Flicker measurement and metrics, and a call for standards

CORM

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What is flicker?

- Variation in time (modulation) of light output (luminous flux, luminance)
- Sensation: the detection of external conditions, which leads to a nervous system response
- Perception: the process by which the brain interprets sensory information, which results in visibility
- "Classical flicker": Light output modulation that is perceptible when the observer's eye, the light source, and objects are still
- Stroboscopic effect: Light output modulation made perceptible by the motion of objects
- Phantom array effect: Light output modulation made perceptible by the motion of the observer's eye

Why worry about flicker?

- Neurological problems, including epileptic seizure
- Headaches, fatigue, blurred vision, eyestrain
- Reduced visual task performance
- Apparent slowing or stopping of motion (stroboscopic effect)
- Distraction, objection

References

- http://grouper.ieee.org/groups/1789/
- Jennifer Veitch, National Research Council, Canada
- Arnold Wilkins, University of Essex
- Frances Wilkinson, York University
- Ingrid Vogels & Dragan Sekulovski, Philips Research
- John Bullough, Lighting Research Center

Roberts J.E. and Wilkins, A.J. (2013)

- Flicker can be perceived during saccades at frequencies in excess of 1kHz. Lighting Research and Technology, 45, 124-132.
  - Experiment 1: 400 saccades with 1, 2, 3 and 5 kHz flicker
  - Experiment 2: corroboration (of Experiment 1) using different apparatus
  - Experiment 3: 20° saccades with 1,2,3 and 5 kHz flicker
  - Experiment 4: modulation thresholds at 120Hz

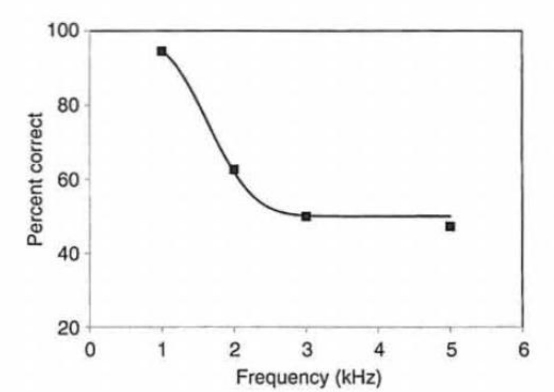


Figure 1 Experiment 1: Percentage of trials in which flicker was correctly detected, shown as a function of flicker frequency

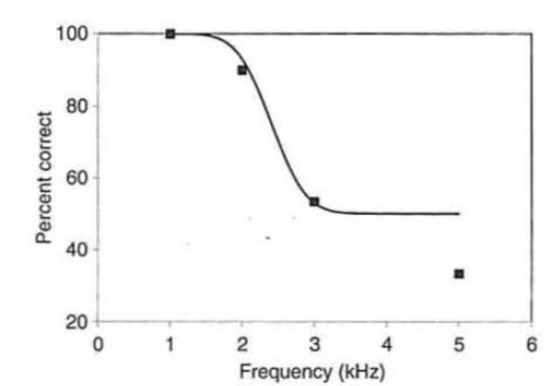


Figure 2 Experiment 3: Percentage of trials in which flicker was correctly detected, shown as a function of flicker frequency

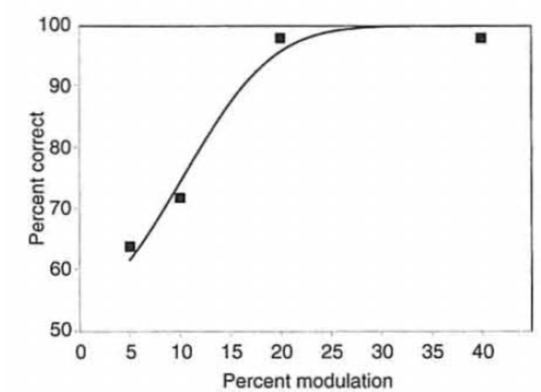


Figure 3 Experiment 4: Percentage of trials in which flicker at 120 Hz was correctly detected, shown as a function of the modulation of the flicker

http://www.essex.ac.uk/psychology/overlays/2013-207.pdf

Who cares about flicker?

- Anyone who is sensitive
- Anyone responsible for human health, well-being and/or performance in spaces with electric lighting
- At-risk populations for specific impairments
  - Photosensitive epileptics: 1 in 4000
  - Migraine sufferers
  - Not all at-risk populations identified
- General at-risk populations
  - Young people
  - Autistic people

What causes flicker?

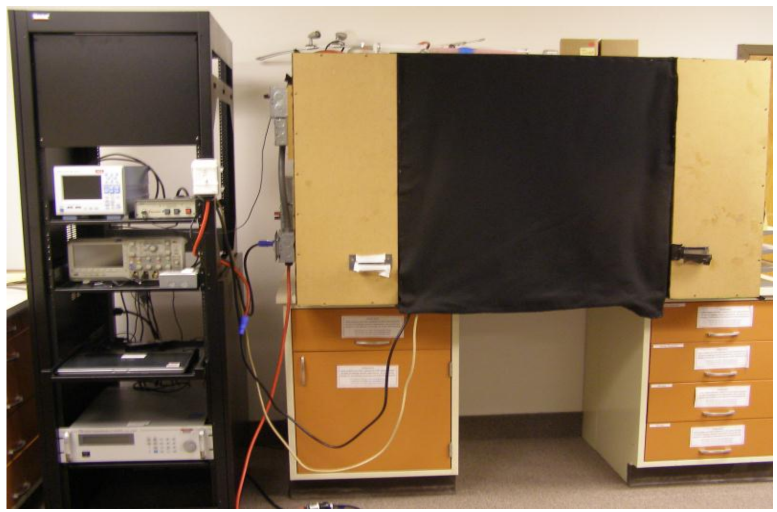
- Present in all traditional commercial electric light sources running on AC power
  - Including incandescent, halogen, fluorescent, metal-halide
  - Typically (but not always) periodic, and property of light source
  - Whether you are aware of it or not
- Not to be confused with electrical flicker
  - Noise on AC distribution line directly creates additional (light) modulation on resistive (incandescent) loads
  - Not a property of the light source
- Measurement and reporting is not a standard practice for commercially available light sources

PNNL photoelectric testing capability

- Light source
  - Controlled by switch (1 measurement)
  - Controlled by phase-control or other (e.g. 0-10V) control device (5 or 10 measurements)
  - Relative light output, efficacy
  - Input power, current
  - Flicker (flicker index, percent flicker)
  - Input power quality (power factor, THD-I)
- Phase-control device (if applicable)
  - Output voltage (Vrms, phase-angle)
  - Input power quality (power factor, THD-I)

PNNL photoelectric test setup

- Regulated power
- Fully automated measurement, data logging, data processing (per control point)



Identify Test Requirements

- Flicker and/or power quality
- Controlled by switch and/or dimmer
- Voltage

Setup test configuration

- Configure per test requirements
- Connect dimmer
- Install DUT

Initiate automated test sequence

- Log measured values
- Repeat for each (one to eleven) control setting

Automated graph and data file output

- Post-process data, as necessary
- Verify results

Prepare Test Report

PNNL photoelectric test setup

Yokogawa
WT500
Power meter

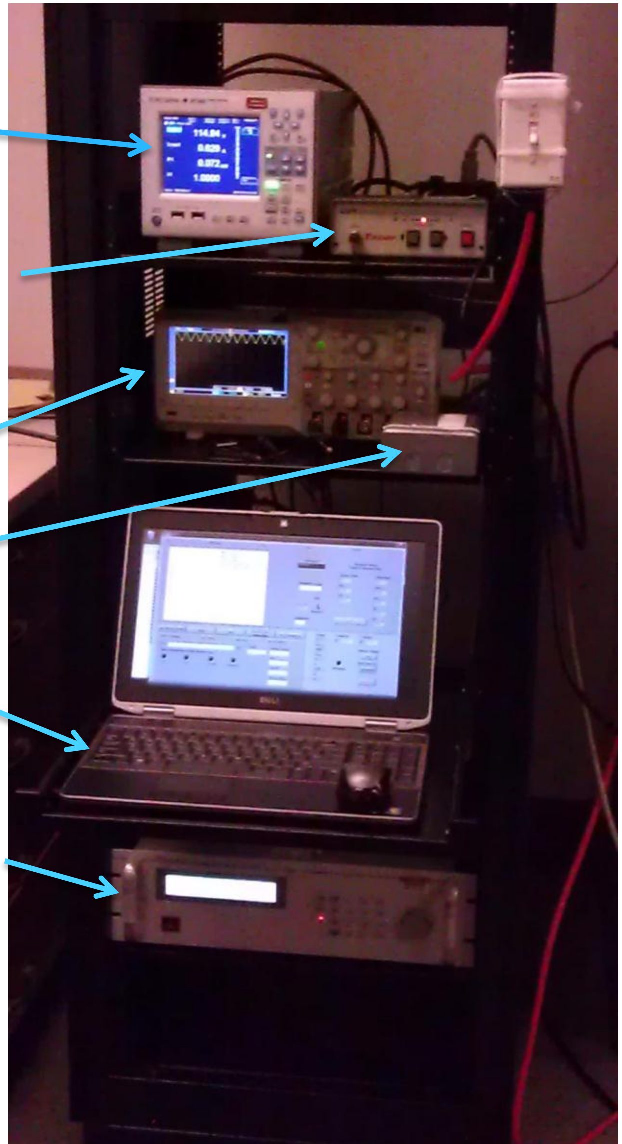
UDT TRAMP
transimpedance
amplifier

Tektronix
DPO 2014
digital
oscilloscope

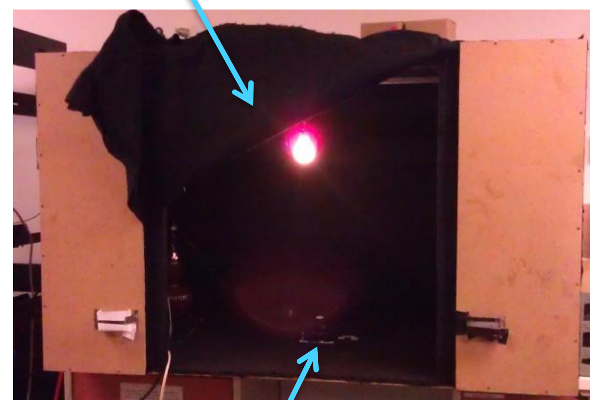
Dimmer

Computer
Running
LabVIEW

Chroma 61502
Power Supply



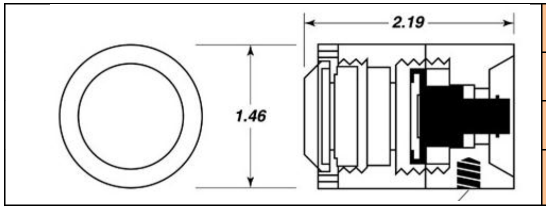
Test Chamber



UDT Model 211
illuminance sensor

PNNL photoelectric test setup

UDT Model 211
illuminance sensor



Photometric filter accuracy (%)	< 1.0
CIE Vλ function f_1' (%)	< 3.0
Dynamic range (lux)	10^{-2} to $5x10^{5}$
Typical (555nm) response (A/lux)	$3.2x10^{-9}$

UDT TRAMP
transimpedance
amplifier

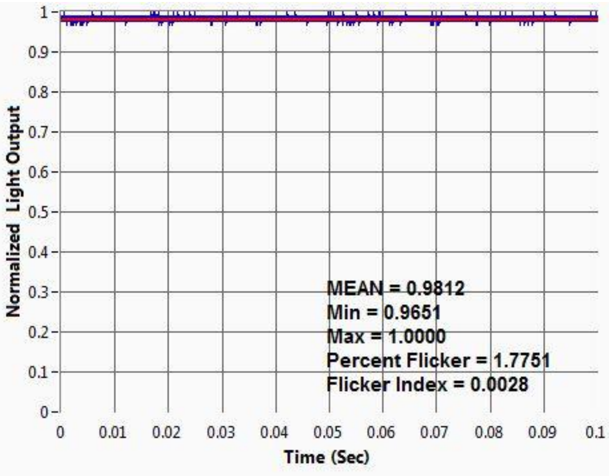
Gain (Volts/Amp)	10^{3}-10^{10}
Noise (mV RMS)	0.5
Current Range (Amps)	10^{-2}-10^{-13}
Overall Accuracy (%)	± 2
Typical Input Impedance (Ω)	0.001
Output Impedance (Ω)	< 1
Output Voltage Range (V)	± 5

Tektronix
DPO 2014
digital
oscilloscope

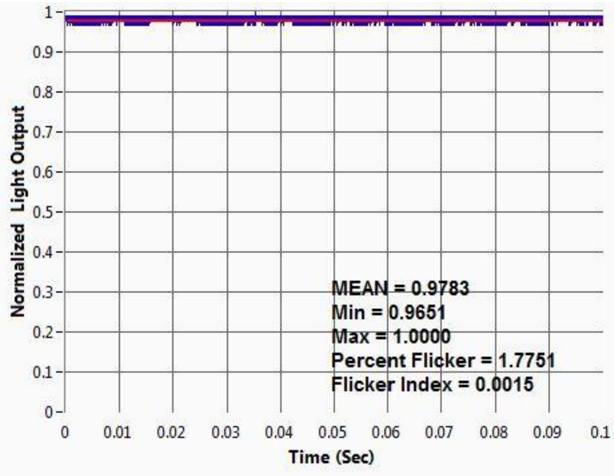
-3dB Analog Bandwidth (MHz)	100
Hardware Bandwidth (MHz)	20
Max. Sample Rate (GS/s)	1
Max Record Length (points)	1M
Input Impedance (kΩ)	101
Max. Input Voltage	±40

Flicker measurement example: integral lamp A

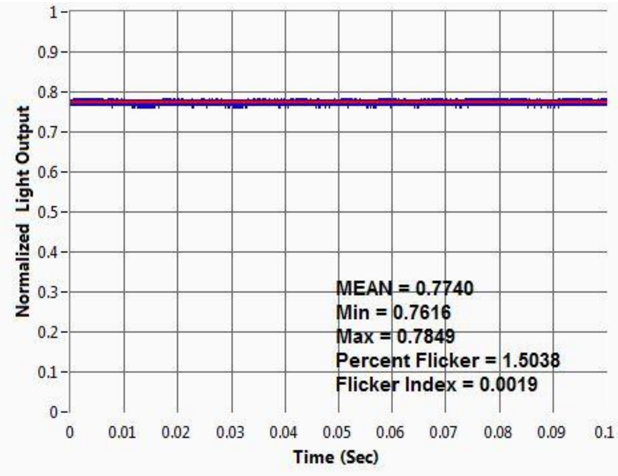
S01: V_{rms} load = 120 (on)



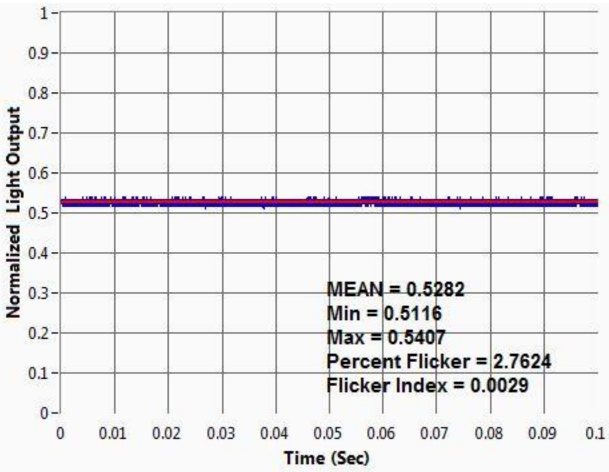
D22: V_{rms} load = 115 (max dim)



