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.

~0-80Hz

No motion

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.

~80Hz-2kHz

Object motion

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

~80Hz-2kHz

Eye motion

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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.

or

or

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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

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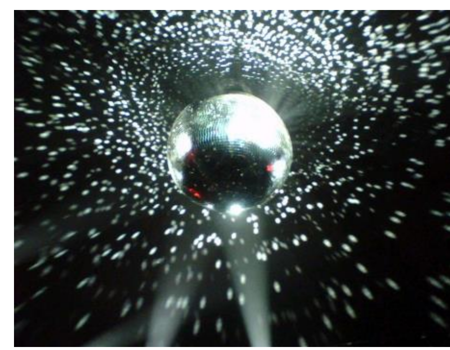
Flicker is sometimes desirable!

- 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…)

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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

Electrical distortion in

Electrons in

Optical distortion out

Light out

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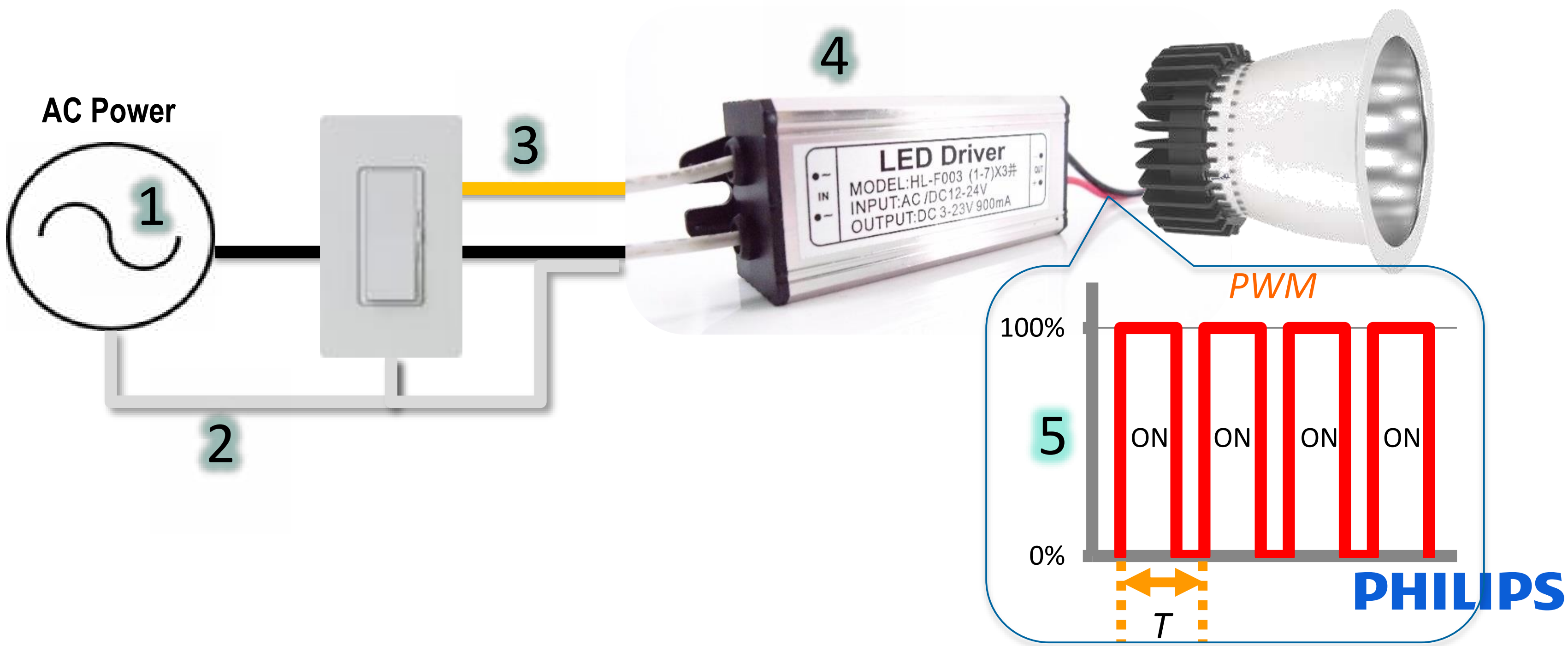
Sources of TLA

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



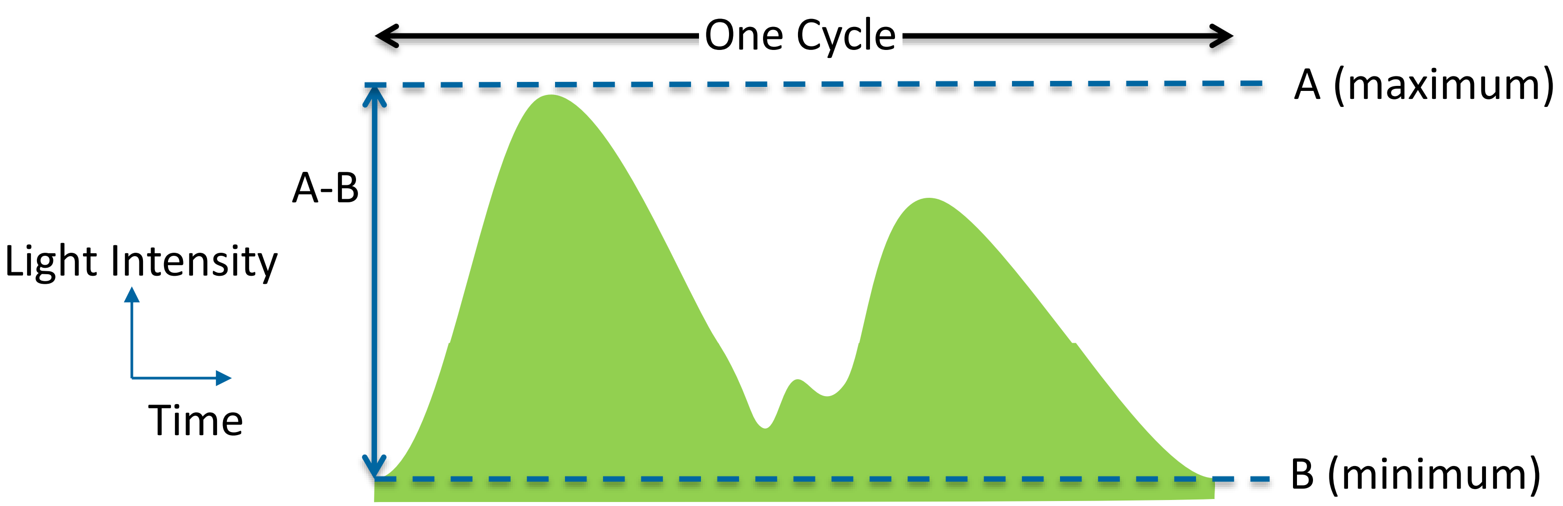
Current flicker metrics

- 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!



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Flicker Index

- Easy to understand
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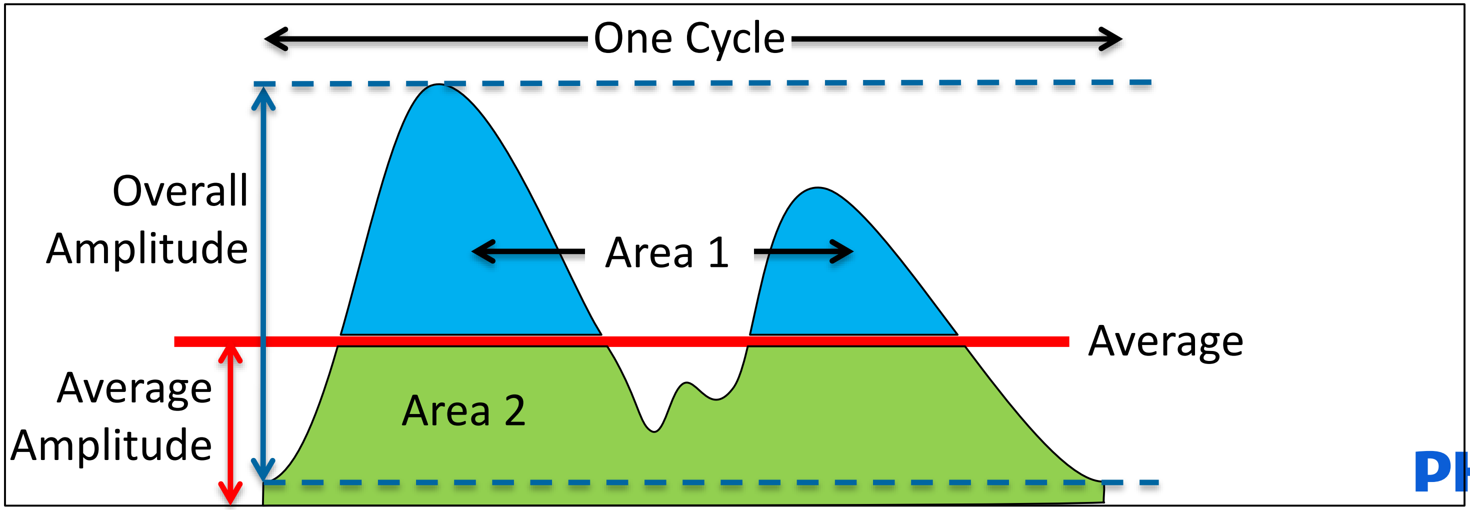
- Does not account for frequency
- Does not account for wave shape
- $FI = \frac{Area\ 1}{Area\ 1 + Area\ 2}$

Does not correspond to human perception!



