ENERGY STAR® Lamps V1.0 Specification Stakeholder Discussion on Dimming

Contents

Dimming Overview
• Issues and possible metrics • Standards
• Industry Efforts
• Definition of Dimming • Limited set of Metrics • Proposals • Test Methods
Next Steps

ENERGY STAR & Dimming

- In person meeting with NEMA
- Round Table Meeting Saint Paul, MN October 21 2012
  - Continue the conversation of dimmable lamp performance
  - Identify existing national, international, and industry efforts and research
- Need for national requirements for dimming
- Smaller group of stakeholders to discuss limited requirements and test method development

The Possibilities

- Define dimming
- Use of Manufacturer-provided Information
  - Compatible with most incandescent dimmers and on a website list specific manufacturer model numbers
  - The maximum number of lamps that may be operated on the dimmer
  - The relative light output at the minimum dimmer setting
- Consider parameters intended to prevent damage to dimmer
  - Inrush Current
  - Continuous Operating Current
  - Voltage Ring-up
  - Current Ring-up

The Possibilities - continued

- Consider parameters intended to prevent damage to lamp
  - Volt-Amperes Withstand
  - Amperes Withstand
  - Asymmetric Voltage Withstand
- Consider parameters intended to characterize the dimmer/lamp system performance
  - Pop-on phase angle (deg) at which the LED will turn on
  - Current required by triac to turn on (mA instantaneous)
  - Light level at turn on compared to set light level (%) to limit overshoot
  - Maximum time to turn on at any set light level (seconds)

The Possibilities - continued

- Consider parameters intended to characterize the dimmer/lamp system performance – continued
  - Maximum Light Output When Operated on a Dimmer
  - Light Output at Minimum Dimming Level
  - Adjusting Between Maximum Light and Minimum Light
    - » Current (mA) required by triac to stay on
    - » Maximum time to change light level
    - » Dead Travel within 120-40 deg phase angle (deg)
  - Light Output Curves with phase angle vs. light output
  - Steady Light Level Between Maximum and Minimum
    - » Variation in relative applied voltage
    - » Variation in relative lumen output
    - » Flicker, shimmer

The Possibilities - continued

- Consider parameters intended to characterize the dimmer/lamp system performance – continued
  - Quiet Operation
    - » Audible noise measurement
    - » Limiting current crest factor
  - Limiting Off State Power Consumption

Dimming in Lamps Draft 2

- Details TBD
  - Minimum Light Level
  - Audible Noise
  - Compatibility
  - Flicker (Operating Frequency)

Stakeholder Comments on Dimming Requirements

- Flicker free
- Continuous dimming
- Suggested dimming ranges
  - Down to 35% of initial lamp output
  - Down to 10% of initial lamp output, citing 20% is too high of a threshold for consumer satisfaction
  - Down to 5% of initial lamp output
- No audible noise
- Remove noise requirement
- Limited set of requirements for lamps compatible with installed base dimmer – flicker, dimming range and in-rush current

Stakeholder Comments on Dimming Requirements – cont'd

- Expanded set of requirements for lamps designed to be compatible with newer dimmer to address other consumer expectations
- Consider requirement for holding current
- Consider color temperature or color shift as a metric for dimming performance
- Strong desire to see dimming requirements in the first version of the Lamps specification
- Dimming requirement should not be included in specification until international and regional dimming standards reach maturity and are published.

Overview of Standards Efforts

National and International Standards Development

NEMA - SSL-6

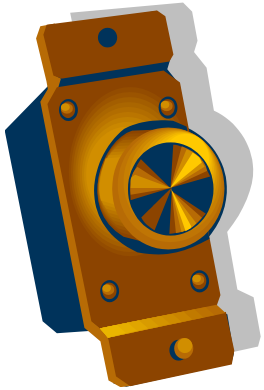
Solid State Lighting for Incandescent Replacement - Dimming

- Contains many performance requirements covering:
  - Protections for dimmers
    - Inrush current
    - Operating current
    - Voltage and current ring-up
  - Protections for lamps
    - Volt-Amperes withstand
    - Amperes withstand
    - Asymmetric voltage withstand

NEMA - SSL-6

Solid State Lighting for Incandescent Replacement - Dimming

- Contains many performance requirements covering:
  - Dimming system performance
    - Off state
    - Transition off-on
    - Transition on-standby
    - Maximum light output on dimmer
    - Light output at minimum setting
    - Adjustment between maximum and minimum light
    - Steady level light between maximum and minimum light
    - Quiet operation
- No test methods included



NEMA – SSL-7 – DRAFT?

