The Path to Successfully Specifying LED Lighting Control



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LUTRON®

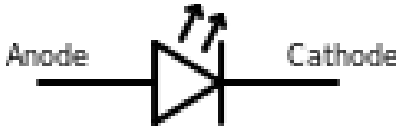
Agenda

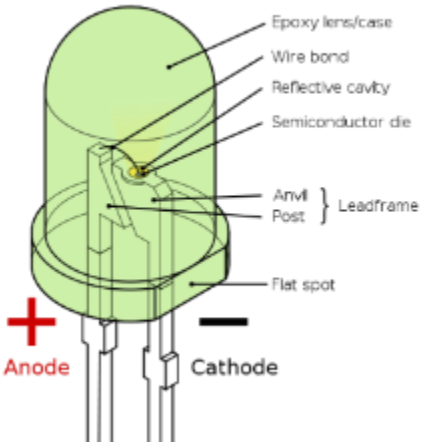
- LED basics
- LED dimming challenges
- Specification guidelines
- Recap

LED Basics

What is an LED?

- LED – Light Emitting Diode – Solid State Lighting
- First practical use in the 1960's
  - Indicators, panel displays, 7 segment displays
- Widely used for general lighting today

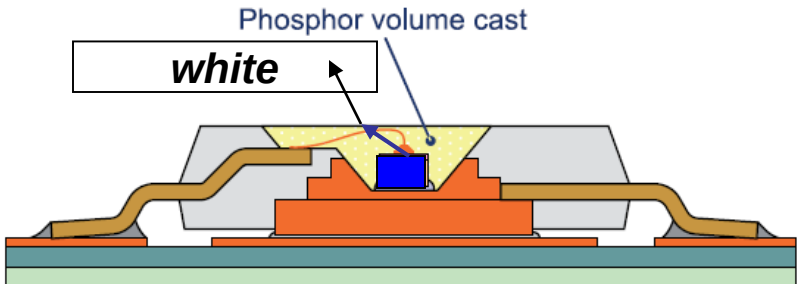


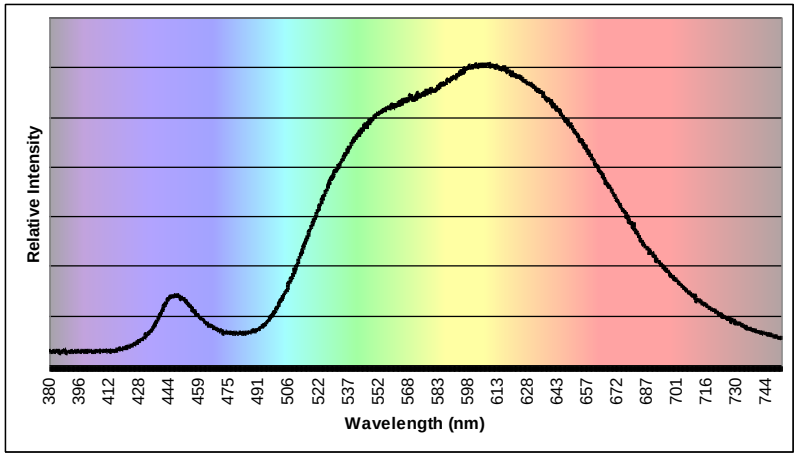


Source: http://en.wikipedia.org/wiki/LED

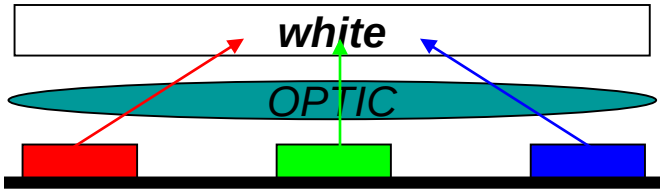
White Light from LEDs

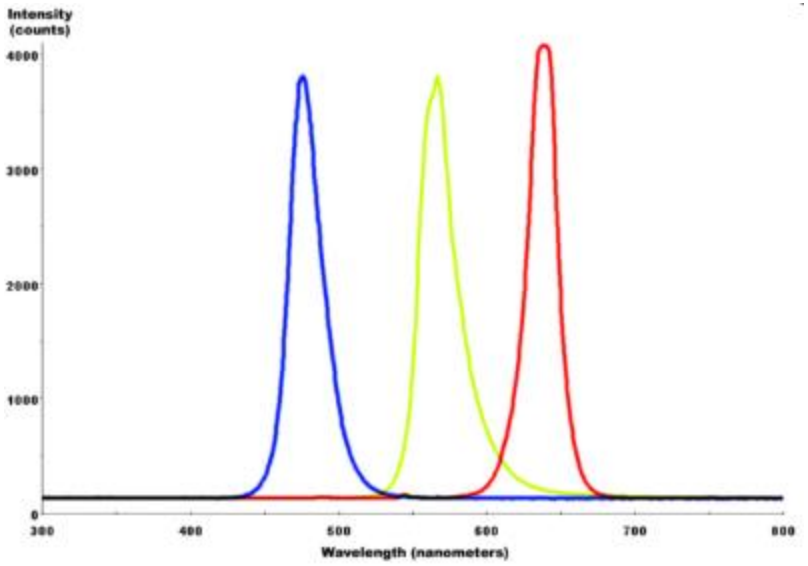
- Phosphor Conversion method:





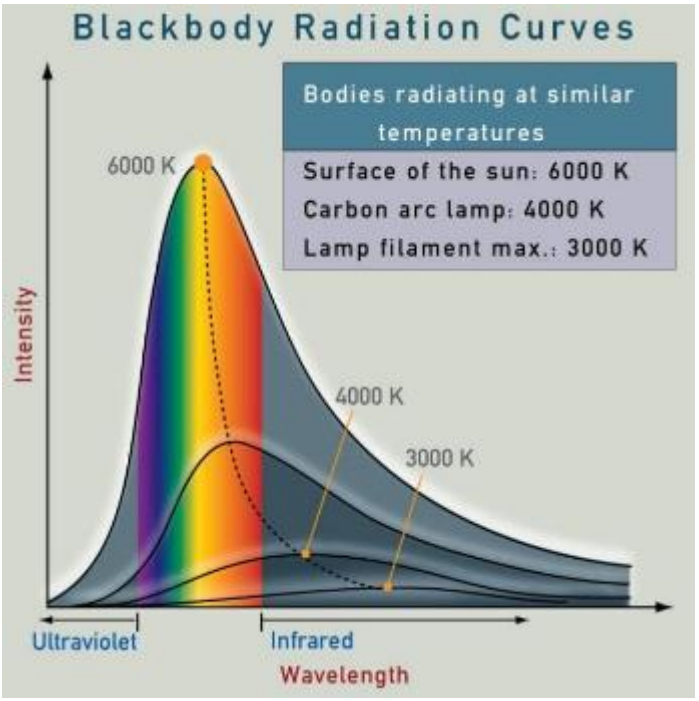
- RGB Method:





