



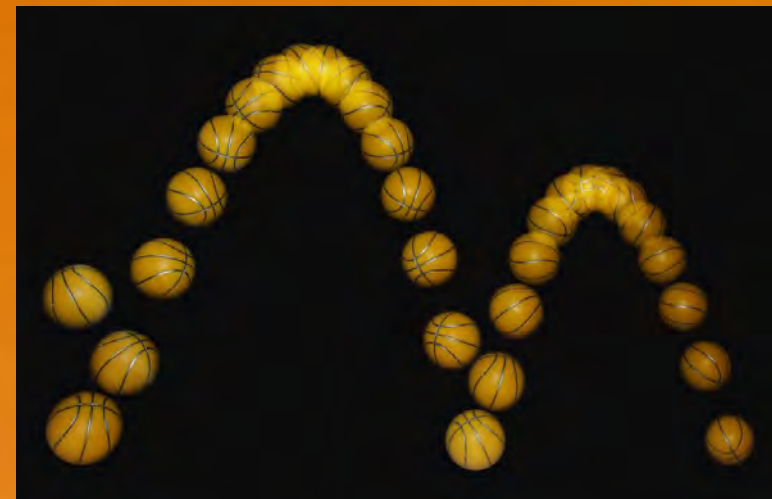
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Flicker: How to avoid it, test for it, and fix it

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Pacific Northwest National Laboratory

LightFair, DOE Booth, Chicago IL, May 2018





What is Flicker? CIE vs. IEEE

CIE 17.443 e-ILV:

Temporal light artifact (TLA): an *undesired change in visual perception* induced by a light stimulus (Temporal Light Modulation, TLM) whose luminance or spectral distribution fluctuates with time

- **Flicker:** Perception of *visual unsteadiness... for a static observer in a static environment. Up to 3 - ~80 Hz*
- **Stroboscopic effect:** change of *motion perception... for a static observer in a non-static environment ~80 Hz - ~2000 Hz*
- **Phantom Array effect** (ghost effect): change in *perceived shape or spatial layout of objects... for a non-static observer in an otherwise static environment* (e.g. saccade, normal head movement, or while driving) ~80 Hz – ~2500 Hz

IEEE 1789-2015: “Variations in luminance over time” (temporal modulation of light)

- Encompasses all of the above effects
- Includes visual and non-visual effects, as measured by (e.g.) EEG testing





What does flicker (TLA) look like??

(ANYONE WITH A HISTORY OF SEIZURES, DO NOT WATCH)



Flicker

(Video)

Stroboscopic Effect

(PAR30 LED lamps Good-Meh-Bad)

Phantom Array Effect

(Cheesy Light rope)



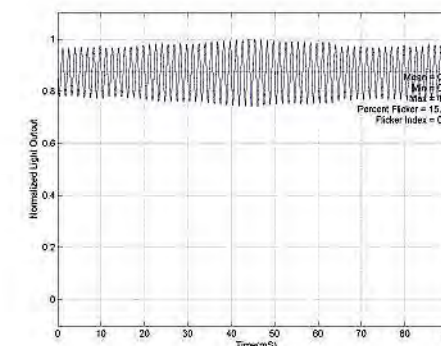
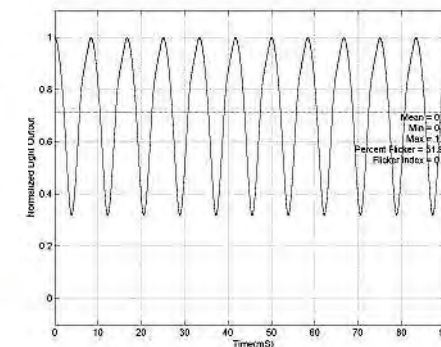
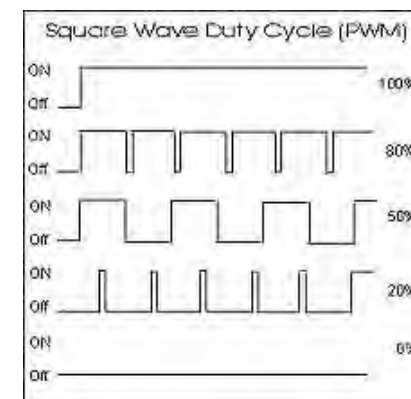
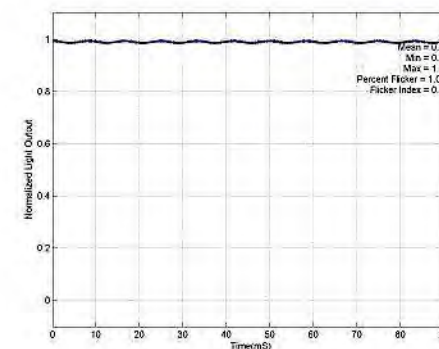
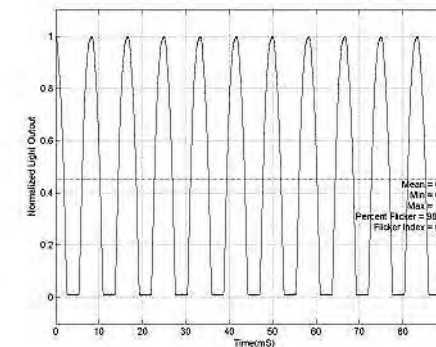
Important factors of flicker

Primary factors of visibility and/or detection

- ▶ **Frequency**, measured in cycles per second = Hertz (Hz)
- ▶ **Modulation depth** (% change in intensity) = $(\text{max}-\text{min}) \div (\text{max}+\text{min})$
- ▶ **Duty cycle** (for square waves): % of cycle time spent above a certain intensity (e.g. 10%)
- ▶ **Relative motion** of light source or illuminated objects, and eyes
- ▶ **Light intensity** and observer adaptation level
- ▶ **Shape of waveform** (sinusoidal, square, inconsistent)

Other factors impacting health

- ▶ **Duration of exposure** – longer is worse
- ▶ **Average luminous intensity (mean luminance)** – brighter is worse
- ▶ **Area of the visual field receiving stimulus** – more is worse
- ▶ **Whether both eyes are being stimulated** – both is worse
- ▶ **Position in the visual field** – central is worse than peripheral
- ▶ **Contrast with background** – more contrast is worse
- **Color contrast of flash (deep red is worse)**





Why do we care?

