Indirect Flicker Perception: Stroboscopic Effects from Light Source Flicker

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Lighting Research Center

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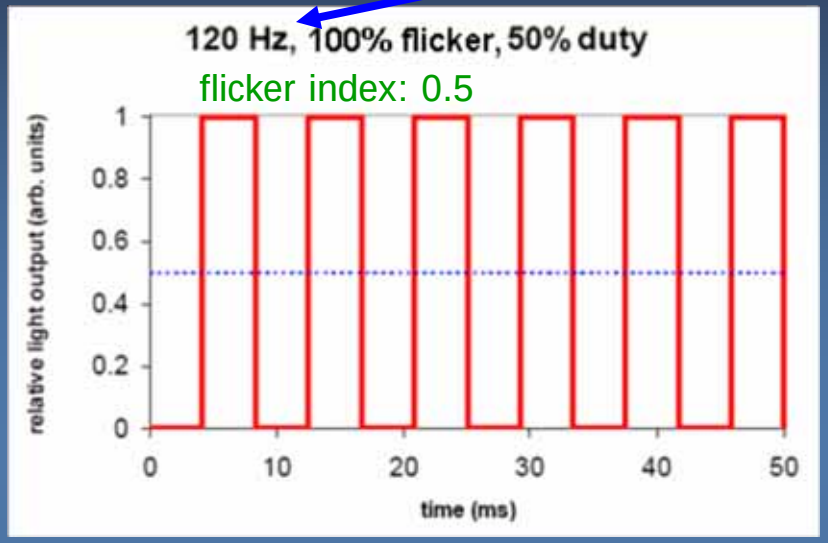
Outline

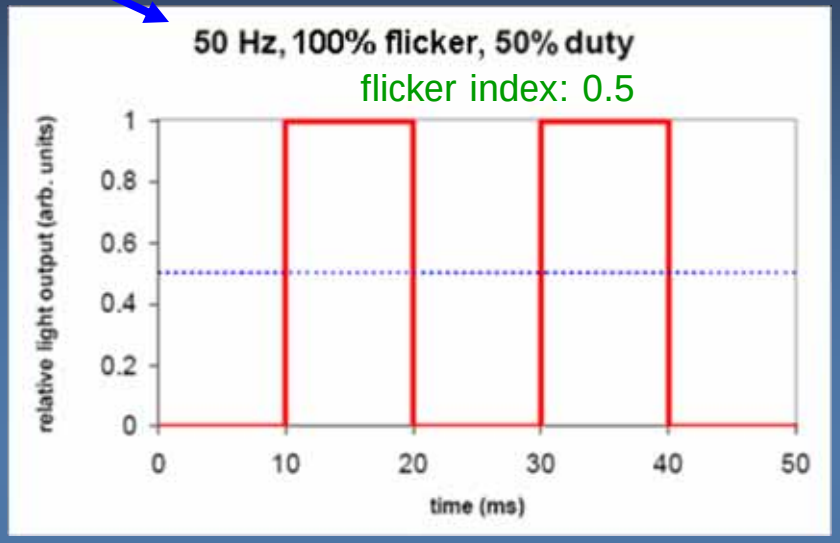
- Terminology overview
- Metrics for detection and acceptability of stroboscopic effects
- Comparison of metrics and specifications for characterizing stroboscopic effects
- Application considerations

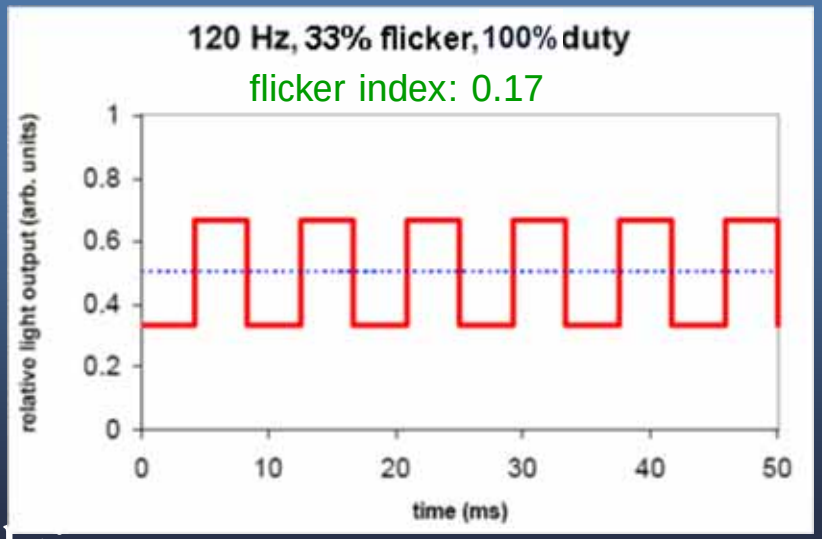
Note: Focus is on visual perception issues

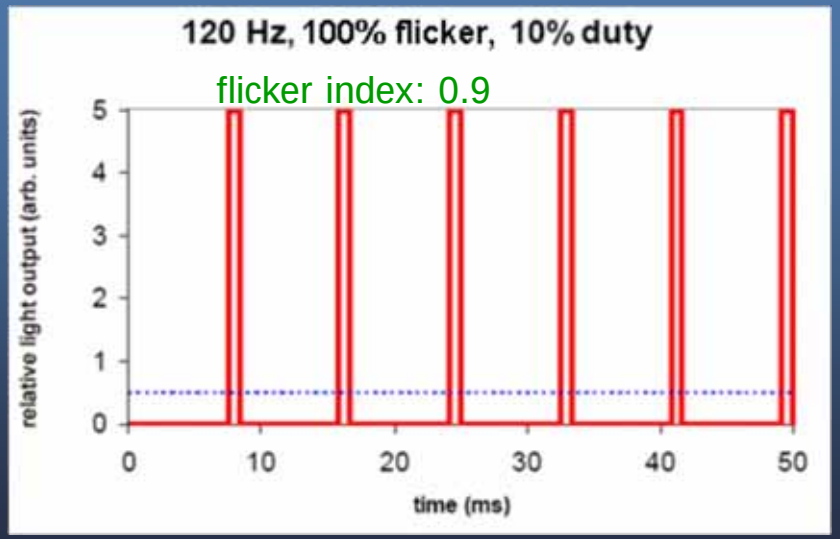
Terminology

Frequency (cycles per second)