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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 → metric
4. Compare the result to a baseline or standard

Accounts for frequency and wave-shape.

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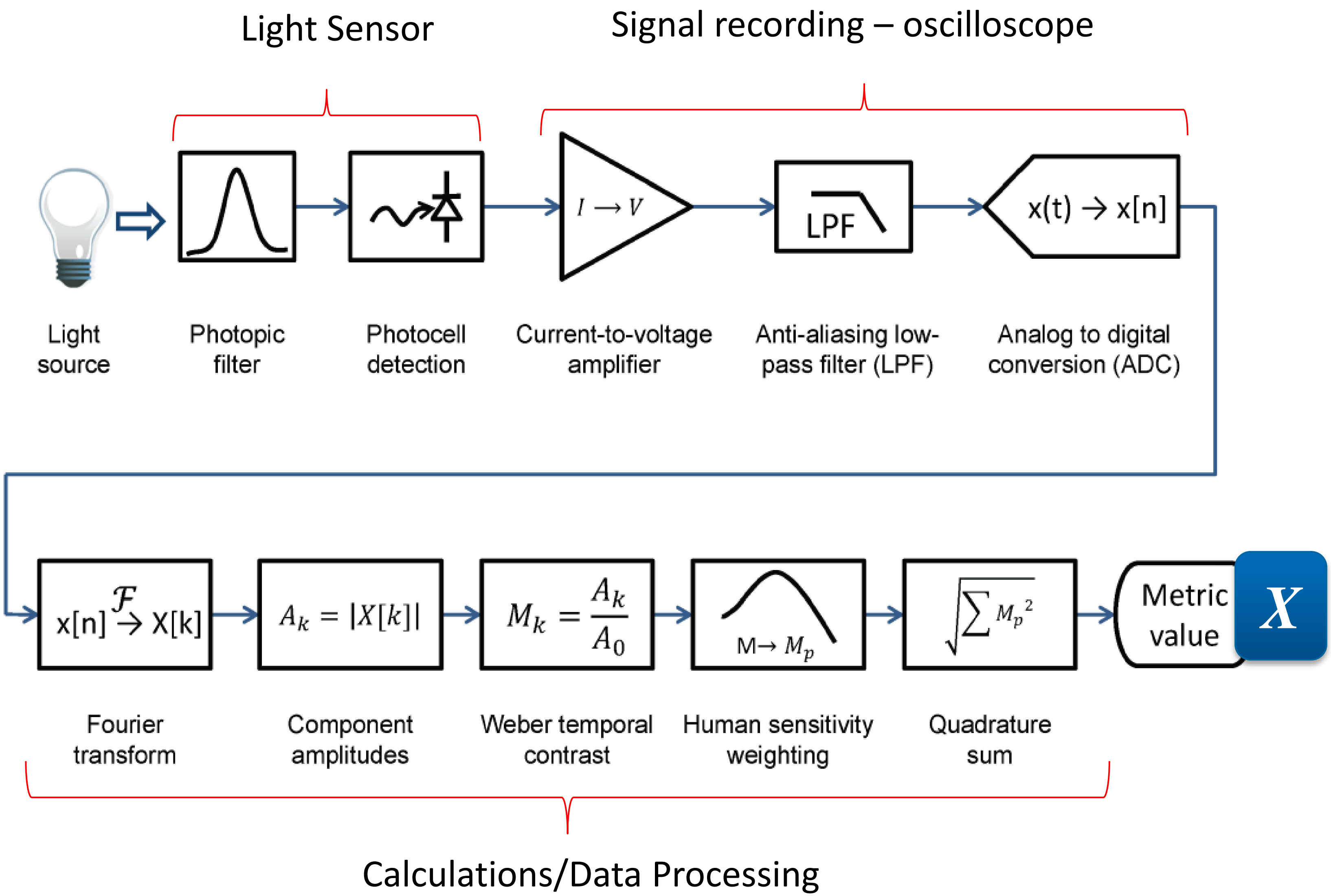
Basic Measurement



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RPI LRC ASSIST metric

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

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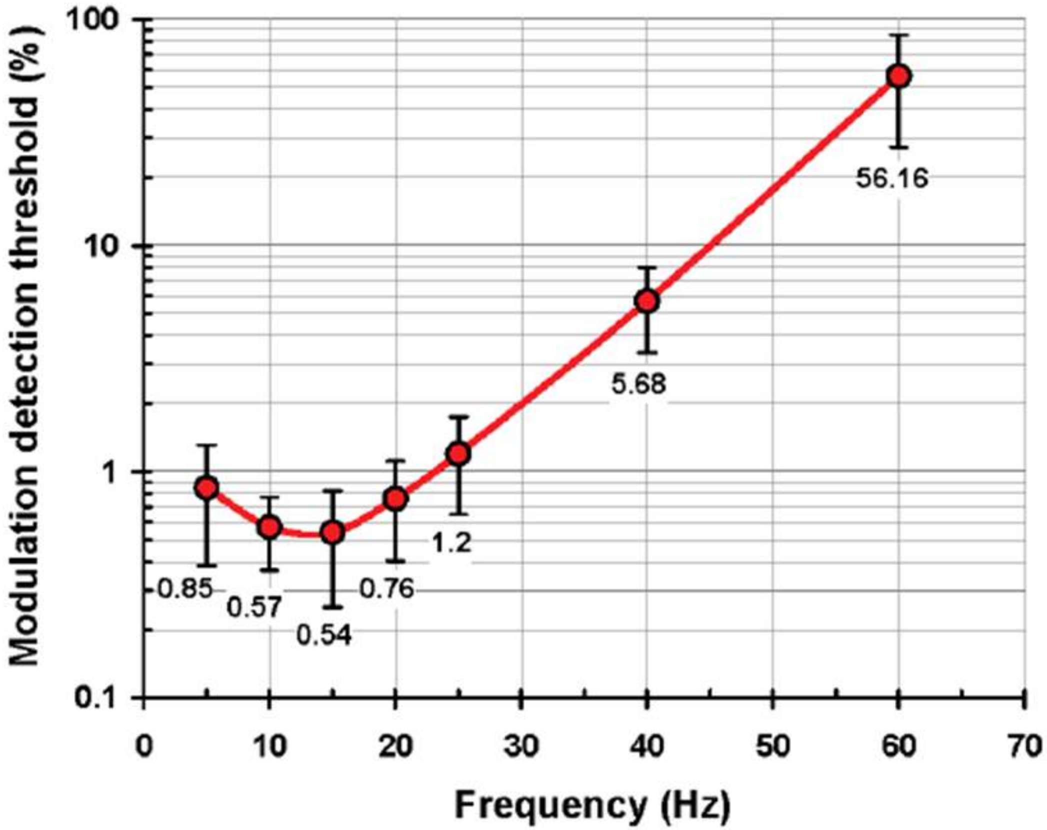
Source: http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp

RPI LRC ASSIST curve



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!

