Measuring the Gamut of Light Source Flicker

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Quality of Lighting

Characteristics	Metrics
Amount	Efficacy Standards (lumens per watt) Light Output, Center Beam Intensity
Spectrum, i.e. color properties	Chromaticity, CCT, Color Rendering Index, MacAdam Color Ellipse
Distribution	Luminous Intensity Distribution, Color Angular Uniformity, Beam Angle, Field Angle
Temporal, i.e. flicker	Start Time, Warm-up/Run-up Time Percent Flicker, Flicker Index, Periodic Frequency

Percent flicker and Flicker Index are inadequate metrics for the wide range of temporal patterns displayed by solid-state lighting.

2

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Flicker Comes in Many Forms
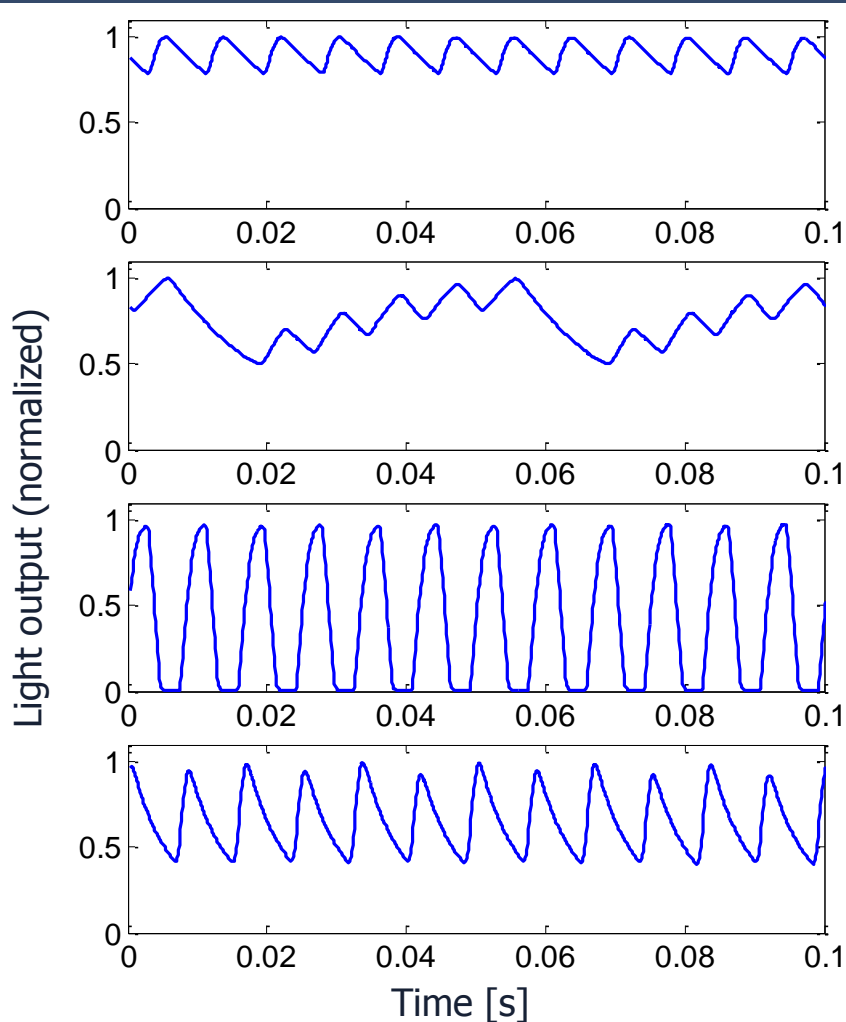
Dimmed Incandescent

Acceptable

LED A-Lamp, dimmer at maximum
Totally unacceptable

AC LED fixture

Acceptable to many for certain applications

LED A-Lamp, dimmer at minimum

Borderline acceptable, noticeable

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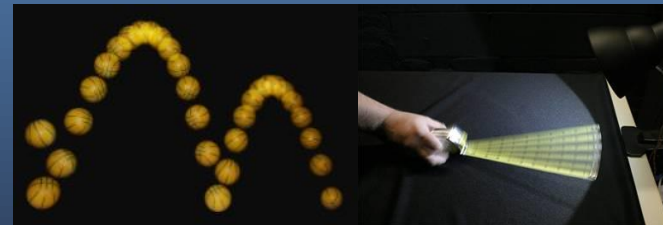
Two Temporal Regimes

Directly Observable

♦ < 100 Hz

♦ Often aperiodic

♦ Usually unintentional

♦ Indicative of malfunction, compatibility issue

Direct Flicker

Indirectly revealed by motion

♦ > 100 Hz

♦ Periodic

♦ Intentional design

 › e.g., PWM

♦ Normal operation

Stroboscopic effects

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Quantifying Flicker Severity

◆ Metrics that account for human sensitivity – for all waveform shapes and frequencies

Direct flicker (< 100 Hz)
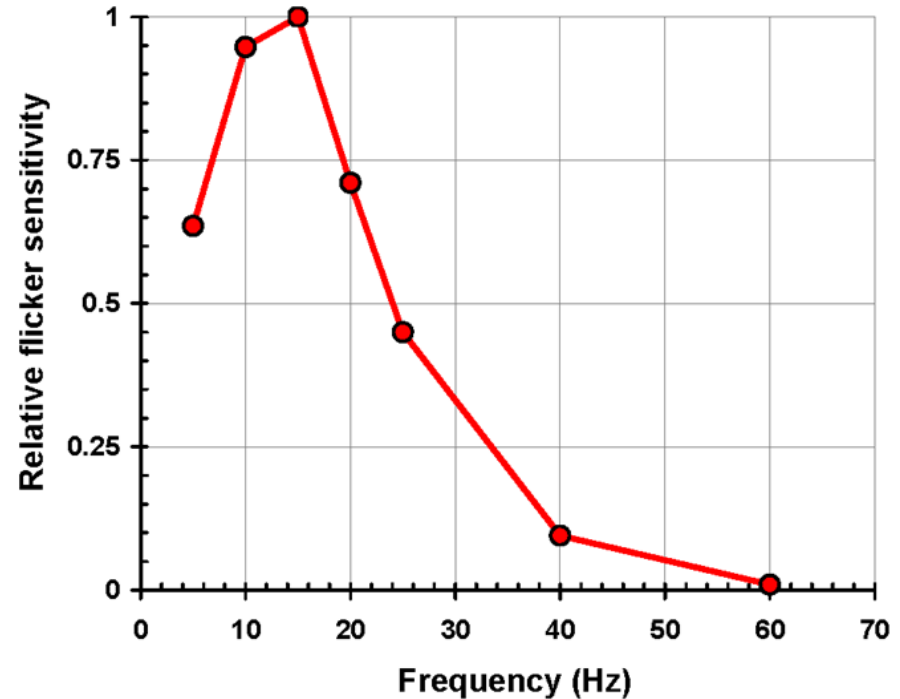
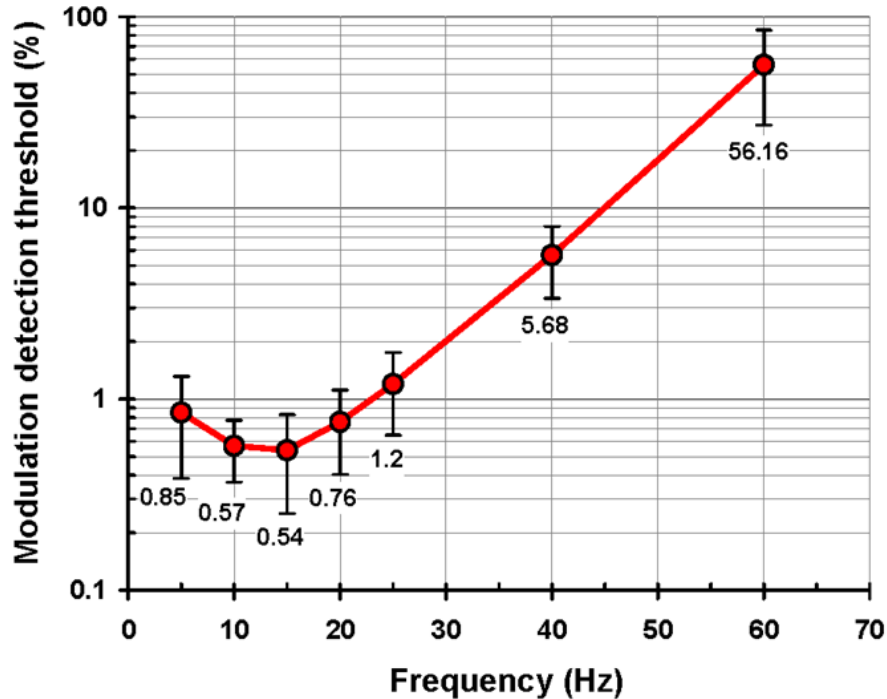- ASSIST Flicker Metric