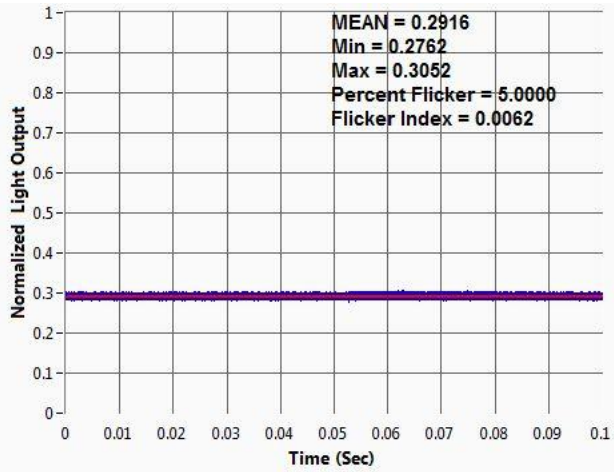
D22: V_{rms} load = 105



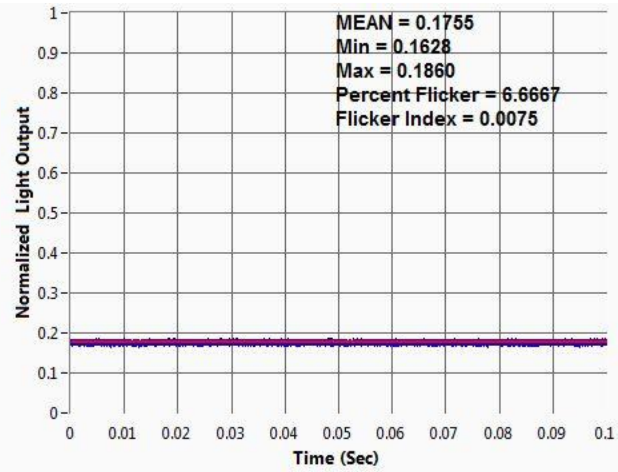
D22: V_{rms} load = 95



D22: V_{rms} load = 85

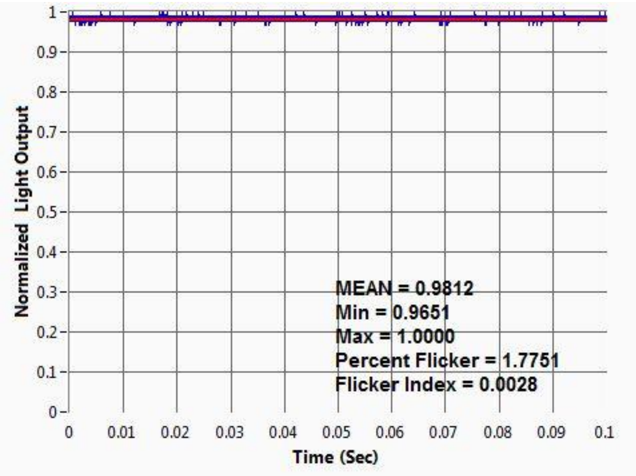


D22: V_{rms} load = 75

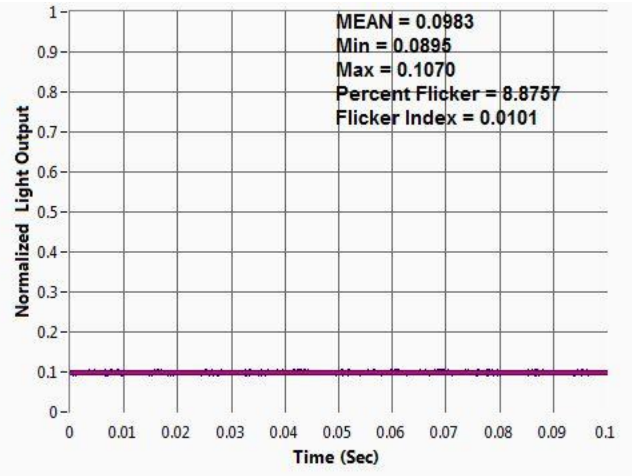


Flicker measurement example: integral lamp A

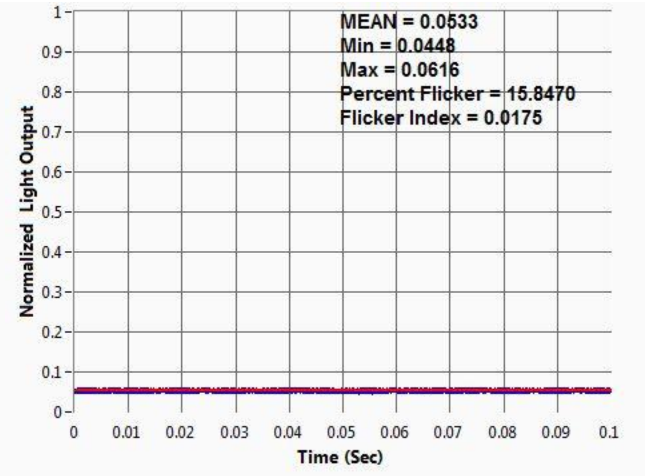
S01: V_{rms} load = 120 (on)



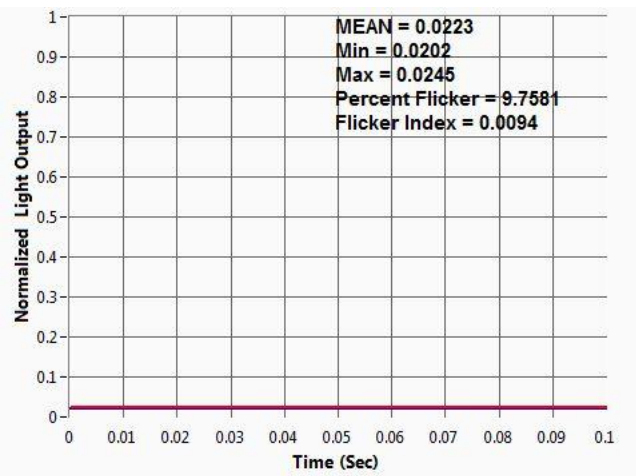
D22: V_{rms} load = 65



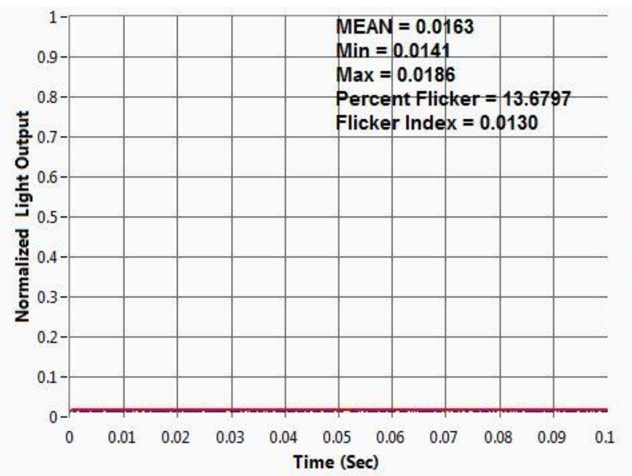
D22: V_{rms} load = 55



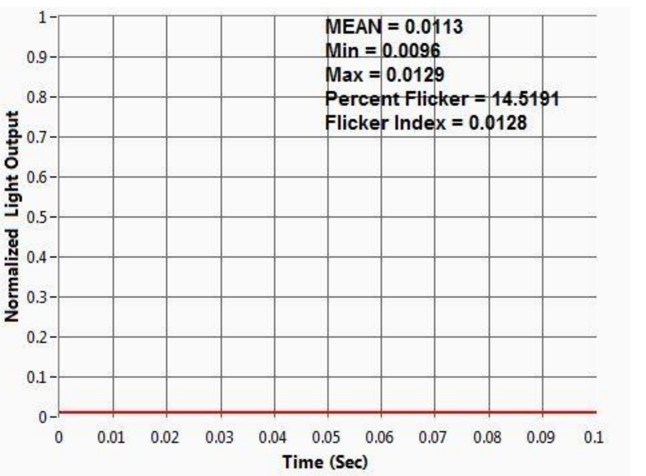
D22: V_{rms} load = 45



D22: V_{rms} load = 35

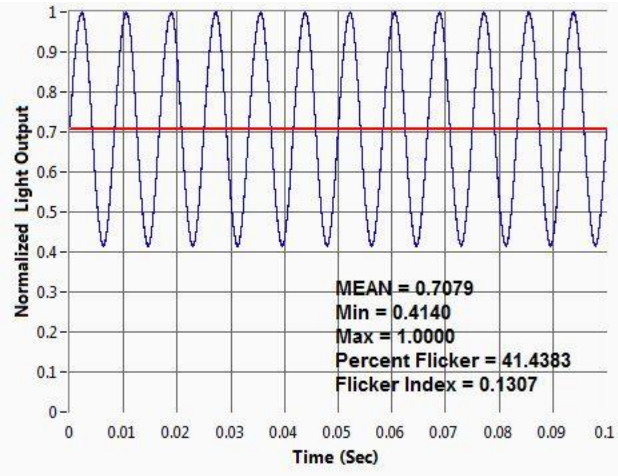


D22: V_{rms} load = 30 (min dim)

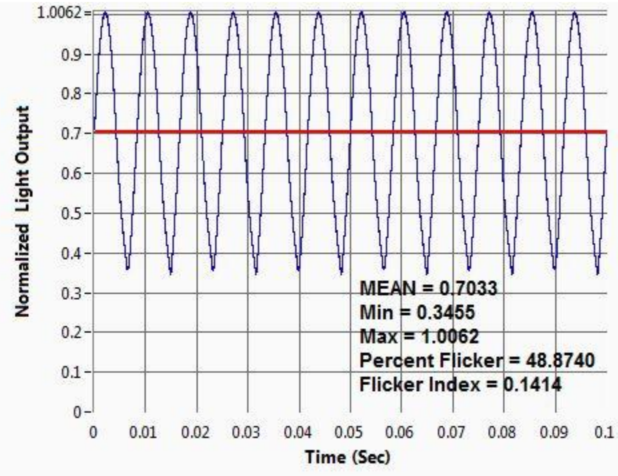


Flicker measurement example: integral lamp B

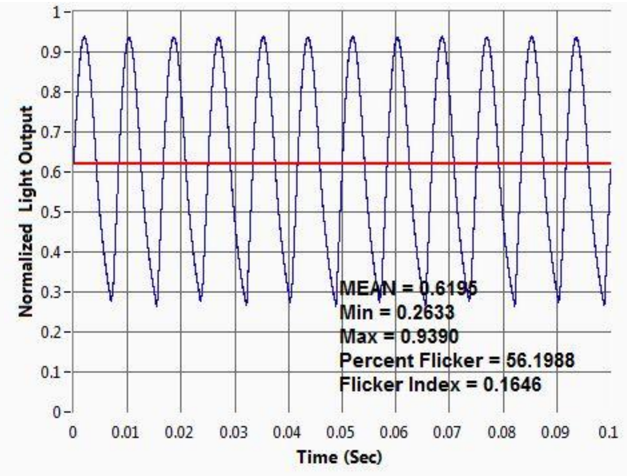
S01: V_{rms} load = 120 (on)



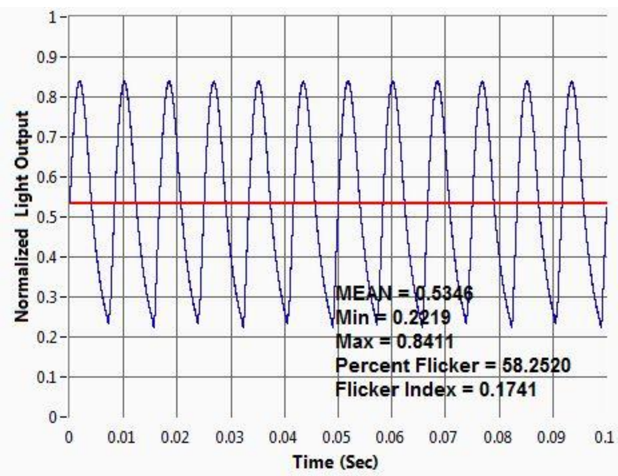
D22: V_{rms} load = 115 (max dim)



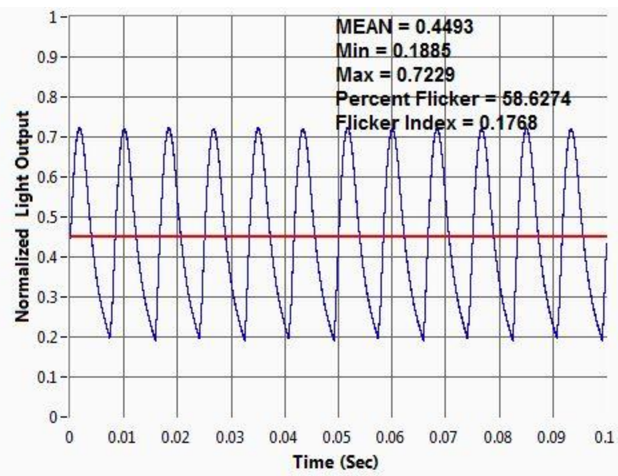
D22: V_{rms} load = 105



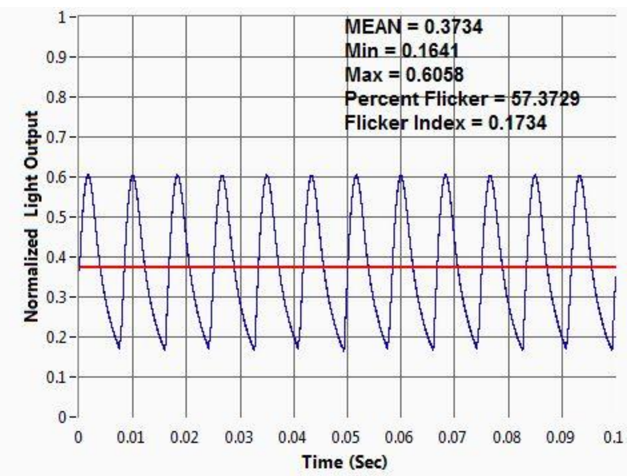
D22: V_{rms} load = 95



D22: V_{rms} load = 85

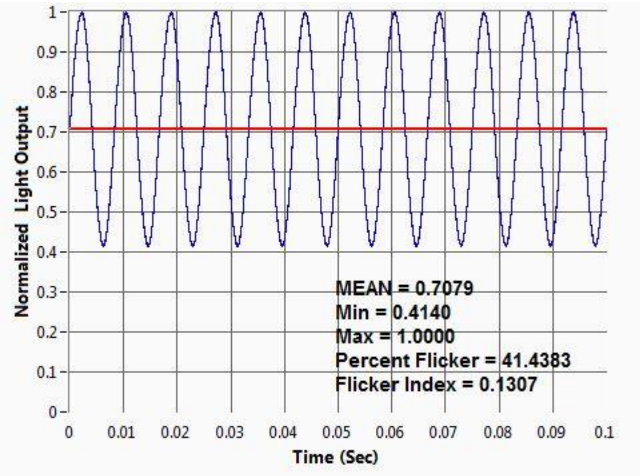


D22: V_{rms} load = 75



Flicker measurement example: integral lamp B

S01: V_{rms} load = 120 (on)