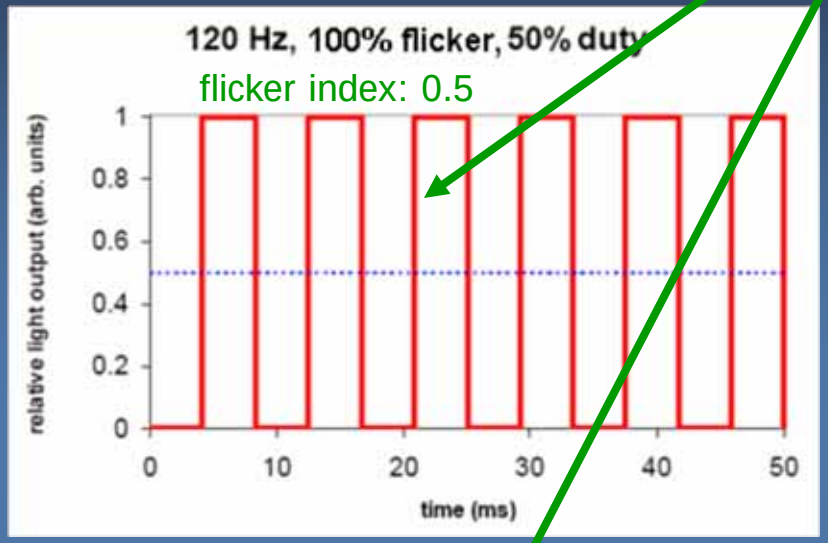


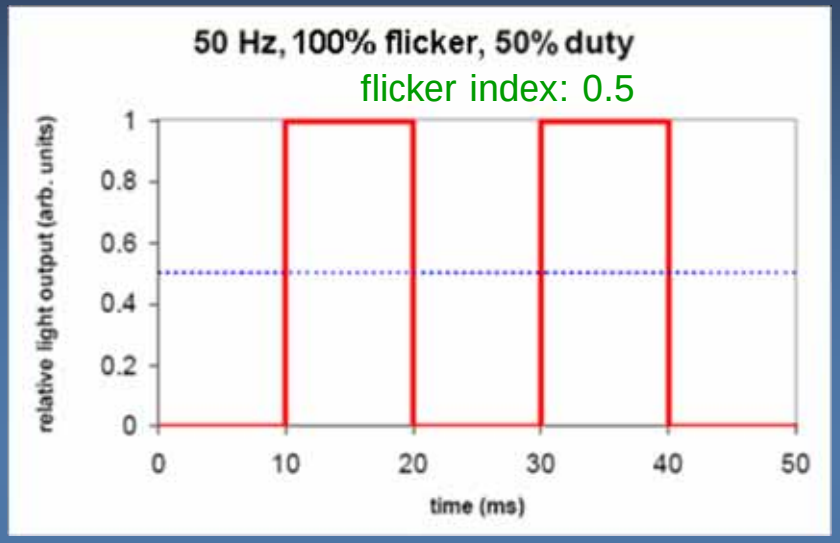


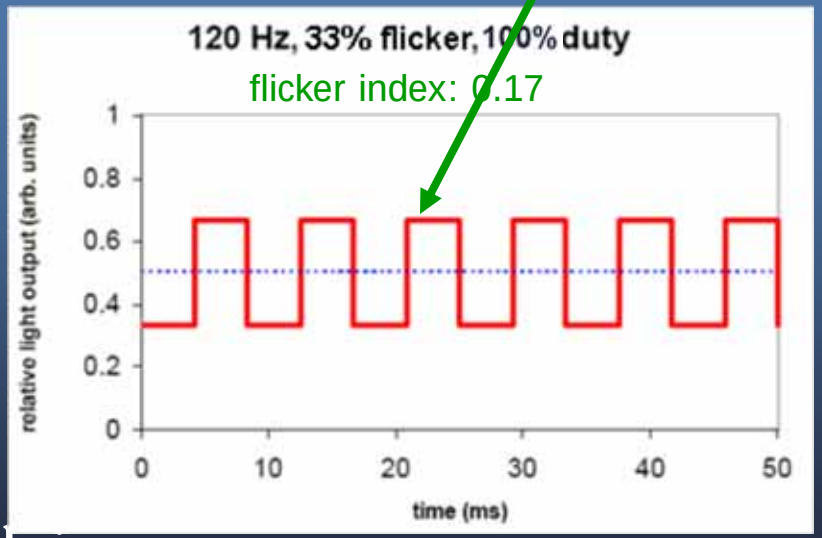


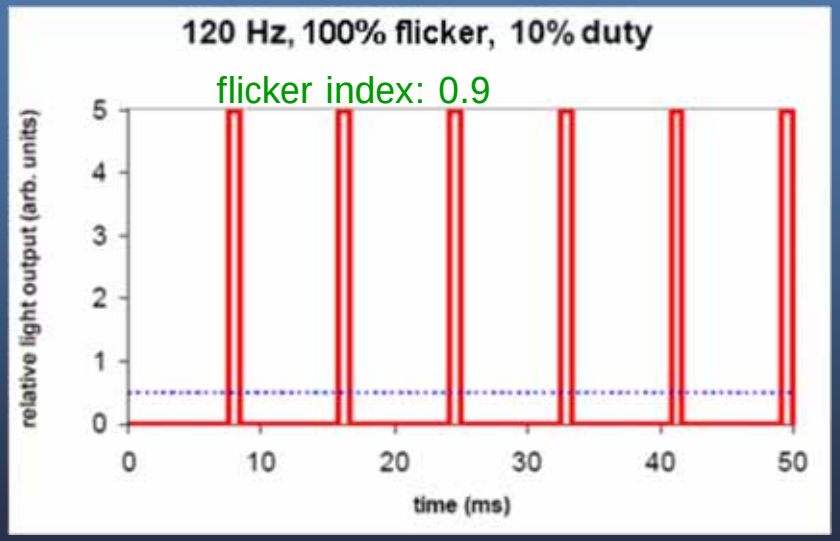
Terminology

Modulation depth (Percent flicker: [max-min]/[max+min])