Stroboscopic effects (> 100 Hz)
(much more complicated)

- Stroboscopic effect Visibility Measure (*SVM*), Philips, Netherlands

- ASSIST metric under development

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Human Sensitivity to Direct Flicker

LRC study results for the sensitivity to sinusoidal flicker

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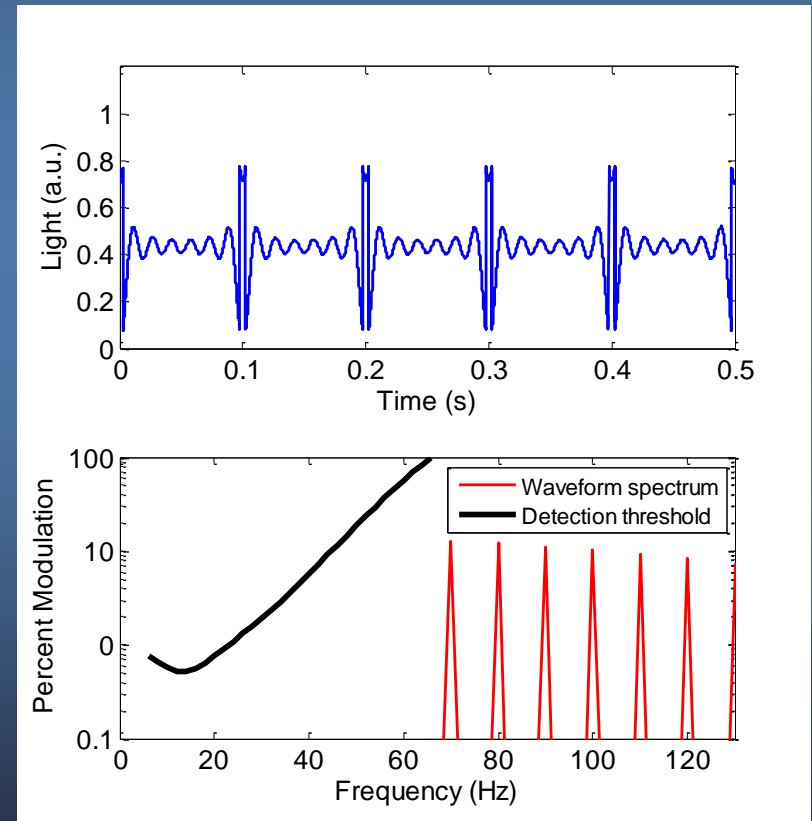# An Example for Metric Comparison

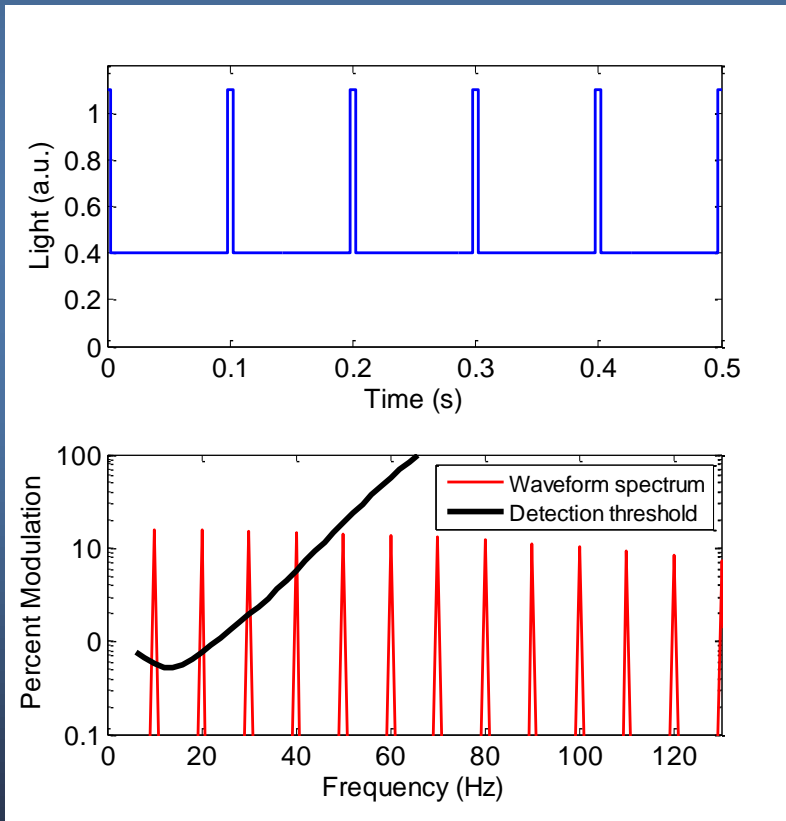47   ←   Percent Flicker   →   76
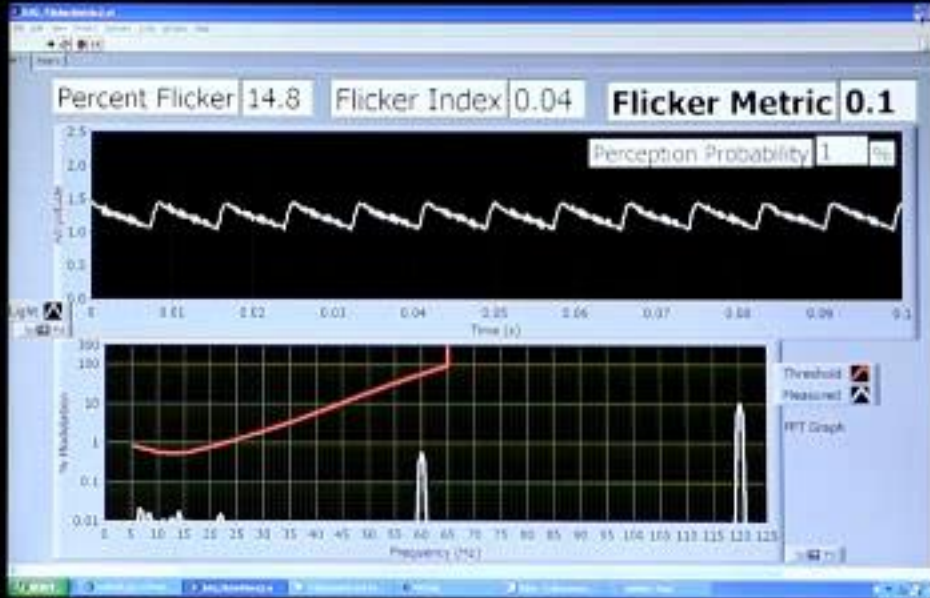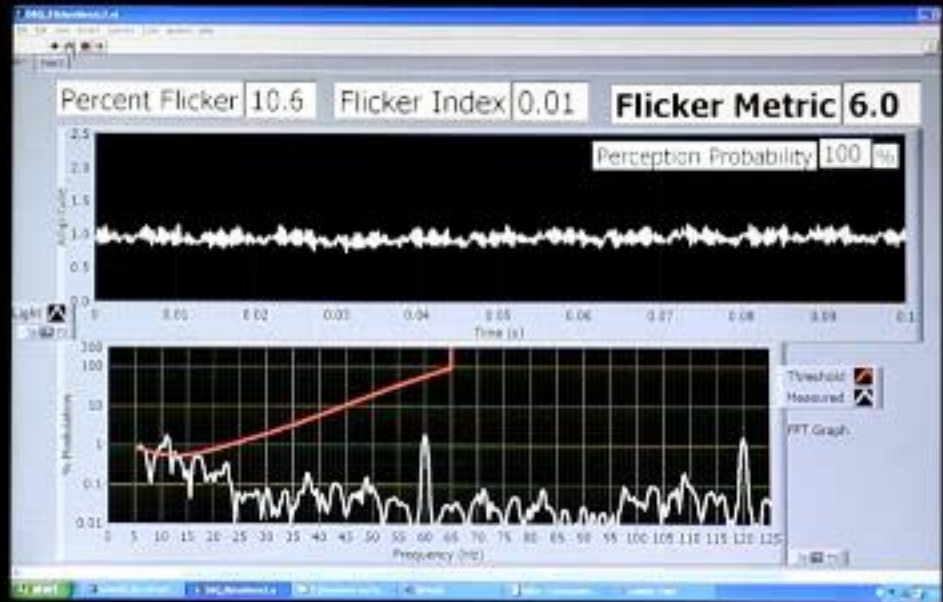
0.075   ←   Flicker Index   →   0.073