- 2-part Document
  - Part 1 – Compatibility and Interoperability
    - In development, anticipated publication second half of 2012
  - Part 2 – Performance
  - Defined compatibility and performance
    - Currently forward phase-cut only
    - Light sources which connect to a branch circuit, and have an electronic power supply
- Defines
  - Design specifications and compliance test procedures for:
    - Lamps / Luminaires
    - Lighting Controls

NEMA – SSL-7 – DRAFT?

- Goal is predictable, specified performance
  - Definition for “dimmable”
- Performance ratings for SSL-7 compliant lamps / luminaires valid on all compliant dimmers
  - Dimming range (maximum and minimum output)
  - Dimmer loading characteristics
- Performance ratings for SSL-7 compliant dimmers valid on all compliant lamps / luminaires
  - Full-featured operation
  - Load ratings (maximum and minimum)
- No backwards compatibility

IEC 60969 Ed. 2 – Tests for Compatibility with Wall Dimmers and Switches - DRAFT

- Has specific requirements for:
  - Inrush Current
  - Start Time
  - Stable Light Level
  - Dimming Range
  - Smooth Light Level Changes
  - Connected Load
  - Turning off
  - Lamp Reliability
  - Dimmer Reliability
  - Noise

- No specific requirements currently outlined
  - August 2011 Draft
- Anticipated Publication 2014

International Energy Agency
4E SSL Annex - DRAFT

- Implements an international program of energy cooperation among 28 member countries
- Has requirements for dimmability for compatibility and flicker
- Flicker
  - References Flicker Index, must be less than or equal to 0.3
  - Flicker index accounts for waveform and modulation, not frequency

Efficient Electrical End-Use Equipment
International Energy Agency

International Energy Agency
4E SSL Annex - DRAFT

- Compatibility
  - Requires marking, and the conditions where the lamp will operate as claimed
  - Provide a website address with:
    - Dimmer makes and models
    - The minimum and maximum number of lamps that can be satisfactorily dimmed on a given dimmer
    - The minimum relative luminous flux that a given lamp-dimmer combination can achieve

European Lamps Commission & CELMA
Ecodesign Working Document July 2011

- Addresses dimming in a very limited manner
  - Compatibility only
  - Packaging requirement only
- Lamp must have a warning if it cannot be dimmed, or can be dimmed only on certain dimmers
- No performance described
- CELMA

UK Energy Saving Trust

EST LED Requirements for Replacement lamps and Modules Version 2.0 - 2010

- Compatibility Focused
- Manufacturer must submit a list of dimmers that they used in internal testing to demonstrate satisfactory performance.
- Specific requirements are required to be displayed on packaging

energy saving trust®

UK Energy Saving Trust

EST LED Requirements for Replacement lamps and Modules Version 2.0 - 2010

- Samples need to be checked for dimming capability over their full claimed range at each photometry point
  - Test is done with the minimum number of lamps relative to the dimmer minimum load, but only measuring the test lamp
  - Must dim over the full claimed range
- Lamps claiming dimmability need to operate on any of the specific types of dimmers:
  - Rotary with push on/off
  - Rotary with on/off at fully dimmed
  - Brightness scroll with on/off
  - Bathroom pull cord acting as a dimmer
  - Dual push button (touch or tactile)
  - Triple push button (on off plus up and down) trailing edge dimmers

UK Energy Saving Trust

EST CFL-Halogen Requirements for Replacement lamps and Modules Version 7.0

- Not as in depth as LED
- Requires a minimum of 10 dimmer types of manufacturer internal testing for compatibility
- Requires life test with ½ of the life at minimum claimed dimming level
  - Test 2 groups, 10 starting at the dimmed state, 10 at non-dimmed, reverse the groups every 1000 hours.
- Also requires dimming limitations on packaging, including operating range

California Energy Commission
Title 20 and 24

- Currently the requirement is focused on the dimmer
- The dimmer must be able to:
  - Reduce power consumption by 65 percent
  - Provide output for reduced flicker operation through the dimming range, producing an amplitude modulation of less than 30 percent for frequencies less than 200Hz
- Does not address lamp performance