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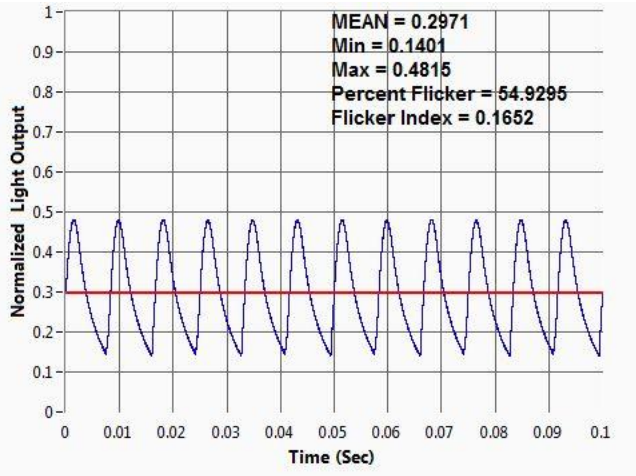
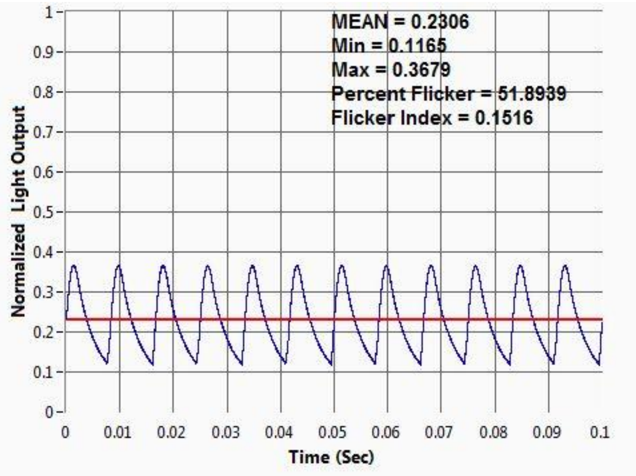
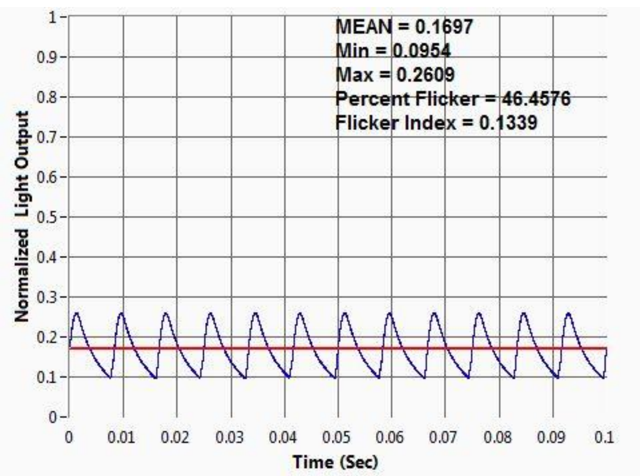


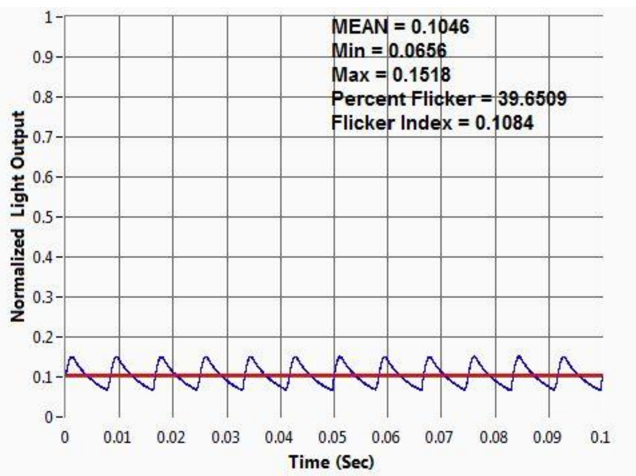
D22: V_{rms} load = 55



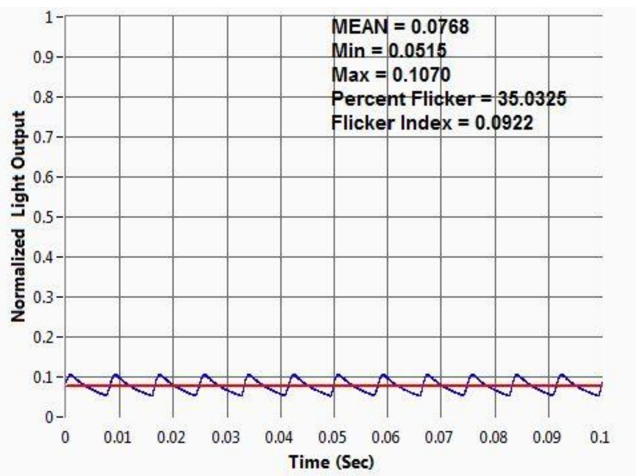
D22: V_{rms} load = 45



D22: V_{rms} load = 35

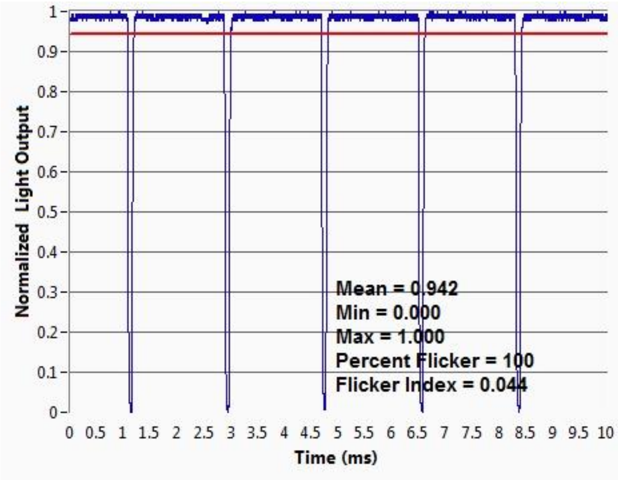


D22: V_{rms} load = 30 (min dim)

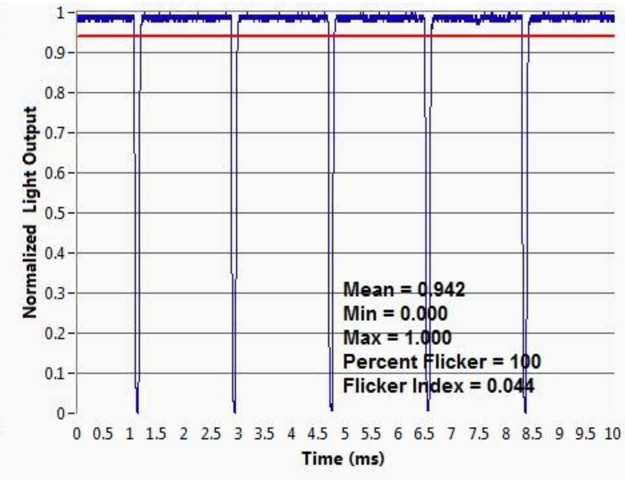


Flicker measurement example: Downlight

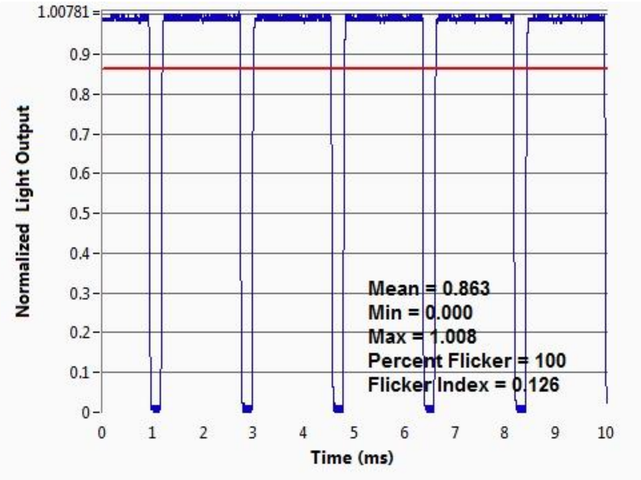
S01: V_{rms} load = 120 (on)



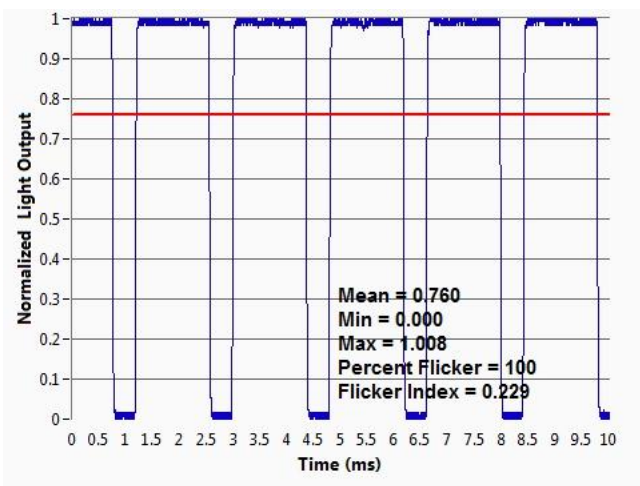
D22: V_{rms} load = 115 (max dim)



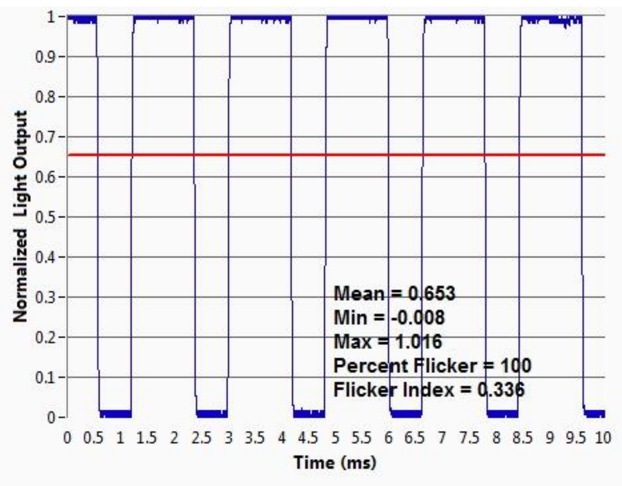
D22: V_{rms} load = 105



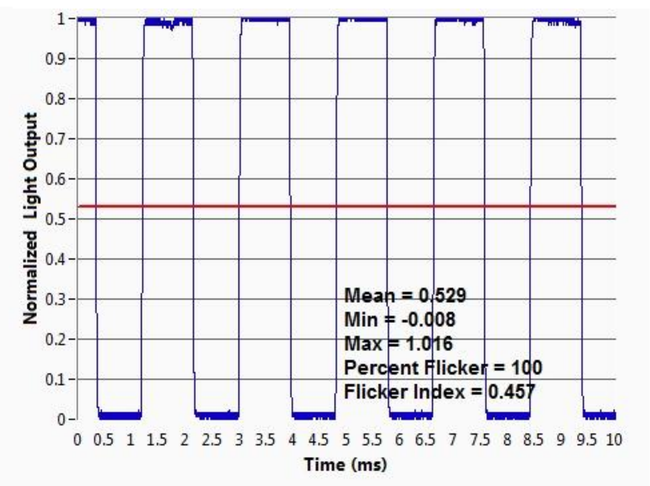
D22: V_{rms} load = 95



D22: V_{rms} load = 85

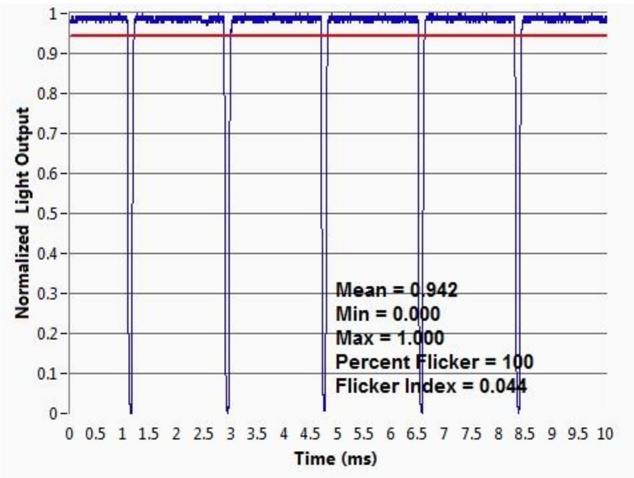


D22: V_{rms} load = 75

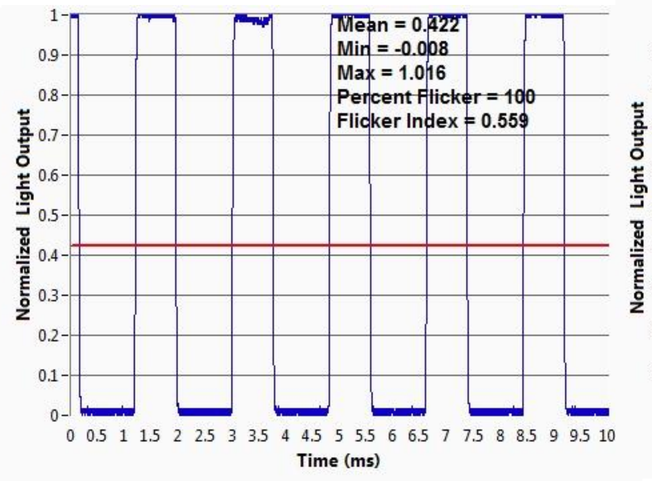


Flicker measurement example: Downlight

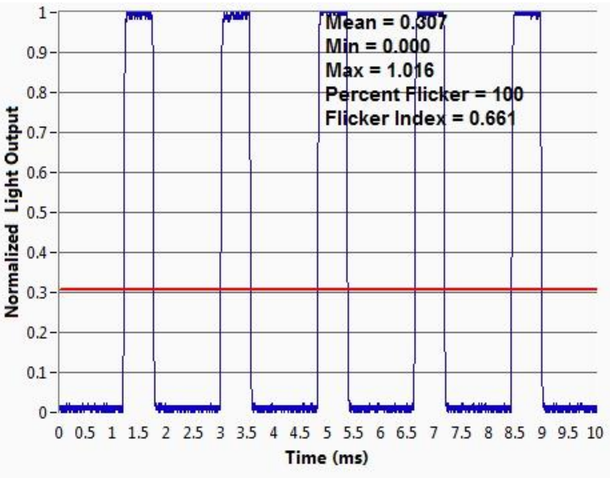
S01: V_{rms} load = 120 (on)