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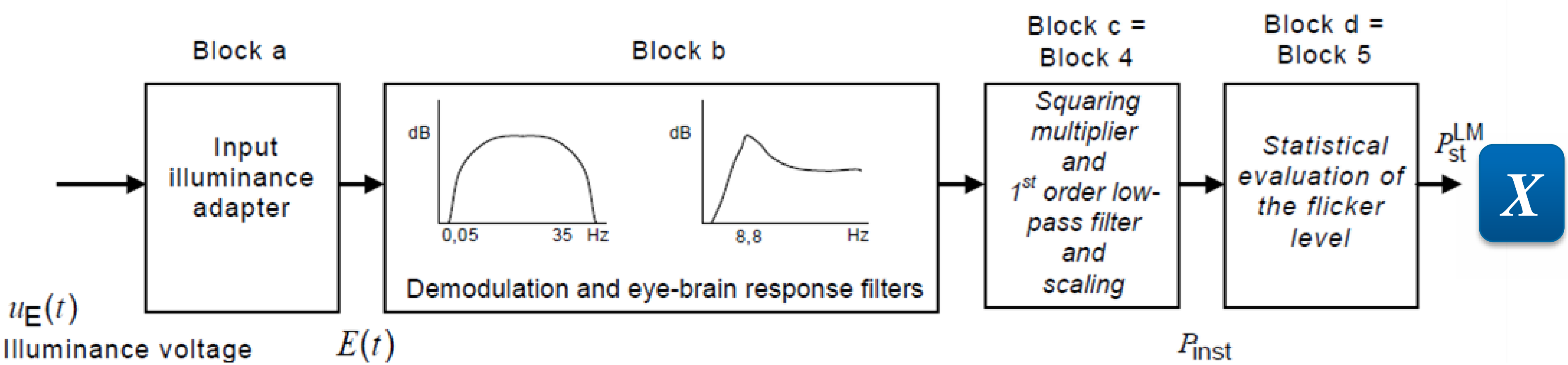
IEC flicker testing (Pst)

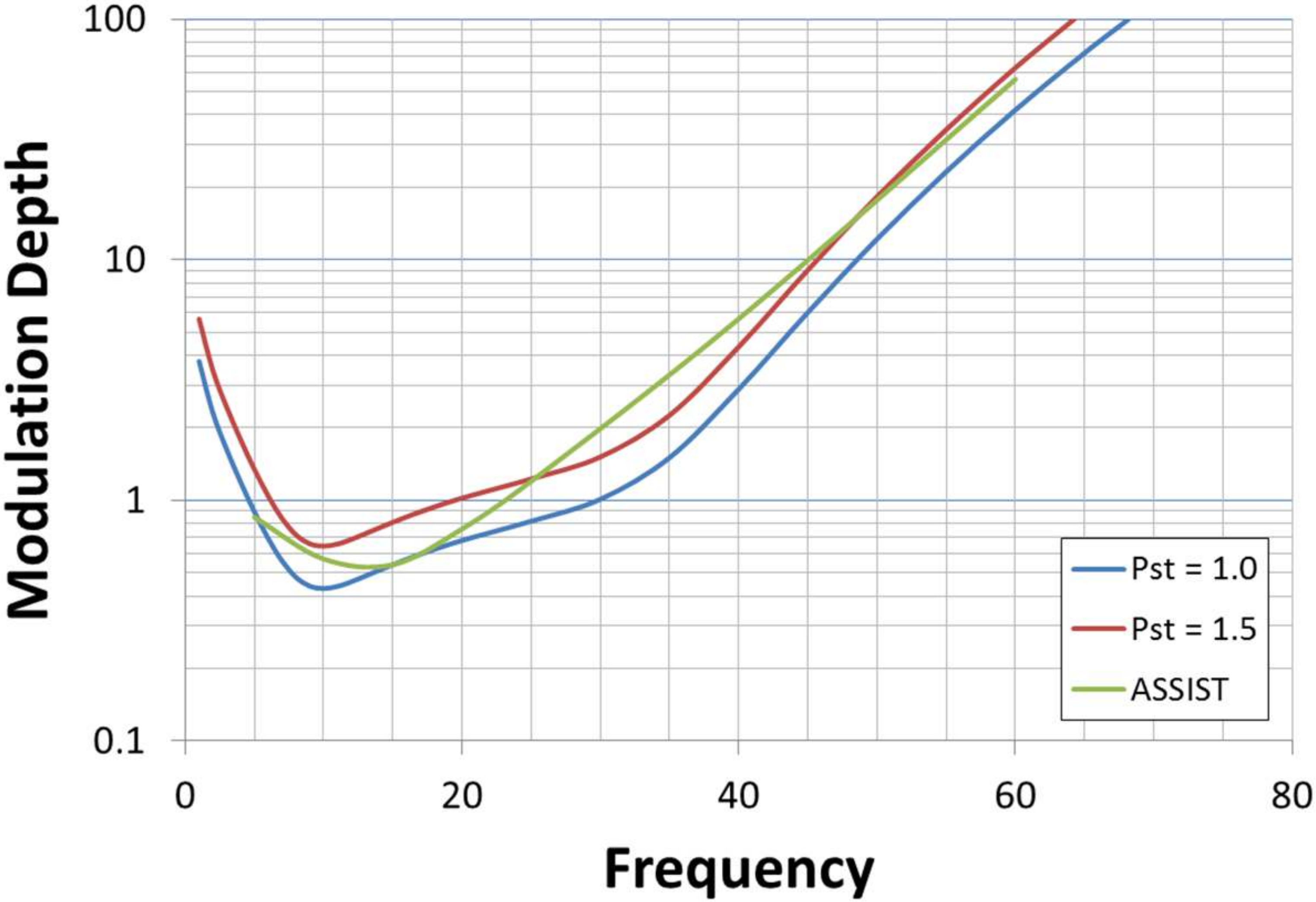
- IEC 61000-4-15
  - "Flickermeter – Functional and design specifications"
- IEC 61000-3-3
  - "Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems"
- IEC TR 61547-1 (Adopts IEC 61000 for use with light)
- Complex; originally developed to quantify power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



Structure of the IEC light flickermeter

Sources: https://webstore.iec.ch/publication/4150 , https://webstore.iec.ch/publication/4173

IEC PST curve – sine wave only



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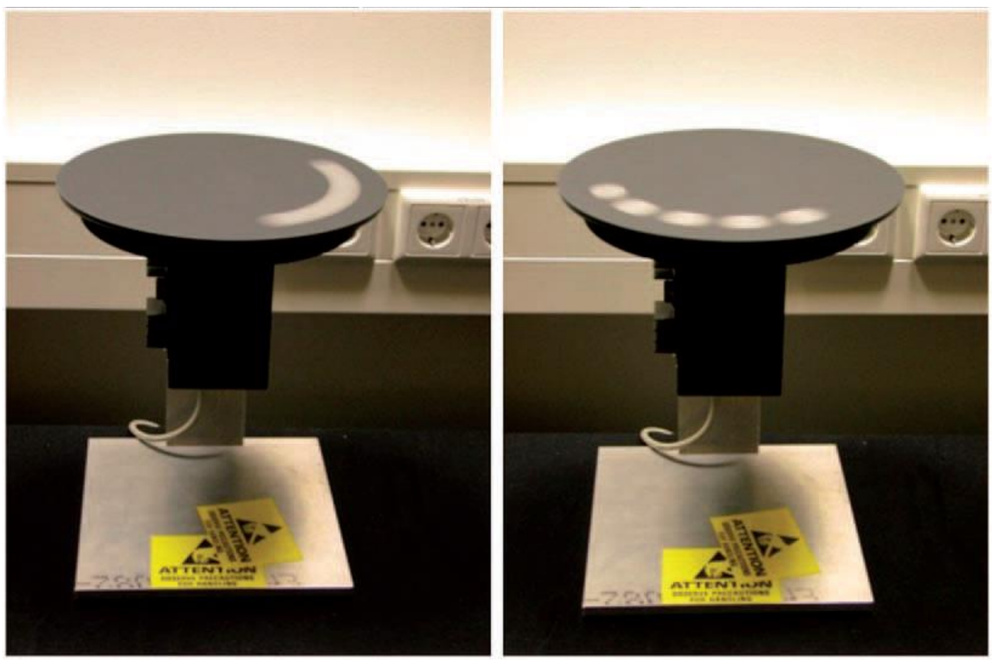
Stroboscopic Visibility Measure (SVM)

