Quantifying the Detection of Directly Perceived Flicker

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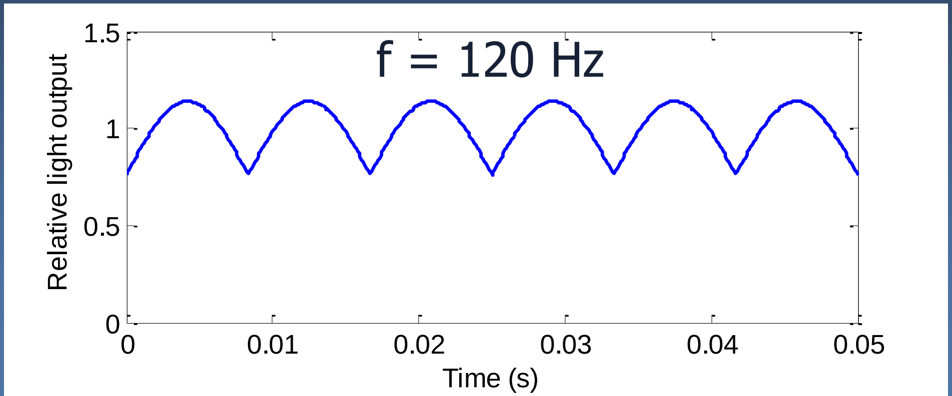
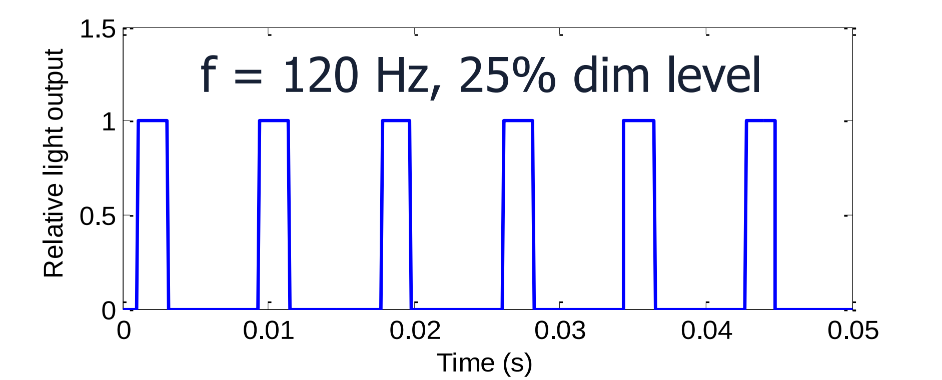
What is flicker?

- Rapid fluctuation of light output over time
  - Unintentional result from operating on 50/60 Hz line power
  - Can be intentional to control light output
    - For example, pulse width modulation (PWM)





Different reasons to be concerned about flicker

- Health
  - Seizures
  - Headaches, stress, general malaise
- Safety
  - Identifying moving machinery
  - Location confusion (phantom arrays)
- Productivity
  - Visual task performance (e.g. legibility)
- Perception
  - Comfort/annoyance
  - Lighting Quality

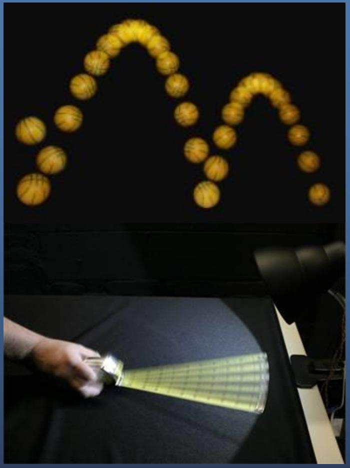
This presentation concerns the human perception of flickering light. Perception is not necessarily related to health, safety and productivity.

For example

- Fluorescent lamp flicker at 100 Hz is not perceptible, yet it is implicated in causing headaches
- Flickering candlelight is generally regarded as safe, but it is obviously perceptible.

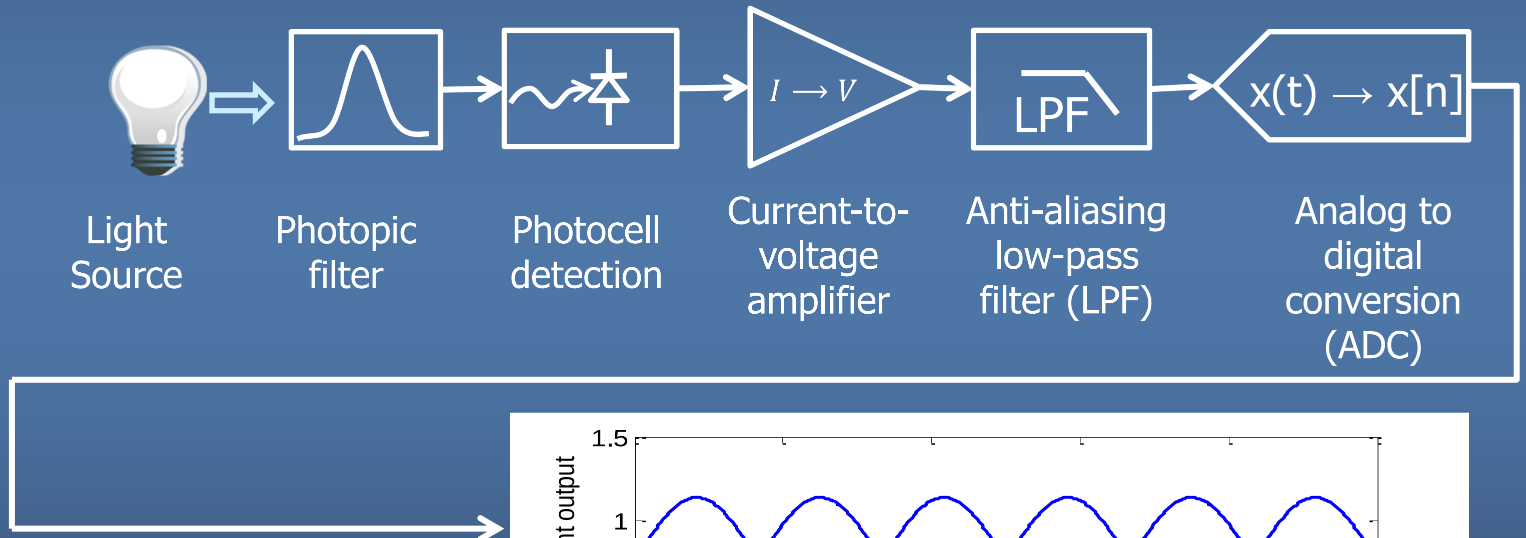
Two flicker regimes

- Flicker can be perceived in two ways:
  - Direct perception of light fluctuation
    - Frequencies < 100 Hz
    - No motion involved
  - Indirect perception of stroboscopic effects (phantom array, wagon-wheel effect)
    - Typically frequencies > 100 Hz
    - Relies on movement of the eye or stimulus
- This presentation is about directly perceived flicker