California Energy Commission

Proposed Voluntary Minimum Specifications for "California Quality" LED Lamps

- **Dimmability**
- To meet the specification, LED lamps shall be capable of continuous dimming, without flicker or noise, from 10-100 percent.
  - The *California-Quality LED Lamp Specification* will use the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A).
  - 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 testing should be conducted by observers who are flicker sensitive.
- To meet the specification, LED lamps shall indicate on the exterior of the packaging the manufacturer and model number for three (3) or more compatible dimmers, with which the lamp can be operated to fulfill the requirements of the Specification.

Overview of Industry Efforts

Program Efforts

California Lighting Technology Center

Dimming Performance Testing

- Funded by:
  - Collaborative Labeling and Appliance Standards Program (CLASP)
  - Pacific Gas and Electric Co. (PGE)
  - Energy Solutions (ES).
- Twenty (20) lamps
  - LED A-Lamp replacement lamps
  - Cross section of commercially available

- Each sample tested at a series of points throughout the dimming curve
  - 100%, 75%, 50% , 25%, 5-10% power.

California Lighting Technology Center

Dimming Performance Testing

- For each dimming level, the following photometric data will be reported
  - Luminous Flux
  - Color Rendering Index (CRI)
  - Correlated Color Temperature (CCT)
  - Chromaticity
- For each dimming level, the following electrical data will be reported
  - Voltage, Current, Wattage
  - Power Factor
  - Total Harmonic Distortion

Top Ten

Dimming Methodology

- Goal:
  - Predict whether a typical consumer would experience acceptable dimming performance
- Dimmer types:
  - Incandescent forward phase cut triac
  - LED specific or reverse phase cut

Top Ten

Dimming Methodology

- Incompatibility behavior issues defined as either:
  - Inconvenient
    - Limited dimming, unequal cut-out and pop-on
    - Does not directly interfere with experience when set
  - Unacceptable
    - Color shift, flicker, audible noise
    - Persistent characteristics that continue when the lamp has been dimmed

Top Ten
Dimming Methodology

- Requirements:
  - Ability to dim
    - Maximum 20% of their full rated light output
  - Hysteresis
    - Ratio of cut-out light level to pop-on light level
    - Less than .25
  - Color Shift
    - No more than a 100K increase in CCT through range
  - Flicker
    - No perceivable flicker in 100-20% output range
  - Noise
    - No perceivable noise in 100-20% output range

Top Ten
Dimming Methodology

- Procedure:
  - Tested lamps on 2 dimmers
  - Tested at
    - 100% or full on position
    - 20% of full on position
    - Lowest flicker free settings (dimming up and down)
  - Noise and Flicker were human observation
    - Two researchers standing in front of an open integrating sphere at three feet
  - Most performance measured via sphere and power analyzer

Takeaways from Other Efforts:

- There are other efforts happening internationally and otherwise
- Areas of overlap in general efforts requirements:
  - Requiring dimming range claims on dimmer pairings for website listing
  - Requiring minimum and maximum recommended lamps on a dimmer
  - Requiring range on packaging
- A few specific test method efforts, however timing of issuance is unclear.
  - IEC
  - NEMA

Stakeholder Presented Methods from Products Partner Meeting

- Cirrus Logic Score-card Method
  - Lamp/Dimmer Compatibility Analysis and Scorecard based on a number of factors including
    - Flicker
    - Smooth Dimming
    - Maximum and Minimum diode current
- Internal Method
  - Used for developing driver I/Cs (integrated circuits) and evaluating designs

LRC Presentation

- Research using NEMA's SSL 6 criteria and applying it to products
  - Not all products passed, including incandescent
- Definition of Dimming
- ASSIST Recommends Document
  - Flicker Parameters for Reducing Stroboscopic Effects from Solid-state Lighting Systems

Dimming for Draft 3

- Definition:
  - A lamp that is capable of producing varying levels of light, for the purposes of this specification, the lamp must be capable of reducing light output to at least 20% when paired with a control or dimmer.
- Packaging guidance
- Flicker
  - Requirements and measurement methods
- Noise
  - Requirements and measurement methods

Packaging Requirements

- Lamps that do not pass all tests must state “Not-Dimmable” on the front of packaging
- Lamps that pass all tests must include an asterisk next to “Dimmable” claims on the front of packaging and include explanation on side or back panel “Not compatible with all dimmers”
  - Lamps that with limited compatibility must list all compatible controls or dimmers on packaging “Only compatible with the following controls/dimmers”

Dimming range

- Minimum Dimming Level
  - When set to produce the minimum stable light level, the light level shall be no more than 20% of the maximum light level.
- Maximum Light Output on a Dimmer
  - When set to produce the maximum level of light, the light level shall be no less than 90% of the baseline light level.