- 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

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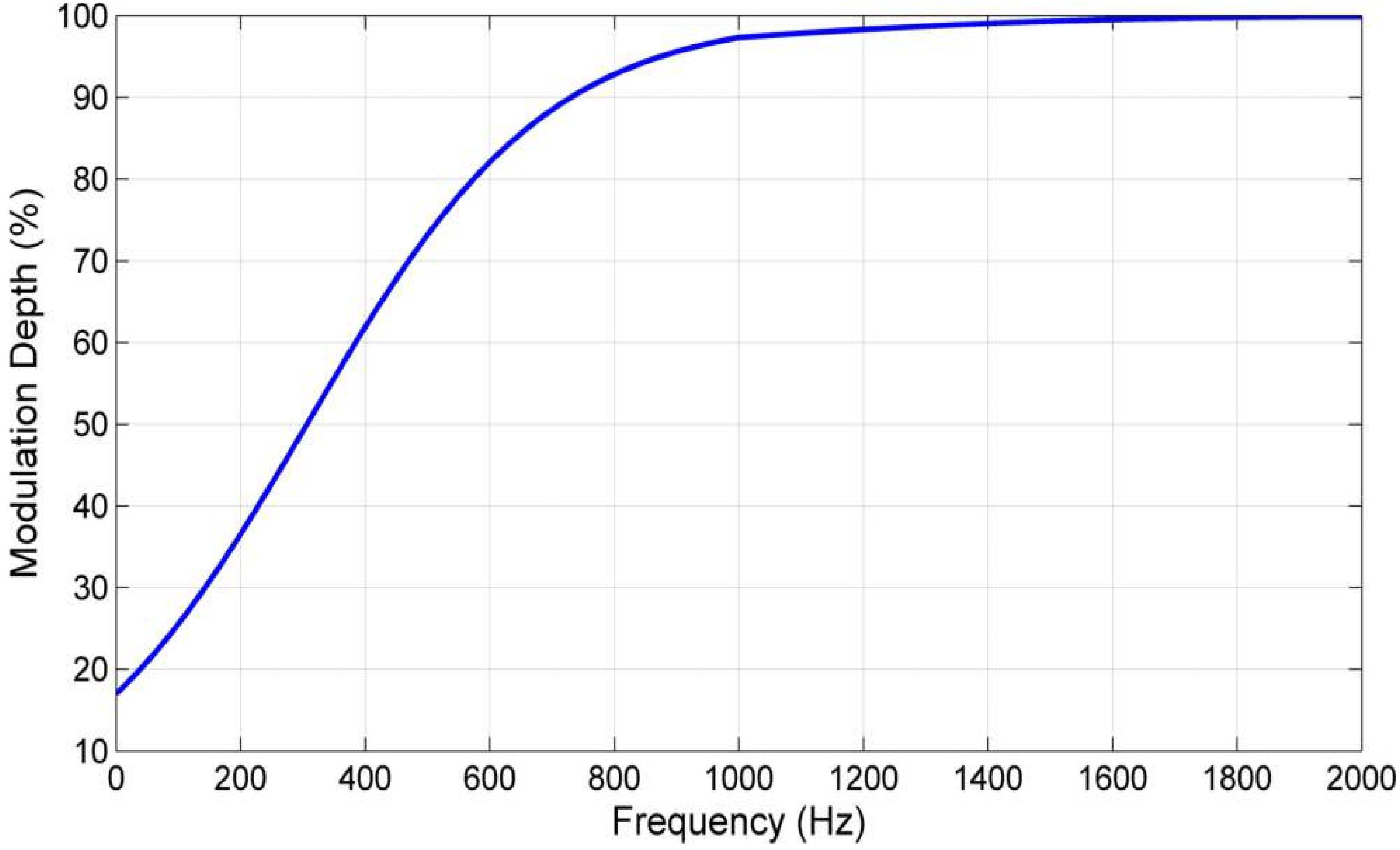
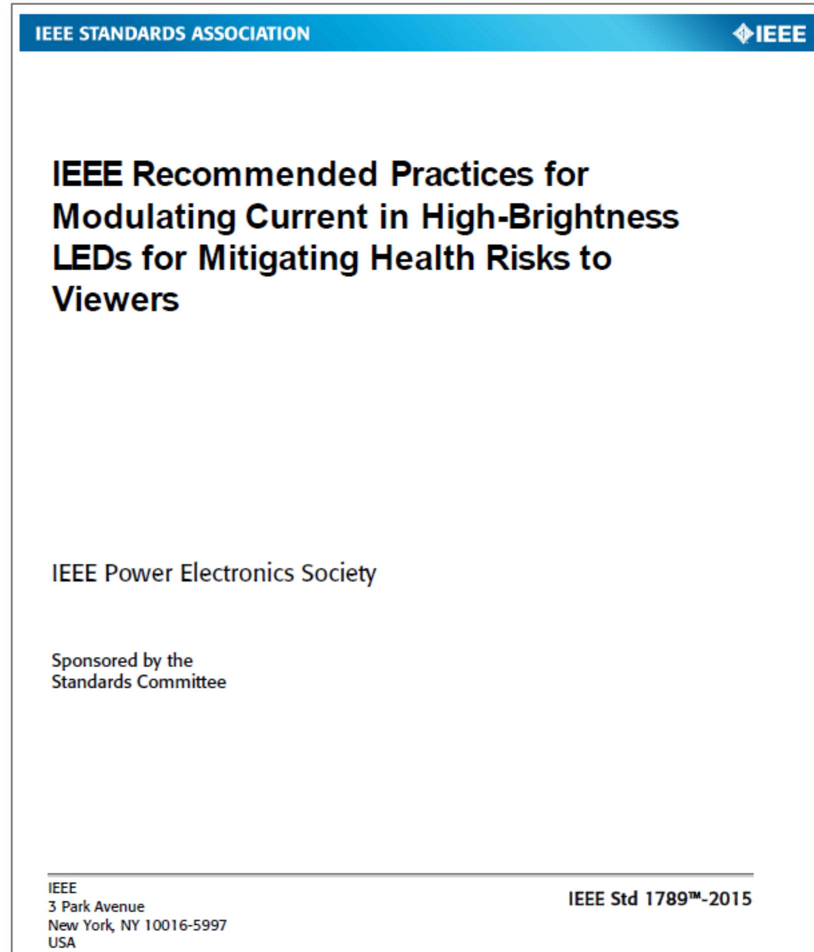
Human Eye Sensitivity
Stroboscopic only, sine wave



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 STANDARDS ASSOCIATION ◆IEEE

