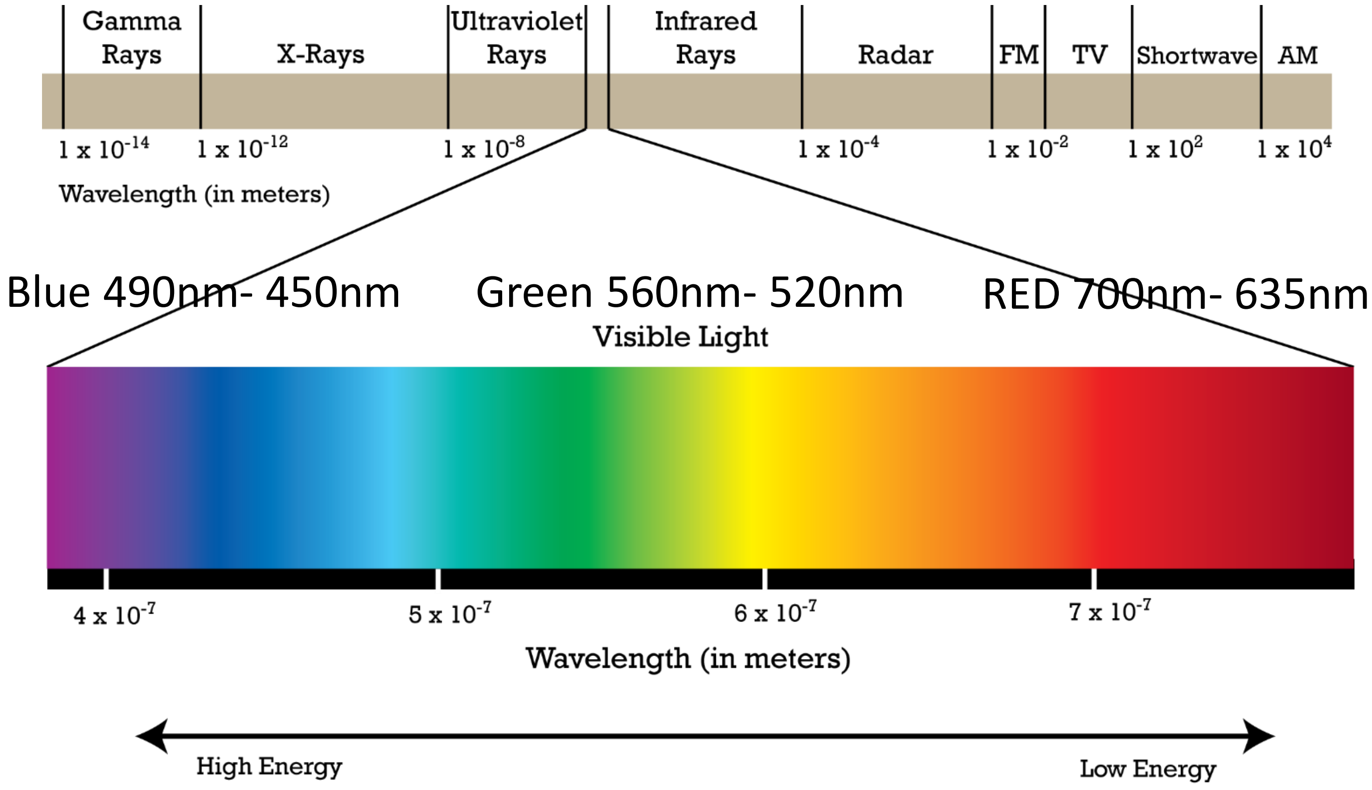
Dimming Control

Dr Ian Rowbottom
Principal Applications Engineer
Lutron Electronics

What is light?

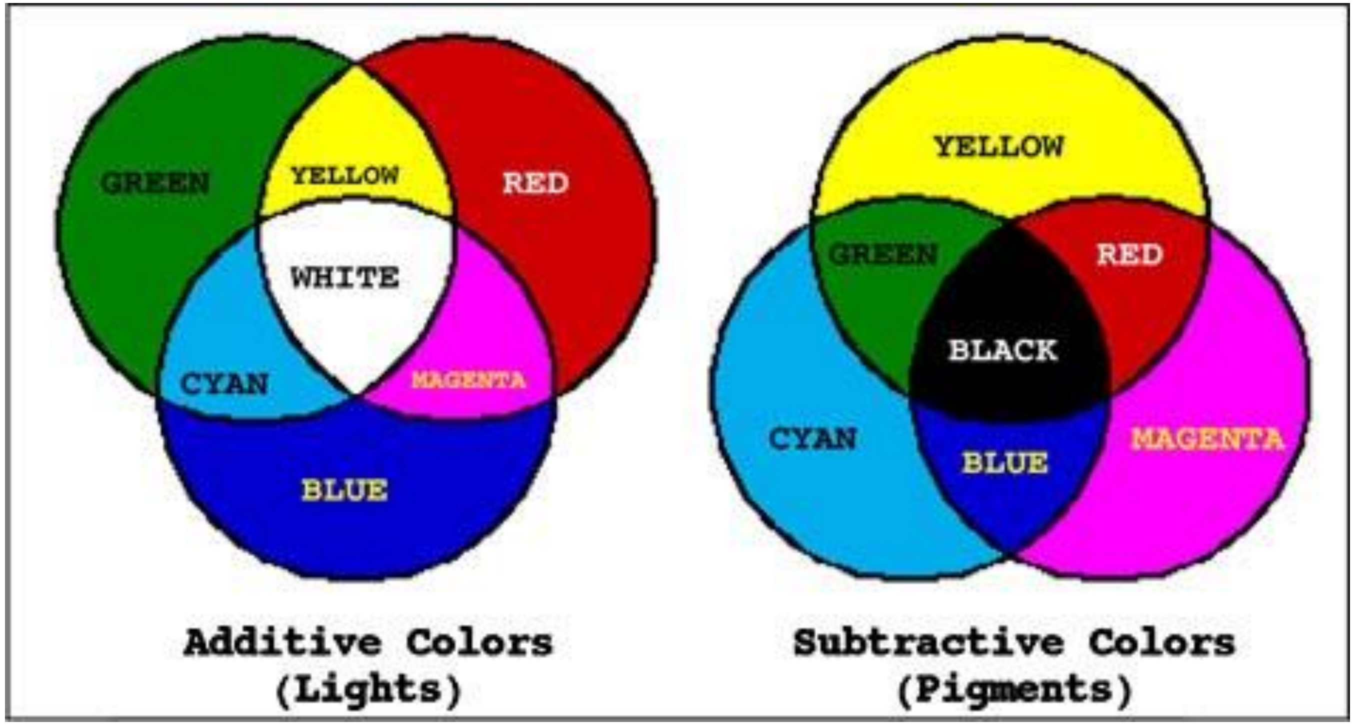
- Electromagnetic energy capable of exciting the retina and causing a visual response. Its not the whole electromagnetic spectrum.



http://www.pion.cz/

What is Color?

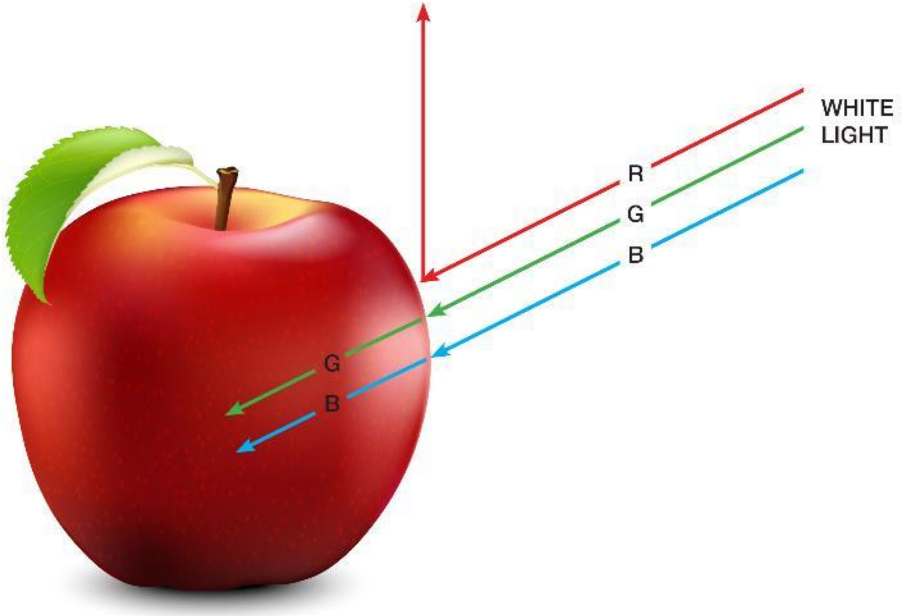
- Objects don't have any color
  - Reflect different light colors to allow the perception of color
- Color Mixing
  - Additive-Light
    - Red, Green, Blue
  - Subtractive-Paint
    - Magenta, Yellow, Cyan



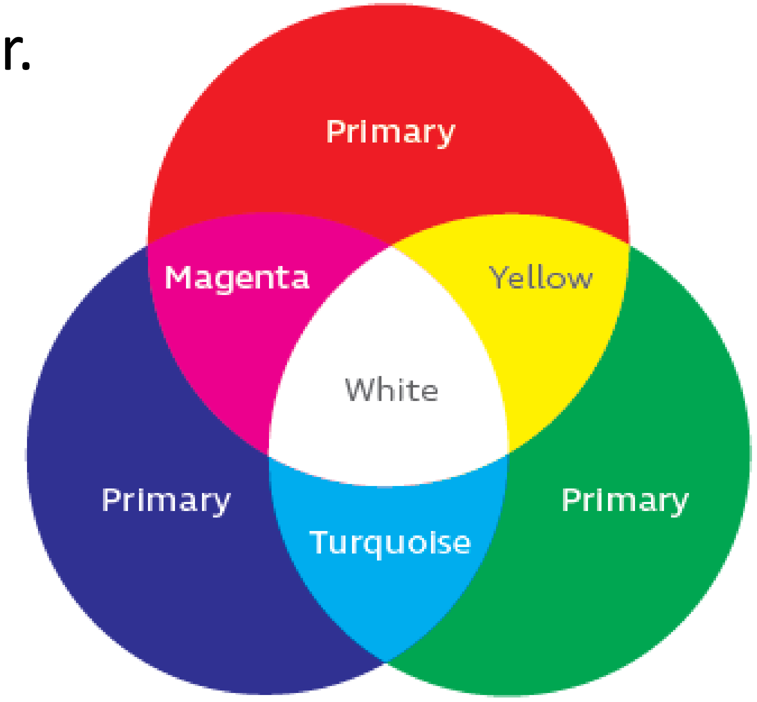
https://www.d.umn.edu

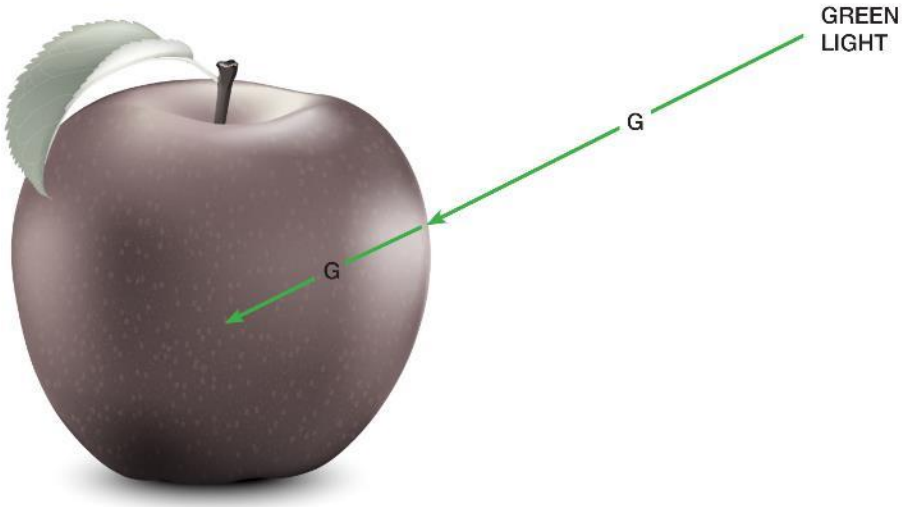
Perceived Color

The three primary colors of light are; red, green and blue. Combined these colors mix to form white light. By mixing these three primary colors many perceived colors can be created. However, the mixed light must possess the wavelengths of light that correspond to the color of the object being lit for the object to be perceived as it’s color.



Different paint pigments absorb and reflect light differently

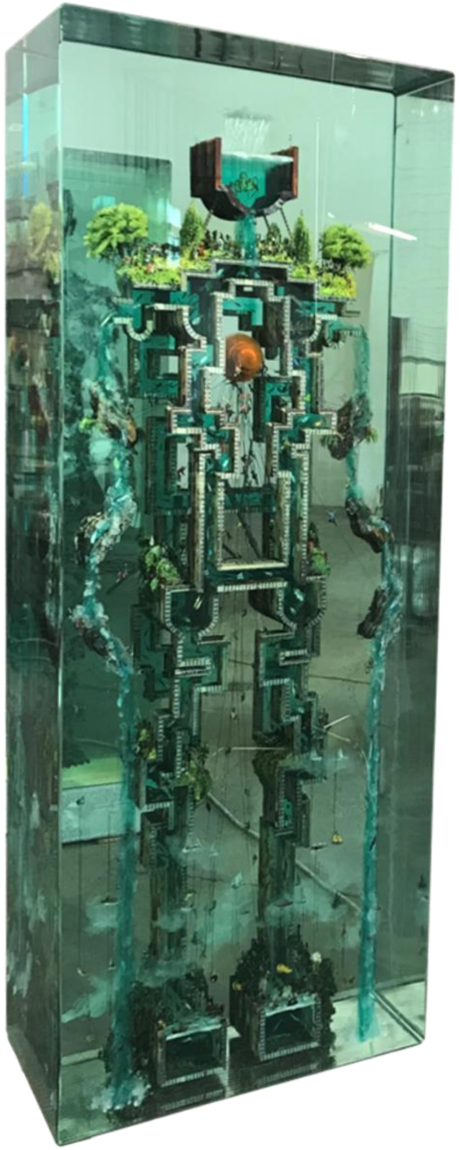




Light is Transformative

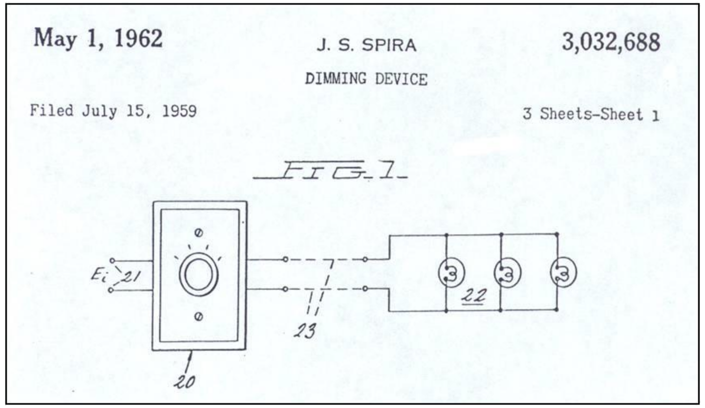
Light is how we see the word –
perception is reality

- Light is essential to how we understand color, shape, space
- Use light to transform artworks and alter our way of seeing and understanding them



LUTRON

The History of Dimming

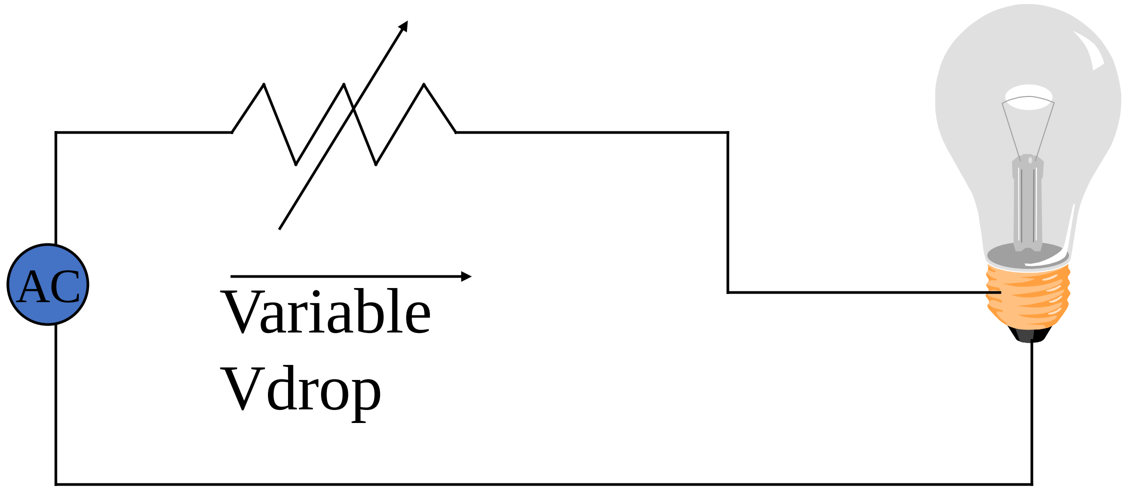


The Rheostat

- First attempt at dimming
- Very large and heavy
- Inefficient method of dimming

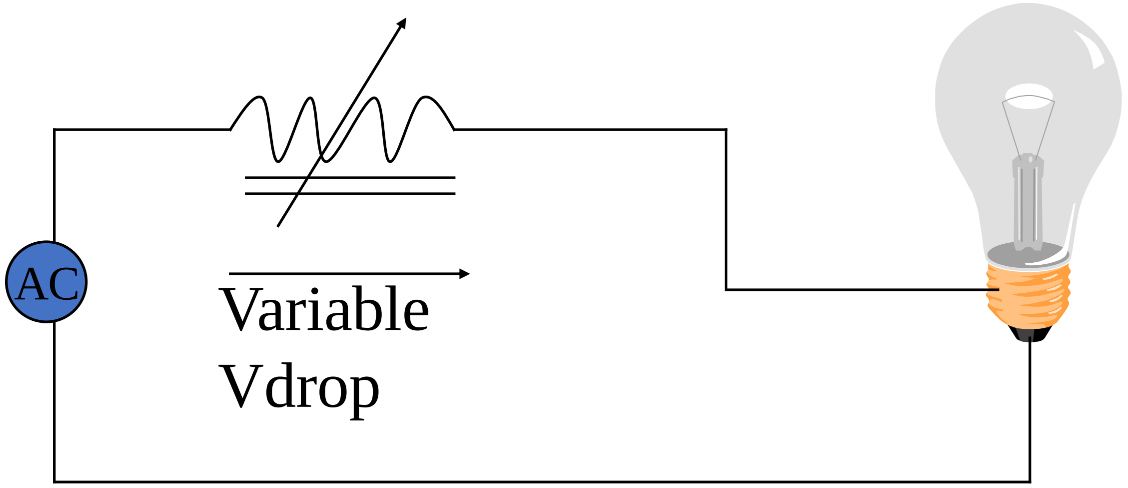
RHEOSTAT DIMMING

- As the resistance is increased, more voltage appears across the rheostat, the lamp voltage drops, the result is dimming.
- The rheostat burns the energy not delivered to the lamp



Variac Dimming

- The Variac is heavy and bulky.
- Relatively inefficient since some of the power is used to magnetize the core and some is lost as heat from the resistance of the windings.



THYRATRON DIMMING

- The Thyratron dimmer is the forerunner of the FET based solid-state dimmer.
- This type of dimmer used a pair of back to back Thyratron tubes. These were the early versions of FET's
- The dimmer is bulky and the vacuum tube is somewhat fragile.

SOLID STATE DIMMING

- Solid state dimming employs a technique called phase control. There are two types of phase control dimming:
  - Forward or conventional phase control (Leading Edge control)
  - Reverse phase control (Lagging Edge Control)
- The two types of phase control are used for different types of load.

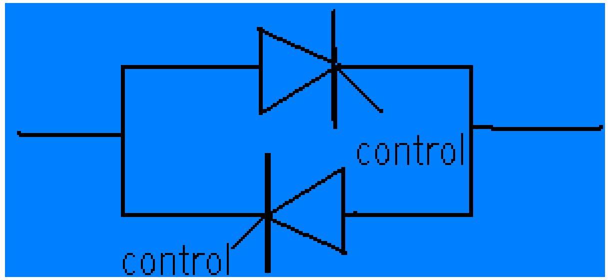
Phase control solid state dimming

- Used for line voltage control of loads:
  - Incandescent/Halogen
  - Magnetic low voltage
  - Electronic low voltage
  - Ballast/Driver driven loads

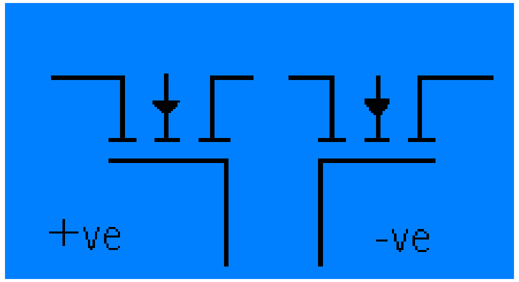
DEVICES USED IN SOLID STATE Phase control DIMMERS

- Several types of solid-state devices are used in phase control dimmers.
- The main type of device used is known as a Thyristor. Thyristors include SCR's and Triacs.
- Recently, transistors such as FET's and IGBT's have been used in place of thyristors.

