Steps for Successful Phase-Cut Dimming of LEDs

Lightfair
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Pacific Northwest National Laboratory
LED dimming fundamentals

- LED sources are inherently controllable (output and color)
- Most control technologies were designed for incandescent (resistive) loads
- LEDs are non-linear loads which (typically) need a “driver”
- The LED “driver” sets its potential dimming performance
- While there is no standard definition for “dimmable”, incandescent sources set a high (and consistent) benchmark
- Not all LED sources/drivers are dimmable, or “designed to dim”
- Not all dimmable LED sources deliver the same level of performance
LED dimming performance variation

• The relationship between control input and what you care about (e.g. power, measured light, perceived light) is not well-defined for most dimming technologies, and can vary significantly across products

• Dimming an LED source can change the behavior of the LED driver
  – Efficiency can degrade, but may be offset by improving LED efficacy
  – LED chromaticity can shift
  – Flicker can be induced or increased
  – Power quality, as quantitatively evaluated by the Power Factor and Total Harmonic Distortion metrics, can be degraded.
  – Performance at different input voltages can vary.

• LED dimming performance with phase-cut dimmers is dependent on the source CAPABILITY and the source-dimmer COMPATIBILITY
**Phase-control dimming presents unique challenges**

**Coincident AC power and control signal**
- Forward or reverse phase-cut AC sine wave
- 2-Wire (hot, dimmed hot) or 3-Wire (hot, dimmed hot, neutral)

\[ V_{\text{r.m.s.}} = 120V \quad V_{\text{r.m.s.}} = 60V \]

**Separate AC power and control signal**
- Fluorescent 3-Wire
- 0-10V
- DALI
- DMX512
Potential compatibility issues with phase-cut dimmers

Dependencies

1) the characteristics of the LED sources (drivers)
2) the characteristics of the dimmer
3) the number and type of light sources on the circuit

• Dimming range
• Dimming curve
• Dead travel
• Pop-on
• Drop-out
• Flashing, Ghosting
• Premature failure
• Audible noise
• Inoperability
• Predictability
Dimming range, dead-travel, pop-on

Dimming range

- Off state
- Low End Level
- Pop-on light level
- Light output level
- High End Level

Dead travel

- Dead travel at Low End Level
- Dead travel at High End Level

Pop-on setting

- Dimmer setting (dimmer conduction time, phase angle, mechanical position of knob or $V_{RMS}$)

Switched output

Source: Modified from NEMA SSL-6
Smoothness, monotonicity, up/down symmetry

Source: Modified from NEMA SSL-6
Phase-cut dimmer loading

- Minimum load varies by dimmer and LED source
- Maximum load varies by dimmer and LED source
- Overloading can lead to premature failure

<table>
<thead>
<tr>
<th>Dimmer</th>
<th>Source</th>
<th>Possible loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>600W incandescent</td>
<td>60W incandescent</td>
<td>1-10</td>
</tr>
<tr>
<td>600W incandescent</td>
<td>12W LED</td>
<td>1-60?</td>
</tr>
<tr>
<td>600W ELV</td>
<td>50W halogen</td>
<td>1-12</td>
</tr>
<tr>
<td>600W ELV</td>
<td>10W LED</td>
<td>1-30?</td>
</tr>
</tbody>
</table>
NEMA SSL-7A

- Defines design specifications for LED sources and dimmers
- Defines compliance test procedures for LED sources and dimmers
- Predicable, specified performance
  - Minimum definition for dimmable
  - Room for product differentiation
- Compliant LED sources will have performance ratings that will be valid with all compliant dimmers
  - Dimming range (relative maximum output, minimum output)
  - Dimmer loading characteristics
- Compliant dimmers will have performance ratings that will be valid with all compliant LED sources
  - Full-featured operation
  - Load ratings (maximum and minimum, if necessary)
# NEMA SSL-7A Types

## LED Light Engine (LLE)

<table>
<thead>
<tr>
<th>Forward-Phase Dimmer</th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Type 2</td>
<td>?</td>
<td>✔</td>
</tr>
</tbody>
</table>

May work with > 1 LLE

“Universal” LLE

“Universal” Dimmer
Commercially available NEMA SSL-7A compliant dimmer

**Diva® 250 W C•L® Dimmer**

Dimmer for CFL, LED, Halogen, and Incandescent dimmable bulbs.