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

IEEE Power Electronics Society

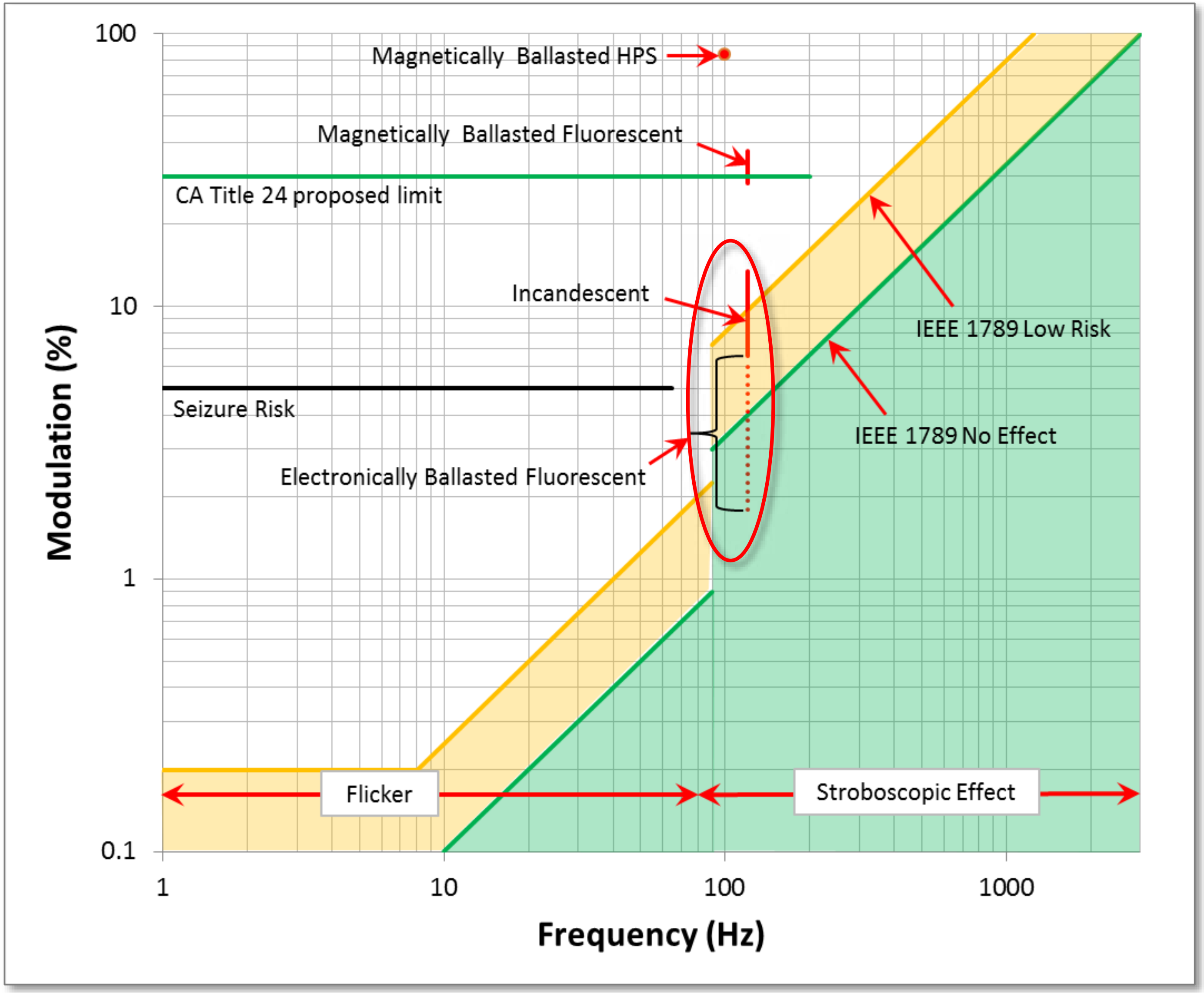
Sponsored by the
Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1789™-2015

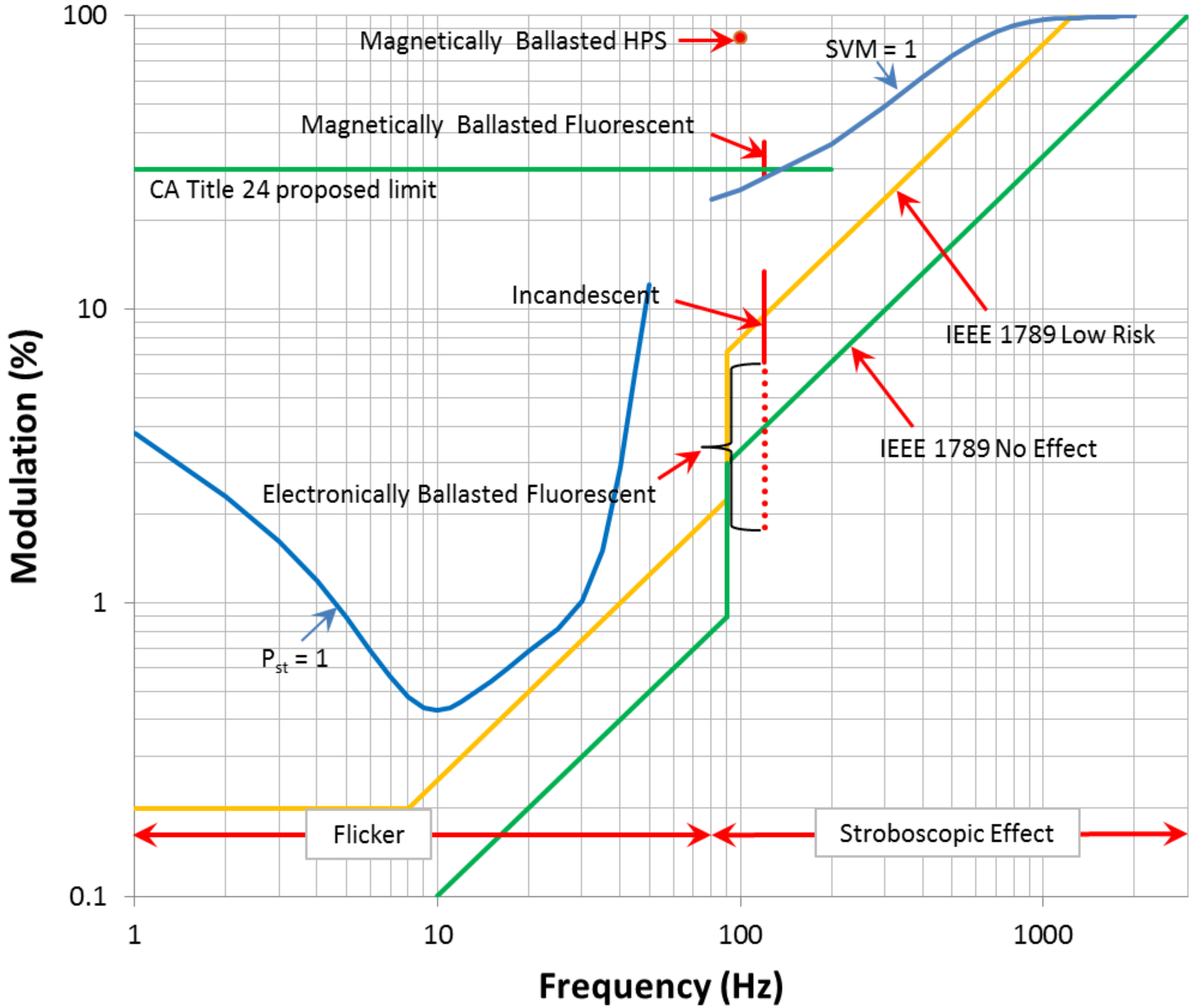
Sources: [1]http://standards.ieee.org/findstds/standard/1789-2015.html
[2]https://www.nema.org/Standards/Pages/Temporal-Light-Artifacts-Flicker-and-Stroboscopic-Effects.aspx

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



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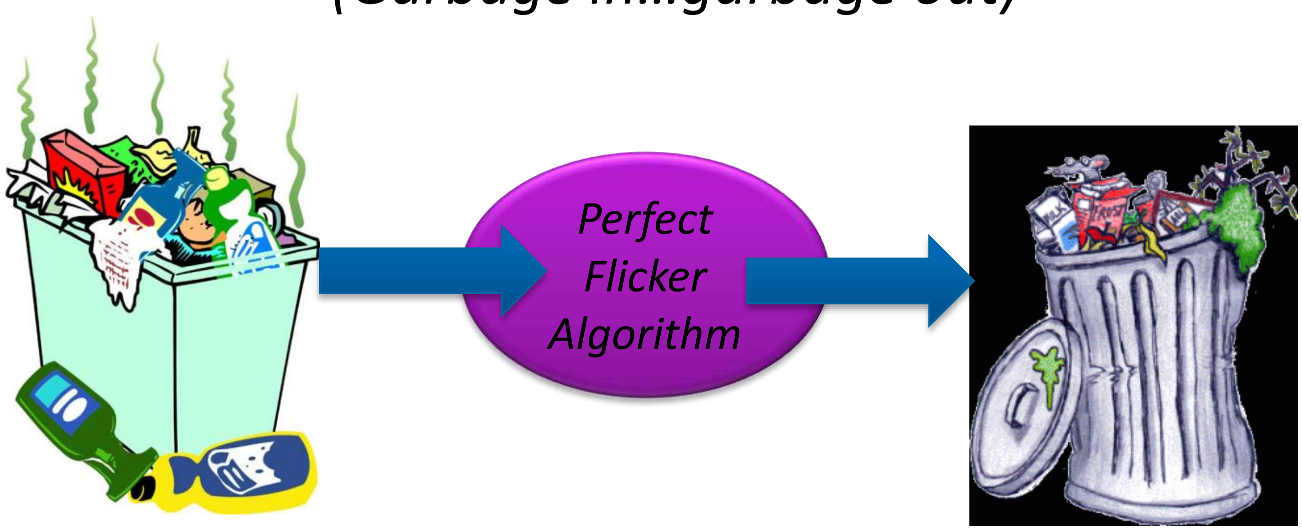
Measurement

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)