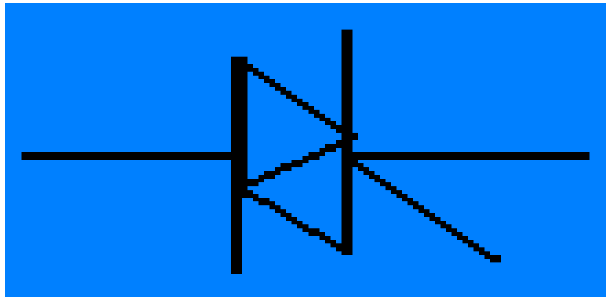
SCR Pair



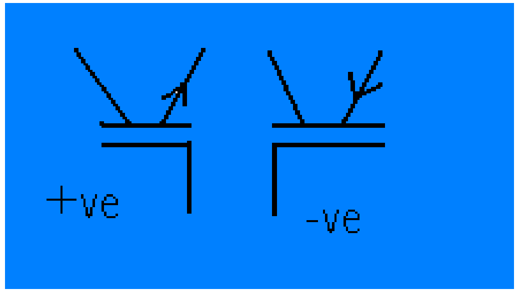
FET Pair



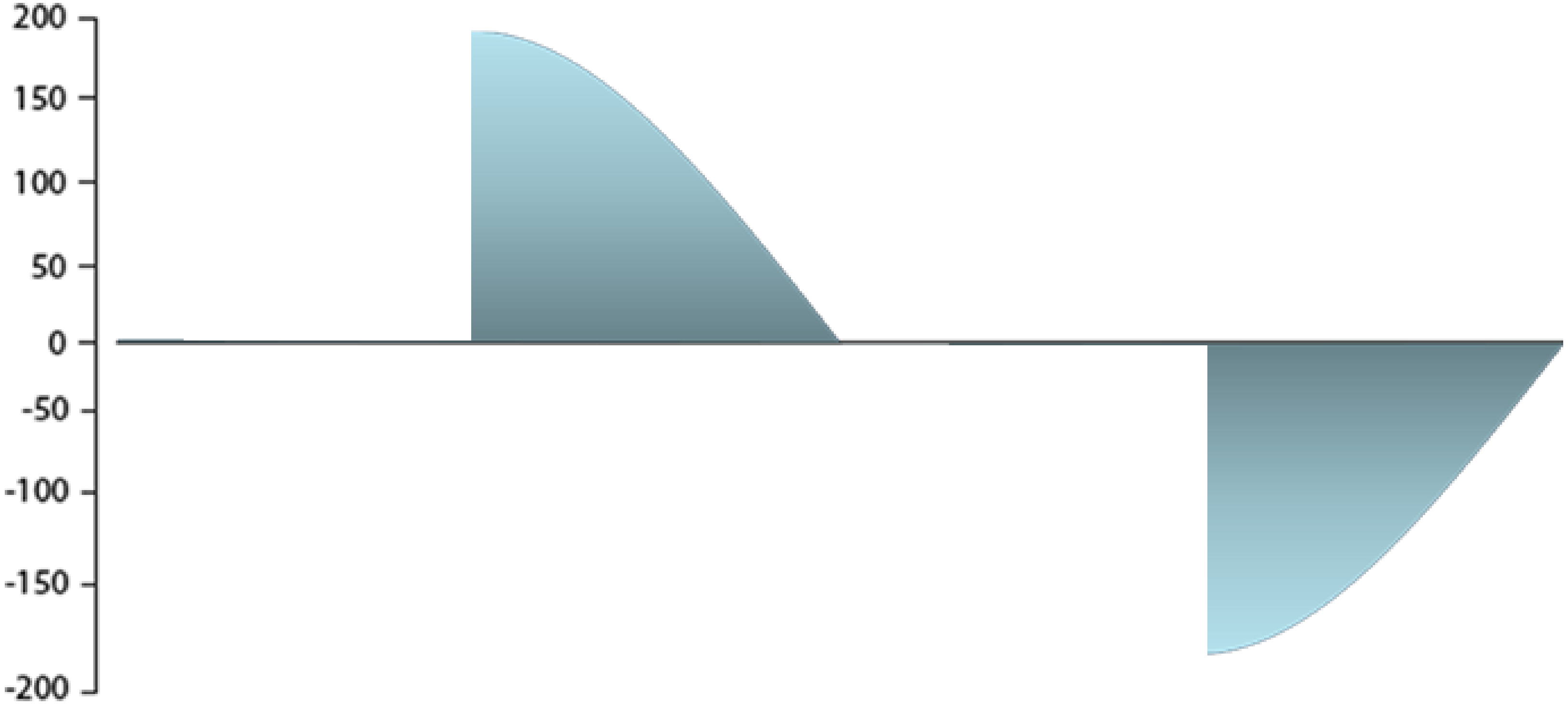
Triac



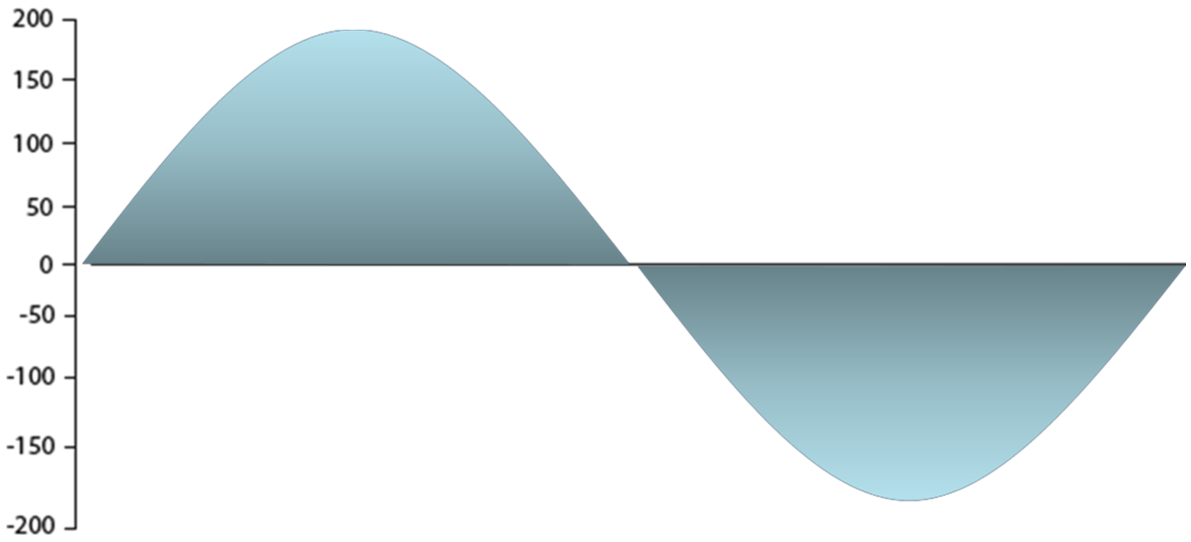
IGBT Pair



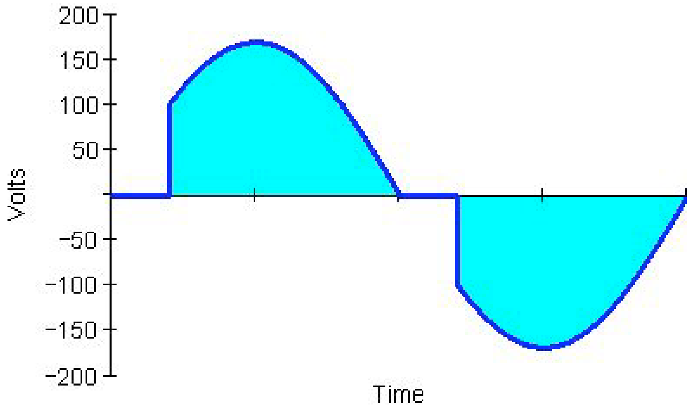
Forward Phase Control

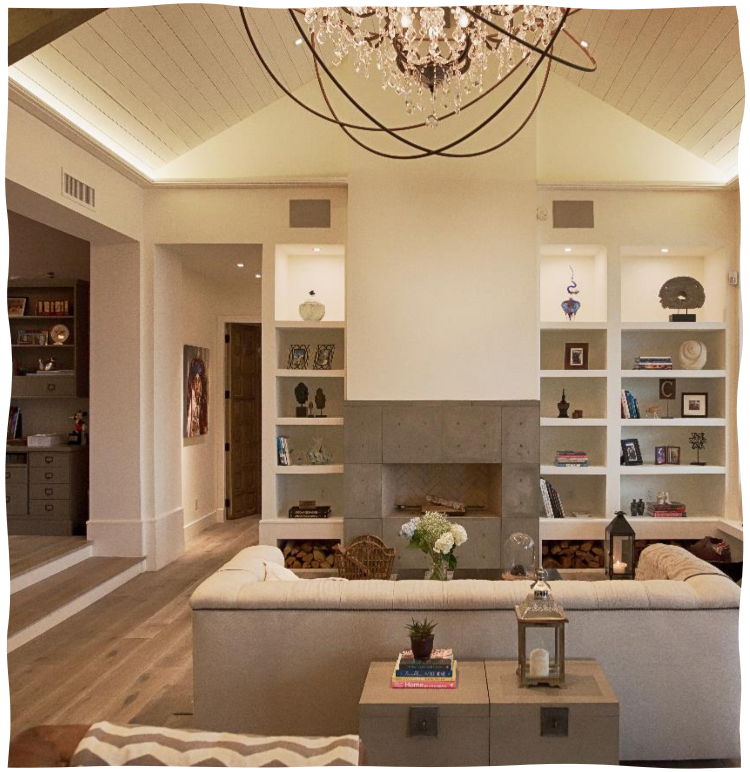


How a forward Phase Dimmer Works

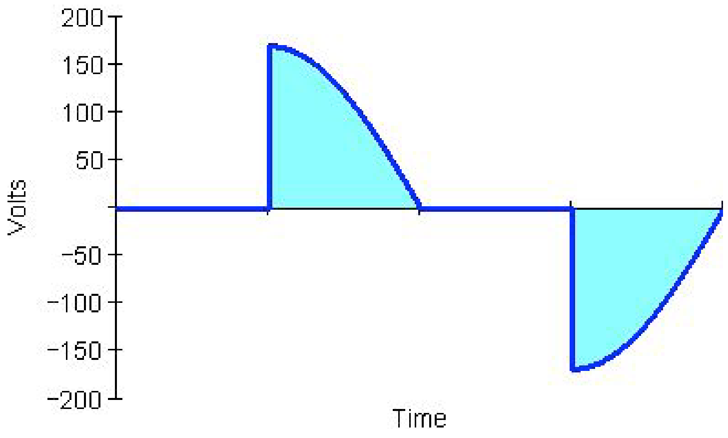


How Basic Dimming Works

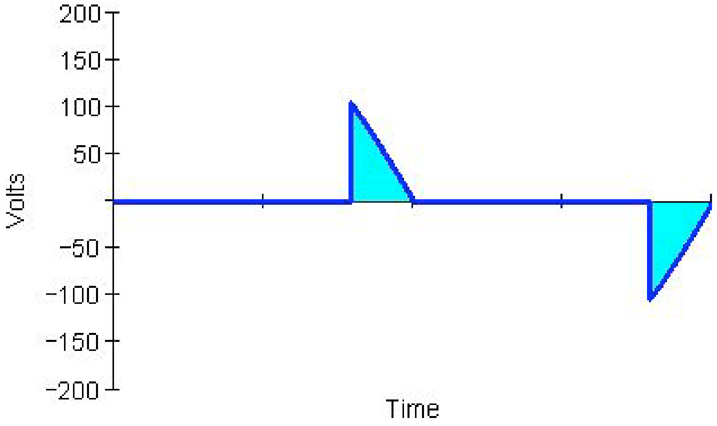




How Basic Dimming Works



How Basic Dimming Works

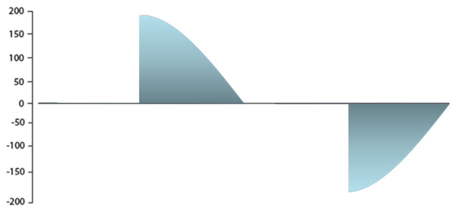


Majority of phase control dimmers use Thyristors

Thyristors turn-on in 1μS, but turn-off at zero current. This very fast turn-on causes two major problems:

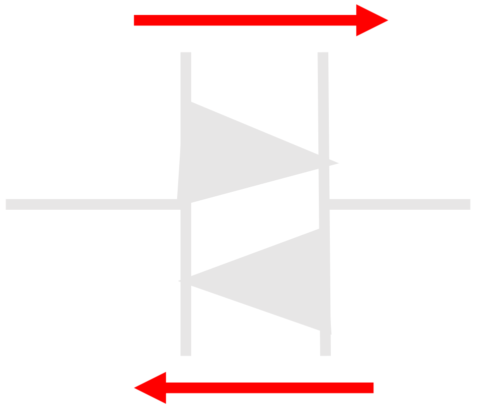
- EMI, a fast-rising voltage generates lots of EMI. This must be avoided by adding a choke in series with the Thyristor. However, the choke can dissipate a substantial amount of power. This is typically 1% of the connected load.
- Capacitive Loads such as electronic Low Voltage transformers cannot be driven by Thyristors unless specifically design to be so driven. Since the thyristor turns-on in 1μS. The current drawn by the load becomes very large:

$$I = C\frac{dv}{dt} = C*\frac{170V}{1\mu S}$$



This large current spike could possibly damage the transformer/driver and the dimmer.

Triacs are a failsafe device



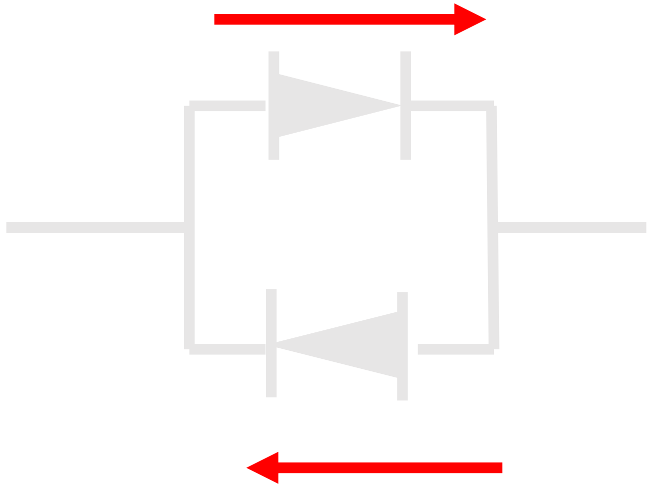
Operational:

Failure: Short - Switch

Failure: Open - Off

Single piece of silicone symmetrical waveform, if either part fails open or shorted; either way safe for magnetic loads

SCRs



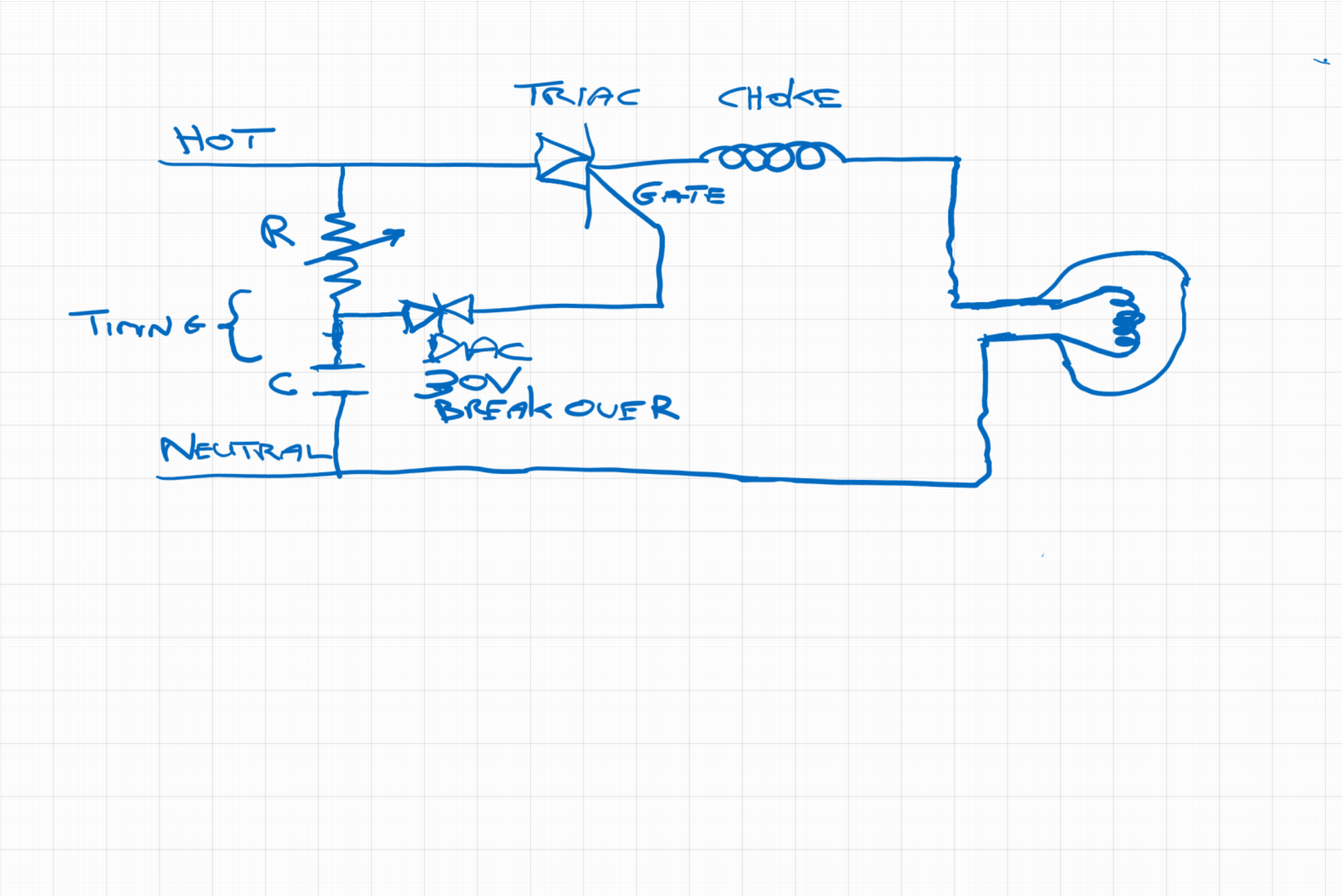
Operational:

Failure: Shorted - Always On

Failure: Open - DC

Two separate pieces of silicone, possible asymmetry and if either one fails open or shorted, bad for magnetic loads

Basic early analog dimmer



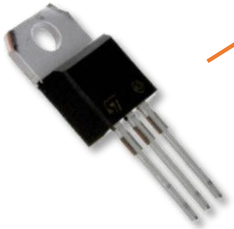
Triac Dimmers

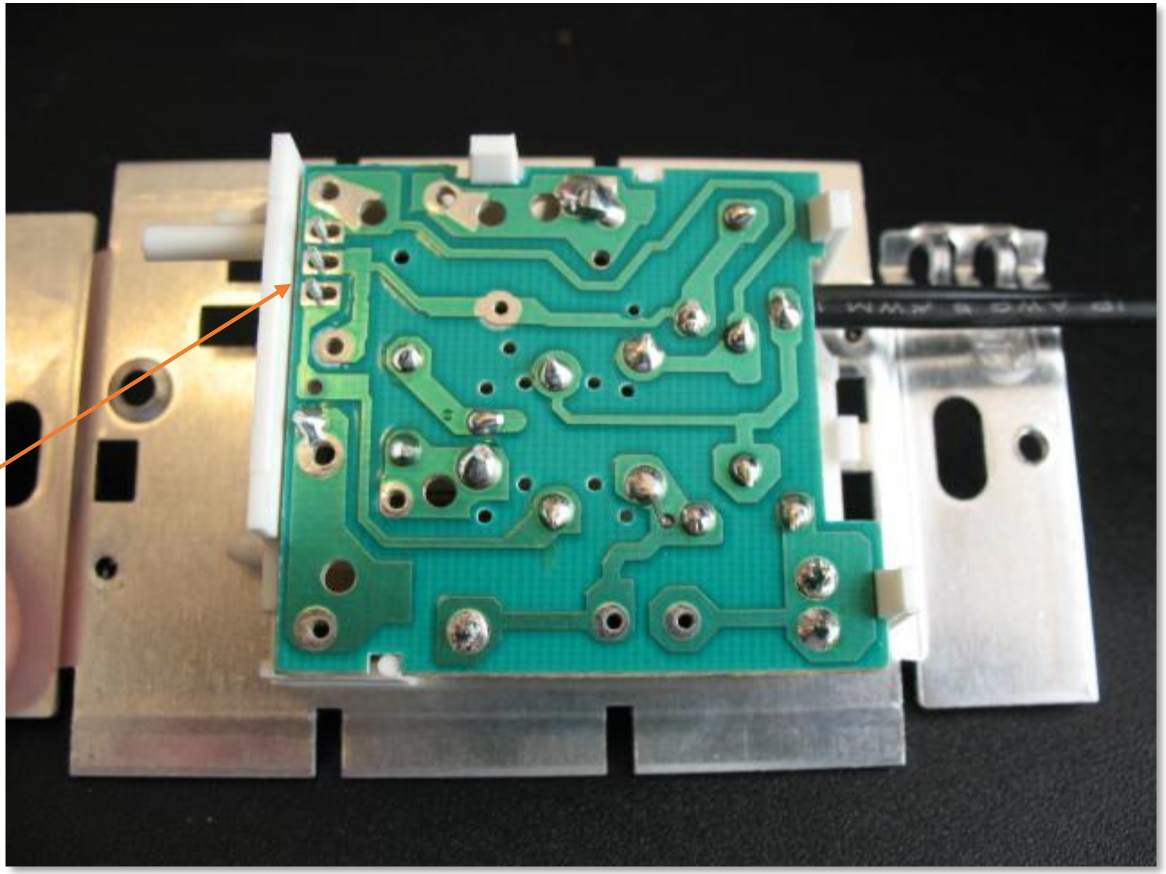
Great for Resistive and Magnetic loads

Dimmer is 98% efficient (1% loss in Traic, 1% loss in Choke)

Needs heatsink to remove triac losses.

