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# Understanding flicker in airfield lighting applications

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# Introduction

- ◆ Nearly all electric light sources produce flicker
  - 120 Hz flicker is common in North America because of 60 Hz alternating current (AC) power
- ◆ New light sources such as light-emitting diodes (LEDs) can use a wide variety of driving methods
- ◆ Quantifying the effects of flicker from light sources can be important in specifying light source performance in many lighting applications

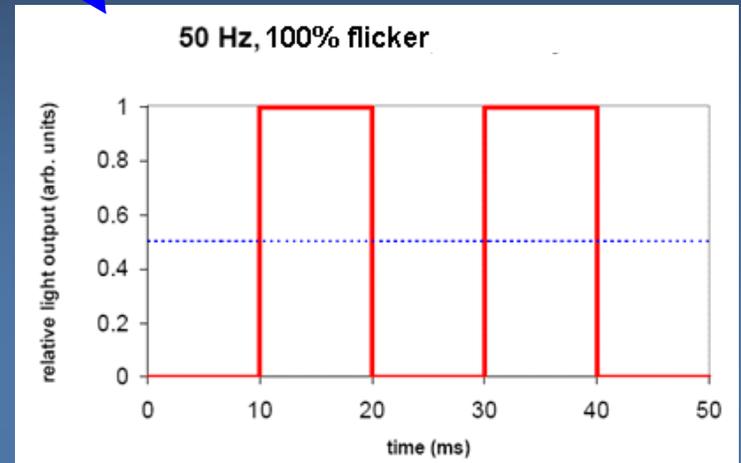
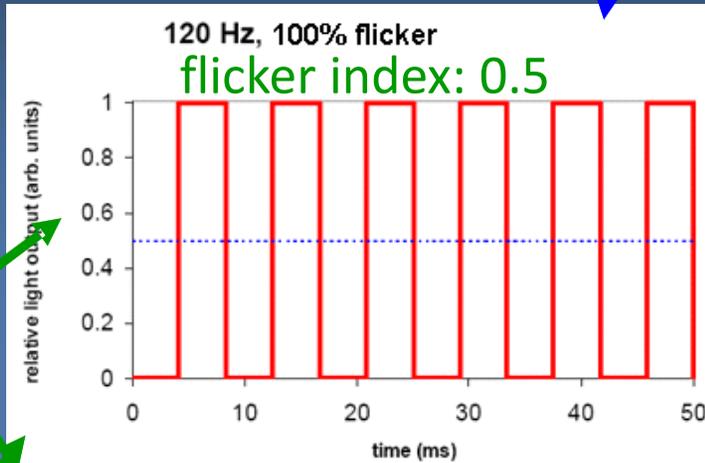
# Perception of Flicker

- ◆ Visual sensitivity to flicker can be characterized in two ways:
  - **Direct** perception of light modulation (at ~80 Hz and lower frequency) (De Lange 1958; Kelly 1961)
  - **Indirect** perception of stroboscopic effects (phantom array, wagon-wheel effect)
- ◆ Characteristics of flicker that might influence perception include (Bullough et al. 2011, 2012, 2013, 2014):
  - Frequency\*
  - Modulation depth\*
  - Duty cycle
  - Waveform shape
  - Correlated color temperature

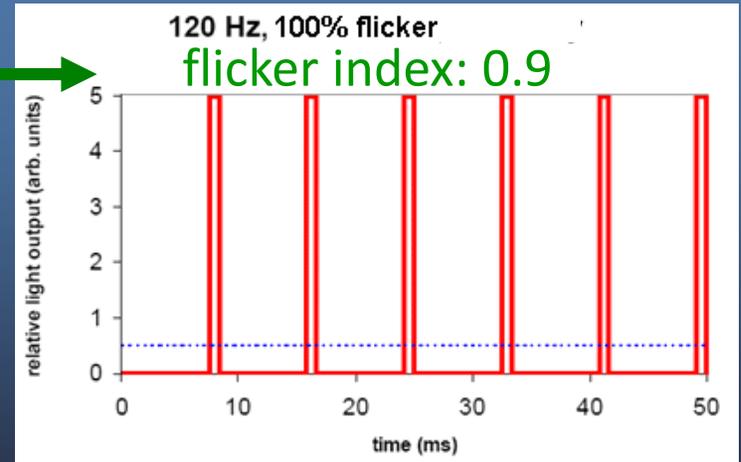
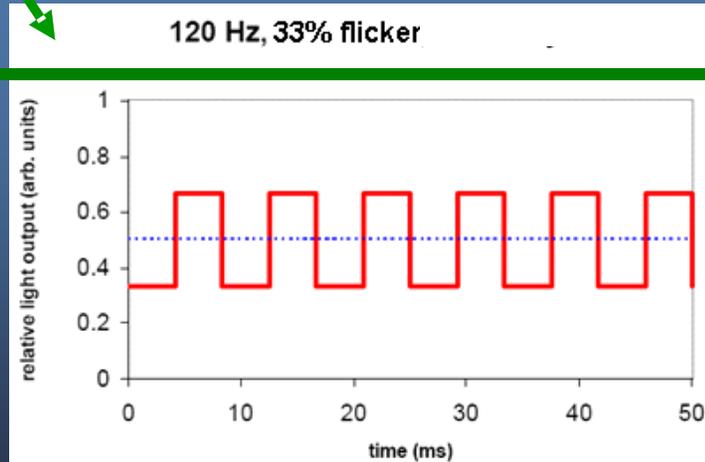
# Flicker Terminology

Frequency  
(cycles per second)