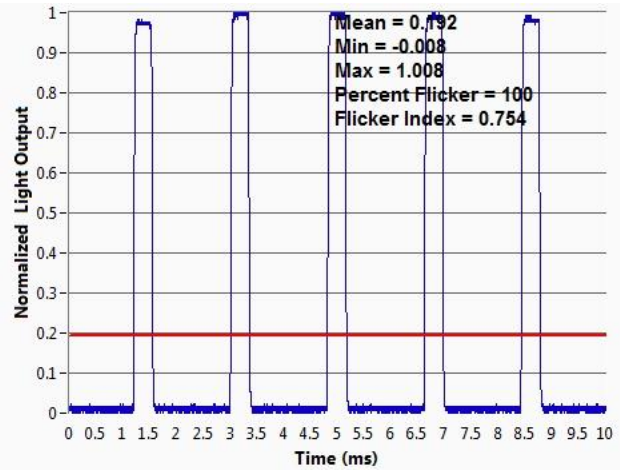
D22: V_{rms} load = 65



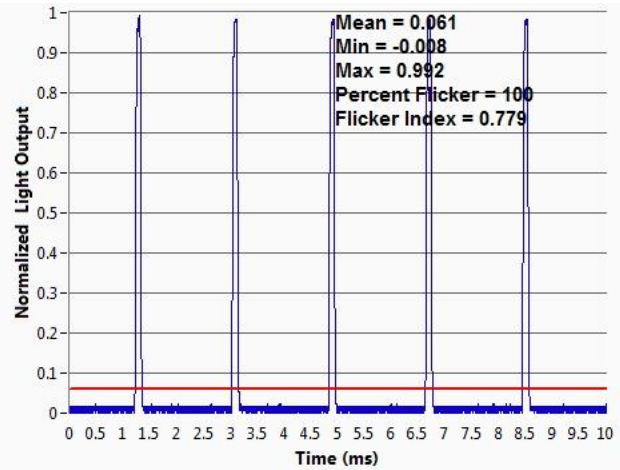
D22: V_{rms} load = 55



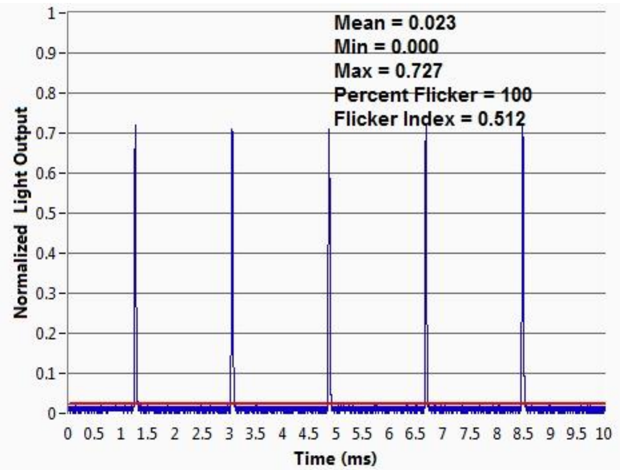
D22: V_{rms} load = 45



D22: V_{rms} load = 35



D22: V_{rms} load = 30 (min dim)

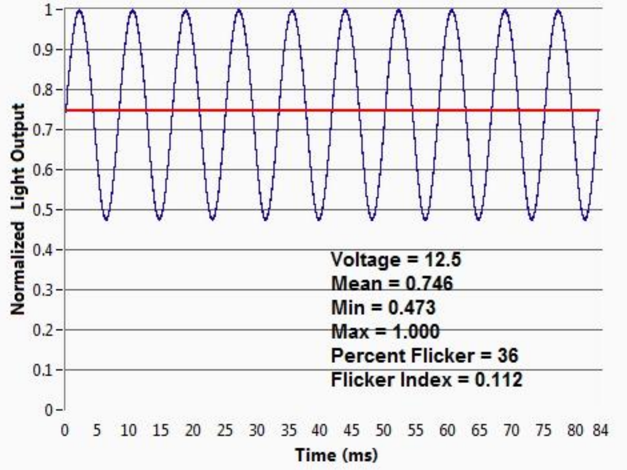


Photoelectric measurement example: troffer

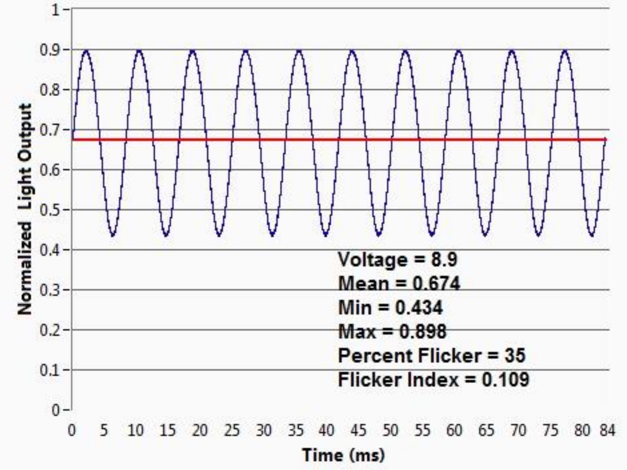
		Catalog Number: ########## Ballast/Driver: Integral Transformer: N/A Dimmable? ☑Yes ☐No Recommended dimmers? ☐Yes ☑No
Full Output Characteristics	Measured (Switch)	Measurement Date: March 21, 2014 Measurement Operator: ##### ##########
Power (watts) Power Factor THD-I (fund) Percent Flicker Flicker Index	40.47 0.98 14.14% 35.8% 0.112	Input Voltage (Range): ☐Vrms ☐V_{DC} Operating Input Voltage During Test: 120 ☑Vrms ☐V_{DC} ☑Switch: S1 ☑Dimmer: D23 Number of dimmed points: ☐0 ☐5 ☑10 Dimming Curve: ☐100%→0% ☑0%→100% ☐N/A
Special Request(s): N/A		
Approved by: ##### ##########		

Photoelectric measurement example: troffer

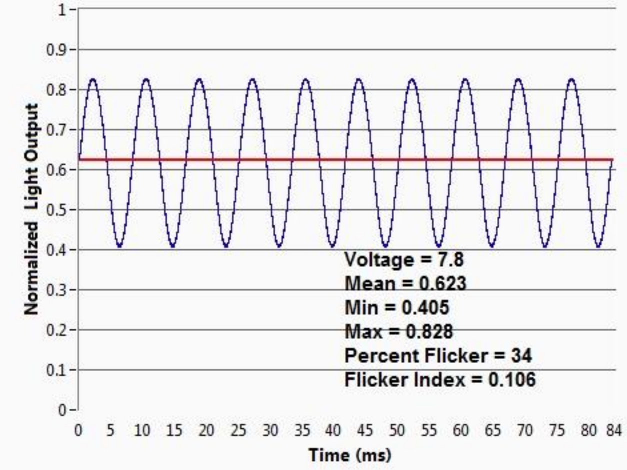
S1: V_{rms} load = 120 (on)



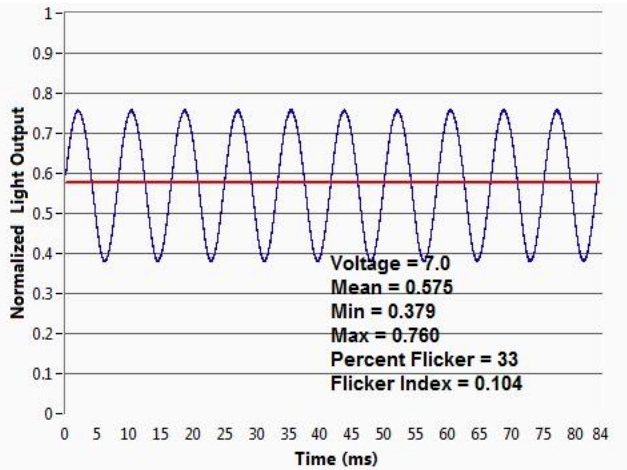
D23: Dimmed level 10 (max)



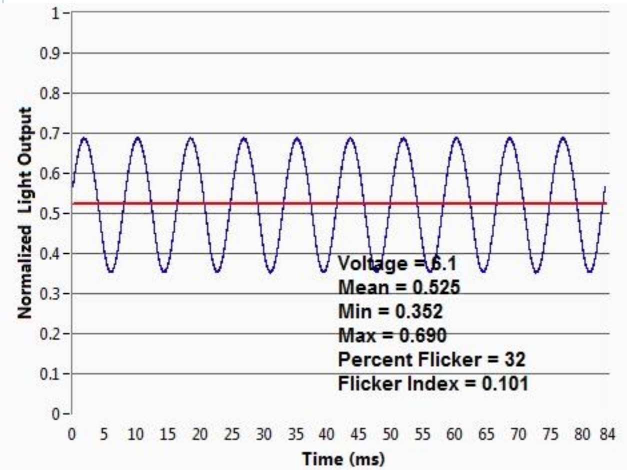
D23: Dimmed level 9



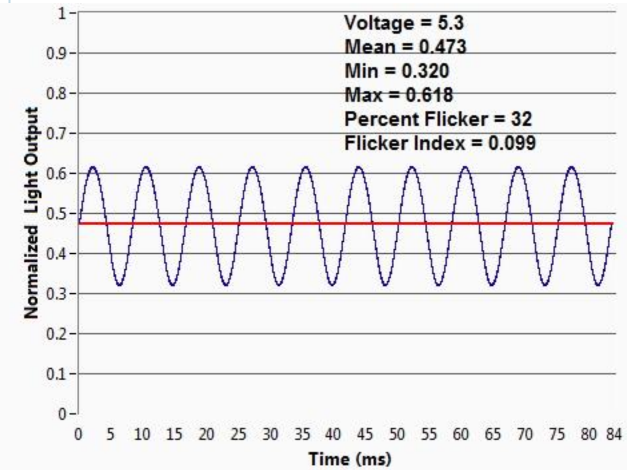
D23: Dimmed level 8



D23: Dimmed level 7

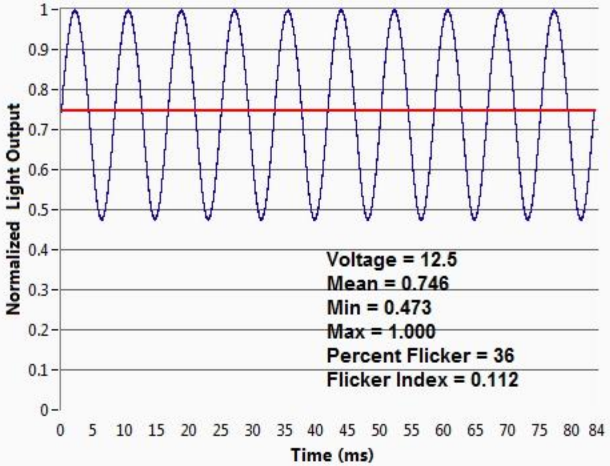


D23: Dimmed level 6

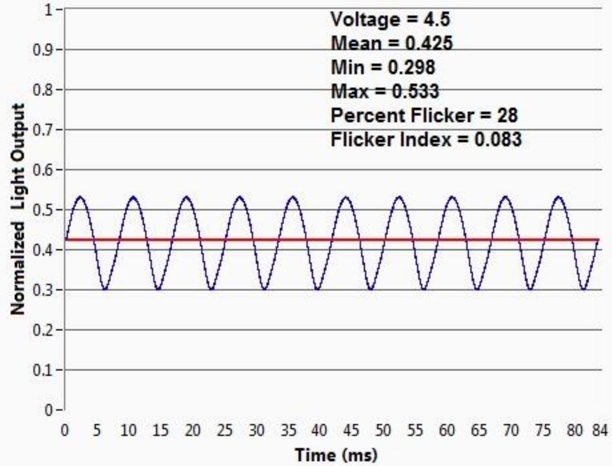


Photoelectric measurement example: troffer

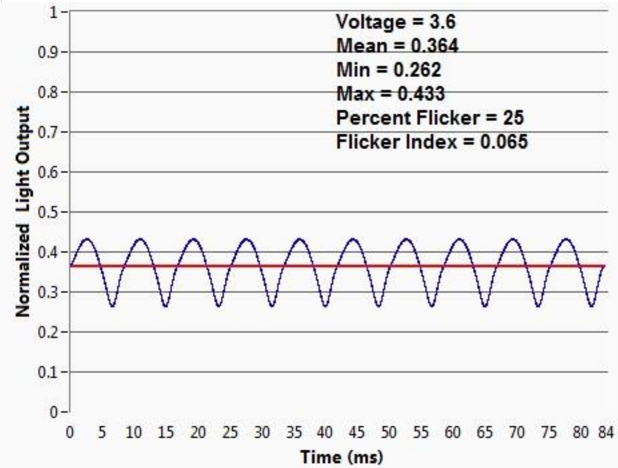
S1: V_{rms} load = 120 (on)



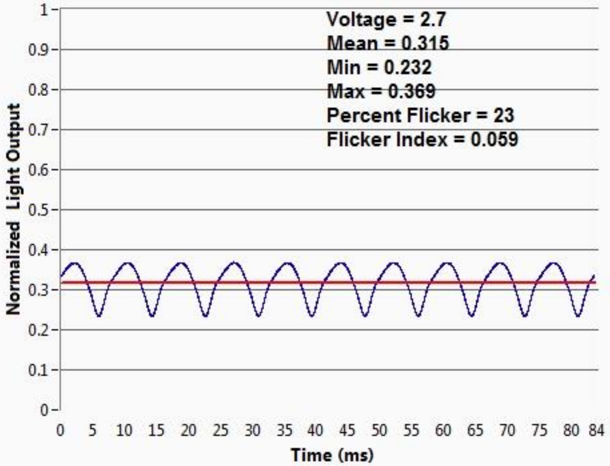
D23: Dimmed level 5



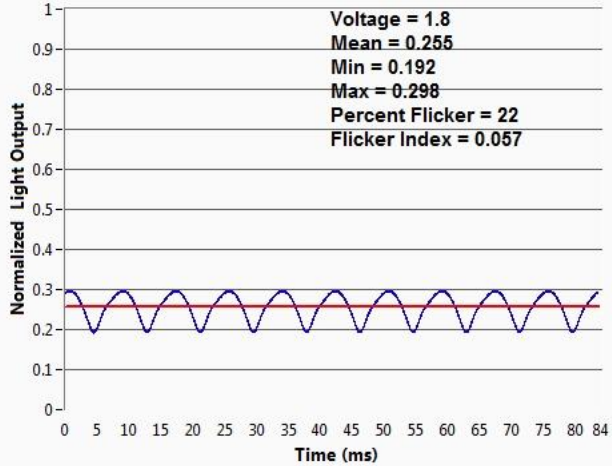
D23: Dimmed level 4



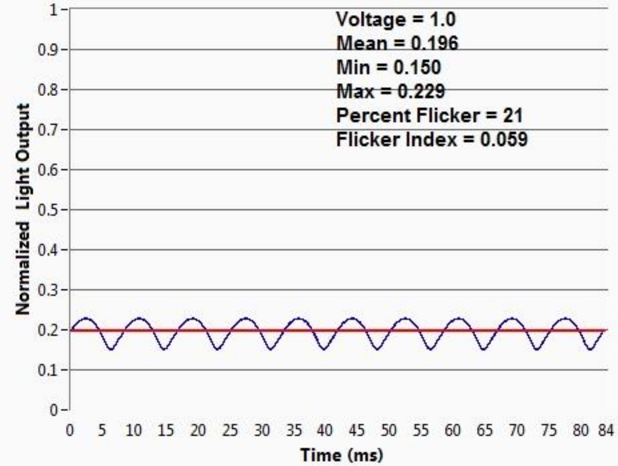
D23: Dimmed level 3



D23: Dimmed level 2

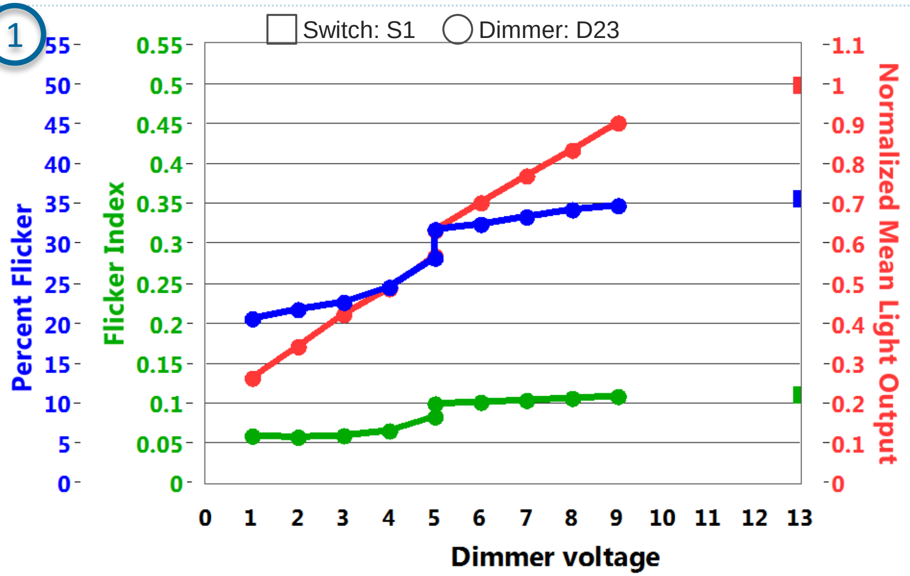


D23: Dimmed level 1 (min)