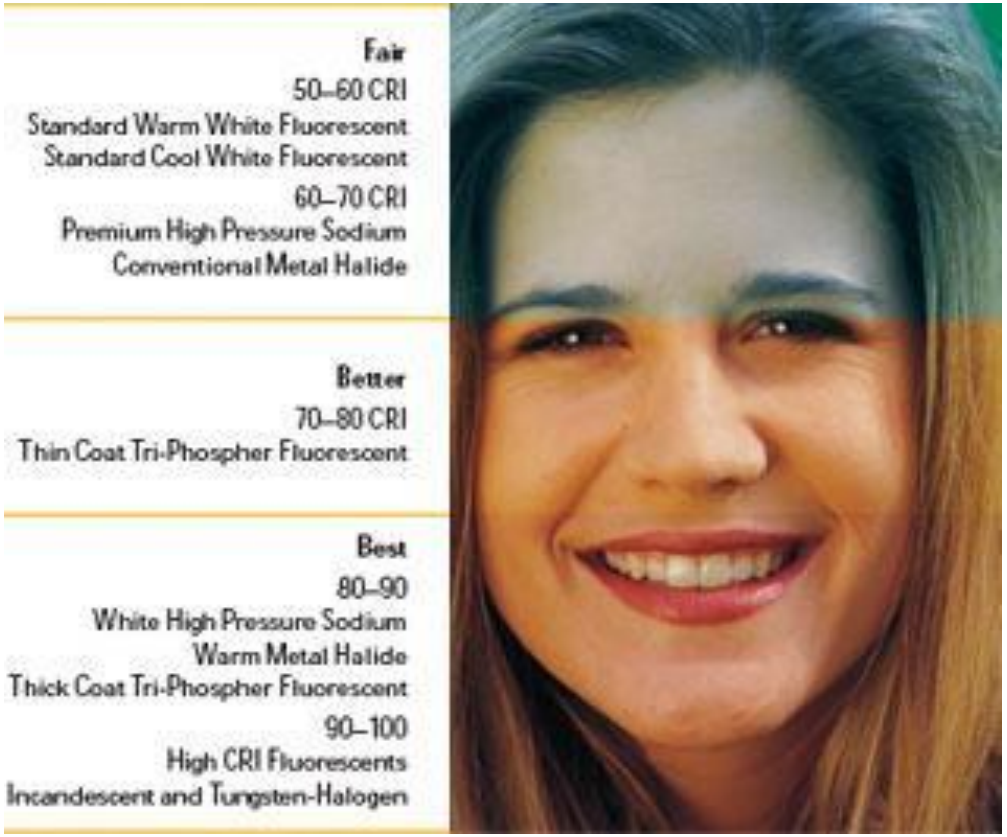
Color Temperature (CCT)

- Correlated Color Temperature (CCT)
  - From heated black body radiator
  - Higher temp = cooler color (Blue)
  - Low temp = warmer color (Red)
  - Measured in degrees Kelvin (K)



Color Rendering Index (CRI)

- CRI attempts to describe how well (accurately) a light source shows color
- Based on eight “standards”
- The “R9” number must be greater than 0 for best color
- *This is still a highly contested issue*



LED Advantages

- High efficacy
  - Fixtures can achieve 150 Lumens Per Watt efficacies (and improving)

Category	Type	Overall luminous efficacy (lm/W)
Incandescent	5–40–100 W tungsten incandescent (120 V)	5-15
	Tungsten quartz halogen (12–24 V)	24
Light-emitting diode	White LED (raw, without power supply)	4.5–150
	Medium wattage LED screw base lamp (120 V)	58–93
	LED troffer or downlight fixture	50-120
	Theoretical limit (white LED with phosphorescence color mixing)	260–300
Fluorescent	9–32 W compact fluorescent (with ballast)	46–75
	T8 tube with electronic ballast	80–100
	T5 tube	70–104
Gas discharge	1400 W sulfur lamp	100
	Metal halide lamp	65–115
	High pressure sodium lamp	85–150
	Low pressure sodium lamp	100–200
Ideal sources	Truncated 5800 K blackbody	251
	Green light at 555 nm (maximum possible luminous efficacy)	683

Source: http://en.wikipedia.org/wiki/Luminous_efficacy

LED Advantages

- Longevity
  - Useful life (L70) of 25,000 to 50,000+ hours
  - Good color stability over time and temperature
- Environmentally friendly
  - No hazardous materials
- Immediate light output
  - No delay or warm up
- Excellent cold-weather performance

LED Limitations

- Higher first cost
  - LEDs for general illumination are (still) expensive
  - More complex than a simple filament lamp
- Thermal Management
  - Heat must be conducted away from LEDs

- Confusing/inconsistent literature and specs
  - Information about dimming varies widely and is sometimes missing completely!

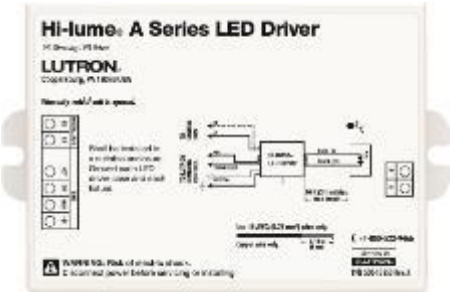
LED Limitations

- Controls compatibility
  - Dimmable fixtures may have unknown or poor performance
  - Not all LEDs are dimmable

- Application-specific challenges
  - No one style is universally accepted
  - High amount of product variation
  - Inexperienced manufacturers / exaggerated claims

- Color consistency
  - Color shift in LED light output can occur over time
  - “Good” color temperature does not equate to high CRI

Lamps vs. Fixtures



Driver

LED Module
Light Engine

Housing

LED Dimming Challenges

Why Dim LEDs?

- Dimming LEDs saves energy
  - 50% dimming = 50% energy savings
  - Add savings to an already efficient source

- Dimming lowers operating temperatures, i.e. longer life
  - Extends component life (electronics & phosphor)
  - Double or triple lumen maintenance

- General dimming benefits
  - Enhance ambiance
  - Space flexibility
  - Improve safety
  - Increased productivity

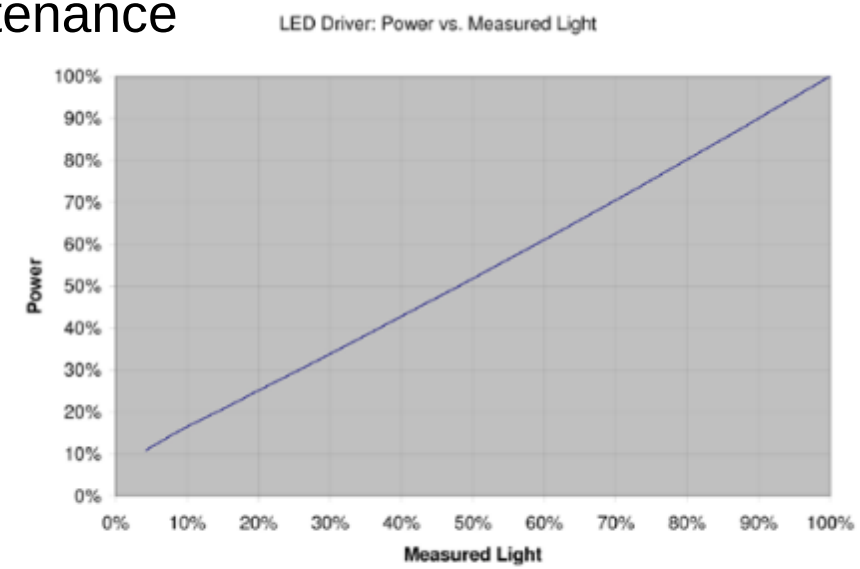


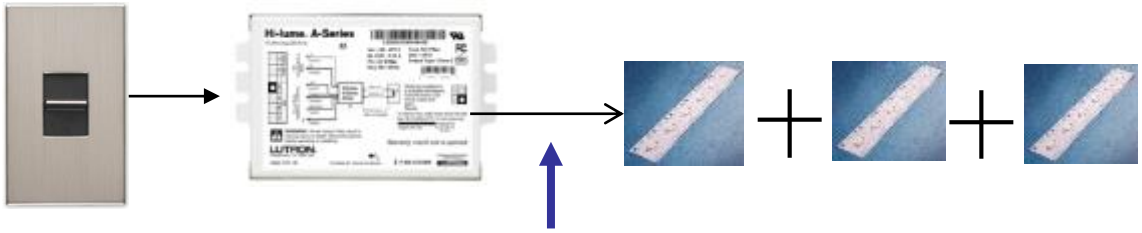
FIGURE 1:
LED Driver: Power vs. Measured Light

How Do We Dim LEDs?