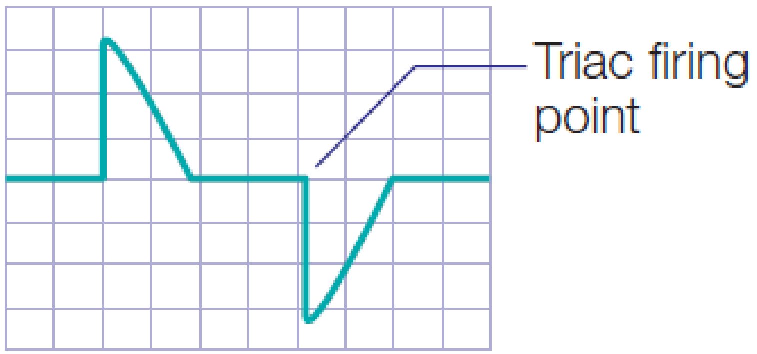
Most use a Microcontroller for control/triac firing

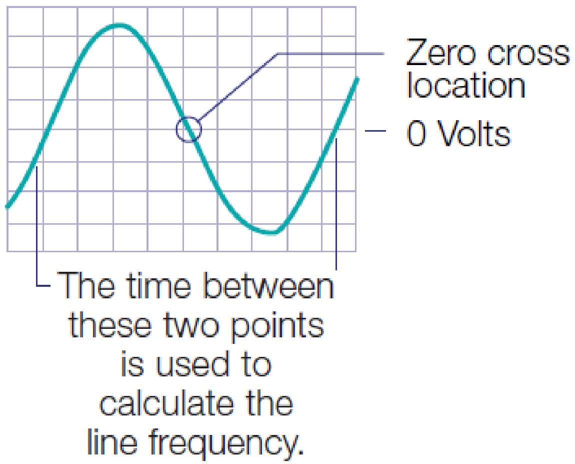




Phase control trigger

- A phase-control dimmer is synchronized to the AC line.
- Timing software internal to the microcontroller synchronizes the dimmer with the AC power line.
- The timing software measures the line frequency and the time at which the AC line crosses through zero.
- Stable, consistent phase-control dimming requires accurate line frequency and clean zero cross information





Electrical Noise can cause timing problems

- Results in
  - Flicker
  - Breathing
  - Sudden dips
  - Uncontrolled operation

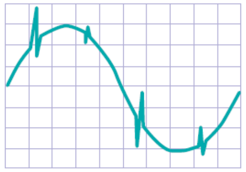


Figure 7 – Impulse Noise
Caused by: Switch arcing (loads switching on/off)

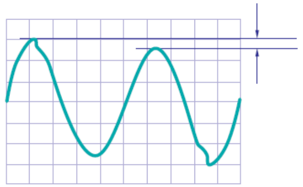


Figure 10 – RMS Voltage Changes
Caused by: Heavy loads switching on/off

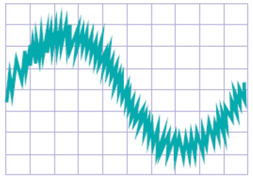


Figure 6 – High Frequency Noise >5kHz
Caused by: Variable-speed motor drives, on-line UPS systems

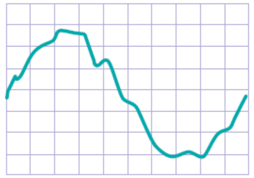


Figure 9 – Notches and Low Frequency Noise 100 - 5kHz
Caused by: Elevators and large industrial loads

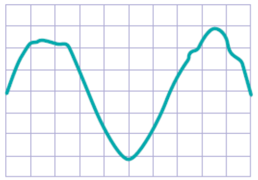


Figure 8 – Low Frequency Non-Harmonics and Signaling Systems
Caused by: Signaling systems, power line carrier communications

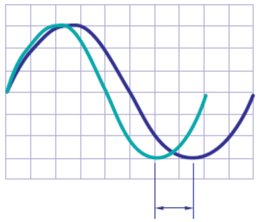
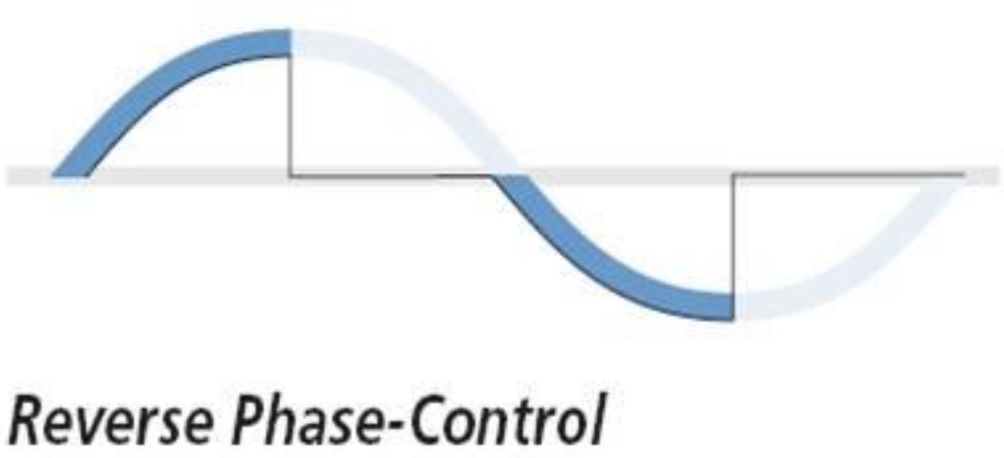
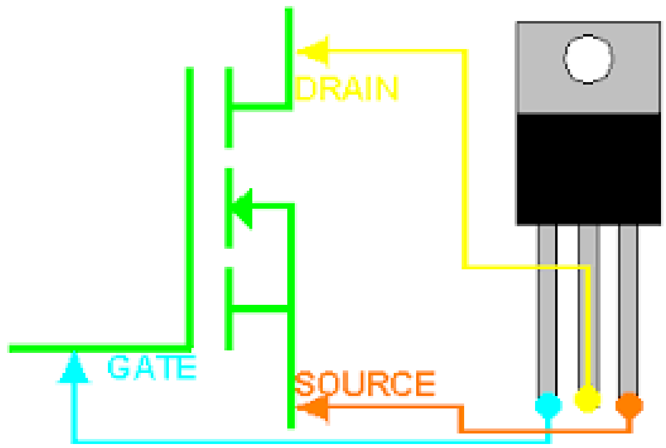


Figure 11 – Variable Fundamental Frequency
Caused by: Backup generators, relatively small power grids

Reverse Phase Control



- Used for Capacitive loads
- More complex dimmer since uses 2 semiconductor devices
- Typically, more expensive dimmer
- Should not be used on magnetic loads (V=Ldi/dt, gives huge voltage spike when the current suddenly stops)



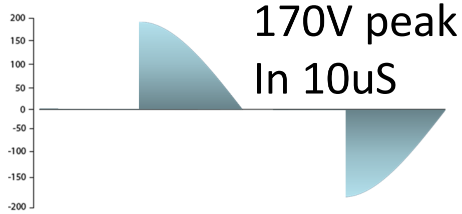
FET's or IGBT's

- FET's and IGBT's can turn-on and turn-off via a control signal, this gives them the ability to either produce a forward phase control or reverse phase control.
- Initially these devices were used to create reverse phase control dimmers to drive capacitive loads such as electronic low voltage transformers. These dimmers required switching devices which can turn-on <u>and</u> off at any time during the line voltage half cycle, hence the use of FET's. (IGBT's being relatively rare in the dimming world)

FET’s and IGBT’s

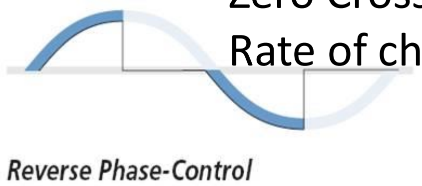
Since an electronic low voltage transformer is capacitive, the load current is given:

$$I = C \frac{dv}{dt}$$



170V peak
In 10uS

Vs.



Zero Crossing
Rate of change

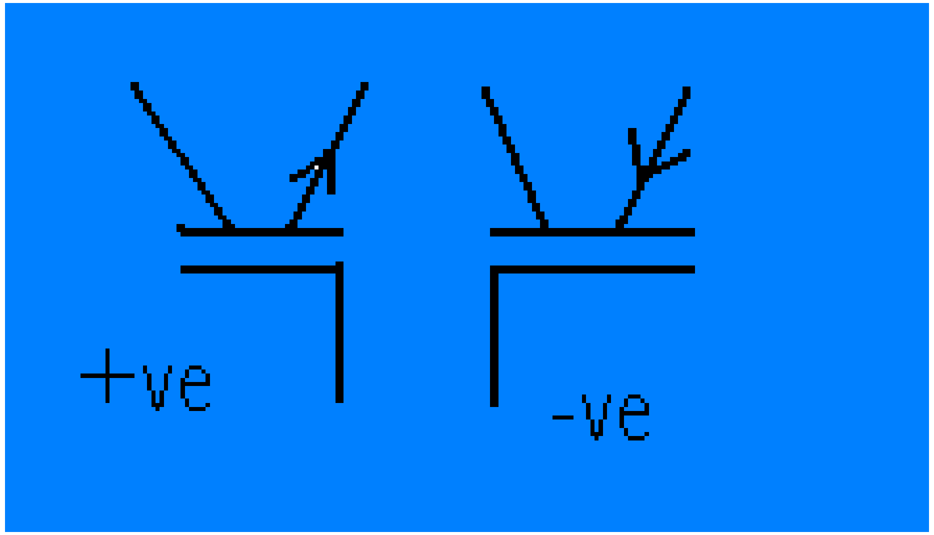
as we have seen, if we use forward phase control, the suddenly applied voltage would result in a very large current spike. The reverse phase control dimmer is different. It turns on the FET or IGBT at zero voltage crossing and then turns off at some time during the half cycle. Since the current at the turn-off point is non-zero, this would be impossible with the Thyristor based dimmer; we have to use a FET or IGBT.

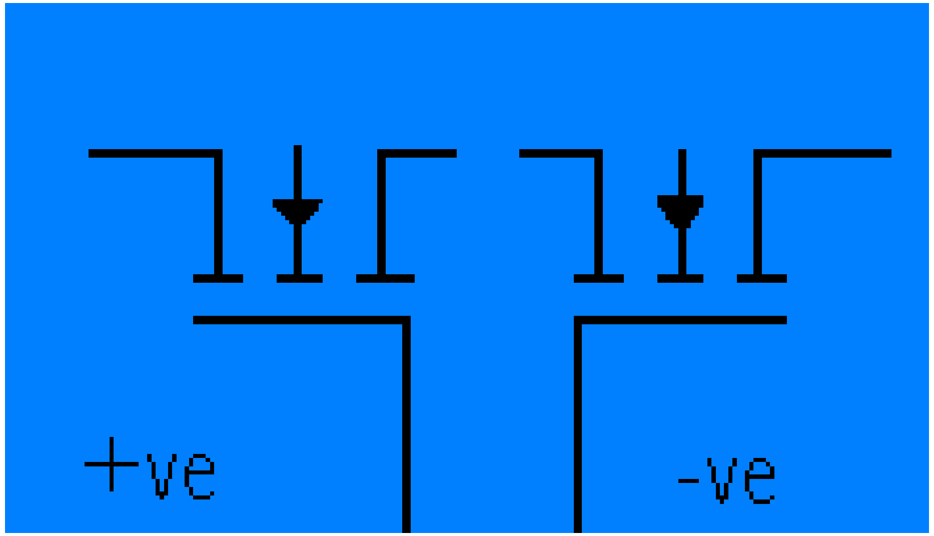
Turn-on and off will be discussed later in greater detail.

FET’s and IGBT’s

- Like SCR’s the FET’s and IGBT’s are uni-directional devices. This means it takes 2 devices to make a line voltage dimmer.
- Since both FET’s and IGBT’s can be turned on and off at any time, they can be used to produce either forward or reverse phase control waveforms.
- The forward voltage drop rises as the current increases, so power loss increases to the square of current as the current rises. (unlike the Thyristor whose power dissipation increases proportionally as the current rises)

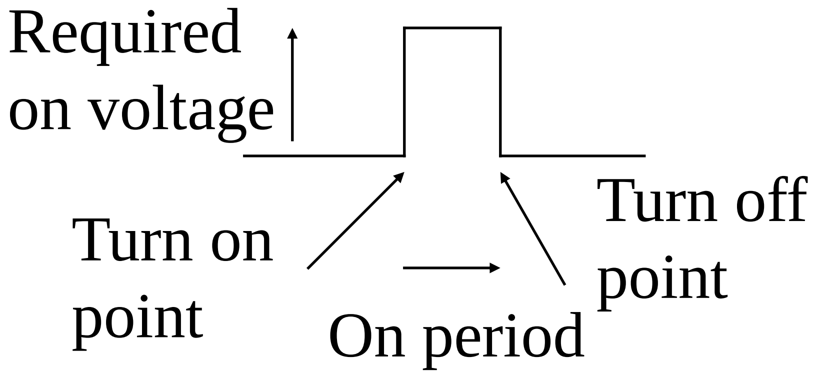
The symbols of FET’s and IGBT’s:





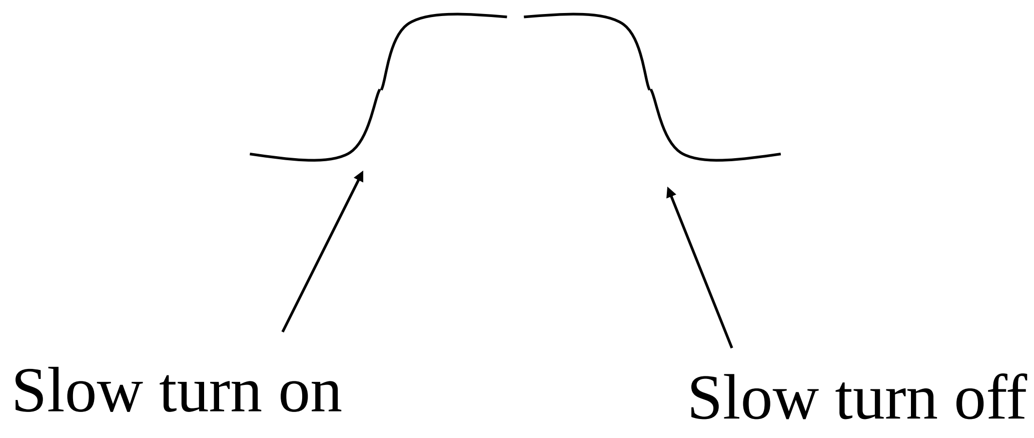
FET's and IGBT's

- One of the advantages that FET's and IGBT's have over thyristors is that the turn on and off durations can be controlled by the external switching circuitry. This requires a more complex firing circuit than was discussed with Thyristors and is usually provided by means of a simple microprocessor or control chip.
- To turn on and off a IGBT or FET, we simply apply a voltage or remove voltage to the gate terminal:



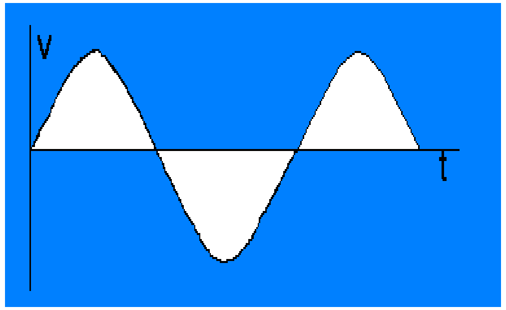
FET’s and IGBT’s

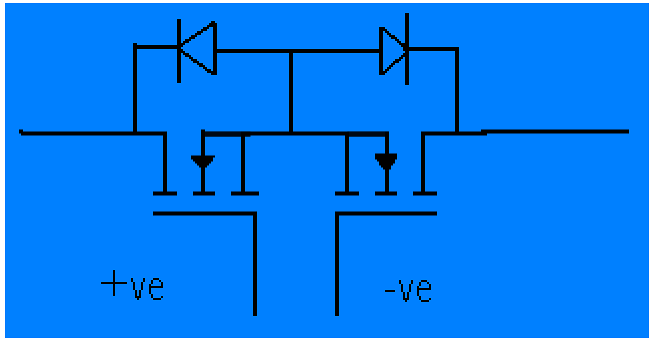
- If we now shape the turn on and off pulse, we could make the FET of IGBT turn on and off much slower:

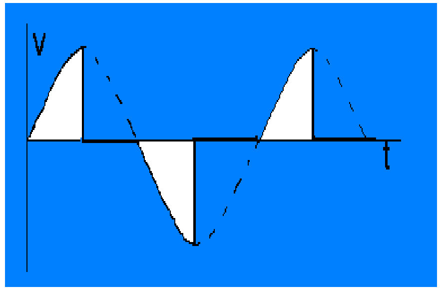


- The shaping of the firing pulse results in a slow turn on and off, this negates the need for a large series choke to reduce the EMI.
- The delayed turn-on and off does result in a larger power dissipation in the device.

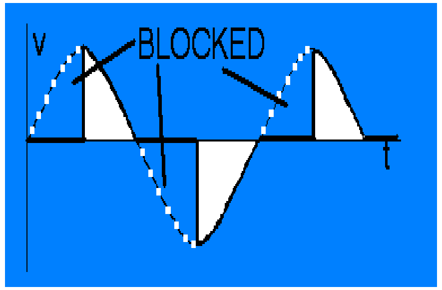
FET DIMMER







OR



- You will notice that 2 diodes are also included in the above dimmer. This is because both FET’s and IGBT’s cannot block large line voltages like Thyristors.
- The diodes block the negative voltages for the FET’s.

FET DIMMER

In any direction, the forward voltage drop of the FET or IGBT dimmer is one FET/IGBT and one diode.

Even with state of the art low resistance FET's, the forward voltage drop is approximately 2-3V at 16A instead of 1-1.2V for a thyristor-based dimmer.

Bulk of the losses in a FET/IGBT based dimmer are in the switching devices.

This causes a considerable engineering challenge to remove this heat from a high-capacity dimmer

FET DIMMER

In both FET and IGBT based dimmers, the forward voltage drop increases as the current increase. (since resistive switches) This fact can be used to give a measure of the load current and be used to turn-off the dimmer during overload situations.

FET dimmers have one advantage over IGBT dimmers in that they can be safely switched off at high currents. For this reason, most forward phase dimmers use FET's

Neutral Connection to the dimmer

Some dimmers do not require a neutral connection

- Steals voltage when the semiconductor is off
- Often has lower performance
  - Triac dimmers may require more connected load
  - Higher low-end to assure enough off state voltage

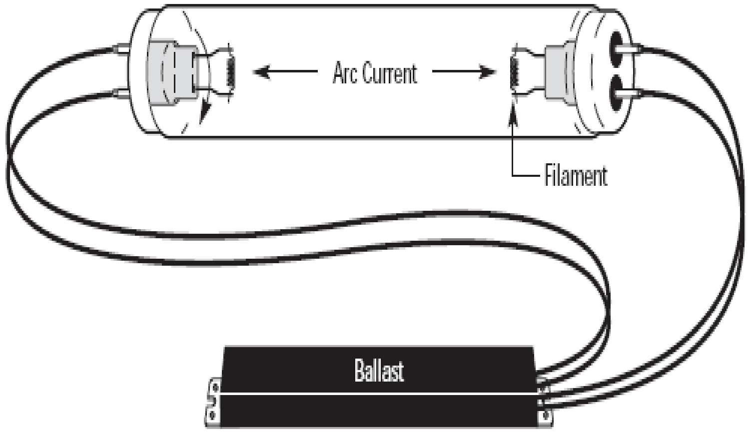
Dimmers with Neutral

- Can achieve very low dimming levels
- More stable as control power supply is referenced to neutral

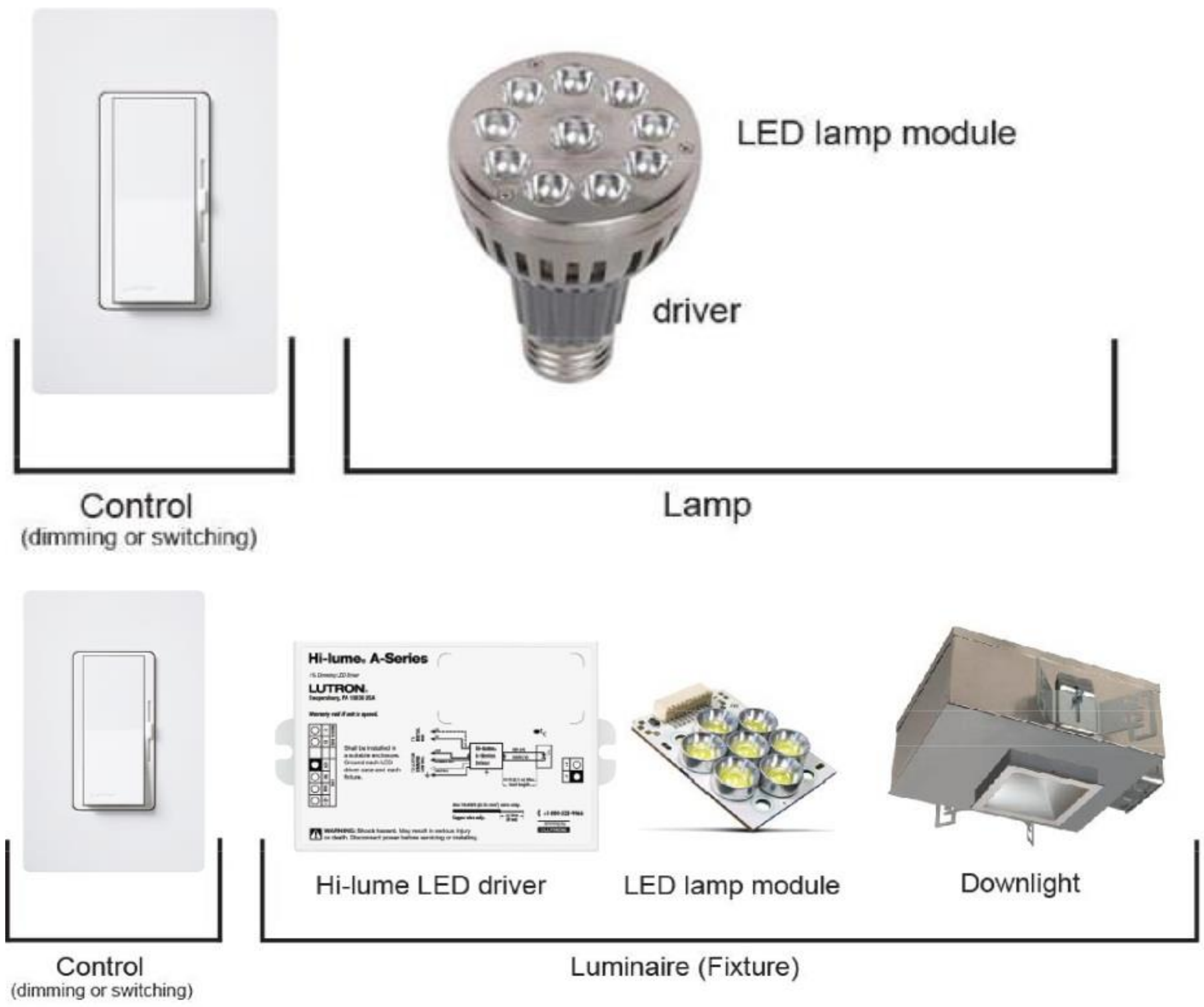
Ballasted or Driver connected Loads

Ballasted or Driver driven loads

- Two predominant load types:
  - Fluorescent lamps
    - Ballast required to limit the current through the discharge
    - Old technology being superseded by LED
  - LED Arrays
    - Driver required to support DC load
    - Regulates the current for dimming

