Dimming Ballasts

Codes and Standards Enhancement (CASE) Initiative
For PY 2014: Title 20 Standards Development

Comments regarding draft regulations:
Dimming Ballasts

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Prepared for:

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1 Comments regarding draft regulations

1.1 The California Investor Owned Utilities (CA IOUs) recommend using an "Integrated Ballast Luminous Efficiency" metric, plus a separate standby mode power limit, to regulate dimming ballast efficiency.

The CA IOUs would like to propose that a standard be set based on a new metric: Integrated Ballast Luminous Efficiency (I-BLE). I-BLE is the weighted average BLE calculated at three distinct operating modes (dimmed levels) of the lamp and ballast system. The weighting in the proposed metric would be based on the same assumed duty cycle (20% time operating at 100% light output, 50% time operating at 80% light output, and 30% time operating at 50% light output) that was used by the California Energy Commission (CEC) to calculate annual ballast energy use. Thus I-BLE is given by:

$$IBLE = 0.2 \times BLE_{100\%} + 0.5 \times BLE_{80\%} + 0.3 \times BLE_{50\%}$$

Southern California Edison (SCE) conducted extensive testing of 34 unique dimming ballast models to measure BLE throughout the dimming range. This test dataset was used by both the CA IOUs and CEC to develop proposed standard levels. A plot of I-BLE as a function of full output lamp arc power for the ballasts tested by SCE is provided in Figure 1 below. Ballasts are color coded according to the number of lamps they operate. Digitally controlled ballasts are marked with orange squares.

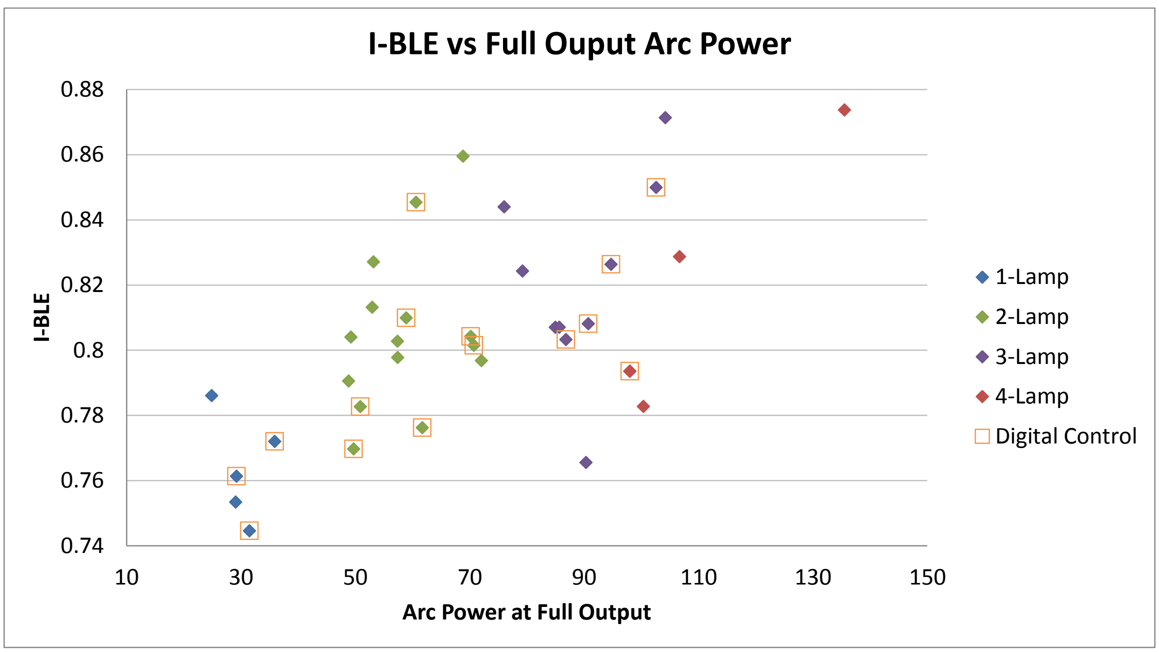

Figure 1. I-BLE as a function of full output lamp arc power.