Photoelectric measurement example: troffer

1



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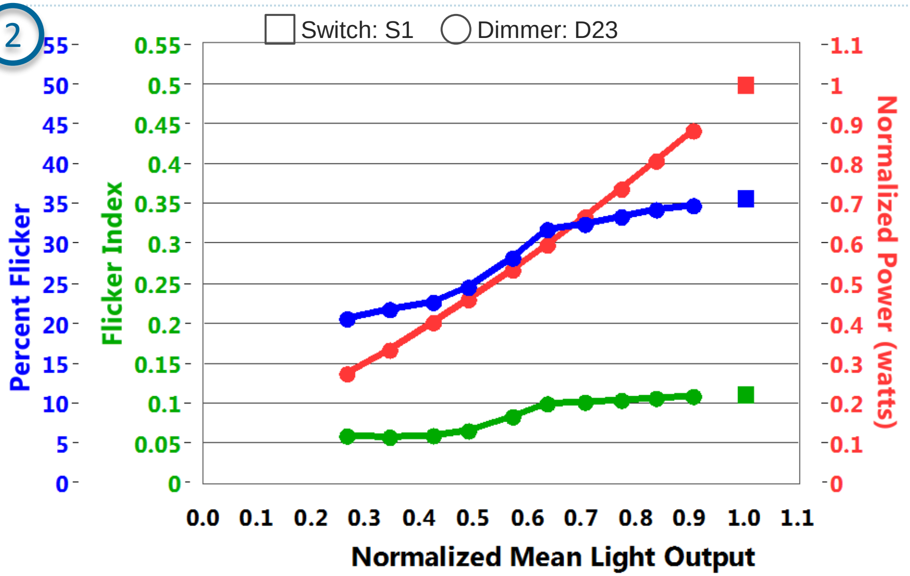

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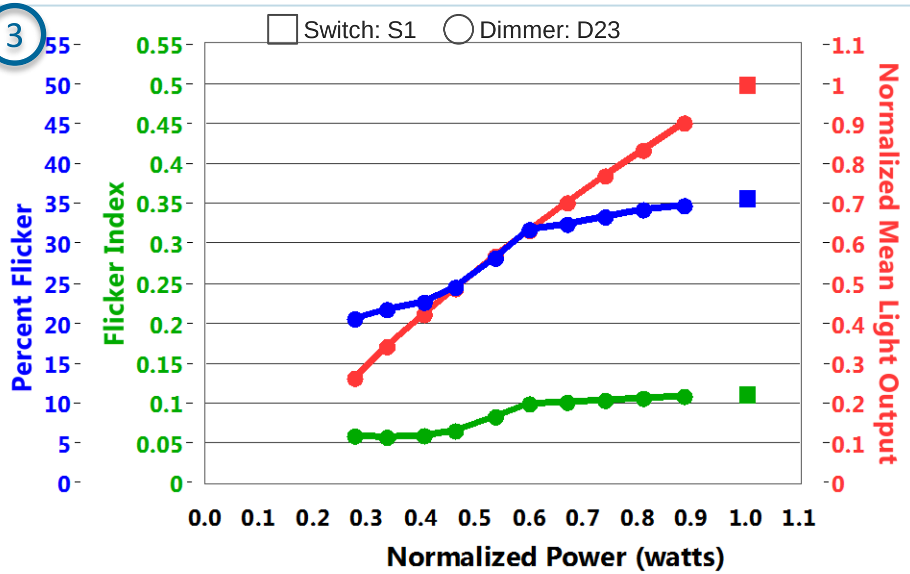
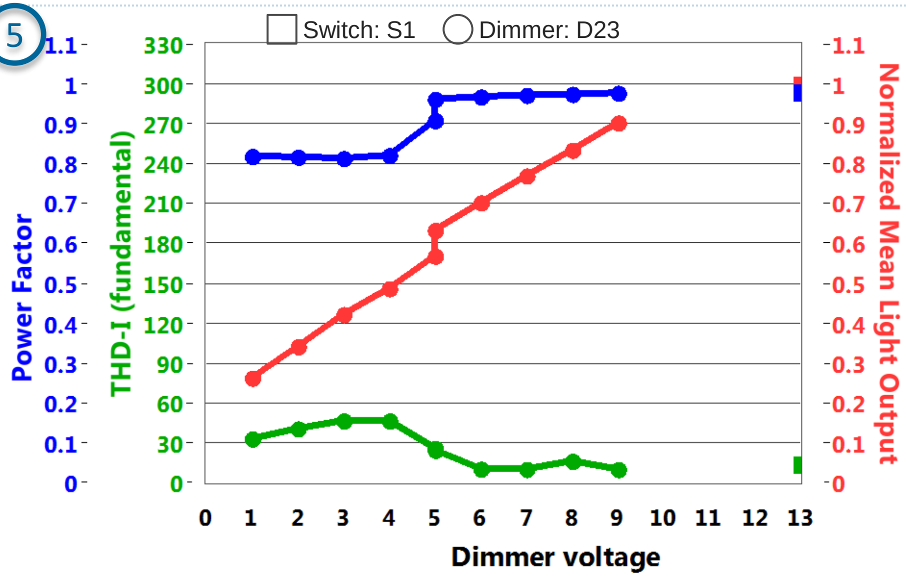


4

Notes

Photoelectric measurement example: troffer

5



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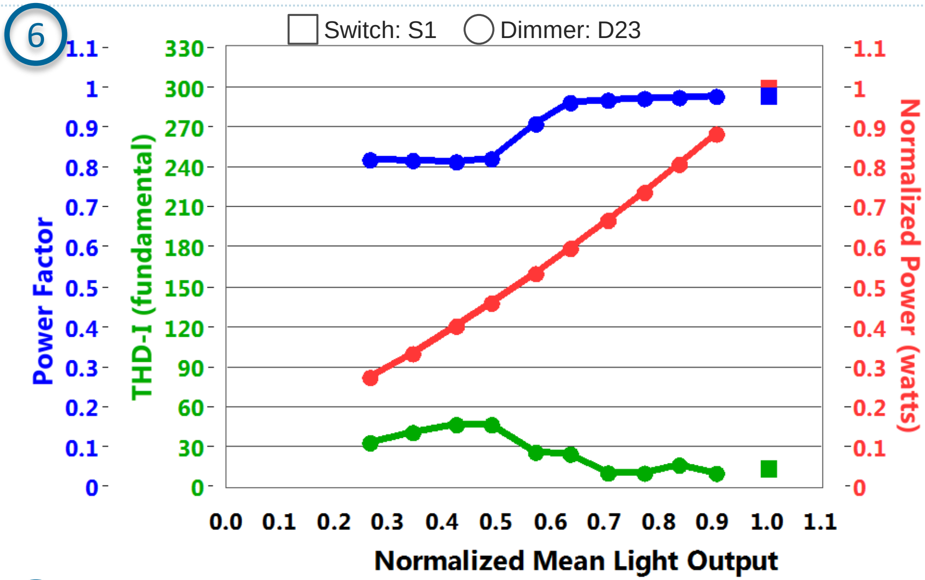

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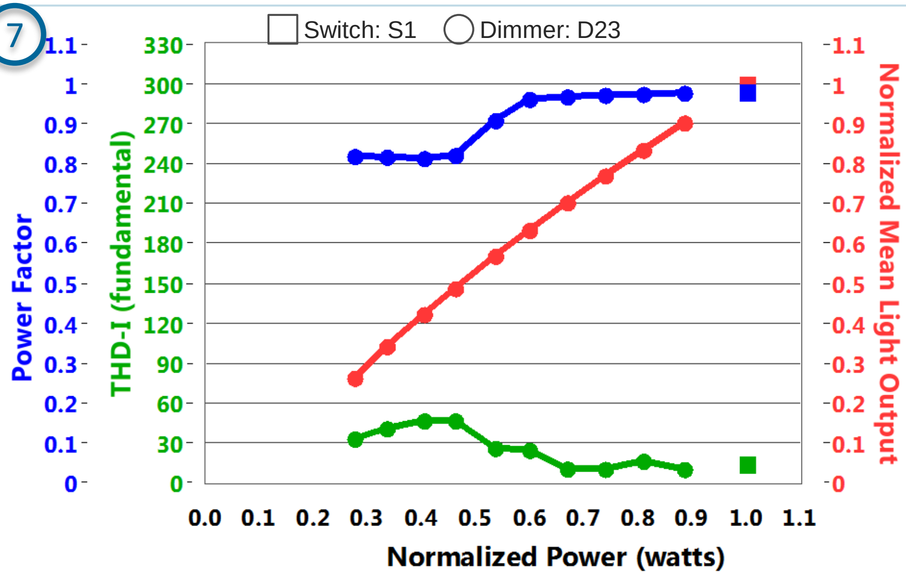

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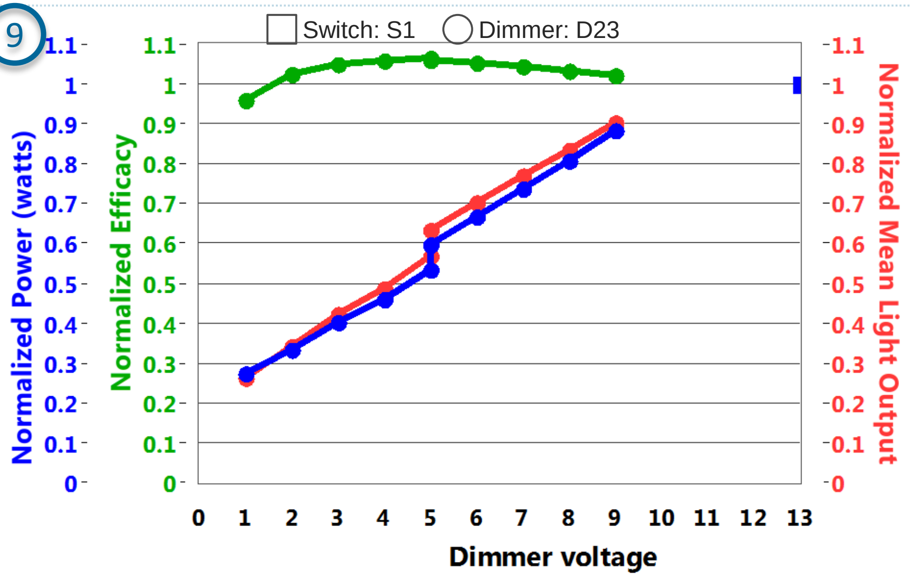
Notes

Photoelectric measurement example: troffer

9



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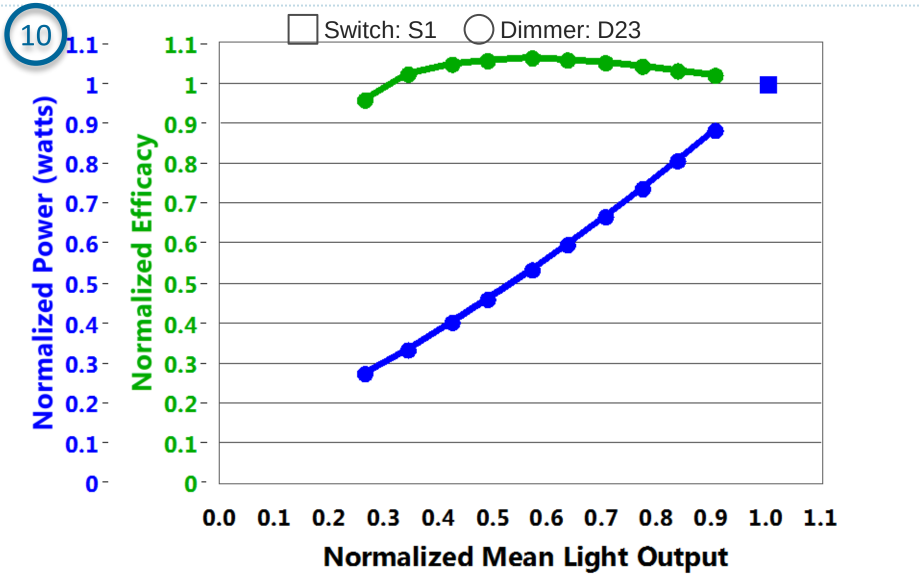

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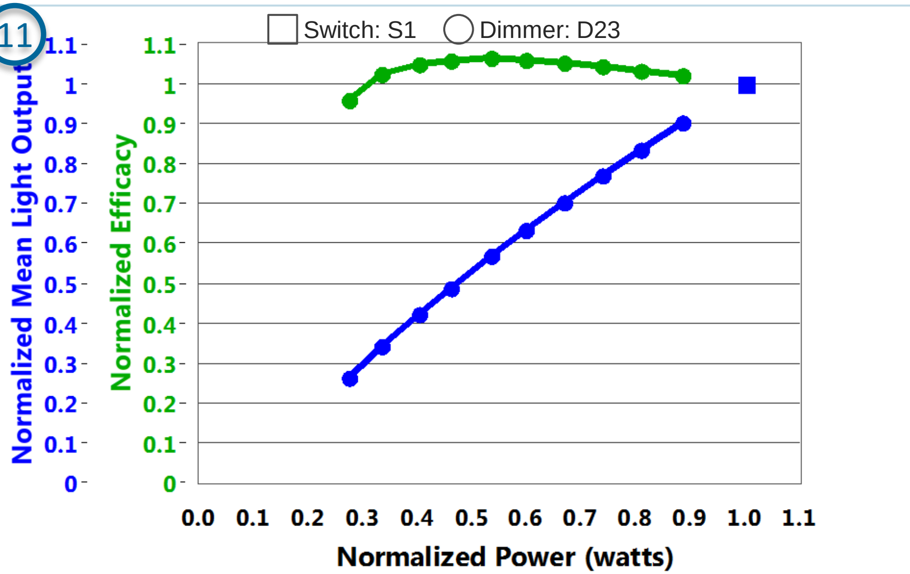


12

Notes

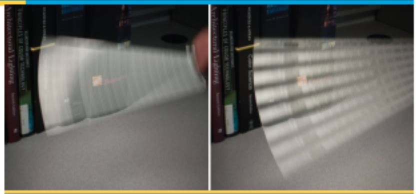
Flicker fact sheet

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Office
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

Flicker

The advancement of commercially available LED products is reopening discussions on how the performance of light sources should be evaluated. This includes questions about the necessity of characterizing light sources for flicker, the (potentially visible) temporal variation of emitted light. While conventional light sources operating on alternating current (AC) modulate light output, the variety and severity of modulation seen with LED products—from good to poor—has sparked new interest in quantifying and understanding its impact.



The stroboscopic effect is just one of many potential consequences of flicker. The lamp used for the image on the left does not flicker and thus the moving object is a smooth blur. Because it does flicker, the lamp used for the image on the right appears to create multiple instances of a moving object.

Introduction

All conventional light sources—including incandescent, high intensity discharge (HID), and fluorescent—modulate luminous flux and intensity, whether perceptible or not. Many terms are used when referring to this time-variation, including flicker, flutter, and shimmer. The flicker produced by electric light sources can be a function of how it converts AC electricity to light, or the result of noise or transient events on AC distribution lines. Electrical flicker should not be confused with photometric flicker, which is modulation that is characteristic of the light source itself, rather than disturbances to its electrical input. Light source characteristics that can affect photometric flicker vary by technology; examples include filament thickness for incandescent, phosphor persistence for fluorescent and coated metal halide, and circuit designs for electronically ballasted or driven sources.