**Features**

- Large paddle switch with a captive linear-slide dimmer for a standard designer wallplate opening
- HED™ Technology: Advanced Lutron® dimming circuitry designed for compatibility with most high efficacy light bulbs
- UL® Listed to control:
  - Dimmable compact fluorescent (CFL) with integrated ballast
  - Dimmable LED with integrated driver
  - Lutron Hi-lume® A-Series LTE LED Driver
  - Halogen
  - Incandescent
- Low-end adjustment to accommodate a wide range of bulbs
- 100% factory tested
- **NEMA SSL-7A Type 2 Compliant**

**Application Requirements**

- *When dimming CFLs or LEDs, only bulbs marked or rated as DIMMABLE may be used.*
- For a list of compatible DIMMABLE CFLs and LEDs please visit www.lutron.com/dimcfilled. For questions call 1.800.523.9466.
- *Some DIMMABLE CFLs and LEDs require a minimum number of bulbs for proper operation. For details and a list of bulbs, please visit www.lutron.com/dimcfilled.*

*Wallplate sold separately*
Managing risk

- Specify the relationship between control input and what you care about (e.g. power, measured light, perceived light), as appropriate.
- Undesirable behavior can be corrected (e.g. by trimming the control output signal range, or linearizing the control input to light source output relationship) during commissioning of some control systems.
- Be aware of the potential for unintended dimming-induced behavior (e.g. efficacy, color shift, flicker, power quality), and evaluate, as appropriate.
- Evaluate LED sources with wide input voltage ranges (e.g. 120-277) at the voltage you intended to use them at.
Managing risk with phase-cut dimmers

- Install 3-wire dimmers in wall-box applications with neutral wires (as now required by code)
- Install NEMA SSL-7a compliant LED sources AND dimmers in existing 2-wire wall-box applications
- Leverage manufacturer guidance for pairing LED sources and dimmers
- Follow loading guidance for new dimmers; de-rate existing dimmers
- Newer, more sophisticated LED sources should continue to perform better than their predecessors
- Consider other (e.g. separate AC power and control signal or wireless) dimming approaches

Design Process for compatibility of controls

A step-by-step process based on the Burden Museum in Troy NY.
Brief examples based on track lighting only
Design Process for compatibility of controls

1. Design the lighting layout and select the control system:
   - Select luminaires and/or lamps, and document these in the lighting schedule.
   - Select the basic control system (make, model, available load type(s) of dimmers). For wall-box dimmers, select a brand and style that offers a range of load options such as INC, MLV, ELV, or has optional interfaces that allow for the control of MLV, ELV or even 0-10V, as needed.

2. Identify and quantify the LED product(s) used in each dimmer control zone:
   - This includes the make and model of LED track head, LED downlight, or LED replacement lamp for a chandelier, for example.
   - Count the number of LED luminaires or lamps, total the LED system watts on that dimming zone, and document these in the dimming schedule.
3. Check the current LED product spec sheet (on manufacturer’s website) for dimming guidance:

- Look for recommended dimmer model numbers or dimmer types (e.g., INC, ELV), as well as minimum and maximum recommended number of sources per single dimming zone.
- Do this for each integral LED lamp or luminaire. Note this in the luminaire schedule or the dimming schedule.

4. Check the dimmer manufacturer’s website for a dimming report for that specific LED source. If there is no dimming guidance from either party, or if there is conflicting guidance, then here are two options:

- Consider selecting a different LED product that is specifically listed for use with that dimmer, or
- Do a mockup to evaluate dimming performance.
5. Complete a dimming schedule by zone that includes the LED luminaire type, type of dimmer for zone, maximum power (in watts) used per zone, and minimum/maximum number of lamps allowed per zone.

6. Repeat the steps above for each dimming zone.
Design Process for compatibility of controls

1. **Design the lighting layout and select the control system:** (Luminaires/lamps and identify make/model of control system)

   - Lighting layout as shown in plans
   - Control system is Lutron Grafix Eye QS *(architectural multi-scene controller).* Load types on unit include INC, MLV, neon, fluorescent, non-dim. Other load types can be controlled by installing an interface (“black box”) between the dimmer and the load that will allow dimming of larger or more complex load types (ELV, 0-10V, DALI, etc.)
2. Identify and quantify the LED product(s) used in each dimmer control zone:
   - This includes the make and model of LED track head, LED downlight, or LED replacement lamp for a chandelier, for example.
   - Count the number of LED luminaires or lamps, total the LED system watts on that dimming zone, and document these in dimming schedule.