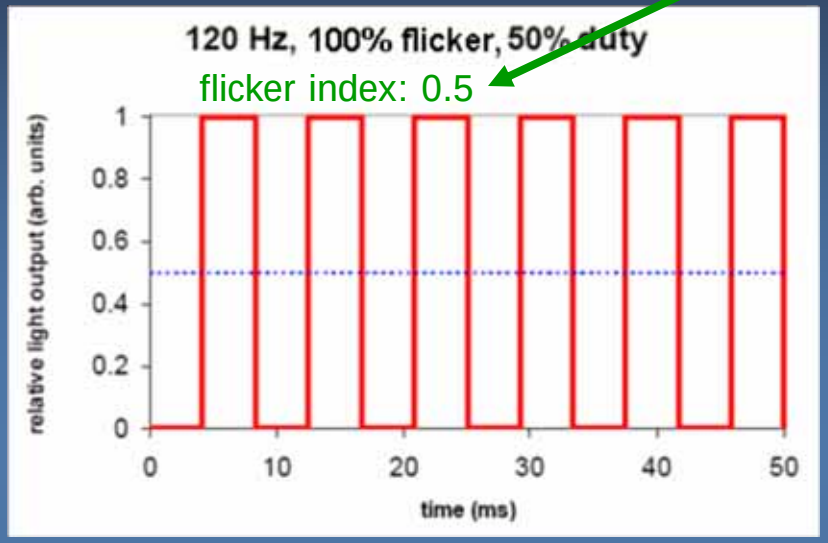


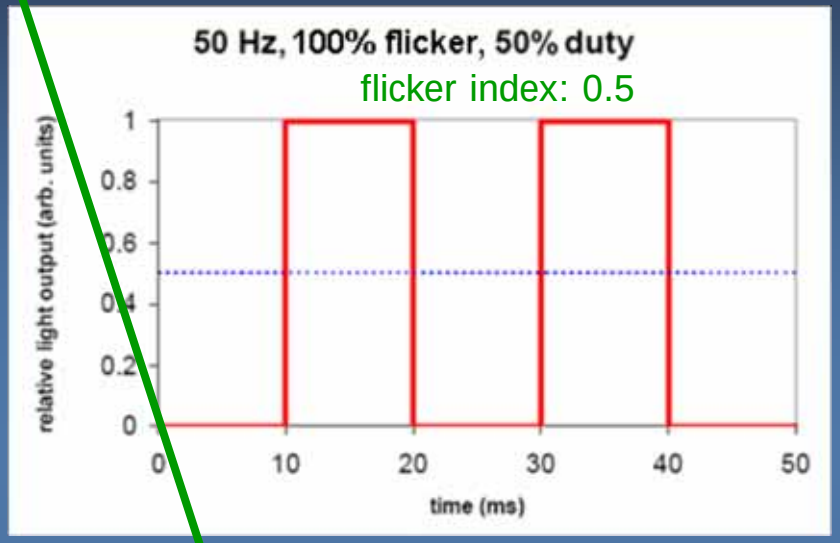


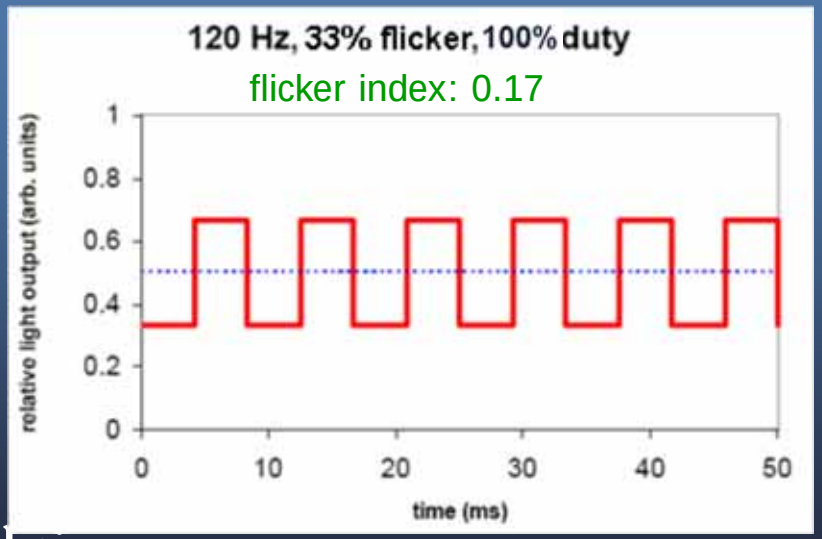


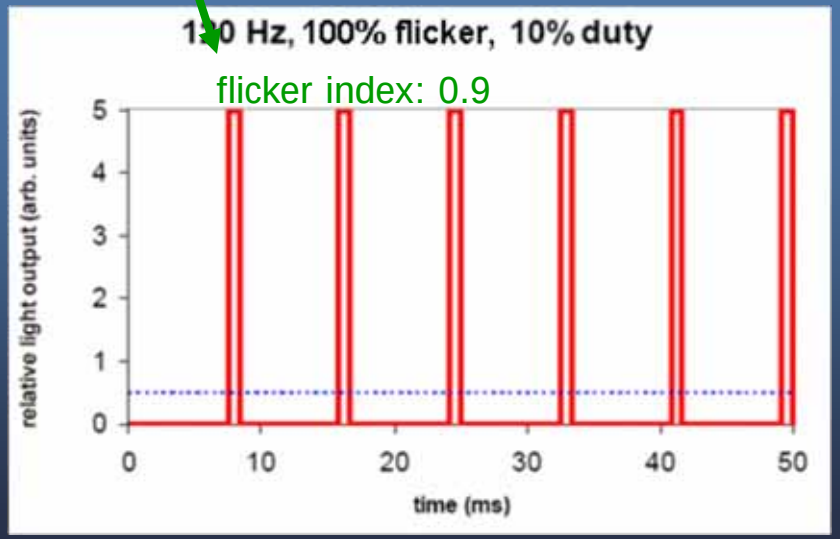
Terminology

Modulation depth
(Flicker index: area above average/total area



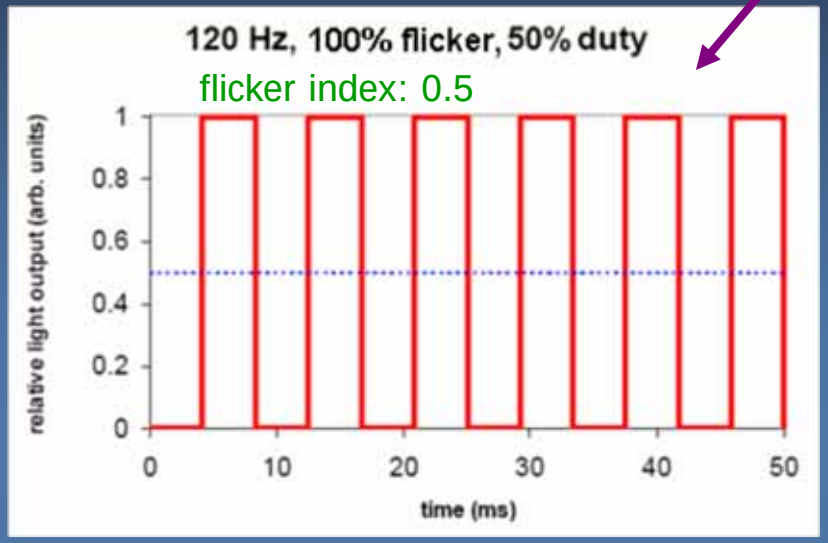


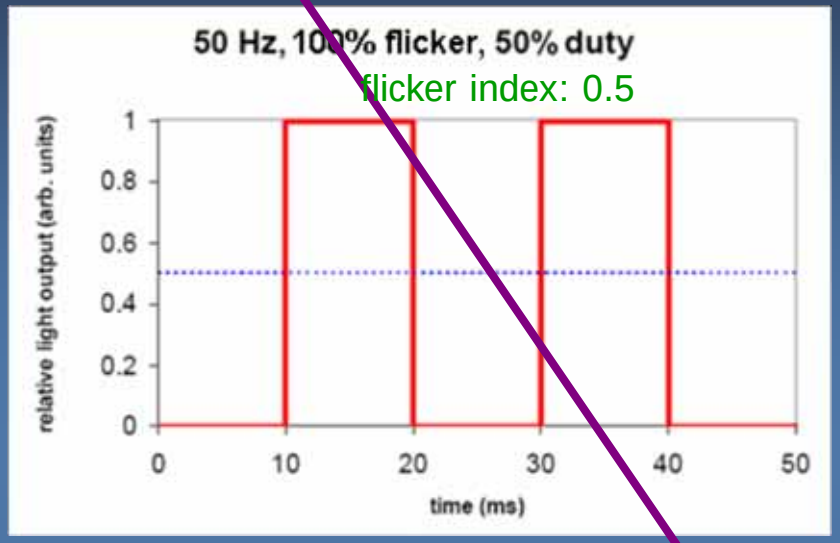


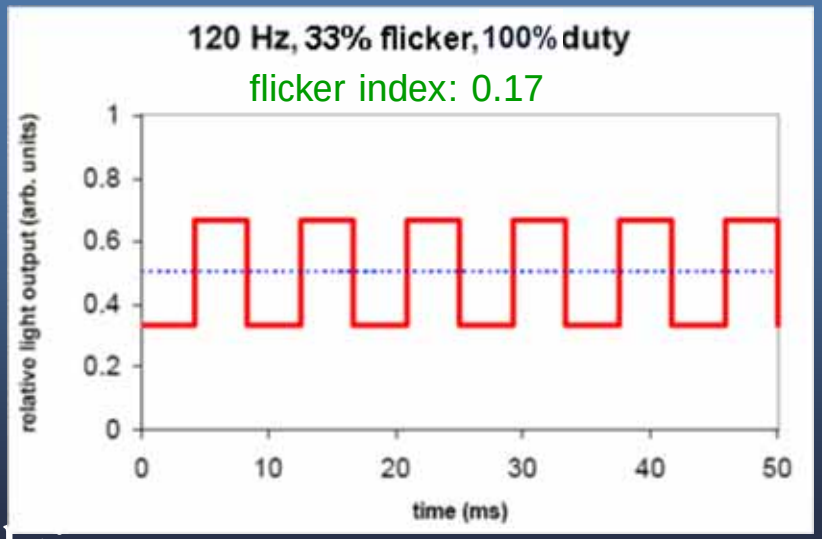


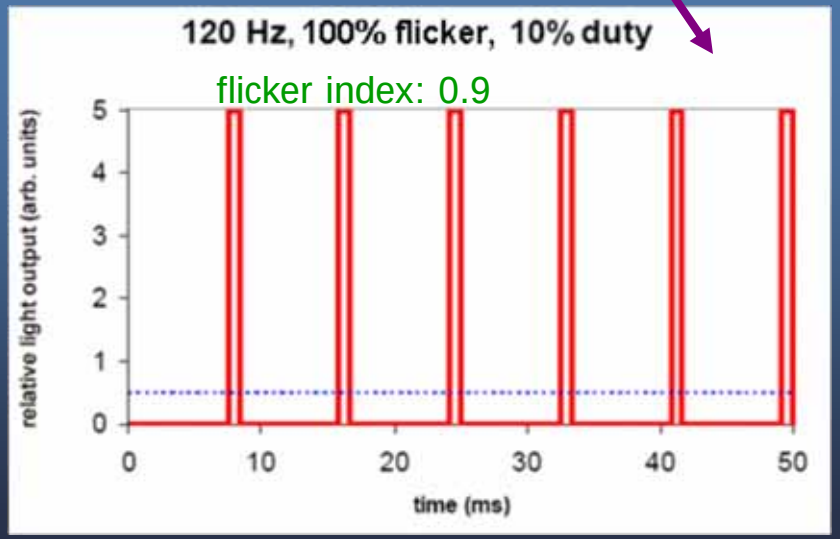
Terminology

Duty cycle (% of time light output > 10% of max)



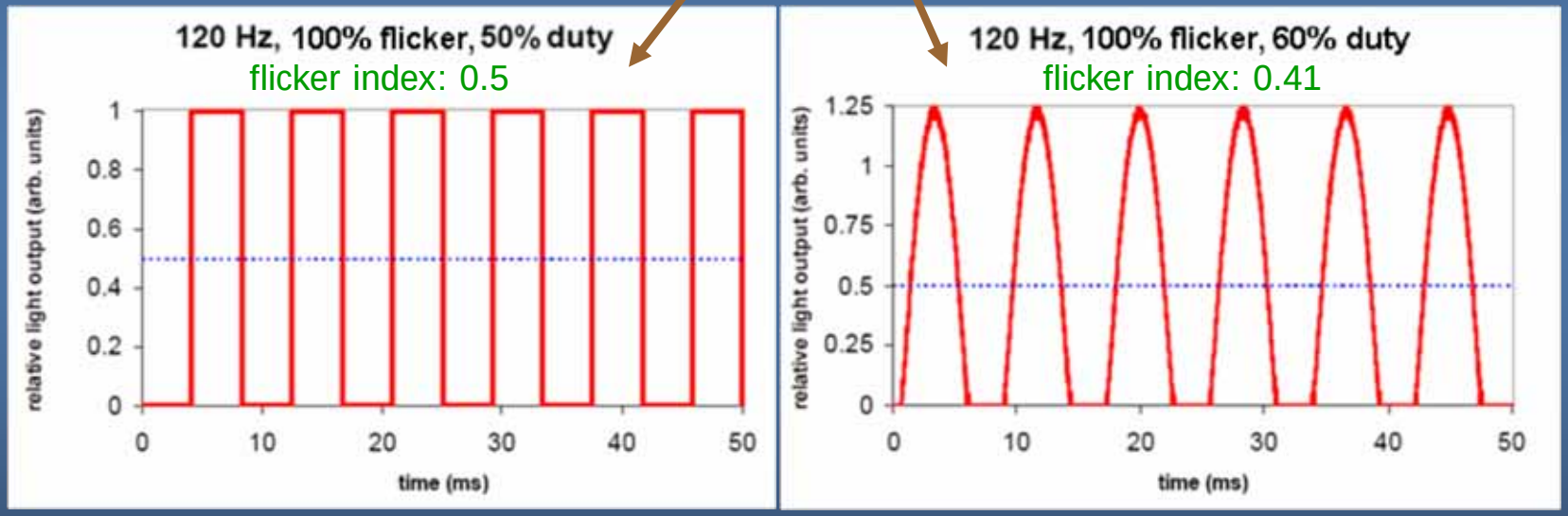




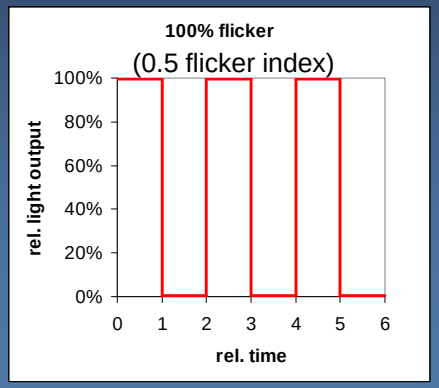


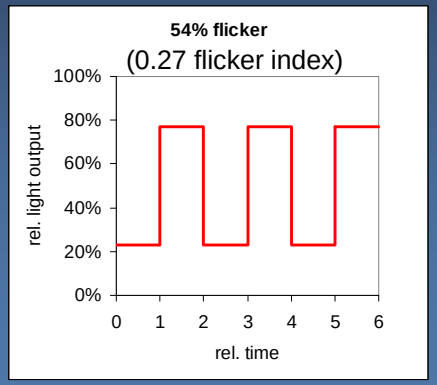
Terminology

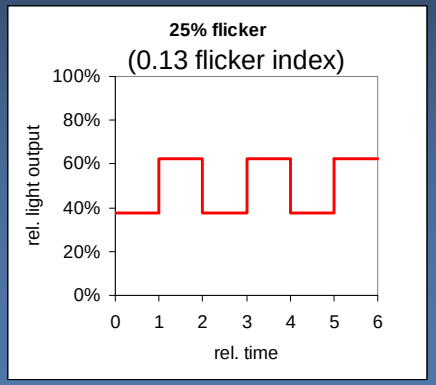
Waveform shape
(rectangular vs. sinusoidal)