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



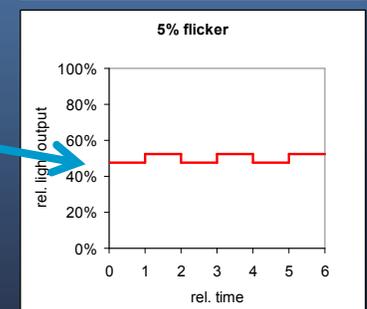
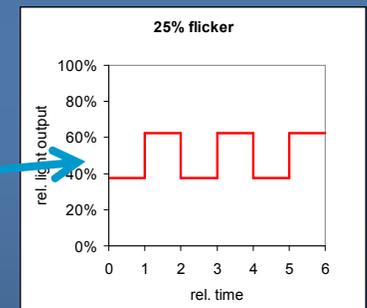
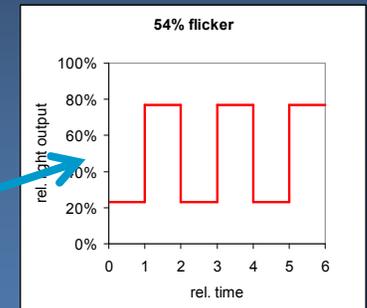
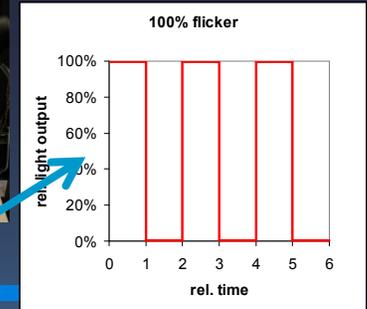
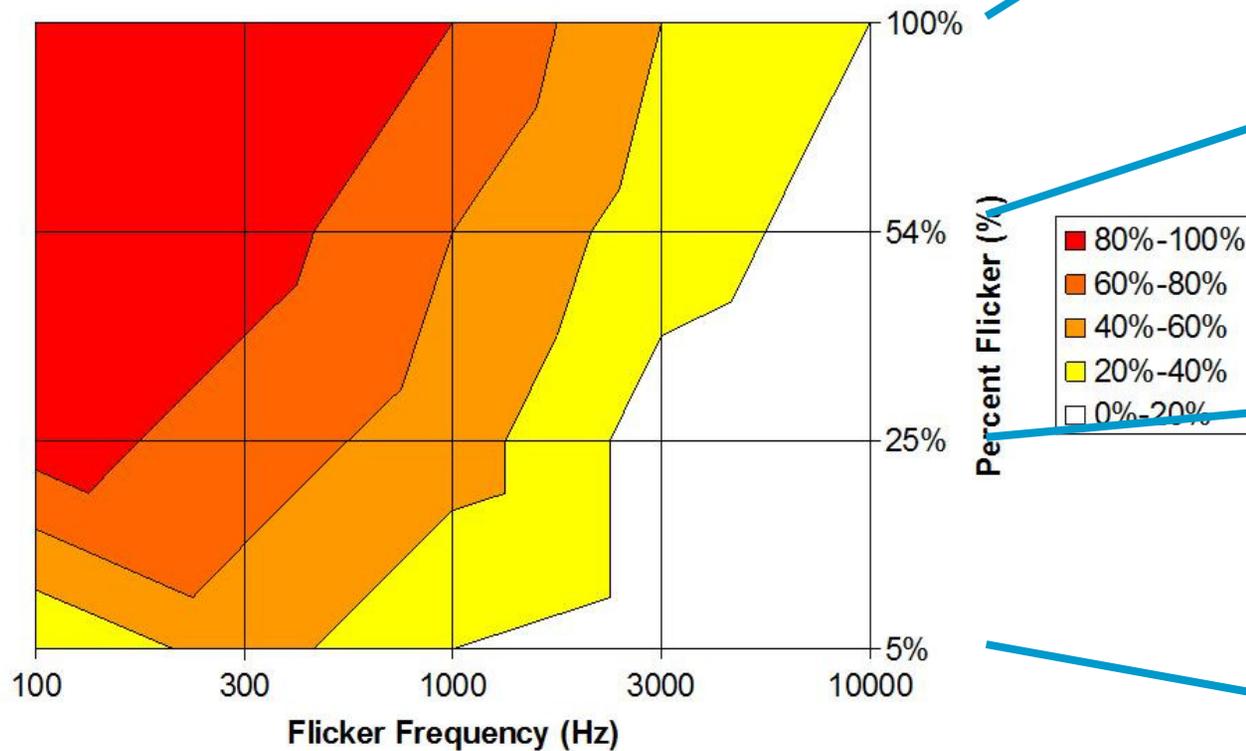
Modulation depth  
(Flicker index: area above average/  
total area)



# Detection of Stroboscopic Effects: Did you see it?

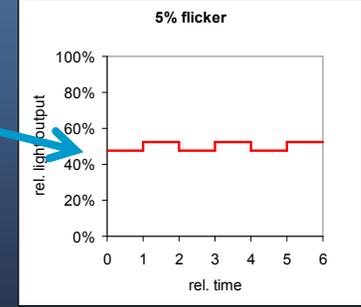
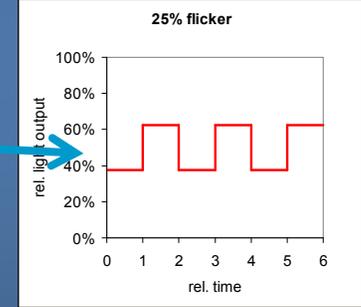
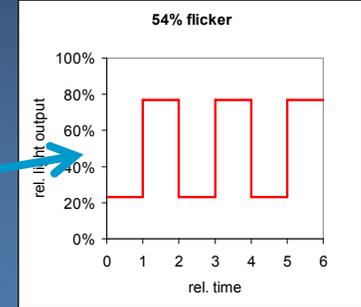
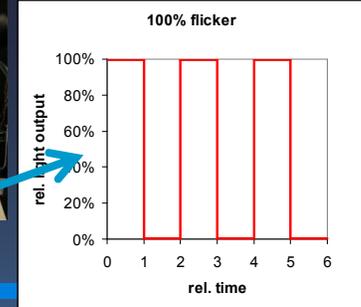
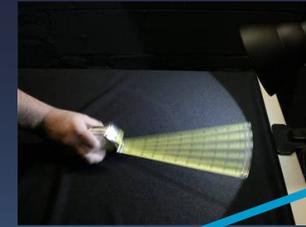