I-BLE is a more effective method for representing dimming ballast efficiency than annual energy use. I-BLE allows for an easier comparison between the efficiencies of different products, particularly when evaluating efficiencies of ballasts with very different ballast factors, or across ballasts designed to operate different numbers of lamps. I-BLE would therefore be a more useful metric for lighting specifiers and for building energy modelers, particularly when the components of I-BLE (BLE at 100%, 80%, and 50%) are measured and reported separately. Finally, unlike the proposed annual energy use metric, I-BLE disaggregates ballast standby mode power, which in turn allows standby mode power to be regulated independently from operating mode ballast efficiency. Regulating these processes separately provides the opportunity to set more stringent standards for both active mode BLE and standby mode power because tradeoffs between active mode efficiency and standby mode energy use are no longer allowed.

The proposed I-BLE-based standard is presented below:

$$I \cdot BLE \geq \frac{AP_{Full\ Output}}{AP_{Full\ Output} * 1.091 + 7.55}$$

$$AND\ standby\ mode\ power \leq 0.5\ W.$$

The CA IOUs recommend that the limit for standby mode power draw should be set at 0.5 W, as opposed to 1 W, as originally proposed in the CA IOU CASE report. Because digitally controlled ballasts spend so much time in standby mode, setting a more stringent requirement of 0.5 W significantly increases the savings of the proposed measure. Compared to a standard set at 1 W, a 0.5 W standard yields an additional 50 GWh of savings after stock turnover.

One digitally controlled ballast in the test dataset uses less than 0.5 W of power in standby mode, proving that this level of power draw is technically feasible for DALI and DALI-like ballasts. Additionally, there are several examples of electronic products such as televisions and cell phones that enter similar standby operating modes that are able to confine standby power to less than 0.5 W. These products illustrate how proper drivers have lead manufacturers to drastically improve standby mode energy performance for certain products. For example, cell phones are products with built-in incentives to reduce standby mode in order to improve battery performance. Meanwhile, televisions serve as an excellent example of the impact of energy policy initiatives. The low standby power achieved by today's models is a direct result of voluntary programs through ENERGY STAR™ and state efficiency standards adopted by CEC that focused on improving standby mode efficiency. Dimming ballasts are similar to televisions in that without proper policy-based drivers, manufacturers have little incentive to improve standby mode performance. Therefore, a stringent standby mode standard is necessary to ensure that these products achieve improved standby mode performance.

Figure 2 below plots the proposed standard level against the I-BLEs of all ballasts in the test dataset.

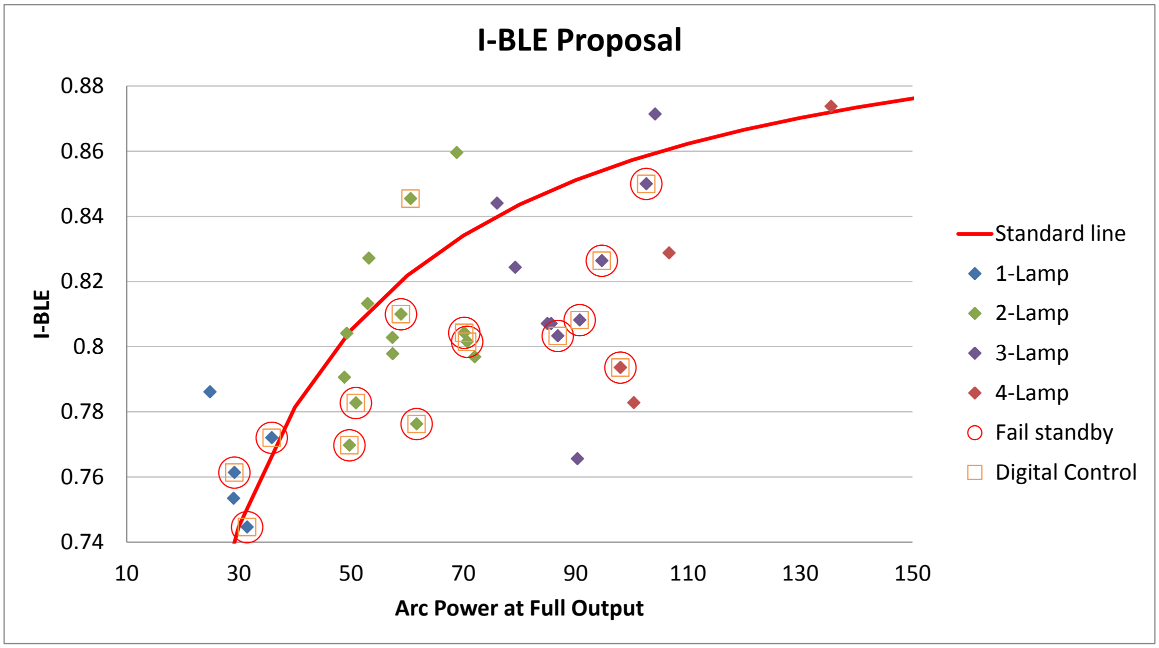

Figure 2. Impact of I-BLE standard proposal on ballasts in the IOU test dataset.