• Control Zone 1: Track T2 + T4 (uses Par38 LED lamps, 16W each, 9 per control zone, 144W total)
• Control Zone 2: the same.
3. **Check the current LED product spec sheet (on mfg’s website) for dimming guidance:**

- **Look for recommended dimmer types (e.g., INC, ELV), min and max recommended number of sources per dimming zone. Repeat for each lamp or luminaire. Note these in luminaire or dimming schedule.**

- **Count how many units (and how many watts total) are on that dimming zone**

- **Philips PAR38 LED lamp dimmer list**

<table>
<thead>
<tr>
<th>Item</th>
<th>Brand</th>
<th>Series</th>
<th>ID</th>
<th>Load</th>
<th>Type</th>
<th>Dimming level Max-(\rightarrow)Min. (flux%) 1 lamp</th>
<th>Flickering 1 lamp</th>
<th>Flickering 3 lamps</th>
<th>Flickering 5 lamps</th>
<th>Flickering 8 lamps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LEVITON</td>
<td>Decora</td>
<td>6161</td>
<td>500W</td>
<td>LE</td>
<td>99%-0</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>LEVITON</td>
<td>Trimatron</td>
<td>6684</td>
<td>600W</td>
<td>LE</td>
<td>100%-0</td>
<td>No</td>
<td>No</td>
<td>at~40%</td>
<td>at~40%</td>
</tr>
<tr>
<td>3</td>
<td>LEVITON</td>
<td>SureSlide</td>
<td>6613</td>
<td>600W</td>
<td>LE</td>
<td>100%-2%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>LEVITON</td>
<td>Illumatech</td>
<td>IPI06-1L</td>
<td>600W</td>
<td>LE</td>
<td>100%-9%</td>
<td>No</td>
<td>at~60%</td>
<td>~40%-50%</td>
<td>~0%-40%</td>
</tr>
<tr>
<td>5</td>
<td>LUTRON</td>
<td>Ariadni</td>
<td>AY-600P</td>
<td>600W</td>
<td>LE</td>
<td>100%-5%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>LUTRON</td>
<td>Diva</td>
<td>DV-600P</td>
<td>600W</td>
<td>LE</td>
<td>99%-2%</td>
<td>No</td>
<td>No</td>
<td>at~70%</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>LUTRON</td>
<td>Diva</td>
<td>DVPDC-203P</td>
<td>200W</td>
<td>LE</td>
<td>99%-29%</td>
<td>No</td>
<td>~0-50%</td>
<td>no dimmability</td>
<td>no dimmability</td>
</tr>
<tr>
<td>8</td>
<td>LUTRON</td>
<td>Glyder</td>
<td>GL-600</td>
<td>600W</td>
<td>LE</td>
<td>100%-2%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>LUTRON</td>
<td>NOVA</td>
<td>NLV-1000</td>
<td>1000W</td>
<td>LE</td>
<td>100%-3%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>LUTRON</td>
<td>Qoto</td>
<td>Q-600P</td>
<td>600W</td>
<td>LE</td>
<td>100%-4%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>at~70%</td>
</tr>
<tr>
<td>11</td>
<td>LUTRON</td>
<td>Skylark</td>
<td>S-600P</td>
<td>600W</td>
<td>LE</td>
<td>90%-3%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>at~80%</td>
</tr>
<tr>
<td>12</td>
<td>LUTRON</td>
<td>Toggler</td>
<td>TG-600P</td>
<td>600W</td>
<td>LE</td>
<td>100%-5%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>at~70%</td>
</tr>
<tr>
<td>13</td>
<td>LUTRON</td>
<td>Credenza</td>
<td>TT-300</td>
<td>300W</td>
<td>LE</td>
<td>100%-0</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>at~40%</td>
</tr>
</tbody>
</table>
4. Check the dimmer mfg’s website for dimming report for specific LED source. If there is no dimming guidance from either party, do mockup.

<table>
<thead>
<tr>
<th>Product</th>
<th>Part Number</th>
<th>Fixtures per Dimmer</th>
<th>Measured Light Output Range $^{(1)}$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>RadioRA 2</td>
<td>RRD-10ND</td>
<td>1-16</td>
<td>4%-100%</td>
<td>Smooth and continuous</td>
</tr>
<tr>
<td>Homworks</td>
<td>HWD-5NE</td>
<td>1-7</td>
<td>3%-100%</td>
<td>Smooth and continuous</td>
</tr>
<tr>
<td>HWD-6NE</td>
<td>1-9</td>
<td>17%-100%</td>
<td>Smooth and continuous</td>
<td></td>
</tr>
<tr>
<td>HW-RPM-4A-120</td>
<td>1-10</td>
<td>8%-100%</td>
<td>Smooth and continuous</td>
<td></td>
</tr>
<tr>
<td>Commercial Systems</td>
<td>QSG-6P</td>
<td>1-14 per output</td>
<td>2%-100%</td>
<td>Smooth and continuous</td>
</tr>
<tr>
<td></td>
<td>LF-RPM-4A-120</td>
<td>1-18 per output</td>
<td>8%-100%</td>
<td>Smooth and continuous</td>
</tr>
<tr>
<td>Interfaces</td>
<td>PHPM-WBX</td>
<td>1-29</td>
<td>7%-100%</td>
<td>Smooth and continuous</td>
</tr>
</tbody>
</table>

$^{(1)}$ Values are based on light output using the specified dimming control, and may not be an indication of the fixture’s full capability.

