In a typical office indoor environment (machine shops and the like excluded), there is not continuous motion at rates sufficient to make SVM visible. Therefore, stroboscopic effect will not be experienced 50% of the time, but only occasionally, when, for example, motion and contrast is sufficient to make it visible and the observer is directly viewing that motion. For documentation of SVM, see IEC TR 63158[6] and references therein.

Summary

The presence of daylight, other light sources, lower contrast, limitations on viewing angle, and other factors will reduce the likelihood of visibility of either flicker or stroboscopic effect even further.

The conclusion is that, although a visibility threshold of 50% seems high at first glance, there is actually a much lower probability that TLA will be observable in real applications at any specific time.

Comment

There is a third source of TLA, which is referred to as "phantom array effect" or "ghosting"[2]. This effect is primarily visible in outdoor nighttime situations where high contrast is present, such as with brake lights on an automobile, but may also be visible indoors if a deeply modulated light source with a high-contrast background (such as a lit troffer in a ceiling) is in direct view of an observer who rapidly moves his or her eyes. A visible array of images of the edges or corners of the luminaire may be formed on the retina. Research is underway to determine a measure to quantify this effect.

An example of phantom array is given in **Figure 2**. An array of images of the taillights of the car is formed when the camera (or an observer's eyes) is suddenly moved. If the taillights were continuously illuminated (as with older incandescent brake lights) the array of images would be a single streak, with uniform intensity along its length. An example of this can be seen in **Figure 3**. Some of the lights appear as streaks with uniform intensity along their length. Some appear as dashed lines (phantom arrays). The lamps creating the dashed lines are strobing on and off. The lamps creating the uniform streaks are continuously lit. The modulation depth of the light waveform determines how clearly separated the dashes are from each other. The frequency of the modulation determines how far apart the dashes are.

Figure 2. An example of a phantom array seen in taillights at night.

Figure 3. Automobile lights at night, with the white ones that are further away demonstrating phantom arrays.

Footnotes

* A person having sensitivity to flicker that matches the sensitivity curve determined by averaging the responses of many individuals.

† Consider for example, the condition when a refrigerator turns on, and a momentary disturbance is

present on the mains voltage from the initial inrush of current. The lights may flicker briefly while that disturbance is present.

References

1. NEMA 77-2017 *Standard for Temporal Light Artifacts: Test Methods and Guidance for Acceptance Criteria*
2. CIE TN 006:2016 *Visual Aspects of Time-Modulated Lighting Systems-Definitions and Measurement Models*
3. IEC 61000-4-15: 2010, *Electromagnetic compatibility (EMC). Part 4-15: Testing and measurement techniques. Flickermeter. Functional and design specifications.*
4. IEC 61000-3-3:2013, *Electromagnetic compatibility (EMC). Part 3-3: Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current smaller than or equal to 16 A per phase and not subject to conditional connection.*
5. IEC TR 61547-1:2017, *Equipment for general lighting purposes. EMC immunity requirements. Part 1: An objective light flickermeter and voltage fluctuation immunity test method.*
6. IEC TR 63158:2018, *Equipment for general lighting purposes – Objective test method for stroboscopic effects of lighting equipment. NEMA 77-2017 Standard for Temporal Light Artifacts: Test Methods and Guidance for Acceptance Criteria*