Detection of Stroboscopic Effects

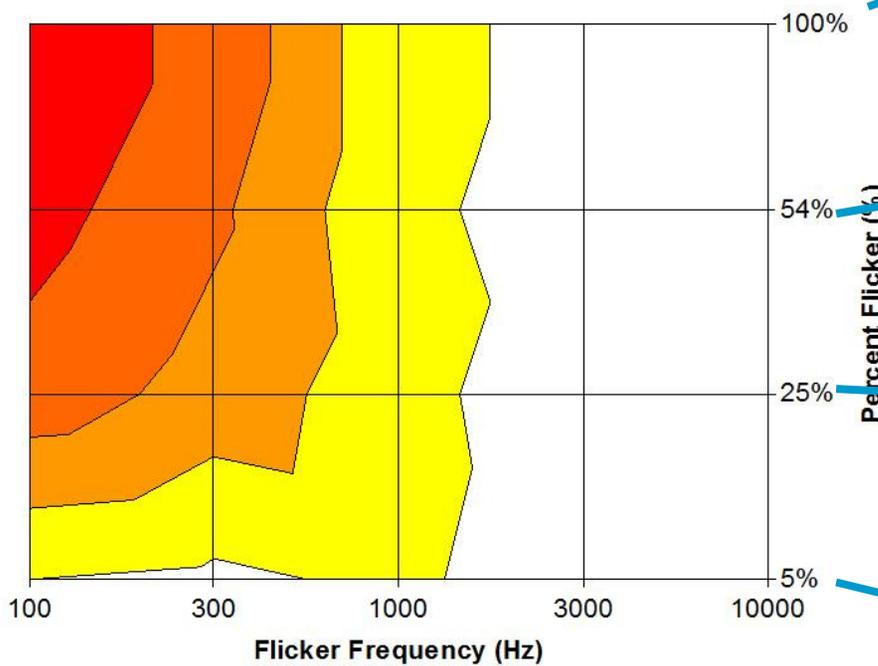


Bullough et al.  
<http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp>

# Acceptability of Stroboscopic Effects: Was it acceptable?



Acceptability of Stroboscopic Effects



- -1-0
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2

- +2: very acceptable**
- +1: somewhat acceptable**
- 0: neither acceptable nor unacceptable**
- 1: somewhat unacceptable**
- 2: very unacceptable**

Bullough et al.  
<http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp>

# Discussion of Results

- ◆ Stroboscopic effects can be visible at frequencies of 1000 Hz or higher
  - However, even when seen, they aren't necessarily unacceptable
  - Both responses can be modeled quantitatively
- ◆ Most light sources flicker!
  - High intensity discharge lamps can produce 50%+ flicker at 120 Hz
  - Incandescent lamps <100 W produce 5%-30% flicker (greater for lower wattages) at 120 Hz

# Quantitative Model

- ◆ Detection (d, from 0%-100%):

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

- ◆ Rated Acceptability (a, from -2 to +2):

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

f: frequency in Hz (from 100-10,000 Hz)

p: percent flicker (from 5%-100%)

*Bullough et al.*

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

**ASSIST** recommends...

Flicker Parameters for Reducing  
Stroboscopic Effects from Solid-state  
Lighting Systems

Volume 11, Issue 1  
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Lighting  
Research Center

 Rensselaer

# Model Application Example

- ◆ A 60 W incandescent lamp, operated on 50 Hz AC power, produces 10% flicker at 100 Hz (IES 2000)
- ◆ What combinations of frequency and percent flicker will produce stroboscopic effects no more detectable than 100 Hz/10% flicker?

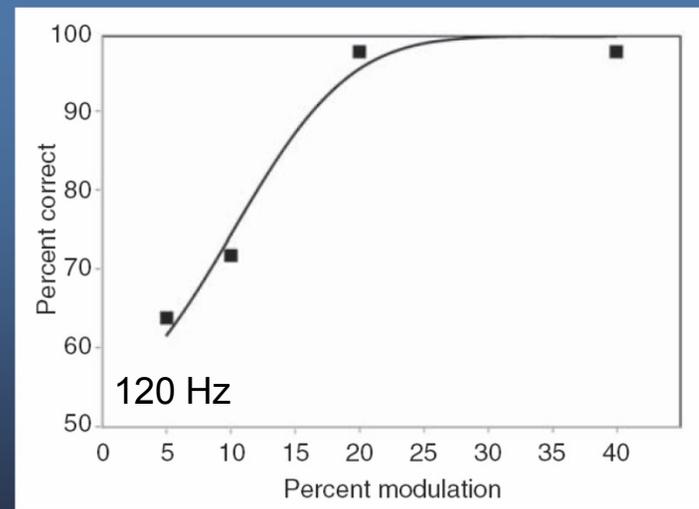
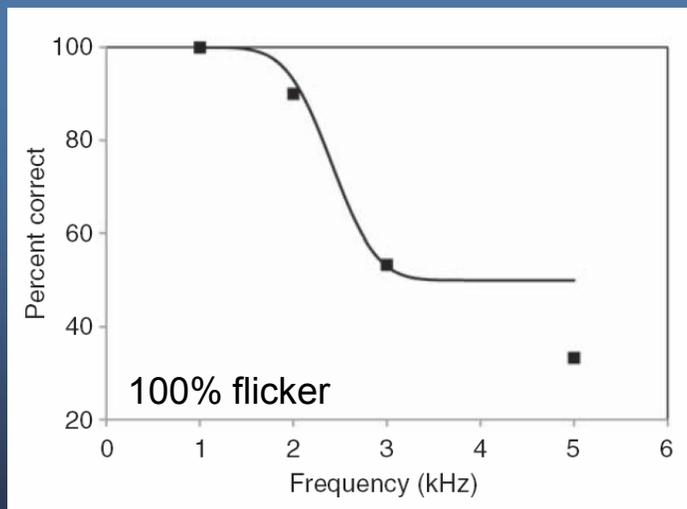
$$p_{max} = 0.16f - 5.6$$

