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

Steps for Successful Phase-Cut Dimming of LEDs

Lightfair

June 3-5, 2014

Michael Poplawski and Naomi Miller

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

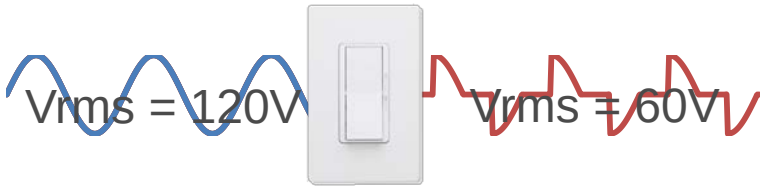
LED dimming performance variation

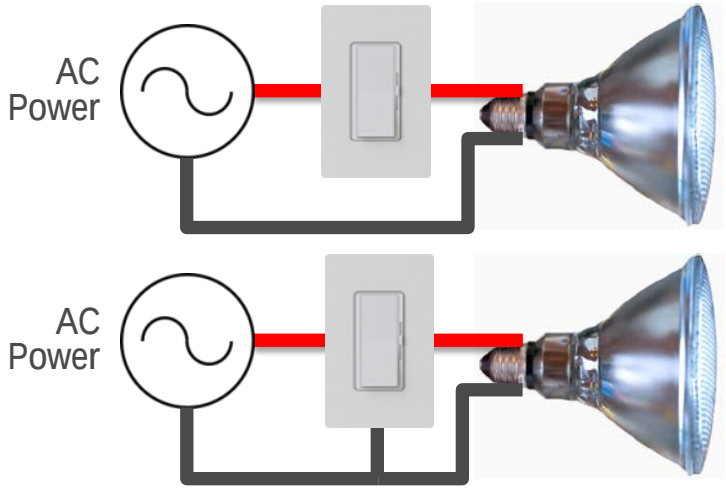
- The relationship between control input and what you care about (e.g. power, measured light, perceived light) is not well-defined for most dimming technologies, and can vary significantly across products
- Dimming an LED source can change the behavior of the LED driver
  - Efficiency can degrade, but 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

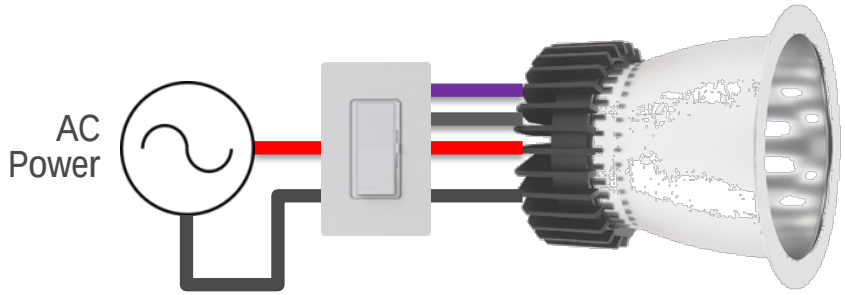
- Forward or reverse phase-cut AC sine wave
- 2-Wire (hot, dimmed hot) or 3-Wire (hot, dimmed hot, neutral)