The red line represents the proposed I-BLE standard level. Ballasts above the line have a higher I-BLE than the standard requires and therefore pass the I-BLE portion of the standard. However, the ballasts circled in red do not pass the separate 0.5 W maximum standby mode requirements. Only ballasts that are above the standard line and not circled in red are considered passing products. This proposal exactly matches the CEC proposal in terms of impact on the market, according to the test dataset, as all ballasts that pass the proposed I-BLE-based standard also pass the CEC proposal and all ballasts that fail the proposed I-BLE standard also fail the CEC proposal.

When calculating energy savings under the same methodology used by CEC, the resulting I-BLE standard, with a 0.5 W maximum standby mode requirement, yields statewide stock energy savings of 422 GWh/yr in 2029. This is a 34 GWh/yr increase in energy savings over the CEC proposal. The increase in savings is a result of the CA IOU proposal no longer allowing tradeoffs between active mode and standby mode efficiency, which in turn allows for more targeted and therefore more effective regulation of both operating modes.

1.2 The CA IOUs recommend setting a power factor (PF) standard for dimming ballasts.

The CA IOUs propose a standard to require a minimum ballast power factor (PF) of 0.9, measured at 100%, 80%, and 50% of full output lamp arc power. PF measurements are already required at each of these measurement points, so this places no additional test burden on manufacturers. Additionally, all ballasts in the test dataset comfortably exceeded 0.9 PF at each of the proposed measurement points. A PF standard of 0.9 provides a backstop to ensure that all products on the market today and in the future provide adequate PF control at full output and when dimmed. The benefit of high power factor ballasts is that there are less losses associated with voltage drop in wires and heating of transformers.

1.3 Improved cathode heating control is a highly effective method for increasing ballast energy efficiency, with no negative impact on ballast utility.

In order to operate a fluorescent lamp below full output, it may be necessary, depending on how much current is flowing through the lamp arc, to provide supplemental heating to the lamp cathodes in order to maintain stable light output. By providing too little or too much cathode heating when operating a fluorescent lamp, a dimming ballast may cause damage to the lamp cathodes, which could lead to poor lamp operation and/or premature lamp failure. LL-9: Dimming of T8 Fluorescent Lighting Systems, published by the National Electrical Manufacturers Association (NEMA), defines the range of heating that should be applied by dimming ballasts to lamp cathodes in order to maintain safe operation of the lamps.