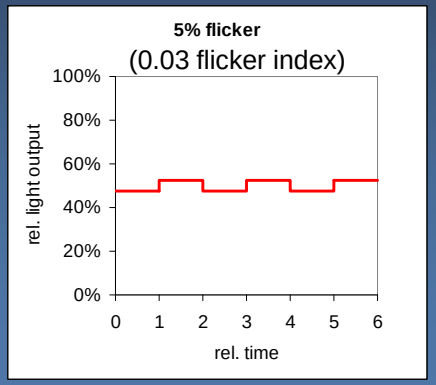


Detection and Acceptability of Stroboscopic Effects





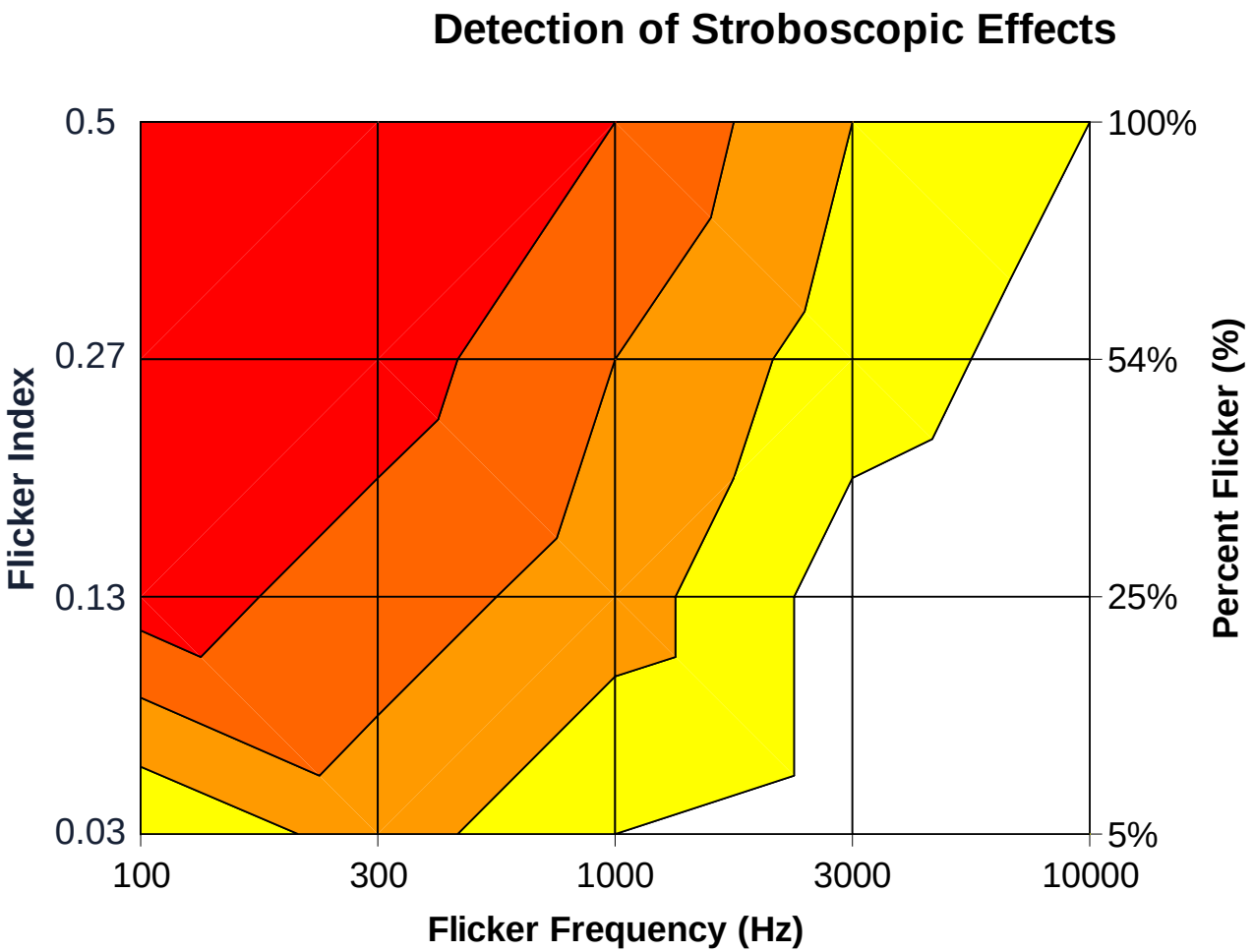


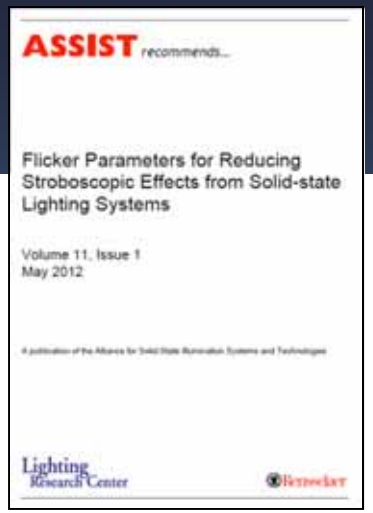


Experimental Task: Waving a light-colored rod against a dark background

Frequency → Percent flicker (flicker index) ↓	100 Hz	300 Hz	1000 Hz	3000 Hz	10000 Hz
100% (0.5)					
54% (0.27)					
25% (0.13)					
5% (0.03)					

Results: Detection

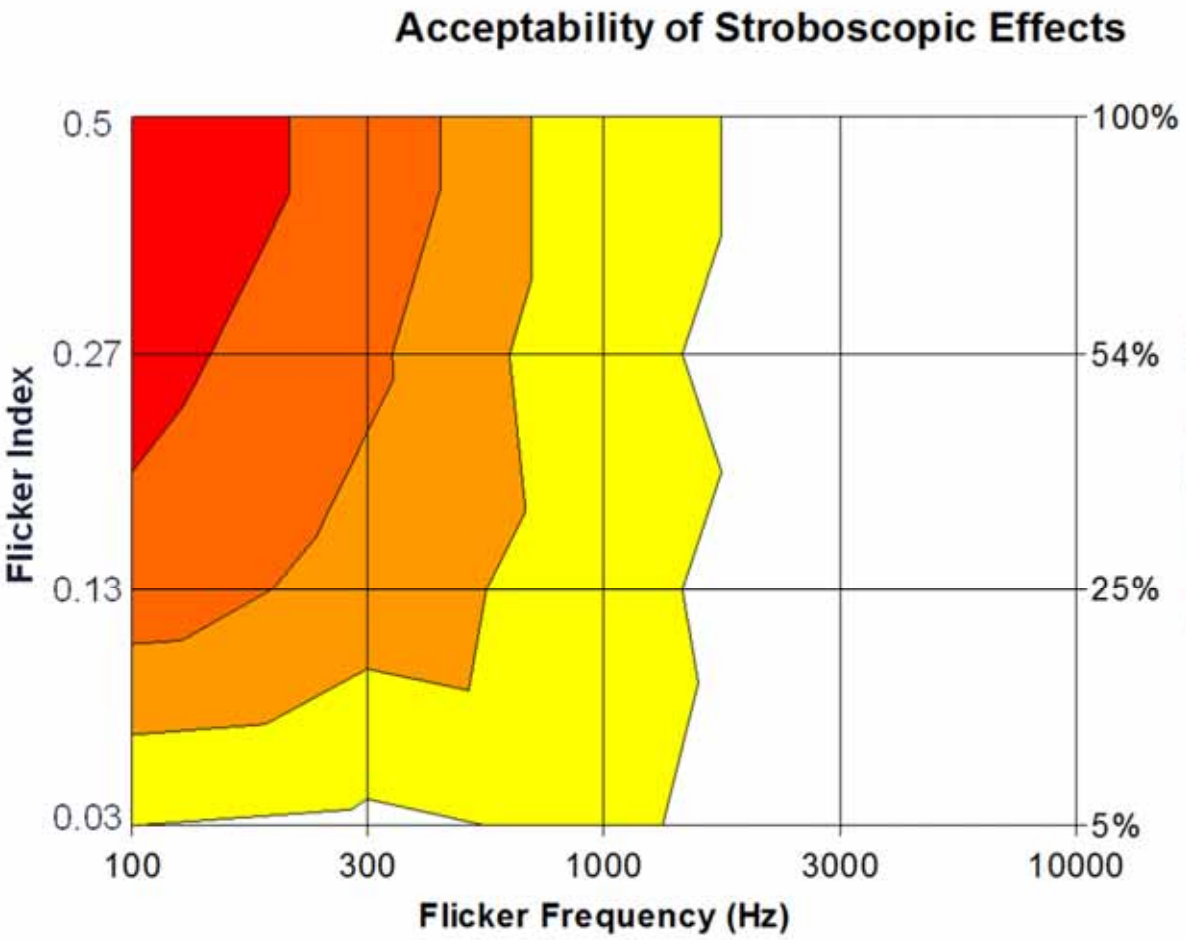


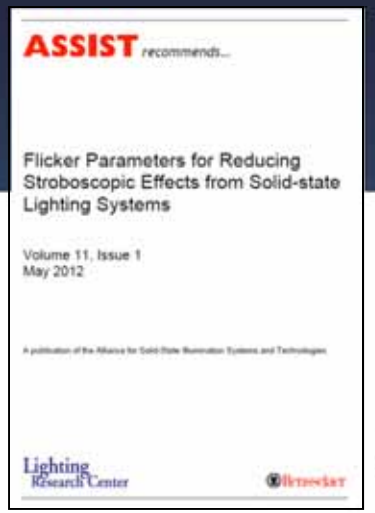


$$d = [(25p + 140)/(f + 25p + 140)] \times 100\%$$

(d=%detection, f=frequency in Hz, p=percent flicker=flicker index × 200)

Results: Acceptability





+2: very acceptable

+1: somewhat acceptable

0: neither acceptable nor unacceptable

–1: somewhat unacceptable

–2: very unacceptable

$$a = 2 - 4/[1 + f/(130 \log p - 73)]$$

(a=rating value, f=frequency in Hz, p=percent flicker=flicker index × 200)

Visual Performance Study

- Predictions of detection and acceptability under three flickering lighting conditions:
  - 100 Hz/0.5 flicker index (100% flicker): 96% detection, -0.6 acceptability
  - 100 Hz/0.13 flicker index (25% flicker): 88% detection, -0.1 acceptability
  - 1000 Hz/0.5 flicker index (100% flicker): 73% detection, +1.4 acceptability

(Bullough, Skinner and Sweater Hickcox 2013)

- Participants performed a low-contrast numerical verification task
- Predicted detection and acceptability was correlated with the number and rate of errors for this visual task

Which Flicker Metrics are Most Useful?