Visible flicker   35   ←   ASSIST Flicker Metric   →   0.3   **No Visible flicker**

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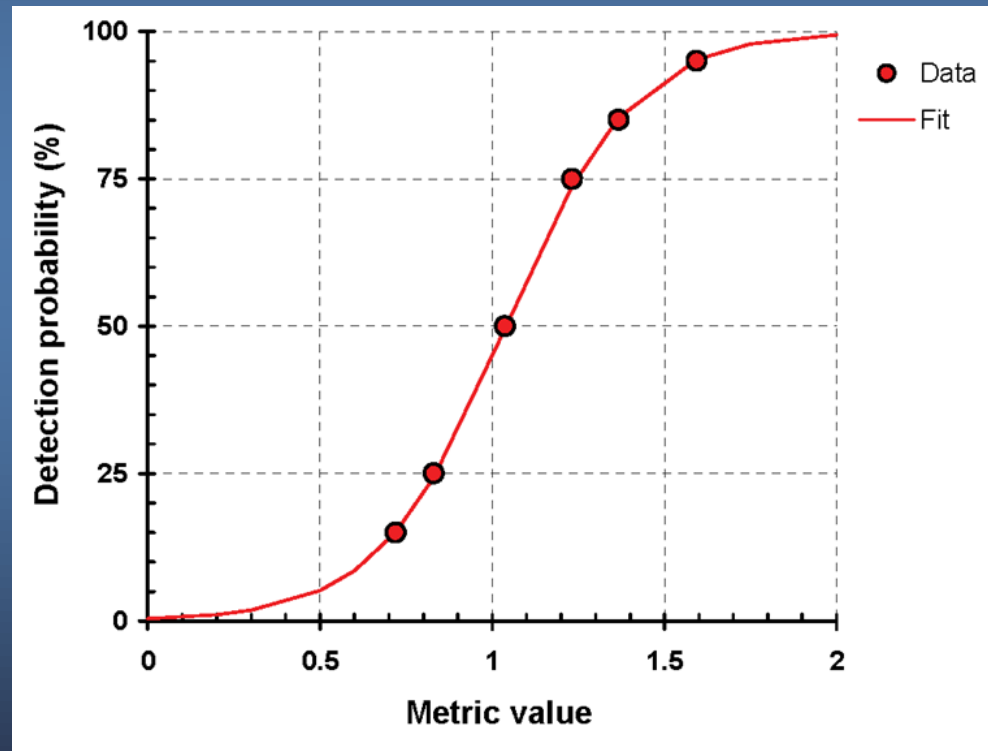
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ASSIST Flicker Metric

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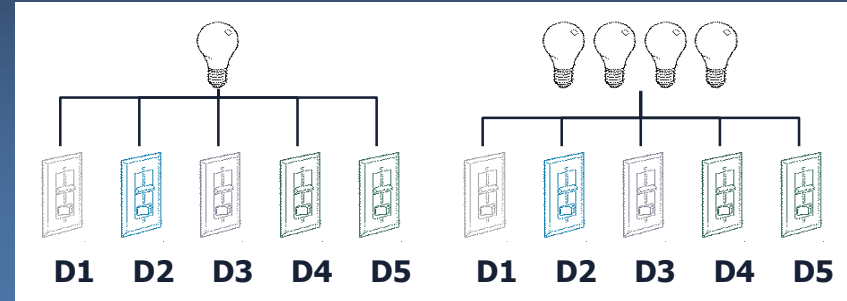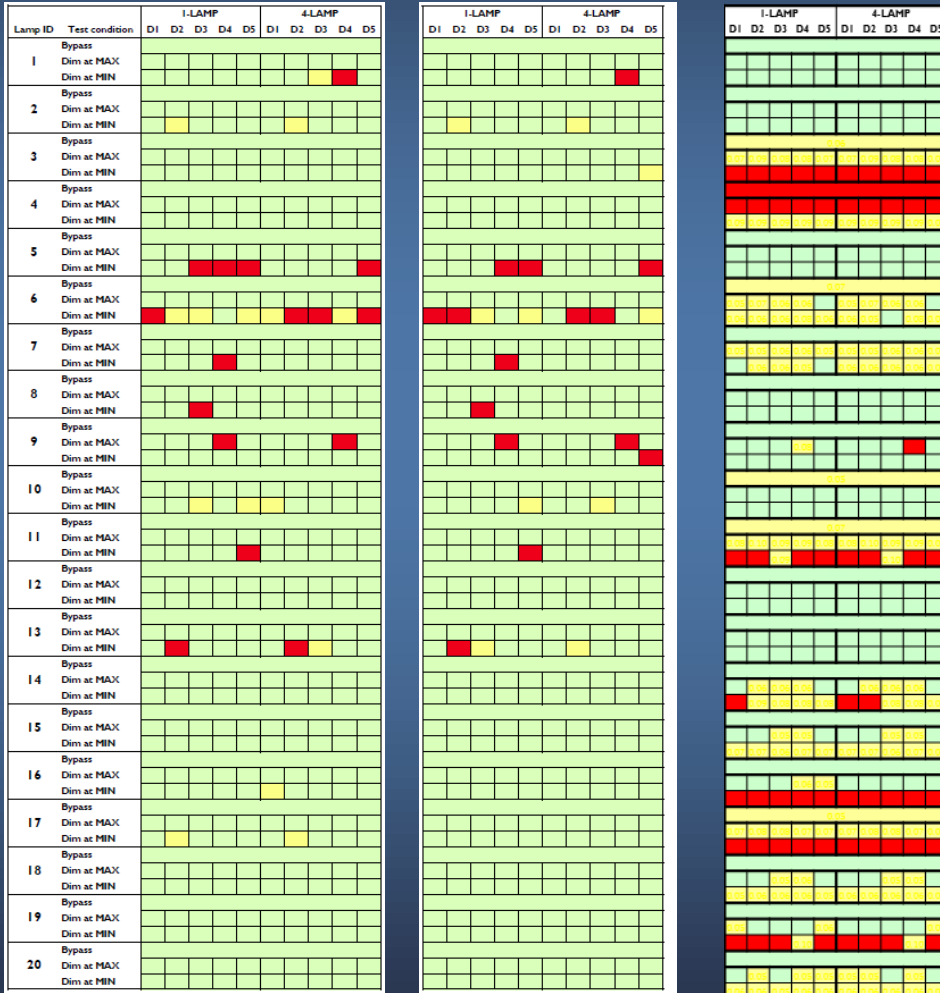Research Center