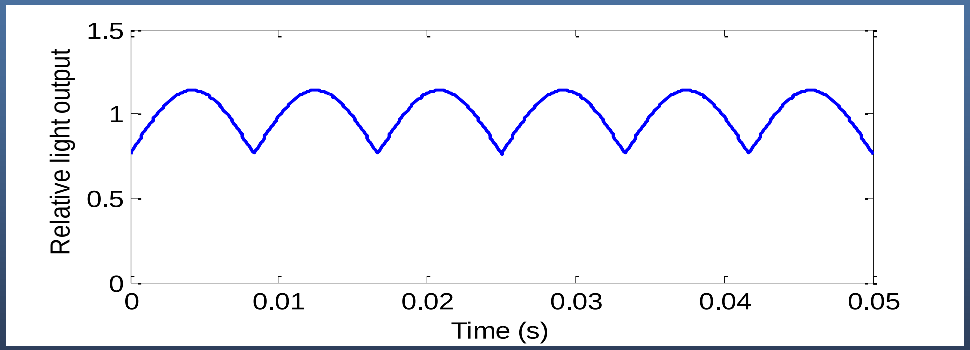


Measuring the light waveform

- The first step in characterizing flicker perception is **accurately** capturing the light waveform



Must resolve amplitude variations < 0.5%



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Measuring Direct Flicker

- The goal of this study was to develop a method and test procedure for quantifying detection of direct flicker.
- Characteristics of flicker that influence perception include:
  - Frequency
  - Waveform shape (including: modulation depth, duty cycle, rise/fall time, etc.)

Included as variables in this study

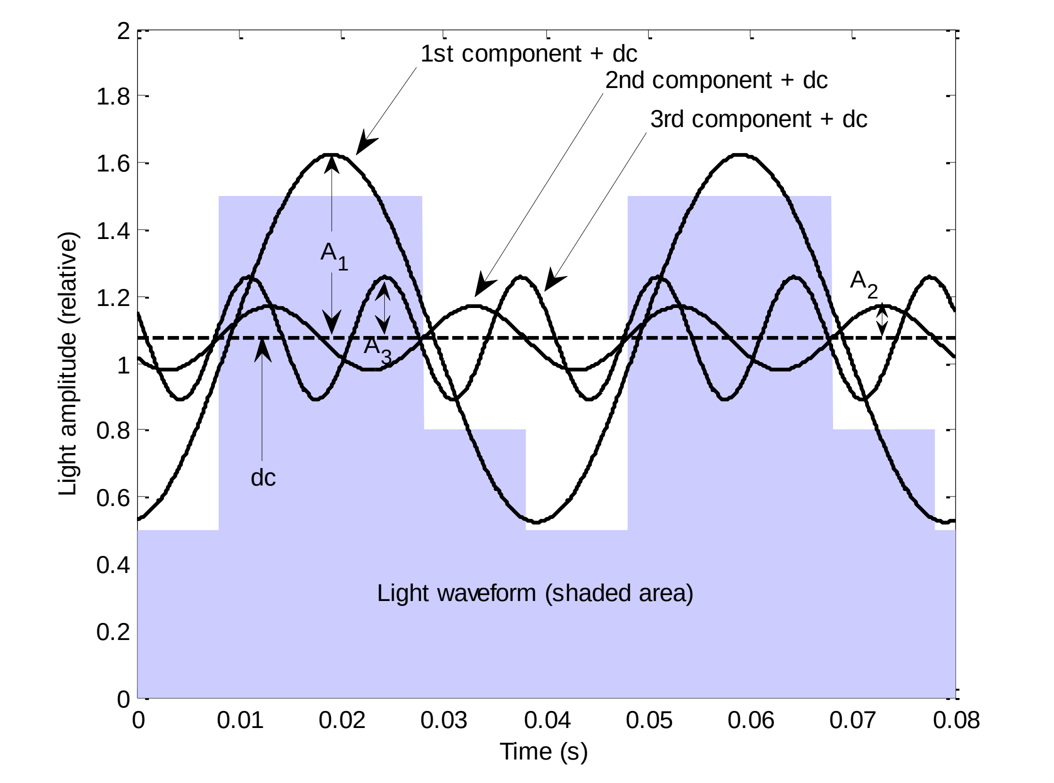
Typical office/home conditions employed

  - Light level
  - Stimulus size (visual solid angle) and retinal image location (central fovea vs periphery)
  - Spectral composition (color); for white light sources there might be a slight influence that is not accounted for by photopic weighting

Approach

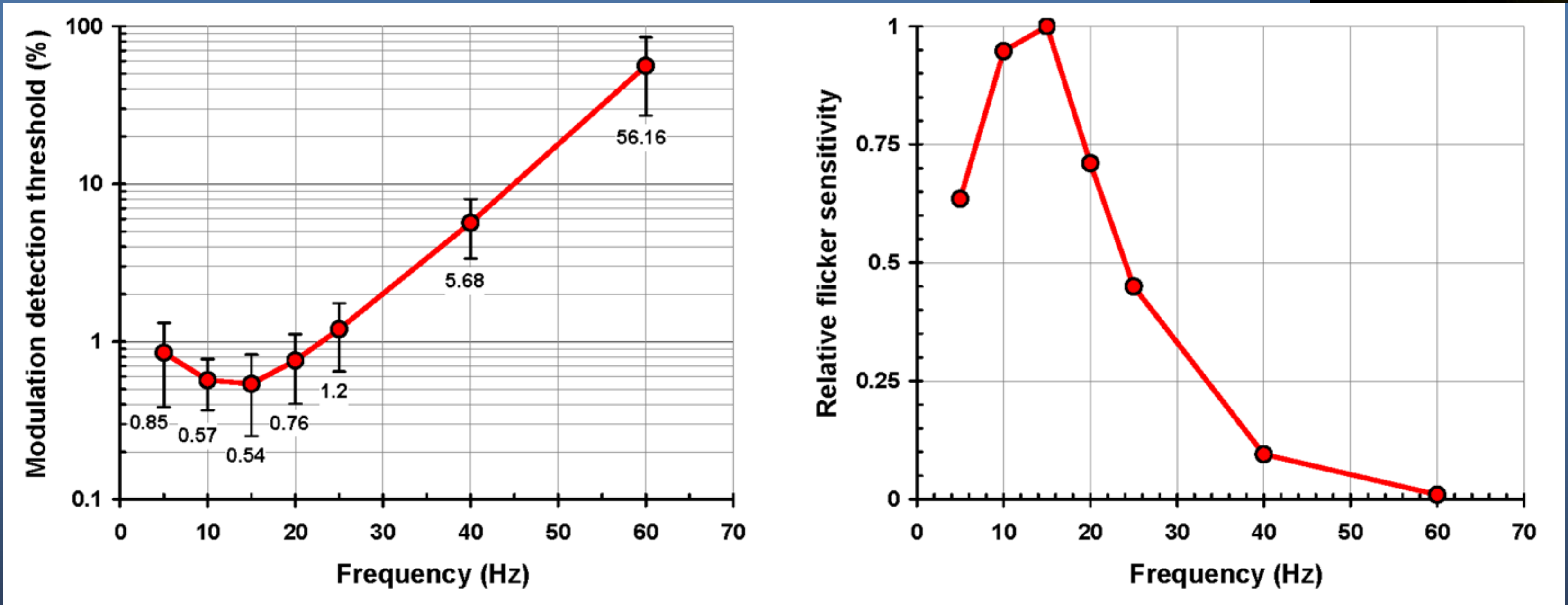
1) Express the light waveform as a series of sinusoidal components of different frequencies (Fourier series)
2) Determine the perceptual strength of each sine wave in the series
3) Combine the individual perceptual strengths to determine the overall effect.