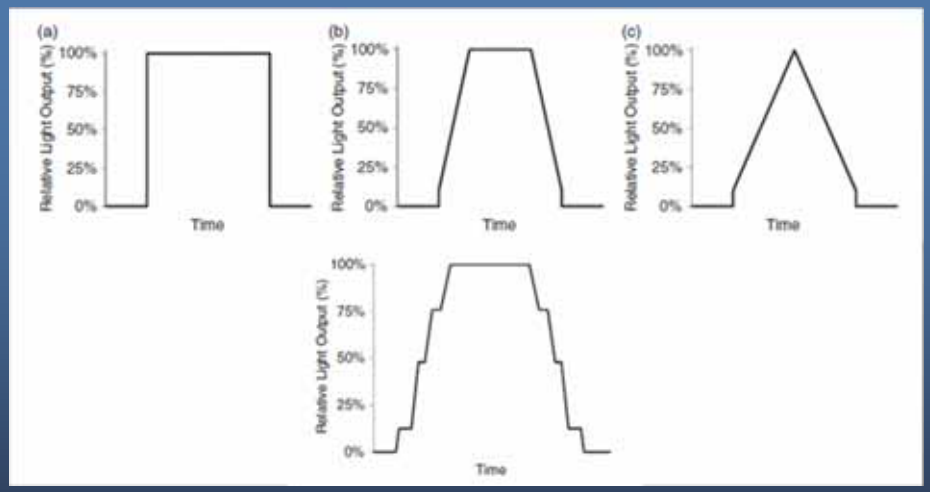
- ASSIST (2012) detection and acceptability models
  - Correspond to the specific visual task conditions used in the underlying experimental data
  - Rapidly waving a light-colored rod against a black background
- Percent flicker
  - Used by IEEE Standard 1789 and California Title 24 requirements
  - Does not incorporate flicker frequency

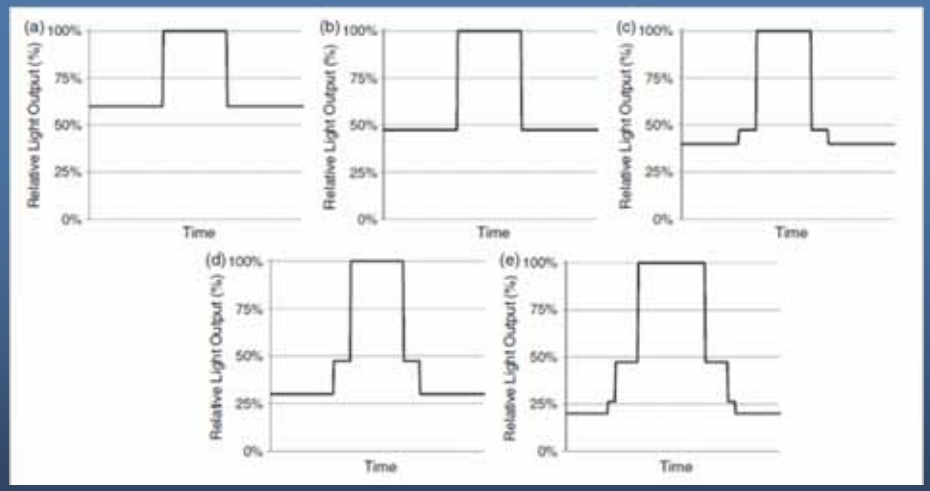
Which Flicker Metrics are Most Useful? (cont'd.)

- Flicker index (Eastman and Campbell 1952)
  - Has historically been reported for many types of lamps
  - Like percent flicker, does not incorporate frequency
- Fourier-based metrics (e.g., Perz et al. 2015)
  - Acknowledges that stroboscopic effects ultimately reduce to a spatial frequency visibility problem
  - Fourier-based approaches should offer the most complete predictive metric

Comparing Metrics

- Bullough and Marcus (2015) evaluated different waveform shapes and duty cycle (60%-90% or 100%) at 100, 120, 300 and 1000 Hz
- Responses to waving a light-colored rod against a dark background, and to a metronome operating at 208 bpm were assessed

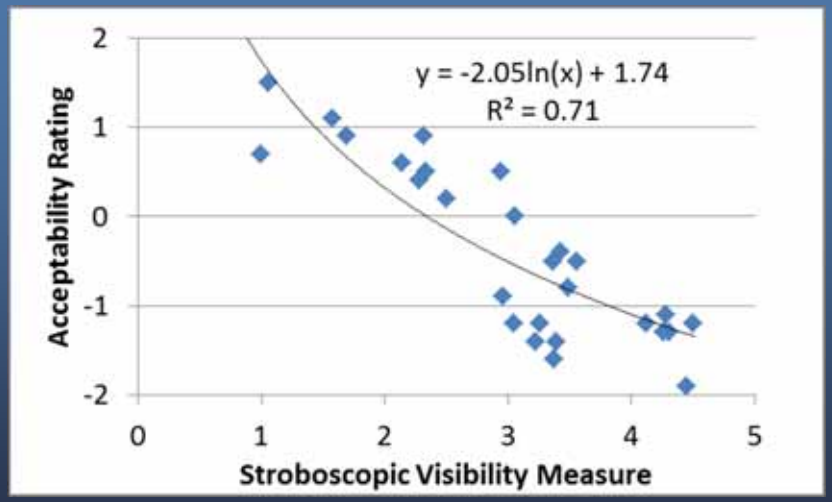


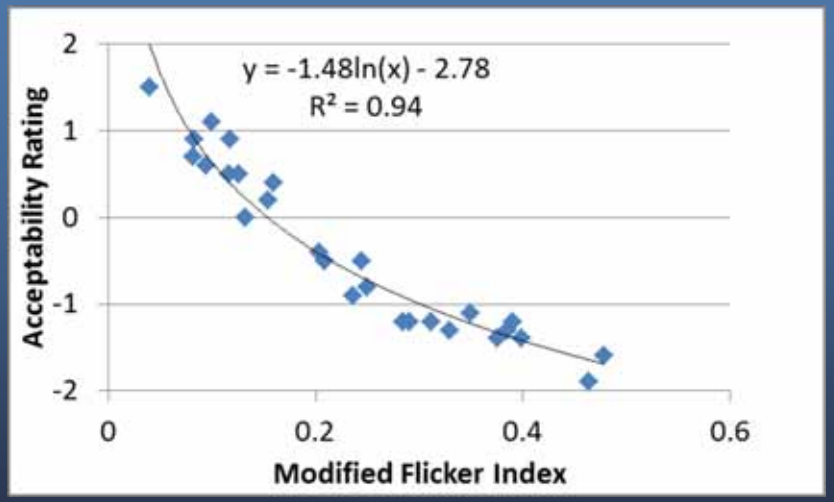


[all waveforms above: 100% flicker]

Experimental Results

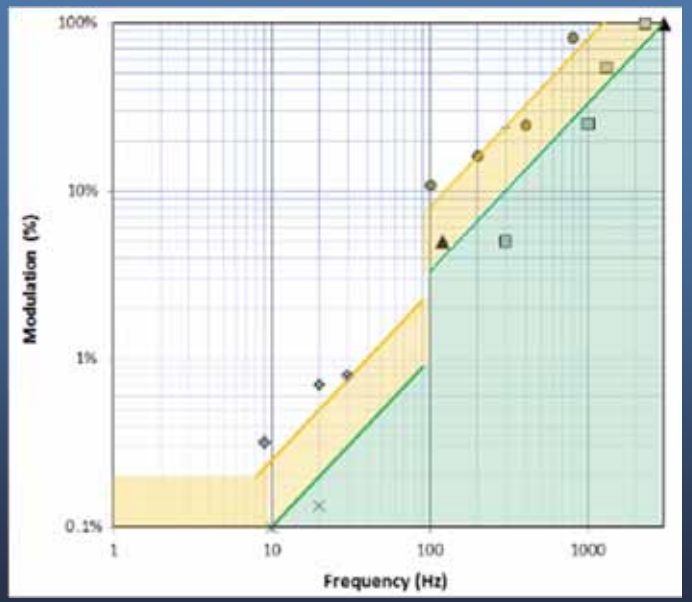
- Percent flicker and flicker index values cannot be compared across different frequencies; Perz et al. (2015) developed a stroboscopic visibility measure (SVM) based on Fourier analysis, which is independent of frequency properties
- In their study of responses to 100-1000 Hz flicker varying in waveform shape and duty cycle (Bullough and Marcus 2015), detection and acceptability were rectified at least as well as SVM by a **modified flicker index** defined as:
  - **Modified flicker index** = Flicker index × 100/*f*, where *f* is the frequency (Hz)