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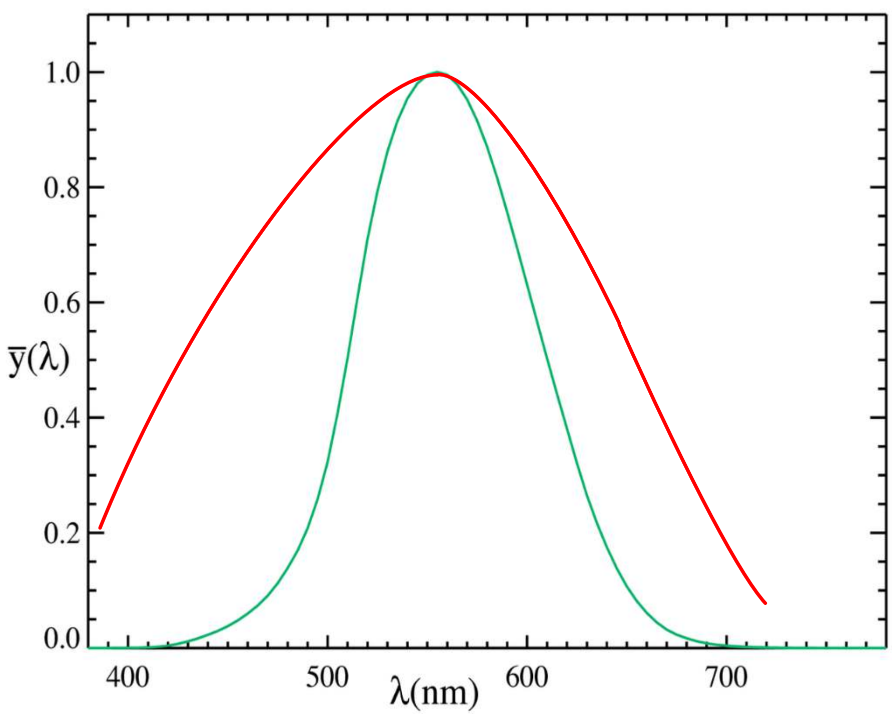
Spectral response of sensor

- Energy Star: "Should match Commission Internationale de l'Eclairage (CIE) spectral luminous efficiency curve"
  – (Should respond in the same manner as the human eye)



Green: photopic human eye response curve

Red: typical filtered photodiode

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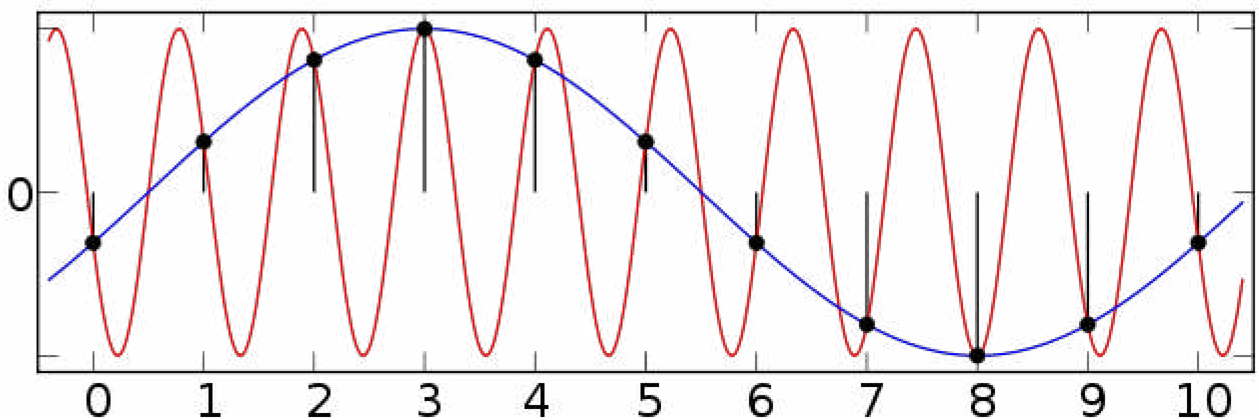
Bandwidth of sensor

- 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



Two different sinusoids that fit the same set of samples.

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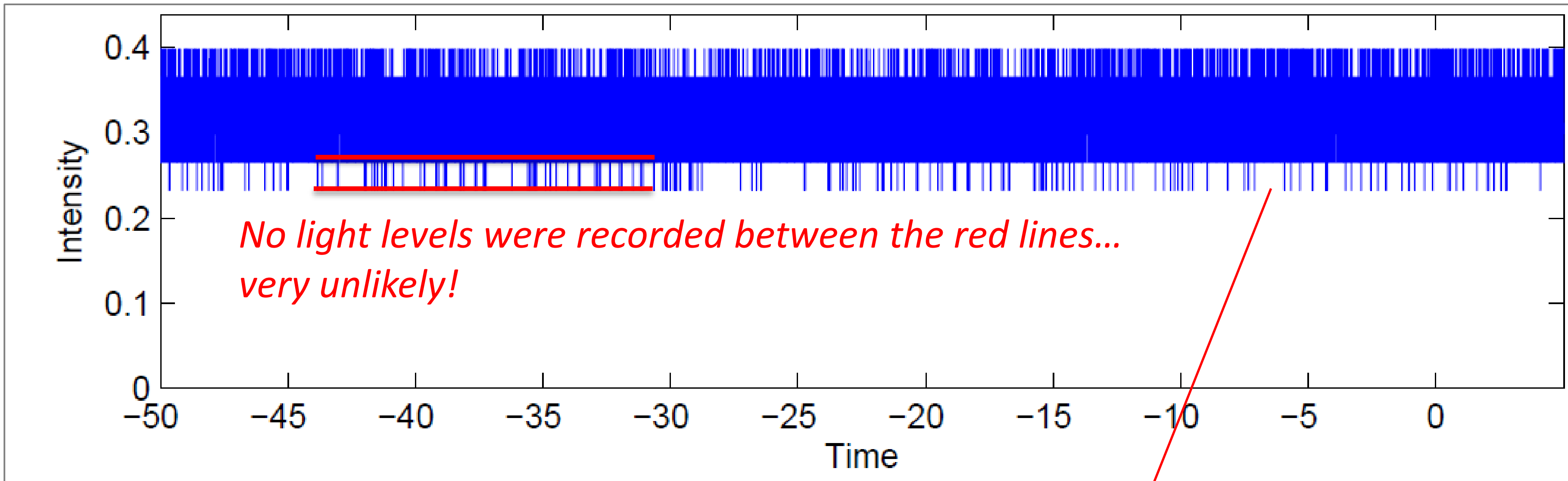
Source: https://en.wikipedia.org/wiki/Aliasing

Sampling frequency of recording device

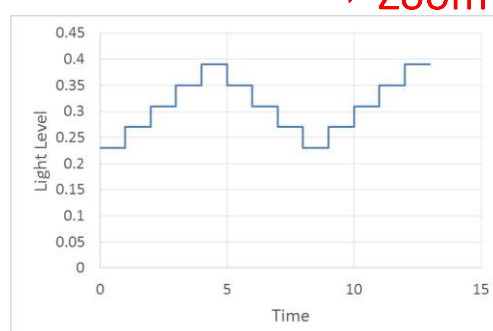
- Minimum: sampling frequency must be 2x the maximum frequency of interest (Nyquist rate)
- Sampling that is too slow can miss higher-frequency components

Resolution of measurement

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



Zoom



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Measurement nuances: Test conditions

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

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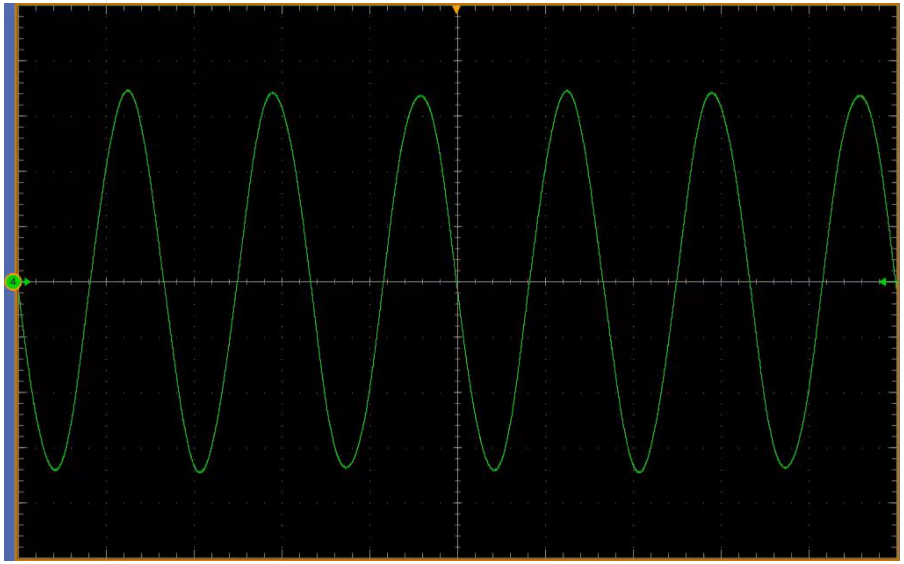
Power source