Step 1 Waveform components



Step 2

- Determine the sensitivity to sinusoidal modulation as a function of frequency. Modulation threshold is the modulation (% flicker) needed for a 50% flicker observation rate.



LRC study results for the sensitivity to sinusoidal flicker

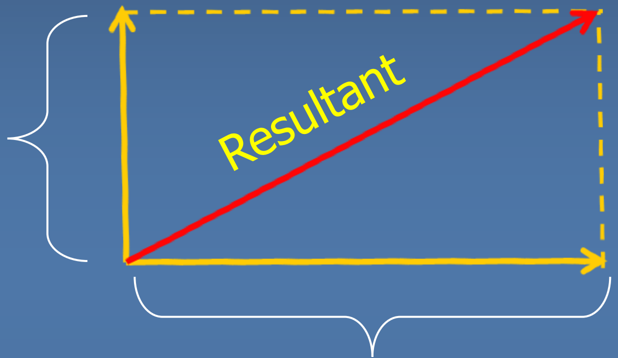
Step 3

- The combined perceptual effect of different frequency components appears to follow rules of Euclidean vector addition (Euclidean distance).

$$Result = \sqrt[n]{\sum_{k} (M_{P_k})^n}$$

$n = 2$

Component 1
(e.g. 20 Hz)



Component 2 (e.g. 40 Hz)

Other ways of combining:
"Manhattan taxicab" distance ($n = 1$)
Arithmetic addition shown by this and other studies as wrong.

"Chess board" or Chebyshev distance ($n = \infty$)
Result = longest vector. Appears in earlier literature (De Lange, 1961).

Perz et al. (2015) found optimal fit to their data with $n = 3.7$, but not much different than $n = 2$.

Experiment verifying Euclidean distance combination

Waveform (sinusoids)	Modulation Percent by Component to Reach flicker Detection Threshold*				Metric value (± 1σ)
	10 Hz	15 Hz	20 Hz	25 Hz	
15Hz + 20 Hz		0.30	0.41 ± 0.03		0.97 ± 0.05
15Hz + 20 Hz		0.49	0.14 ± 0.05		0.94 ± 0.03
20Hz + 25 Hz			0.38 ± 0.09	0.24	0.84 ± 0.18
20Hz + 25 Hz			0.34 ± 0.06	0.36	0.87 ± 0.10
10Hz + 15 Hz	0.12	0.57 ± .04			1.09 ± 0.07
10Hz + 15 Hz	0.30	0.44 ± .14			0.95 ± 0.24
10Hz + 15 Hz	0.48	0.35 ± .05			0.95 ± 0.06
15Hz + 25 Hz		0.30		0.39 ±0.07	0.84 ± 0.10
10Hz + 25 Hz	0.24			0.57 ±0.05	1.01 ± 0.08
10 Hz + 15Hz + 25 Hz	0.18	0.18		0.54 ±0.05	0.98 ± 0.07

*** ± values indicate components that were adjusted by subject, the other components were fixed.**

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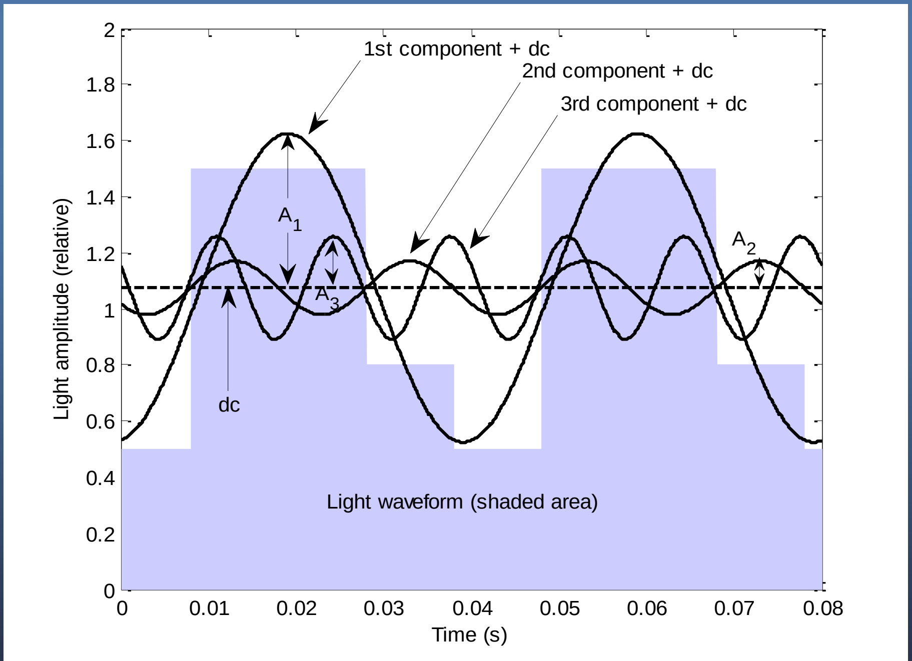
Proposed ASSIST Flicker Metric (Direct Flicker)

- Collect light waveform
  - X_n = sampled waveform, Sampling frequency > 1000 Hz, 0.1% amplitude resolution
- Fourier transform
  - $X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{i2\pi kn}{N}}$, $A_k = \frac{\sqrt{Re(X_k)^2 + Im(X_k)^2}}{N}$, $k = 1, 2, 3, \ldots$
- Divide by dc (Weber contrast)
  - $M_k = \frac{A_k}{A_0}$
- Weight by human threshold sensitivity
  - $M_{P_k} = \frac{M_k}{M_{DTH_k}}$
- Sum independent frequency components
  - $M_P = \sqrt{\sum_k (M_{P_k})^2}$
  - $k = 1, 2, 3, \ldots$