*f*: frequency (100-10,000 Hz)  
*p<sub>max</sub>*: percent flicker (5-100)

- ◆ At 120 Hz,  $p_{max} = 14\%$  flicker
- ◆ At 250 Hz,  $p_{max} = 34\%$  flicker
- ◆ At 1000 Hz,  $p_{max} = 100\%$  flicker *(ASSIST recommends 2012)*

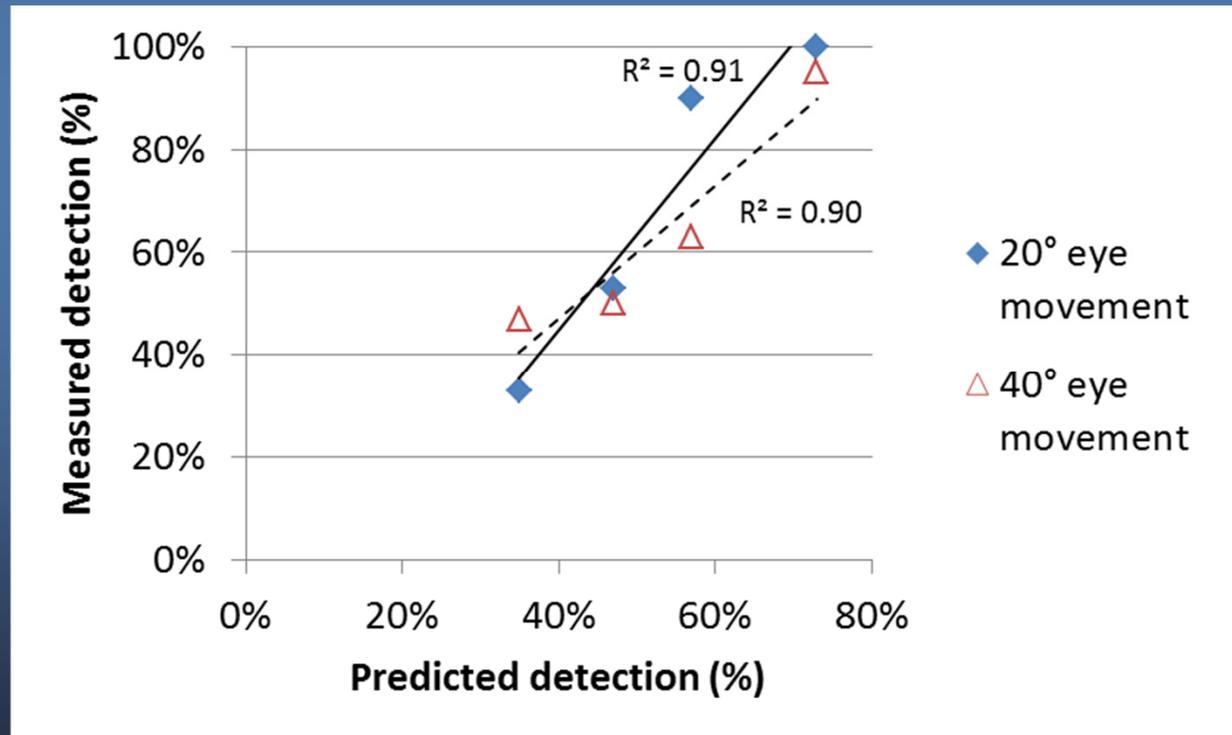
# Phantom Array

- ◆ Detection of stroboscopic effects in airfield lighting is most likely caused by “phantom array” effect
- ◆ Roberts et al. (2012) evaluated ability to detect the “phantom array” for different frequencies and percent flicker values
  - Phantom array perception



# Phantom Array

- ◆ Comparison of predicted and measured detection of stroboscopic effects predicted by Bullough et al. and measured by Roberts and Wilkins



# Discussion

- ◆ Nonvisual effects of flicker are not addressed in these studies
  - Effects include photosensitive epilepsy, migraines, eyestrain (especially in region from 5-30 Hz)
  - These effects may be limited to specific sensitive subpopulations
  - Currently under study by an IEEE Working Group (PAR 1789)