Separate AC power and control signal

- Fluorescent 3-Wire
- 0-10V
- DALI
- DMX512



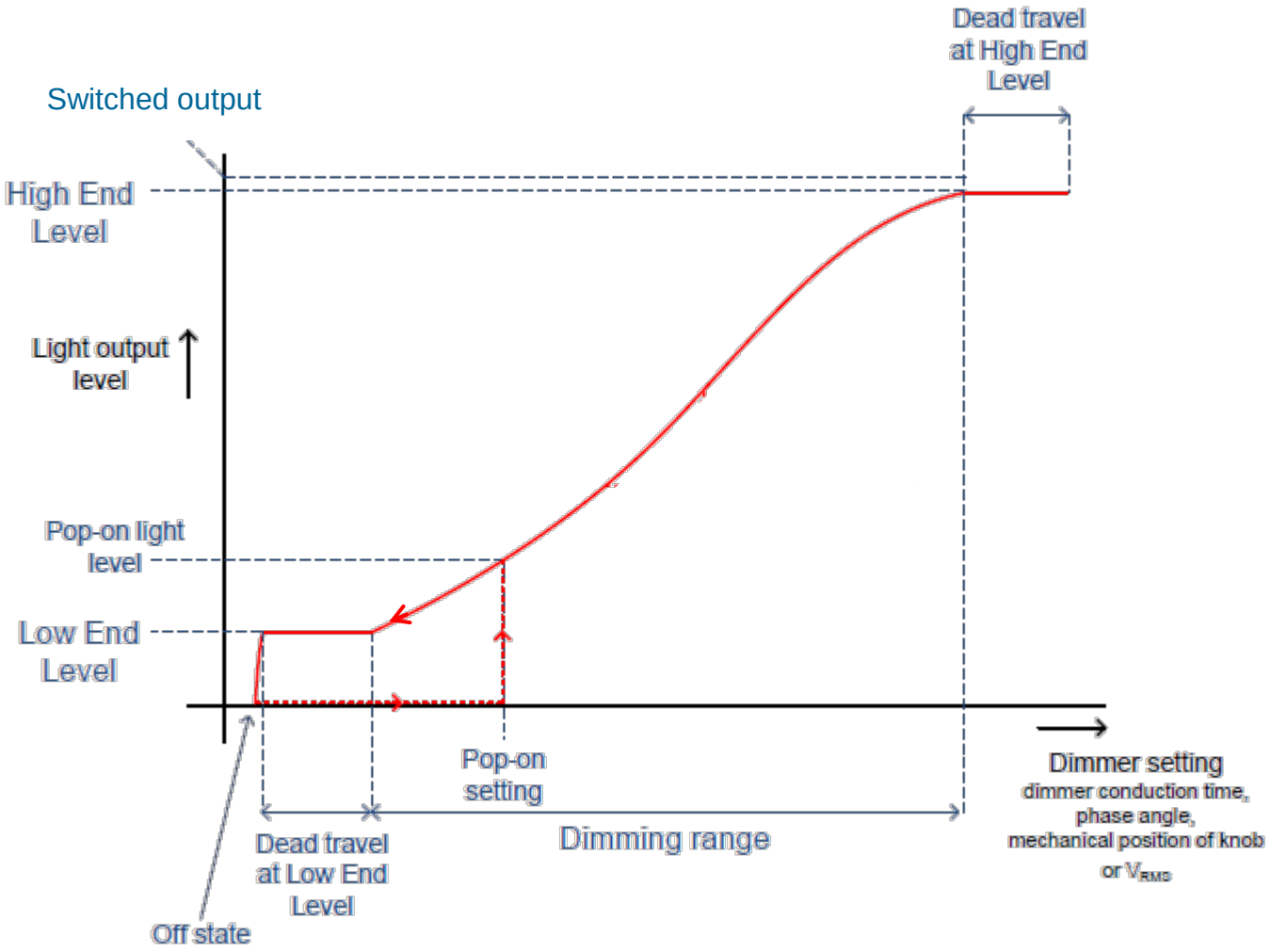
Potential compatibility issues with phase-cut dimmers

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

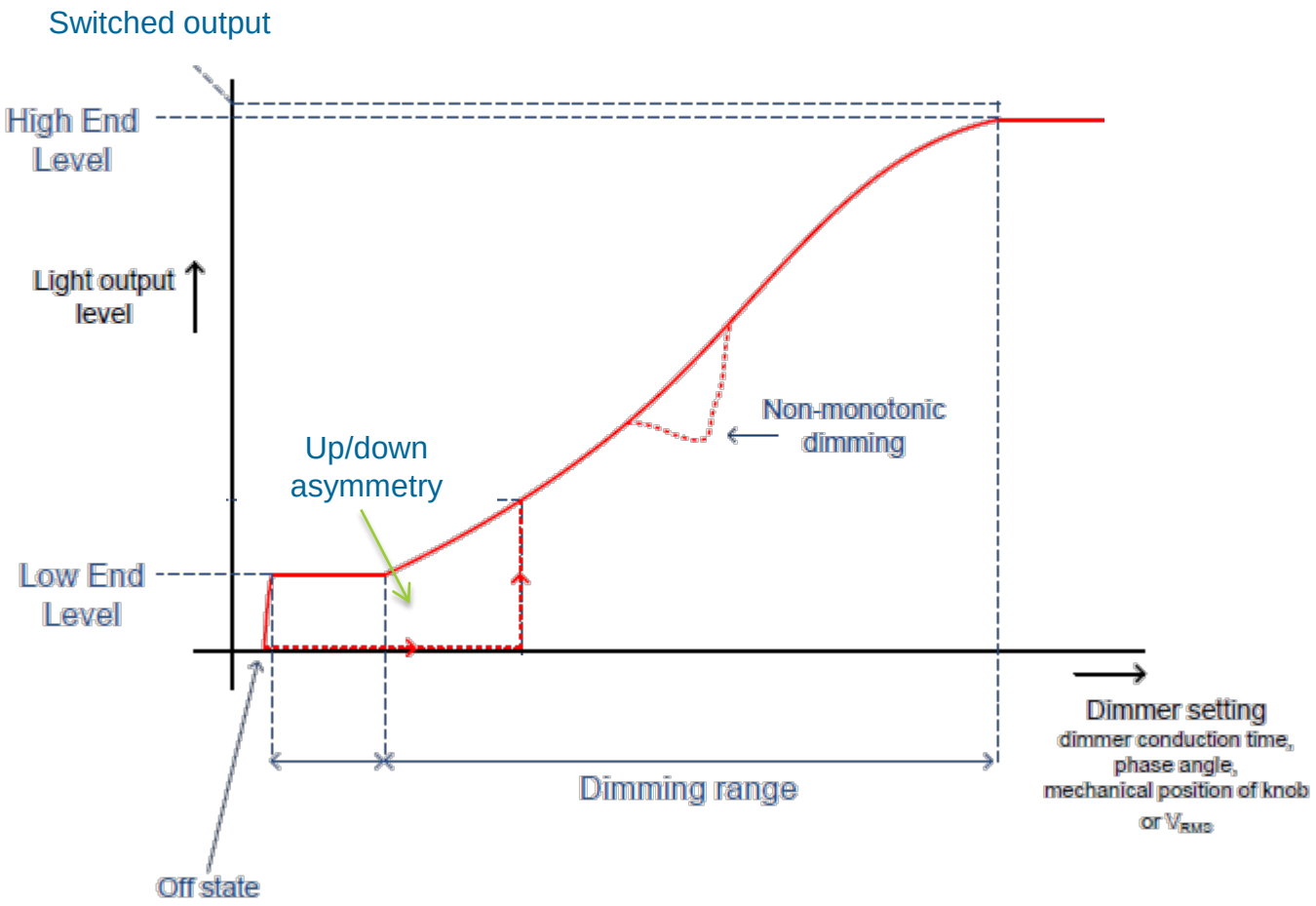
- Dimming range
- Dimming curve
- Dead travel
- Pop-on
- Drop-out
- Flashing, Ghosting
- Premature failure
- Audible noise
- Inoperability
- Predictability