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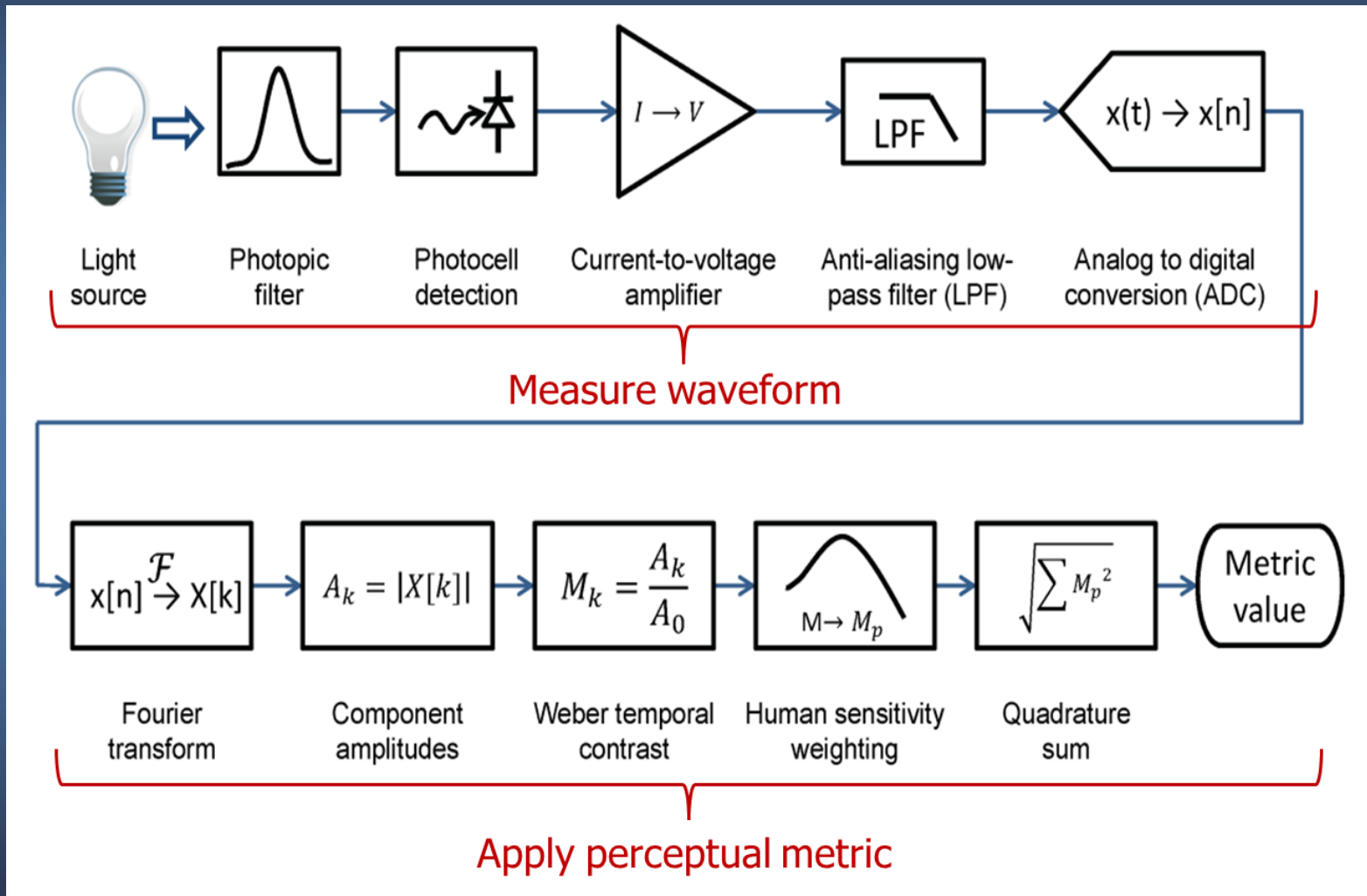
Interpreting metric values

- A value of 1 is just-perceptible flicker
  - 50% observation rate

Bodington, D., A. Bierman, and N. Narendran. 2016. A flicker perception metric. Lighting Research and Technology 48(5): 624–641.

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Metric Performance

Observed Flicker Metric Flicker Index

5 dimmers, 1-lamp and 4-lamp load

Lamp ID	Flicker observations										
		1-LAMP					4-LAMP				
		D1	D2	D3	D4	D5	D1	D2	D3	D4	D5
I	Bypass										
	Dim at MAX										
	Dim at MIN										

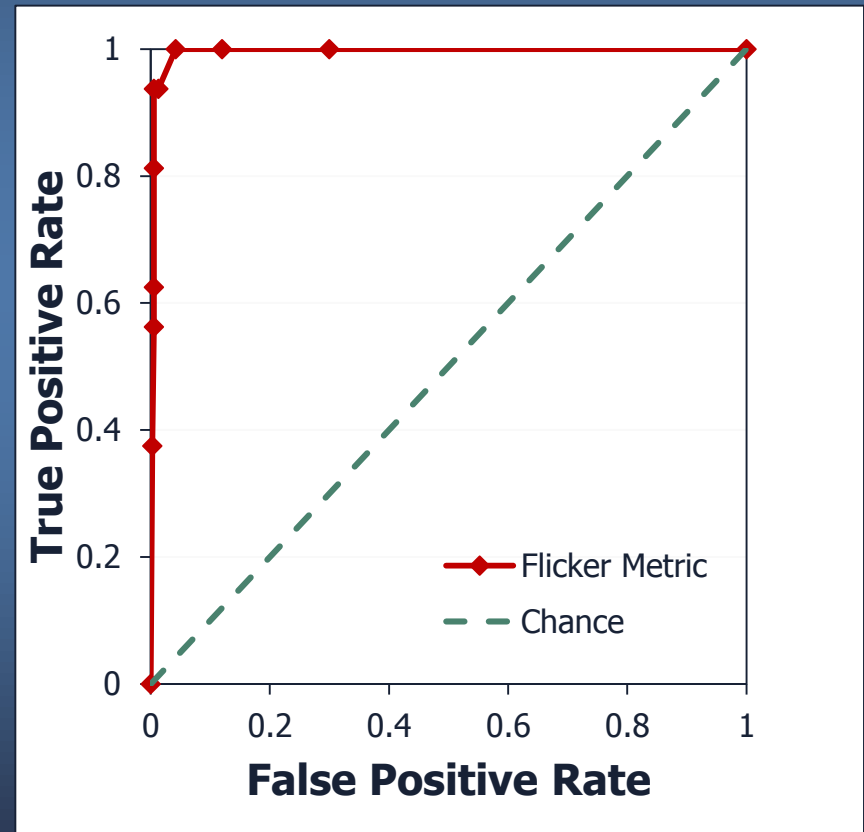|	
▮ (light green)	Did not observe flicker
▮ (yellow)	Perceived minimal flicker, undecided
▮ (red)	Definitely see flicker