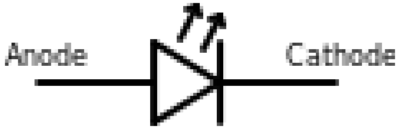


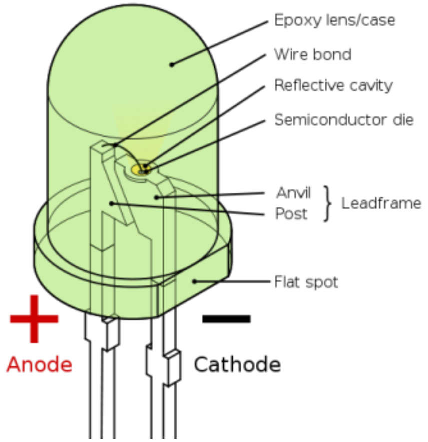
LED Deep Dive

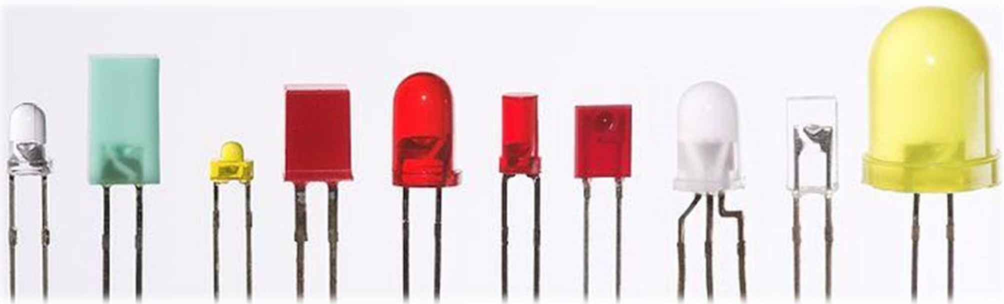


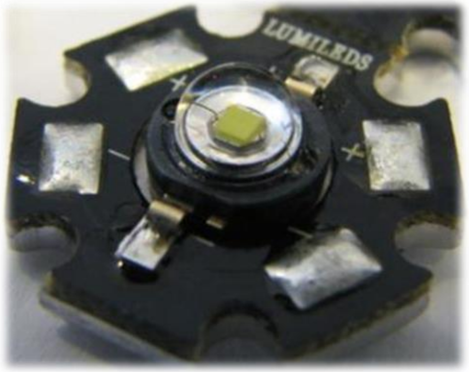
What is an LED?

- 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





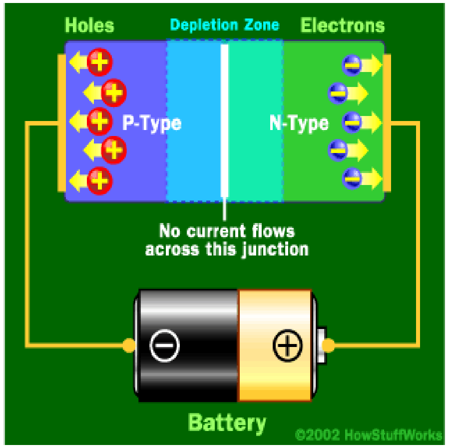




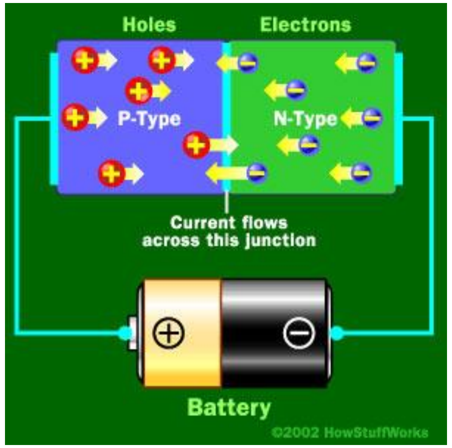
Source: http://en.wikipedia.org/wiki/LED

LED BASICS

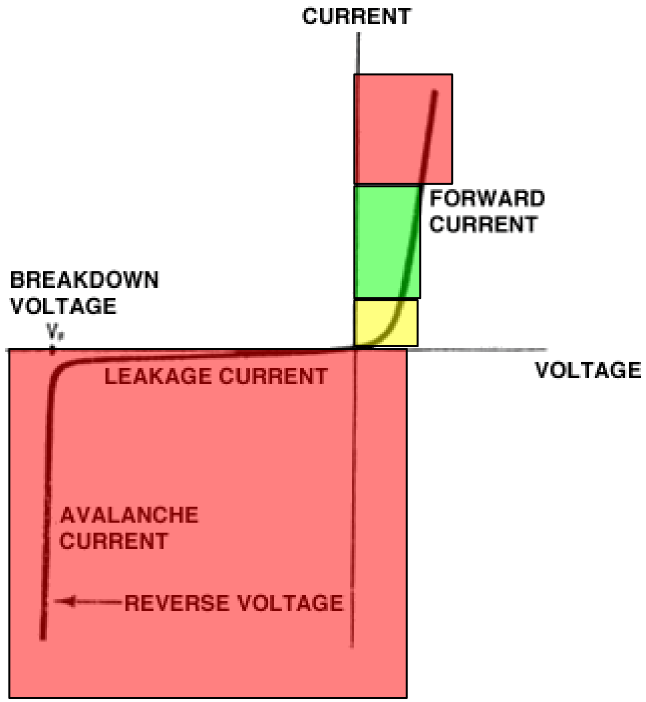
- To get light out of an LED we need to forward bias the LED
- If the reverse breakdown voltage of the LED is exceeded, the LED will fail
- If there is too much forward current, the LED will fail
- To maintain the light output over the life of the LED, we need a reliable way to keep it working in the green region



Reverse Bias



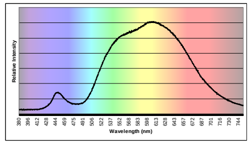
Forward Bias

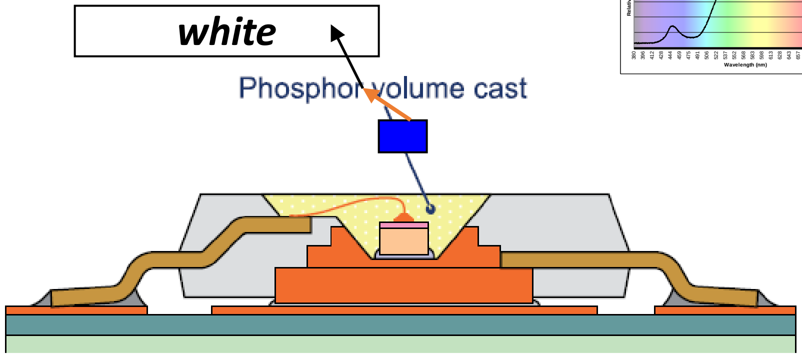


[Video]

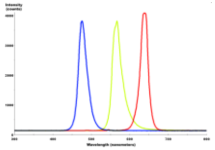
White Light from LEDs

- Phosphor Conversion method:





- RGB Method:



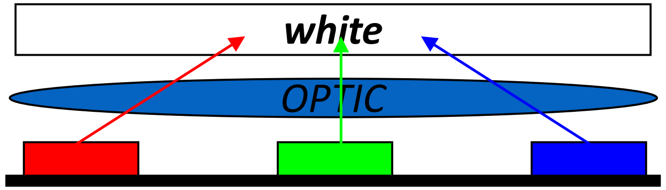


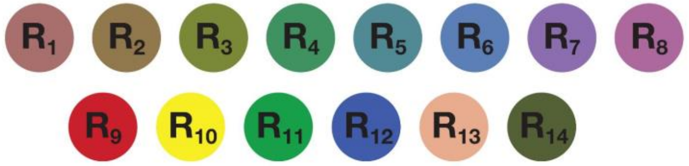
Table 1. Relative advantages and disadvantages of methods for creating white light with LEDs.

Mixed-color white LEDs	Phosphor-converted white LEDs
Advantages	*Advantages*
• higher overall luminous efficacy • good color rendering properties • complete flexibility for achieving any desired color property	• results in a single, compact, white light source • Closer to blue more efficient
Disadvantages	*Disadvantages*
• difficult to completely mix light • difficult to maintain color stability over life and at different operating conditions, including dimming	• lower overall luminous efficacy • uniform application of phosphor in manufacturing process is more difficult to control • limited range of available color properties based on phosphor availability

Source: 2003 Rensselaer Polytechnic Institute

Color Rendering Index (CRI)

- CRI describes how well (accurately) a light source shows color
- Based on eight “standards”



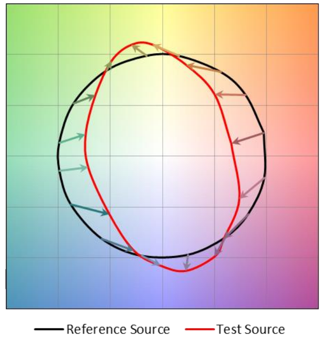
- A Red swatch has been added (R9) that is an indication of red, which is important in rendering skin tones.
- *This is still a highly subjective issue*
- Higher = better
- LEDs typically > 80 (and >95+ is available)
- Sunlight / Incandescent lamps = 100 (maximum)

Illuminating Engineering Society has developed a new metric TM-30

IES TM-30-15:

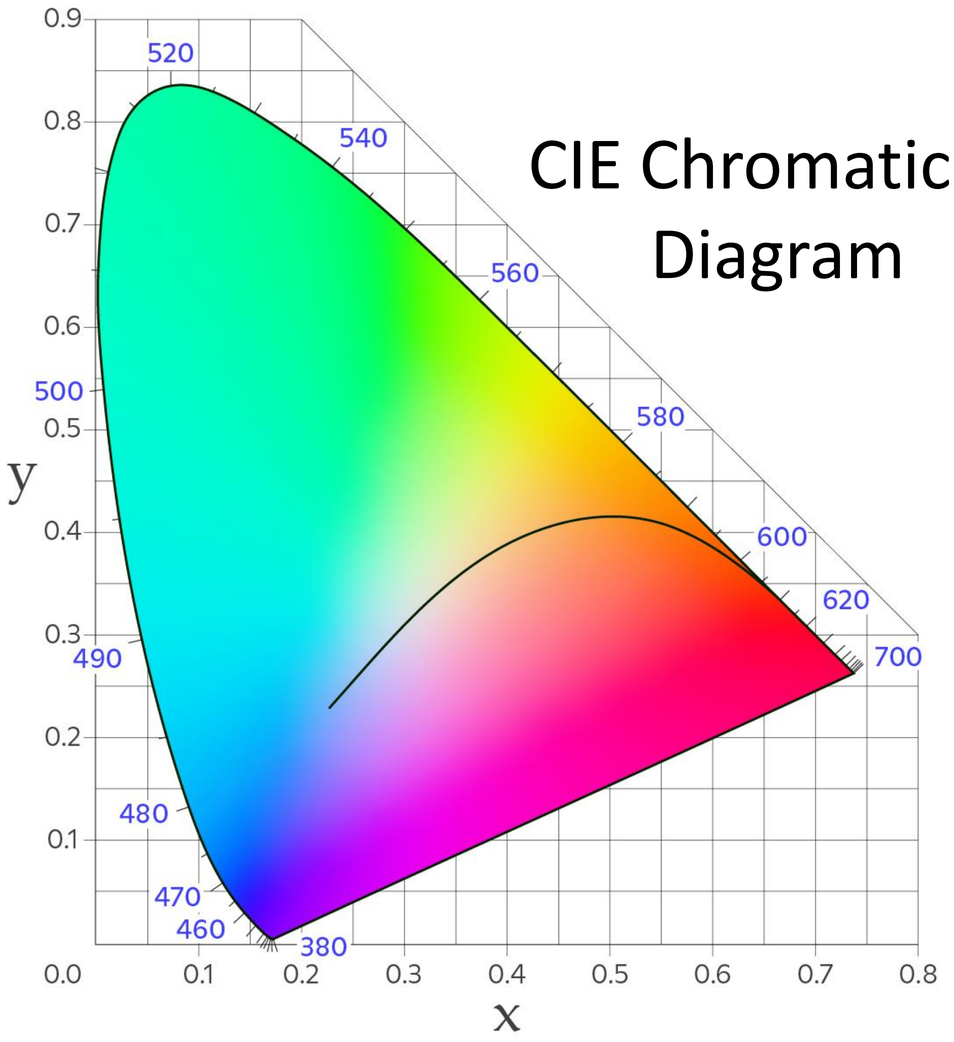
IES Method for Evaluating Light Source Color Rendition

- 99 Color Evaluation Samples
- Adopted more uniform color space
- Contains two single value metrics and color vector graphic
  - R_f: Color fidelity (CRI, but with above improvements)
  - R_g: Color Gamut Index, >100 renders more saturated than the index. <100 less saturated.



CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

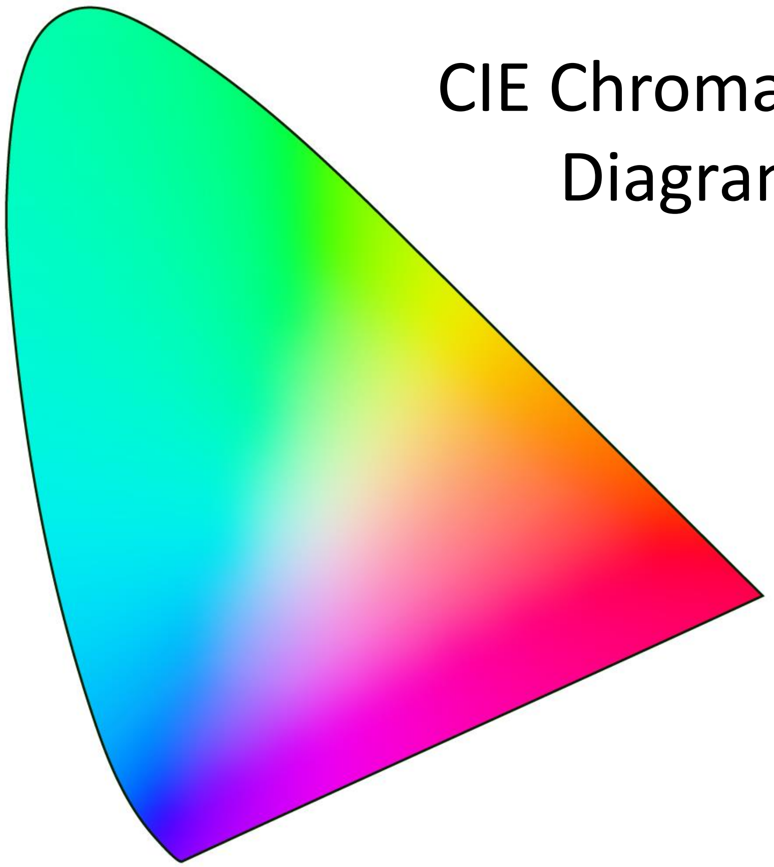


CIE Chromaticity Diagram

CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

1. Representation of Visible Colors

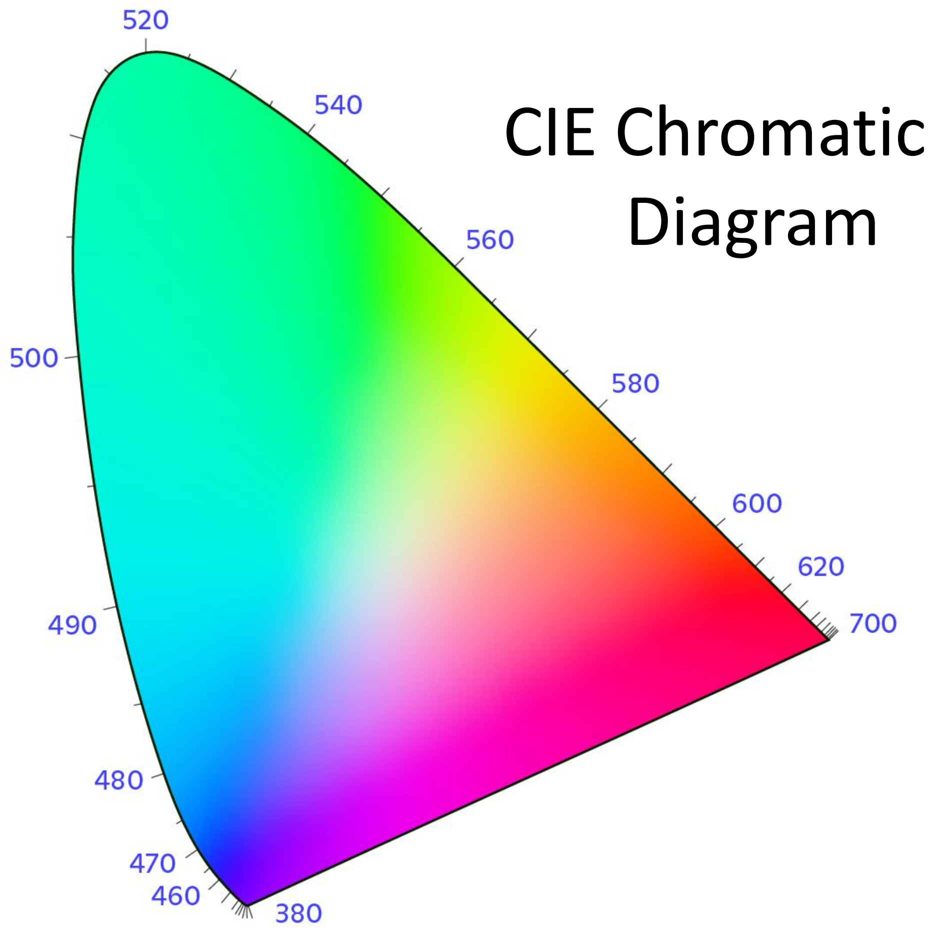


CIE Chromaticity Diagram

CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

1. Representation of Visible Colors
2. Spectral Color Wavelength

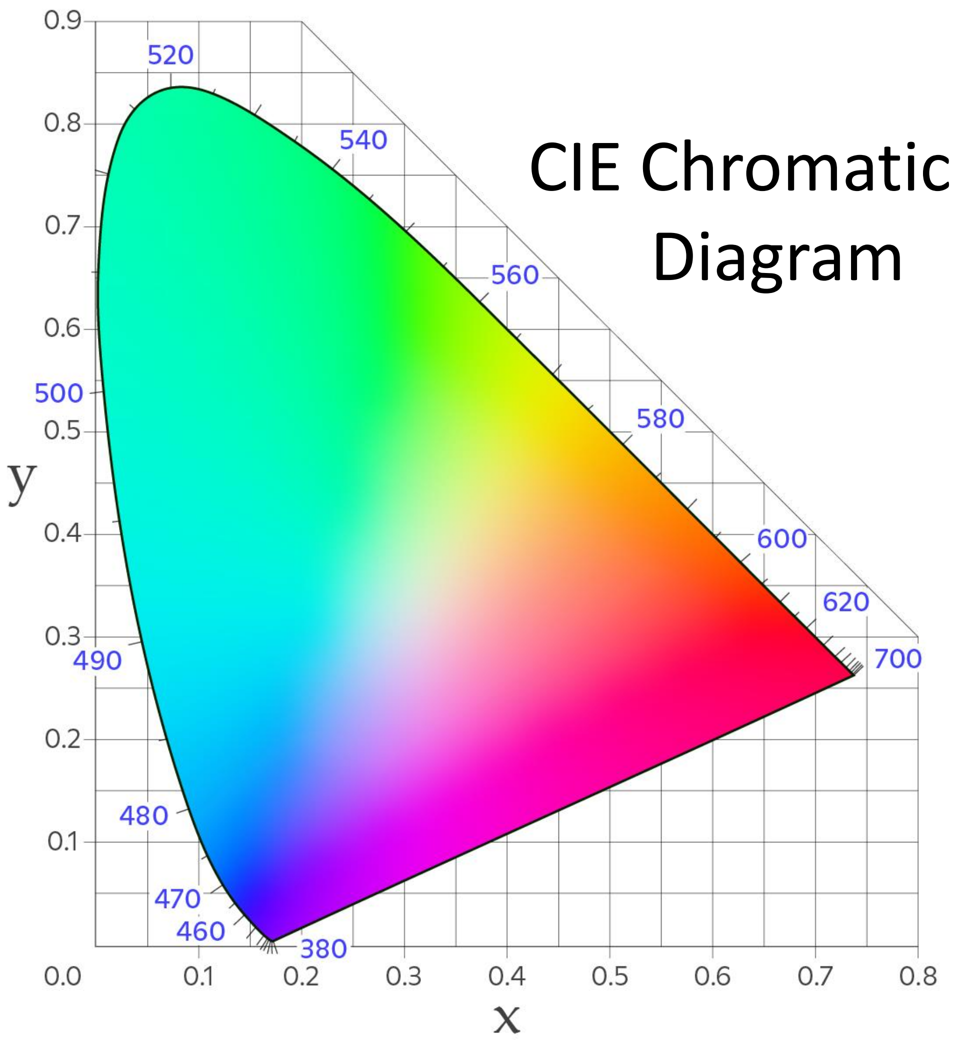


CIE Chromaticity Diagram

CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

1. Representation of Visible Colors
2. Spectral Color Wavelength
3. *x* / *y* Axes

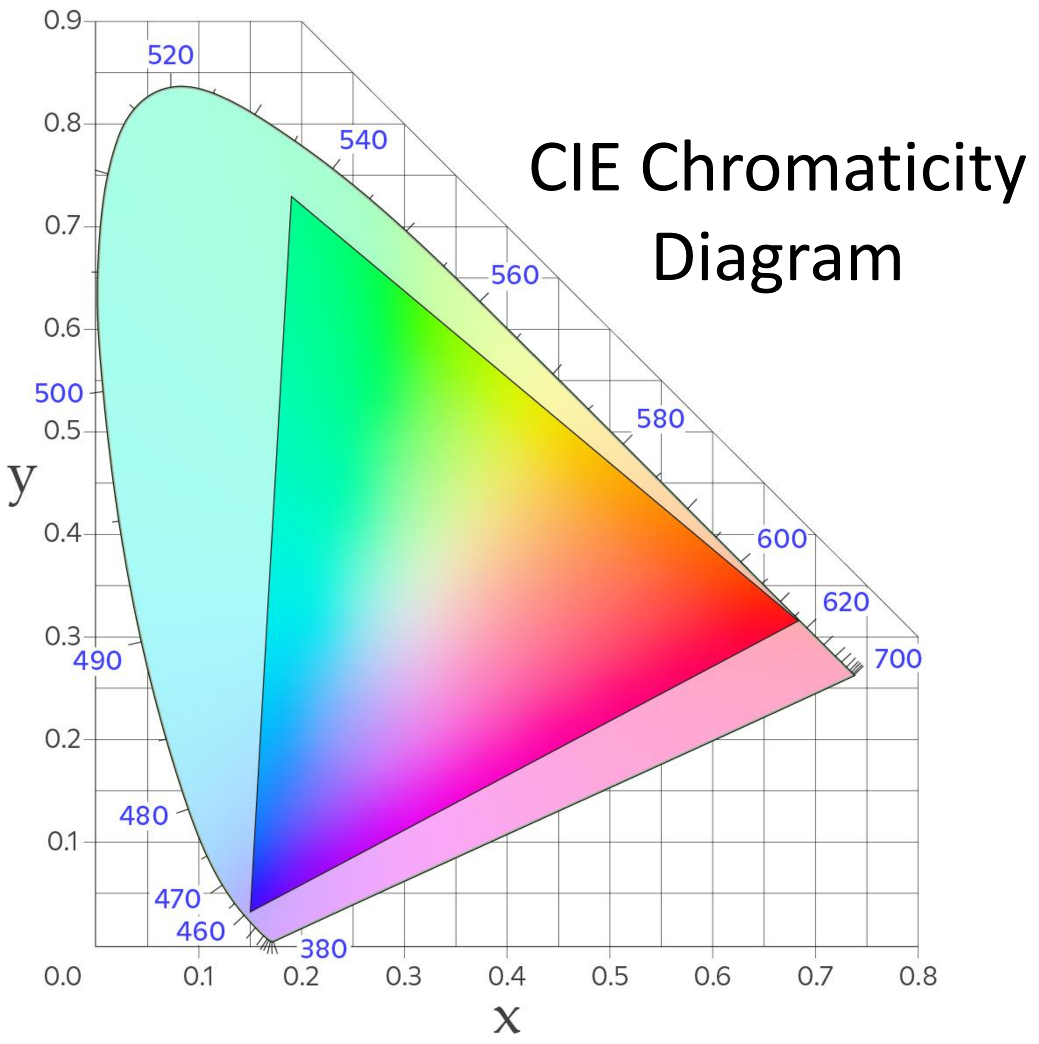


CIE Chromaticity Diagram

CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

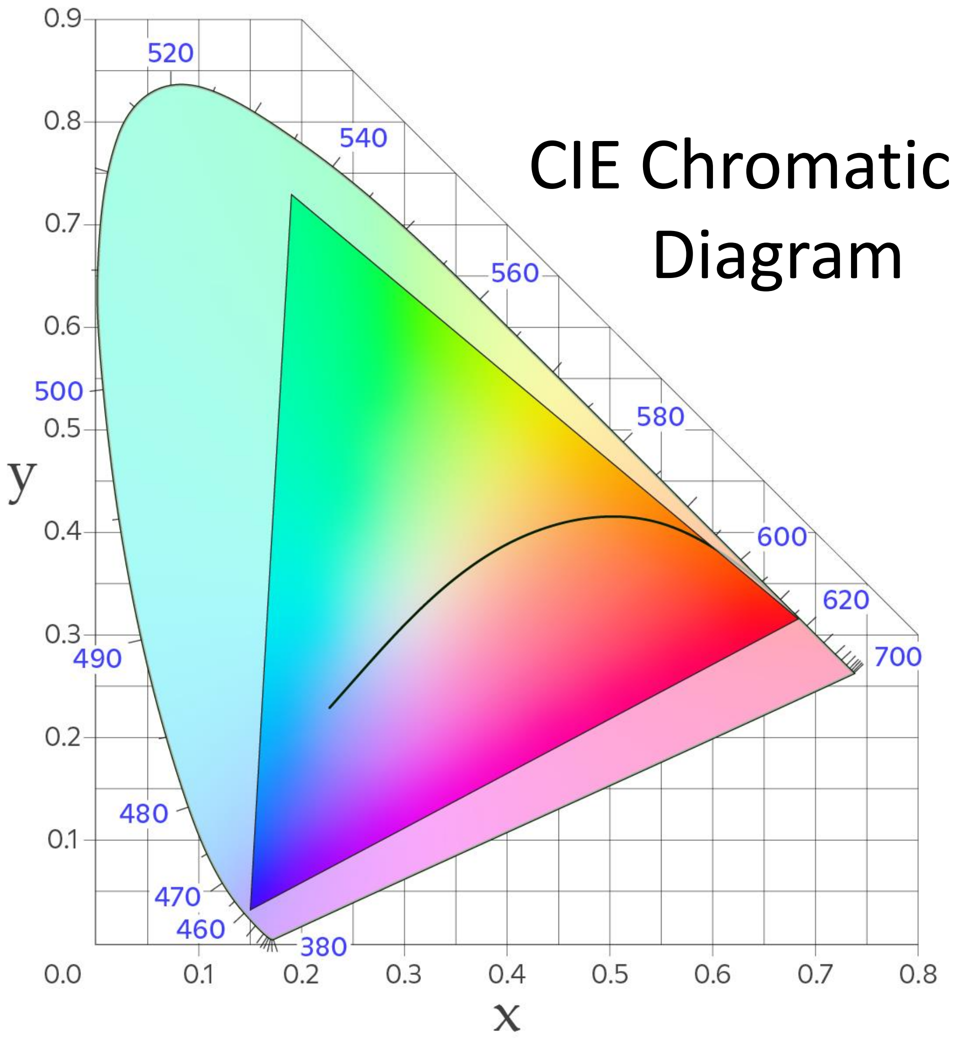
1. Representation of Visible Colors
2. Spectral Color Wavelength
3. *x* / *y* Axes
4. Gamut



CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

1. Representation of Visible Colors
2. Spectral Color Wavelength
3. *x* / *y* Axes
4. Gamut
5. Black Body Curve



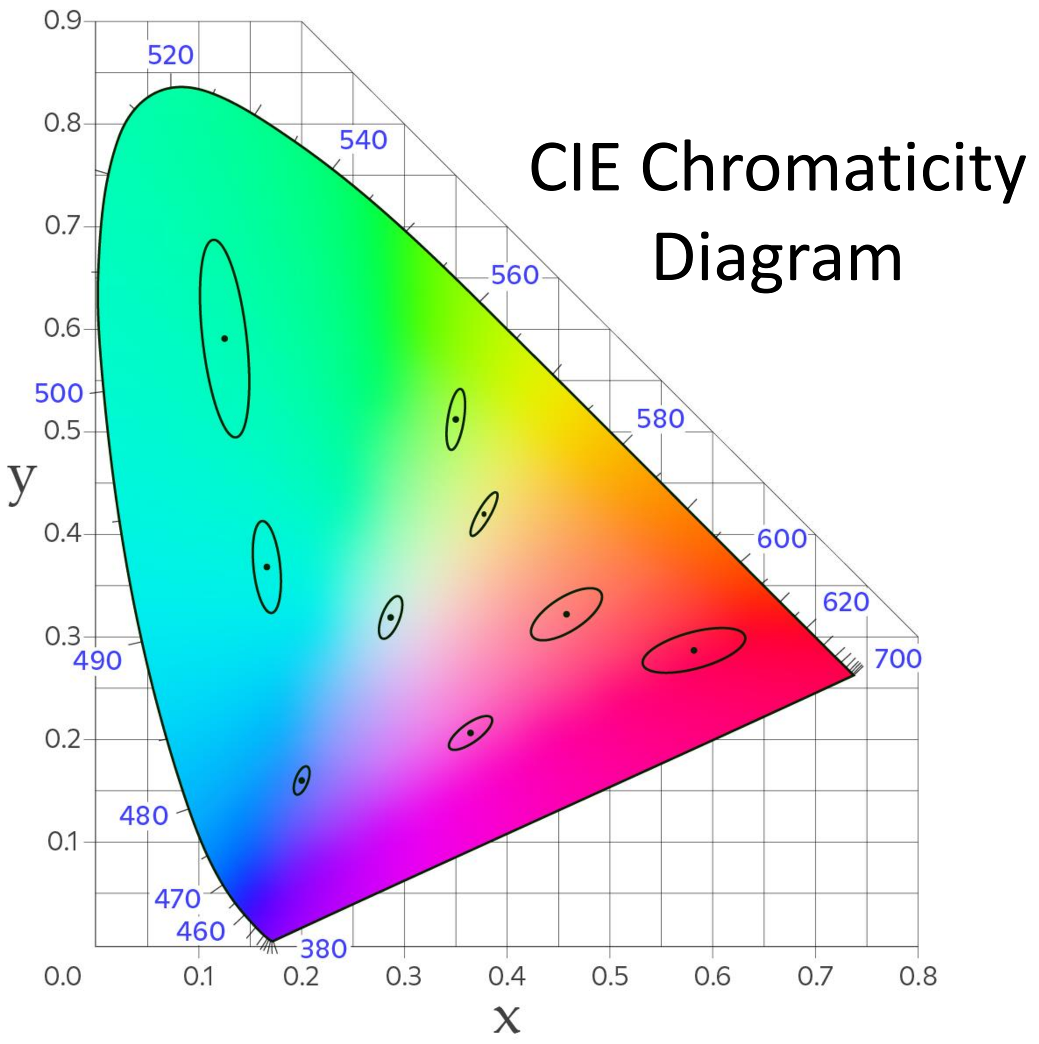
CIE Chromaticity Diagram

CIE Chromaticity Diagram

The CIE is a color matching system to represent human color perception. Components are:

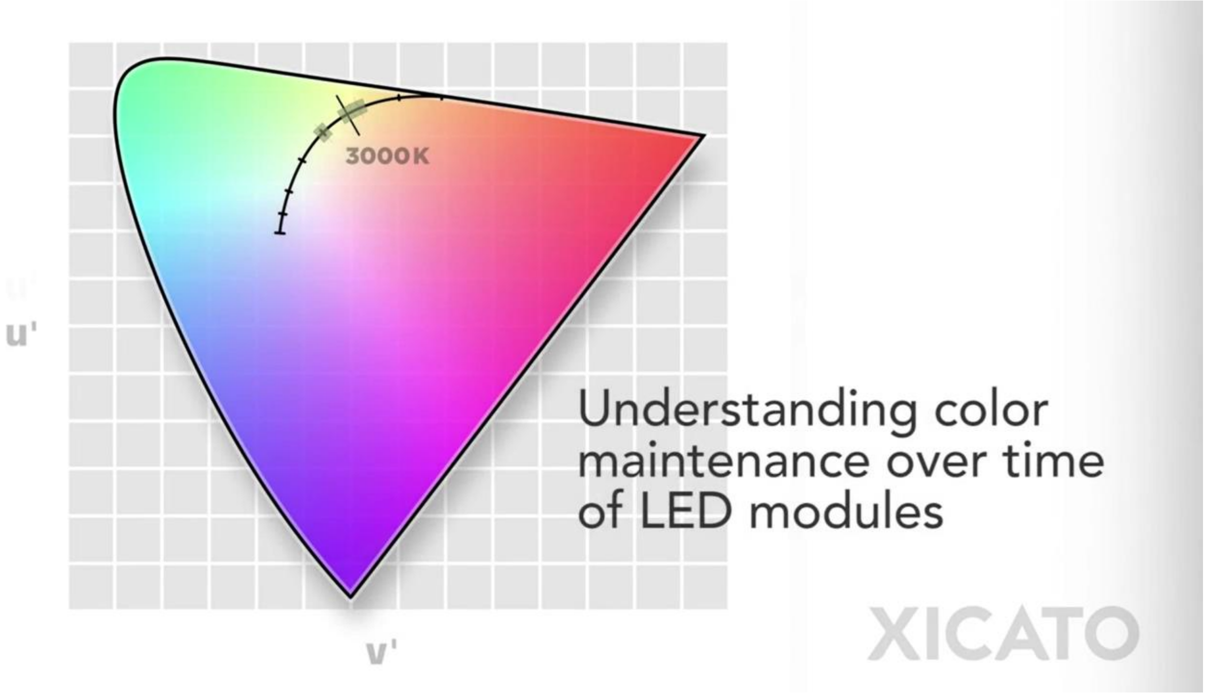
1. Representation of Visible Colors
2. Spectral Color Wavelength
3. *x* / *y* Axes
4. Gamut
5. Black Body Curve
6. MacAdam Ellipses*

*Not shown to scale

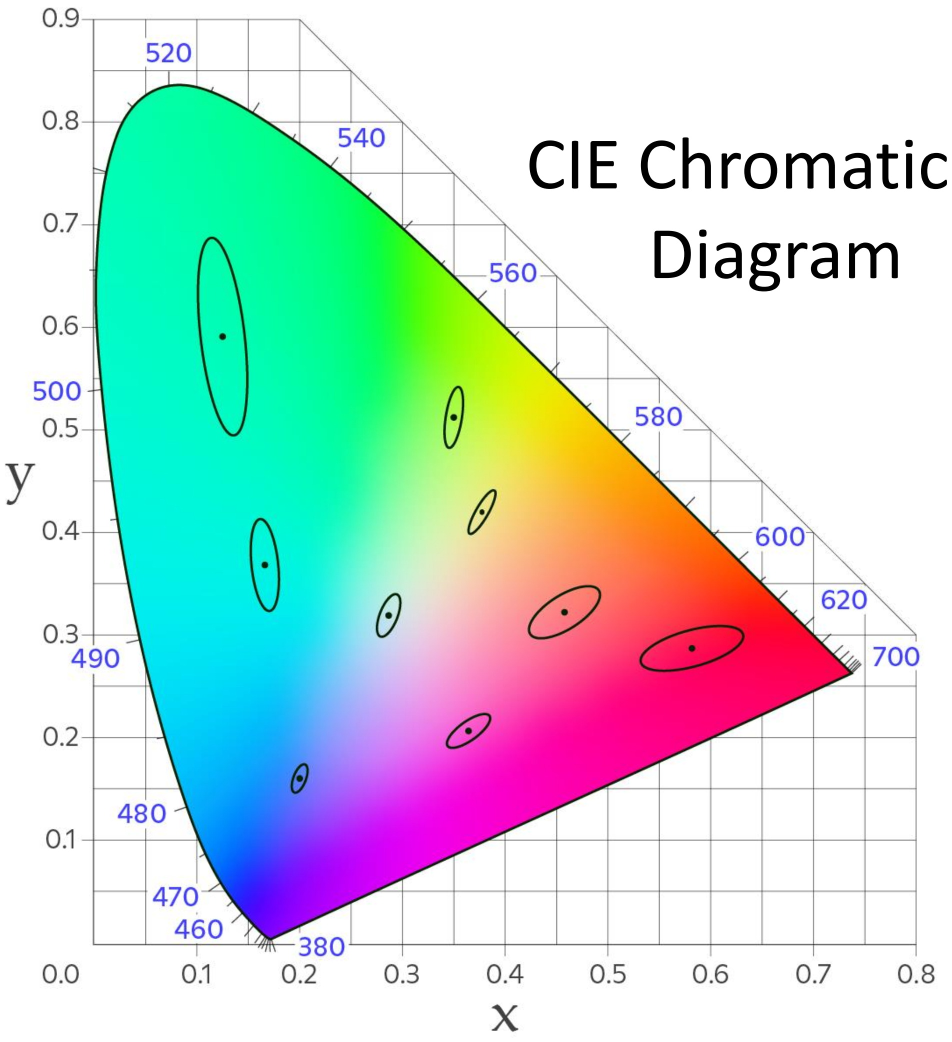


CIE Chromaticity Diagram

Let's watch a video to help explain Color Consistency (MacAdam Ellipses)



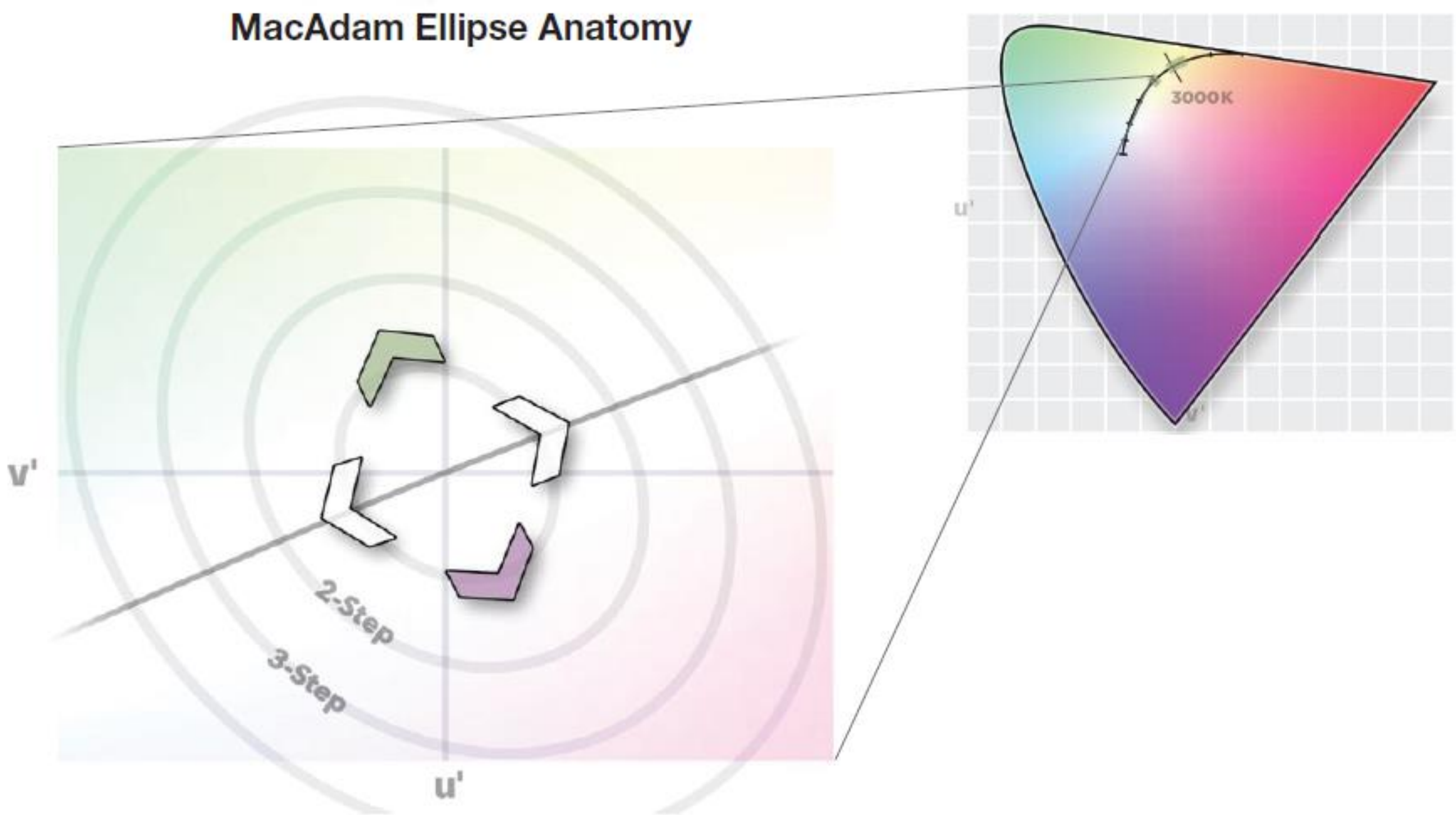
CIE Chromaticity Diagram



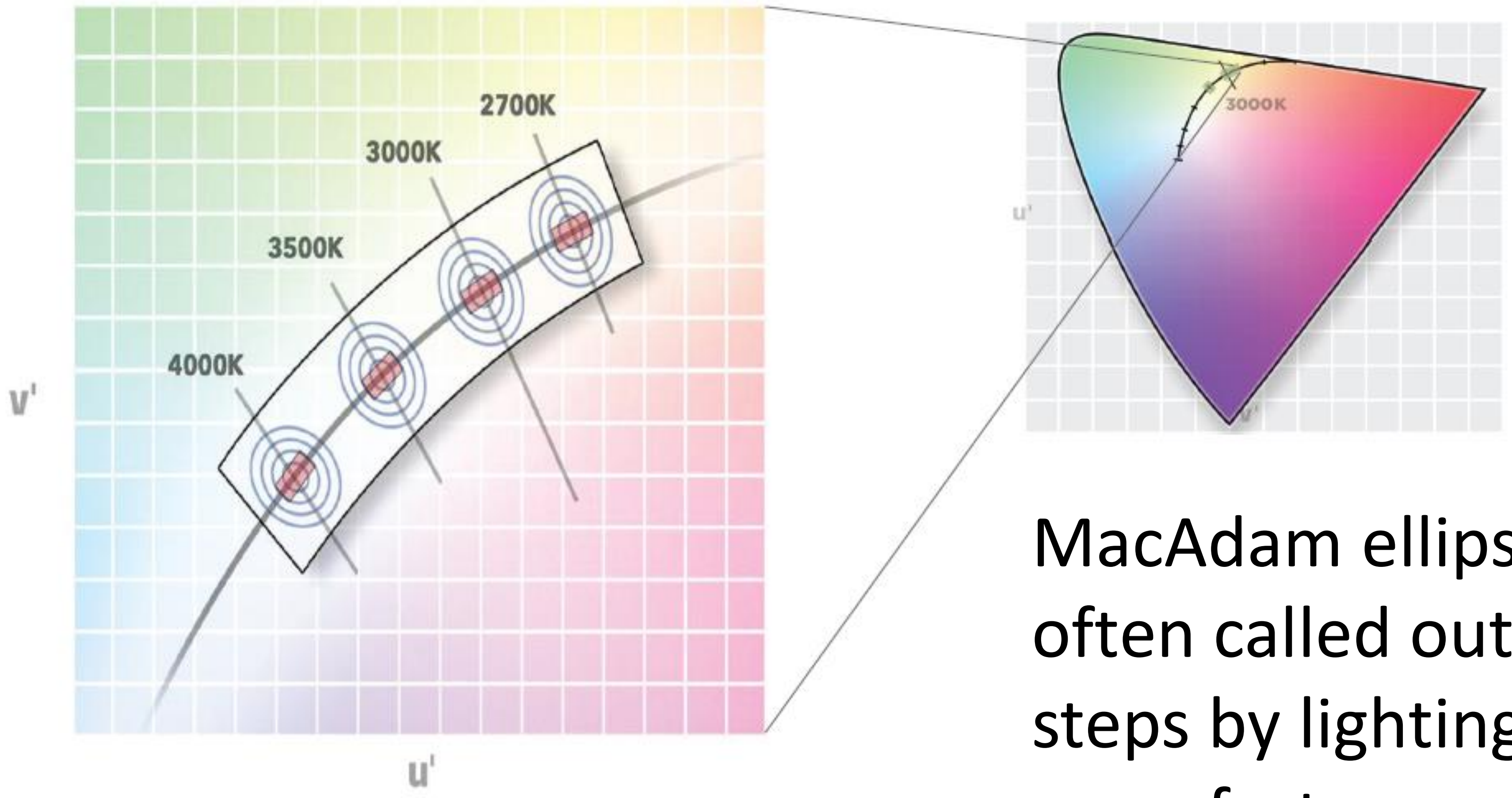
Color Consistency – MacAdam Ellipse

The TM-30 metric from before has chosen a different color space that is more even distributed, such that the macadam ellipses actually appear as circles of the same size across the entire color space.