- ▶ Photoepilepsy – flashing lights (and other repetitive patterns) stimulate epileptic seizures
- ▶ Stroboscopic effect – dangerous when working with rotating machinery
- ▶ Migraine or severe paroxysmal headache often associated with nausea and visual disturbances
- ▶ Increased repetitive behavior among persons with autism
- ▶ Asthenopia (eye strain), including fatigue, blurred vision, conventional headache, decreased performance on sight-related tasks, etc.
- ▶ Other: panic attacks, anxiety, increased heart rate, vertigo
- ▶ Also: interference with machine vision and imaging devices (video & security cameras, etc.)



Health.com

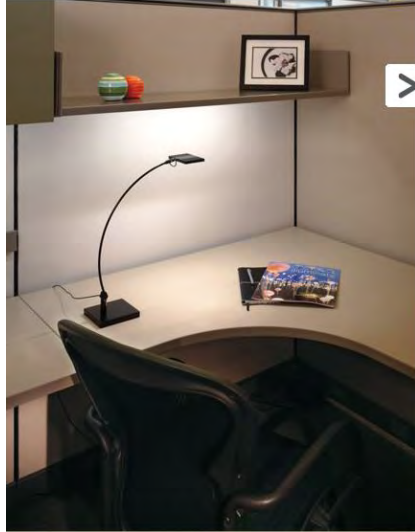
Where do we care?



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General lighting



Task lighting



Industrial spaces



Hospitals/clinics

Video
conferencing
Rooms



Classrooms



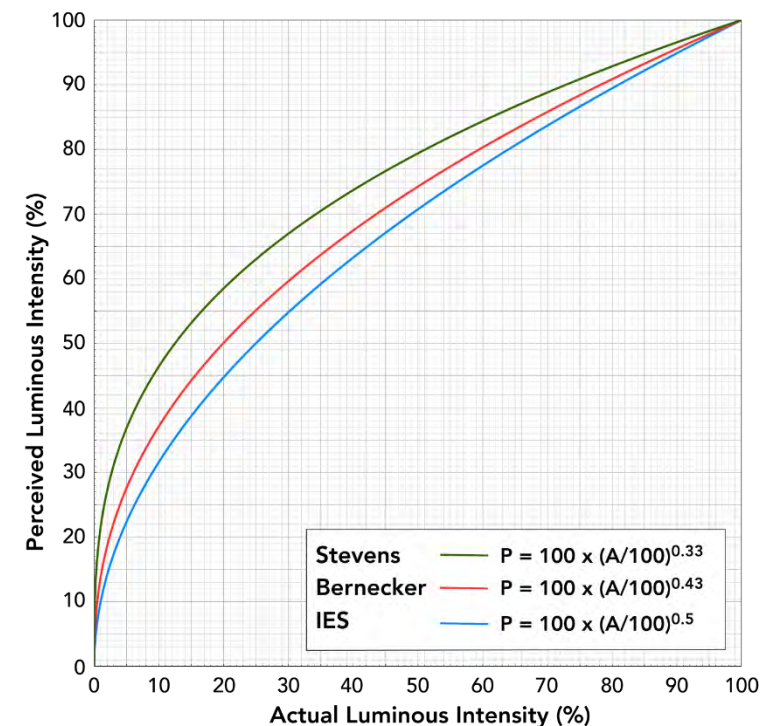
Offices



Why do we care, especially now?

LEDs

- ▶ Inherently fast-responding devices
- ▶ No persistence in light output compared to incandescent or fluorescent sources
- ▶ Relies on the DRIVER to provide visibly continuous light
- ▶ Pairing the driver with a dimmer especially tricky, especially at very low dimming levels, especially if color or white tuning is involved
- ▶ Human visual perception is not linear – by a long shot!
- ▶ To get a light source to LOOK like it's dimmed to 10% output, actual output need to be <1% output. Differences between actual and perceived are particularly large at low relative intensity levels



Actual versus perceived dimming levels

Don't blame the LEDs.
Blame the driver and the dimmer, knowing
that this is NOT an easy problem to solve!