“Compatibility” Testing

- Lamps must test with 10 dimmers
  - From at least 3 different manufacturers
  - One must be marketed or specified for use with an energy efficient lighting technology
  - At least one of the following five types:
    - Single Phase Shift
    - Double Phase Shift
    - Microprocessor with Power Supply
    - Voltage Compensation
    - Electronic Low Voltage, Reverse Phase
- Exception – Limited Controls (e.g. Wireless)
  - If lamp is compatible with a limited set of dimmers/controls, the limited set of controls must be listed on the packaging and be tested with lamp against all dimming performance requirement.

Measurement points

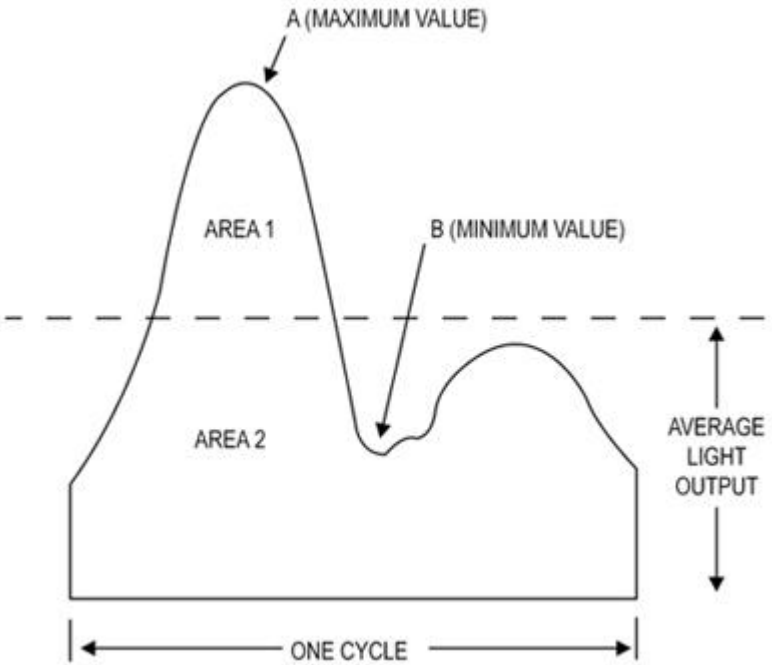
- At this time, EPA is exploring 3-4 measurement points to represent performance:
  1. Full light output without dimmer/control
  2. Full light output on dimmer/control
  3. 20% of maximum light output on dimmer/control
  4. If lamp manufacturer wants to claim less than 20% of maximum light output on dimmer / control