- **Constant Current and Constant Voltage**
  - Constant Current
    - LED module with known characteristics
    - Typically used in downlights

Constant Current Output

  - Constant Voltage
    - Variable amount of LED fixtures
    - Typically for linear lighting – Coves, under cabinet, LED tape



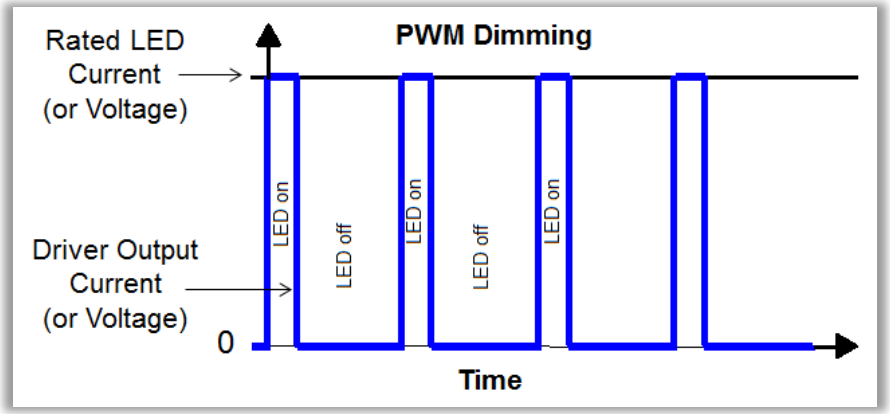
Constant Voltage Output

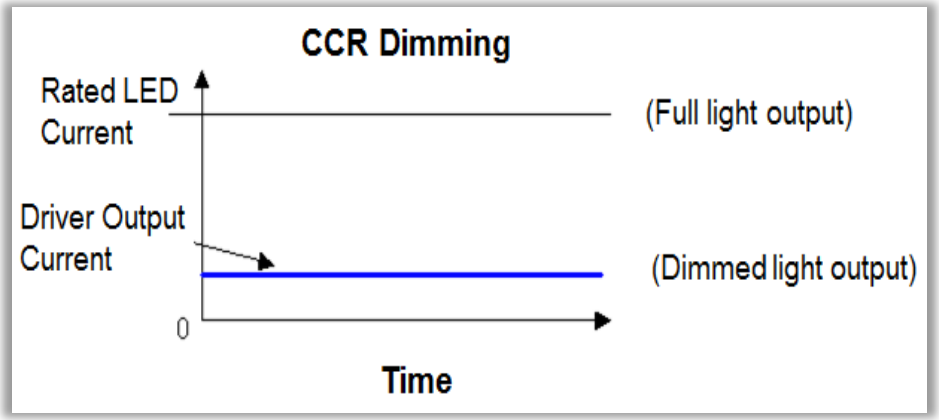
How Do We Dim LEDs?

- **Pulse Width Modulation (PWM) or Constant Current Reduction(CCR)**

PWM
- Most common
- Both Constant Current and
- Constant Voltage drivers

CCR
- Only Constant Current drivers
- Eliminates flicker
- Solves video interference issues





Dimming Challenges

- Understanding LED complications is essential
  - Inexperienced luminaire manufacturers
  - Multitude of control types
  - Performance issues

- Driver-related challenges
  - LEDs are *fast* and can be susceptible to flicker
  - Stability of (DC) output from driver is important
  - Driver must be designed for the same lifetime and application as the LEDs

Dimming Challenges

- Driver Issues
  - Flicker/Shimmer/Strobe
  - Pop-on
  - Drop out
  - Popcorn
  - Poor Low End
  - Dead Travel
  - Steppy Dimming
  - Audible noise

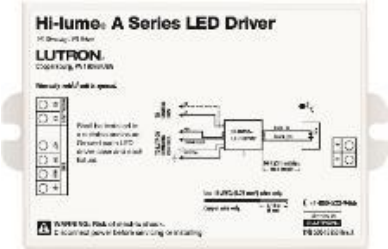
- Light Engine Issues
  - Color Temperature
  - Color Rendering
  - Color Shift

Why LED Drivers are so important!

If you only remember two things…

1. ***The LED driver design determines the best possible dimming performance***

Selecting a reliable driver will eliminate the common concerns of LED lighting (flicker, loading, dimming performance)



2. ***The compatibility between the LED driver and the control determines to what degree the <u>driver</u> can deliver upon its designed performance***

Selecting a reliable control ensures that the driver performs to the best of its ability.

Specification Guidelines

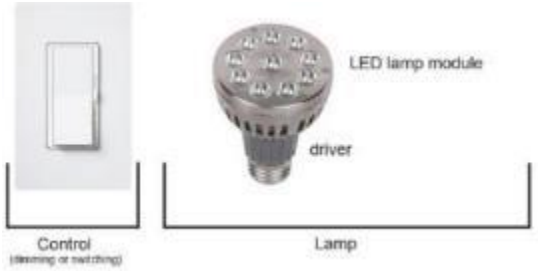
Steps for a successful LED control system

Ask…and answer…the following questions to match expectations with performance:

1. What type of LED product am I using: a lamp or fixture?
2. What type of control does the LED product need?
3. What is the dimming range of the lamp/fixture?
4. What is the dimming performance of the product?
5. What is the minimum or maximum number of lamps/fixtures that can be connected to one dimmer?

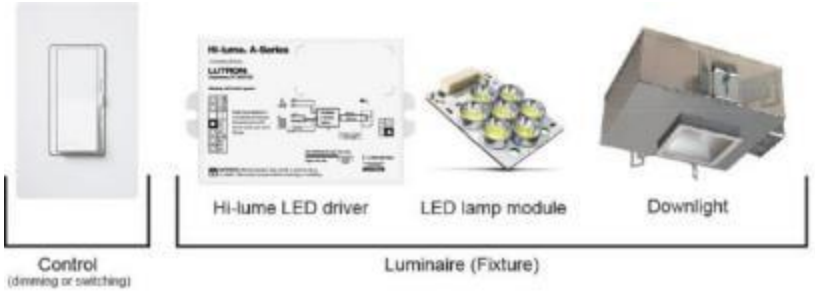
1) What type of LED product am I using?

LED Lamp (LEDi)



- Designed to replace standard incandescent lamps
- Screw or pin base
- Integral drivers determine dimming performance
- Typically controlled with phase control dimming

LED Fixtures



- Variable in purpose
- Usually have an external driver, selected by the OEM mounted as part of the fixture housing
- OEMs offer multiple driver options to support different control technologies and applications

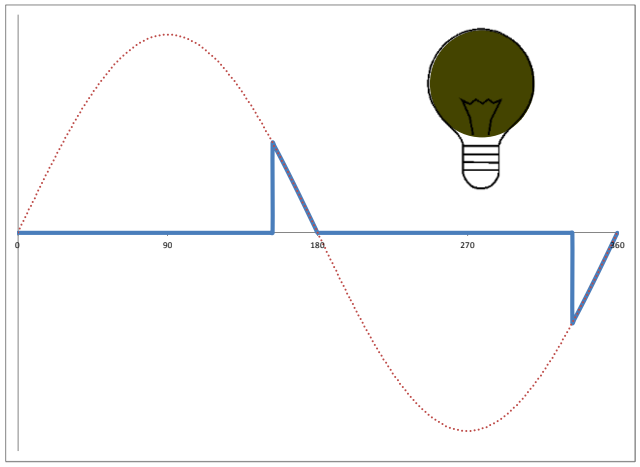
2) What control type does the LED (driver) need?

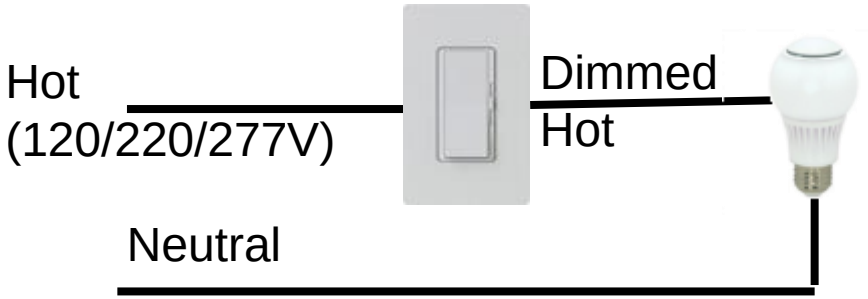
- Control type refers to the signal and wiring between the control and LED lamp/fixture
  - LEDi Lamps generally use only forward/reverse phase control
  - Fixtures can use any method
  - The control MUST match the control type needed by the driver!

- Control Options
  - Forward Phase
  - Reverse Phase
  - 3 Wire
  - 0-10V
  - DMX 512
  - DALI / EcoSystem

2) What control type does the LED (driver) need?