Dimming range, dead-travel, pop-on



Source: Modified from NEMA SSL-6

Smoothness, monotonicity, up/down symmetry



Source: Modified from NEMA SSL-6

Phase-cut dimmer loading

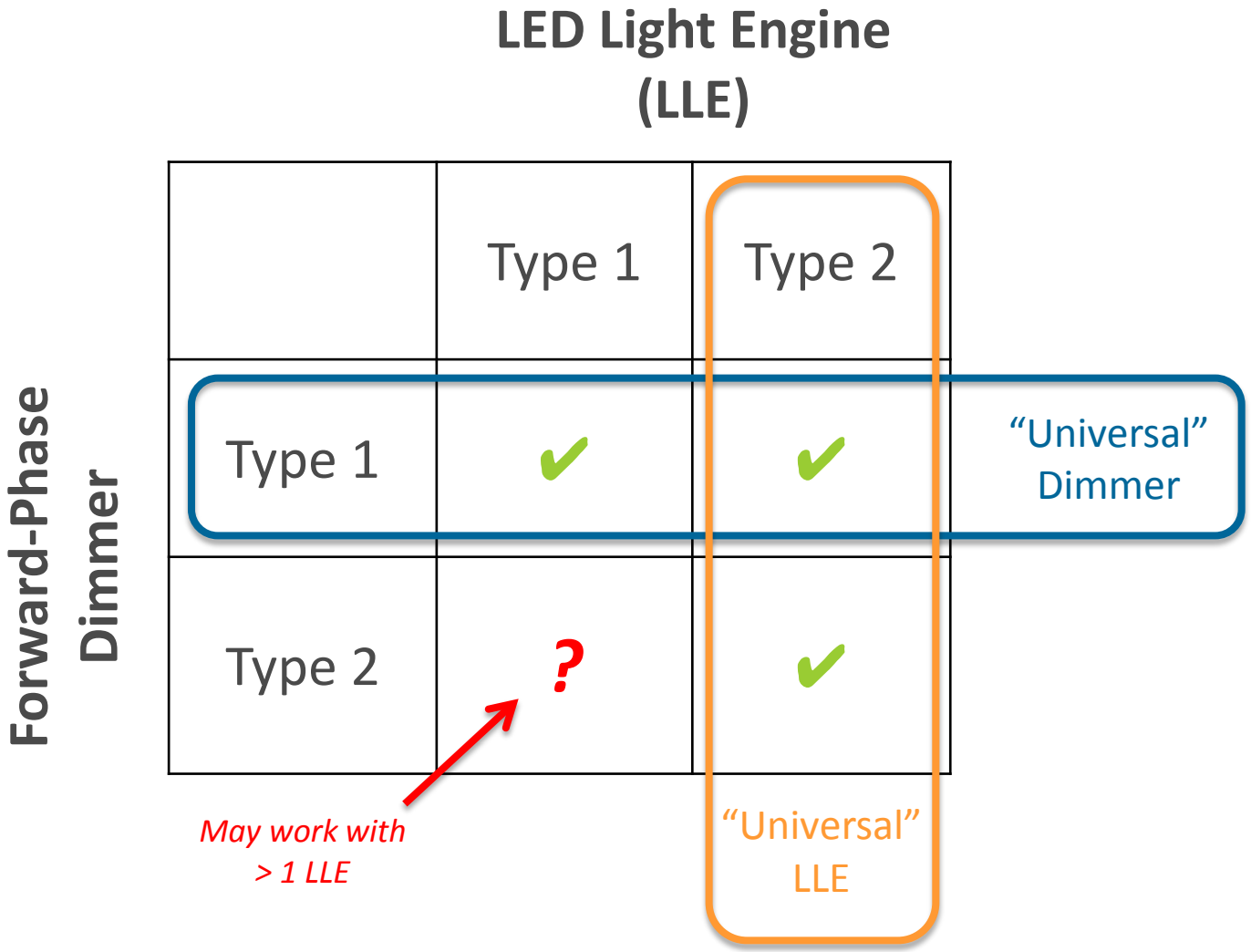
- Minimum load varies by dimmer and LED source
- Maximum load varies by dimmer and LED source
- Overloading can lead to premature failure