Flicker Requirements

Based on Flicker Index

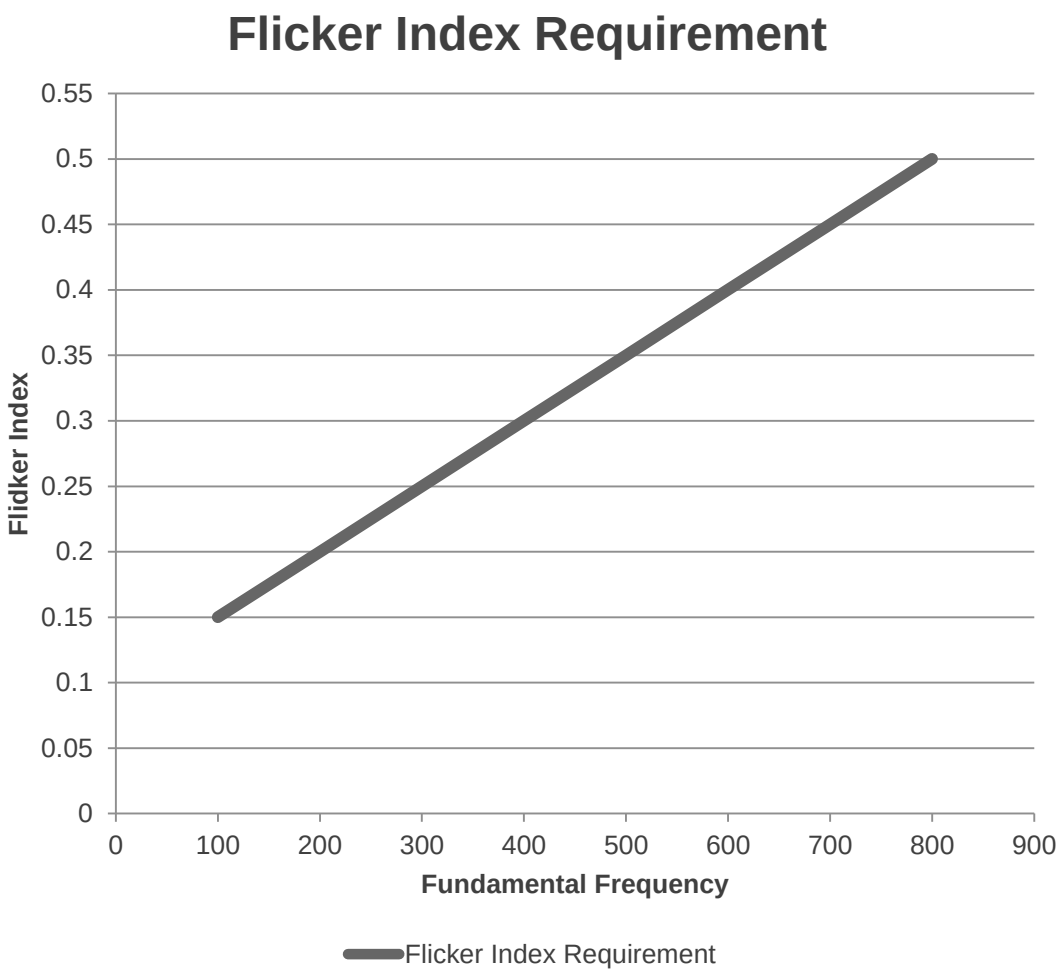
- Flicker index is a relative measure of the cyclic variation in output of various sources at a given power frequency (IES Handbook 10th Ed)
- Range is 0 to 1
- Accounts for different waveforms.

Flicker Index = Area 1 / (Area 1 + Area 2)



Flicker Requirements

- Sensitivity to flicker decreases with frequency
- Requirement:
  - 15% Flicker Index at 100 Hz, increasing linearly to 50% at 800 Hz.
  - No requirement above 800 Hz.
- Required at all measurement conditions:
  - Full output – no dimmer/control
  - Full output – on a dimmer/control
  - 20% of baseline light level
  - Minimum claimed light level
- Allows for PWM dimming >800Hz
  - Lower frequency acceptable if Flicker Index can be met
- Testing requires digital storage oscilloscope and linear response photodiode.



Noise

- Requirement: 24 dBA (Class A)
- Measurement basics:
  - Tested in an anechoic chamber
  - The tested dimmer is located outside of the chamber.
  - Before measurement, noise baseline level is taken and corrected
  - Measurements to be taken at 1 foot/1 meter distance, at 6 points around the lamp
    - Industry practice varies with measuring distances of 1 foot and 1 meter. EPA will examine both distances for round robin and pick one based on results.

Next Steps

- Round Robin testing in progress to help refine and validate test methods and inform requirements, sample size, etc.
- Outline of requirements appear in Draft 3.
- Test methods to be released separately after completion of round robin.
- Contact lamps@energystar.gov

Dimming Updates for Draft 4

- Updates to:
  - Definitions
  - Flicker Work
  - Dimming Requirements
  - Recommended Practices for Dimming

Additional Definitions

- Flicker (pg. 4)
  - CIE 17.443 e-ILV
- Flicker Index (pg. 4)
  - ANSI/IES RP-16-10
- Percent Flicker (pg. 5)
  - ANSI/IES RP-16-10

Flicker References

- Multiple articles referenced in determining flicker parameters including:
  - Modeling the visibility of the stroboscopic effect in temporally modulated light systems, M. Perz, I. Vogels, D. Sekulovski, Dec. 2011
  - Alliance for Solid State Illumination Systems and Technologies (ASSIST). *ASSIST Recommends… Flicker Parameters for Reducing Stroboscopic Effects from Solid-state Lighting Systems*, Lighting Research Center, May 2012.
  - Solid State Technology Fact Sheet : Flicker, U.S. Department of Energy and PNNL, March 2013.