- 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

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Ambient light

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

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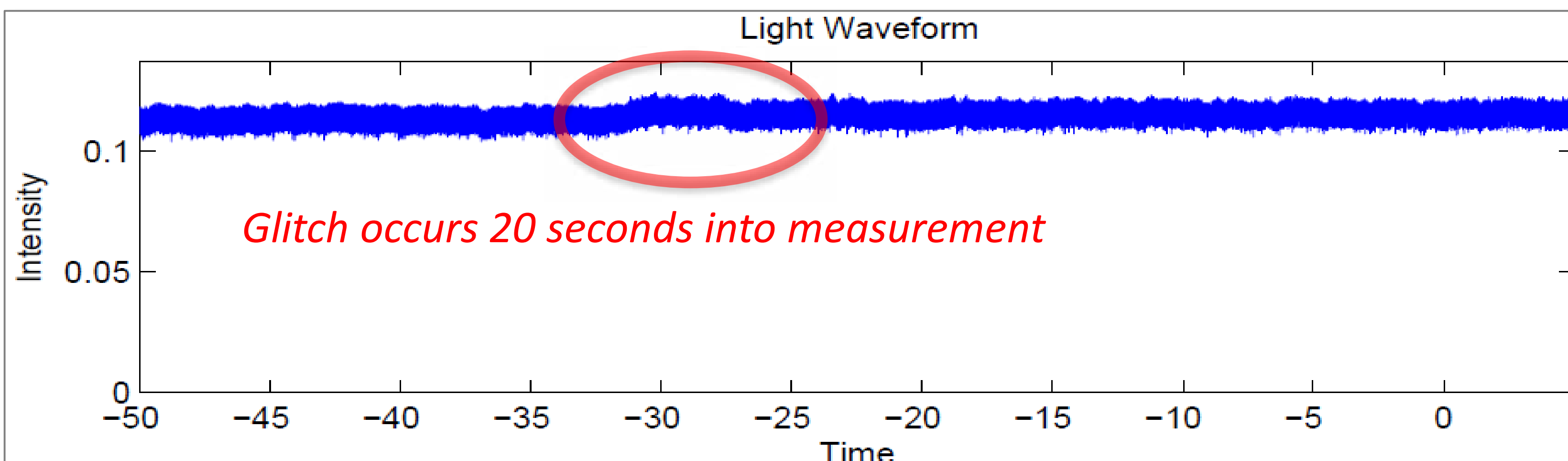
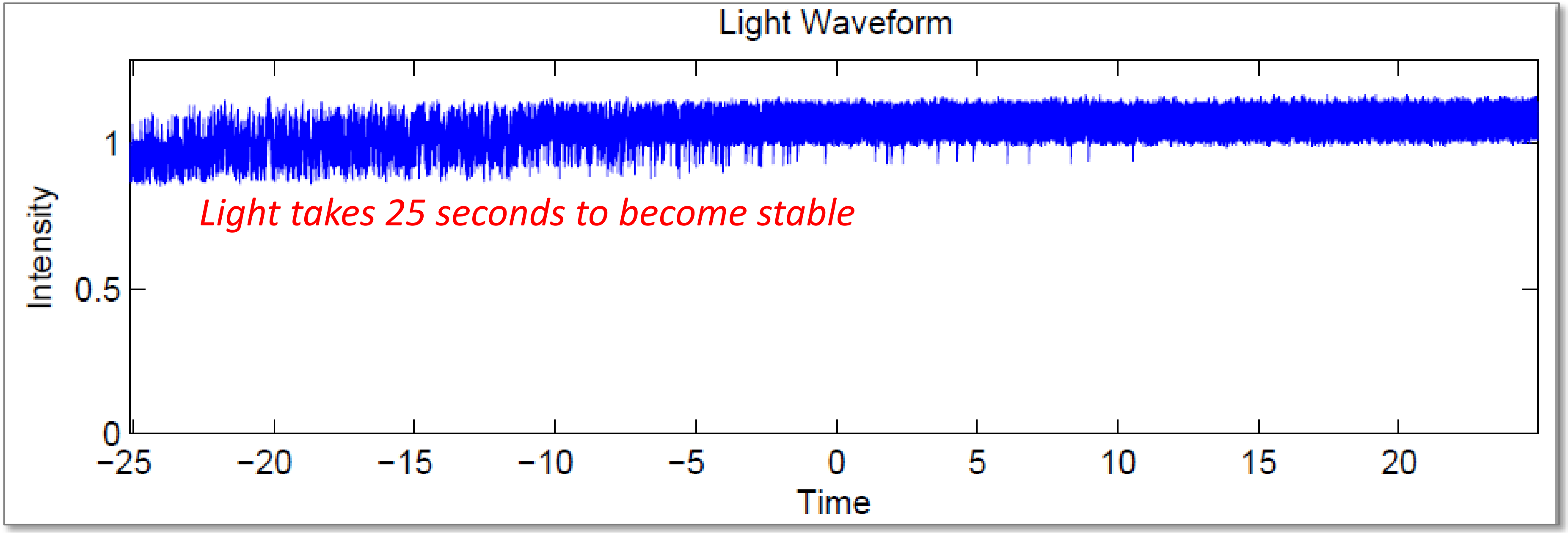
Sampling time

- 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)



Stabilization

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



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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:

Metrics with Dimmer					
Level	% Flicker	Flicker Index	LRC	SVM Metric	Pst Metric
High	29.4	0.077	0.368	0.294	0.637
Medium	39.0	0.097	0.442	0.390	0.547
Low	30.0	0.075	0.576	0.300	1.028