Implications of Results

- Data from Bullough and Marcus (2015) have several implications for specifications to limit perception of stroboscopic effects:
  - Metrics based on flicker index (such as modified flicker index) are superior to those based on percent flicker, such as IEEE 1789 and California Title 24
  - Whether percent flicker or flicker index is used in a specification for stroboscopic effects, it should be proportional to the frequency, not to the logarithm of the frequency (such as in IEEE 1789)

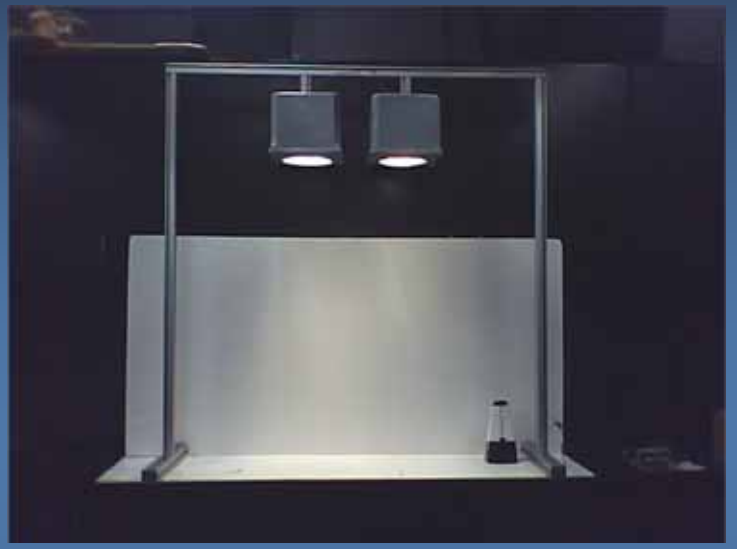


Limitations of Flicker Index-Based Metrics

- All waveforms studied thus far regarding the perception of stroboscopic effects have had one primary frequency component (100 Hz, 120 Hz, etc.)
- When two or more frequency components exist simultaneously within a waveform (e.g., both 120 Hz and 240 Hz) and with similar strength, defining the primary frequency is not straightforward
  - Presents difficulties for specifying the modified flicker index
- For such cases, Fourier-based approaches to specifying flicker for stroboscopic effect perception may be most appropriate

Application Dependence of the Perception of Stroboscopic Effects

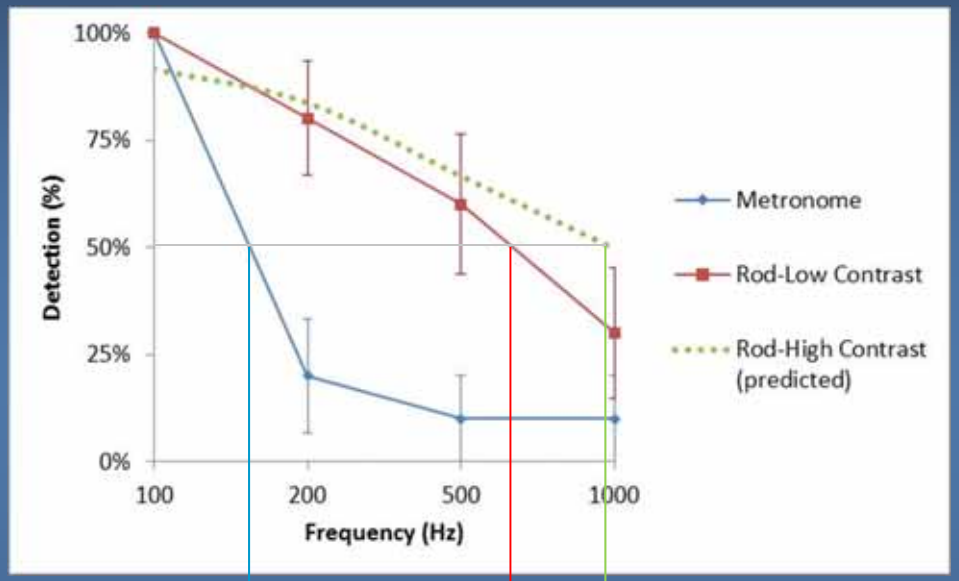
- Horizontal illuminance on desktop: 300 lx
- Light-colored surfaces
- Flicker frequencies (**always at 33% flicker, 0.17 flicker index**):
  - 100, 200, 500, 1000 Hz
- Questions:
  - Stroboscopic effects detected while waving white rod?
  - Stroboscopic effects detected with metronome (208 bpm)?
  - Acceptability of any flicker from lighting?



+2	Very acceptable
+1	Somewhat acceptable
0	Neither acceptable nor unacceptable
-1	Somewhat unacceptable
-2	Very unacceptable

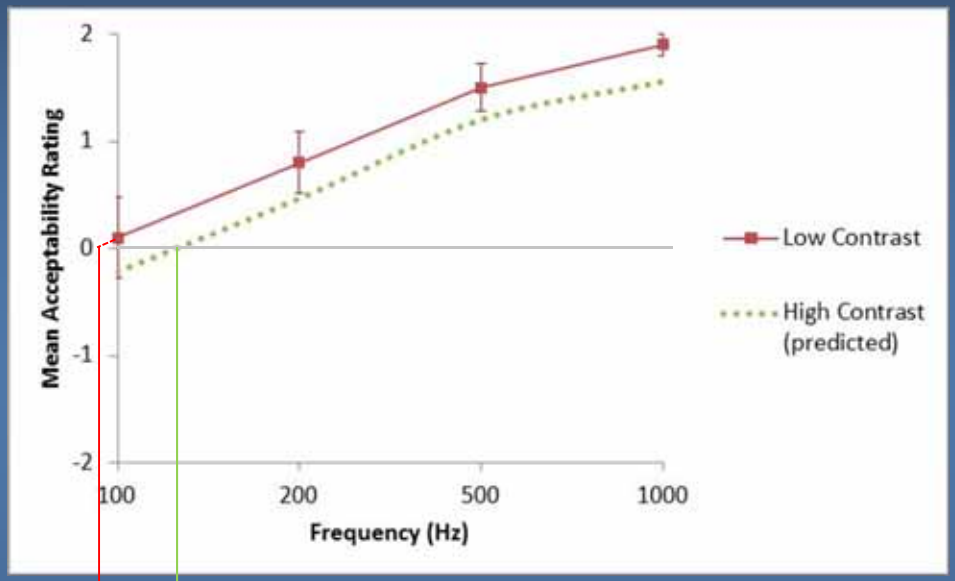
Experimental Results

Detection



162 666 985 (all Hz)

Acceptability

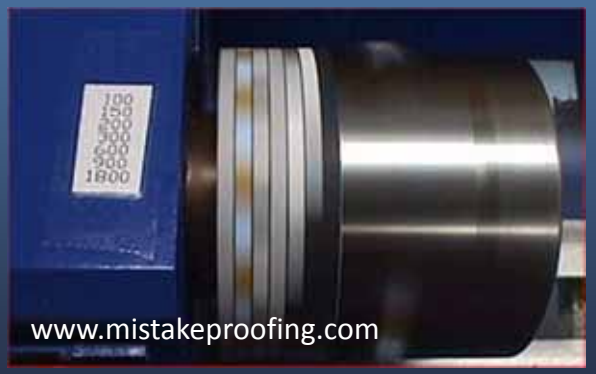


86 125 (all Hz)

Thresholds for detection (50%) and for acceptability (rating=0) occurred at systematically lower frequencies with lower contrast and slower movement speed. In other words, sensitivity to stroboscopic effects was reduced under the tested conditions relative to those used to develop the ASSIST predictive model (2012)