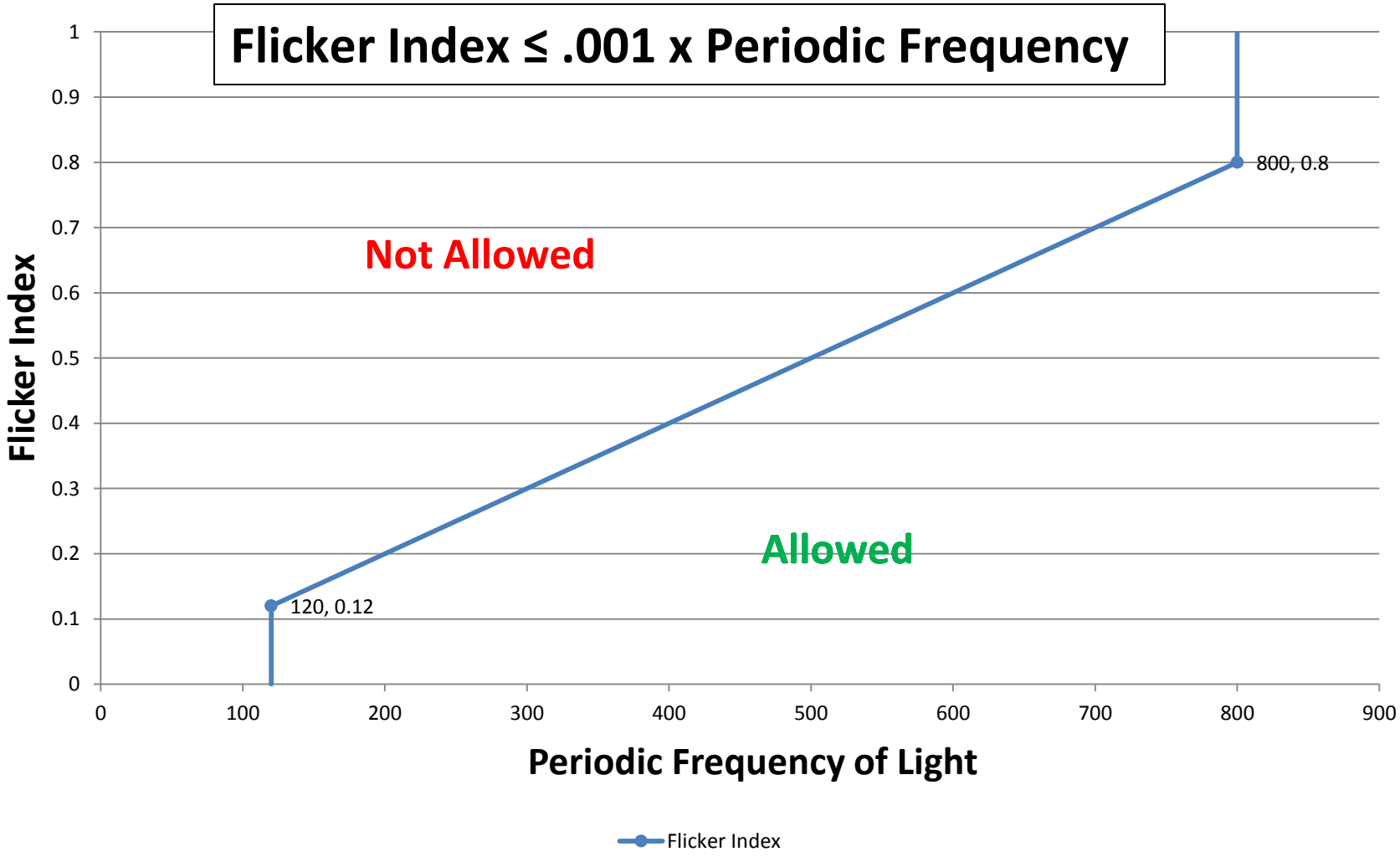
Flicker Requirements

- Lower limit at 120 Hz ≤ 0.12 Flicker Index
  - Frequency consistent with non-dimmable lamp frequency requirement
  - See DOE Fact Sheet on Flicker
- Upper limit at 800 Hz ≤ 0.80 Flicker Index
  - See referenced articles
  - 0.80 Flicker Index results from considerations for PWM dimming down to 20%