Dimmer	Source	Possible loading
600W incandescent	60W incandescent 	1-10
600W incandescent	12W LED 	~~1-30?~~ 3-10
600W ELV	50W halogen 	1-12
600W ELV	10W LED 	~~1-30?~~ 2-30

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



Commercially available NEMA SSL-7A compliant dimmer

369810a 1 04.08.14

Diva® 250 W C•L® Dimmer

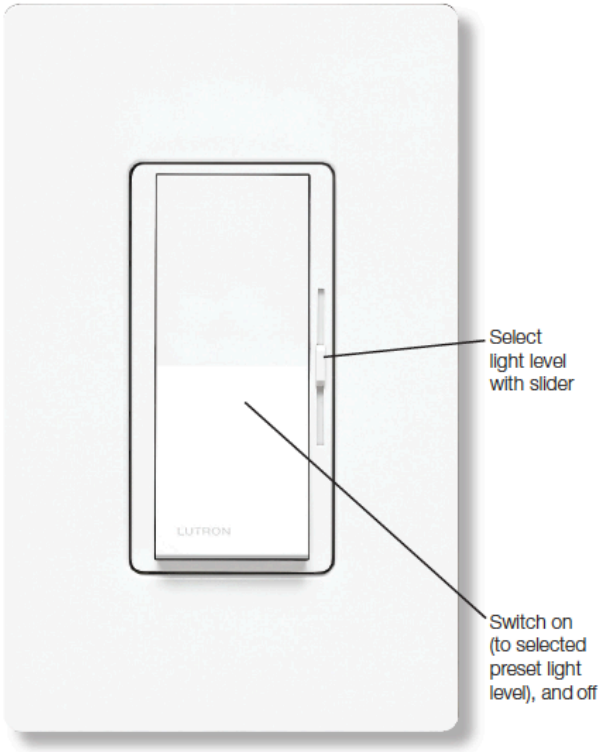
Dimmer for CFL, LED, Halogen, and Incandescent dimmable bulbs.

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/dimcflled. 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/dimcflled.



* 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

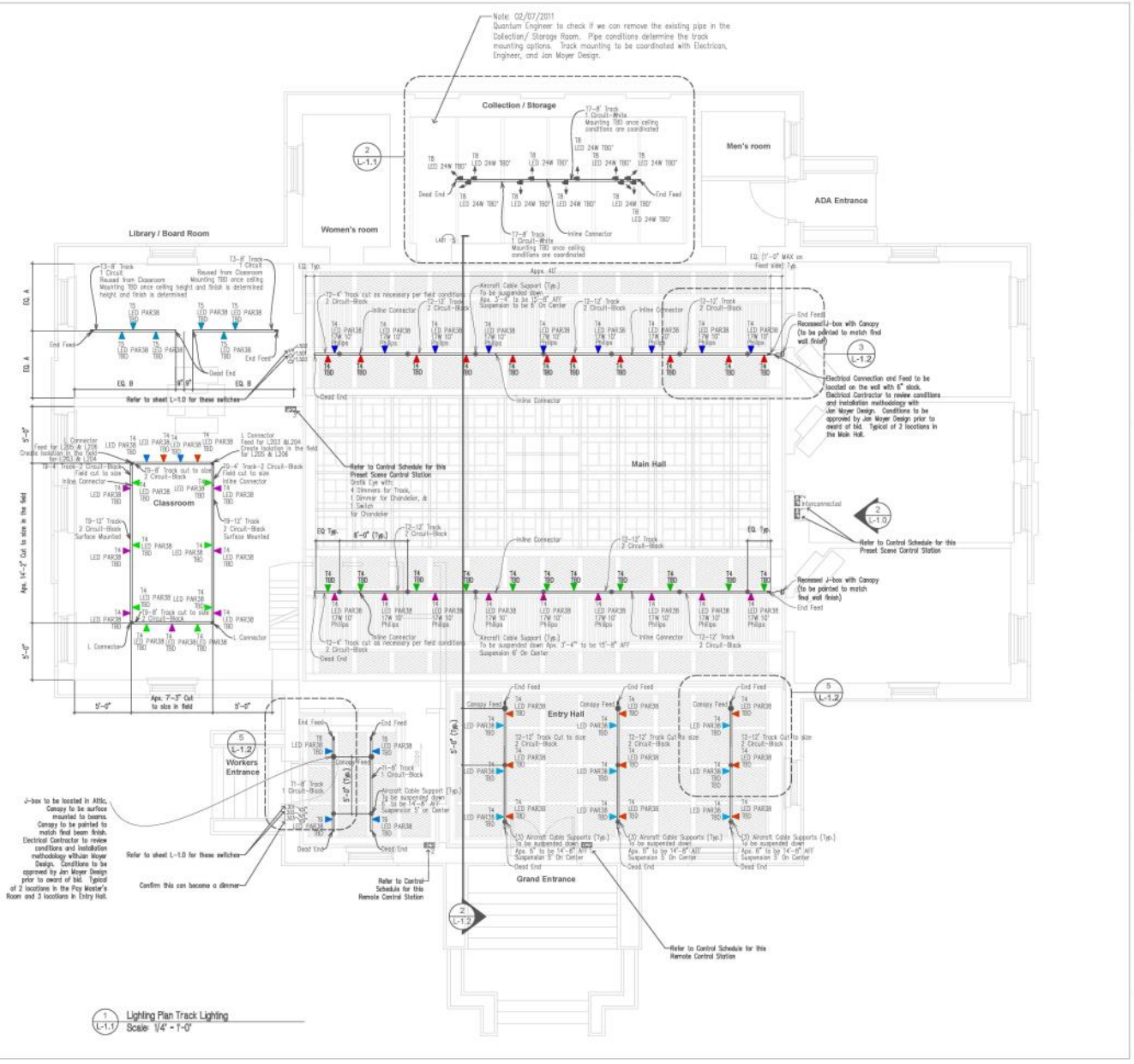
- Install 3-wire dimmers in wall-box applications with neutral wires (as now required by code)
- Install NEMA SSL-7a compliant LED sources AND dimmers in existing 2-wire wall-box applications
- Leverage manufacturer guidance for pairing LED sources and dimmers
- Follow loading guidance for new dimmers; 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