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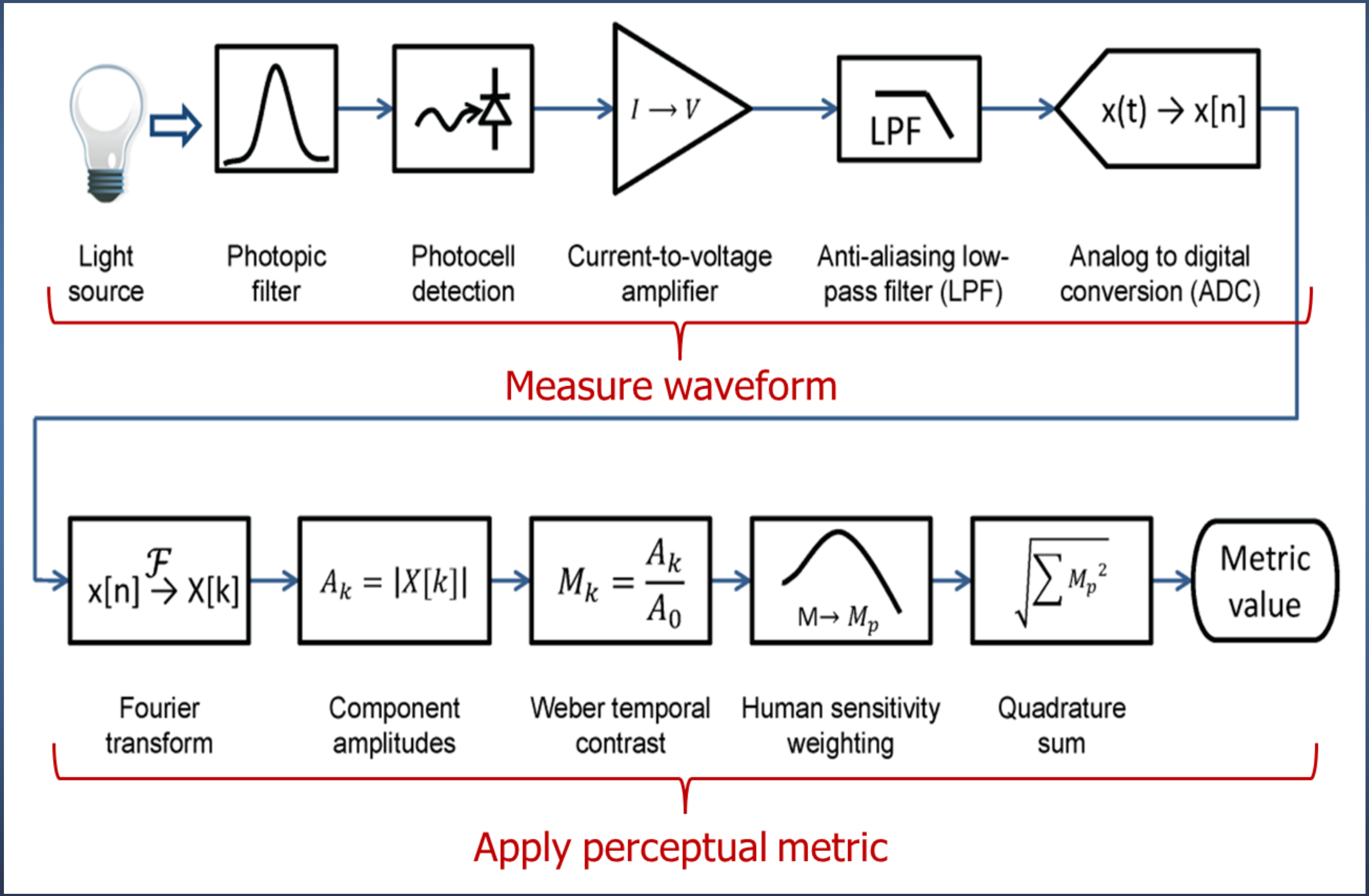
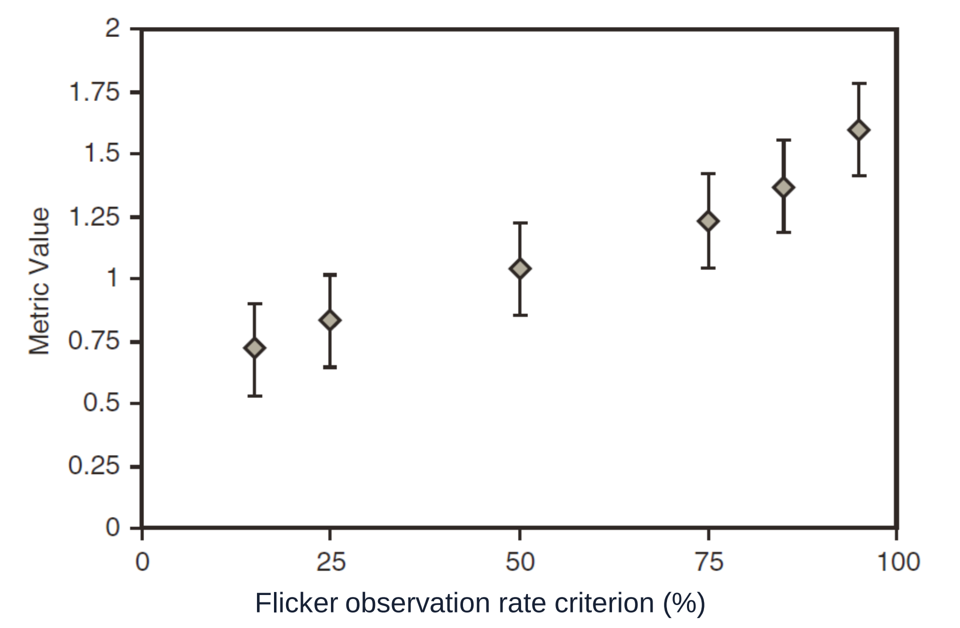
ASSIST Flicker Metric



Testing the Proposed Metric

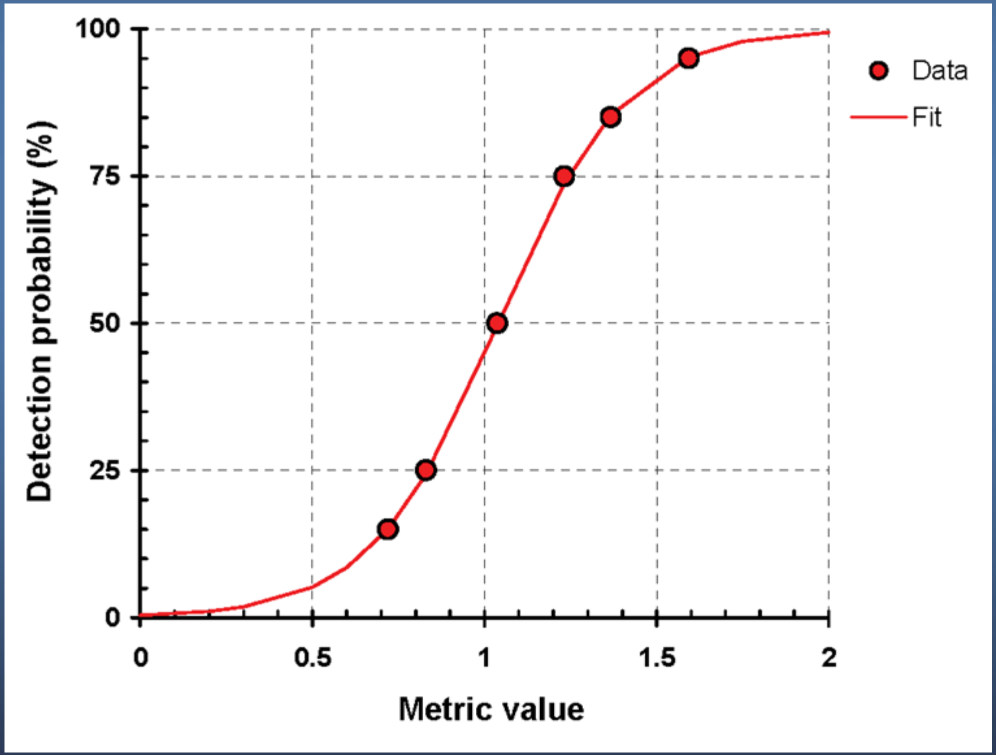
- The observed rate of flicker detection matched (within experimental uncertainty) with the metric value for all waveforms tested
  - Over 200 different waveforms tested (square, rectangular, sine waves)
  - (Also tested actual LED A lamps at full power and dimmed)



Bodington, D., A. Bierman, and N. Narendran. In press. A flicker perception metric. *Lighting Research and Technology*, published online ahead of print 13 April 2015.