Flicker Requirements

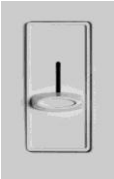
- Equation (0.001 X periodic frequency) derived from the value of the lower limit and upper limit end points
- Equation (0.001 X periodic frequency) included to provide a simplified method of determining the flicker index requirement using the lamps measured frequency value
- For waveforms with an indeterminate period, a 30% flicker threshold should be applied

Graphical Representation of Flicker Requirement



Section 12: Dimming Performance

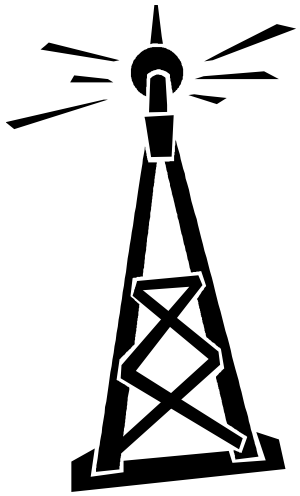
- Reporting Requirement
  - Test using Recommended Practices
  - Not required to be done at EPA-recognized laboratory for Third Party Certification
- Technology-Neutral
  - Applicable to CFL and LED lamps
  - Applicable to lamps utilizing phase-cut and non-phase cut dimming
- Based on manufacturer claimed dimming level
  - Proportional / relative value
  - Can be measured with:
    - Integrating Sphere equipment or
    - Photodetector



Section 12: Dimming Performance

Dimmer Selection – Non-Phase Cut Dimming

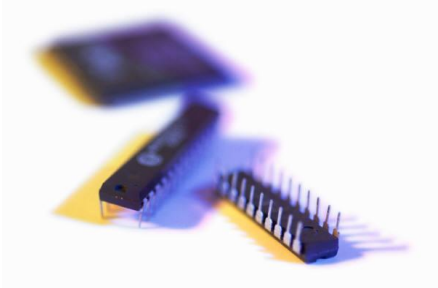
- Non-Phase Cut
  - Does not alter the line voltage to the lamp
  - Examples:
    - Wireless controls, adjustment control on lamp, or power line communication
- For lamps designed for non-phase cut dimming, **testing is limited to** manufacturer listed compatible controls.
- Packaging:
  - Compatible controls must be listed on packaging
  - Must have an asterisk (*) next to the word “dimmable” in packaging and marketing materials
    - Point to “*only compatible with…” statement

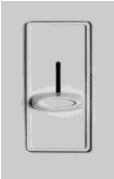


Section 12: Dimming Performance

Dimmer Selection – Phase Cut Dimming

- For lamps designed for phase-cut dimming, must be tested on 10 dimmers from at least 2 different manufacturers
- One dimmer must be specified as compatible for use with energy efficient lighting
  - CFL and/or LED
- At least one dimmer must have one of the following features:
  - Microprocessor with Power Supply
  - Voltage Compensation
  - Pre-set levels