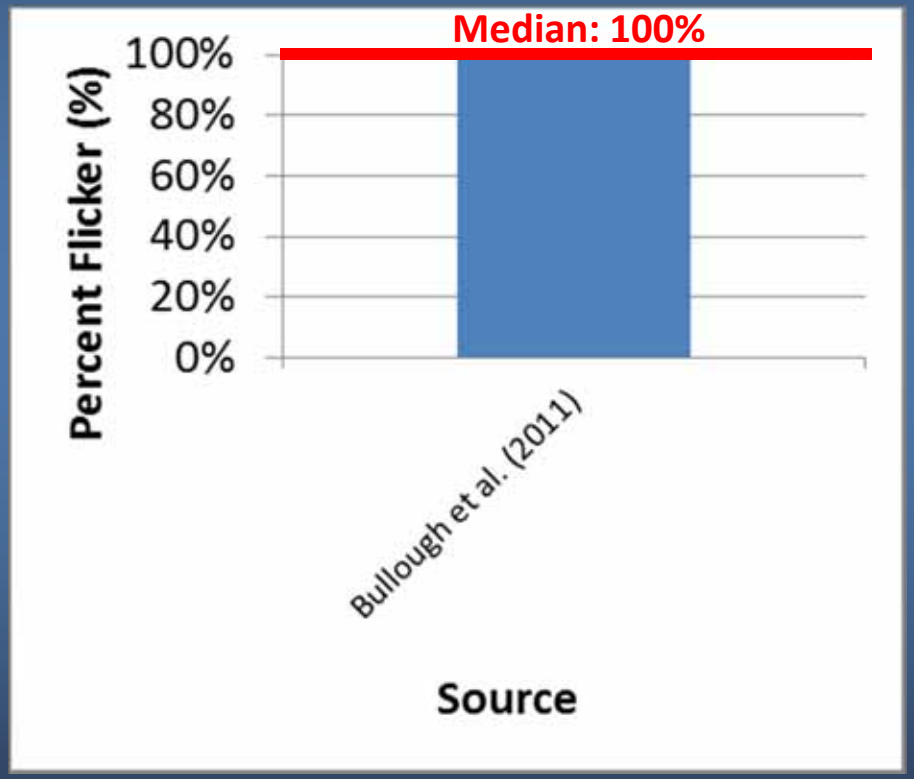
Classification of Lighting Applications

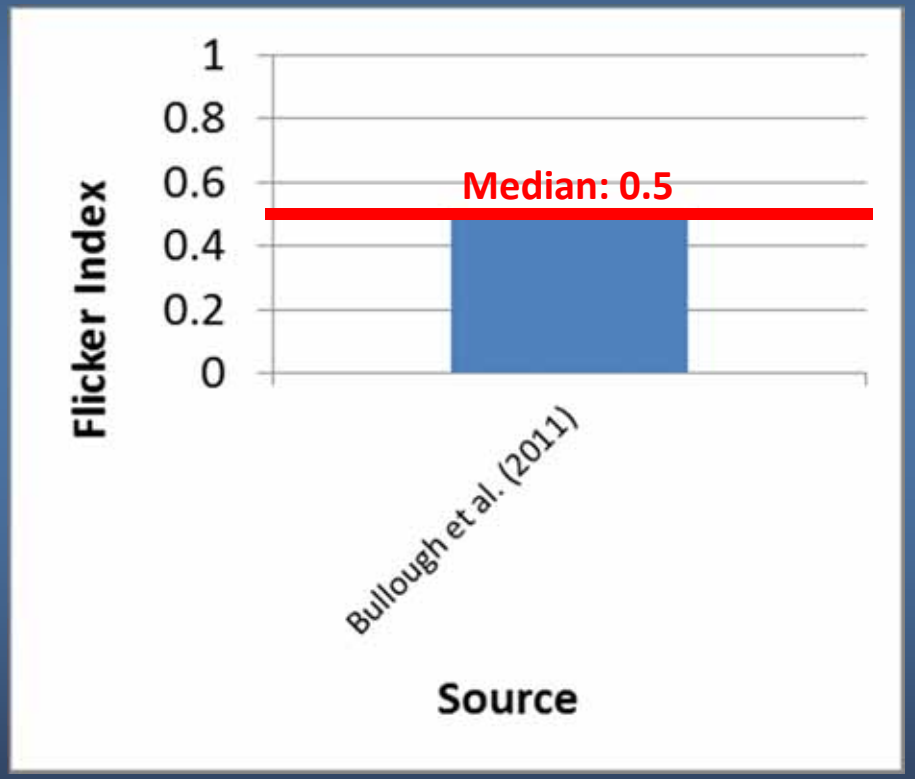
- Perceptions of stroboscopic effects depend not only on the frequency and on the amount of modulation, but also on the nature of the visual task
  - Outdoor lighting, viewing stationary/self-luminous displays: **low importance**
  - Reading, paper-based visual tasks: **medium importance**
  - Industrial machinery, viewing sports events: **high importance**



What is the Lowest Modulation (at 100 or 120 Hz) at which Stroboscopic Effects were Problematic?

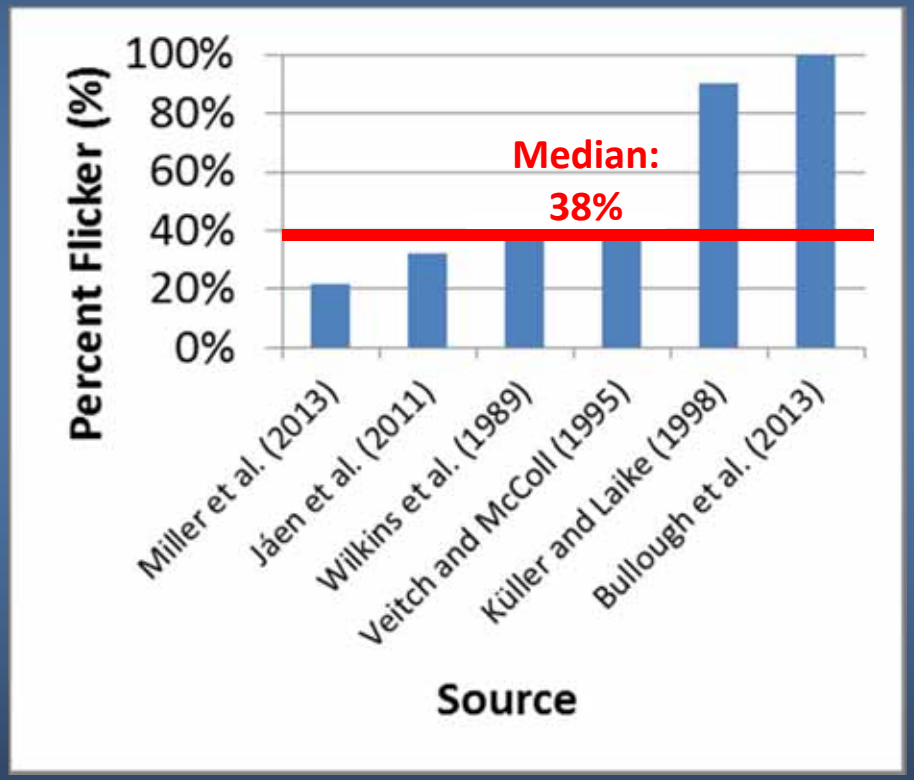
When the perception of stroboscopic effects is of low importance:

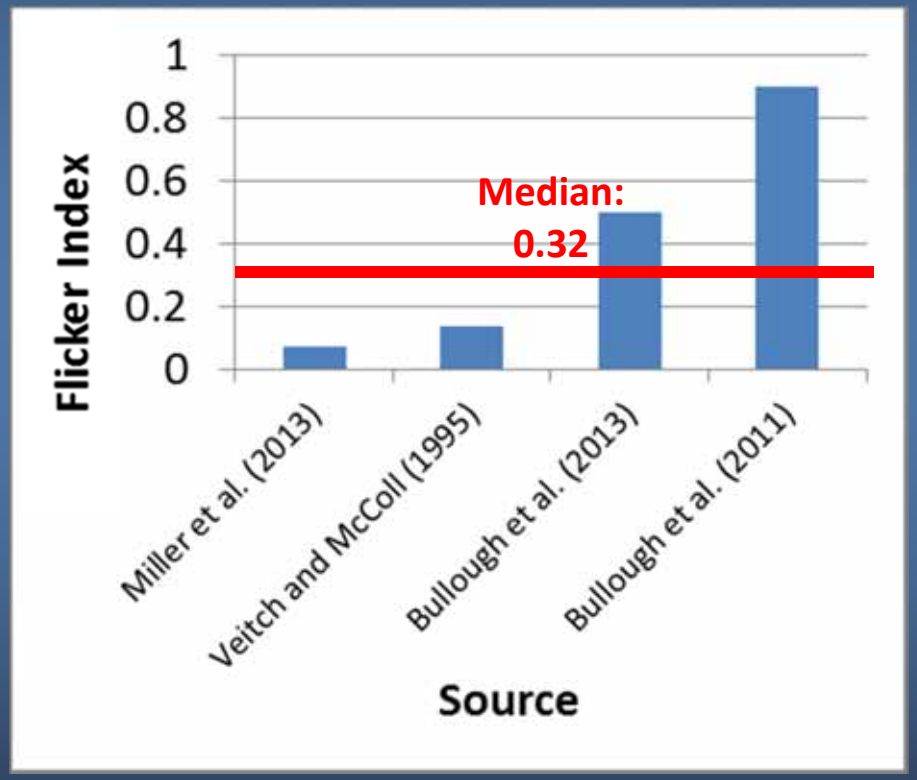




What is the Lowest Modulation (at 100 or 120 Hz) at which Stroboscopic Effects were Problematic?

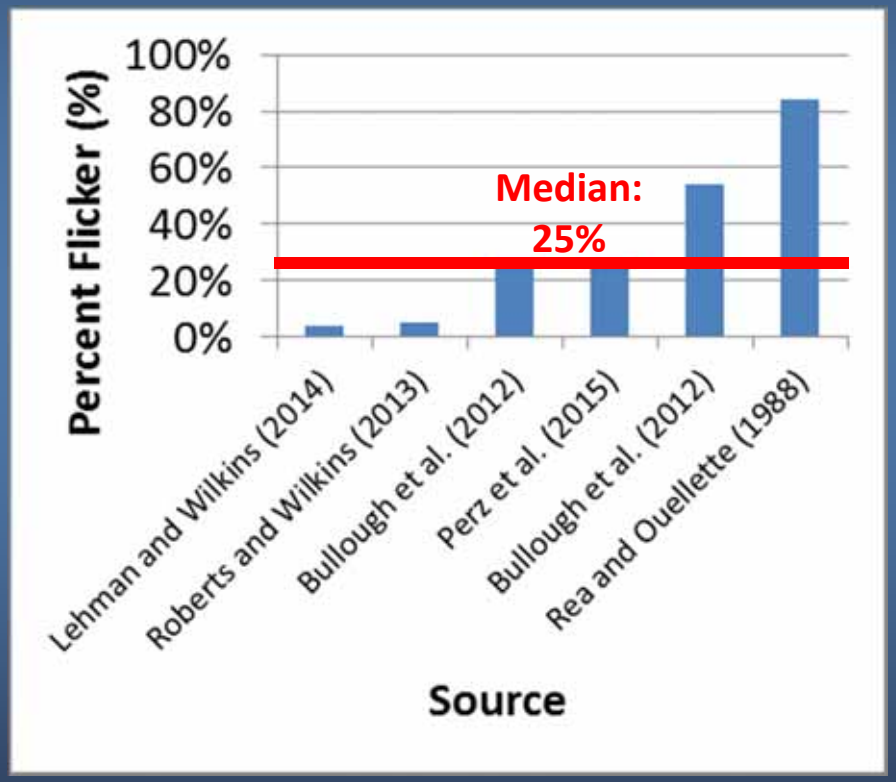
When the perception of stroboscopic effects is of medium importance:

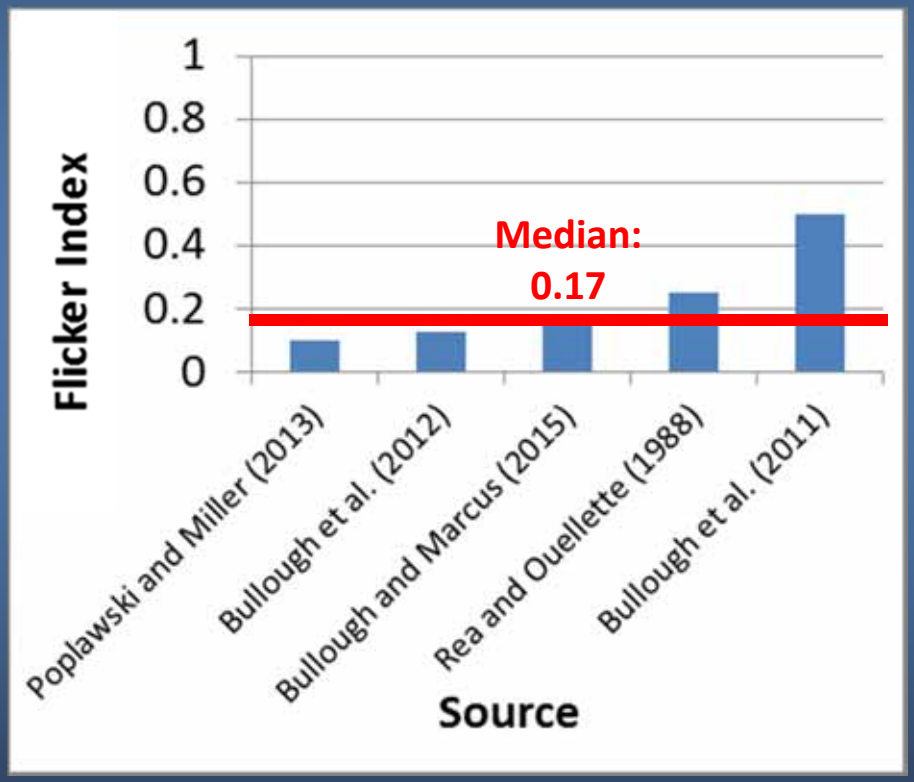




What is the Lowest Modulation (at 100 or 120 Hz) at which Stroboscopic Effects were Problematic?

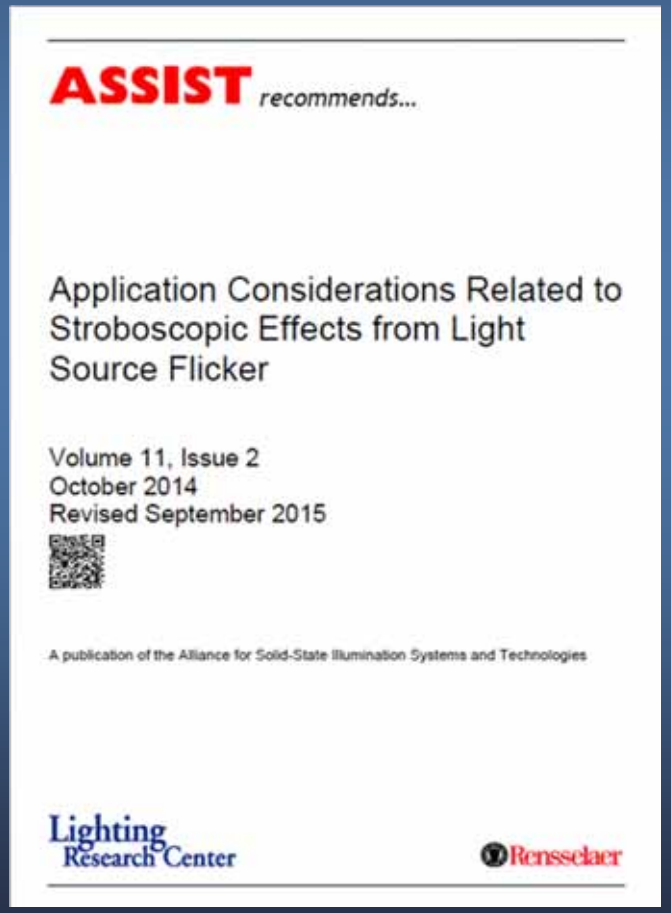
When the perception of stroboscopic effects is of <u>high</u> importance:





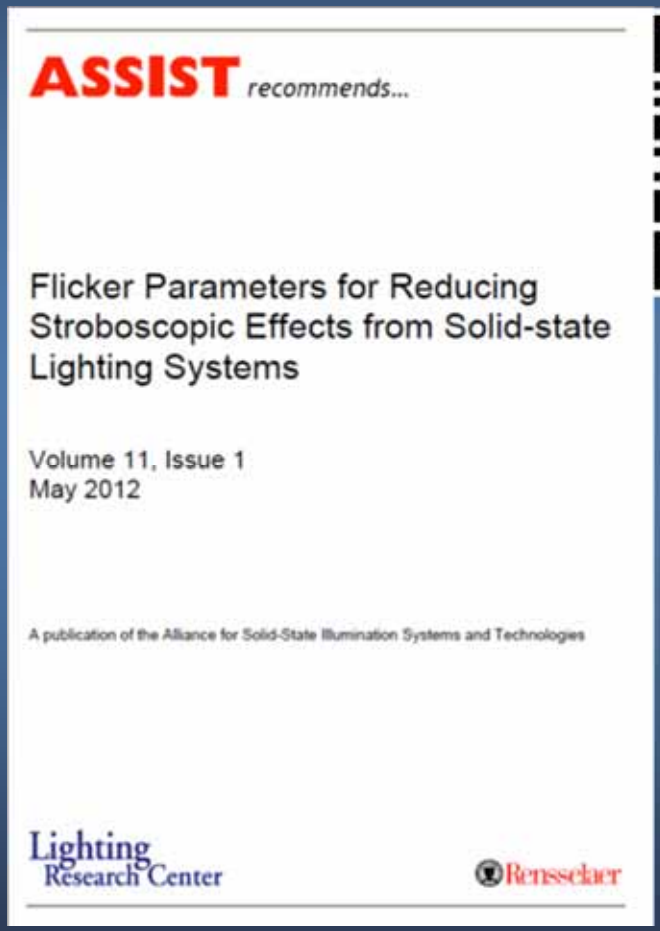
Preliminary Recommendations for Limiting Stroboscopic Effect Perception

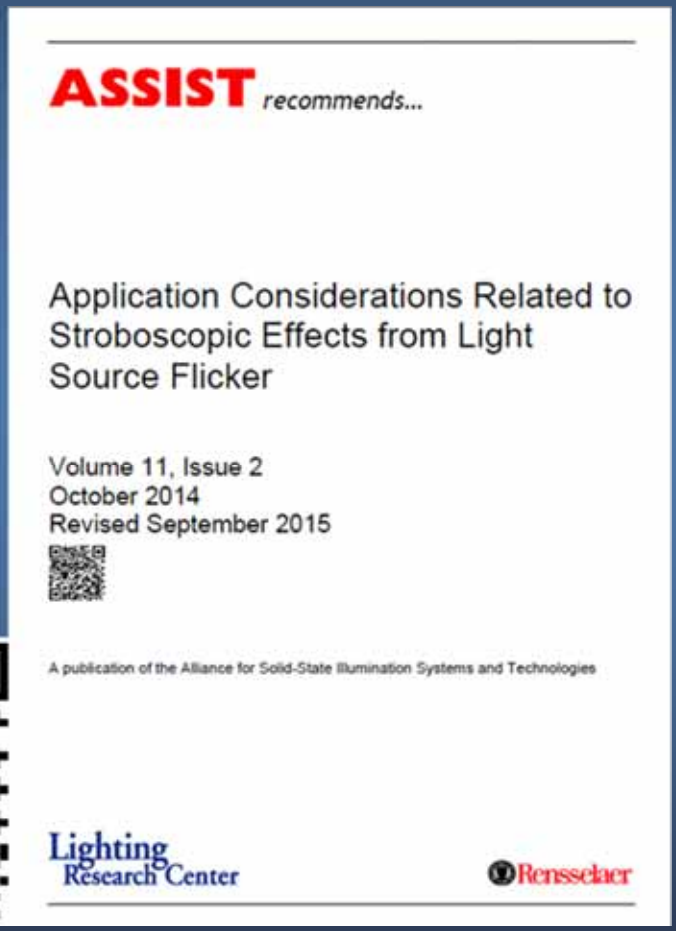
- When stroboscopic effects (at 100-120 Hz) are of…
- Low importance:
  - 100% flicker or 0.5 flicker index
- Medium importance:
  - 38% flicker or 0.32 flicker index
- High importance:
  - 25% flicker or 0.17 flicker index
- Could use modified flicker index as a frequency-independent specification metric (w/caveats)



Thank you!

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





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