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Metric Performance: ROC Curve

Receiver Operating Characteristic

◆ Flicker Index

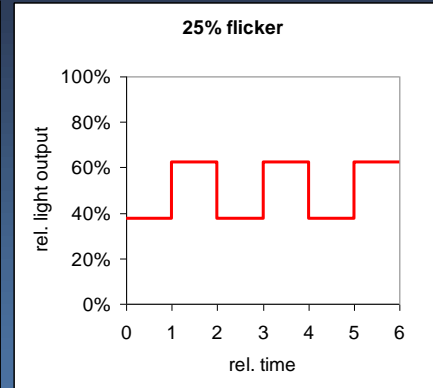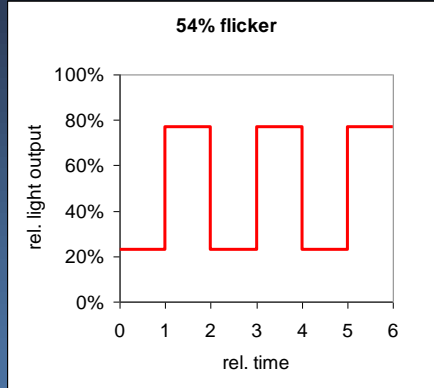◆ ASSIST Flicker Metric

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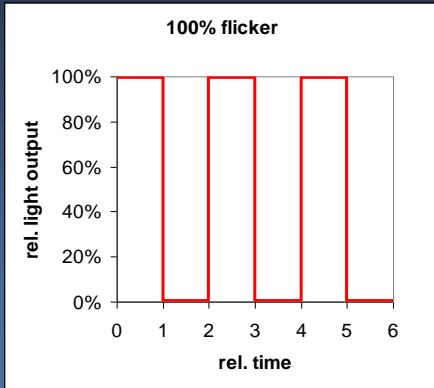
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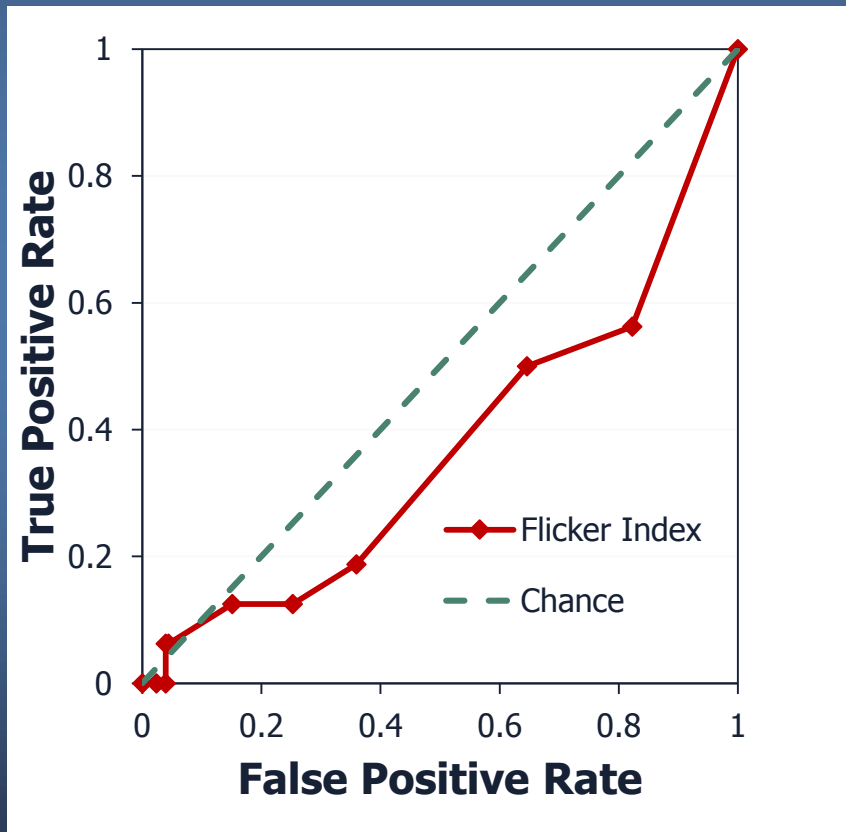
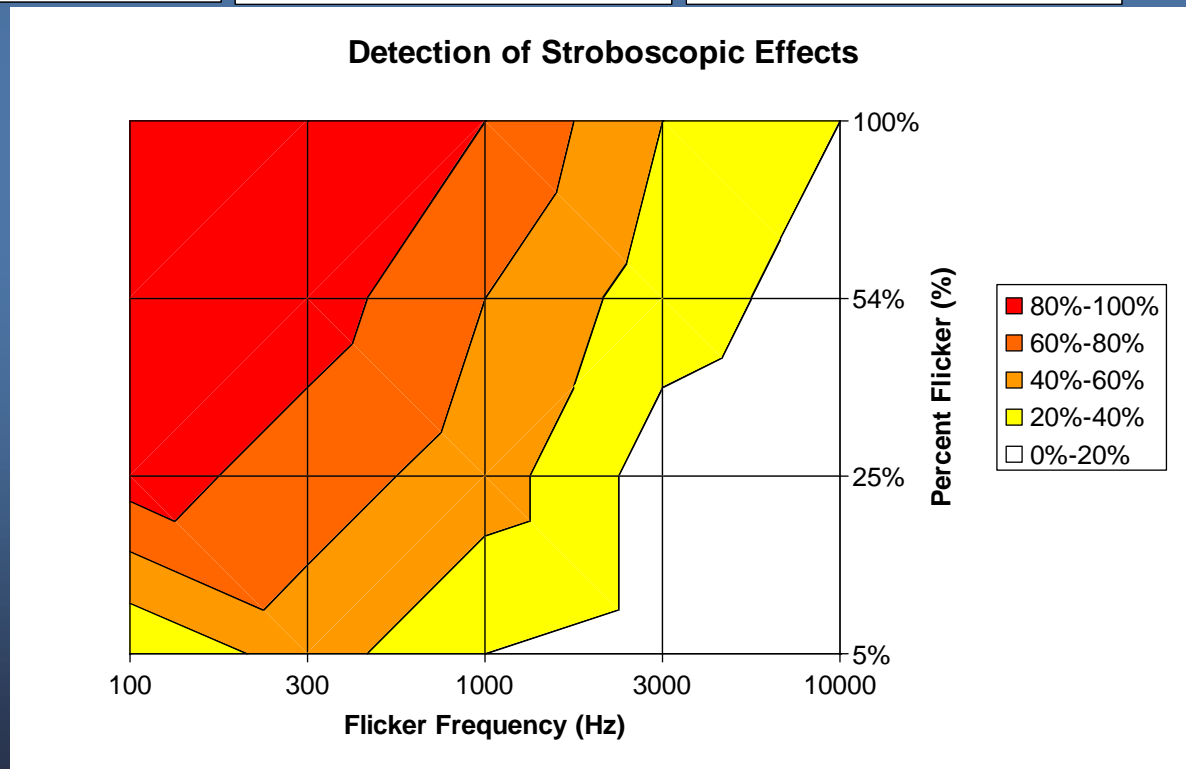# Detection of Stroboscopic Effects (f > 100 Hz)
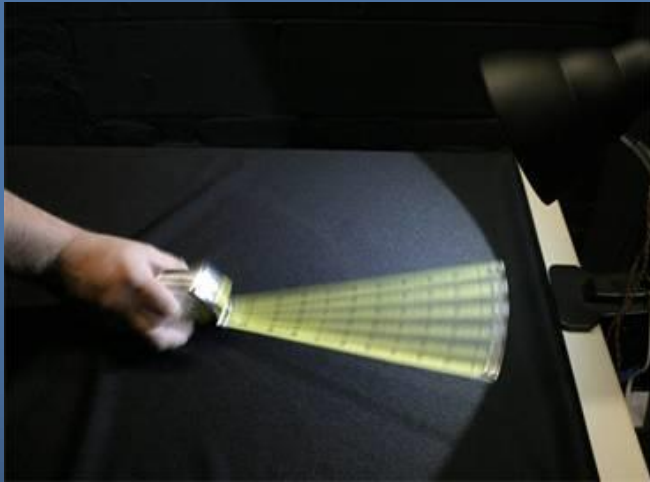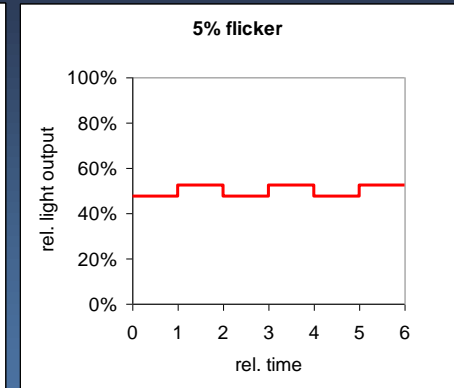
Bullough J.D., K. Sweater Hickcox, T.R. Klein, A. Lok, and N. Narendran. 2012. Detection and acceptability of stroboscopic effects from flicker. *Lighting Research and Technology* 44(4): 477–483.