Using the newer TM-30 Color Space



Color Consistency – MacAdam Ellipse

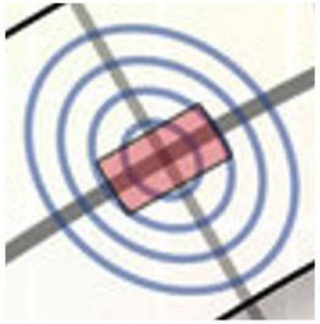


MacAdam ellipses are often called out as steps by lighting manufacturers

Color Consistency

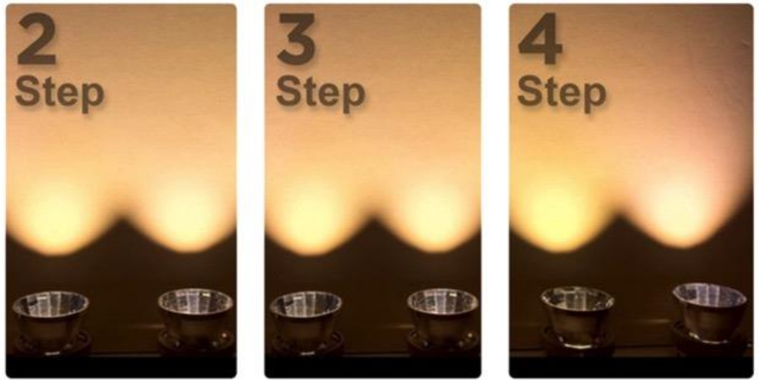
Color Consistency Comparison

- 3-step consistency is standard
- 2-step consistency is industry leading
- 1x2 step consistency is industry best



Color Consistency

The average amount of variation in chromaticity among a batch of supposedly identical lamp samples at time of manufacture



CIE Chromaticity Diagram

The Black Body Curve

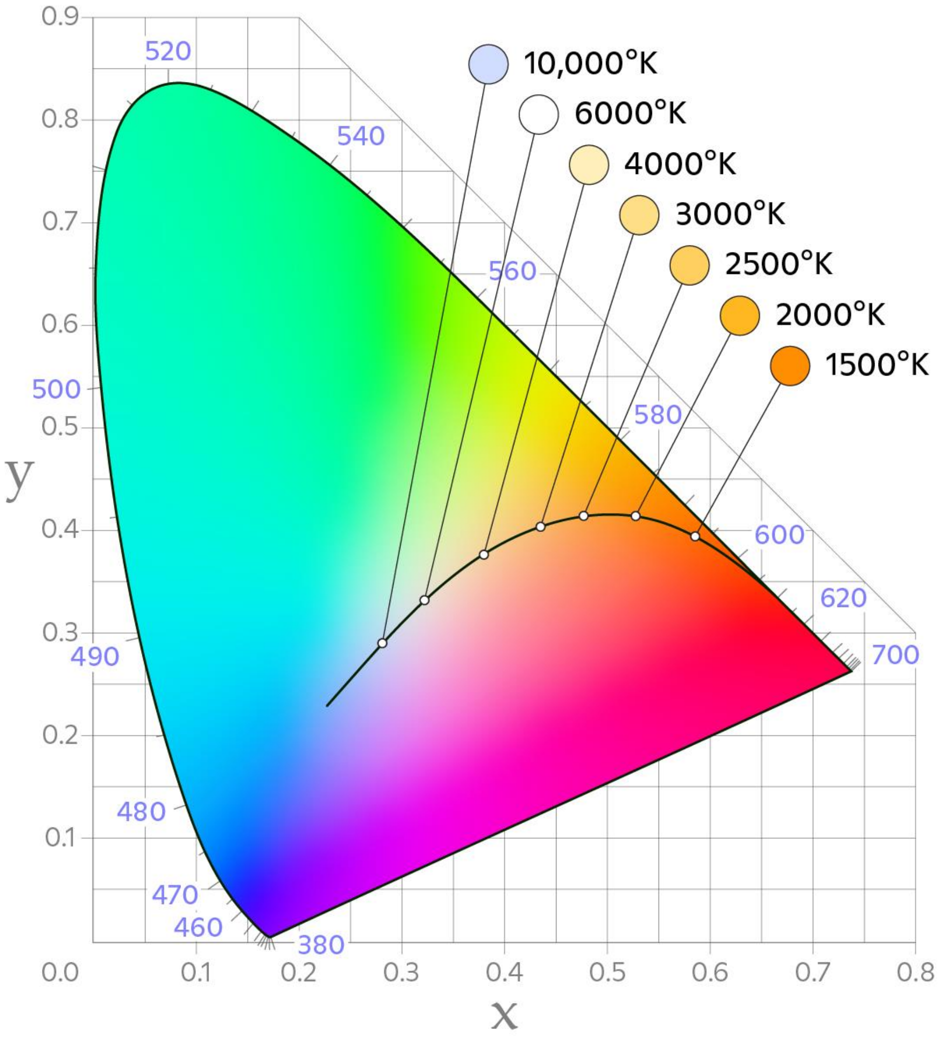
- Black Bodies are naturally black substances that emit various levels of white light when heated to specific temperatures in degrees Kelvin (K)
- The Black Body curve represents the total range of naturally occurring white light.
- Common examples of black bodies are light bulb filaments, candles and Heated Nails!.

Artic Sky: 10,000°K

Incandescent: 3000°K

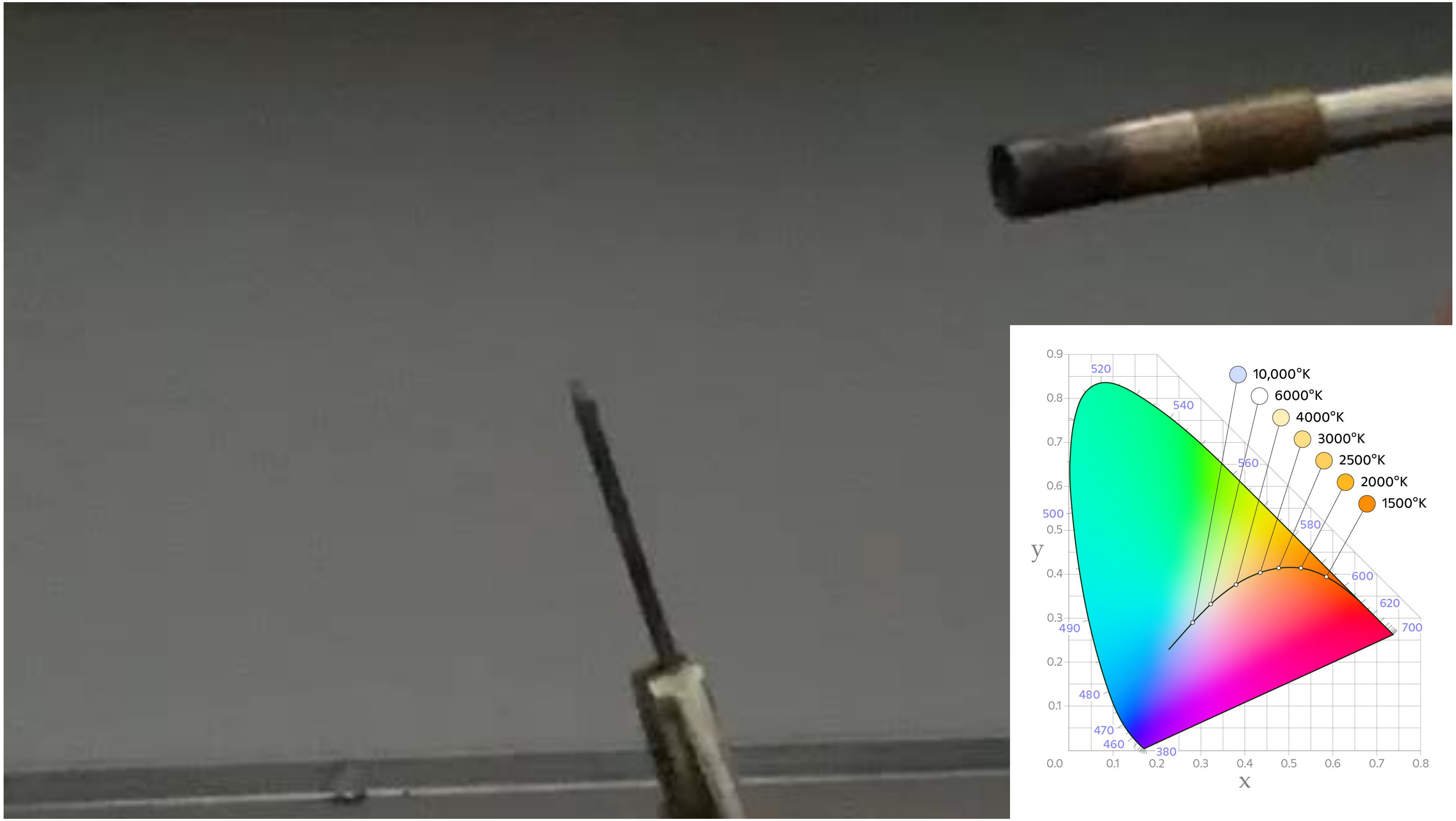
Sunrise: 2000°K

Candlelight: 1500°K



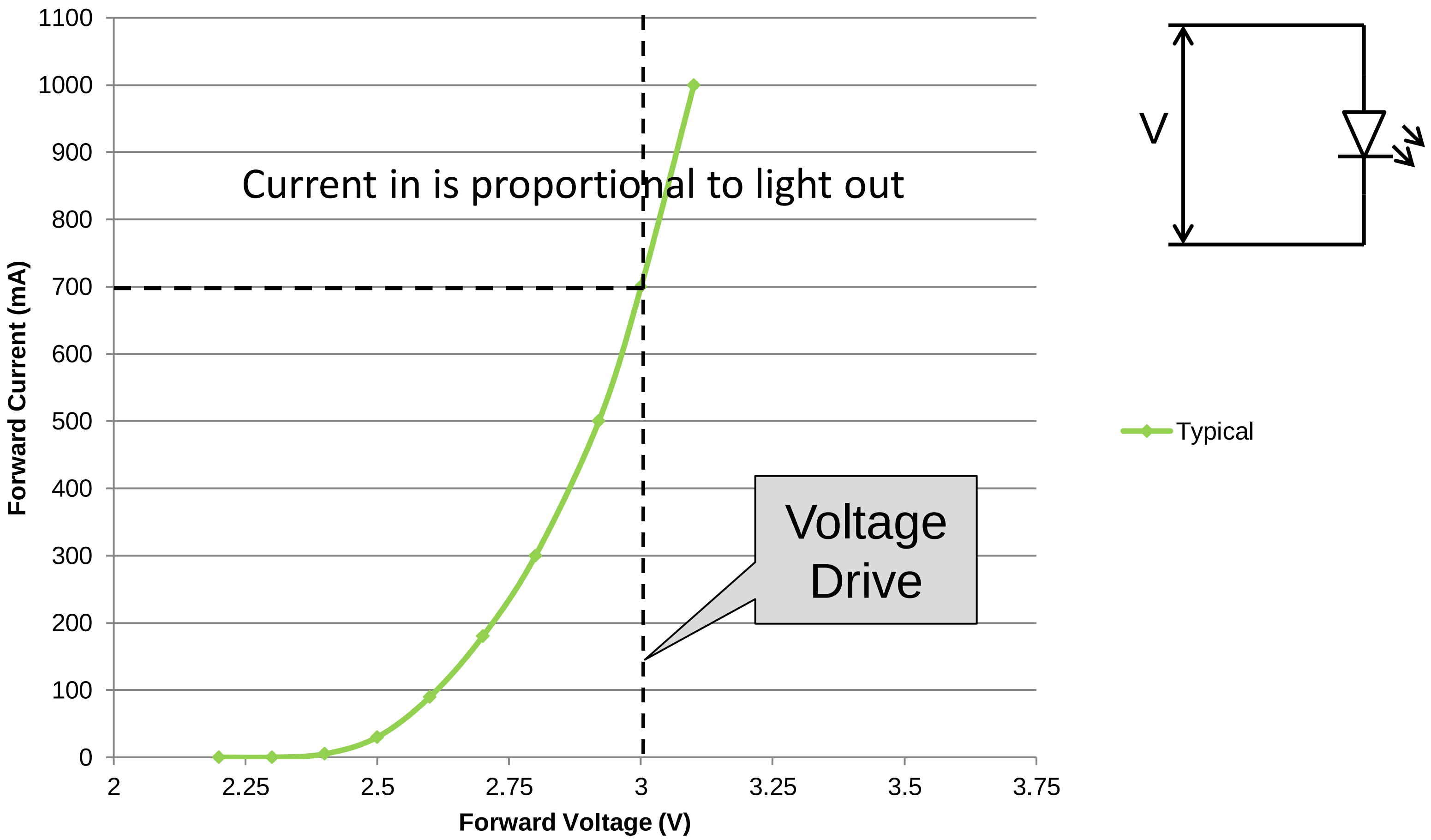
Correlated Color Temperature (CCT)

Correlated Color Temperature (CCT)



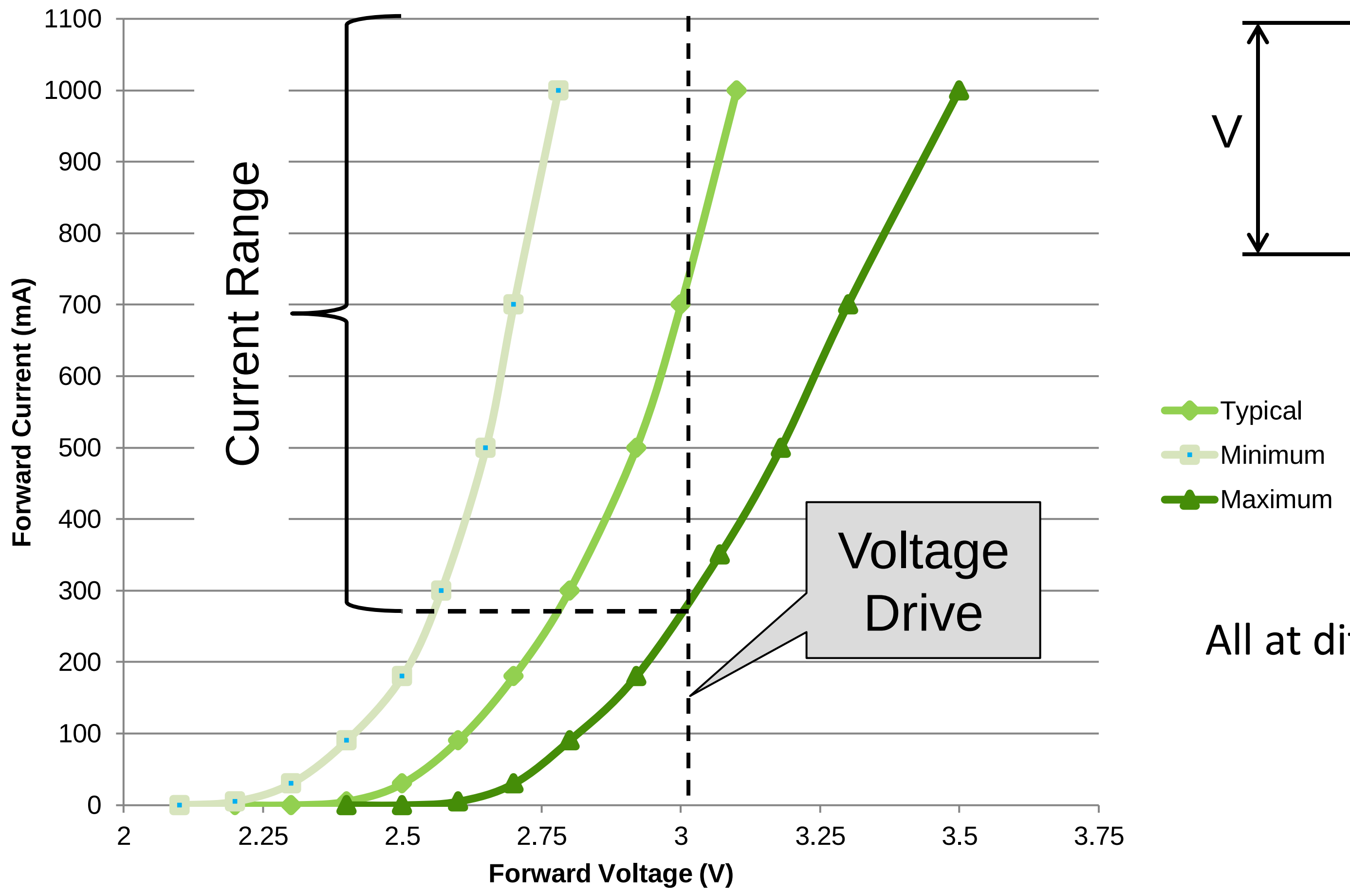
How do we control an LED?

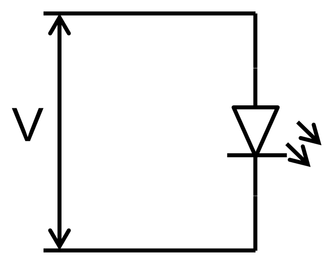
DRIVING AN LED – VOLTAGE DRIVE



What happens when things change?