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2013_gateway_dimming.pdf

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

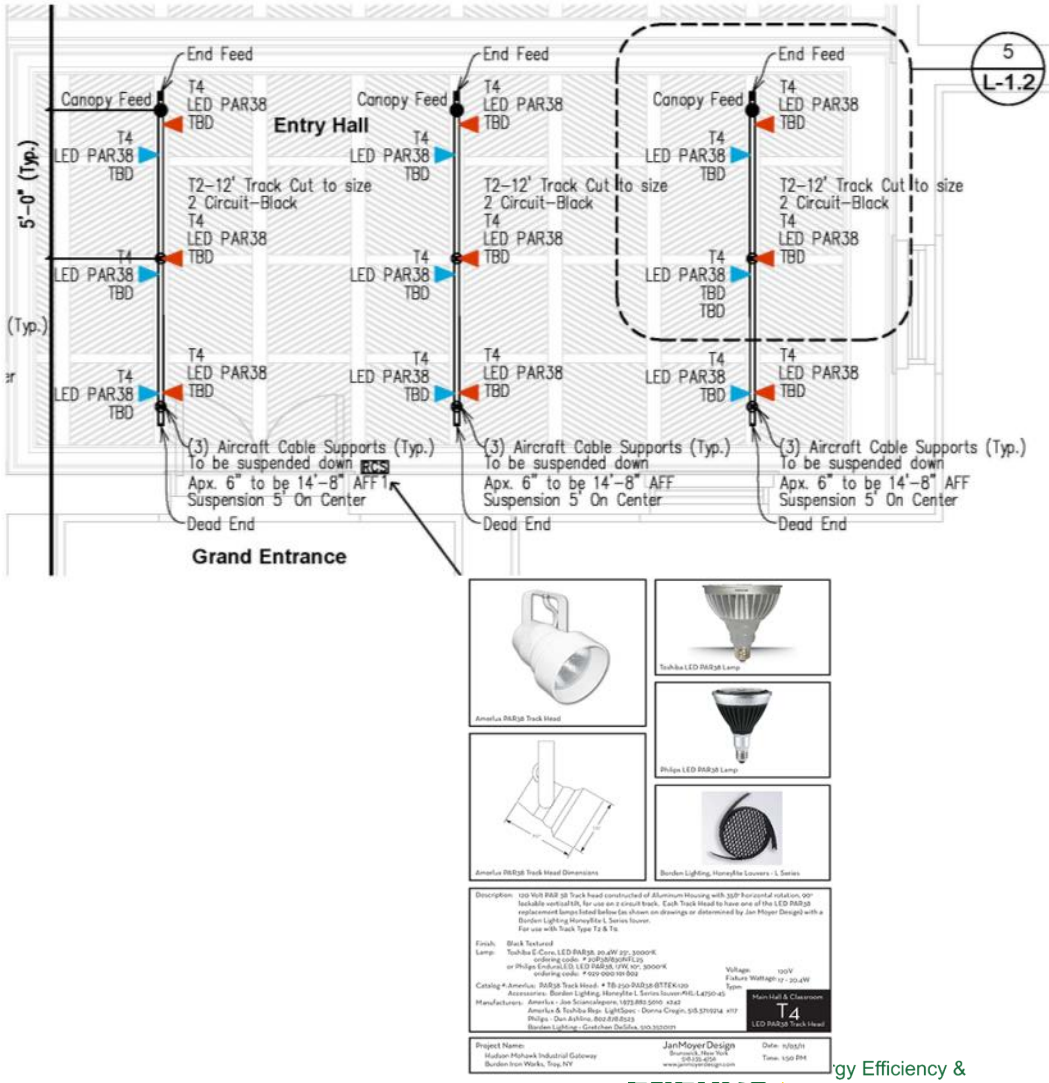
1. ***Design the lighting layout and select the control system: (Luminaires/lamps and identify make/model of control system)***

- **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.)