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Origin of Stroboscopic Effects (f > 100 Hz)

Light waveform
(dc)

Moving

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Origin of Stroboscopic Effects (f > 100 Hz)

How high frequency flicker is revealed

Temporal

Spatial

Light waveform

Time
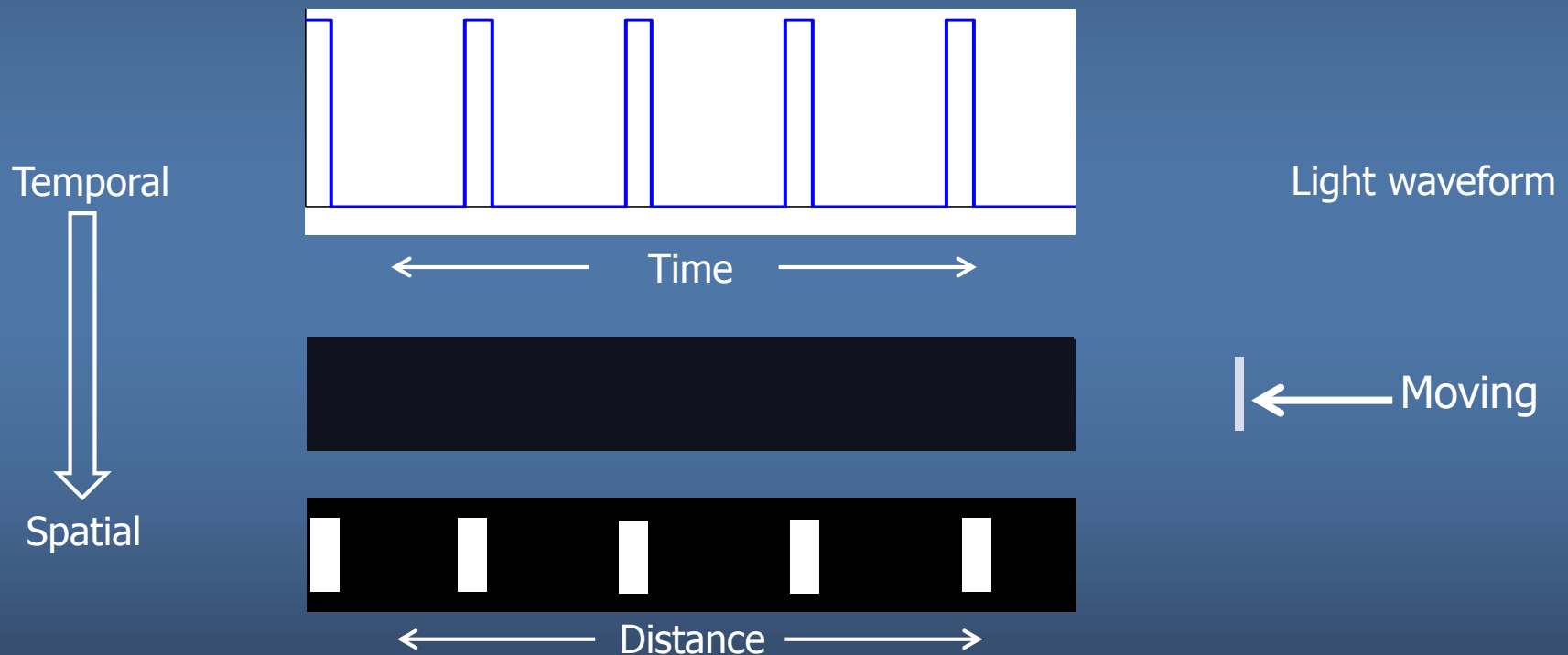
Moving

Distance

Spatially-manifested flicker contrast

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Spatial contrast for one single frequency

Δt = 1/f = 0.01 s
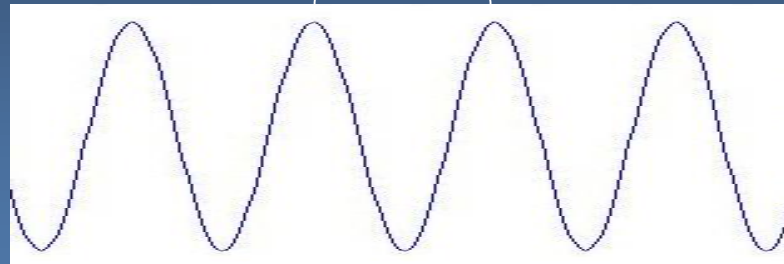
Light waveform, f = 100 Hz

Moving, v = 4 m/s

θ
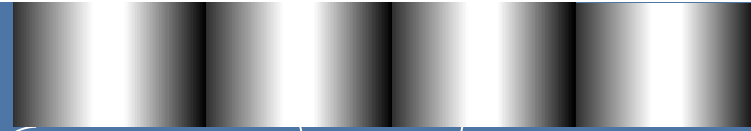
Distance, d = 4 m

ω = v/d = 1 rad/s
(57 degrees/s)

θ = ωΔt = ω/f
= 0.01 radians
(0.57 degrees)

Spatial frequency = 1 cycle/θ = f d/v
= 100 cycles/radian
(1.75 cycles/degree)

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Current Research: An Index for Stroboscopic flicker