LED flicker characteristics are primarily a function of the LED driver. Different circuit architectures present different sets of performance trade-offs for a driver designer, with cost and form factor restrictions further limiting the choices available. For example, a low cost requirement for a small integral lamp may force a fundamental trade-off between flicker and power factor. Dimming an LED source can increase or induce flicker, most notably when phase-cut controls are used and/or pulse-width modulation (PWM) is employed within the driver to reduce the average light output from the LED source.

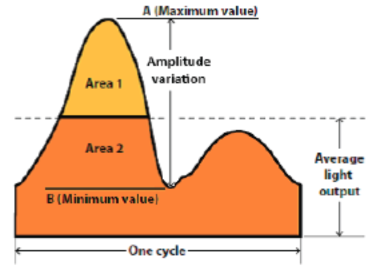
Why Flicker Matters

Photometric flicker from magnetically-ballasted fluorescent, metal halide, and high-pressure sodium lamps has been a concern of the lighting community because of its potential human impacts, which range from distraction or mild annoyance to neurological problems. The effects of flicker are dependent on the light modulation characteristics of the given source, the ambient light conditions, the sensitivity of the individuals using the space, and the tasks performed. Low-frequency flicker can induce seizures in people with photosensitive epilepsy, and the flicker in magnetically-ballasted fluorescent lamps used for office lighting has been linked to headaches, fatigue, blurred vision, eyestrain, and reduced visual task performance for certain populations. Flicker can also produce hazardous phantom array effects—which may lead to distraction when driving at night, for example—or stroboscopic effects, which may result in the apparent slowing or stopping of moving machinery in an industrial setting.

When discussing the potential human impacts of flicker, it is important to understand the difference between sensation and perception. Sensation is the physiological detection of external conditions that can lead to a nervous system response, while perception is the process by which the brain interprets sensory information. Some sensory information is not perceived, and some perceptions do not accurately reflect the external conditions. As a result, some people who suffer from flicker sensitivity may not be aware that flicker is the reason they are suffering, or even that the light source responsible for their suffering is flickering. Furthermore, not all human observers are equally sensitive to the potential effects of flicker. Populations that tend to be more susceptible to the effects of flicker include children, people with autism, and migraineurs. While the sizes of some specific at-risk populations have been characterized—approximately 1 in 4,000 humans suffer from photosensitive epilepsy, for example—most have not.

Quantifying Flicker

The photometric flicker found in electric light sources is typically periodic, with its waveforms characterized by variations in amplitude, average level, periodic frequency (cycles per unit time), shape, and, in some cases, duty cycle. Percent Flicker and Flicker Index are metrics historically used to quantify flicker. Percent Flicker is better known and easier to calculate, but Flicker Index has the advantage of being able to account for differences in waveform shape (or duty cycle, for square waveforms). Both metrics account for amplitude variation and average level, but since both are based on the analysis of a single waveform period, neither is able to account for differences in periodic frequency. An example of a periodic waveform is shown in Figure 1, along with equations for both flicker metrics.



$$\text{Percent Flicker} = 100\% \times \frac{A-B}{A+B} \qquad \text{Flicker Index} = \frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}}$$

Figure 1. Periodic waveform characteristics used in the calculation of flicker metrics. *Modified from IES Lighting Handbook, 10th Edition.*

Measuring and reporting flicker is not a standard practice for commercial light sources. Although industry bodies have developed flicker metrics, they have not produced complementary standardized measurement procedures to ensure appropriate comparisons of reported values. Conventional lighting technologies exhibit little variation in flicker for a given source type; for example, all incandescent A19 lamps behave similarly. However, the type of ballast has a substantial affect, although just knowing whether it is magnetic or electronic has usually been sufficient for flicker characterization. As a result, there has historically been little need for measuring and reporting the flicker performance of a specific product.

Flicker in Commercially Available Light Sources

Evaluating the performance of any new technology should start with an understanding of how the incumbents perform. Figure 2 illustrates the luminous flux variation over time and flicker metrics (Percent Flicker and Flicker Index) of six conventional lamps, including incandescent, electronically ballasted metal halide, and both magnetically and electronically ballasted fluorescent products, as measured by the DOE CALiPER program. For conventional sources (including magnetically ballasted fluorescent), the maximum Percent Flicker is on the order of 40% and the maximum Flicker Index is roughly 0.15.

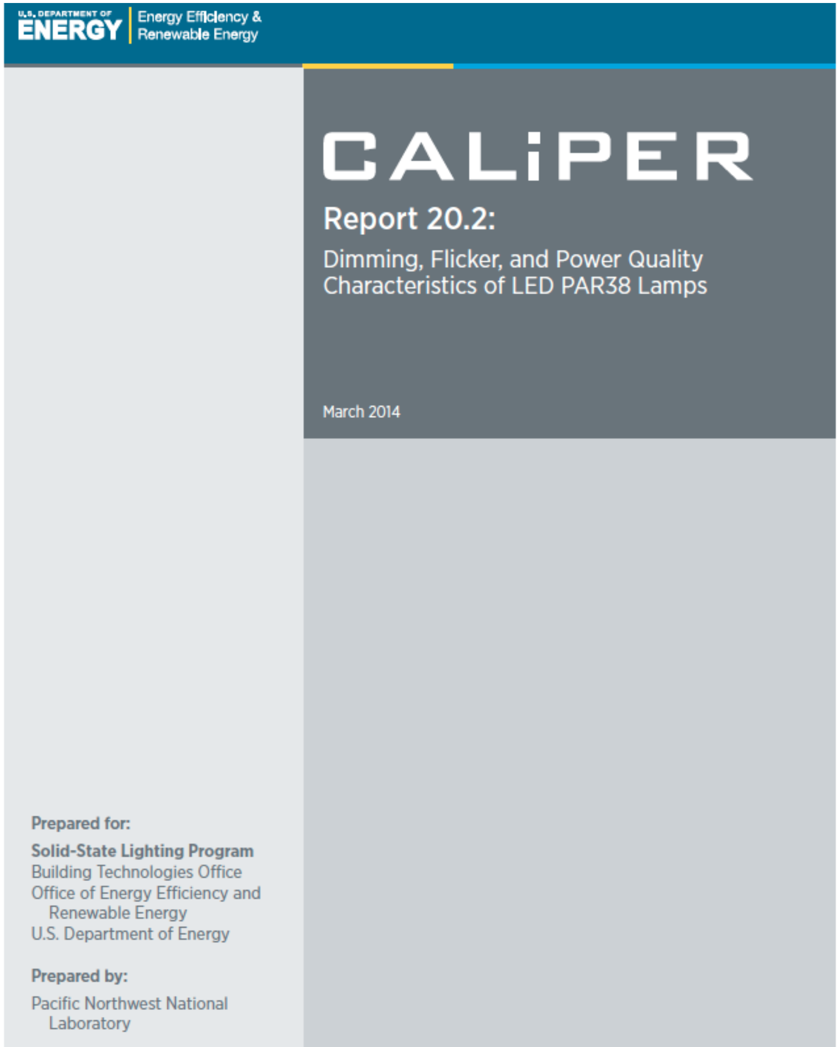
LED products, by contrast, exhibit a wide variation in characteristics, as shown in Figure 3. These examples were chosen to demonstrate—to some degree—the extent of variation seen in commercially available products, and do not represent a statistical sample of all products on the market or even all products measured by DOE. Note that LED sources exhibit variation across all the flicker waveform attributes, exceeding the ranges exhibited by conventional lighting. Some LED sources produce little to no discernible flicker, while others exhibit large variation in amplitude (as evidenced by waveforms with a Percent Flicker value of 100%) and shape. Perhaps most significantly, some of the periodic frequencies measured by CALiPER are not seen in typical conventional sources, and flicker characteristics do not appear to correlate well with any LED source characteristics (e.g., product type, driver type, or input power). Flicker frequency is not captured by the existing flicker metrics, even though flicker may be less noticeable when the modulation is at a higher frequency.

Recommendations

Flicker can be a significant detriment to lighting quality, but it is rarely considered in the design or specification process. The flicker characteristics seen in some products pose a concern for anyone responsible for human health, well-being, or performance in spaces with electric lighting. Standardized flicker measurement procedures are not yet in place, and existing flicker metrics have inadequacies that may be exposed by LED products. Further, there are no well-defined thresholds that would enable those metrics to be used to identify problematic flicker for specific applications or populations. Nevertheless, flicker metrics can be a first step to compare two sources—lower values are better. If flicker waveforms are available, the specifier can identify better products by looking for less amplitude modulation, a higher average level (relative to the maximum and minimum values), and a higher periodic frequency.

In the absence of flicker metrics and waveforms, specifiers can pursue qualitative means for evaluating flicker. Specifiers should consider how the risk of flicker-related problems is heightened or reduced by a given light source, the type of space, its occupants, and the tasks being performed. LED systems should always be visually evaluated, ideally with flicker-sensitive clients. Waving a finger or pencil rapidly under the LED source, or spinning a flicker wheel, can expose the presence of flicker through the stroboscopic effect, even for those who are not naturally sensitive. Low flicker sources should always be used for both ambient lighting and task lighting in offices, classrooms, laboratories, corridors, and industrial spaces. Minimizing flicker is especially important where susceptible populations spend considerable time, such as hospitals, clinics, medical offices, classrooms, and daycare centers. In contrast, flicker may be less of a concern for parking lots, roadways, or other exterior lighting where light levels are lower and people spend less time. Indoors, sources with more flicker may be acceptable when used for accent lighting of objects, or when mixed with low-flicker lighting systems or daylight. A number of task dependent factors can be considered when evaluating flicker risks, including the duration of direct exposure (longer is worse), the retinal area being stimulated (greater is worse), the contrast with surround luminance (more

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/flicker_fact-sheet.pdf


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

CALiPER

Report 20.2:

Dimming, Flicker, and Power Quality Characteristics of LED PAR38 Lamps

March 2014

Prepared for:

Solid-State Lighting Program
Building Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by:

Pacific Northwest National Laboratory

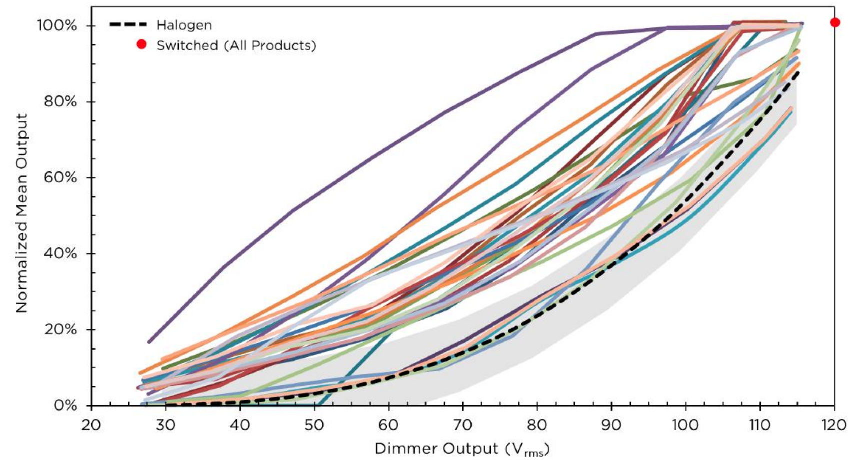


Figure 2. Dimming curves for 31 of the 33 dimmable LED lamps, and the average of the six halogen benchmarks. The curves for the two AC LED products are not shown—due to interactions between the lamp and dimmer, the nominal voltage targets were not achieved. The region shaded gray shows a ±10% tolerance for the halogen output.

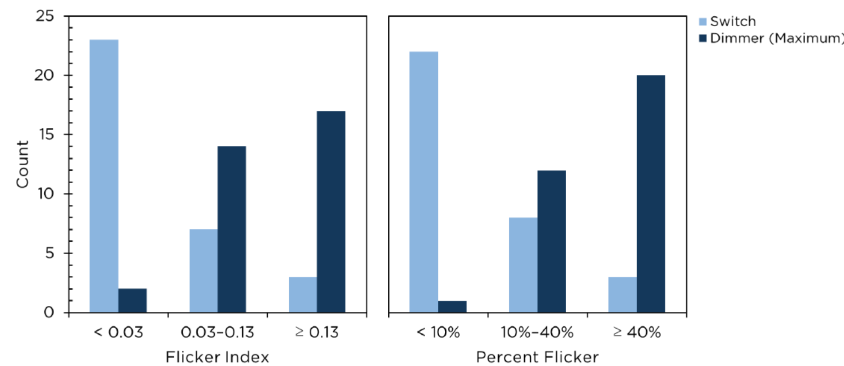


Figure 4. Histograms of Flicker Index (left) and Percent Flicker (right) for the 33 dimmable LED products tested. The values for the dimmer are the highest recorded over the dimming range. Comparing the dimmer values to the switch values shows that flicker becomes more prevalent when an LED lamp is dimmed.

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_20-2_par38.pdf

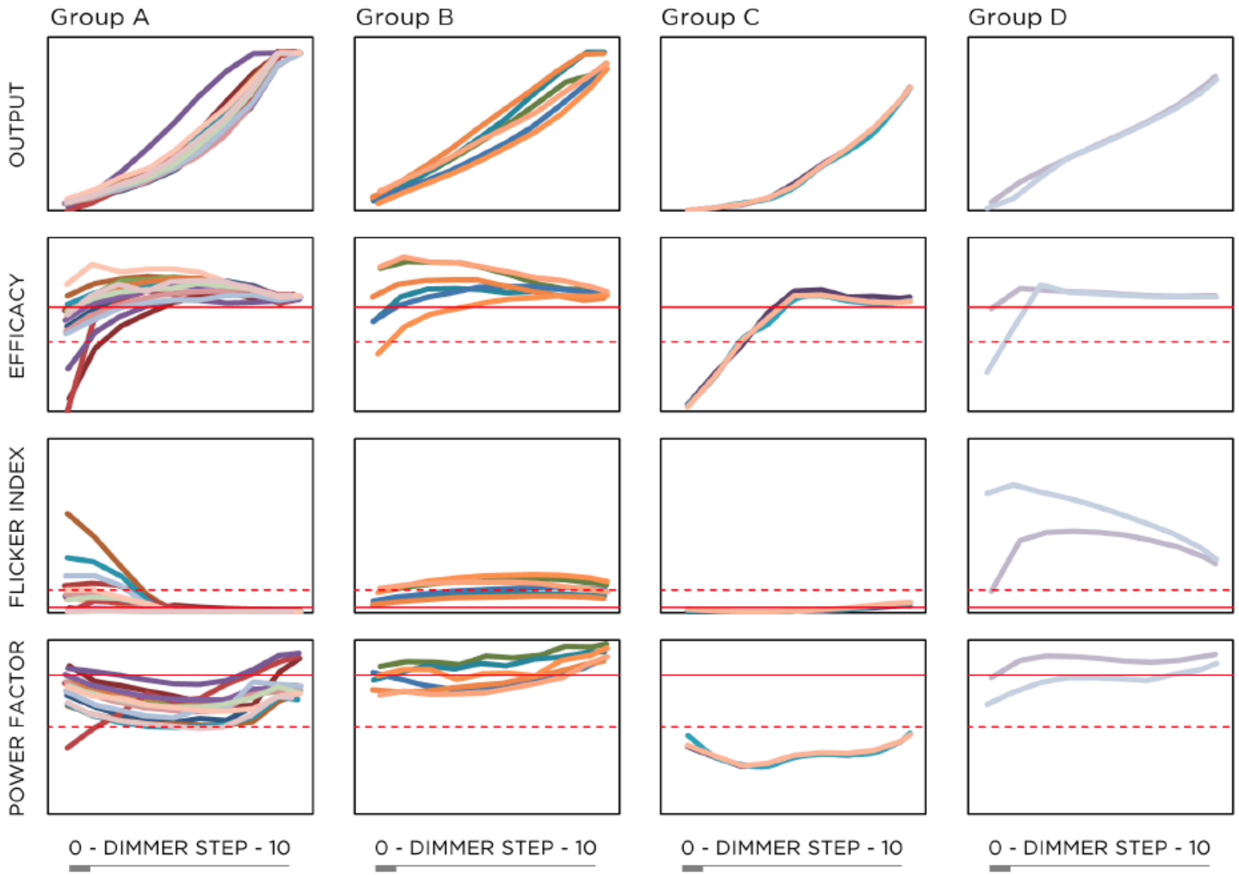


Figure 7. Performance of individual products arranged by group. Uncategorized products are not shown.