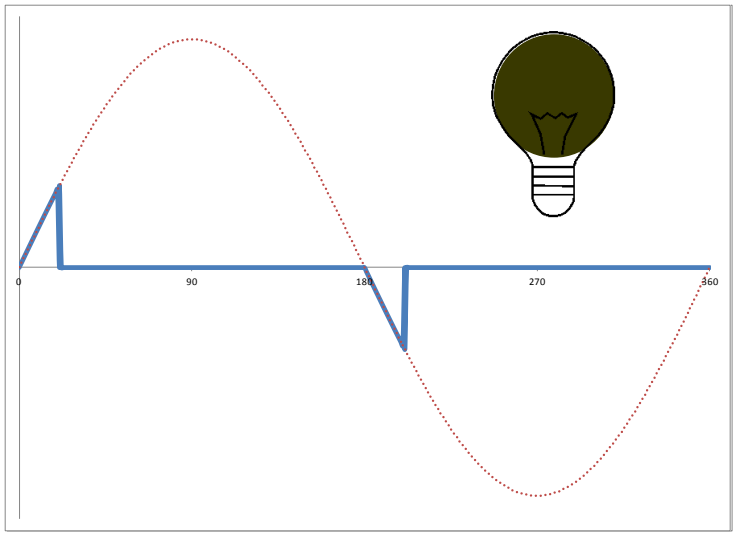
- Forward Phase analog (Leading Edge/Triac)
  - Most common dimming method
    - 150 million dimmers in use
  - Designed for resistive (incandescent, halogen) or magnetic low-voltage (MLV) loads
  - Installed base of incandescent dimmers not intended for LEDs
    - Performance issues and compatibility problems likely

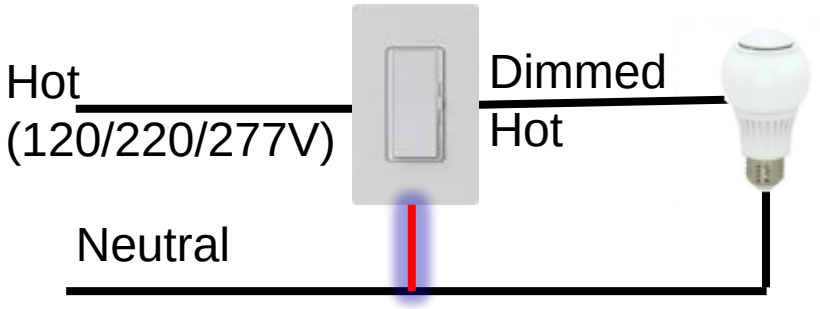




2) What control type does the LED (driver) need?

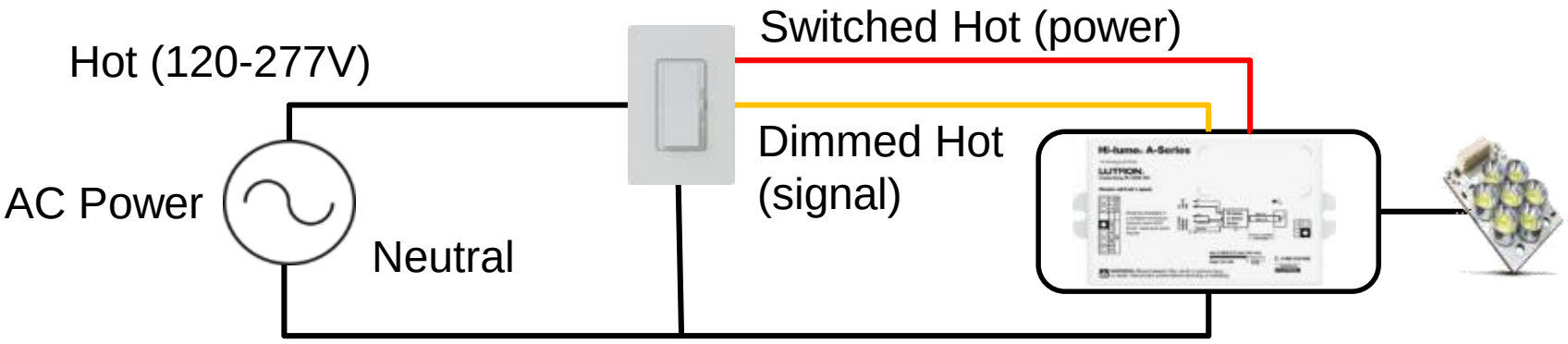
- Reverse Phase analog (Trailing Edge/FET)
  - Typically used for ELV loads,
  - Smaller installed base, usually require a neutral wire
  - Sometimes perform better with LEDs





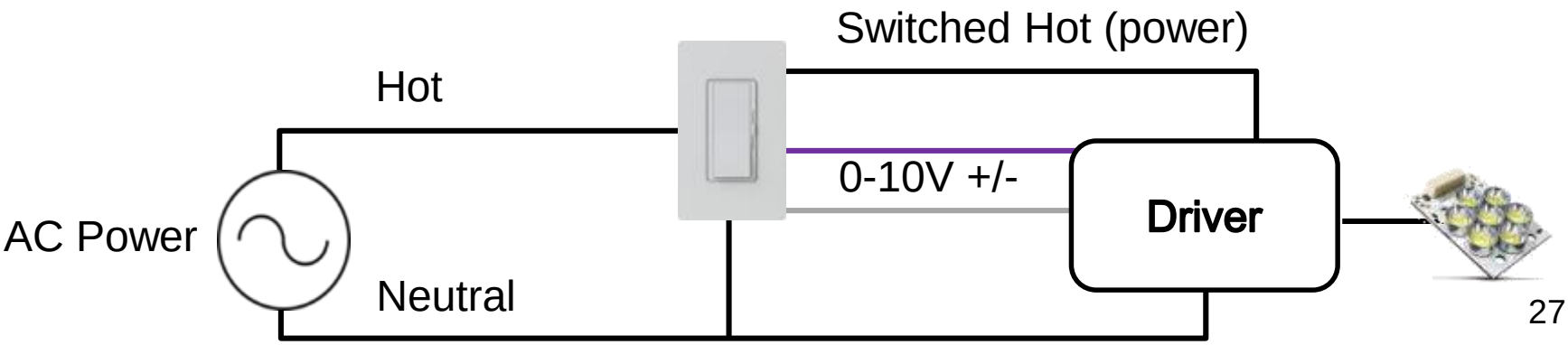
2) What control type does the LED (driver) need?

- 3-Wire analog
  - Fluorescent standard, control signal carried separate from power
  - Less prone to noise, but requires a third line voltage wire
  - Easier to design a high quality LED driver



2) What control type does the LED (driver) need?

- 0-10V analog
  - Analog control standard, low voltage wiring to each fixture in lighting control zone
  - IEC standard 60929 for architectural lighting
    - ANSI theatrical standard also exists
    - The two standards are not cross-compatible!
  - Requires 0-10V low voltage control output AND line voltage switching



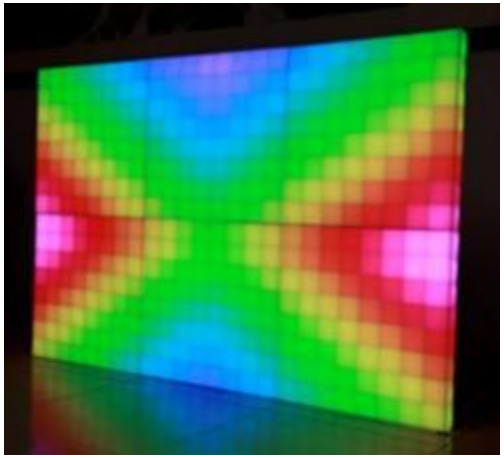
2) 0-10V System Risks and Limitations

- Risks:
  - IEC 60929 or ESTA?
  - Noise coupling into 0-10V wires can become visible variations in light
  - Wiring is polarity sensitive
  - 2 Amps of nominal load current (240W @ 120V) can cause enough inrush current to false-trip commonly available breakers due to driver inrush

- Limitations:
  - It's a 20th century analog solution for customers expecting 21st century digital flexibility

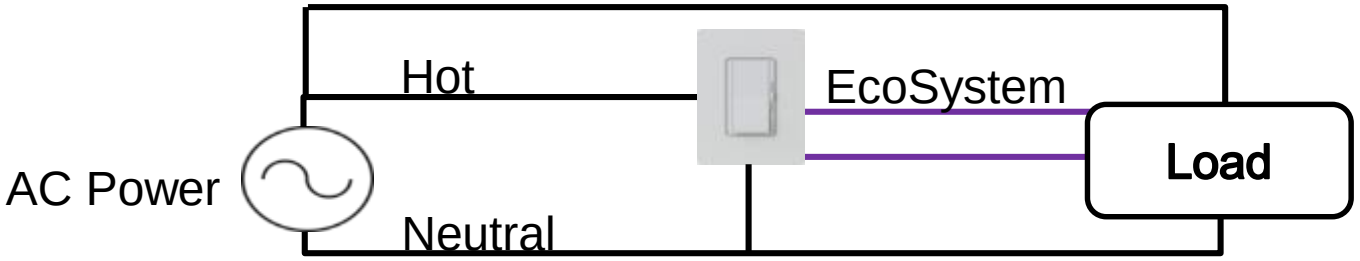
2) What control type does the LED (driver) need?