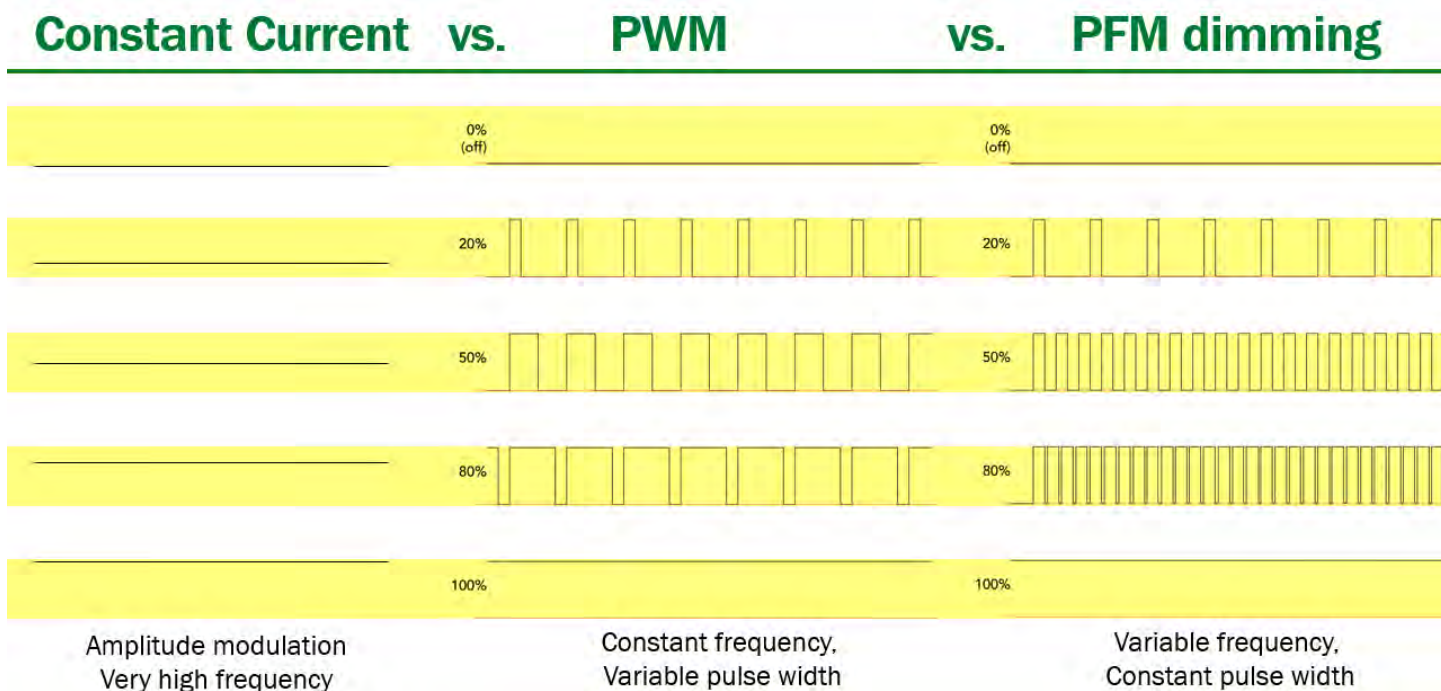
Dimming drivers

Ways for drivers to dim LEDs

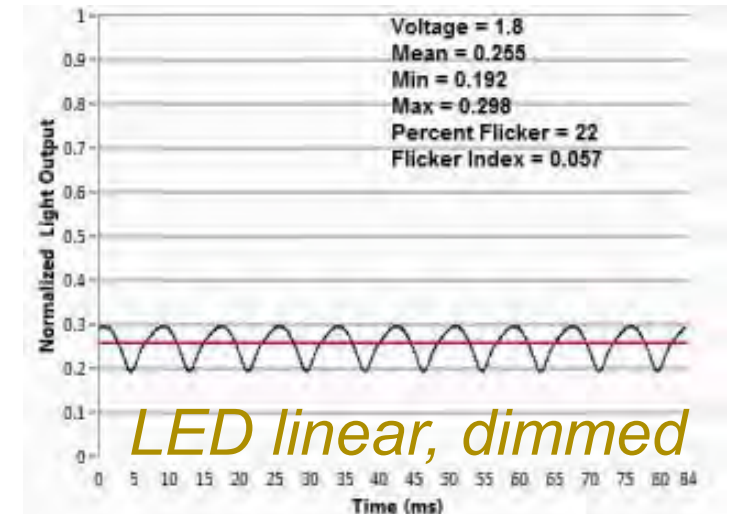
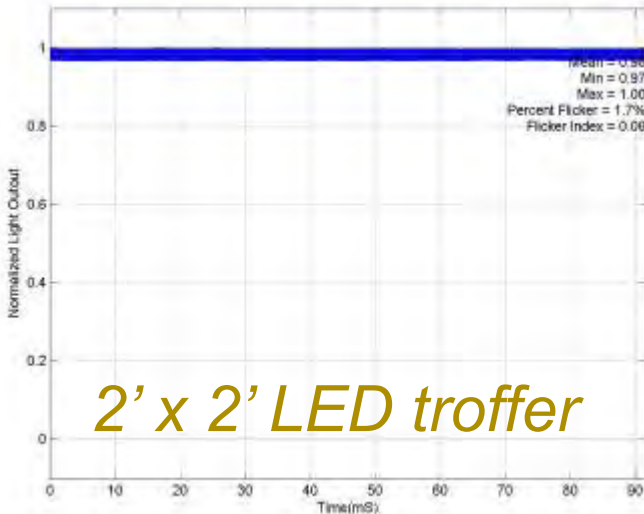
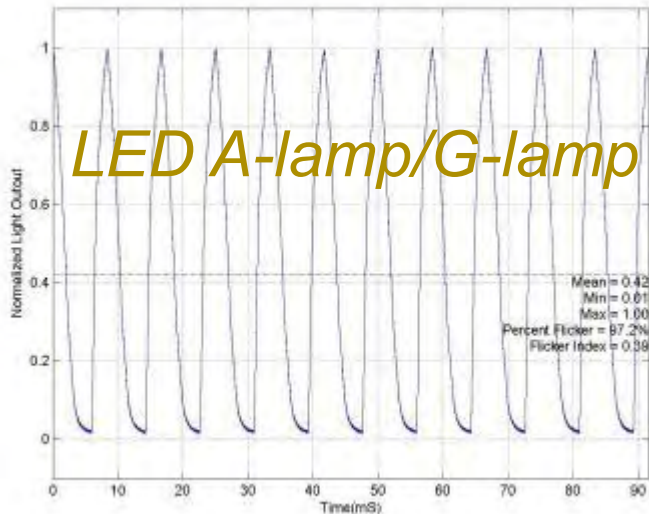
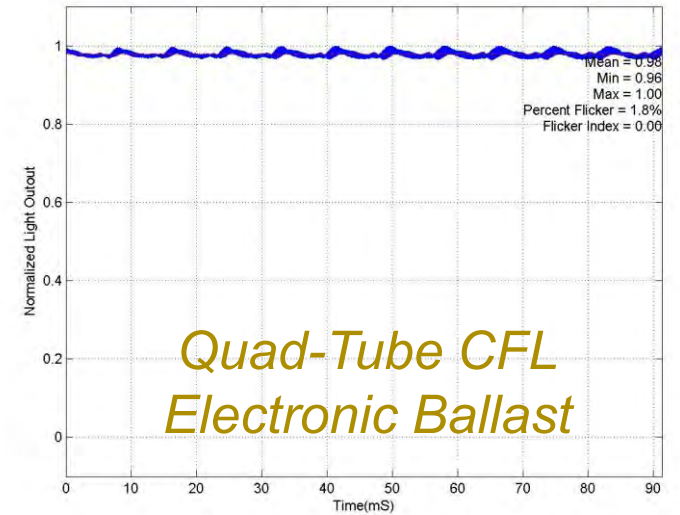
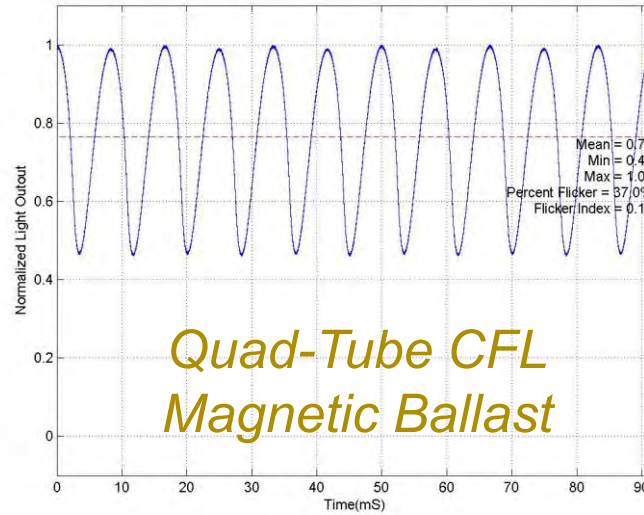
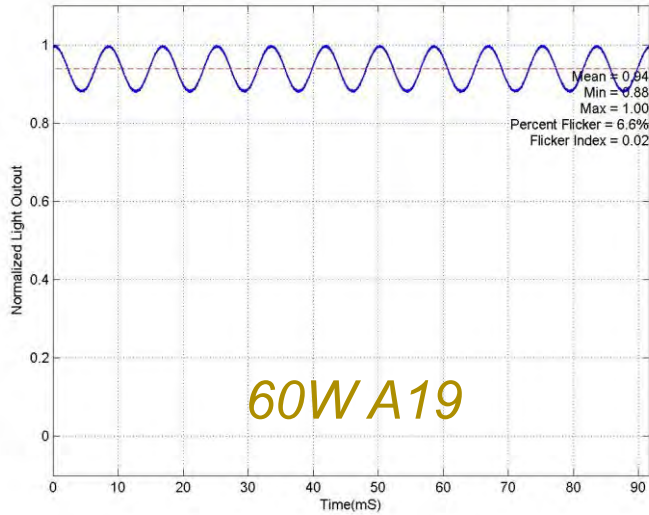
- ▶ Constant Current Reduction (CCR)
- ▶ Pulse Width Modulation (PWM)
- ▶ Pulse Frequency Modulation (PFM)