♦ Similar approach as Flicker Metric for direct flicker

  › Spatial Contrast Sensitivity Function (CSF) in place of temporal sensitivity
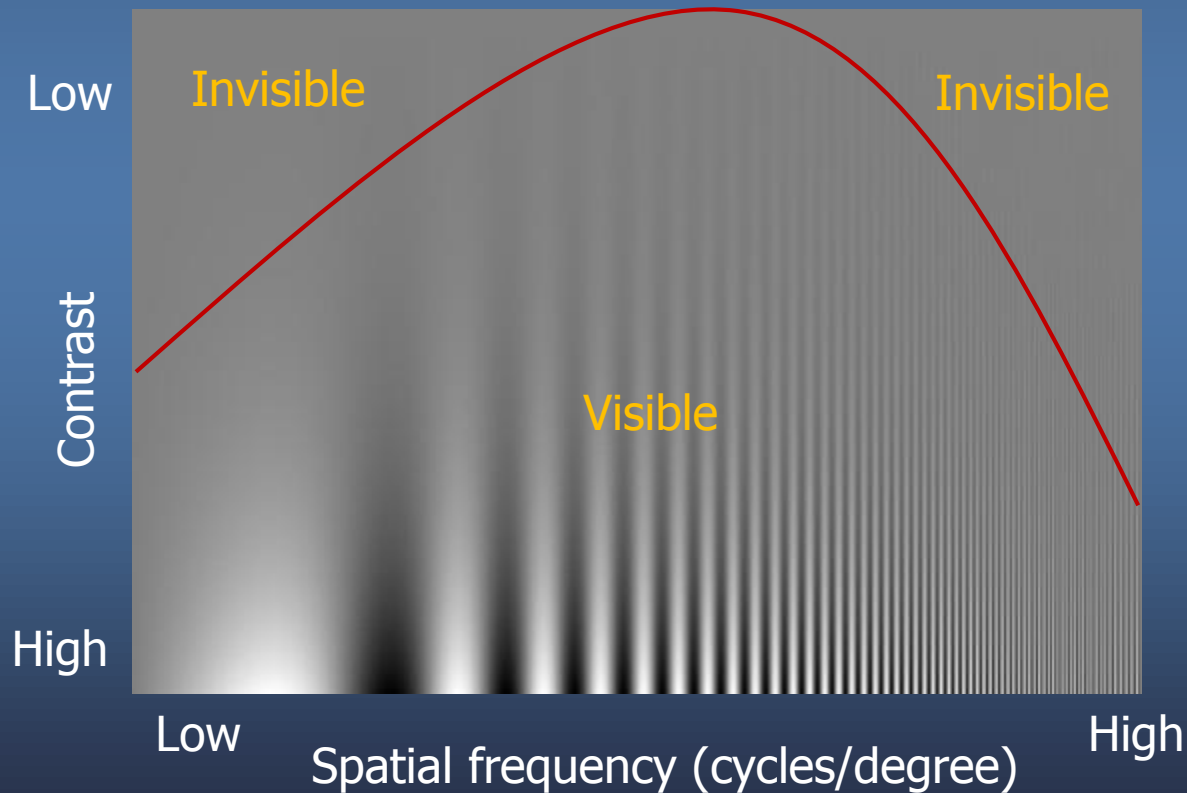
Low   Invisible   Invisible

Contrast

                        Visible

High

Low   High

Spatial frequency (cycles/degree)

Predicting Visibility of Stroboscopic Effects

Spatial Contrast Sensitivity Function

Contrast from flickering light

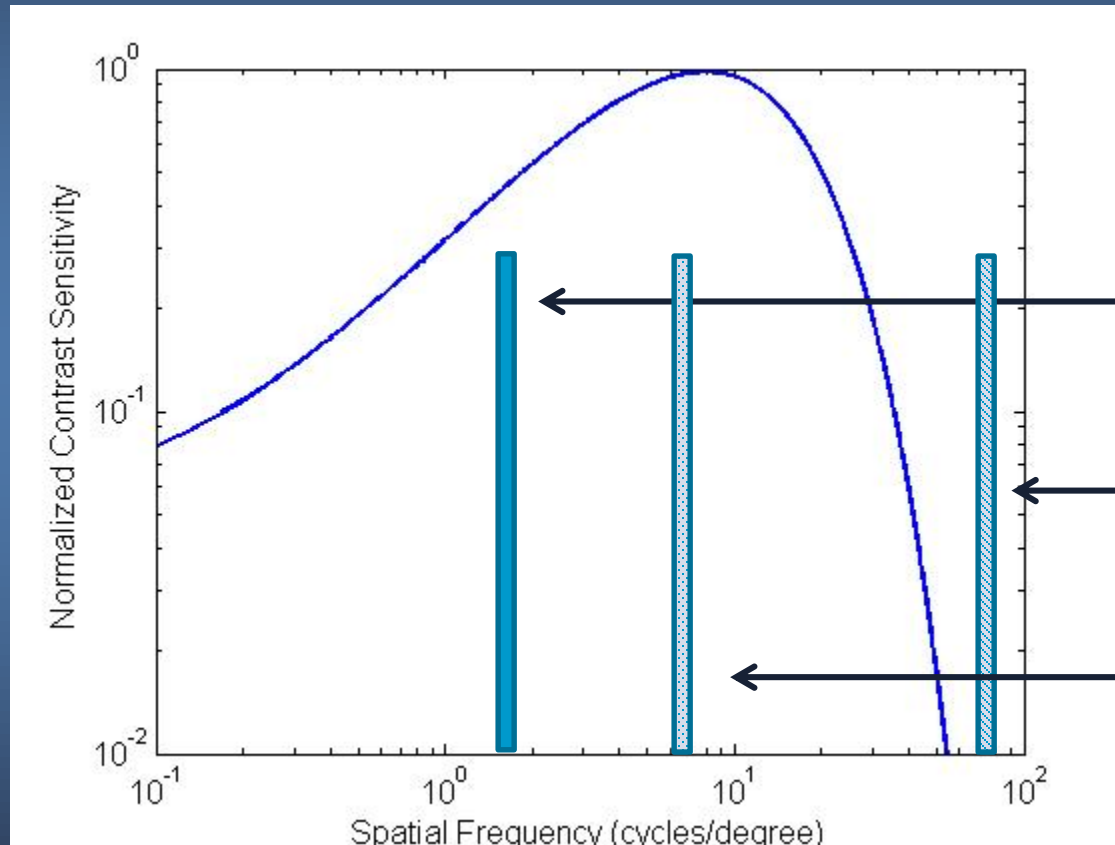100 Hz **sine** wave
Object moving at 4 m/s
Visible

4000 Hz **sine** wave
Object moving at 4 m/s
Not visible

4000 Hz **sine** wave
Object moving at 40 m/s
Visible

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Predicting Visibility of Stroboscopic Effects