- DMX-512 digital
  - Popular in theater applications & RGB (Red Green Blue) LED control
  - Multiple channels for individual color control
  - Complicated wiring for general illumination



2) What control type does the LED (driver) need?

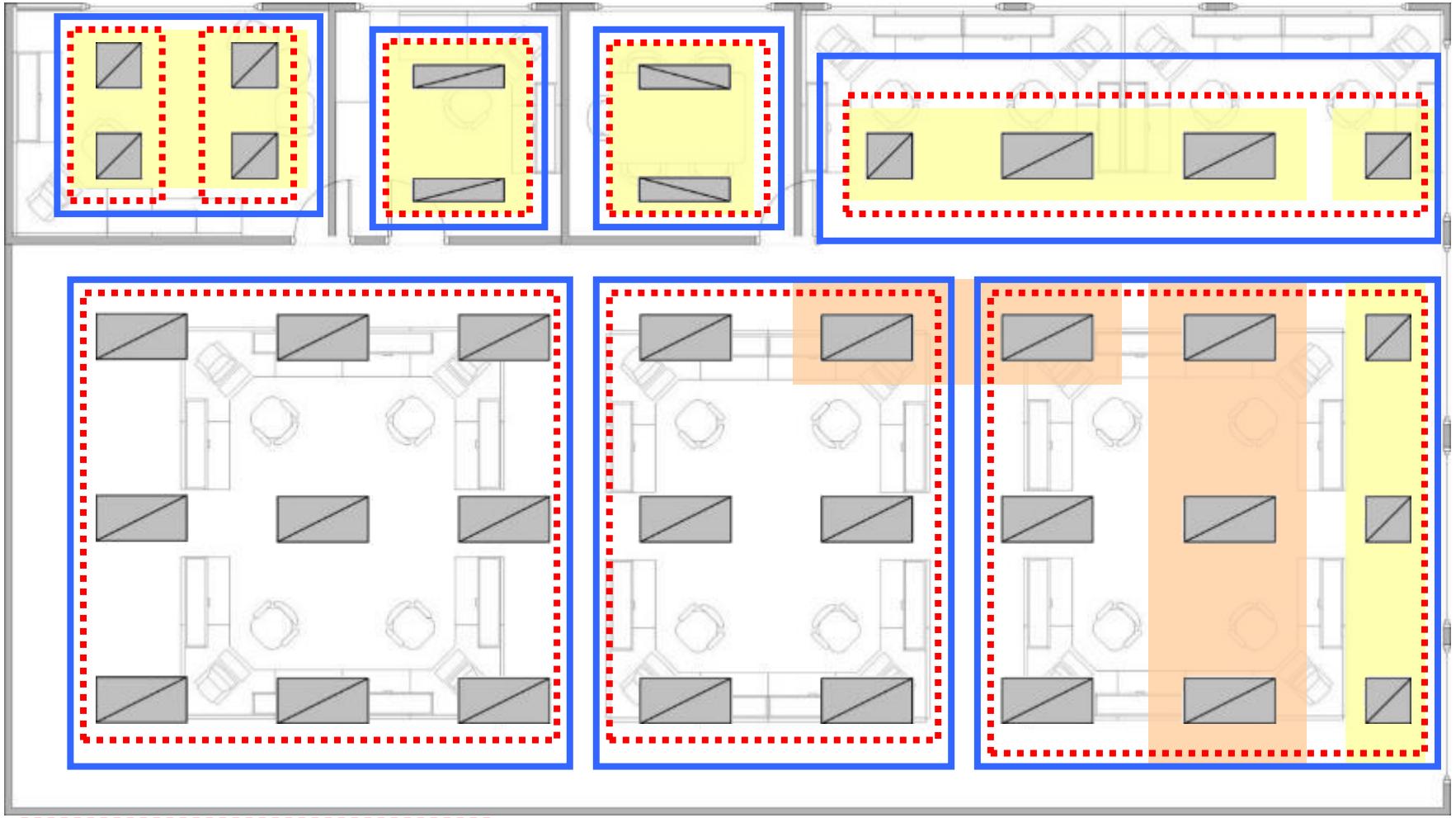
- DALI / EcoSystem
  - Digital Addressable Lighting Interface
  - EcoSystem is based off of DALI IEC standard (with some manufacturer-specific extensions)
  - Allows digital addressing of individual ballasts/drivers in fixtures & status feedback
  - Allows assignment to daylight sensors, occupancy/vacancy sensors, timeclocks and multiple controls for one or many fixtures without added wiring



2) Analog vs. Digital

	DALI/EcoSystem	0-10V
Re-zoning ability	Simple reprogramming	Re-circuiting and re-wiring
Polarity and topology free wiring	Yes	No
Lights track together	Yes	May not over long wire runs
Noise immunity	Yes	No
Single standard	Yes	No
Driver feedback	Extensive	No
BMS integration	Fixture by fixture information	Generally circuit level information (depends on amount of control interfaces)