[Can introduce color shift]

[These can be combined as a dimming strategy, but PWM and PFM can introduce temporal light artifacts (TLA)]



Nearly all light sources exhibit some flicker



Flicker metrics over time

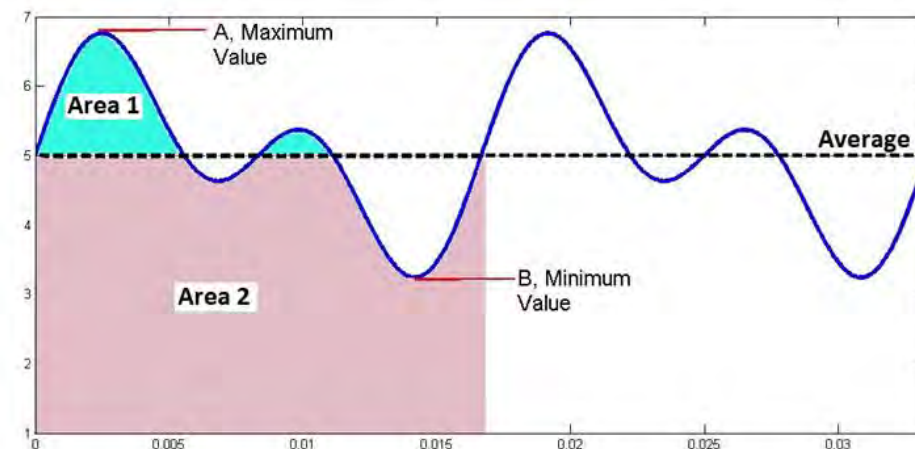
Illuminating Engineering Society

▶ Percent flicker

- 0-100% scale
- Older, but more well-known and more commonly used
- Accounts for average, peak-to-peak amplitude
- Does not account for shape, duty cycle, frequency

▶ Flicker index

- 0-1.0 scale
- Newer, but less well-known and rarely used
- Accounts for average, peak-to-peak amplitude, shape, duty cycle
- Does not account for frequency



Source: *IES Lighting Handbook, 10th Edition*

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



Flicker metrics over time (Thanks Jim Gaines & NEMA!)