Interpreting metric values (M_P)

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



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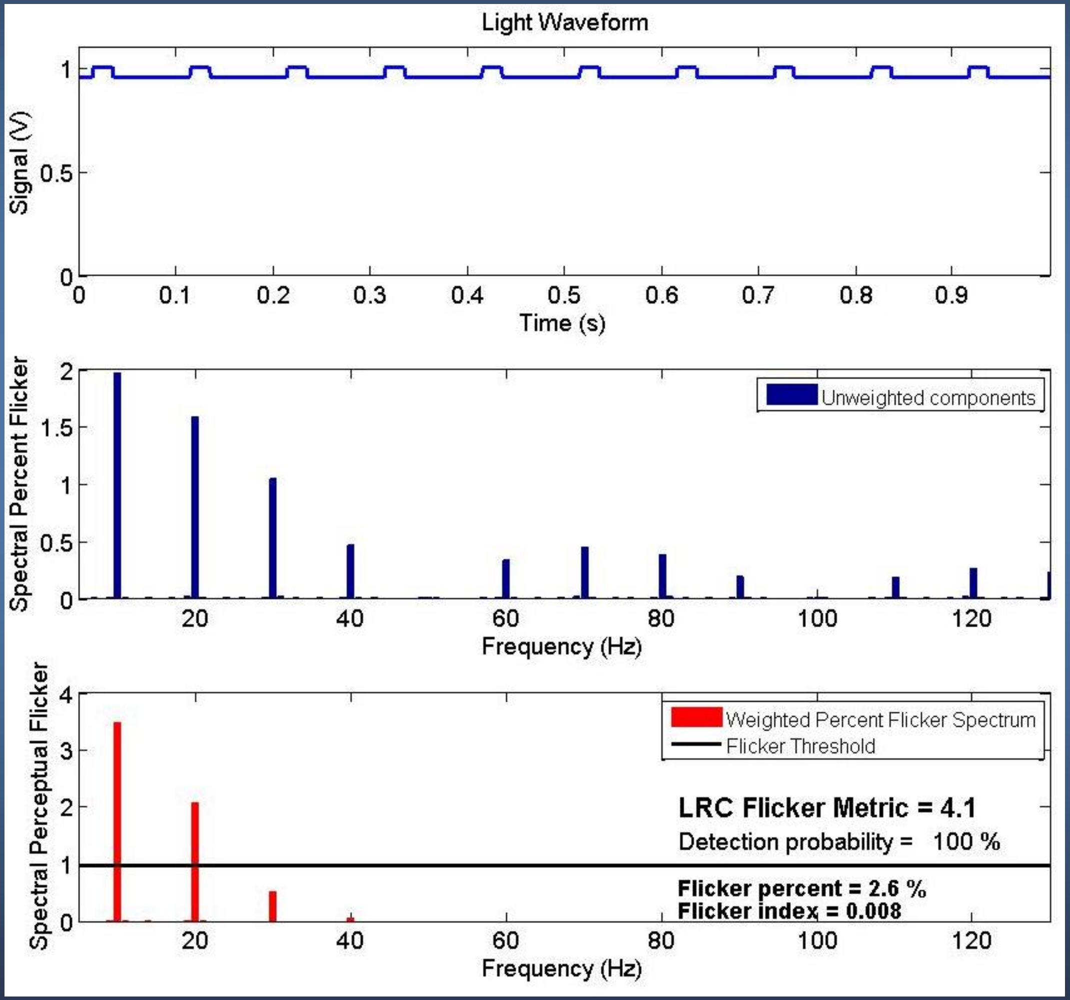
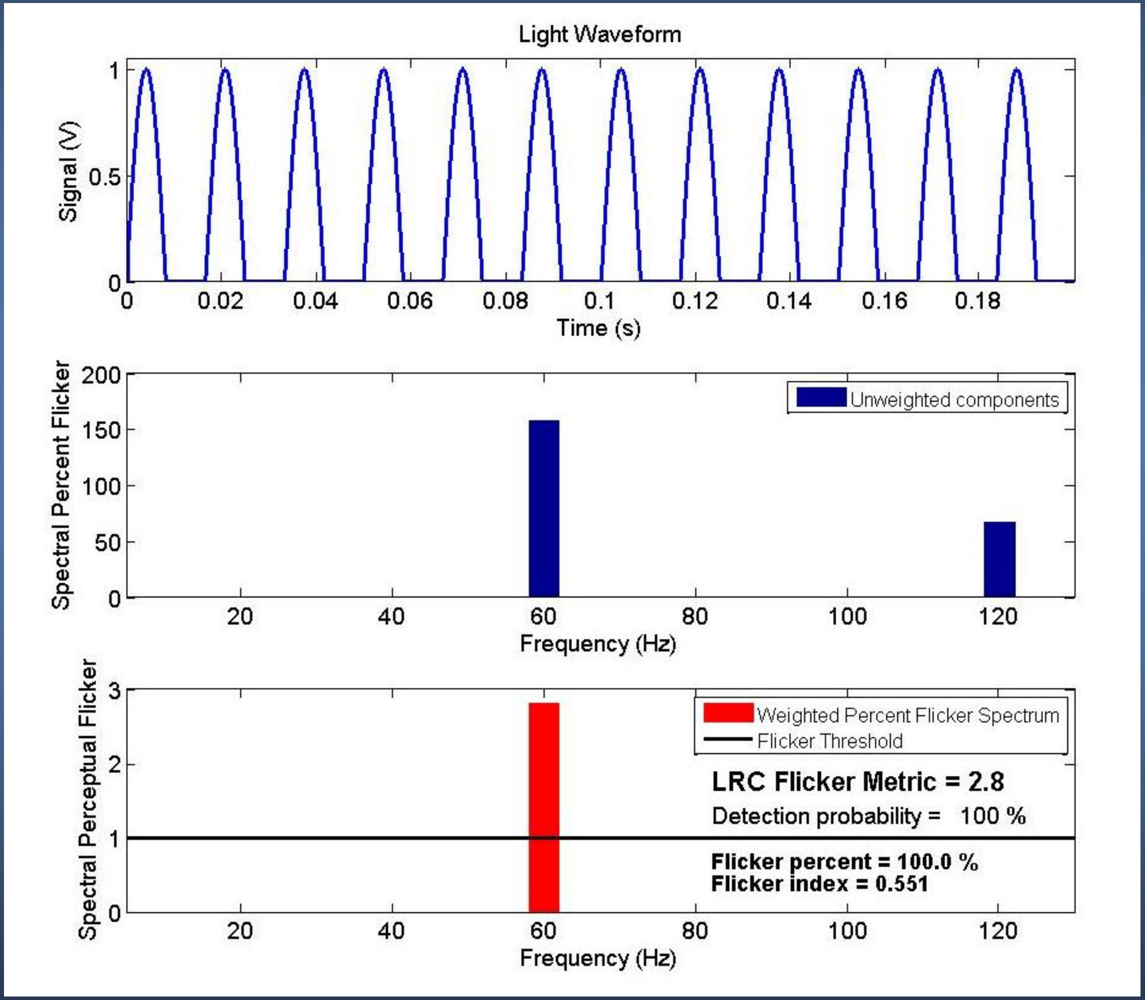
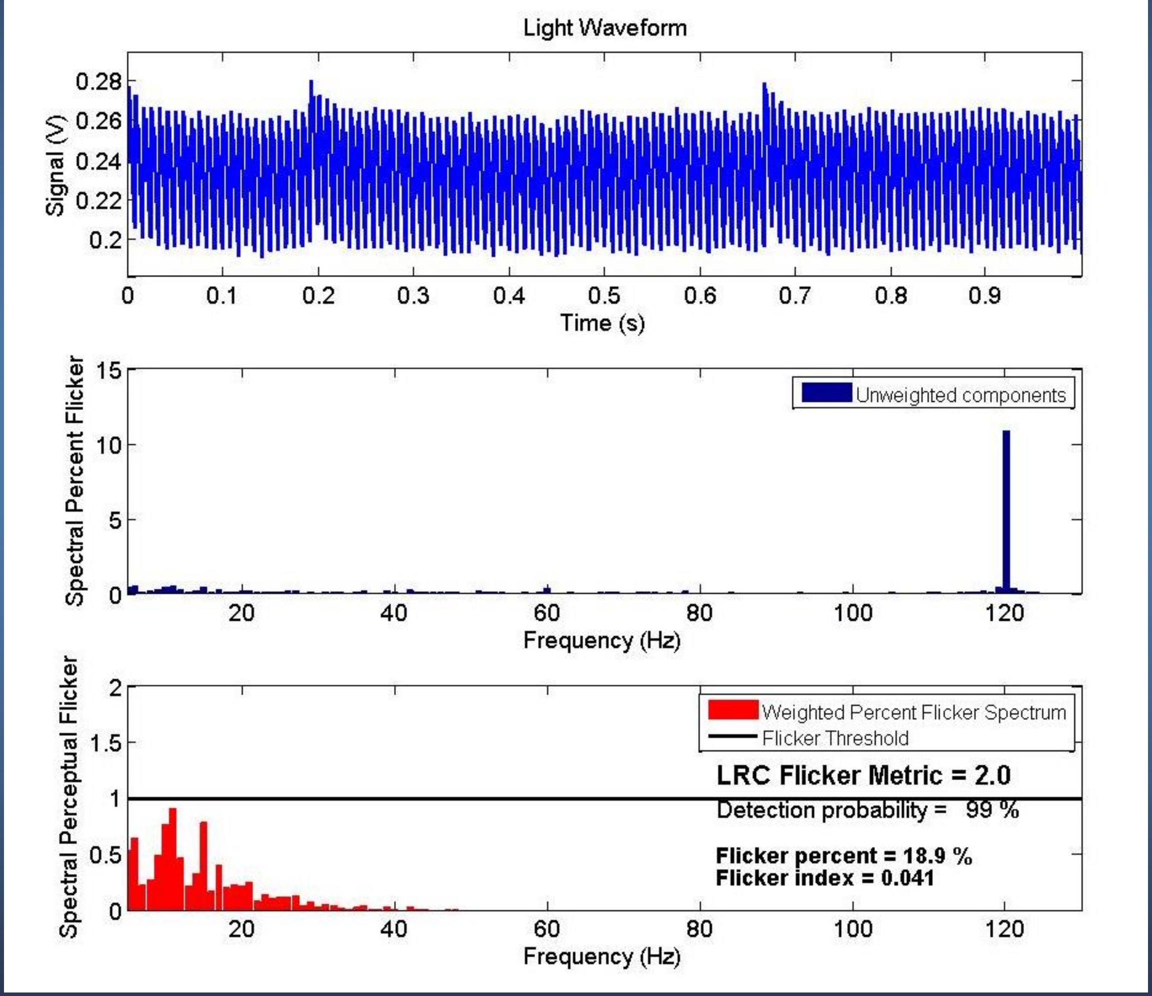
Example waveform #1