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_20-2_par38.pdf

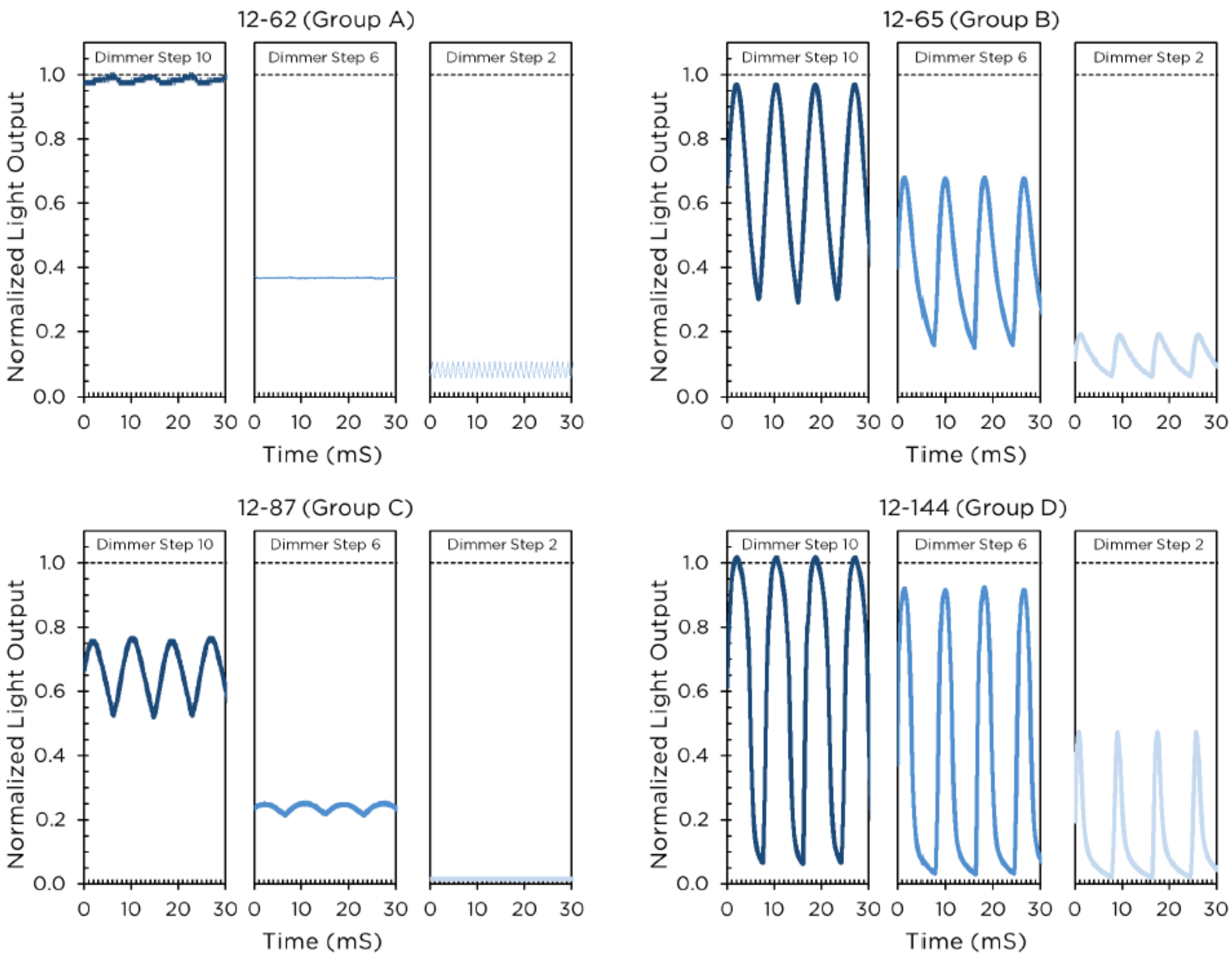
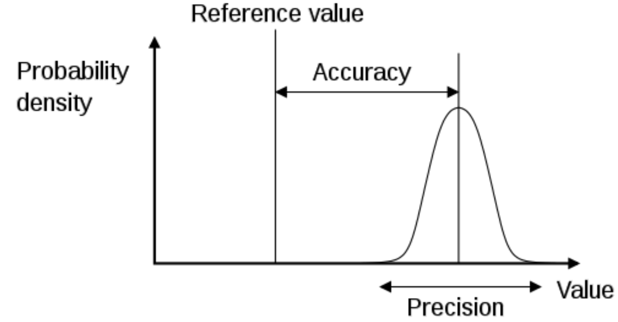


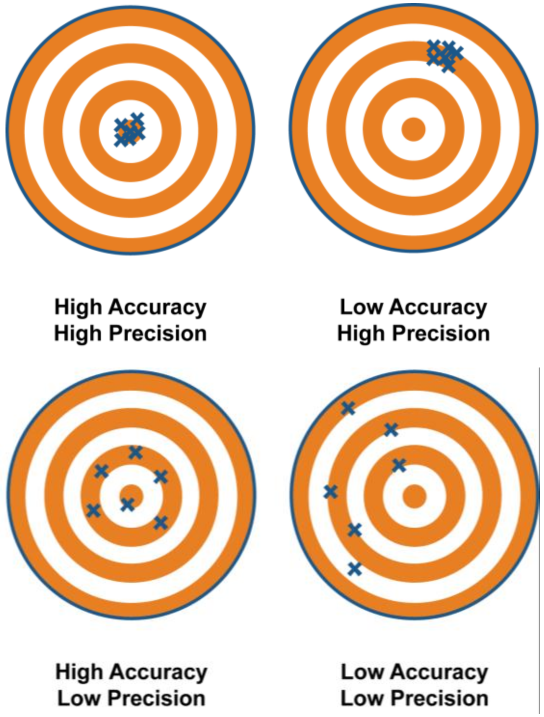
Figure 9. Flicker waveforms (light output over time) for one product from each identified group. Each set of three plots shows the listed product with the dimmer at step 10, 6, and 2.

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_20-2_par38.pdf

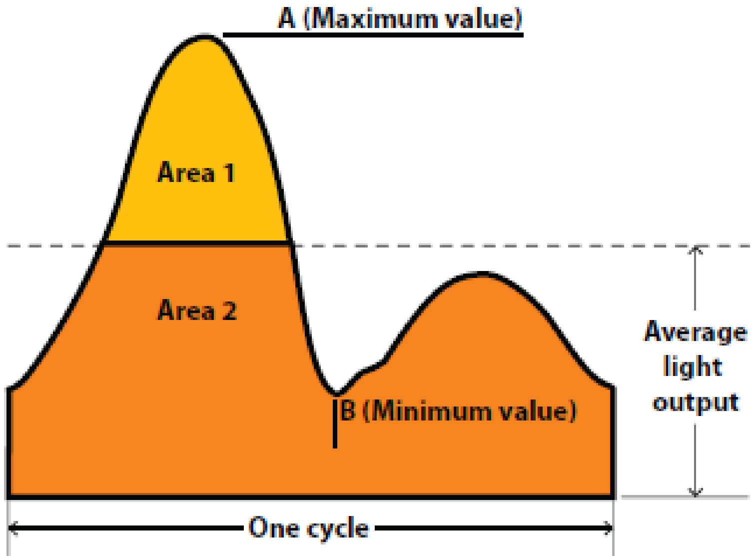
Flicker test method considerations

- Test setup
  - Power supply
  - Sensor
  - Measurement environment
- Hardware signal processing (e.g. amplifier linearity)
- Data sampling
  - Sampling step, duration
  - Data set size
  - Measurement time
- Software signal processing (e.g. filtering, numeric representation resolution)
- Accuracy, precision vs. signal frequency, duration, etc.
- Data suitability for calculating standard metrics





Existing flicker metrics



Source: IES Lighting Handbook, 10th Edition

Percent Flicker = $100\% x \frac{A - B}{A + B} \neq 100\% x \frac{A - B}{Average}$

Flicker Index = $\frac{Area\,1}{Area\,1 + Area\,2}$

New flicker metrics

- Existing single-value metrics (i.e. flicker index and percent flicker) are insufficient because they do not account for frequency.
- Many ideas for new single-value or two-value metrics
  - Percent Flicker and Frequency
  - Flicker Index and Frequency
  - Probability of detection (empirically derived)
  - Acceptability rating (empirically derived)
  - Frequency (component) truncated/weighted percent flicker
  - Frequency (component) truncated/weighted flicker index
- A single-value metric is preferred over a two-value metric (i.e. flicker index and frequency) for user simplicity
- Frequency component truncation or weighting requires FFT analysis
- FFT approaches have data sampling implications
- Data sampling
  - Nyquist frequency (Hz) = sampling rate / 2
  - FFT spectral resolution (Hz) = 1 / sample duration

FFT Basics

- FFT = decomposition of sampled periodic signal into a sum of sinusoidal signals
- Many software tools have integrated FFT algorithms
  - Microsoft Office Excel
  - Mathworks Matlab
- Algorithms most efficient (fastest) for 2^n samples
  - 2^9=512, 2^{12}=4096, 2^{16}=65536
  - Can pad with zeroes to increase sample size
- Varying software tool specific performance
  - Speed: Mathworks Matlab > Microsoft Office Excel
  - Maximum samples: 4096 for Microsoft Office Excel

PNNL data sampling

- Nominal sampling plan, focused on time-domain
  - Samples = 125,000
  - Sampling Step = 1uS
  - Sampling Duration = 0.125 seconds
  - Sampling Rate = 1000 Ksamples/second
- Truncated and subsampled to fit 2^n and maximum sample limitations

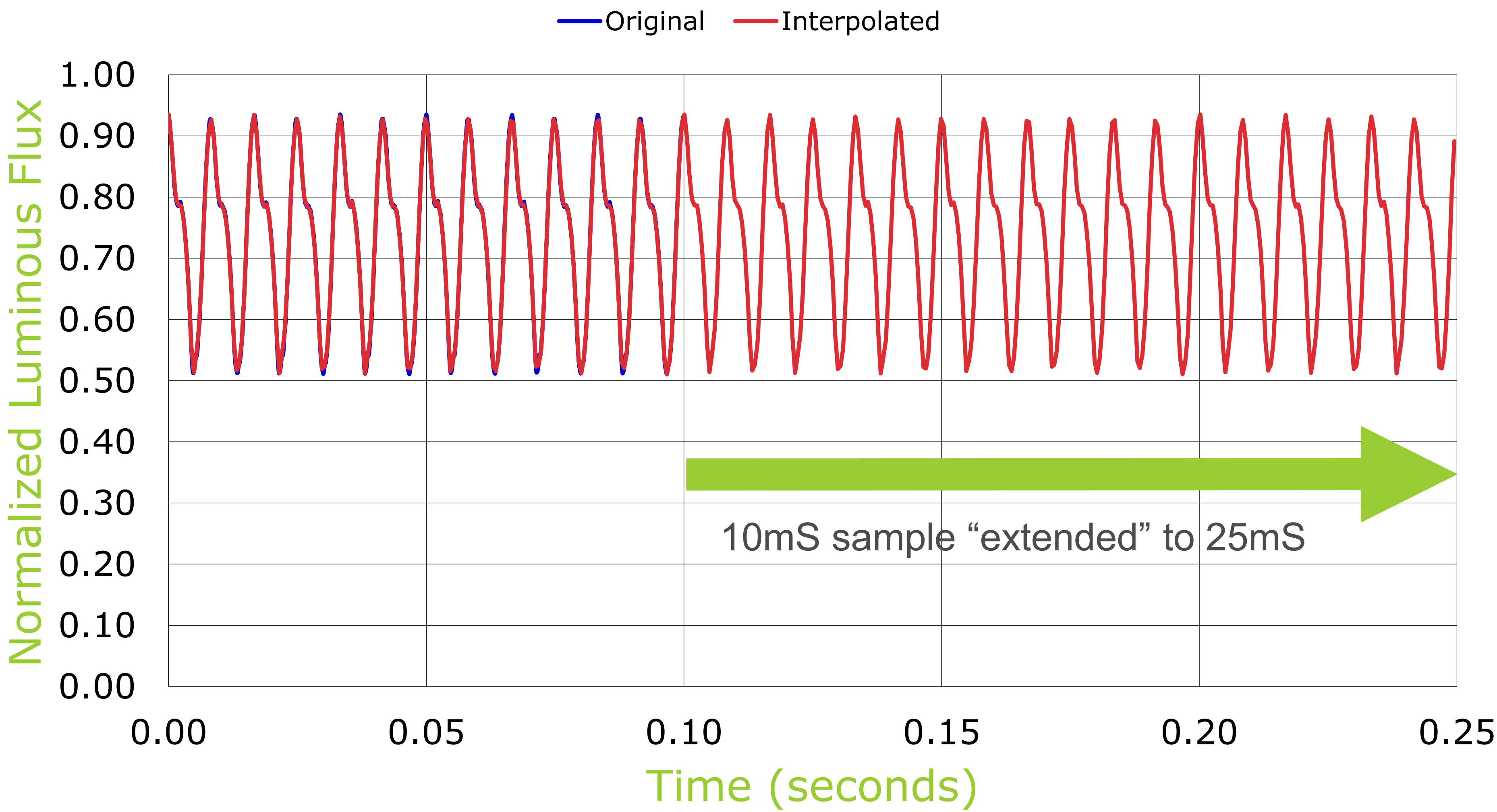
	Full	**2^{16}**	**2^{12}**	**2^9**	
Samples	125000	65536	4096	512	samples
Sampling Step	0.0010	0.0010	0.0010	0.0010	msec
Sampling Duration	0.1250	0.0655	0.0041	0.0005	sec
Sampling Rate	1000	1000	1000	1000	Ksamples/sec
FFT Resolution	8.00	15.26	244.14	1953.13	Hz