Design Process for compatibility of controls

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.**



Design Process for compatibility of controls

*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**

Item	Brand	Series	ID	Load	Type	Dimming level Max.->Min. (flux%) 1 lamp	Flickering 1 lamp	Flickering 3 lamps	Flickering 5 lamps	Flickering 8 lamps
1	LEVITON	Decora	6161	500W	LE	99%-0	No	No	No	No
2	LEVITON	Trimatron	6684	600W	LE	100%-0	No	No	at ~40%	at ~40%
3	LEVITON	SureSlide	6613	600W	LE	100%-2%	No	No	No	No
4	LEVITON	Illumatech	IPI06-1L	600W	LE	100%-9%	No	at ~60%	~40%-50%	~0%-40%
5	LUTRON	Ariadni	AY-600P	600W	LE	100%-5%	No	No	No	No
6	LUTRON	Diva	DV-600P	600W	LE	99%-2%	No	No	No	at ~70%
7	LUTRON	Diva	DVPDC-203P	200W	LE	99%-29%	No	~0-50%	no dimmability	no dimmability
8	LUTRON	Glyder	GL-600	600W	LE	100%-2%	No	No	No	No
9	LUTRON	NOVA	NLV-1000	1000W	LE	100%-3%	No	No	No	No
10	LUTRON	Qoto	Q-600P	600W	LE	100%-4%	No	No	No	at ~70%
11	LUTRON	Skylark	S-600P	600W	LE	90%-3%	No	No	No	at ~80%
12	LUTRON	Toggler	TG-600P	600W	LE	100%-5%	No	No	No	at ~70%
13	LUTRON	Credenza	TT-300	300W	LE	100%-0	No	No	No	at ~40%

Design Process for compatibility

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.

LUTRON®
Product Report Card

Manufacturer: Philips
Applicable Model Numbers: 92900017 1200/1300/1400

Manufacturer's Description
Type of Fixture: PAR38 Indoor Flood
Operating Voltage: 120 VAC
Input Power: 16 W
Current: 185 mA
Frequency: 60 Hz
Control Types: Not Specified
Dimming Range: Not Specified
Equivalent Incandescent Output Power: 45 W
Lumens: 650 lm (3000K)

Lutron Test Results
Date Tested: May 4, 2010
Model Number Tested: EnduraLED PAR38 dimmable 120V 16W
Smooth and Continuous: Yes
Test Notes: None

Lutron Recommended Compatible Products

Product	Part Number	Fixtures per Dimmer	Measured Light Output Range (1)	Comments
RadioRA 2	RRD-10ND	1-16	4%-100%	Smooth and continuous
Homeworks	HWD-5NE	1-7	3%-100%	Smooth and continuous
	HWD-6NE	1-9	17%-100%	Smooth and continuous
	HW-RPM-4A-120	1-18 per output	8%-100%	Smooth and continuous Maximum of 29 fixtures
Commercial Systems	QSG-6P	1-14 per output	2%-100%	Smooth and continuous Maximum of 35 fixtures
	LP-RPM-4A-120	1-18 per output	8%-100%	Smooth and continuous Maximum of 29 fixtures
Interfaces	PHPM-WBX	1-29	7%-100%	Smooth and continuous

(1) Values are based on light output using the specified dimming control, and may not be an indication of the fixture's full capability

Comments: Some dimmers may require a low-end trim adjustment. The ability to set the low-end trim is available on select 3-Wire Fluorescent dimmers, Homeworks, and Commercial Systems products. Refer to product documentation or www.lutron.com for details.

- **Lutron Report Card for Philips PAR38 LED lamp says 1 to 14 lamps per zone**

Design Process for compatibility of controls

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

PSC-1	***Museum Main Hall and Entry Hall, Track Lighting***						
Control Zone Number	***Zone Lighting Description***	***Fixture Type***	***Fixture Quantity***	***Fixure Load Type***	***Maximum Watts per Track Head***	***Total Zone Watts***	***Remarks***
1	Track accent 1 - Entry Hall	T4	9	LED integral lamps for Forward Phase Incandescent Dimmer	16	144	**Dimming mfg recommends 1 to 14 lamps per dimmer, smooth dimming down to 2%**
2	Track accent 2 - Entry Hall	T4	9		16	144	
3	Track accent 1 - West	T4	9		16	144	
4	Track accent 2 - West	T4	11		16	176	
5	Track accent 1 - East	T4	11		16	176	
6	Track accent 2 - East	T4	9		16	144	
				TOTAL LOAD (WATTS)		**928**	

- And…Control Zone 2 is the same as Zone 1!

Design Process for compatibility of controls

TA DA!