DRIVING AN LED – VOLTAGE DRIVE

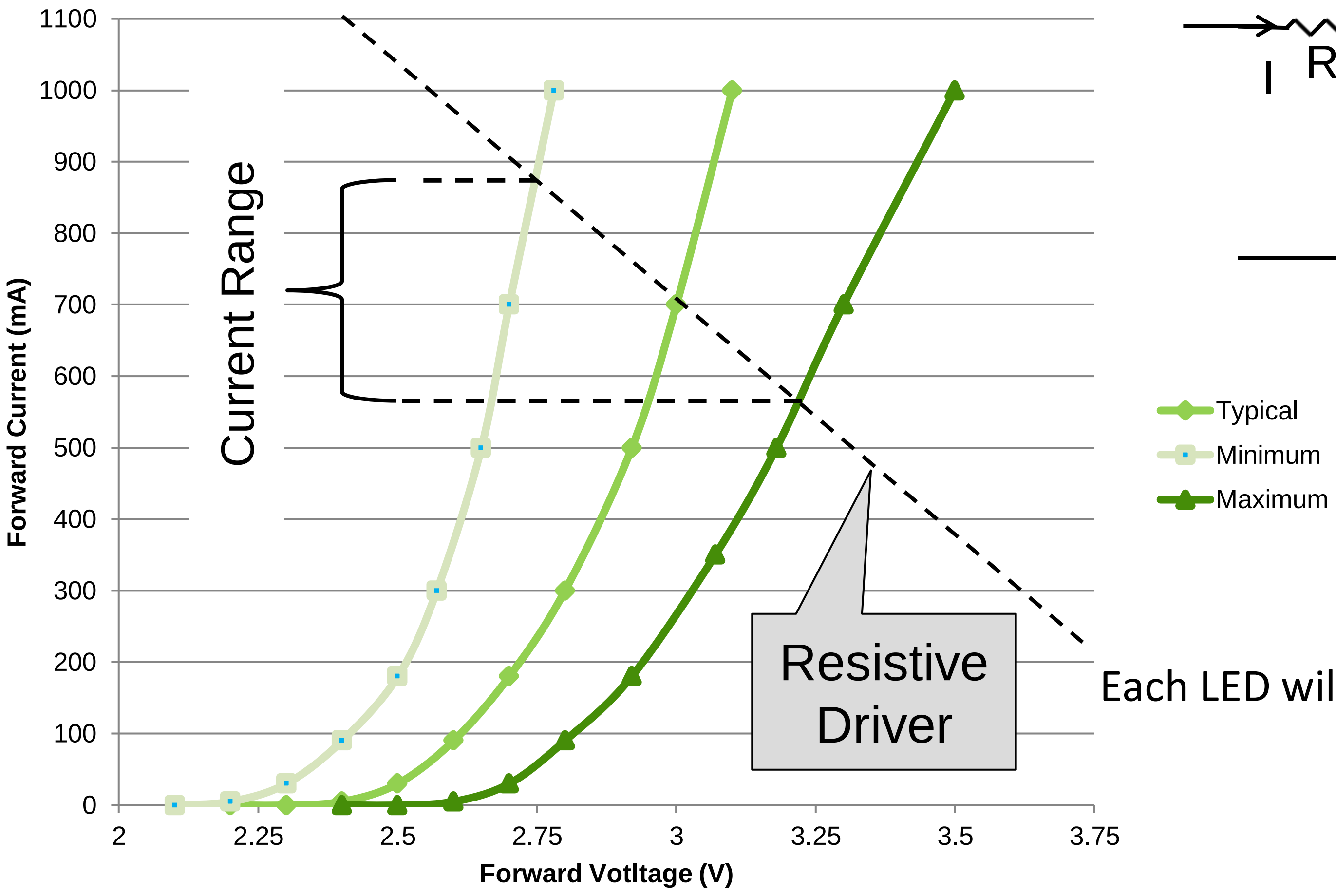


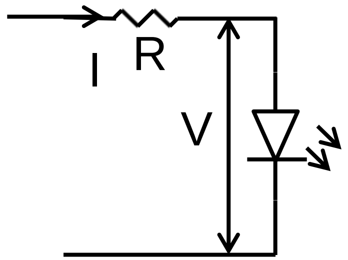


All at different light levels

NOT RECOMMENDED
(No current regulation)

DRIVING AN LED – EXTERNAL RESISTOR

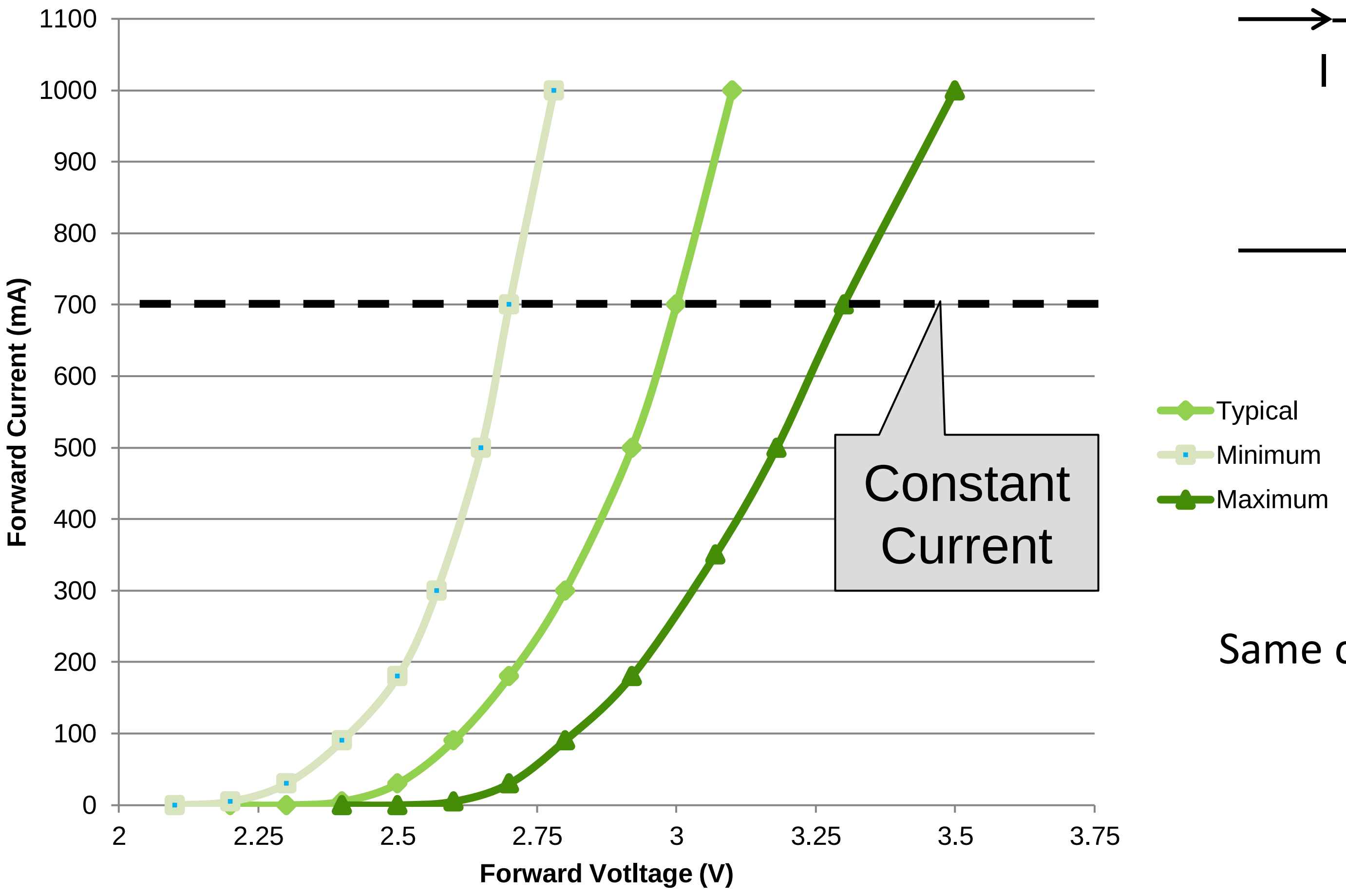


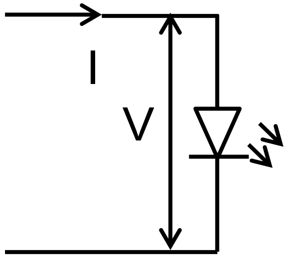


Each LED will be at a different light level

NOT RECOMMENDED
(Poor current regulation)

DRIVING AN LED – CONSTANT CURRENT DRIVE



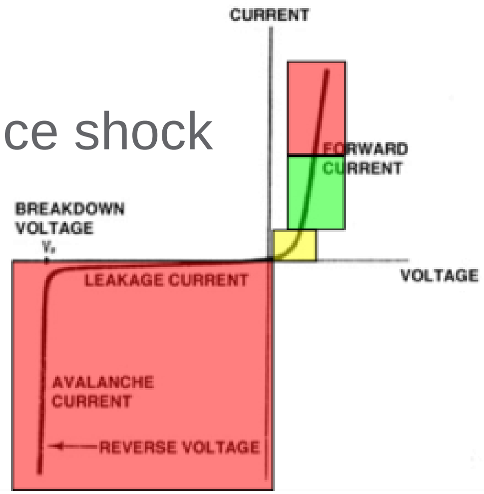


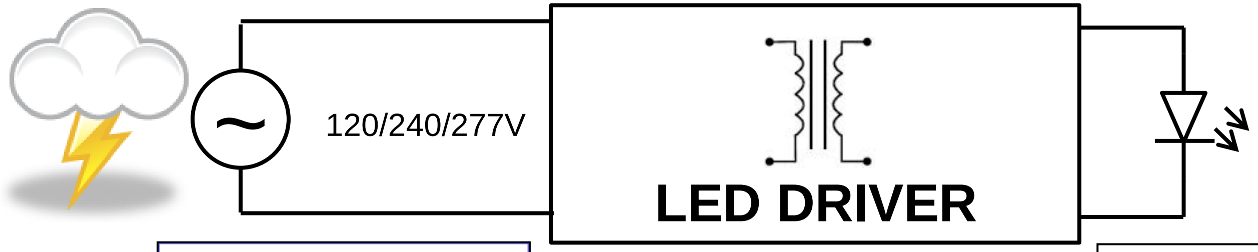
Same current = Same light

RECOMMENDED

WHAT IS AN LED DRIVER?

- Driver = The “ballast” for an LED system
- Transforms system voltage (e.g., 120, 240, 277V) to DC current
- Fundamental purpose: drive the LED array at a specific voltage and current (stay in green region)
- Regulates output (voltage/current) to counter system fluctuations (stay out of red regions)
- Isolate the LED system from the high voltage to reduce shock hazard and increase safety and reliability





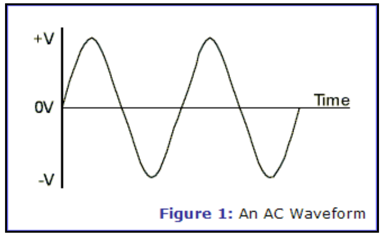
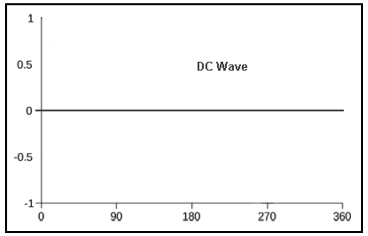
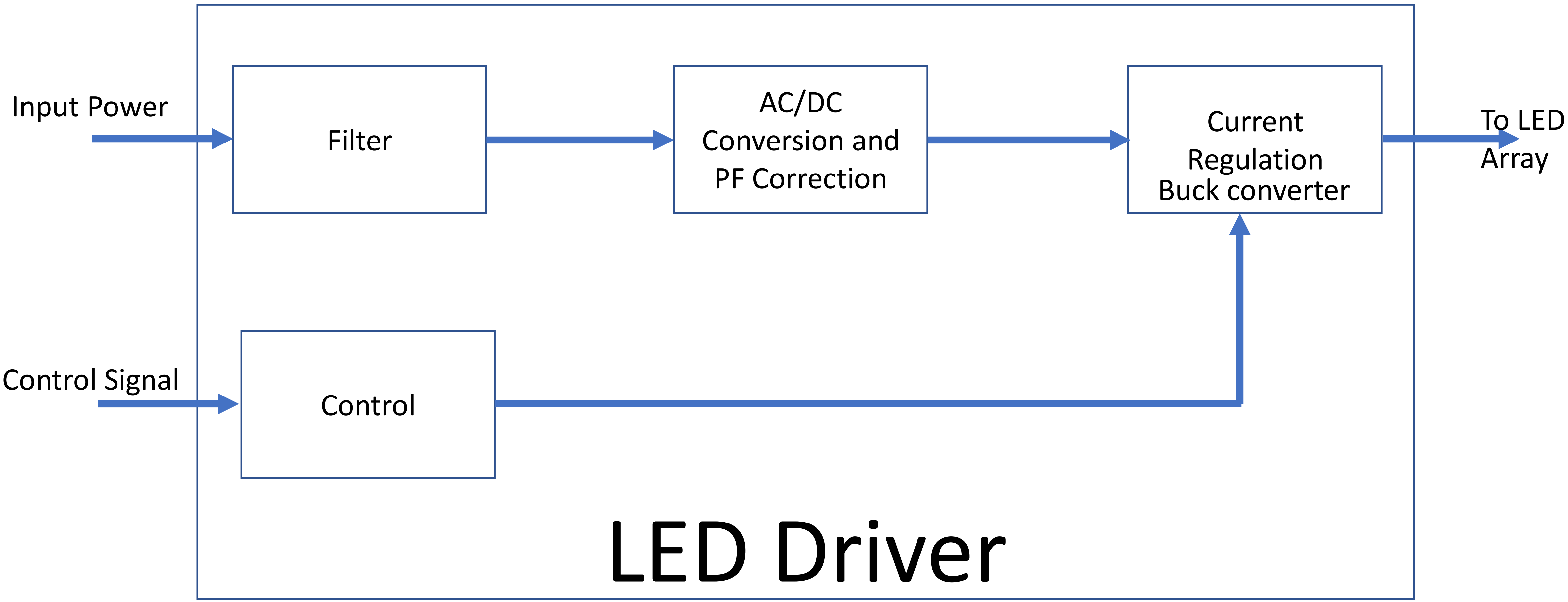


Figure 1: An AC Waveform

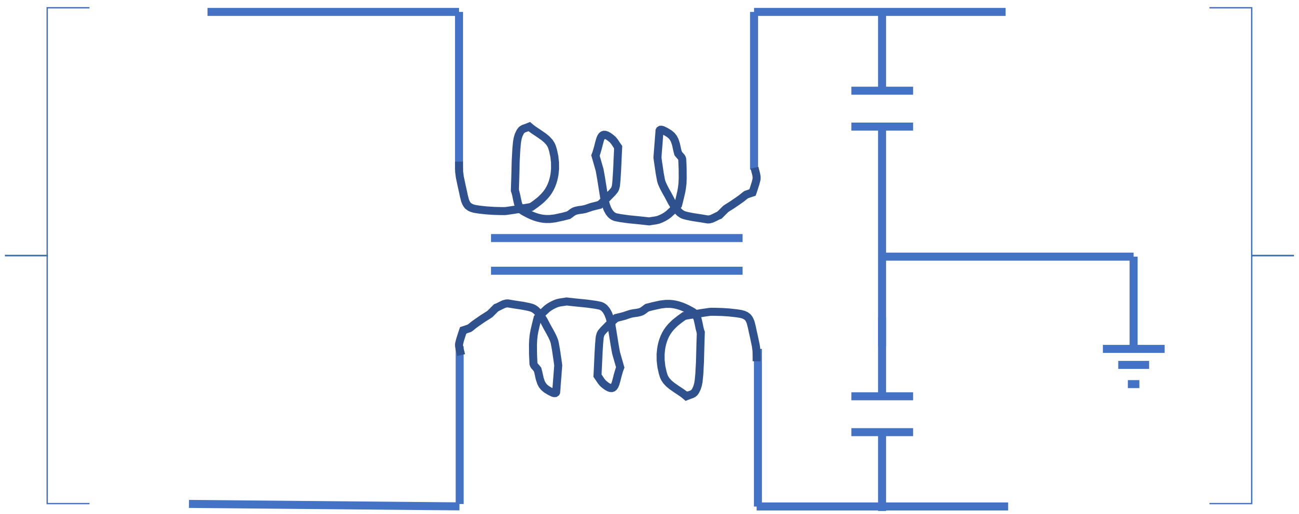


What is inside a typical LED driver?



Filter section

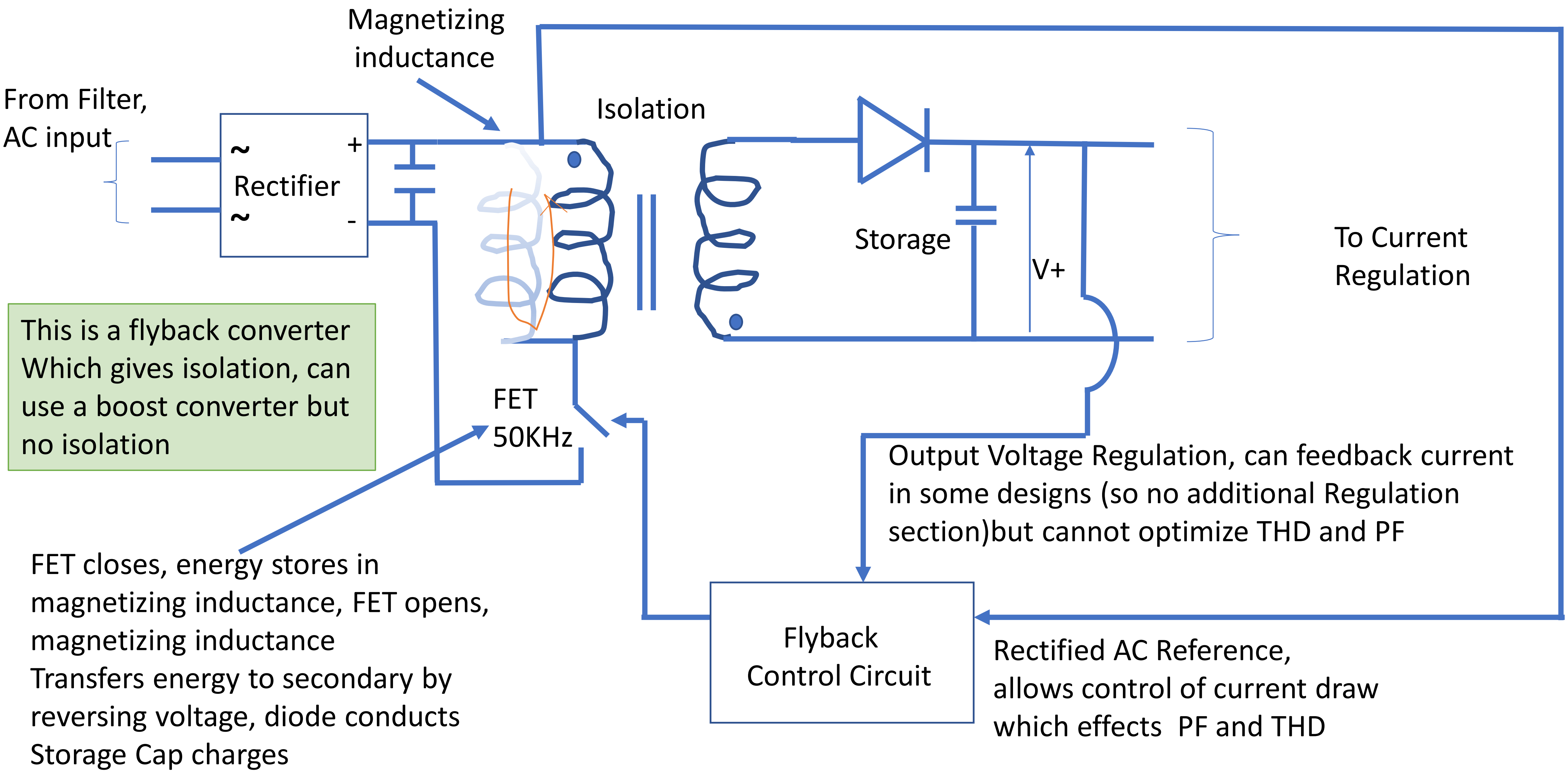
AC Input



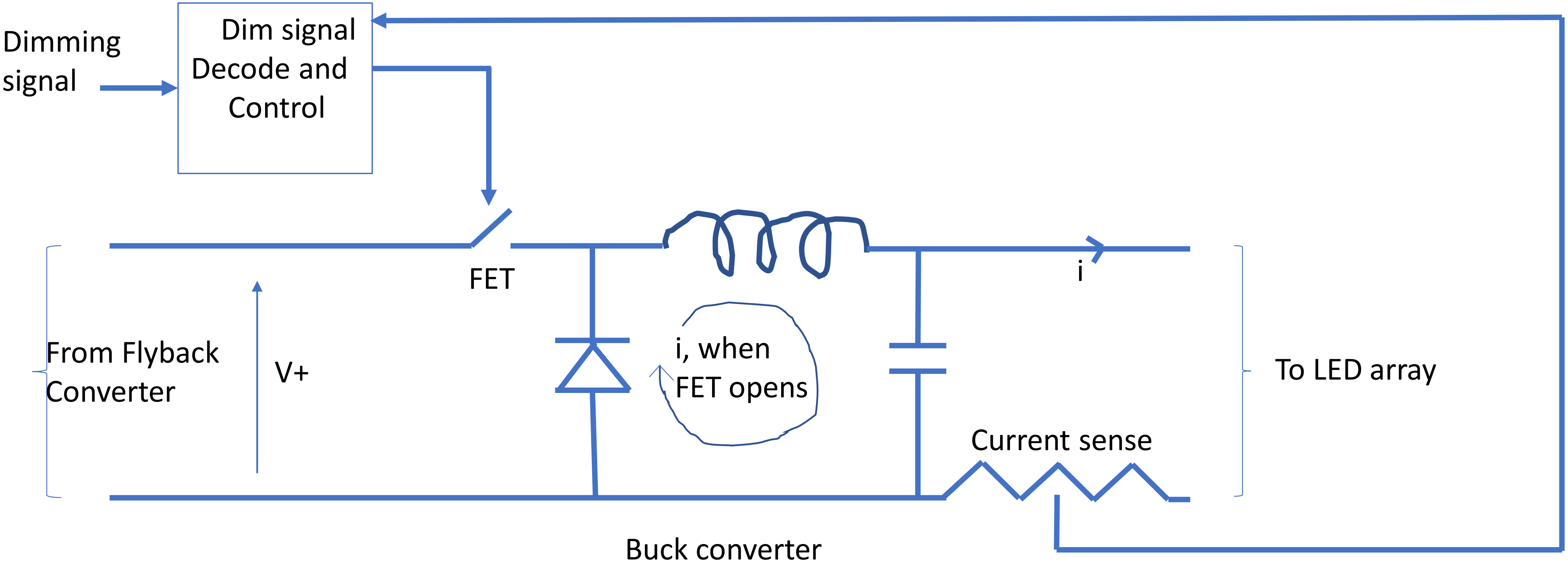
To AC/DC conversion
And active PF correction