Modified data sampling

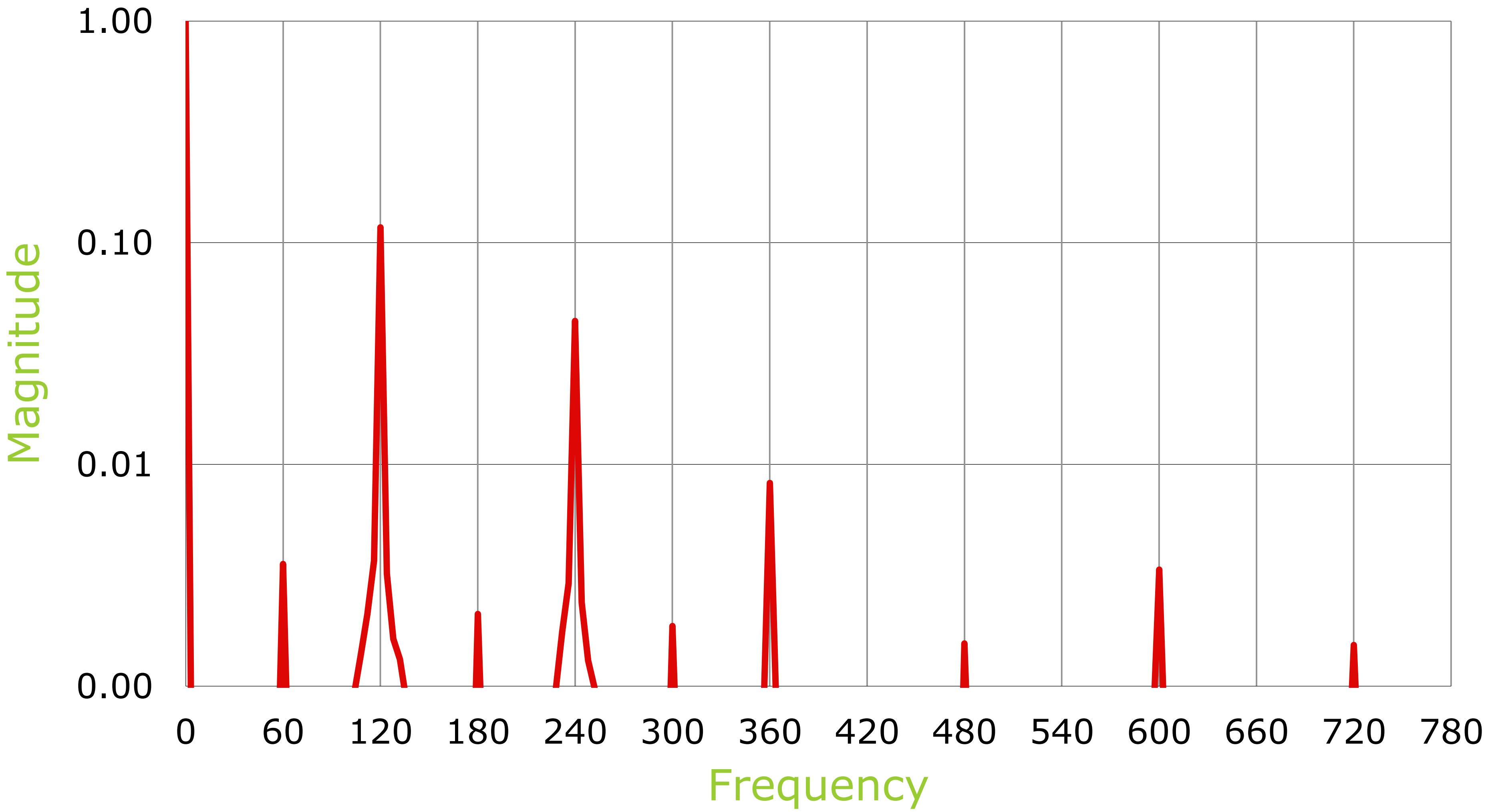
- Focused on time domain and frequency domain
  - Nyquist frequency ≥ 2kHz
  - FFT spectral resolution close to AC mains line frequency (e.g. 60 Hz) or integer divisible (e.g. 30, 20, 15, 5, 4, 3, 2 Hz)
- Sample modification
  - Interpolate to create new sampling step
  - Repeat sample set to extend sample duration
  - Subsample to reduce total number of samples

	Full	2^{16}	2^{12}	2^{9}	2^{9}	
Samples	125000	65536	4096	512	512	samples
Sampling Step	0.0010	0.0010	0.0010	0.0010	0.4883	msec
Sampling Duration	0.1250	0.0655	0.0041	0.0005	0.2500	sec
Sampling Rate	1000	1000	1000	1000	2.0	Ksamples/sec
FFT Resolution	8.00	15.26	244.14	1953.13	4.00	Hz

Sample interpolation and extension



FFT of extended sample



A call for standards…

- Multiple organizations that develop lighting specifications have attempted to create criteria for flicker, or announced intentions to develop such criteria in the near future.
- The success of these efforts will likely hinge on the use of standardized test and measurement methods and metrics.
- IES Working Group S408-10: Optical Waveform Measurement
- TC 1-83: Visual Aspects of Time-Modulated Lighting Systems
    1. To investigate and report on current research on the perception of visual artifacts of temporally modulated lighting systems, including flicker, the stroboscopic effect and the phantom array effect.
    2. Design methodology and gather data on the visibility of temporal artifacts.
    3. Build a model for the visibility of temporal artifacts and their dependence on environmental, demographical and lighting parameters.

ENERGY STAR

- ENERGY STAR considered flicker reporting and minimum performance requirements for Lamps Specification

  https://www.energystar.gov/products/specs/sites/products/files/Dimming%20Work%20for%20Lamps_0.pdf

- Published Lamps Specification V1.0 contains (only) flicker reporting requirement

12.3. Flicker:

Lamp Type	ENERGY STAR Requirements	Methods of Measurement and/or Reference Documents	Supplemental Testing Guidance
All Lamps Marketed As Dimmable	Lamp average light output periodic frequency, highest percent flicker, and highest flicker index shall be reported.	**Measurement:** ENERGY STAR Recommended Practice - Light Source Flicker	**Sample Size**: 1 lamp per dimmer and 4 lamps per dimmer See Section 8 of the Recommended Practice - Light Source Flicker, for reporting information.

https://www.energystar.gov/products/specs/sites/products/files/ENERGY_STAR_Lamps_V1_0_Final_specification.pdf

ENERGY STAR

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ENERGY STAR®, a U.S. Environmental Protection Agency program, helps us all save money and protect our environment through energy efficient products and practices. For more information, visit www.energystar.gov.

Dear ENERGY STAR® Lamps Stakeholders:

With the transition to the Lamps V1.0 specification approaching, EPA wants to ensure all partners are aware of upcoming milestones:

- After **May 30, 2014**, EPA-recognized certification bodies will stop certifying new product submittals to the CFL V4.3 and Integral LED Lamps V1.4 specifications. Models currently certified to these specifications will maintain their certification status until September 30, 2014.
- As of **September 30, 2014,** any lamp manufactured must be certified to the Lamps V1.0 specification to bear the ENERGY STAR mark. All products certified to the CFL V4.3 or Integral LED Lamps V1.4 specifications will be removed from the list of ENERGY STAR certified products.

EPA recommends manufacturers review all currently certified models to evaluate which products will be recertified to the Lamps V1.0 specification. To determine what testing is needed to recertify products, please refer to the Recertification Testing Guides for CFLs and LED lamps and consult your certification body.

For any questions concerning any of the above dates or requirements, please email lighting@energystar.gov.

Thank you for your continued support of ENERGY STAR.

For more information, visit: www.energystar.gov

California Title 20

- Appliance Efficiency Regulations (California Code of Regulations, Title 20, Sections 1601 through 1608) published in both 2012 and 2014 contain flicker requirements for dimming controls

  Dimmer controls that can directly control lamps shall provide electrical outputs to lamps for reduced flicker operation through the dimming range so that the light output has an amplitude modulation of less than 30 percent for frequencies less than 200 Hz without causing premature lamp failure.

http://www.energy.ca.gov/2012publications/CEC-400-2012-019/CEC-400-2012-019-CMF.pdf

http://www.energy.ca.gov/2014publications/CEC-400-2014-009/CEC-400-2014-009-CMF.pdf

Voluntary California Quality LED Lamp Specification

To meet the specification, LED lamps shall be capable of continuous dimming, without flicker or noise, from 10-100 percent. For these lamps, the California-Quality LED Lamp Specification will use the test procedures (e.g., for flicker and noise) cited in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A). The test procedures used in the California Specification will update in line with future revisions to ENERGY STAR, but the requirement for dimming down to 10% will not update .

http://www.energy.ca.gov/2012publications/CEC-400-2012-016/CEC-400-2012-016-SF.pdf

Voluntary California Quality LED Lamp Specification

There is currently no quantitative test procedure for visual flicker or audible noise, but nevertheless we recommend that utilities conduct flicker and noise testing as part of the approval procedure for lamp rebates, because flickering lamps would seriously compromise user acceptance. At present, conformance with the California Specification must be judged using a subjective test, i.e., by direct observation. Observers have different levels of sensitivity to flicker; some observers are unable to detect line frequency flicker while others detect it in their peripheral vision. Flicker sensitivity is mostly independent of the observer's age. Flicker testing should be conducted by observers who are flicker sensitive.

http://www.energy.ca.gov/2012publications/CEC-400-2012-016/CEC-400-2012-016-SF.pdf

Manufacture compliance claims

LED Lamp Project Lights the Way to Flicker-Free Replacement

Jade Sky Technologies and UC Davis's California Lighting Technology Center demonstrate the lighting market's readiness to meet tough new quality standards

MILPITAS, Calif., May 15, 2014 PRNewswire-iReach

"In addition to validating efficacy and CRI targets, test data shows the lamps submitted by JST were able to maintain a photometric flicker well below that required by **California's Appliance Efficiency Regulations (Title 20)**, over a dimming range of 0 to 100 percent light output. The lamps also measured above the minimum standard power factor over the entire dimming range used for testing. Perhaps most noteworthy of all for lamp and luminaire manufacturers, both the omni-directional and directional lamps tested for the project exhibited **smooth dimming** on all seven dimmers used for testing, with **no flashing, flickering, pop on, cycling or other undesirable behaviors**."

http://www.digitaljournal.com/pr/1922124

Manufacturer reporting

CREE LED Lighting

LED Components & Modules

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Cree Services provide a comprehensive suite of Thermal, Electrical, Mechanical, Photometric and Optical tests (TEMPO) for LED luminaires.

TEMPO delivers the accumulated advantage of Cree's LED system knowledge and include important tests that are not available elsewhere, such as binning and color point evaluation, chemical compatibility and TM-21 lifetime projection.

TEMPO measurements are performed at Cree Technology Centers worldwide on equipment with calibrations that are traceable to NIST. Cree Durham Technology Center (NVLAP lab code 500070-0) is accredited by The National Voluntary Laboratory Accreditation Program (NVLAP) to satisfy the requirements of ISO/IEC 17025:2005, IES LM-79-08 and LM 58-94.

Driver Output Frequency (Hz)	Number Tested	Percent of Total
100	26	25%
120	41	40%
>120 & <10,000	8	8%
DC	28	27%
Total	103	

Table 3: Driver output frequency for tested LED luminaires and lamps

Driver Output Frequency (Hz)	Percent Flicker Range	Number Tested	Percent of Total
100	0-20%	18	69%
	20-100%	8	31%
120	0-30%	29	71%
	30-100%	12	29%

Table 4: Percent flicker for LED luminaires and lamps

Category Number	Category Name	Number Tested	Minimum Percent Flicker	Maximum Percent Flicker
1	Screw-base lamp	12	13.1%	58%
2	Tube replacement	6	18.5%	41%
3	MR16/GU10	4	1.7%	76%
4	Other lamp	3	2.8%	6%
5	Street/roadway	10	1.1%	97%
6	High/low bay	16	0.8%	57%
7	Linear/troffer	16	0.7%	47%
8	Down light	13	1.2%	77%
9	Other outdoor	18	1.6%	37%
10	Other indoor	4	0.8%	37%

Table 5: Range of percent flicker for LED luminaires and lamps

http://www.cree.com/~/media/Files/Cree/LED%20Components%20and%20Modules/XLamp/White%20Papers/Flicker.pdf

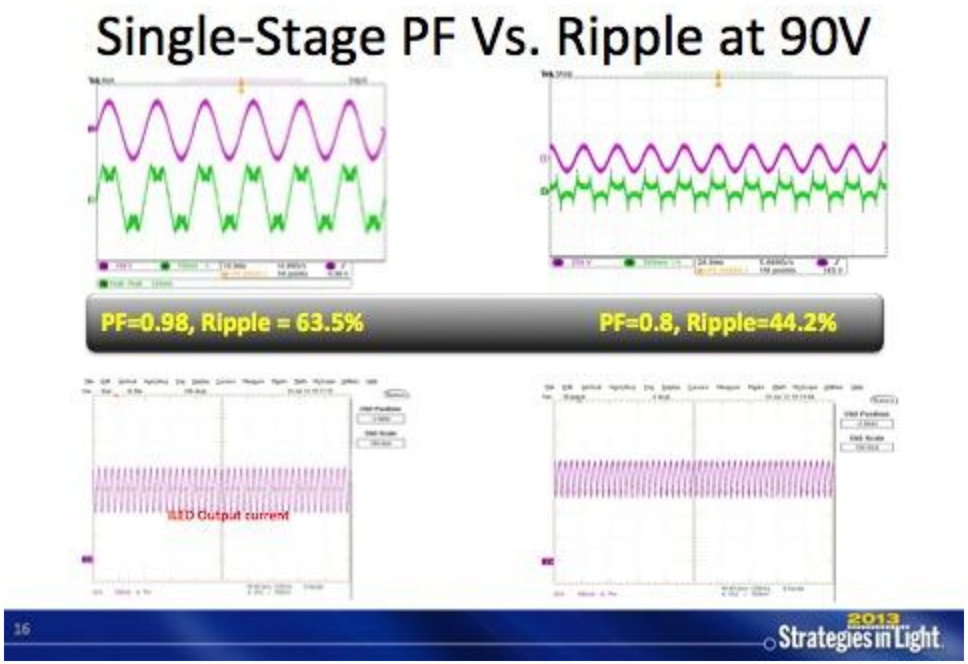
Potential test and measurement variation

Lab	Product ID	Power (Watts)	Power Factor	Current THD	Percent Flicker	Flicker Index
CA Consultant	RR-01	17.52	0.9802	12.39%	100.0%	0.266
PNNL	RR-01	20.53	0.9604	26.13%	99.8%	0.226
	Difference*	15.82%	2.04%	71.34%	0.20%	16.29%
CA Consultant	RR-02	12.45	0.8627	48.51%	29.8%	0.091
PNNL	RR-02	13.10	0.8800	38.29%	30.1%	0.093
	Difference*	5.09%	1.99%	23.55%	1.04%	2.02%
CA Consultant	RR-03	9.79	0.7365	66.44%	11.2%	0.012
PNNL	RR-03	9.70	0.7500	95.00%	11.0%	0.009
	Difference*	0.92%	1.82%	35.38%	1.98%	25.56%
CA Consultant	RR-04	9.97	0.8574	50.05%	100.0%	0.165
PNNL	RR-04	10.20	0.8600	55.00%	100.0%	0.170
	Difference*	2.28%	0.30%	9.42%	0.00%	2.91%

*Difference = ABS(Value 1 – Value 2) / Mean (Value 1, Value 2)

Closing thoughts

- The lighting industry needs a standardized method for reporting flicker performance
- Significant flicker performance variation continues to exist for LED products
- Well-known LED driver cost, flicker, power factor trade-offs



To reduce the minimum LED current, follow the below design guide:

- Reduce DIM resistors (R5 and R6) to decrease minimum DIM voltage. (DIM offset voltage by DIM internal current source (7.5 µA) is reduced by smaller R6.)
- Increase the bleeder capacitor (C1). (When reducing minimum LED current, bleeder current should be larger to stabilize input current without flicker. However, increasing C1 reducees PF. This is always trade-off of "flicker-free design vs. PF" in RC bleeder structure.)

https://www.fairchildsemi.com/an/AN/AN-FEBL021H.pdf

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Questions?

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