Spatial Contrast Sensitivity Function

Contrast from flickering light

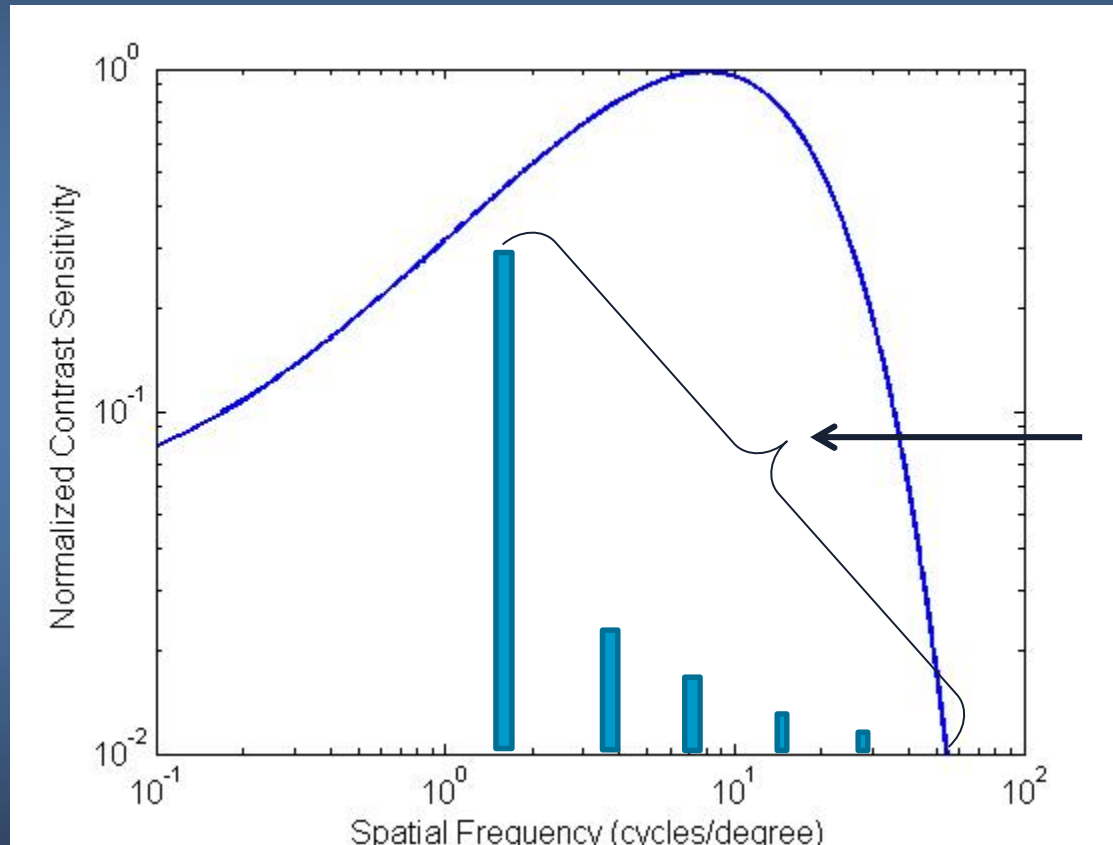100 Hz **square** wave Object moving at 4 m/s

Harmonic components from square edges increase overall visibility

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Predicting Visibility of Stroboscopic Effects

Effective flicker contrast =

$$\sqrt[n]{\sum \left(\text{CSF} \times \text{Spatially-converted waveform spectrum} \right)^n}$$
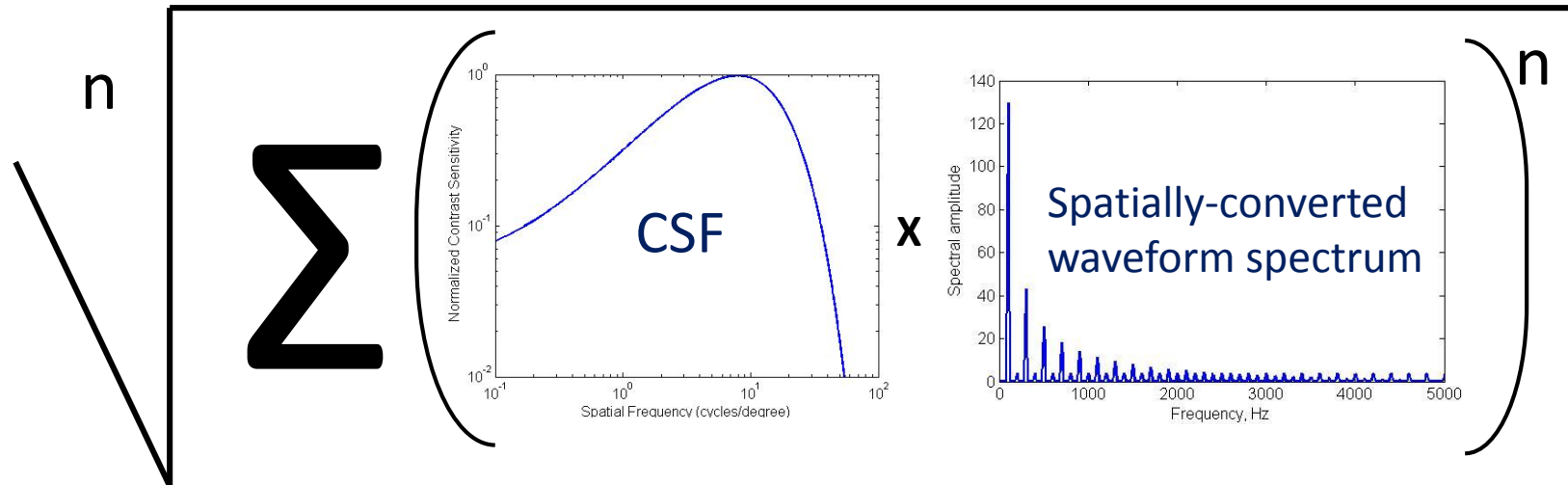
- Currently testing/verifying this metric

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A Stroboscopic Index

◆ **Test objects moving at particular speeds are needed for index—analogous to CRI color samples**

CRI Test Color Samples

https://pinshape.com/items/7866-3d-printed-light-flicker-detecting-top
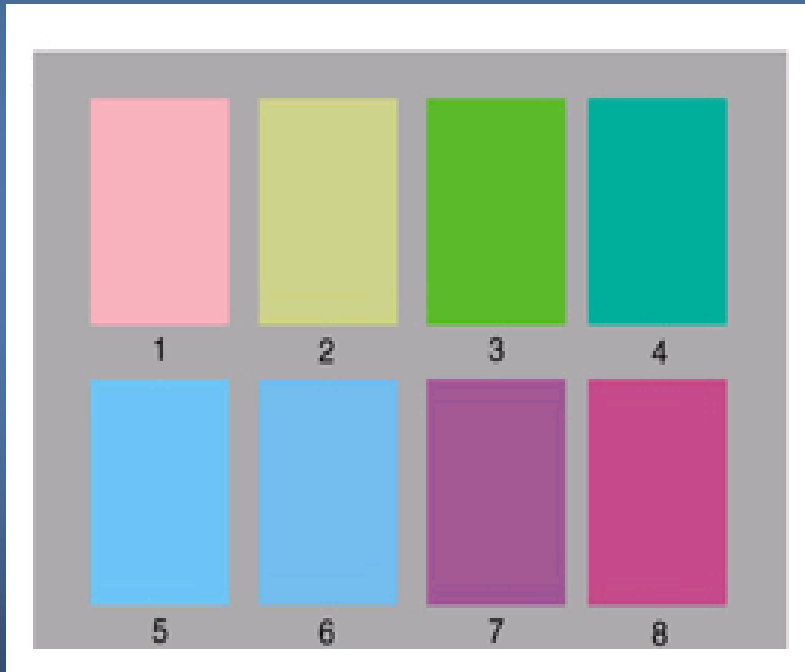
Flicker test patterns and speeds

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Summary

- Temporal light characteristics are an important aspect of quality lighting
- f < 100 Hz: Directly observable flicker
  - ASSIST flicker metric: Ready for implementation
- f > 100 Hz: Stroboscopic effects
  - Interaction of light source with movement
  - Empirical data provides guidance for acceptable light source operation
  - Quantitative metric under development
    - Approach similar to direct flicker metric
    - Analogous to CRI: Test color samples → moving target samples

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Acknowledgments

- LRC Staff and students
- ASSIST Sponsors

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Thank you

◆ For more information visit
http://www.lrc.rpi.edu/programs/solidstate/assist/flicker.asp