# Summary

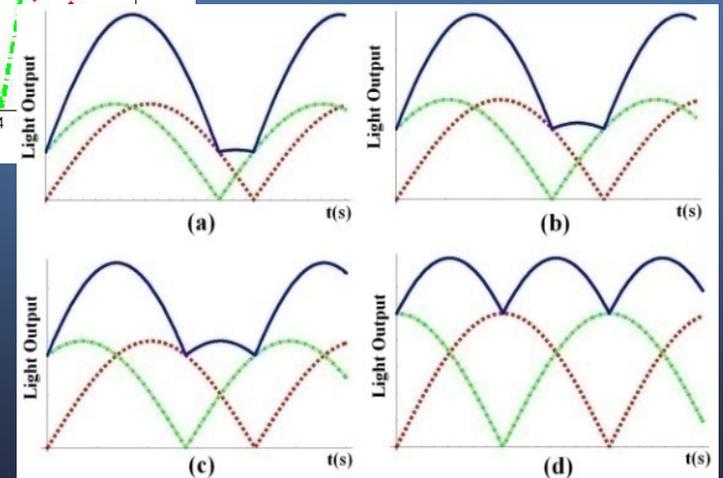
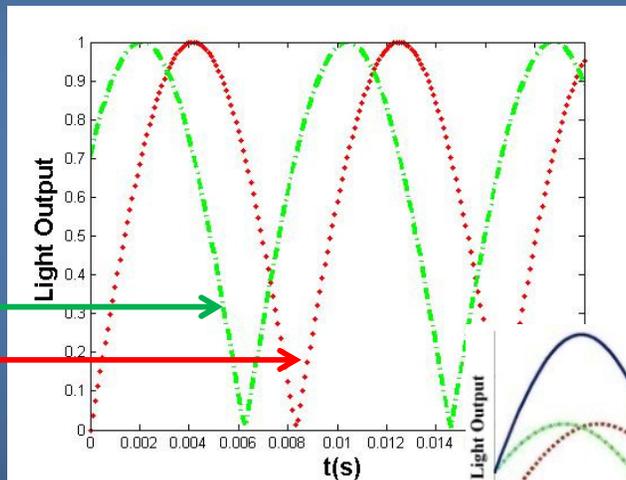
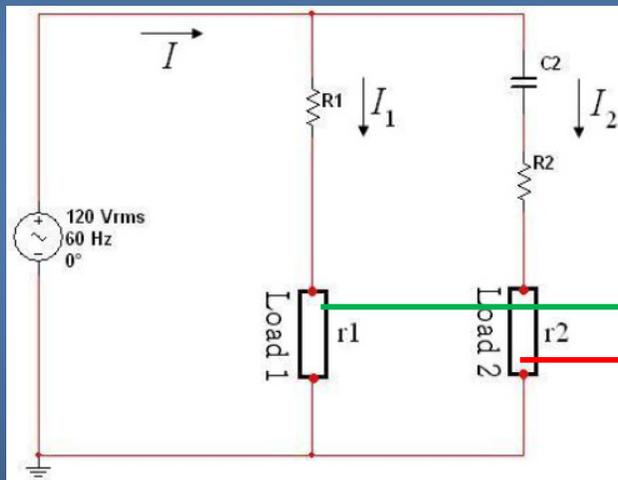
- ◆ All electric light sources produce some flicker
- ◆ A model of the detection and acceptability of stroboscopic effects from flicker has been developed (Bullough et al. 2012)
- ◆ Even when stroboscopic effects can be detected they are not necessarily unacceptable (for short periods of time)

# Implications for LED driving circuitry

- ◆ LEDs driven directly from mains voltage can offer potential benefits
  - › Disadvantage: flicker at 120 Hz
- ◆ Objective of study: to develop a circuit design that results in
  - › Percent Flicker (%F) < 33% (based on Bullough et al.)
  - › Power Factor (PF) > 0.7 (from standards requirements)
  - › Power Efficiency ( $\eta$ ) > 85% (from specifications of LED drivers in market)

# Proposed Method

- ◆ A circuit that results in a phase shift between two loads (composed of LEDs) to reduce percent flicker



# Acknowledgments

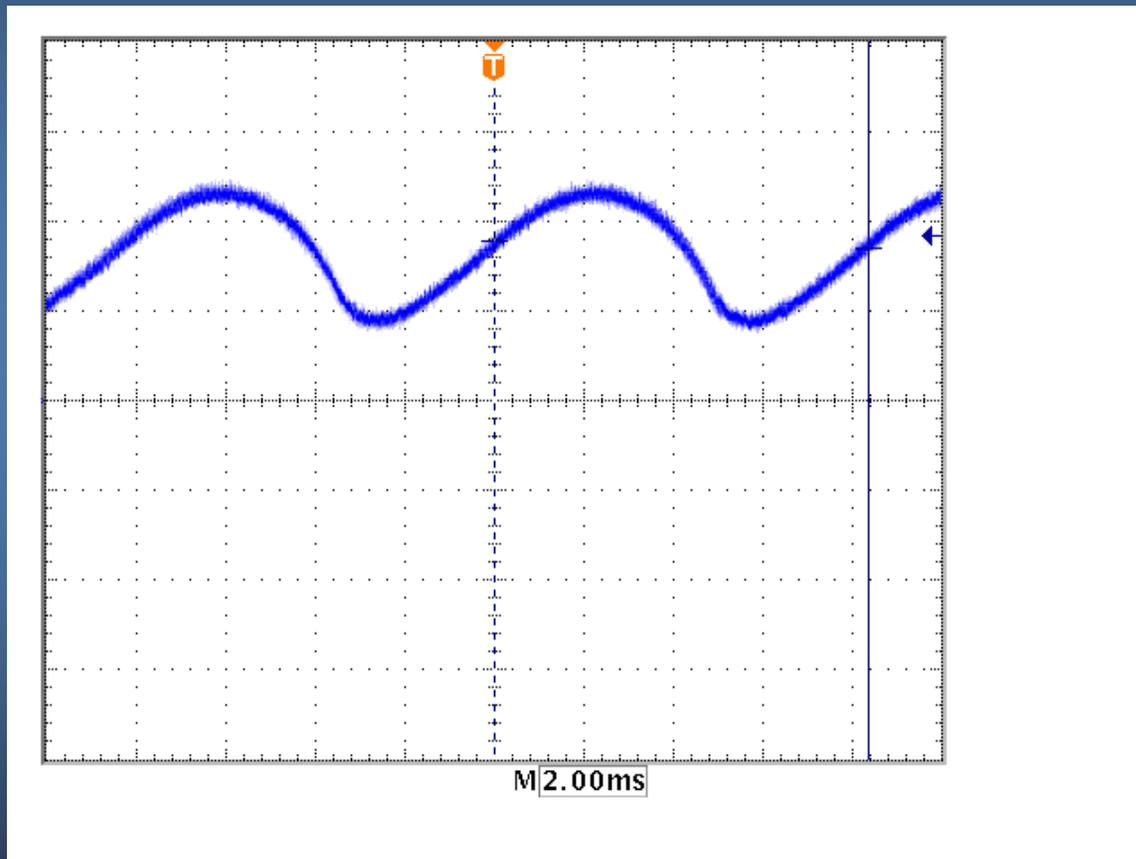
- ◆ Federal Aviation Administration
  - › Funding through Cooperative Agreement 10-G-013
  - › Don Gallagher served as technical monitor
- ◆ LRC faculty, staff, and students
  - › Nicholas Skinner, Kathryn Sweater Hickcox, Andrew Bierman, Yiting Zhu, Yi-wei Liu, Terry Klein, Martin Overington, Howard Ohlhous