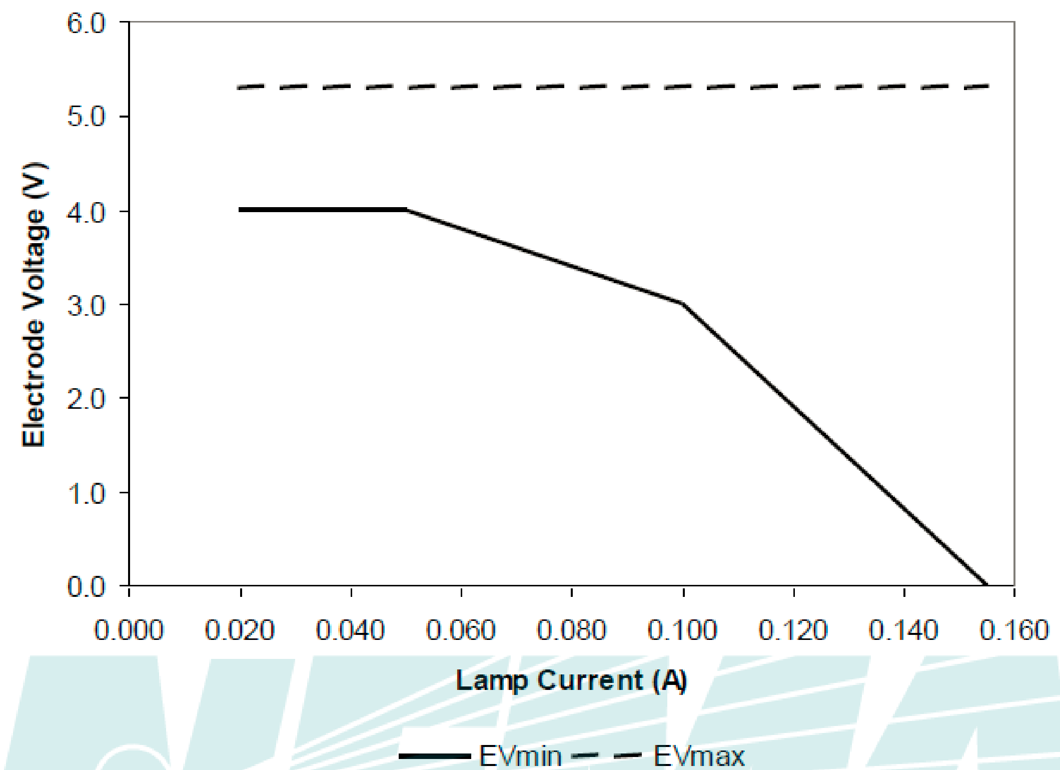

Figure 3. Range of cathode heating to maintain safe operation of fluorescent
Source: NEMA. "LL-9: Dimming of T8 Fluorescent Lighting Systems." Pg 3. 2011.

Figure 3 presents the minimum and maximum electrode voltages that the ballast is required to supply for maintaining safe lamp operation, as a direct function of lamp arc current.

The dotted line represents the maximum voltage at 5.3V. This can be translated to power using the formula:

$$P = \frac{V^2}{R}$$

Where R is defined in LL-9 as 12 Ohms ± 2 Ohms

We have conservatively chosen 10 Ohms to develop an estimate of maximum power required for cathode heating.

$$P = \frac{5.3^2}{10} = 2.8\,Watts$$

This results in a maximum power allowance of 2.8 W per cathode (or 5.6 W per lamp). This maximum amount of cathode heating power that should not be exceeded does not change throughout the full range of lamp arc currents; however, the amount of current that must be minimally provided, as defined by the solid black line, does change. As shown in Figure 3, above 155 mA of lamp arc current, zero cathode heating is required; as the lamp arc current drops below 155 mA, steadily more power for cathode heating is required. The difference between the maximum and minimum amount of cathode heating that could be used at a given lamp arc current, as defined in LL-9, represents the range of possible efficiencies that can be achieved by improving control of cathode heating. At 155 mA and above, this is a difference of up to 5.6 W per lamp, between ballasts that provide the minimum required versus maximum recommended heating to the lamp cathodes.

In the IOU test dataset, all ballasts operated lamps at significantly higher than 155 mA of lamp arc current at full output, suggesting that all ballasts, when set to 100% output, are able to safely operate the lamp without providing any supplemental cathode heating. When dimming, for most lamp-ballast test runs, the lamp arc current typically did not drop below 155 mA until the lamp arc power dipped to around 70% of the maximum full output arc power. All of these ballasts would be able to eliminate cathode heating and improve ballast efficiency at both the 100% and 80% arc power measurements.

Improved control of cathode heating at lamp arc currents above 155 mA is a significant energy savings opportunity. As previously mentioned, LL-9 shows that the difference between the most efficient and least efficient ballasts (in terms of cathode heating control) can be up to 5.6 W of power per lamp. This represents over 17% of the total power needed by a standard 32 W lamp at full output. The standards proposed by CEC, as well as the IOU proposal, will generate significant energy savings by effectively requiring high ballast efficiencies at 100% and 80% full output, where most dimming ballasts have the opportunity to drastically reduce the amount of heating provided to the lamp cathodes while remaining in the LL-9-defined zone of safe operation. The proposed standards can generally be met more easily by ballasts that utilize better control over cathode heating.

Manufacturers have indicated that various patents and intellectual property issues prevent dimming ballasts from using the same methods for achieving control of cathode heating. It is important to note that neither the proposed CEC standard, nor the CA IOU proposal presented in the document, require any specific reductions to cathode heating. Rather, better control of cathode heating is simply identified as one method for improving ballast efficiency. Furthermore, in the test dataset, ballasts from multiple manufacturers exhibited efficiency curves that show that they are able to provide some level of more precise cathode heating control. The CA IOUs therefore do not believe that patents for cathode heater control will prevent manufacturers from designing products that are capable of meeting the proposed standard levels.

