Temporal Light Artifacts
(Flicker + Stroboscopic Effect)

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Outline

Introduction to Temporal Light Artifacts (TLA)

Measurements of TLA

Standards
**Definition: Temporal Light Artifacts (TLA)**

**Flicker**
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.

\(~0-80\text{Hz}\)

**Stroboscopic Effects**
Change 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.

\(~80\text{Hz}-2\text{kHz}\)

**Phantom Array**
Perception of a spatially extended series of light spots when making a *saccade* (image transition across the retina) across a light source that fluctuates with time.

\(~80\text{Hz}-2\text{kHz}\)
Definition: Temporal Light Artifacts (TLA)

Temporal Light Artifact (TLA)
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.
What is the problem with TLA?

• May cause eye strain or headaches
• May impair visual or cognitive performance
• Distracting
• May trigger medical conditions (*in severe cases*)
• Interferes with optical equipment (cameras, bar code readers, etc.)
• Could slow adoption of LED lighting due to perceived poor performance
Flicker is sometimes desirable!

- Sunlight through trees
- Reflections off of water
- Campfires, candles
- Motion pictures
- Emergency vehicles
- Attention-getting signage
- Entertainment

(Although TLA in general lighting probably is bad...)
Why do LEDs flicker?

• They don’t! *(inherently...)*
• They faithfully reproduce light based on the amount of current flowing through them
Sources of TLA

1. Source voltage changes (noise)
2. Externally coupled noise sources
3. Dimmer phase angle instabilities (when dimming)
4. Driver instabilities
5. Driver (intended) operation
Current flicker metrics

• Simple
  – Percent Flicker
  – Flicker Index

• Complex
  – RPI LRC ASSIST
  – IEC $P_{st}$
  – SVM
  – IEEE 1789
Percent Flicker (or % Modulation, or Modulation Depth)

- Easy to understand
- Easy to calculate
- Assumes periodic waveform
- Does not account for frequency
- Does not account for wave shape

\[ PF = 100\% \times \frac{A-B}{A+B} \]

**Does not correspond to human perception!**
Flicker Index

- Easy to understand
- Assumes periodic waveform
- Does not account for frequency
- Does not account for wave shape

\[ FI = \frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}} \]

Does not correspond to human perception!
Better ways to measure TLA

Recent perception work:
1. Take Fourier transform of light waveform
2. Weight the Fourier components by human sensitivity
3. Sum the weighted components $\rightarrow$ metric
4. Compare the result to a baseline or standard

Accounts for frequency and wave-shape.
Basic Measurement

Light Sensor

- Light source
- Photopic filter
- Photocell detection

Signal recording – oscilloscope

- Current-to-voltage amplifier
- Anti-aliasing low-pass filter (LPF)
- Analog to digital conversion (ADC)

Calculations/Data Processing

- Fourier transform
- Component amplitudes
- Weber temporal contrast
- Human sensitivity weighting
- Quadrature sum

Metric value

x[n] → X[k]

A_k = |X[k]|

M_k = \frac{A_k}{A_0}

\sqrt{\sum M_p^2}
RPI LRC ASSIST metric

- Accounts for wave shape and frequency
- Based on human perception trials
- Focuses on *visible* flicker: <80Hz

Source: [http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp](http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp)
Flicker is visible above the line.
The human eye is most sensitive at 5-20 Hz. We can see less than 1% variation in light intensity!
IEC flicker testing (Pst)

- **IEC 61000-4-15**
  - “Flickermeter – Functional and design specifications”
- **IEC 61000-3-3**
  - “Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems”
- **IEC TR 61547-1 (Adopts IEC 61000 for use with light)**
- Complex; originally developed to quantify power line quality

**Structure of the IEC light flickermeter**

Sources: [https://webstore.iec.ch/publication/4150](https://webstore.iec.ch/publication/4150), [https://webstore.iec.ch/publication/4173](https://webstore.iec.ch/publication/4173)
IEC PST curve – sine wave only
Stroboscopic Visibility Measure (SVM)

• Measures primarily stroboscopic effects >80Hz (for moving objects), not static flicker
• Not yet well known or widely used in industry
• Based on human perception trials

Source: Modeling the visibility of the stroboscopic effect occurring in temporally modulated light systems
http://lrt.sagepub.com/content/early/2014/05/12/1477153514534945.full.pdf?ijkey=GcQ3UW7Qz2UwqtM&keytype=ref
Human Eye Sensitivity
Stroboscopic only, sine wave
IEEE 1789-2015

• "IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers"\(^1\)
• Survey of previous studies.
• Results are somewhat controversial\(^2\)

IEEE 1789-2015 and common sources

Source: IEEE Std 1789-2015, Figure 18 “Low Risk Level and No Observable Effect Level”
Comparison of several TLA metric limits
Measurement
Measurement nuances: Equipment

- Spectral response of sensor
- Bandwidth and linearity of sensor
- Sampling frequency of recording device
- Vertical resolution of measurement

An algorithm is only as accurate as the data provided to it!

(Garbage in...garbage out)
Spectral response of sensor

  – (Should respond in the same manner as the human eye)

![Graph showing spectral response curves]

**Green**: photopic human eye response curve

**Red**: typical filtered photodiode
Bandwidth of sensor

- If a sensor has intrinsic filtering (by design or otherwise), it may ignore higher-frequency signals.
- Common light meters or commodity devices may only measure signals at a few hundred Hz (or less).
- Bandwidth that is TOO high may pick up undesired noise.