# Comparison of Light Source Temporal Waveforms

- Equipment:
  - Oscilloscope
  - Photocell/resistor pair
- Photocell was affixed to a stand within the beam of the light source
- Light source was powered up and allowed to warm up/stabilize
- Waveform showing the temporal modulation of the source was captured from the oscilloscope



# Comparison of Light Source Temporal Waveforms (cont'd.)

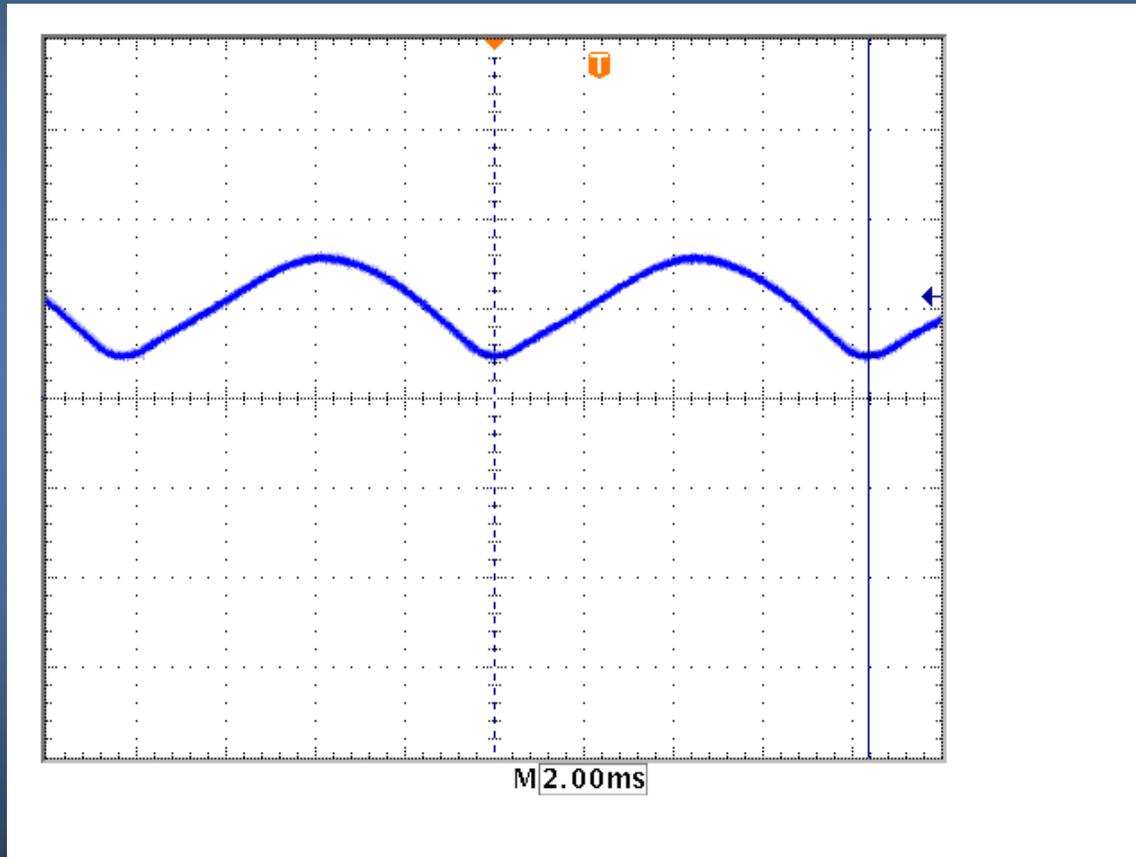