IEC 61000-4-15

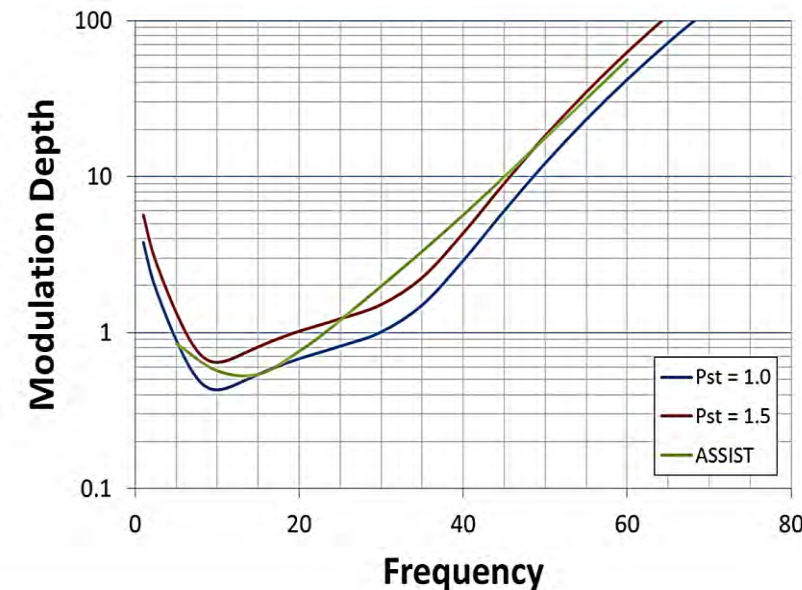
- “Flickermeter” – Functional and design specifications

IEC 61000-3-3

- “Limitation of voltage changes, voltage fluctuations and flicker” in public electric supply systems, up to 80 Hz
- Complex; originally developed to quantify power line quality

LRC ASSIST Flicker Perception Metric (M_p)

- Follows the IEC Flickermeter approach, but without the model of the incandescent lamp.
- Based on response of 10 subjects
- Covers frequencies from 5 Hz to 80 Hz



Plot of the visibility threshold ($P_{st} = 1$ and ASSIST), for visible flicker, expressed in terms of modulation depth, as a function of frequency. The curve is for a single sine wave modulation.

P_{st}

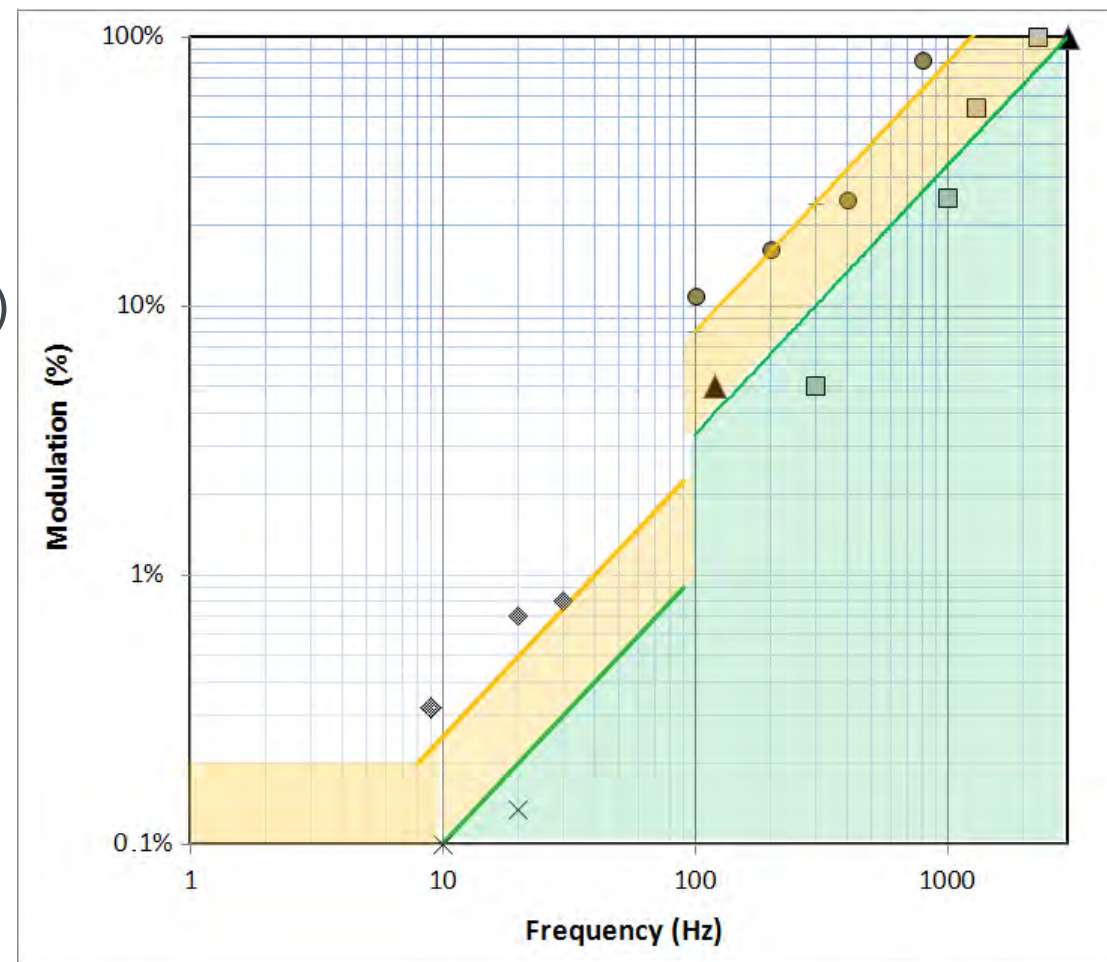
Limited to visible flicker up
to 80 Hz
Values above 1.0
considered acceptable



Flicker metrics over time

IEEE Standard P1789-2015 Methodology

- ▶ Focused on *health* risks from flicker
- ▶ Plotted data from multiple studies based on risk level, probability of exposure, and severity of exposure
- ▶ Characterized data reliability (from opinion to solid data)
- ▶ Plotted % Flicker (modulation) and frequency for no effect level (green, factor of 0.03) and low risk level (yellow, factor of 0.08).
- ▶ Goal was simple metric, easy to calculate and understand
- ▶ BUT... Hard to evaluate complex waveforms, doesn't account for wave shape, doesn't account for low duty cycle (e.g., dimming).
- ▶ And, does conservative approach suit all applications?





