What You Need to Know about LED Flicker and Dimming

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Michael Poplawski
Pacific Northwest National Laboratory
michael.poplawski@pnnl.gov
Why do flicker & dimming matter for LEDs?

Flicker implications

• Neurological problems, including epileptic seizure
• Headaches, fatigue, blurred vision, eyestrain
• Apparent slowing or stopping of motion
• Reduced visual task performance
• Distraction

Dimming benefits

• Energy savings
• Increased visual task performance
• Enhanced ambience
• Fewer light sources to specify, maintain, stock
• Enhanced space flexibility, satisfaction
• Demand response load shedding
What is flicker?

• Modulation of light output (luminous flux)
• All commercial electric light sources running on AC power modulate light output
  – Including incandescent, halogen, metal-halide, fluorescent
  – Typically periodic, and property of light source
  – Whether you are aware of it or not
• Not to be confused with electrical flicker
  – Not a property of the light source
  – Noise on AC distribution line directly creates additional (light) modulation on resistive (incandescent) loads
• Measurement of light modulation, or (photometric) flicker, is not a standard practice for commercially available light sources
Incandescent flicker

60W A19

75W A19

30W R20

45W R20
Magnetically-ballasted fluorescent flicker

- T12
- T12 U-Shape
- Quad-Tube CFL Reflector
- Quad-Tube CFL
Electronically-ballasted fluorescent flicker

- A19 CFL
- Quad-Tube CFL
- R20 CFL
- MR16 CFL
Examples of LED flicker
More examples of LED flicker

R38/PAR38

“AC LED” Module

2’ x 2’ troffer
Flicker metrics

• Percent flicker
  – 0-100% scale
  – More well-known and more commonly used (in research)
  – Also referred to as Peak-to-Peak Contrast, Michelson Contrast in literature

• Flicker index
  – 0-1.0 scale
  – Less well-known and rarely used

• Both based on analysis of one cycle of periodic waveform
• Neither account for frequency

Source: IESNA Lighting Handbook, 10th Edition

• Percent Flicker = 100% \times \frac{A-B}{A+B}
• Flicker Index = \frac{Area\ 1}{Area\ 1+Area\ 2}
Mitigating the effects of flicker

- Degrees of mitigation
  - Detection
  - Objection
  - Implication(s)

- All other things being equal
  - Higher modulation frequency results in reduced effects
  - Lower modulation depth results in reduced effects
  - Lower duty cycles results in increased effects
  - Greater eye motion results in increased effects

Source: http://www.lrc.rpi.edu/programs/solidstate/assist/flicker.asp
Why is LED dimming problematic?

- LEDs are inherently dimmable
  - PWM vs. CCR
- LEDs are non-linear devices, which (typically) need a Driver
- Most control technologies were designed for incandescent (resistive) loads
- Wide variation in LED source and dimmer designs
  - Dimming curves, for both
  - Dimmer circuit loading

- Compatibility
  - Dead travel
  - Popcorn
  - Flashing, Ghosting
  - Pop-on, Drop-out
  - Audible noise
  - Inoperability
  - Premature failure

- Performance
  - Dimming range
  - Dimming curve
  - Efficacy
  - Flicker

- Predictability
Two approaches to dimming

Coincident AC power and control signal

- Forward or reverse phase-cut AC sine wave
- 2-Wire (hot, dimmed hot) or 3-Wire (hot, dimmed hot, neutral)
- Dimming performance highly dependent on dimmer compatibility with LED driver

Separate AC power and control signal

- Fluorescent 3-Wire
- 0-10V
- DALI
- DMX512
Some phase-cut LED dimming challenges

1) Increased \( I_{\text{RMS}} \) increases component stress

2) Low PWM duty cycle and/or frequency creates objectionable flicker

3) TRIAC current too low, and/or timing circuit unstable

4) Reduced \( V_{\text{RMS}} \) and/or conduction angle difficult to measure

5) No suitable path through LED source for dimmer standby current
Some examples of LED dimming performance

Dimming Behavior of Sample 0
Relative Spot Illuminance

Dimmer Position (% of Fully On)

Dimmer FULLY ON
DIMMER FULLY OFF

Dimming Behavior of Sample 07-09A
Relative Spot Illuminance

SSL, R30
9 W

Dimming Behavior of Sample 07-09A
Relative Efficacy

SSL, R30
9 W
LED lamp + Dimmer A

No dimmer

100% dimmer

~75% dimmer

~50% dimmer

~25% dimmer

~0% dimmer
LED lamp + Dimmer B

- No dimmer
- 100% dimmer
- ~75% dimmer
- ~50% dimmer
- ~25% dimmer
- ~0% dimmer
LED flicker key points

• Unprecedented types, levels of flicker can be found in current LED sources
  – Wide variation
  – Little can be assumed
  – Not all claims equal
  – Difficult to predict
• Currently no standard, suitable measurement procedure or metric for LED flicker
  – Magnetically-ballasted fluorescent sources typically have percent flicker < 40%, flicker index < 0.15
• Varying population susceptibility
• Varying risk levels for different lighting conditions
LED dimming key points

• Dimming LED products today in the real world is currently doable, but challenging
  – Particularly with phase-cut dimmers
  – Wide variation in compatibility and performance
  – Little can be assumed
  – Not all claims are equal
  – Difficult to predict
• Driver circuit design differences, trade-offs matter
• Dimmer circuit design differences, trade-offs matter
• LED driver PWM vs. CCR trade-offs may matter
  – Low frequency PWM results in increasing flicker as duty cycle is decreased
• Currently no standard measurement procedure or metric 
dimming performance, or dimming compatibility
• Dimming can induce or increase flicker
Recommendations

• Learn how to qualitatively identify presence of flicker
• Learn/use lighting design techniques to mitigate flickering sources
• Look for manufacturer dimming compatibility and performance tables
  – Min/max load, min/max dimmed level, flicker
  – Coming soon to DOE LED Lighting Facts

• Consider approaches which use separate AC power and control signal, if possible
• Try new LED source and LED-specific dimmers
• Mock up installations
  – All LED sources, all dimmers
  – All source combinations
  – Yes, this means full circuits
  – Beware LED source or dimmer substitutions, model updates (all bets are off)