2) Office Space Example



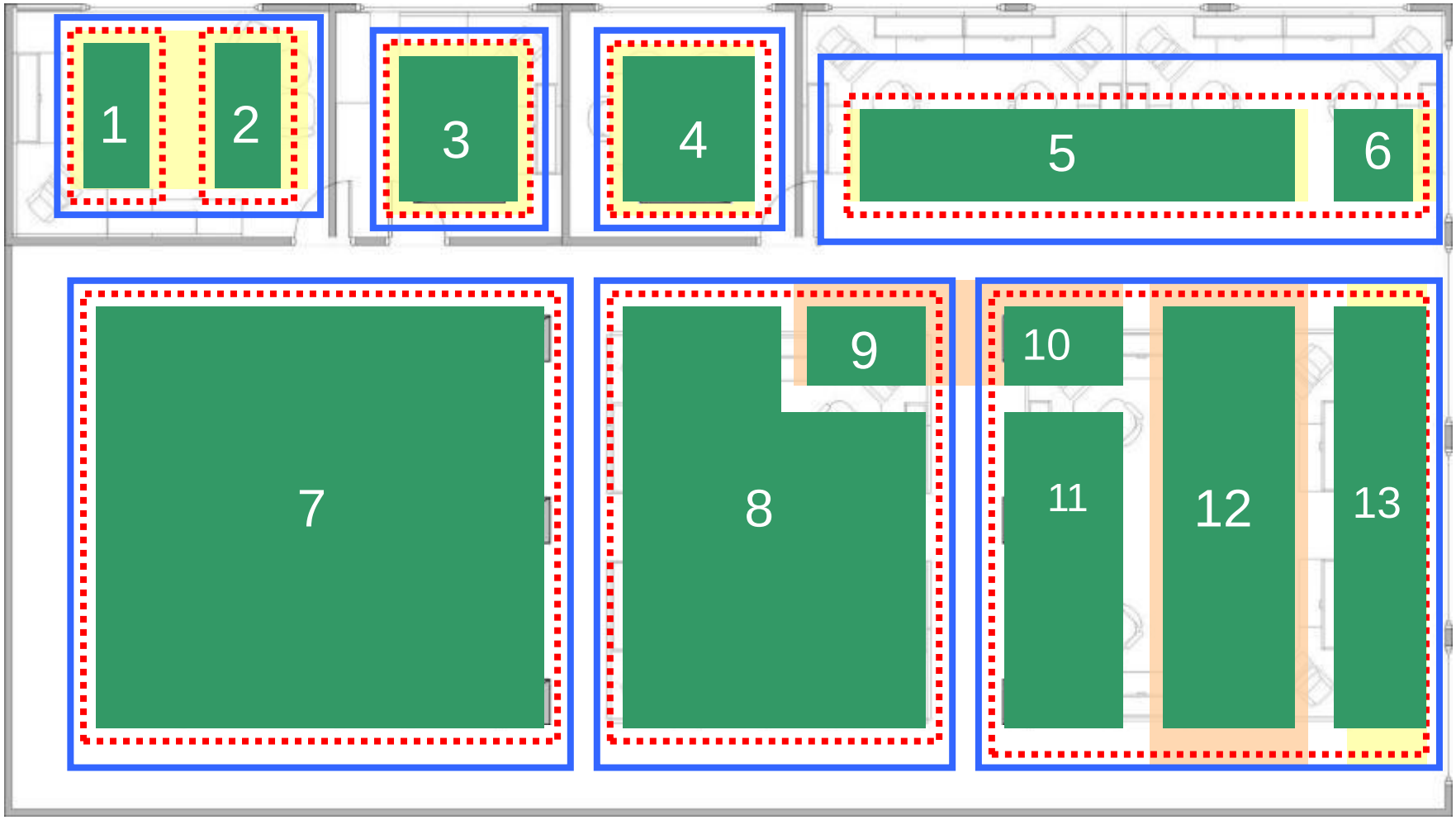
Personal Control Zone

Occupancy Zone

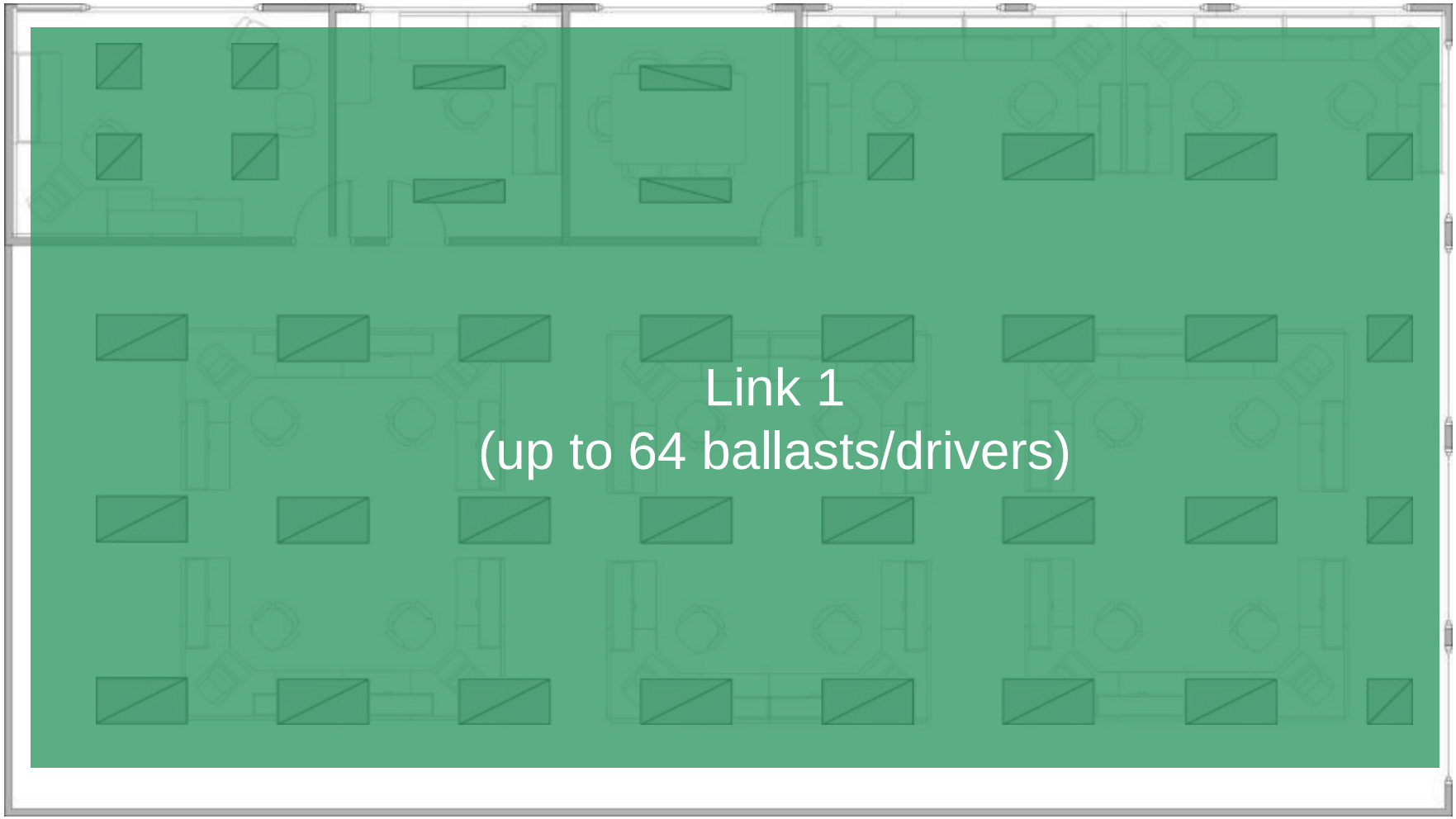
Primary Daylight Zone

Secondary Daylight Zone

2) Office Space – 0-10V Control Loops



2) Office Space – DALI/EcoSystem Link



DALI is limited to only 16 groups

2) Office Space BOM

BOM Comparison:

	DALI/EcoSystem	0-10V
Daylight sensors	5	5
Occupancy sensors	7	7
Wall controls	8	8
Controller	1	13
Wire Runs	1	13

2) Special case: MR16 lamps

- Two compatibility requirements
  - LED lamp and step-down transformer
  - Step-down transformer and dimmer
- Step-down transformer characteristics (MLV vs. ELV) are often not known for retrofits
- Both magnetic and electronic transformers designed for LV systems were typically designed for resistive incandescent/halogen (not LED) loads
  - MLV dimmer + magnetic transformer or ELV dimmer + electronic transformer provides no guarantee of successful dimming of retrofit LED loads

3) What is the dimming range of the fixture?

- Dimming range varies greatly
  - Some may dim only to 40%, others to 1%
    - Incandescent lamps dim to well below 1% (orange filament glow)

- Select a dimming range suitable for your application
  - 20% dimming: suitable for a lobby, atrium or office
  - 1% dimming: needed for restaurants, residences, media rooms

- Measured light vs. perceived light
  - Be aware when comparing and selecting products
  - Comparisons across manufacturers may not be equivalent

3) LED Report Cards for LEDi

LUTRON®

Product Report Card

Manufacturer: Cree
Model Number Tested: CR6
Other Model Numbers: CR6-GU24

Manufacturer's Description

Type of device: LED
Operating voltage: 120 V
Input Power 11 W
Input Current: Not Specified
Input Frequency: 60Hz

Control Type: Unspecified Phase Control
Dimming Range: 100% - 5%
Output Power: Not Specified
Lumen Output: 575 lm