Flicker metrics over time

Stroboscopic effect Visibility Measure (SVM)

- ▶ Developed by Philips Eindhoven researchers based on human subjects testing, converted into a Standard Observer
- ▶ Predicts visibility of strobe effect based on wave shape and duty cycles, above 80 Hz.
- ▶ Uses Fast Fourier Transform (FFT) analysis
- ▶ SVM value of 1 means for this waveform, standard observers will be able to see flicker 50% of the time. <1 is harder to see; >1 is easier to see.
- ▶ Less conservative than IEEE Standard P1789-2015

Questions and modifications:

- Does *visibility* of the strobe effect equal neurological response?
- Does the standard observer predict the responses of migraineurs and autists?
- Assumes a fixed head/gaze. How realistic is this?
- Doesn't predict the visibility of phantom array effect
- What threshold values are recommended for different applications?

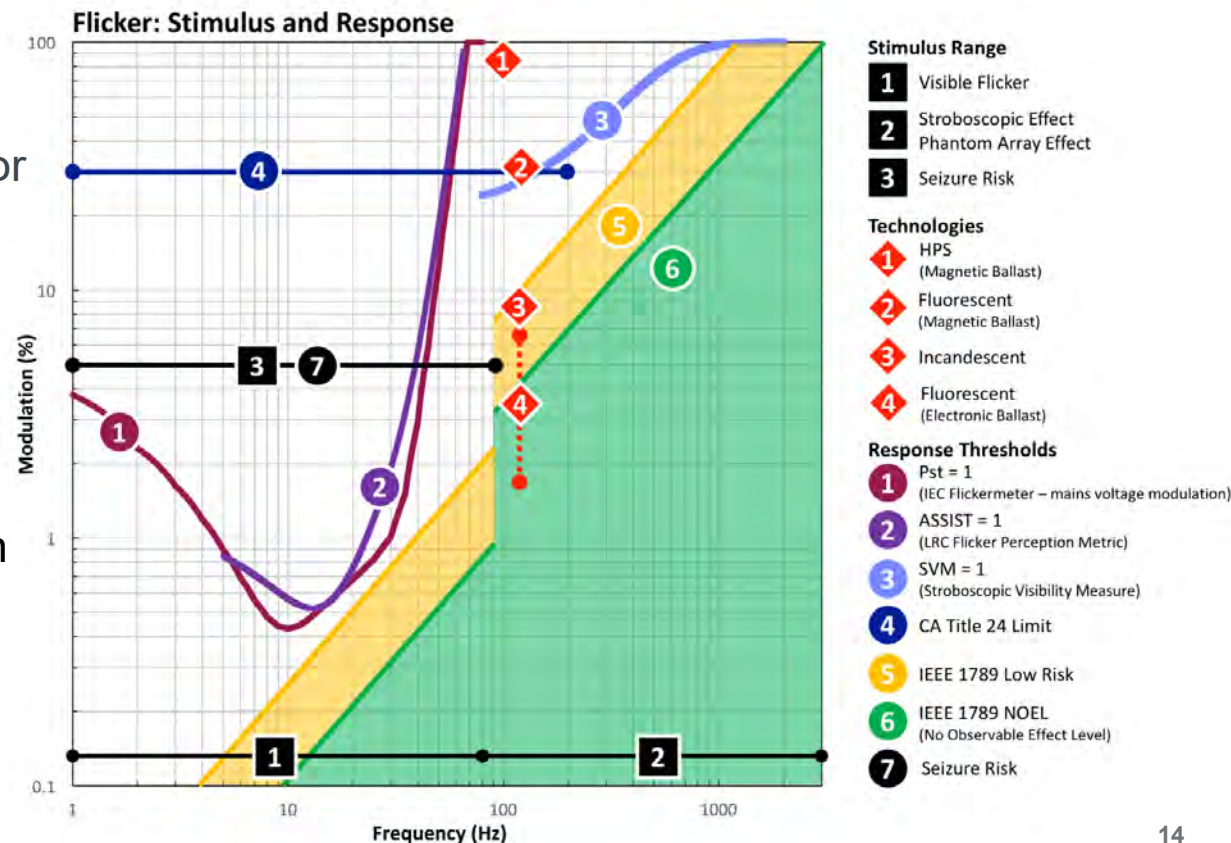


Flicker metrics over time

NEMA 77-2017 Temporal Light Artifacts (P_{st} + SVM)

- ▶ Based on flicker visibility. Assumes visibility = neurological effect
- ▶ Uses Pst standard (flickermeter) below 80Hz
- ▶ Uses SVM above 80 Hz, with a max value of 1.6, because products performing at that level have been on the market for years without complaints
- ▶ Strength: a group of manufacturers has signed on to this standard. It's a first step, although the numbers need to be tweaked based on application and experience
- ▶ Weakness: Not complete. Fixed gaze only. No differentiation between “standard observer” and sensitive individuals. Doesn't account for phantom array effect. Assumes flicker visibility = neurological effect.

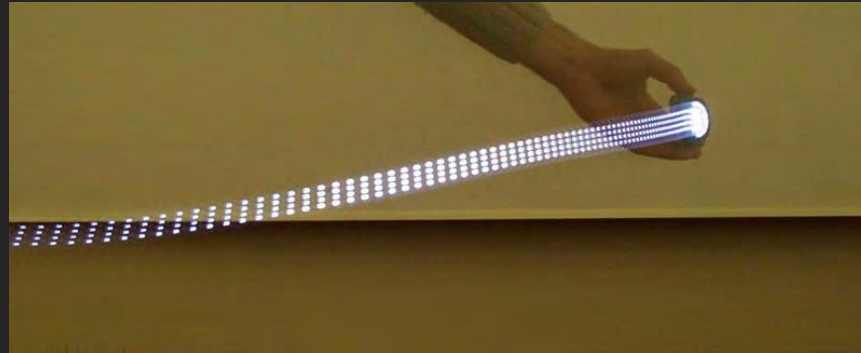
Plots of all metrics using frequency and % Flicker (aka % Modulation).