1.4 The CA IOUs recommend setting a standard to regulate dimming ballast flicker.

High frequency electronic fluorescent ballasts eliminated many of the flicker issues associated with magnetic fluorescent ballasts when operating lamps at full output. However, when operating lamps below full output, some fluorescent lamps operated by dimming electronic ballasts have been observed to flicker, particularly towards the lower regions of the dimming range (as was experienced by the SCE test lab during BLE testing). This has led to lost energy savings as users disable or avoid using controls/dimming functionality to avoid lamp flicker.

A number of possible mechanisms might contribute to fluorescent flicker when dimming:

1. Dimming could be implemented with pulse width modulation and the frequencies could be low enough to cause flicker.
2. Dimmer is designed to be used with a triac based dimmer, which controls the conduction angle and "phase cuts" the power wave form at 60 Hz. This could result in some of this wave form being transmitted into the light output especially when dimmed to very low levels.
3. Precise control of cathode heating during dimming is required to maintain arc stability and lamp life. Some manufacturers may be able to control arc stability for some lamps better than others.
4. Depending on lead length and capacitive coupling, the voltage can drop in the lamp leads and result in the arc becoming unstable as the ballast is dimmed.
5. Combinations of all of the above.

Significant energy savings in Title 24 are predicated on the ability of lighting systems to dim without flicker. The Title 24, Part 6 building energy efficiency standards, rely on fluorescent lighting systems to save energy as follows:

- Section 130.1(d) states that when there is more than 120 W of luminaires within one window head height of windows and within 70% of the ceiling of skylights, the lighting shall be controlled by daylighting controls that reduce lighting power to no greater than 35% of full power.
- Section 140.6(d) states that when there is more than 120 W of luminaires in the secondary sidelit zone (between one window head height and two window head heights from windows) the lighting shall be controlled by daylighting controls that reduce lighting power to no greater than 35% of full power.

If fluorescent systems flicker when they are dimmed, the dimming control will be disabled by the building operator. The energy savings associated with daylighting controls for one year's new construction is estimated to be 95 GWh/yr.[1] These savings would be lost if daylighting is disabled due to flicker. A dimming specification that prevents flicker from even one out of 5 ballasts sold in California would save around 20 GWh/yr.

[1] P. 99 *Nonresidential Daylighting* 2013 California Building Energy Efficiency Standards California Utilities Statewide Codes and Standards Team October 2011.
http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Lighting_Controls_Bldg_Power/2013_CASE_NR_Daylighting_Oct_2011.pdf

1.4.1 Current flicker requirements in Title 20 for controls

Up until the 2013 version of the Title 24 standard, flicker specifications were contained in the Title 24 standard. During the 2013 revisions to the Title 24 standard these requirements were moved to the Title 20 requirement for dimmer controls, as described below:

> Section 1605.3(I)(F)(2) - 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.[2]

1.4.2 Test procedure

The CA IOUs have developed a test procedure for measuring flicker from light sources such as fluorescent systems and LEDs. This test procedure draws heavily from the flicker test guidelines provided in ENERGY STAR™'s Product Specification for Lamps, Version 1.0, released in August of 2013[3], which is already being used by test labs to measure flicker for LEDs. The proposed test procedure improves on the ENERGY STAR™ guidance document by providing a greater degree of specificity in measurement equipment and parameters. The impact of fluctuating light on perceived flicker and on human health and performance impacts from imperceptible flicker is a function of both percent amplitude modulation (percent flicker) and the frequency at which this fluctuation occurs. Thus the test method proposed by the CA IOUs adds to the ENERGY STAR™ test method a calculation approach for filtering out fluctuations (amplitude modulation) at higher frequencies, which have reduced impact on human health and performance. A draft of the test procedure is provided in Appendix A. Since current requirements for flicker apply to dimmers only, the CA IOUs propose that the test method be placed in Section 1604(l)3, which lists test methods for emergency lighting and self-contained lighting controls. Test procedures for various lighting products contained in other sections will then reference Section 1604(l)3 for flicker testing.

The CA IOUs are also currently in the process of conducting flicker testing on dimming ballasts from several major manufacturers with Underwriters Laboratories. Results of these tests are expected by the end of June 2014 and will be provided once available.