Example waveform #2



Example waveform #3



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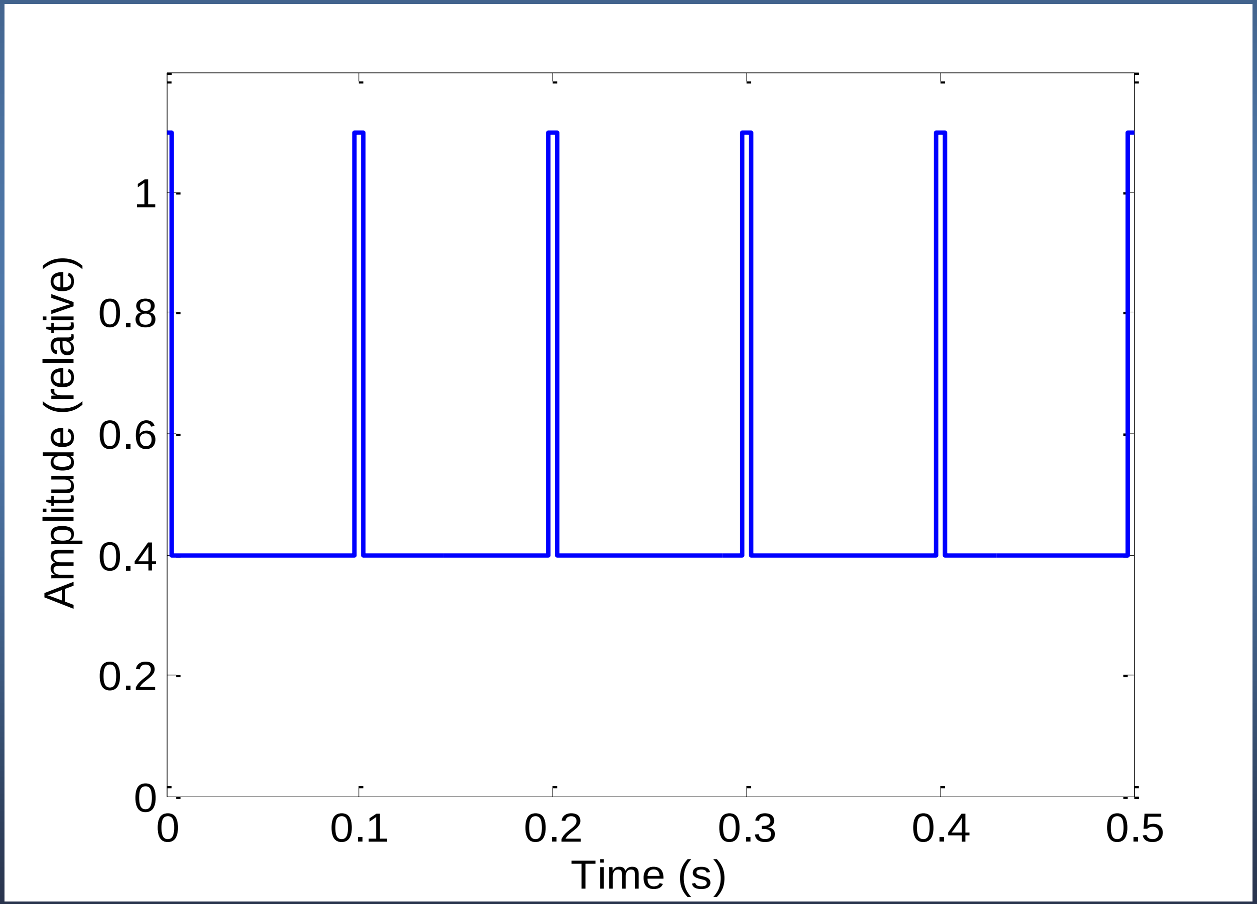
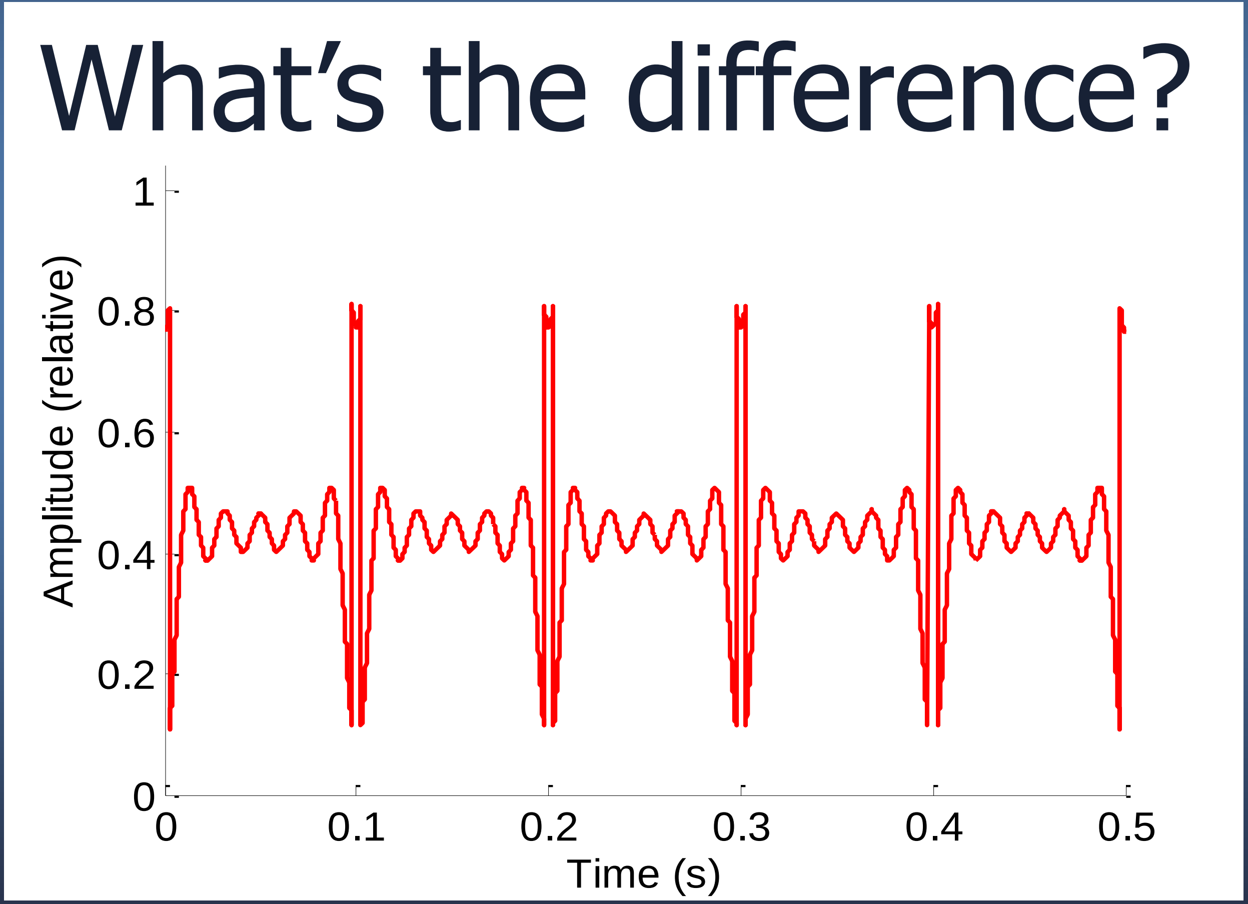
An example for metric comparison

This is very **obvious flicker**: 5% duty cycle at 10 Hz
47% flicker, Flicker Index = 0.075, ASSIST Flicker Metric = 35.4