Flicker metrics over time

Phantom array effect (ghost effect) measure

- Investigated by Wilkins and Roberts
- No specific metric yet for phantom array effect
- Is it the same effect as stroboscopic effect? Can the metric be the same?



<https://www.led-professional.com/resources-1/articles/lighting-with-leds-2013-more-than-just-illuminating-objects>



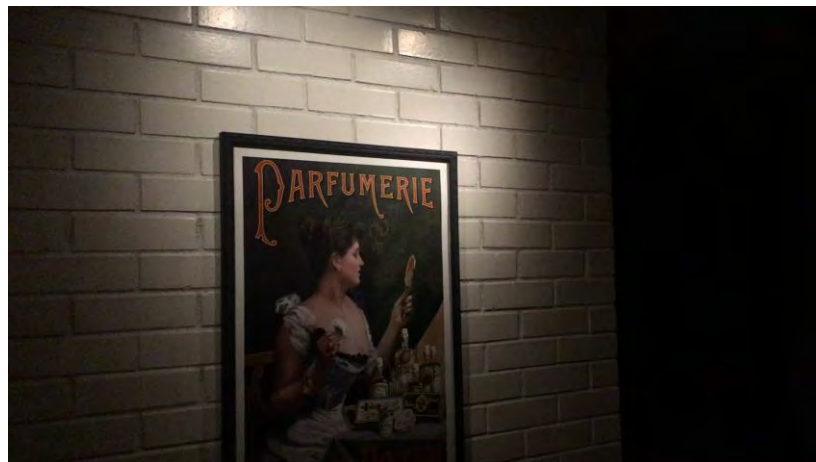
What you can do, starting today

Specifiers:

1. Insist on seeing an LED luminaire or lamp in operation before specifying it. See it in dimmed operation. Use the waving finger/waving wand test.
2. Buy a good quality hand-held flicker meter that measures AT LEAST up to 2000 Hz and learn to use it.
3. Become familiar with flicker metrics. Encourage manufacturers to publish flicker metrics on their cut sheets
4. Ask your clients about sensitivity to flicker
5. Decide which applications need careful attention to flicker
6. Write language into your specification, such as:
 - “Dominant flicker frequency shall always be ≥ 100 Hz for any static dim level.”
 - “As defined in the IEEE 1789-2015 standard, must remain in the ‘No Effect’ zone to at least 2% dim level, and in the ‘Low Risk’ zone to at least 0.5% dim level.”
7. **If you suspect flicker in a sample or on a job site**, take a cell phone and set it on SLO-MO video (240 frames per second). This slows down the flicker rate by a factor of 8, making it more visible. Film for 5 seconds. Play back the video on the phone. Flashing, stripes, or other artifacts *may* indicate flicker or strobe or phantom array effect. **NO GUARANTEE, BUT IT’S A GOOD INDICATOR, AND IT’S FUN.**



Demo: Flicker effects from Slo-Mo video



120 Hz, 100% Flicker

SVM > 4

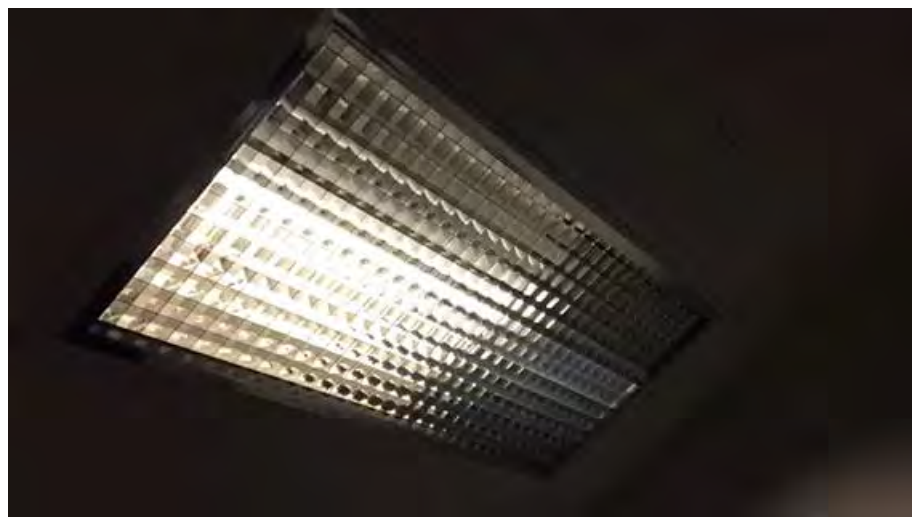
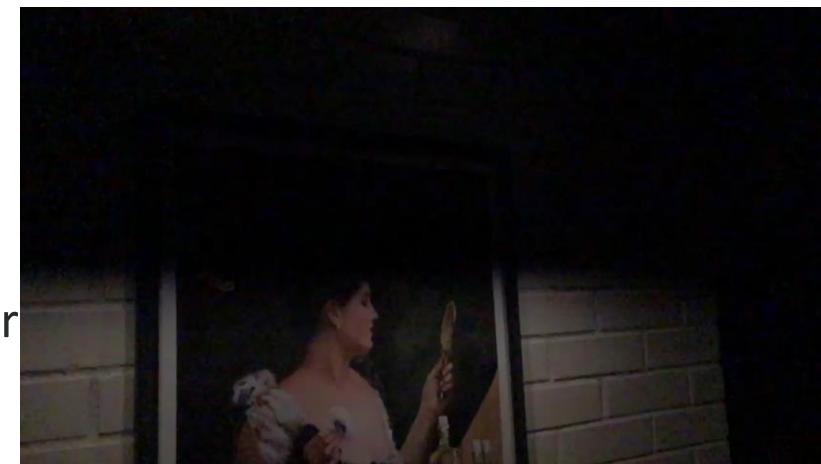
Video at 30 fps