1.4.3 Recommendation

The CA IOUs recommend CEC adopt a flicker standard for dimming ballasts that matches existing Title 20 flicker requirements for dimmer controls and Title 24 requirements for lighting systems. Measurement points are needed throughout the dimming range – 100%, 80%, 50% and 20% to ensure flicker performance criteria are met at each operating mode. Dimming ballasts that meet the standard would be "certified" for flicker-free operation with dimmer control/lamp combinations they were tested with.

If CEC cannot adopt a standard for dimming ballast flicker at this time, the CA IOUs would also support a test and list requirement based on the test procedure proposed in Appendix A. This would provide important performance information to lighting specifiers, and is a useful first step towards addressing the flicker problem in dimming fluorescent systems. A test and list requirement for dimming ballasts will ensure that lighting designers have the information needed to ensure that

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[2] 2012 Title 20, Section 1605.3(l)2F *Dimmer Controls*.

[3] https://www.energystar.gov/products/specs/sites/products/files/ENERGY%20STAR%20Lamps%20V1%200%20Final%20Test%20Methods%20and%20Recommended%20Practices.pdf

lamp-ballast-control systems will meet Title 20 controls or Title 24 lighting system flicker requirements. Otherwise, no other methods currently exist for enforcing those flicker requirements.

Appendix A: Draft Flicker Test Procedure

Section 1604. Test Methods for Specific Appliances.

(j) Fluorescent Lamp Ballasts.

(1) The test method for fluorescent lamp ballasts is 10 CFR Section 430.23(q) (Appendix Q to Subpart B of Part 430) (2008).

(2) The test method for dimming fluorescent lamp ballasts that dim lamp (reduce input power) by more than 50% is ....

(3) The test method for measuring flicker of dimming fluorescent lamp ballasts that dim lamp (reduce input power) by more than 50% is in Section 1604(l)3.

(k) Lamps.

(1) The test method for federally-regulated general service fluorescent lamps and federally regulated incandescent reflector lamps is 10 CFR Section 430.23(r) (Appendix R to Subpart B of Part 430) (2008).

(2) The test method for state-regulated general service incandescent lamps and state-regulated incandescent reflector lamps is 10 CFR Section 430.23(r) (Appendix R to Subpart B of Part 430) (2008).

(3) The test method for medium base compact fluorescent lamps is 10 CFR Section 430.23(y)

(Appendix W to Subpart B of Part 430) (2008).

(4) The test method for measuring flicker of dimmable compact fluorescent lamps is in Section 1604(l)3.

(l) Emergency Lighting and Self-Contained Lighting Controls.

(1) **Emergency Lighting.** The test method for illuminated exit signs is 10 CFR Section 431.204(b) (2008)

(2) **Self-Contained Lighting Controls.** There is no test method for self-contained lighting controls.

(3) Dimming systems flicker. The test method for components of dimming systems including dimming lamps, dimming ballasts and dimming controls is as follows:

(A) Equipment Combinations

Flicker measurements of a phase cut dimmer controlling an incandescent line voltage lamp shall be considered representative for that dimmer with any line voltage incandescent lamp.

Flicker measurements of a phase cut dimmer controlling a transformer for low voltage incandescent lamps shall be representative only for that combination of dimmer and transformer with any incandescent lamp.

Flicker measurements of all non-incandescent lamp sources controlled by a phase cut dimmer represents only the specific combination of phase cut dimmer, ballast or driver, and lamp. These results cannot be applied to other combinations of dimmer, ballast, driver or lamp.

Flicker measurements of light sources controlled by 0-10 volt control, digital control, wireless control or powerline carrier control, the flicker measurement is specific to that combination of ballast or driver and lamp. Test results of the lamp and ballast or driver combination can be applied to other systems that have another control providing the control signal (0-10 volt, digital etc.).

(B) Test Equipment Requirements

Test Enclosure: The test enclosure does not admit stray light to ensure the light measured comes only from the UUT (unit under test). Provision shall be made so the test enclosure is able to maintain a constant temperature of 25°C ±5°C.

Photodetector: The photodetector fits the Commission Internationale de l'Eclairage (CIE) spectral luminous efficiency curve, V(λ)within 5% (f1'<5%). The linearity of response over the measurement range shall be less than 1%. The response time of the sensor shall be 10 microseconds or less.