An example for metric comparison

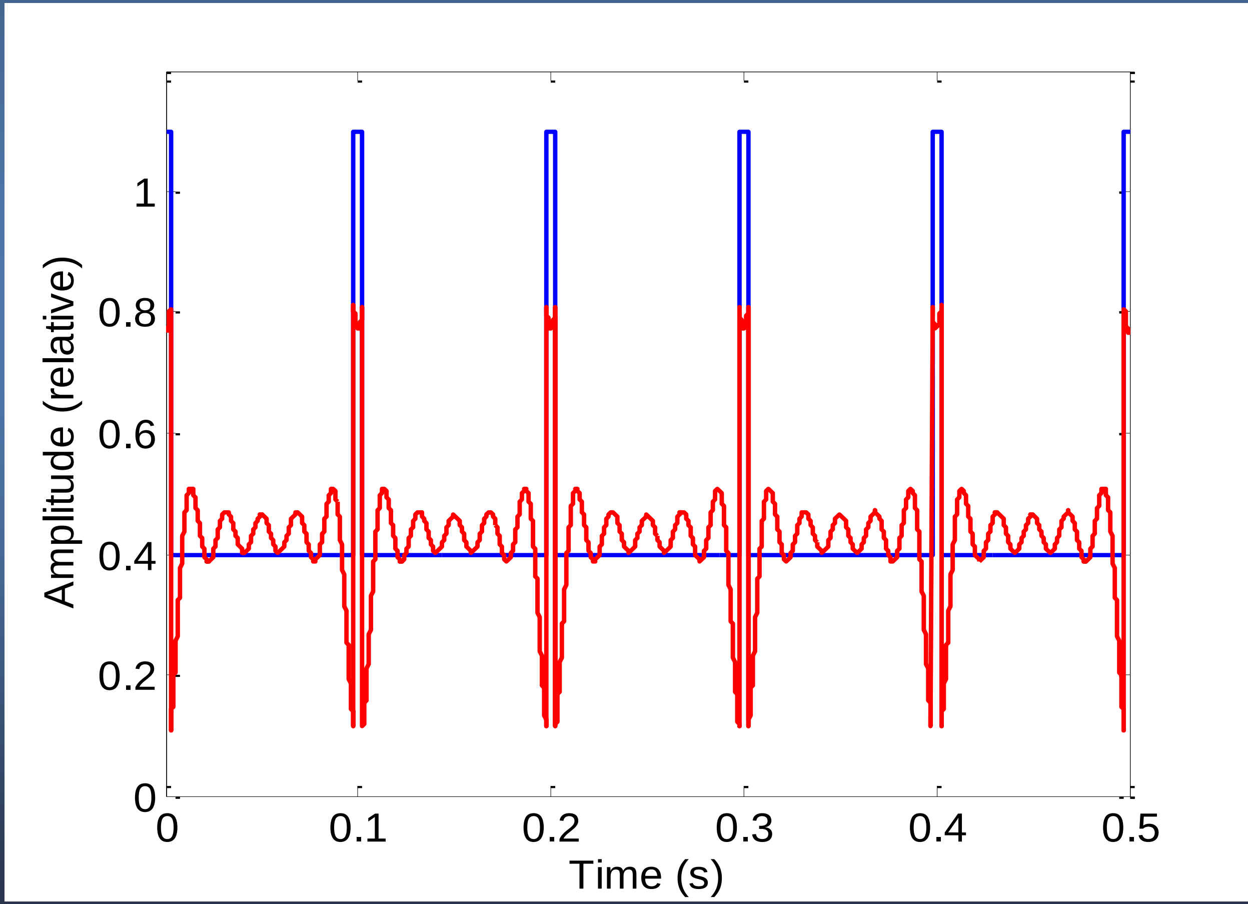
This flicker is **undetectable**: 5% duty cycle at 10 Hz
76% flicker, Flicker Index = 0.073, ASSIST Flicker Metric = 0.3



An example for metric comparison

Low frequency (f<70 Hz) removed

(keeping the dc component)



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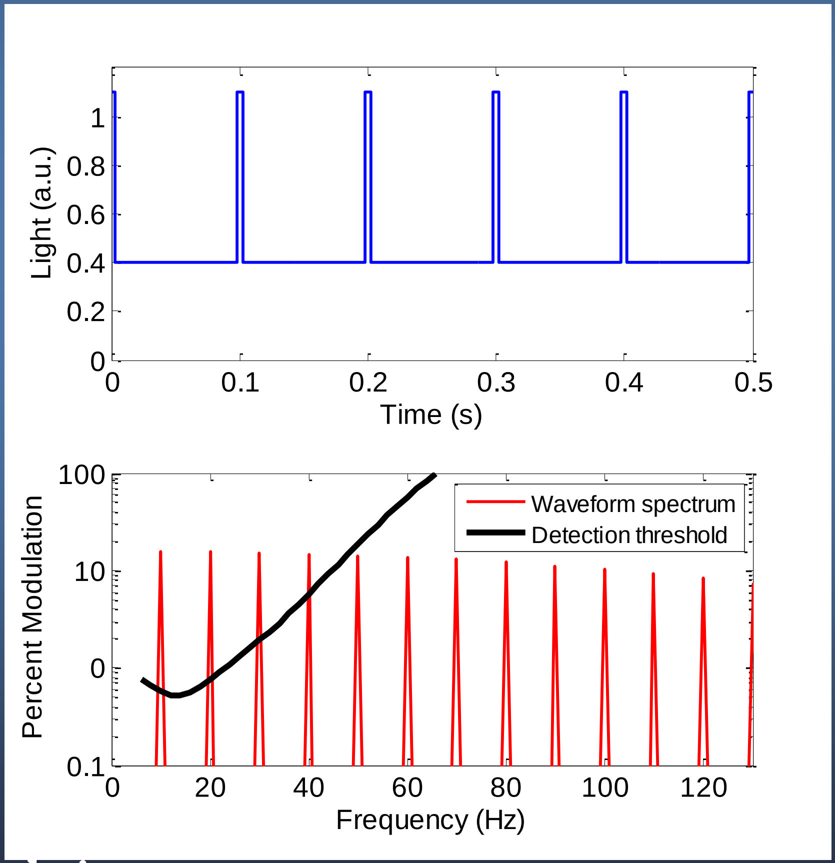
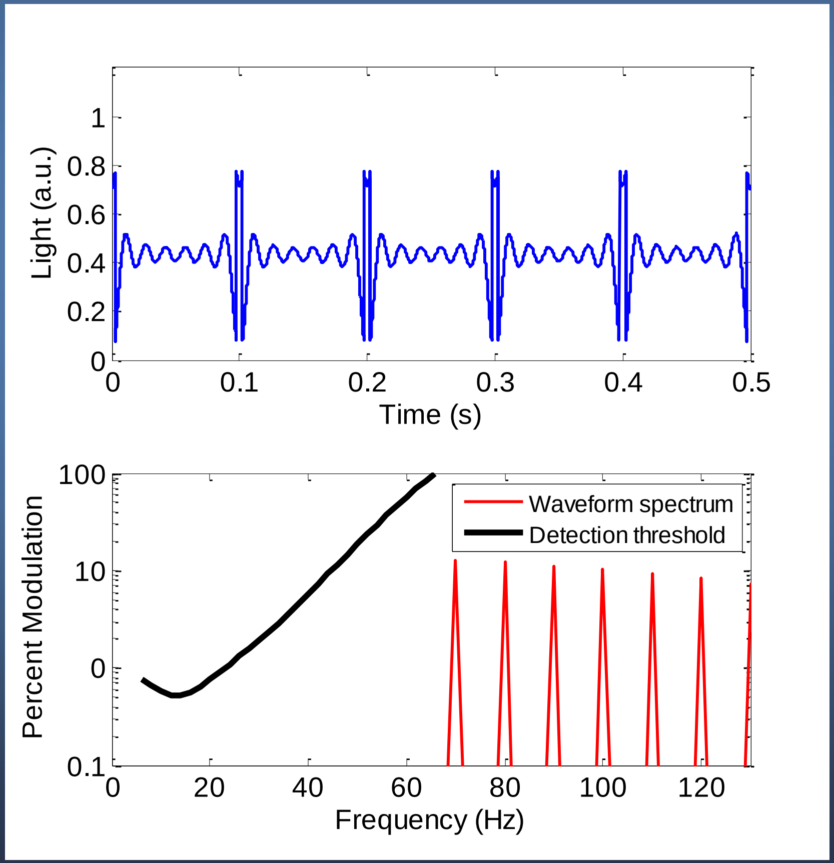
An example for metric comparison

Visible flicker					No Visible flicker
	47	←	Percent Flicker →	76	
	0.075	←	Flicker Index →	0.073	
	35	←	ASSIST Metric →	0.3	





Thank You!

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

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