Lutron Test Results

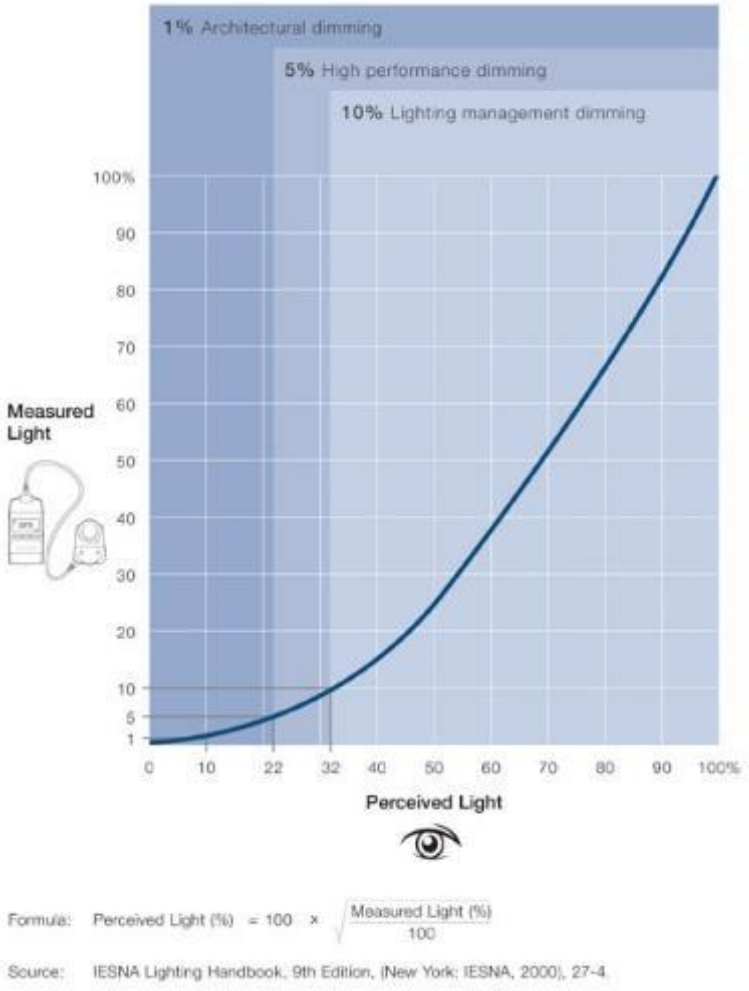
Date Tested: 28-Jul-10
Figure of Merit: 0.59
Test Voltage: 120 V
Test Notes: None

Lutron Recommended Compatible Products

Lutron products not in this list can be considered to be not compatible, based on our testing.

Product	Model Number	Fixtures per Dimmer		Measured Dimming Range (1)		Perceived Low End (2)	Comments
		Minimum	Maximum	Low End	High End		
Wallbox Dimmers							
Diva C•L Skylark Contour C•L Lumea C•L Toggler/Ariadni C•L	DV_CL-153P CTCL-153P LGCL-153PH TGCL-153P / AYCL-153P	1	14	1%	99%	10%	Low end trim required
Commercial Systems							
Panel Module	HW/LP-RPM-4A-120	1	17	1%	99%	10%	Low end trim required
Grafik QS	Grafik Eye QS Main Unit	1	7	1%	99%	10%	16 fixtures maximum per unit
Residential Systems							
Panel Module	HW/LP-RPM-4A-120	1	17	1%	99%	10%	Low end trim required
Grafik QS	Grafik Eye QS Main Unit	1	7	1%	99%	10%	16 fixtures maximum per unit
RadioRA 2	RRD-10ND	1	5	1%	93%	10%	Low end trim required
RadioRA 2	RRD-6NA	1	6	1%	99%	10%	Low-end trim required Startup at low-end slightly unstable "Blip" turned off through APM
Interfaces							
	PHPM-WBX with DVF-103P	1	18	1%	98%	10%	Slight buzzing throughout range
	PHPM-PA with Grafik Eye QS	1	18	1%	99%	10%	Low end trim required
Notes:	(1) Values are based on light output using the specified dimming control, and may not be an indication of the fixture's full rated capability (2) Perceived light level percentage is the square root of the measured light level percentage, per IESNA Lighting Handbook						

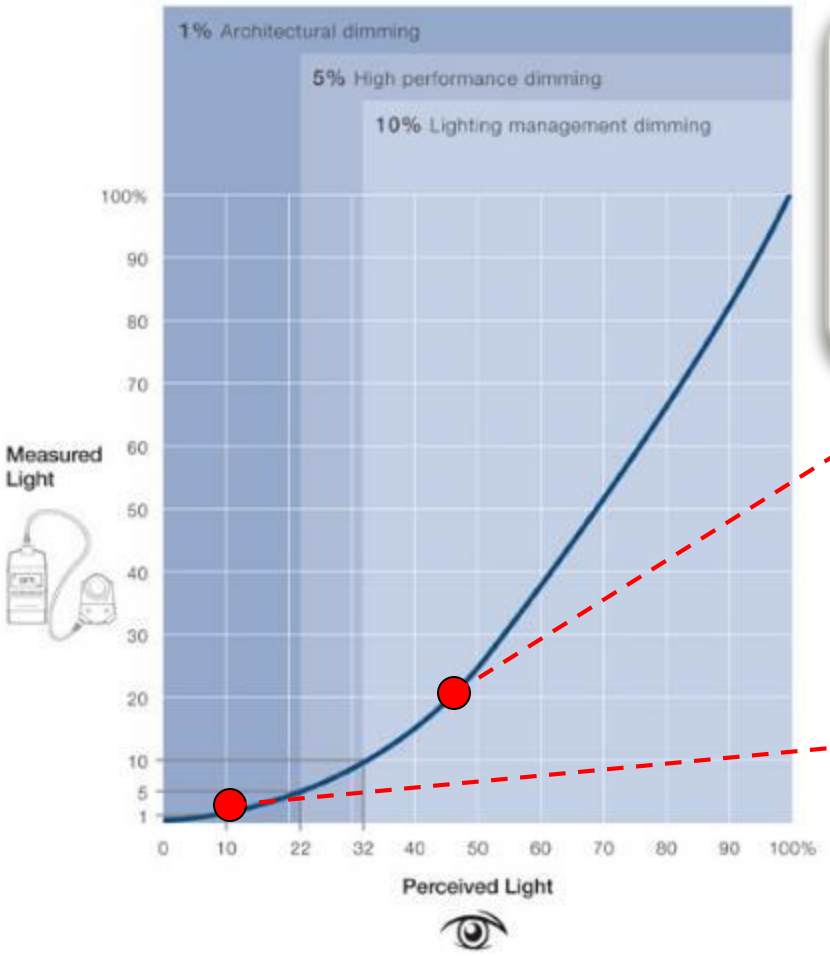
3) What is the dimming range of the fixture?



Measured vs. Perceived Light

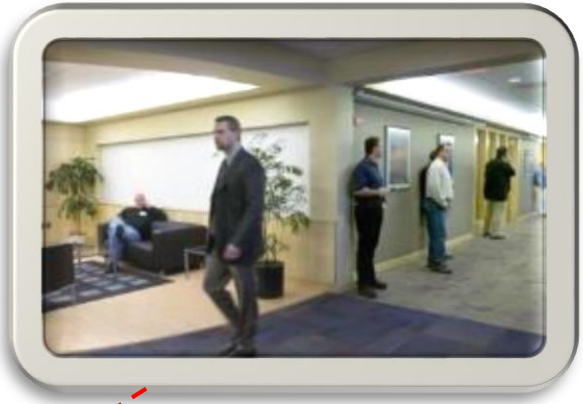
- **Measured light:** the amount of light as shown on a light meter
- **Perceived light:** the amount of light that your eye interprets due to dilation
- **20% measured = 45% perceived**

3) What is the dimming range needed?



Formula: $\text{Perceived Light (\%)} = 100 \times \sqrt{\frac{\text{Measured Light (\%)}}{100}}$

Source: IESNA Lighting Handbook, 9th Edition, (New York: IESNA, 2000), 27-4.



Lobby or Atrium:
A 20% light level is acceptable for this application

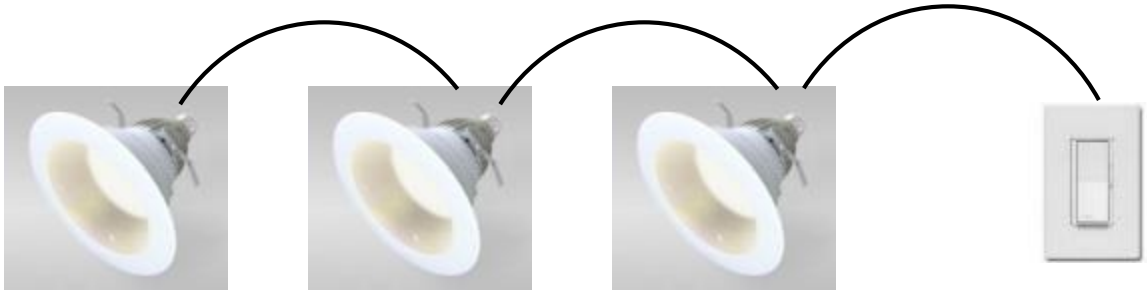
Residences and Restaurants:
A 1% light level is necessary for these applications

4) What is the dimming performance?