Signal amplifier: If a signal amplifier is needed to increase the voltage to a range appropriate for the signal recording device, the bandwidth of the signal amplifier shall be at least 20 kHz for the amplification gain required to conduct the test.

Device for data collection: Digital oscilloscope with data storage capability or similar equipment able to store high frequency data from the photodetector, at a sample rate greater than or equal to 100 kHz for a minimum record rate of greater than or equal to 1 second (e.g. at least 100,000 samples at 100 kHz).

(C) Flicker Test Conditions

Product wiring setup: Fluorescent ballasts shall be wired in accordance to the guidelines provided in Section 1604(j).

Product pre-conditioning: All fluorescent lamps shall be seasoned (operated at full light output) at least 100 hours before initiation of the test. Seasoning of other lamps types is not required.

Input power: Input power to UUT (unit under test), shall be provided at the rated primary voltage and frequency within 0.5% for both voltage and frequency. When ballasts are labeled for a range of primary voltages, the ballasts should be operated at the primary application voltage. The voltage shall have a sinusoidal wave shape and have a voltage total harmonic distortion (THD) of no greater than 3%.

Temperature: Temperature shall be maintained at a constant temperature of 25°C ±5°C.

Dimming levels: Measurements shall be taken within 2% of the following increments of full light output: 100%, 80%, 50%, and 20%. When the minimum light output of the systems is greater than 20% of full light output, then the flicker measurements are taken at the minimum light output. For dimming fluorescent ballasts, lamp arc power may be used as a proxy for light output for the purpose of setting dimming levels for collecting test measurements.

(D) Test Procedure

Lamp stabilization: Lamp stabilization shall be determined in accordance with: IES-LM9-09 circleline, and u-tube fluorescent systems; Section 1604 (j) for linear fluorescent systems; IES-LM66-11 for compact fluorescent systems; IES_LM-79-08 for light emitting diode systems and IES-LM-46-04 for high intensity discharge systems. Lamp light output shall be stabilized in advance of taking measurements at each dimming level.

Sampling frequency: Sampling frequency shall be greater than or equal to 20kHz.

Sampling duration: Sampling duration shall be greater than or equal to 1 second.

For each dimming level after the lamps have stabilized, record lighting measurements (in footcandles or volts) from test equipment with readings taken at intervals of no greater than 50 microseconds. These readings are compiled for a test period of no less than one second into a comma separated data file (*.csv).

(E) Calculations

Use CEC Flicker Data Analysis Tool to perform the following data manipulation and calculation tasks for each dimming level (100%, 80%, 50%, 20% or minimum dimming):

Calculate percent amplitude modulation of unfiltered data over the duration of the test for a given dimming level using the following equation:

$$\text{Percent Amplitude Modulation} = \frac{(\text{Max} - \text{Min})}{(\text{Max} + \text{Min})} \times 100$$

Where,

Max is the maximum recorded light level or voltage from the test apparatus during the duration of the test for a given dimming level.

Min is the minimum recorded light level or voltage from the test apparatus during the duration of the test for a given dimming level.

Conduct a Fourier analysis to transform data for each dimming level into the frequency domain.

Filter frequency data to evaluate the data under four additional different conditions: frequencies under 40 Hz (data above 40 Hz is set to 0), and frequencies under 90 Hz, 200 Hz, 400 Hz and 1,000 Hz.

Perform inverse Fourier transform to place data back in time domain.

Calculate percent amplitude modulation on resulting time domain data for each filtered dataset over the full sampling duration (at least one second of data).

(F) Test Report and Data Format

The data to be recorded are listed in Table X.

Table X. Data To be Recorded

Data	Units/Format
Date	mm/dd/yyyy
Test Operator	Company, Contact Name, Phone Number
Sampling Frequency	Hz
Measurement Period	sec
Amplitude modulation at 100%	% at 40Hz, 90Hz, 200Hz, 400Hz and 1,000Hz
Amplitude modulation at 80%	% at 40Hz, 90Hz, 200Hz, 400Hz and 1,000Hz
Amplitude modulation at 50%	% at 40Hz, 90Hz, 200Hz, 400Hz and 1,000Hz
Amplitude modulation at 20% (or lowest output achievable)	% at 40Hz, 90Hz, 200Hz, 400Hz and 1,000Hz
Raw Photometric Flicker Waveform (unfiltered)	.csv data file listing measured data for the full sampling period of the UUT