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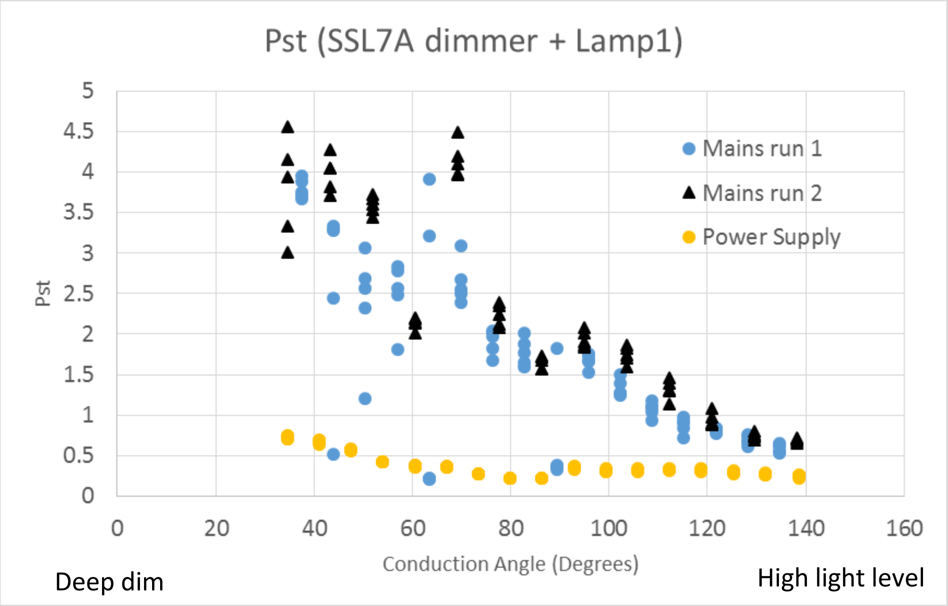
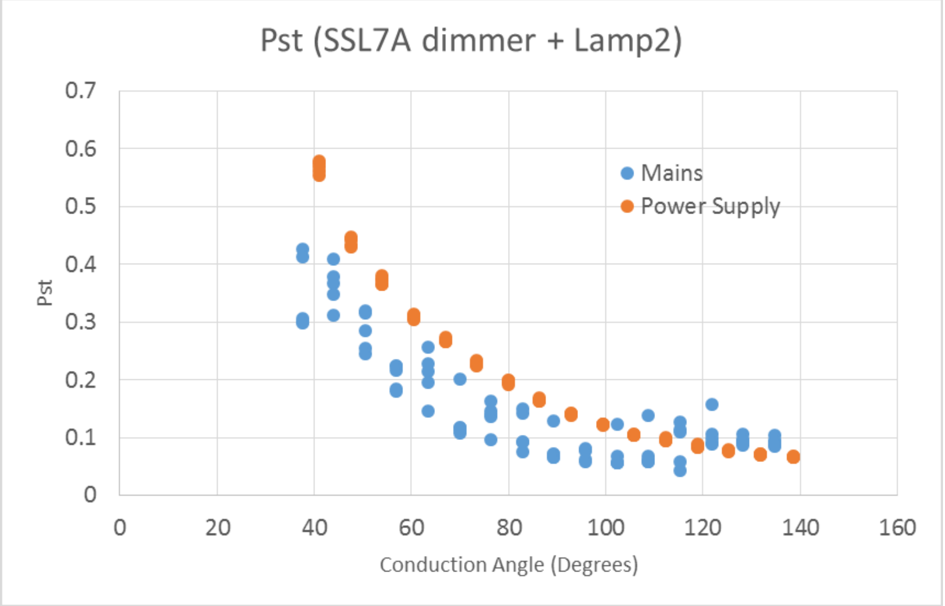
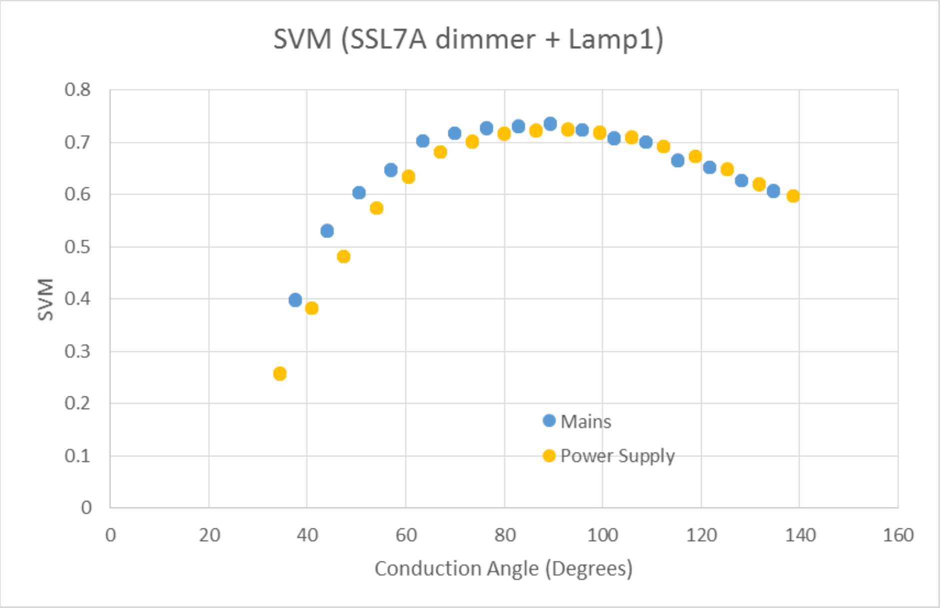
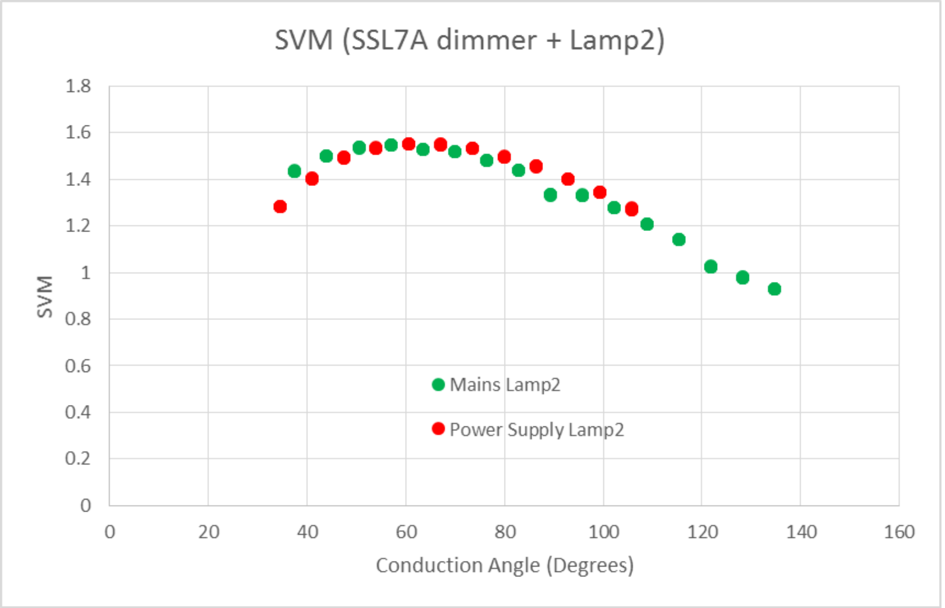
Round Robin: Detailed look







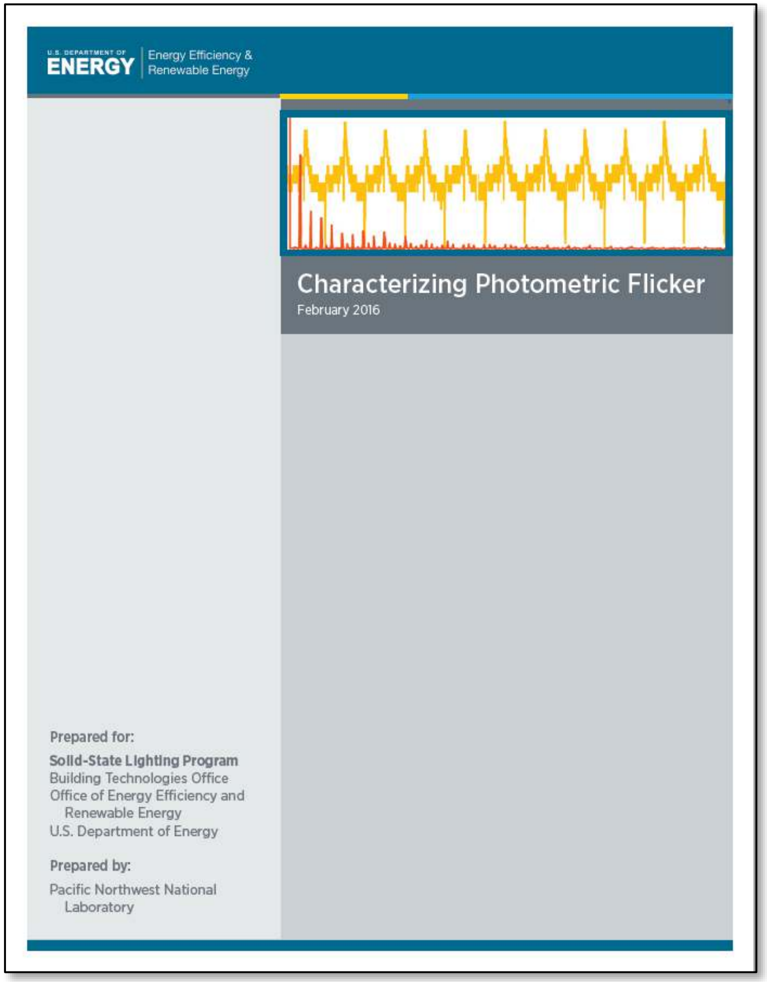


NEMA TLA next steps

- 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



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Source: http://energy.gov/eere/ssl/downloads/characterizing-photometric-flicker

Other Industry Efforts

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

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

- Third-party flicker testing services[2]

Sources: [1] http://div1.cie.co.at/?i_ca_id=549&pubid=466
[2] https://ul.com/newsroom/pressreleases/ul-launches-verification-service-for-low-optical-flicker/

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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!

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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

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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

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