- Potential LED aesthetic issues:
  - Flicker/Shimmer
    - The unexpected modulation of light level that is perceptible to the human eye (not always visually seen!)
  - Pop-on
    - The level the light is at when it is turned off is the level it should return to when it is turned back on
  - Drop-out
    - The light should only turn off when the switch is turned off.
  - Dead-travel
    - Adjusting the control without a corresponding change in light level
  - Audible Noise
    - From control *or* lamp
  - Popcorn
    - Multiple lamps on the same control turn on at different times

5) How many LEDs can be connected?

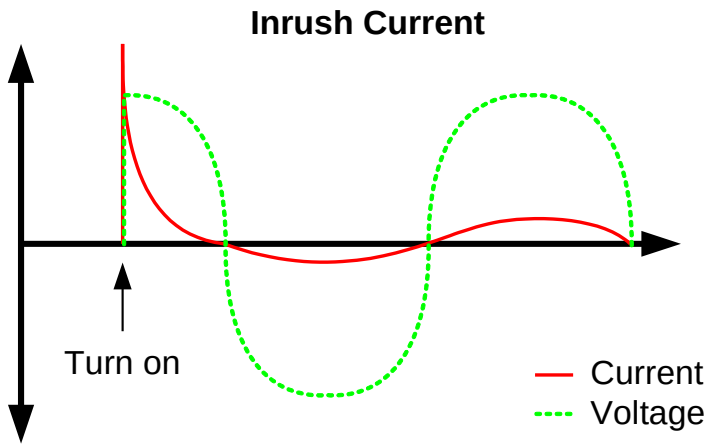
- Minimum number of lamps
  - Dimmer / driver performance may suffer with too little load
  - Most incandescent dimmers require a 25 – 40 watt minimum



- Maximum number of lamps
  - The simple calculation is wrong for incandescent dimmers
    - 600 watt (incandescent) dimmer / 10 watt LED = 60 LEDs per dimmer: WRONG!
  - Start-up inrush and repetitive current increases control stress (and therefore potentially decreases control lifetime!)
  - Observations have shown a 10 watt LED may be equivalent to a 100w incandescent in terms of maximum control stress

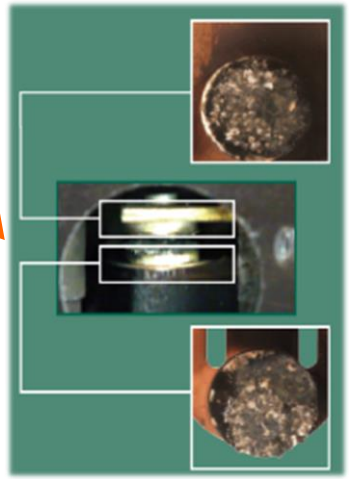
5) How many LEDs can be connected?

- Initial inrush current
  - Created by connection to power, occurs once per power-up
  - Commonly 10-50x nominal RMS current
  - Causes excessive wear on switch or relay contacts, leading to premature failure (welding) of switch or relay
- Specify that drivers and controls must be NEMA 410 compliant



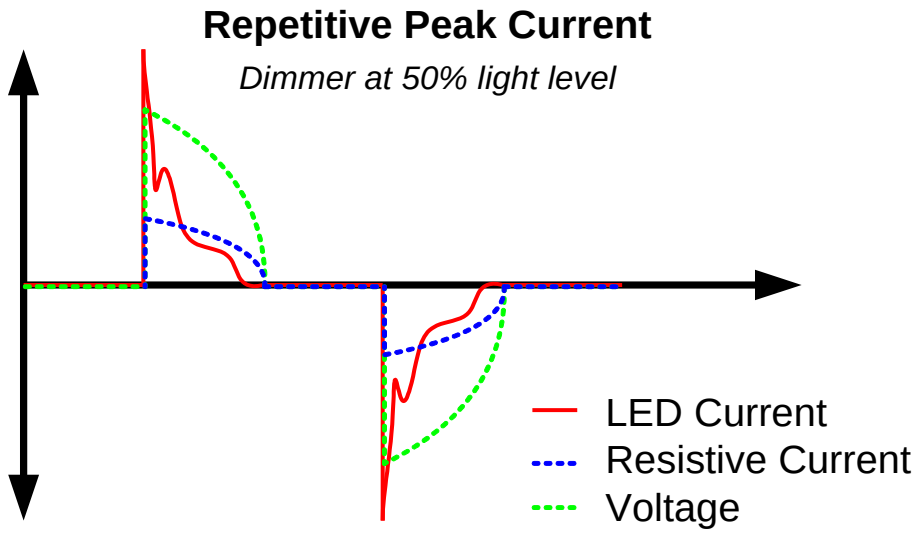
Mechanical and electrical wear (high inrush)

Relay contacts
120VAC, 16A
50k cycles



5) How many LEDs can be connected?

- Repetitive peak current
  - Created by forward phase-cut, occurs every half-cycle
  - Relevant for forward-phase dimmers
  - Commonly 5-10x nominal RMS current
  - Major contributor to audible noise in light sources and controls



5) Dimmer load ratings

- Some dimmers have LED-specific load ratings and ratings for mixed loads
- LED load power ratings are LOWER than incandescent ratings

Total CFL/LED Wattage Installed (Watts per bulb x # of bulbs)		Maximum Allowable Incandescent/Halogen Wattage*	
		No sides removed	1 side removed
0 W	+	600 W	500 W
1 W – 25 W	+	500 W	400 W
26 W – 50 W	+	400 W	300 W
51 W – 75 W	+	300 W	200 W
76 W – 100 W	+	200 W	100 W
101 W – 125 W	+	100 W	50 W
126 W – 150 W	+	0 W	0 W

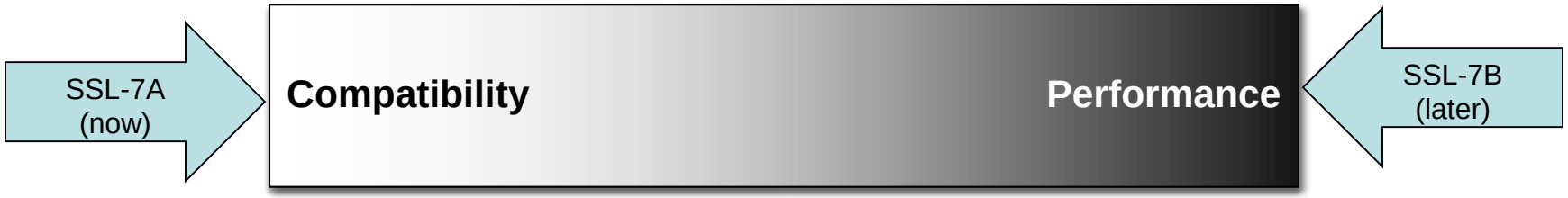
2 load ratings!

5) How many LEDs can be connected?

- The worst-case stress caused by the load determines how many of that load can be connected to a control
- Follow manufacturer's recommendations for number of loads on a single control, or use LED-specific dimmers
- A new standard, NEMA SSL-7A will help alleviate this concern

5) SSL-7A Overview

- SSL-7A was written by NEMA to standardize phase-control dimming of LED loads
- SSL-7A is a voluntary interface standard: it specifies the interaction between lamps and dimmers



- Being adopted by CEC, Energy Star, Title 20 and others

Recap

Steps for a successful LED control system

Ask…and answer…the following questions to match expectations with performance:

1. What type of LED product am I using: a lamp or fixture?
2. What type of control does the LED product need?
3. What is the dimming range of the lamp/fixture?
4. What is the dimming performance of the product?
5. What is the minimum or maximum number of lamps/fixtures that can be connected to one dimmer?

Risk Mitigation

- Understand product dimming performance
  - “Dims from 100%-0%” (what’s just before 0%?)
- Follow recommendations from fixture and/or control manufacturer
  - Beware: they may vary!
- Do mock-ups
  - Use real amounts of load in real applications
- Develop trusted sources
  - Who will support you if things don’t go as expected?
- Understand that installed legacy dimmers weren’t designed for new LED loads
- System “tuning” may be needed
  - Load type setting
  - Low end / high end trim adjustment

Any Further questions?