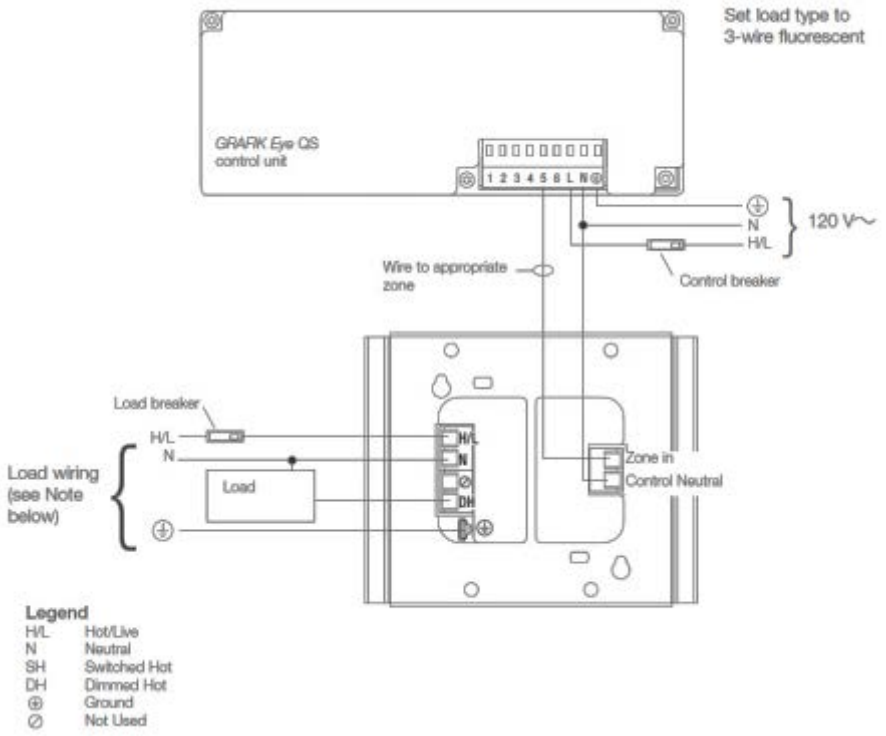
First 2 LED luminaire and control zones *done*.

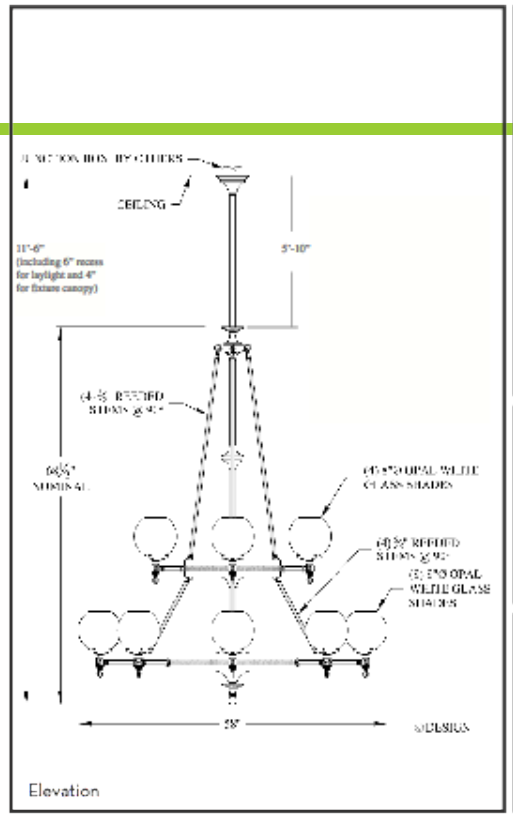
What if there are too many LEDs for the dimmer?

What a Phase-Adaptive Power Module does:

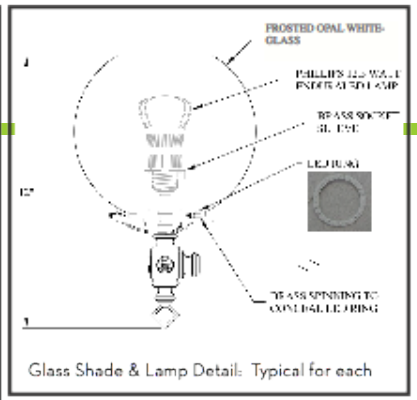
Module wired between dimmer channel and load

- 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.





Elevation



Glass Shade & Lamp Detail: Typical for each

Philips Endura LED A19

Plan View

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 #L101
Amber LED ring, Load #L102

Finish: Brass with Incralac Laquer

Lamp: Each Globe: Q. 1, Philips Endura LED, 12.5W, 120V, 2700°K A19 LED med. base (provided by contractor)
Q. 1, Superbrightleds.com, AE Angel Eye LED Ring: # AE80-A24, Amber 2.1W, 12V, 1200°K, 2.36" diameter, Driver: # HMA-30NU-R12 (LED Ring and Driver integral to the chandelier)

Voltage: 120V

Fixture Wattage: 150W LED A19
25.2W LED Ring

Type: Main Hall **CH1** Large Chandelier

Catalog #: **Custom Fixture: # CD-7064-12, 12 Arm**
Spare Replacement Glass Shade: Q.1, 8" dia. Frosted Opal White Glass

Manufacturer: St. Louis Antique Lighting Co.
Ann Marie - ambehm@slalco.com, 314.863.1414