Source: https://en.wikipedia.org/wiki/Aliasing
Sampling frequency of recording device

- Minimum: sampling frequency must be 2x the maximum frequency of interest (Nyquist rate)
- Sampling that is too slow can miss higher-frequency components
Resolution of measurement

- Insufficiently-quantized data
- The amplitude of the signal should be increased and retested

No light levels were recorded between the red lines... very unlikely!
Measurement nuances: Test conditions

• Power source
• Mechanical stability
• Ambient light
• Sampling time
• Stabilization
Power source

• Power sources that are “too perfect” (power supplies) may mask poor real-world behavior

• Normal building power may have noise sources (motors, elevators) that are impossible to duplicate

• A test source can reliably and repeatedly reproduce common noise; for example:

\[ y(t) = 120 \times \sqrt{2} \times \sin(2 \times \pi \times 60 \times t) + 2.25 \times \sin(2 \times \pi \times 200 \times t) \]
Mechanical stability

- Mechanical vibrations may result in false detection of TLA (especially with light gradients)
- This can be coupled in from nearby equipment or even footsteps
Ambient light

• External light sources can suppress or corrupt proper flicker measurement
• Measurements should be taken in a dark box
• Zero light = zero signal
Sampling time

• Energy Star: “The equipment measurement period shall be ≥ 100 ms”
• What if flicker is seen only every 2s? Every 20s?
• Large measurements at high resolution create large files
  – 20k samples/second * 60 seconds = 1.2M samples
  – Some equipment or software cannot handle such large files well (e.g. Excel)

Glitch occurs 20 seconds into measurement
Stabilization

• Lamps may behave differently during their first few seconds or minutes of operation
• When should the measurement be taken?

Light takes 25 seconds to become stable
Standards
NEMA TLA standard

The purpose of the standard is:

1. Recommend a method of quantifying the visibility of temporal light artifacts (TLA), and
2. Propose application-dependent limits on TLA

The NEMA group will define the measurement procedure and propose initial broad application-dependent limits, which will later be refined by IES.
NEMA TLA results (so far)

• Data has been collected through a Round Robin study
  – 3 dimmer models
  – 7 light source models
  – Measure each combination, with no dimmer and at three different settings with dimmer

Summary from one manufacturer:

<table>
<thead>
<tr>
<th>Level</th>
<th>% Flicker</th>
<th>Flicker Index</th>
<th>LRC</th>
<th>SVM Metric</th>
<th>Pst Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>29.4</td>
<td>0.077</td>
<td>0.368</td>
<td>0.294</td>
<td>0.637</td>
</tr>
<tr>
<td>Medium</td>
<td>39.0</td>
<td>0.097</td>
<td>0.442</td>
<td>0.390</td>
<td>0.547</td>
</tr>
<tr>
<td>Low</td>
<td>30.0</td>
<td>0.075</td>
<td>0.576</td>
<td>0.300</td>
<td>1.028</td>
</tr>
</tbody>
</table>
Round Robin: Detailed look

**Pst (SSL7A dimmer + Lamp1)**

- Mains run 1
- Mains run 2
- Power Supply

**Pst (SSL7A dimmer + Lamp2)**

- Mains
- Power Supply

**SVM (SSL7A dimmer + Lamp1)**

- Mains
- Power Supply

**SVM (SSL7A dimmer + Lamp2)**

- Mains Lamp2
- Power Supply Lamp2
NEMA TLA next steps

• Finalize metrics for manufacturers to report
  – High frequency → SVM
  – Low frequency → Pst – still some work
• Propose limits on the metrics for different (broad) applications
• Transfer methodology to IES for detail on applications and associated limits
• Immediate interest in using NEMA TLA metric as part of a consumer dimming logo
DoE Flicker Characterization Study

- Report on the performance of commercially available flicker meters against a benchmark

- Purpose of the study:
  - Help specifiers determine the flicker behavior of lighting products
  - Accelerate the development of standard test and measurement procedures

- Published in February 2016

Other Industry Efforts

• CIE working group: *TC 1-83: Visual Aspects of Time-Modulated Lighting Systems*¹

![CIE logo]

• Third-party flicker testing services²

![UL logo]

Sources: ¹ [http://div1.cie.co.at/?i_ca_id=549&pubid=466](http://div1.cie.co.at/?i_ca_id=549&pubid=466)
Conclusions
Recap: Characteristics of a good TLA metric

• Accounts for frequency
• Accounts for wave shape
• Covers visible flicker and stroboscopic effect
• Adaptable for different applications
• Straightforward to measure, calculate, and understand
• Widely adopted

No one metric today meets all of these!
Unintended consequences

• Adding stroboscopic measurements to flicker tests may cause otherwise “good” lamps to fail
  – Most manufacturers’ visual tests today don’t account for stroboscopic flicker

• Improper use of flicker metrics may mandate high-levels of performance, even when unnecessary

• Poor testing procedures may cause invalid results, or incorrectly attribute flicker to the control or driver

• Flicker tests may add to already-lengthy testing
Demonstration invitation

- Where do you see flicker?
- Where do you see stroboscopic effect?
- Shows effects of frequency, wave shape, modulation depth, and duty cycle on TLA visibility