- Lutron Report Card for Philips PAR38 LED lamp says 1 to 14 lamps per zone.
5. Complete a dimming schedule by zone that includes the LED luminaire type, type of dimmer for zone, maximum power (in watts) used per zone, and min/max number of lamps allowed per zone.

- Dimming Schedule

<table>
<thead>
<tr>
<th>PSC-1</th>
<th>Museum Main Hall and Entry Hall, Track Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control Zone Number</strong></td>
<td><strong>Zone Lighting Description</strong></td>
</tr>
<tr>
<td>1</td>
<td>Track accent 1 - Entry Hall</td>
</tr>
<tr>
<td>2</td>
<td>Track accent 2 - Entry Hall</td>
</tr>
<tr>
<td>3</td>
<td>Track accent 1 - West</td>
</tr>
<tr>
<td>4</td>
<td>Track accent 2 - West</td>
</tr>
<tr>
<td>5</td>
<td>Track accent 1 - East</td>
</tr>
<tr>
<td>6</td>
<td>Track accent 2 - East</td>
</tr>
<tr>
<td><strong>TOTAL LOAD (WATTS)</strong></td>
<td><strong>928</strong></td>
</tr>
</tbody>
</table>
Design Process for compatibility of controls

TA DA!
First 2 LED luminaire and control zones done.
What if there are too many LEDs for the dimmer?

What a Phase-Adaptive Power Module does:

Module wired between dimmer channel and load

- Automatically senses load type and can be adapted to INC, ELV, MLV, or 2-wire fluorescent
- Increases allowed control zone load, from 600W to 16A (1920W), for example, so it can handle the larger LED effective load
- Can it be used for a non-dim load? No. But there is a different module that can be.
Description: 120V Large 2 Tier Chandelier with 58" overall diameter, 68 1/2" fixture height, and 11' 6" overall height with bottom of fixture at 10' 6" A.F.F. Consists of 12 white glass shades with 2 operating conditions: 21st century dimmable medium base white LED A19 (provided by contractor) & 19th century simulated 'Gas Light' with Amber LED ring and Driver that is non-dimmable (LED Ring and Driver are integral to the chandelier). Refer to drawings and control schedule for additional information.

Location: Q. 1, Main Hall.
LED A19, Load #1101
Amber LED ring, Load #1102

Finish: Brass with Incolac Lacquer
Lamp: Each Globe. Q. 1, Philips Endura LED, 12.5W, 120V, 2700K A19 LED med. base (provided by contractor)
Q. 1, Superbrightleds.com, AE Angel Eye LED Ring. # AE80-404, Amber 21W, 12V, 1200K, 2.3" diameter, Driver. # 1MA 50VU 112 (LED Ring and Driver integral to the chandelier)

Catalog #: Custom Fixture. # CD7066-12, 12 Arm Spare Replacement Glass Shade; Q.3, 8" dia. Frosted Opal White Glass

Manufacturer: St. Louis Antique Lighting Co.
Ann Marie: ambehm@slalco.com, 314.863.4644

Project Name: Hudson Mohawk Industrial Gateway
Burden Iron Works, Troy, NY

JanMoyerDesign Brunswick, New York 518.235.4756
www.janmoyerdesign.com

Date: 5/25/12
Time: 2:25 PM
Design Process for compatibility of controls

Until..............................................

...........time passes..............

.......and lamps have changed to a different chip
and driver.....

...and the specified LED strips are no longer available...
Design Process for compatibility of controls

So........

You do it again for those luminaires/light sources that have changed and revise your specs and controls

(and try to get more design fees. 😞)
Maintaining compatibility

• Effect of time on specifications:
  – Project delays
  – LED/driver generation changes
  – Dimmer evolution
  – Luminaires discontinued or changed design

• Substitutions of dimmer, luminaires, lamps, transformers.....

• Effect of mixing light sources on single dimming circuit (different LED drivers, mixed halogen and LED, mixed LV and 120V....)
Conclusion and Wrap-up

• Promise of SSL-7A work on future
  – Forward-phase cut dimmers
  – LED systems designed for that SSL-7A compatible dimming signal

• Development of better, smarter drivers?

In the meantime....

• Do your homework for LEDs and controls
• Mockups, mockups, mockups
• Be tough on substitutions
Read about dimming in a DOE GATEWAY report on line

Questions?

Lightfair
June 3-5, 2014

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