The Past and Future of Measuring Flicker

Ethan Biery
Lutron Electronics
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Why do LEDs flicker?

• They don’t! *(inherently...)*

• They faithfully reproduce light based on the amount of current flowing through them

• LEDs respond QUICKLY to changes in current
  • No intrinsic filtering (unlike incandescent)
Why do LEDs flicker?

- An LED driver’s job is to regulate current to the LEDs
  - Simpler drivers have a harder time avoiding current fluctuation, and are more prone to causing flicker
  - Voltage changes to the input of the driver (power line or control noise) can cause changes to the output

[Diagram showing electrical and optical distortion]
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 state-of-the-art in TLA measurement

• Today’s best equipment for measuring flicker:
  
  Unfortunately, results may vary due to:
  • Age
  • Visual acuity
  • Fatigue
  • Ambient light
  • Experience
  • Viewing angle
  • Brightness...

Flicker is best perceived off of a reflected surface, not directly viewing the source.
Current flicker metrics

• Simple, but limited meaning
  • Percent Flicker
  • Flicker Index

• Complex, but useful
  • RPI LRC ASSIST
  • IEC PST
  • SVM
  • IEEE
Percent Flicker (or % Modulation, or Modulation Depth)

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

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

No relation to human perception!
Flicker Index

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

No relation to human perception!
Frequency independence

• Both graphs have same Flicker Index and Percent Flicker:
  • Same maximum
  • Same average
  • Same minimum
  • Same areas

• They will appear very different to an observer
  • 1Hz vs. 10Hz?
  • 10Hz vs. 100Hz?
Uses of Flicker Index and Percent Flicker

• Poor indicator of perceivable flicker
  • But, could be used to compare lamps with similar characteristics (operating frequency)

• Energy Star Lamps specification
  • Values are to be reported only; no limit

• California Title 24 Joint Appendix (JA) 8
  • Percent Flicker must be <30% at <200Hz
Better ways to measure TLA

1. Examine frequency components
2. Determine which frequencies are of interest (and how “interesting” they are)
3. Sum the result together
4. Compare that against a baseline or standard
1. Examine frequency components

- Most “real” waveforms (light, sound, etc.) can be mathematically represented by a combination of several simpler (sinusoid) waveforms
  - Like a chord is a combination of musical notes
- The mathematical operation to determine these source waveforms is the *Fast Fourier Transform* (FFT)
2. Determine interesting frequencies

- Remove (filter) frequencies that are irrelevant
  - For example, those above human perception
- Add a weighting factor to remaining frequencies
3. Add result together

- Normalize and perform a summation algorithm over the resulting (weighted) frequencies
  - Sum-of-squares, etc.
- Result is an integer value
4. Compare result against a standard

• Is lower or higher “better”? 
• What’s an acceptable range? 
• Does it vary based on application?
Example: RPI LRC ASSIST metric

- Accounts for wave shape and frequency
- Based off of (limited) human perception trials
- Focuses on *perceptible* flicker: <100Hz
- Complex measurement and analysis:

Source: http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp
Example: IEC flicker testing ($P_{st}$)

- 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/4173
IEC PST and ASSIST result curves
Example: Stroboscopic Visibility Measure (SVM)

- Measures primarily stroboscopic effects >80Hz (for moving objects), not necessarily static flicker
- Not yet well known or widely used in industry
- Based off of human perception trials
IEEE 1789-2015

• “IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers”¹

• Results drawn from multiple studies

• Results were somewhat controversial²

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
# Analysis of an industry standard

<table>
<thead>
<tr>
<th>WHAT do you measure?</th>
<th>HOW is it measured?</th>
<th>HOW is it analyzed?</th>
<th>WHAT are the limits?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light?</td>
<td>Sensor specs?</td>
<td>ASSIST?</td>
<td>&lt;1?</td>
</tr>
<tr>
<td>Current?</td>
<td>Sensitivity?</td>
<td>PST?</td>
<td>&gt;1?</td>
</tr>
<tr>
<td>Voltage?</td>
<td>Frequency?</td>
<td>Flicker Index?</td>
<td>&gt;1.6?</td>
</tr>
</tbody>
</table>
The purpose of the document is:

1. Describe a reproducible method of measurement suitable for general-purpose LED lighting

2. Recommend an algorithm for quantifying the visibility of temporal light artifacts (TLA)

3. Propose application-dependent limits on TLA
   - Initial limits for basic applications
   - More refined limits are expected by other standard-setting bodies
NEMA TLA proposal (so far)

• A single value does not accurately capture all application-specific requirements
  • Some applications may be more sensitive to visible flicker (task-based work)
  • Some applications may need minimal stroboscopic flicker (video, motion-based work)

• A dual-value metric is most suitable
NEMA TLA next steps

• Being evaluated by CIE

• Immediate interest in using NEMA TLA metric as part of a consumer dimming logo (NEMA “dimming mark”)

• For further reading: DOE Flicker Characterization Study\(^1\)
  • Report on the performance of commercially available flicker meters against a benchmark
  • Published in February 2016

Source: \(^1\)http://energy.gov/eere/ssl/downloads/characterizing-photometric-flicker
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

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

• Flicker tests may add to already-lengthy testing

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

• Should I be concerned about TLA?
  • Yes! It is a source of occupant discomfort and dissatisfaction

• Are there standards I should be citing for flicker?
  • Not yet! Current standards are either useless or overly stringent for most applications.

• How can I minimize chances of having flicker?
  • Work with quality manufacturers
  • Realize that low cost often correlates with less filtering (and more TLA)
  • Spec digital control schemes over analog ones

• Look for the NEMA LSD-75 (TLA) Whitepaper by end of Q1 2017!
Thank You

Ethan Biery
Lutron Electronics
ebiery@lutron.com