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……

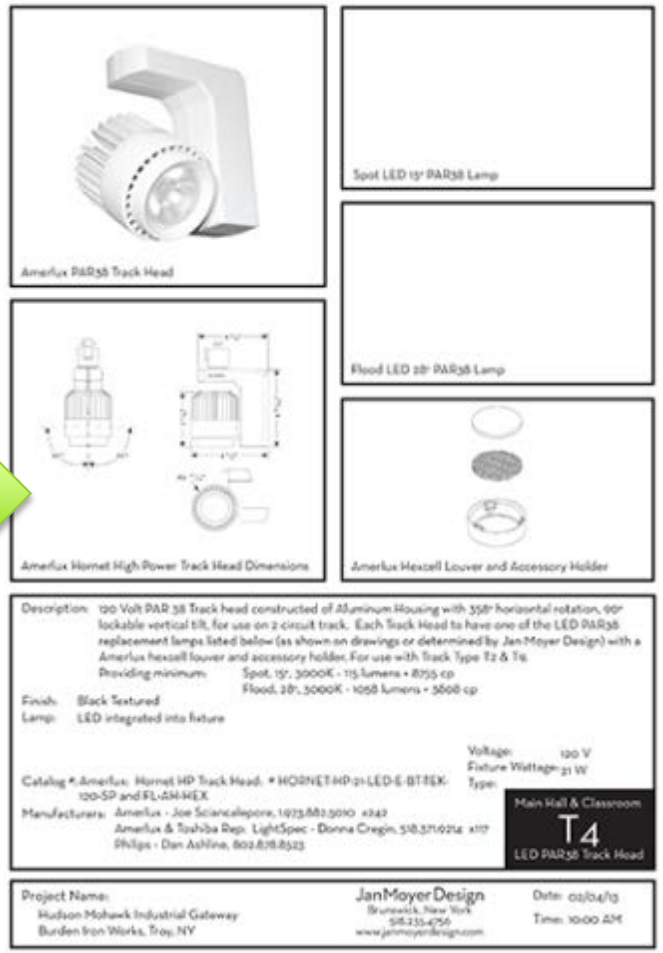
……time passes……

…….and lamps have changed to a different chip

and driver…..

…and the specified LED strips are no longer available…


Amerlux PAR38 Track Head
Toshiba LED PAR38 Lamp
Philips LED PAR38 Lamp
Amerlux PAR38 Track Head Dimensions
Borden Lighting, Honeylite Louvers - L Series
Description: 120 Volt PAR 38 Track head constructed of Aluminum Housing with 358° horizontal rotation, 90° lockable vertical tilt, for use on 2 circuit track. Each Track Head to have one of the LED PAR38 replacement lamps listed below (as shown on drawings or determined by Jan Moyer Design) with a Borden Lighting Honeylite L Series louver.
For use with Track Type T2 & T4
Finish: Black Textured
Lamp: Toshiba E-Core, LED PAR38, 20.4W 27°, 3000°K
ordering code: # 20P38/830/NFL25
or Philips EnduraLED, LED PAR38, 17W, 10°, 3000°K
ordering code: # 929 000 101 602
Catalog #: Amerlux: PAR38 Track Head: # TB-250-PAR38-BTTEX-120
Accessories: Borden Lighting, Honeylite L Series louver:#HL-L4750-45
Manufacturers: Amerlux - Joe Sciancalepore, 1.973.882.5010 x242
Amerlux & Toshiba Rep: LightSpec - Donna Cregin, 518.371.9214 x117
Philips - Dan Ashline, 802.878.8523
Borden Lighting - Gretchen DeSilva, 510.357.0171
Voltage: 120V
Fixture Wattage: 17 - 20.4W
Type:
Main Hall & Classroom
T4
LED PAR38 Track Head
Project Name:
Hudson Mohawk Industrial Gateway
Burden Iron Works, Troy, NY
JanMoyer Design
Brunswick, New York
518.235.4756
www.janmoyerdesign.com
Date: 11/01/11
Time: 1:50 PM


Amerlux PAR38 Track Head
Spot LED 15° PAR38 Lamp
Flood LED 28° PAR38 Lamp
Amerlux Hornet High Power Track Head Dimensions
Amerlux Hexcell Louver and Accessory Holder
Description: 120 Volt PAR 38 Track head constructed of Aluminum Housing with 358° horizontal rotation, 90° lockable vertical tilt, for use on 2 circuit track. Each Track Head to have one of the LED PAR38 replacement lamps listed below (as shown on drawings or determined by Jan Moyer Design) with a Amerlux hexcell louver and accessory holder. For use with Track Type T2 & T4.
Providing minimum: Spot, 15°, 3000K - 115 lumens = 8755 cp
Flood, 28°, 3000K - 1058 lumens = 3808 cp
Finish: Black Textured
Lamp: LED integrated into fixture
Catalog #: Amerlux: Hornet HP Track Head: # HORNET-HP-31-LED-E-BTTEX-120-SP and FL-AM-HEX
Manufacturers: Amerlux - Joe Sciancalepore, 1.973.882.5010 x242
Amerlux & Toshiba Rep: LightSpec - Donna Cregin, 518.371.9214 x117
Philips - Dan Ashline, 802.878.8523
Voltage: 120 V
Fixture Wattage: 31 W
Type:
Main Hall & Classroom
T4
LED PAR38 Track Head
Project Name:
Hudson Mohawk Industrial Gateway
Burden Iron Works, Troy, NY
JanMoyer Design
Brunswick, New York
518.235.4756
www.janmoyerdesign.com
Date: 02/04/13
Time: 10:00 AM

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

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

Read about dimming in a DOE GATEWAY report on line

Questions?

Lightfair

June 3-5, 2014

Michael.Poplawski@PNNL.gov

and Naomi.Miller@PNNL.gov

Pacific Northwest National Laboratory