Fluorescent lamp on  
magnetic ballast

Frequency: 120 Hz

Percent flicker: 36%

# Comparison of Light Source Temporal Waveforms (cont'd.)

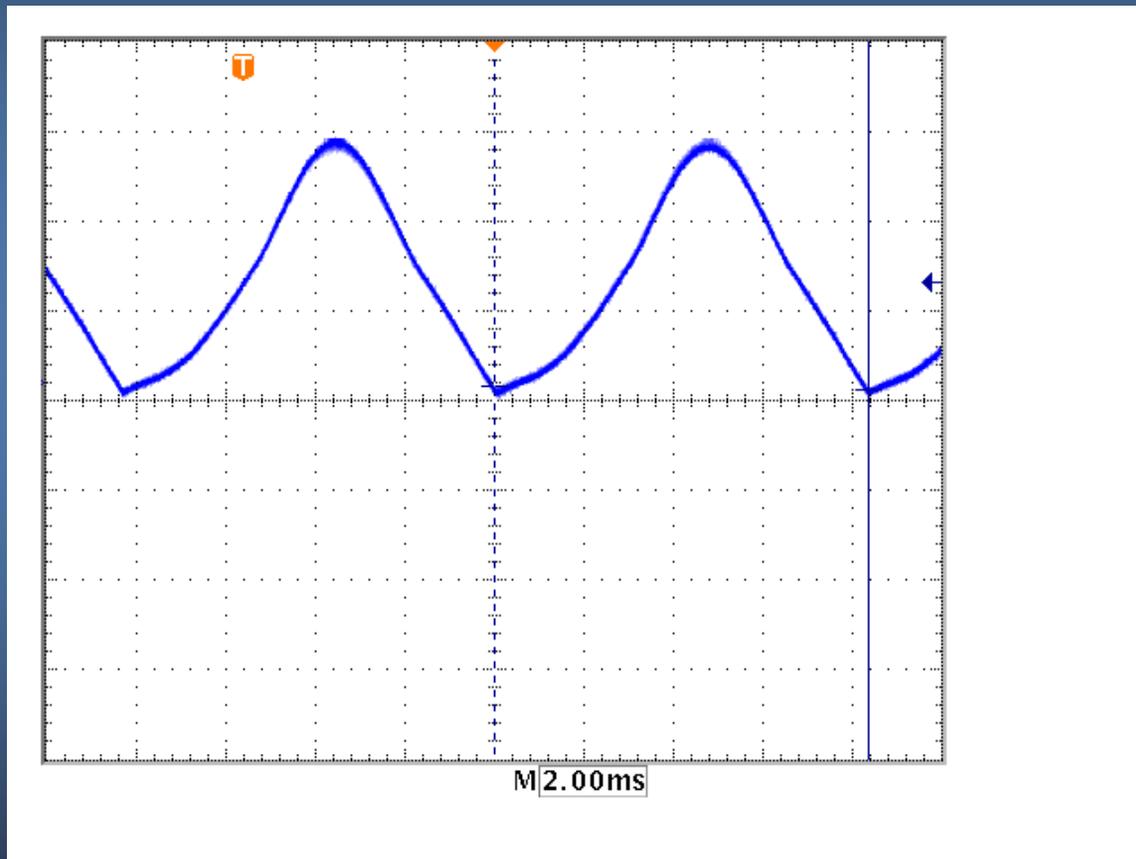


Metal halide lamp

Frequency: 120 Hz

Percent flicker: 52%

# Comparison of Light Source Temporal Waveforms (cont'd.)

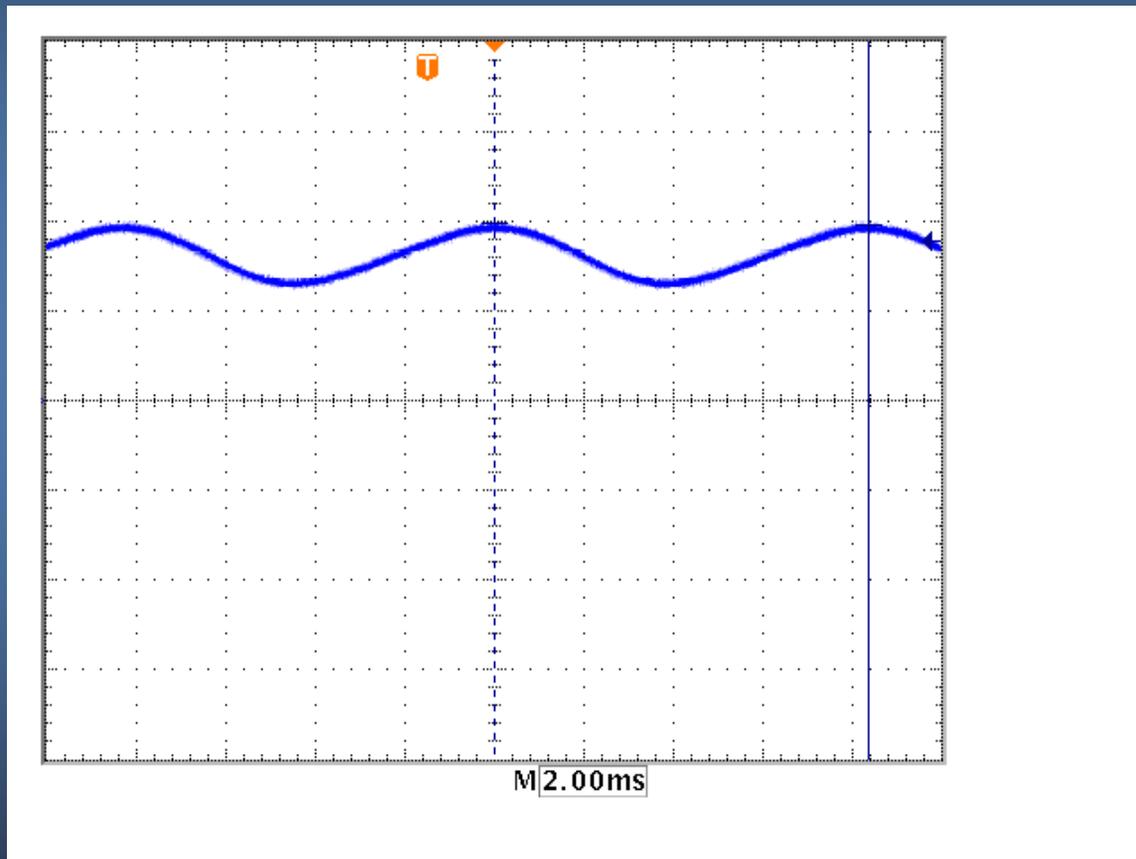


High pressure sodium  
lamp

Frequency: 120 Hz

Percent flicker: 95%