(not Slo-Mo)

120 Hz, 100% Flicker

SVM > 4

Video at 240 fps



30,000 Hz, 2% Flicker

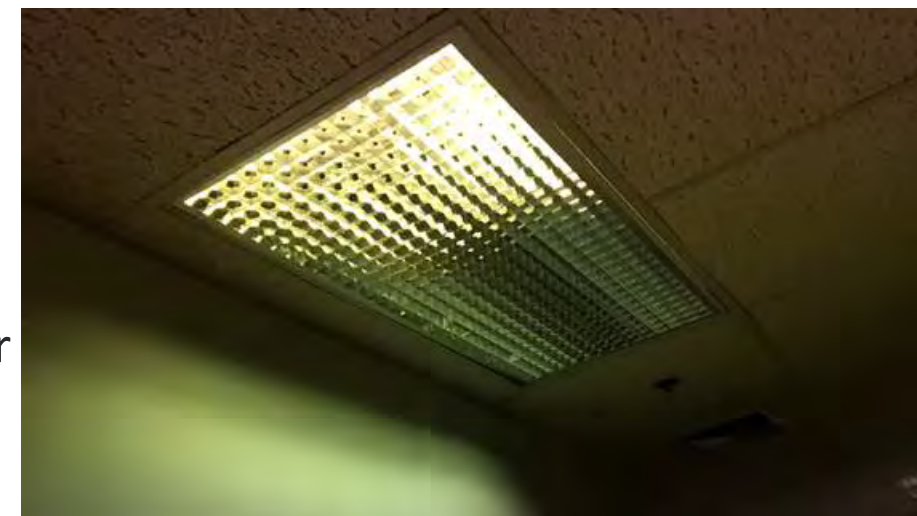
Video at 240 fps

SVM 0.02

120 Hz, 70% Flicker

Video at 240 fps

SVM 2.0





How do you measure flicker?

Bench top flicker meters available, reliable, and expensive.

<https://www.energy.gov/eere/ssl/downloads/characterizing-photometric-flicker>

Handheld flicker meters now available, less expensive, and mostly reliable for calculated metrics.

[Handheld flicker meter report expected early summer]

Manufacturers' To Do List:

1. Buy a flicker meter that measures *at least* up to 2000 Hz
2. Test for flicker over full dimming range.
3. Use/Demand drivers that meet high standards of low flicker
4. Use/Publish flicker metrics on datasheets

- ▶ %Flicker (i.e., modulation depth)
- ▶ Flicker Index
- ▶ Flicker Frequency
- ▶ SVM, Pst or Mp





How to FIX flicker in the field

- **Call the luminaire manufacturer to plead for help.**
- **Options include:**
 - ◆ **Change the driver.**
 - ◆ **If it's phase-cut dimming, change the dimmer.**
 - ◆ **Last resort is change the luminaire, except for ...**



<https://martinevans.files.wordpress.com/2010/04/homer2.gif>

- ◆ **Move far away and change your cell phone number 😊**



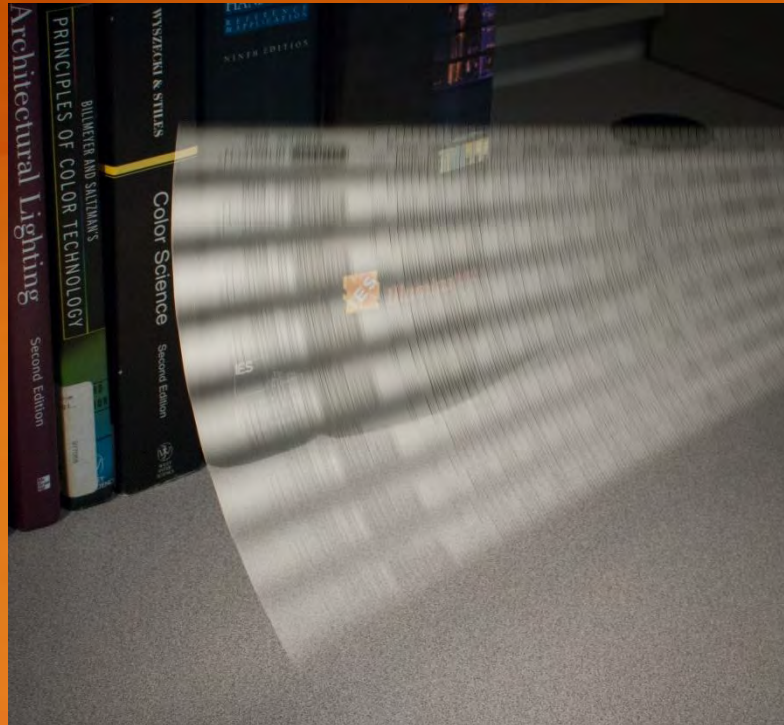
Crib notes for the pop quiz on TLM, TLA, aka flicker

- ▶ Almost all light sources flicker to some extent
- ▶ Modulation depth, frequency, duty cycle, waveform over time are factors
- ▶ LEDs aren't the problem
- ▶ The driver/electronics for the LED is the source of flicker
- ▶ Interaction with a dimmer can make flicker worse, especially at low levels
- ▶ ALL flicker metrics are imperfect
- ▶ W-i-d-e individual variation in sensitivity to flicker
- ▶ Responses can range from none to migraines to risky seizures
- ▶ Setting safe levels is difficult because we have so little neurological data



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Thank you for listening!
Questions? Comments? Complaints?



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