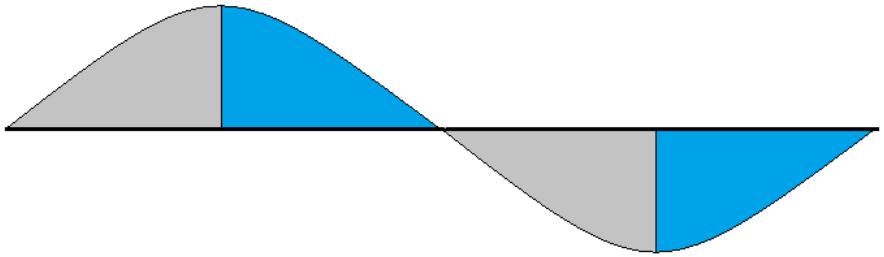




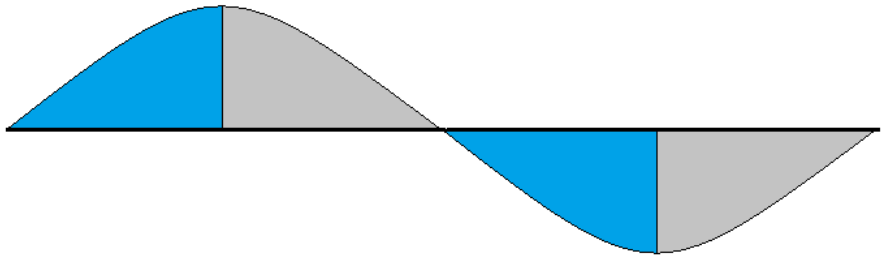
Section 12: Dimming Performance

Dimmer Selection

- At least one dimmer must be of one of the following types:
  - Single (Forward) Phase shift



  - Double Phase Shift
  - Electronic Low Voltage/Reverse Phase

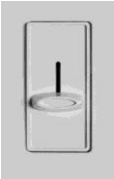


Section 12.1: Maximum Light Output

- Lamp light output on the <u>maximum control setting</u> of a dimmer/control must be:
  - No less than 20% below the light output of the lamp without a dimmer
  - No more than 10% above the light output of the lamp without a dimmer
- 80% of tested lamp/dimmer combinations must meet the requirement
- Example:
  - If a lamp produces 1000 lumens without a dimmer, it must produce between 800 and 1100 lumens at the maximum control setting when on a dimmer

Section 12.2: Minimum Light Output

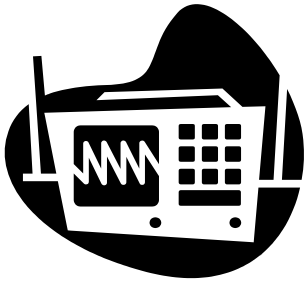
- Lamp light output on a dimmer/control shall be no more than 20% of the maximum light output of the lamp on each tested dimmer/control
  - If no specific level claimed, must test at 20%
  - If a manufacturer claims a lower level, test at the claimed level
  - E.g. if a lamp claims to dim down to 5%, test at 5% of the maximum light output on a dimmer.
- 80% of tested lamp/dimmer combinations must meet the requirement.
- Example:
  - If a lamp produces 1000 lumens without a dimmer, produces 900 lumens on a dimmer at the maximum control setting, and claims dimming down to 5%, it must meet reach down to 45 lumens, and meet flicker and noise



Section 12.3: Flicker

- Lamp shall have a light output with a:
  - Waveform periodic frequency of ≥ 120 Hz and
  - Have a flicker index less than or equal to the values in the table below when evaluated at dimmer's maximum setting and dimmed conditions.

Light output waveform periodic frequency (in Hertz)	Flicker Index
120 – 800	(0.001 times the periodic frequency)
Greater than 800	Not applicable



  - The flicker requirement is not applicable to lamps waveform periodic frequency of > 800 Hz
  - For waveforms with an indeterminate period, a 30% flicker threshold should be applied
  - Can be measured simultaneously with light output

Section 12.4: Audible Noise

- Lamp shall not emit not emit noise above 24dBA at 1 meter.
  - Tested at six points about the lamp
    - Can be tested stationary with 6 microphones
    - Can be rotated using 1 microphone
  - Testing is sound of one lamp only
    - Dimmer and any additional lamps on circuit external to measurement area
- 80% of tested lamp/dimmer combinations must meet the requirement.

Recommended Practices for Dimming

- Recommended Practices for evaluating dimming performance released with Draft 4
  - Flicker
  - Light Output on a Dimmer (Minimum and Maximum)
  - Noise
- Developed in cooperation with stakeholders
  - Round robin testing with EPA-recognized laboratories.
- Reported performance values
  - Does not require 3rd party laboratory or accreditation

Recommended Practices

- All Recommended Practices (RPs):
  - Measurement on single lamp
  - Tested with 10 dimmers, 1 and 4 lamp circuit configurations
  - 3 measurement points
    - Without a dimmer
    - On a dimmer at maximum control position
    - On a dimmer at minimum claimed dimming level

Next Steps

- Continue Round Robin testing in progress to help refine and validate recommended practices and inform requirements, sample size, etc.
- Recommended practices released with Draft 4.
- Contact lamps@energystar.gov