# Comparison of Light Source Temporal Waveforms (cont'd.)

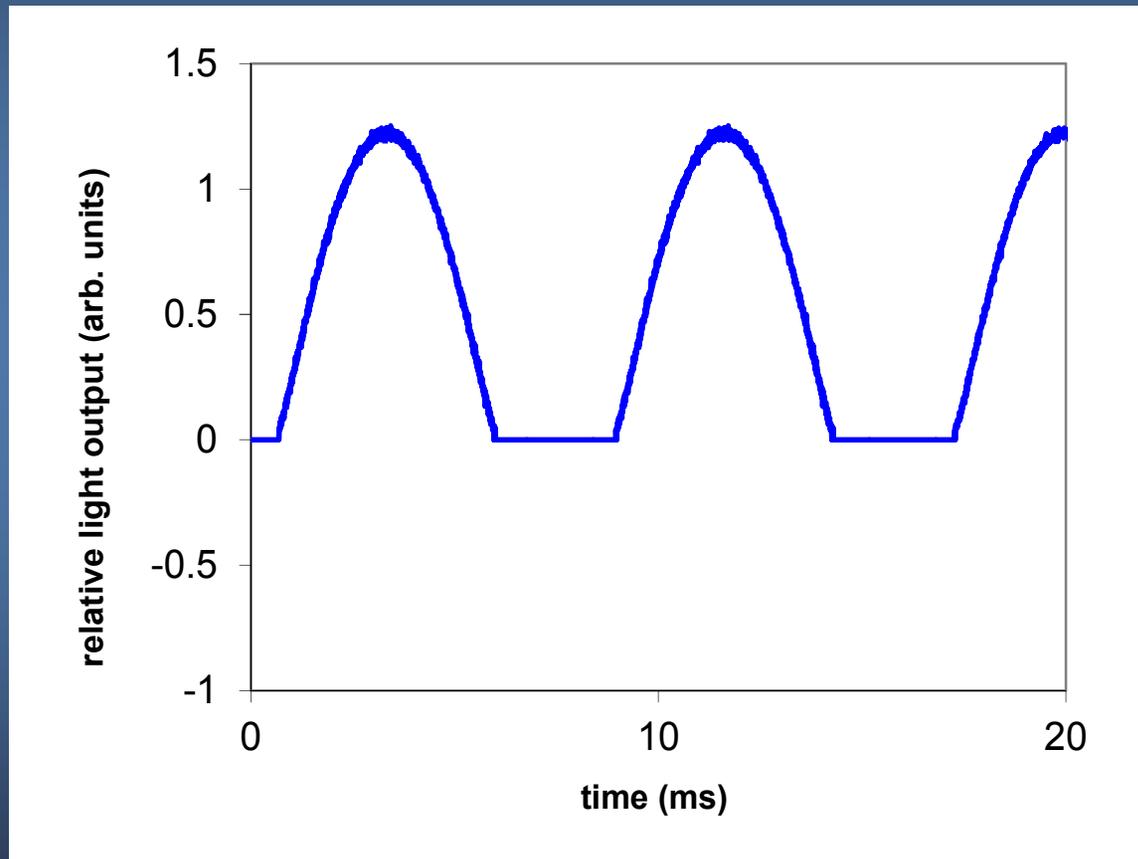


Light-emitting diode

Frequency: 120 Hz

Percent flicker: 18%

# Comparison of Light Source Temporal Waveforms (cont'd.)

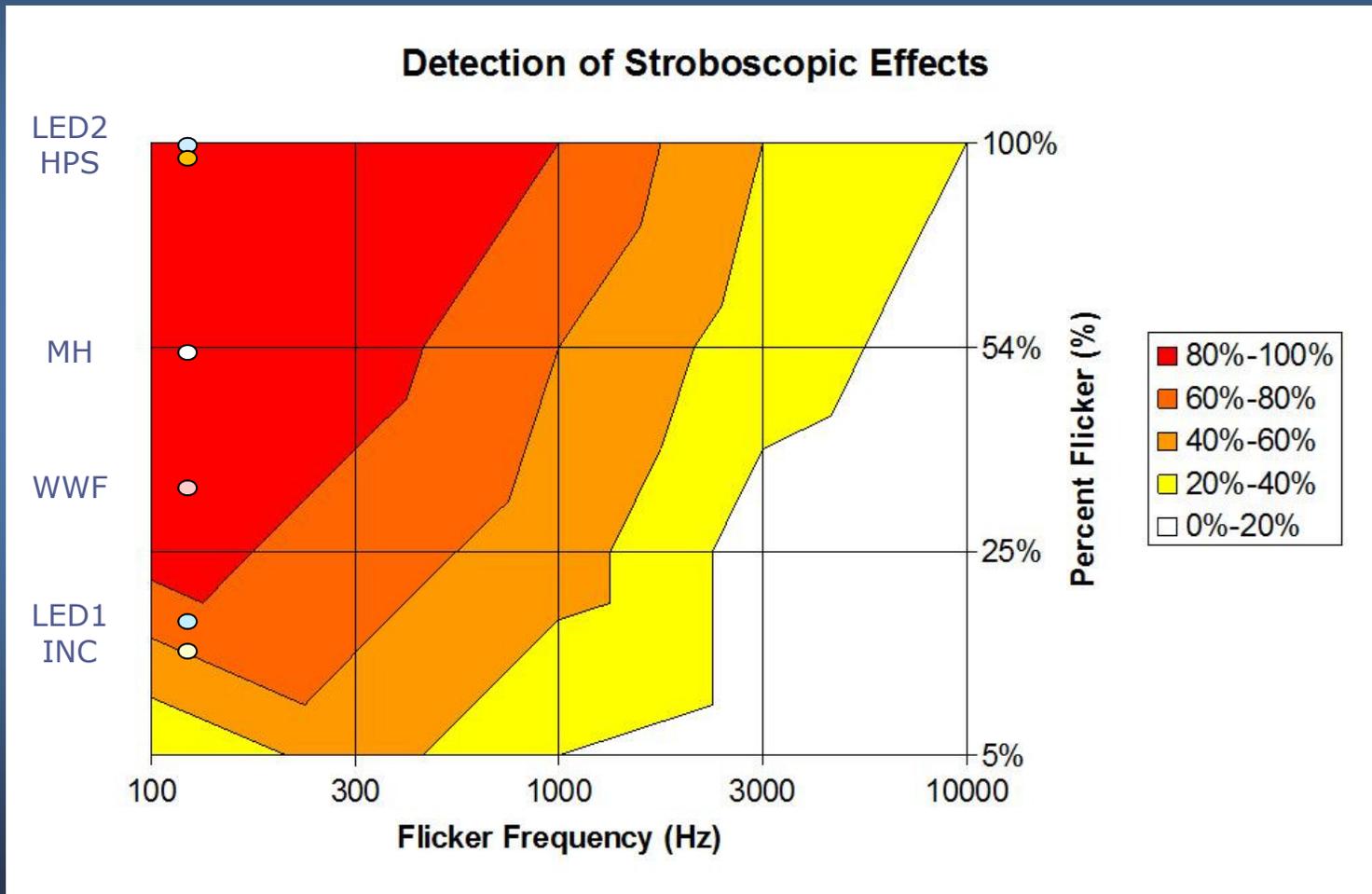


Light-emitting diode

Frequency: 120 Hz

Percent flicker: 100%

# Comparison of Light Source Temporal Waveforms (cont'd.)



# Comparison of Light Source Temporal Waveforms (cont'd.)

Acceptability of Stroboscopic Effects