The filter controls the amount of EMI generated by the LED Driver

AC/DC conversion and active PF correction

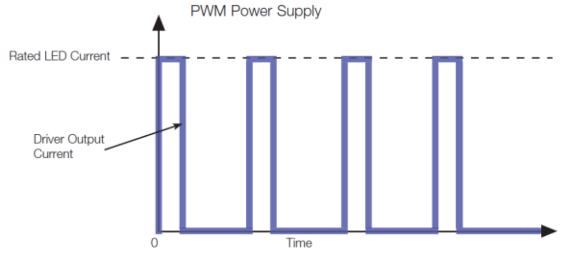


Current Regulation - Output

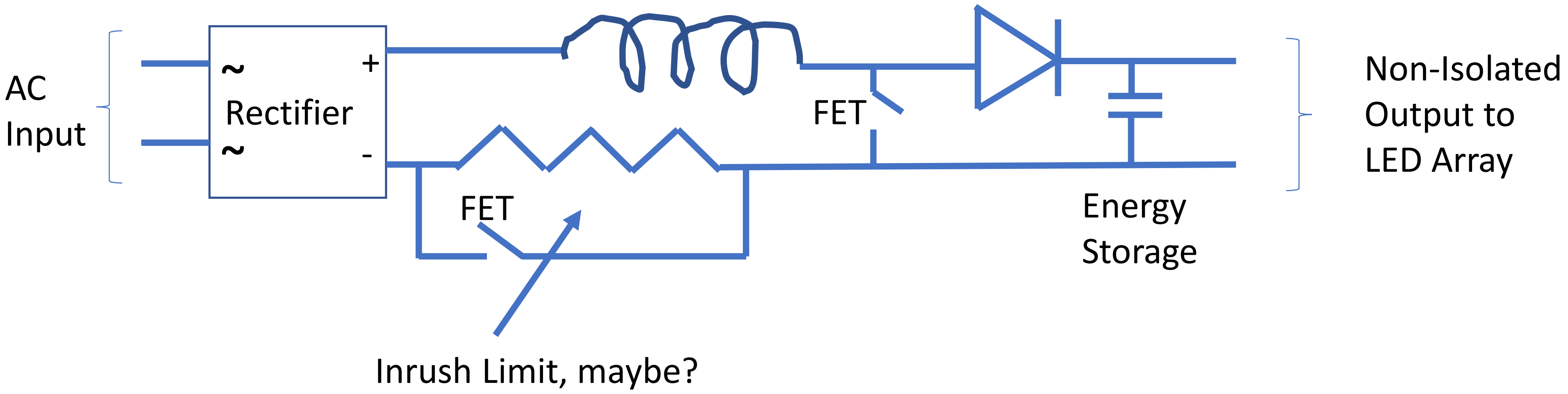


Buck converter
50KHz

Constant voltage may just use V+ and a series switch or maybe voltage feedback from output of buck converter to control circuit



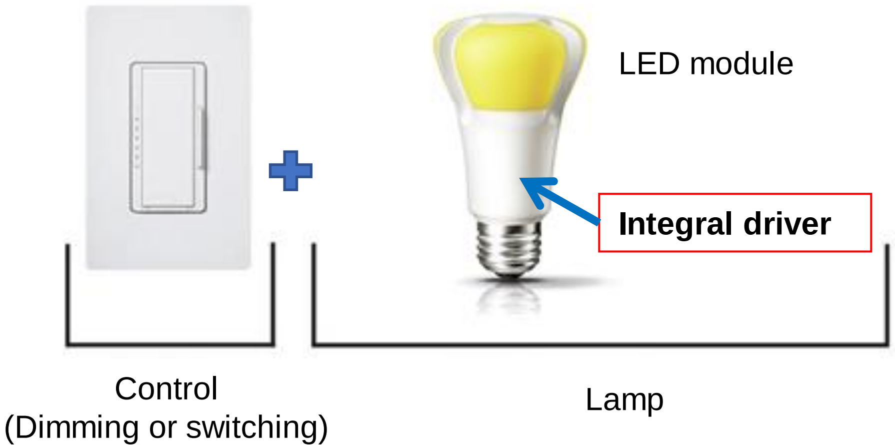
Boost Converter-Less parts but not as high performance



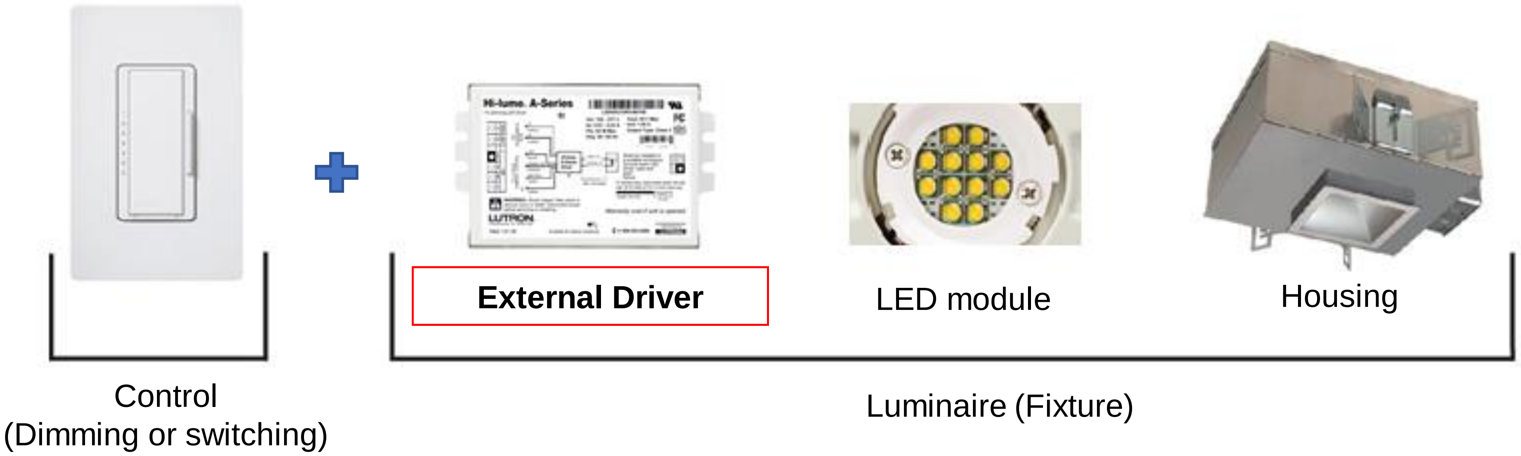
- Non-Isolated Output
- If driven by phase control
  - Low PF
  - High THD
- Storage cap non-isolated from input = High Inrush

LED SYSTEM ARCHITECTURE

- LED Lamp (LEDi)
  - Line voltage control or Wireless
  - Often lower performance
    - Dimming
    - CRI
    - THD
    - EMI
  - Typically, less costly



- LED Fixture
  - All control types
  - Often higher performance
  - Higher cost



DRIVER SELECTION PROCESS

- UL qualification applies to lamps and external blocks/drivers
  - ‘Married’ (in case of LED lamps) or not (in case of most new fixtures)
  - Loads are not standardized (compared to when all we had was T8 32 W)

Define Requirements

- Indoor/outdoor
- Lumens/footcandles
- Watts
- Physical size

Estimate Efficacies

- Optical
- Thermal
- Electrical

Calculate number of LEDs

- What Driver current to use
- Lumens per LED
- No. of LEDs

LED Configuration

Series

Series-parallel

Determine driver current & voltage

Select Driver

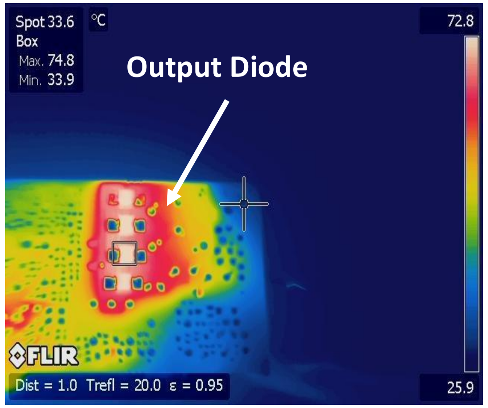
Class 1 vs. Class 2

Constant Current vs. Constant Voltage

Dimming

WHAT IS A DRIVER: EFFICIENCY

- Loss = heat = reduced lifetime
- Contributors to efficiency loss (more current = more loss)
  - Electrical component losses
    - Some scale linearly with current
    - Some scale with the square of the current
    - Some are fixed
  - Power conversion losses (DC-DC)



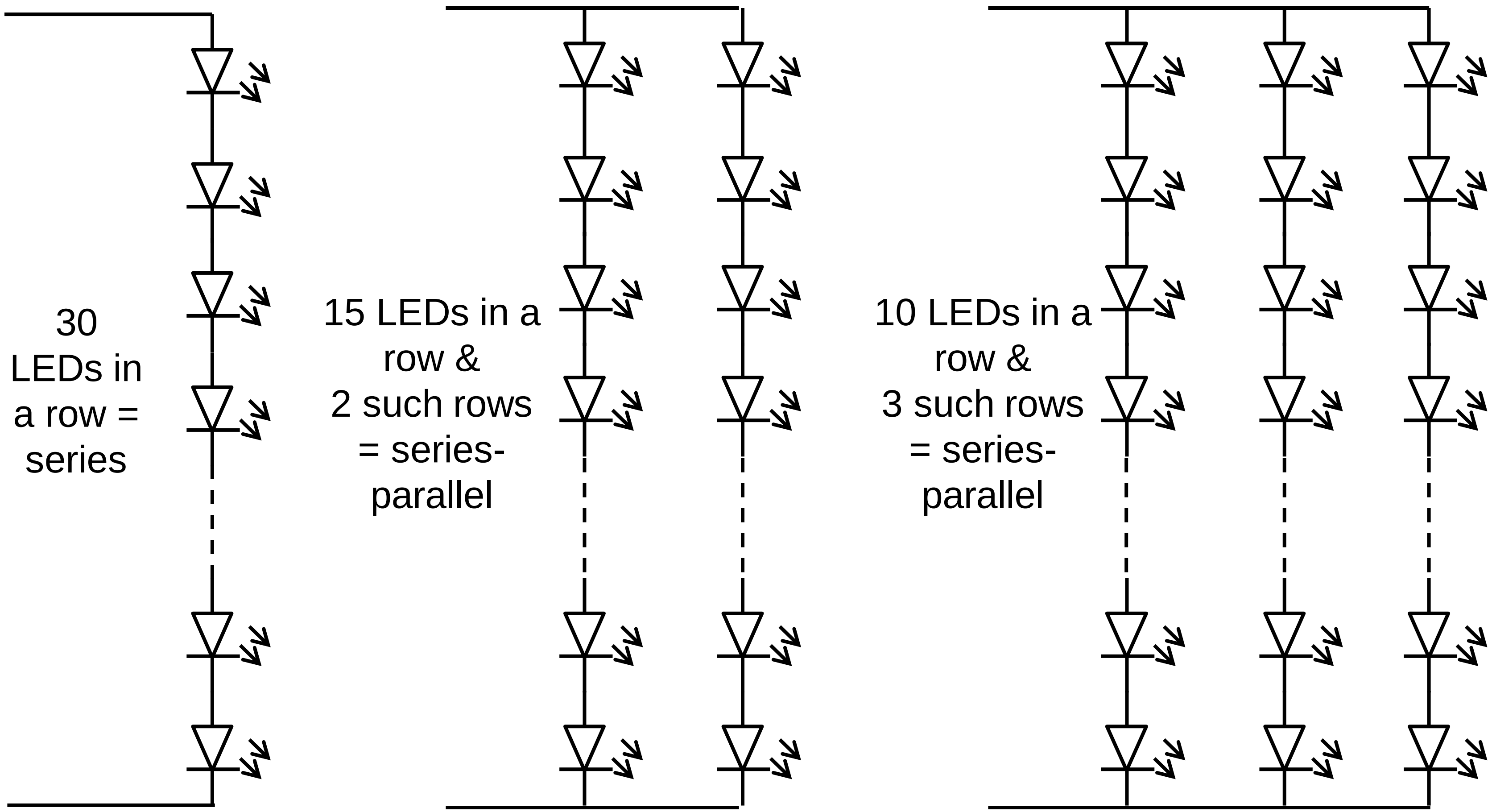
- Fixed overhead (micros and control circuits) make dimmed levels and lower wattage drivers less efficient

Breakdown of losses in a typical high-power driver

Total Input Power		**162 W**
First stage Power losses (4.4W)	*EMI Filter loss*	0.5 W
	Rectifier loss	1.0 W
	Sensing resistor loss	0.3 W
	PFC loss	2.5 W
Second stage Power losses (8.4W)	*LCC converter loss*	7.3 W
	Primary Side Power supply	0.8 W
	Secondary Side Power supply	0.3 W
Total Output Power (W)		**149 W**
Efficiency		**92%**

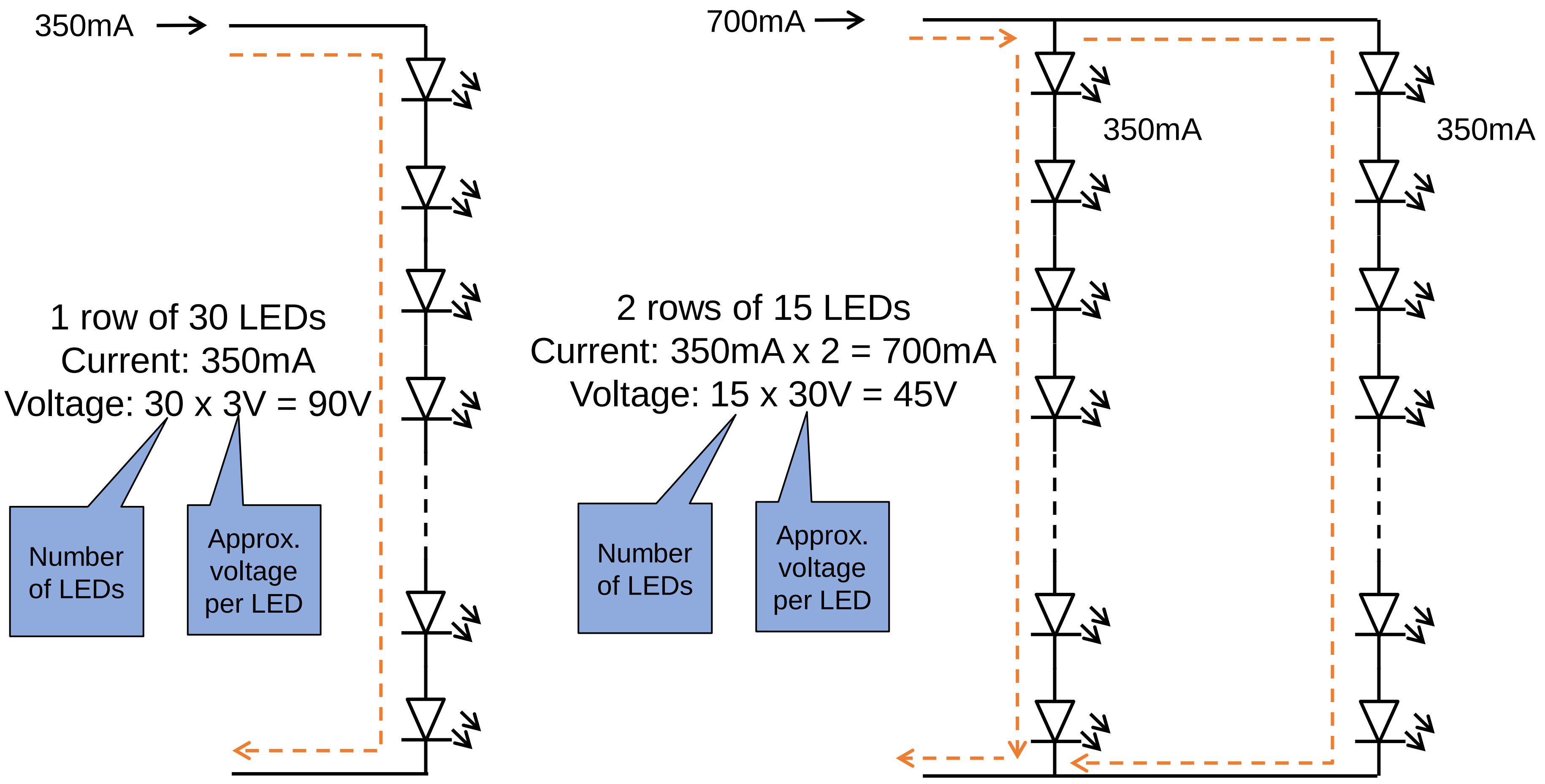
SERIES AND SERIES-PARALLEL

- Say a particular fixture's lumen output requires 30 LEDs
- How can you connect these 30 LEDs?



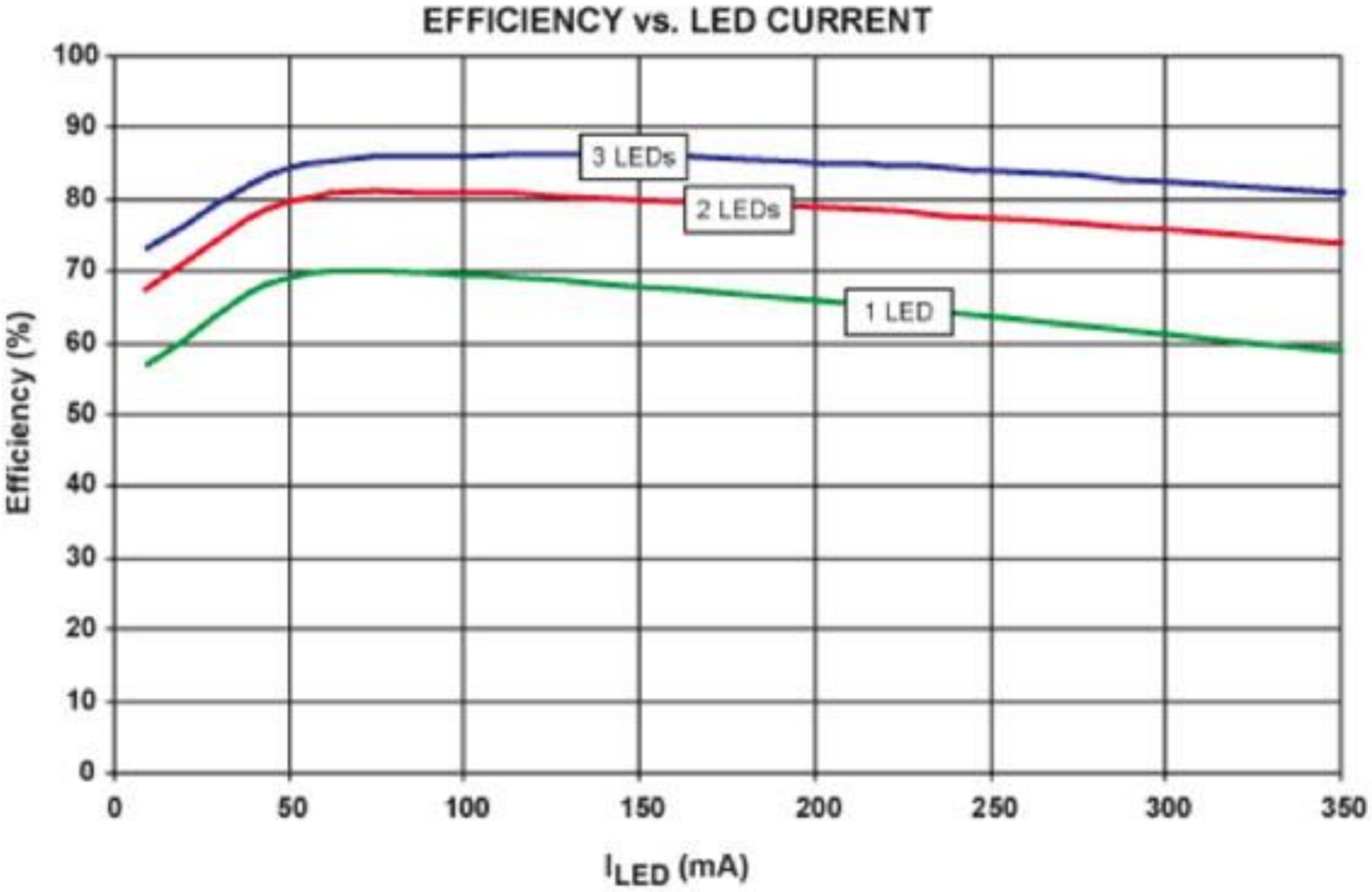
DRIVE CURRENT & VOLTAGE

- Say a particular fixture's lumen output requires 30 LEDs
- How can you drive each LED at 350mA?



UL Class 2 designation, 60Vdc, 42.4V AC/ PWM, 100W!

LED DRIVE CURRENT TRADEOFFS



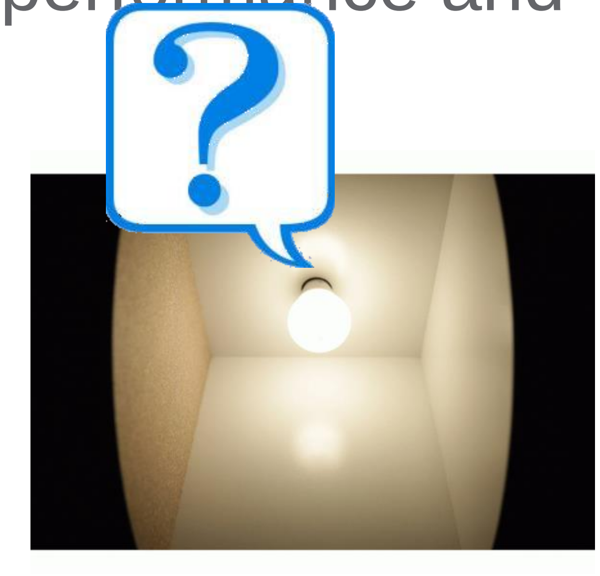
Source: Identifying the Causes of LED Efficiency Droop , Digikey.com

- LEDs have a “sweet spot” for operating most efficiently
- “Droop” of LED must be considered when selecting an operating point
  - Droop: loss of efficiency at higher drive currents

DIMMABLE LED DRIVERS

- The quality and design of the LED Driver determines the best possible dimming performance of the LED fixture or LED screw-in lamp

- Compatibility between the dimmer and the driver determines how well they will deliver the expected performance and lifetime together



Lamp images: CNET.com

What is good dimming performance?

Dimmer + Driver + LED Light Engine = Performance

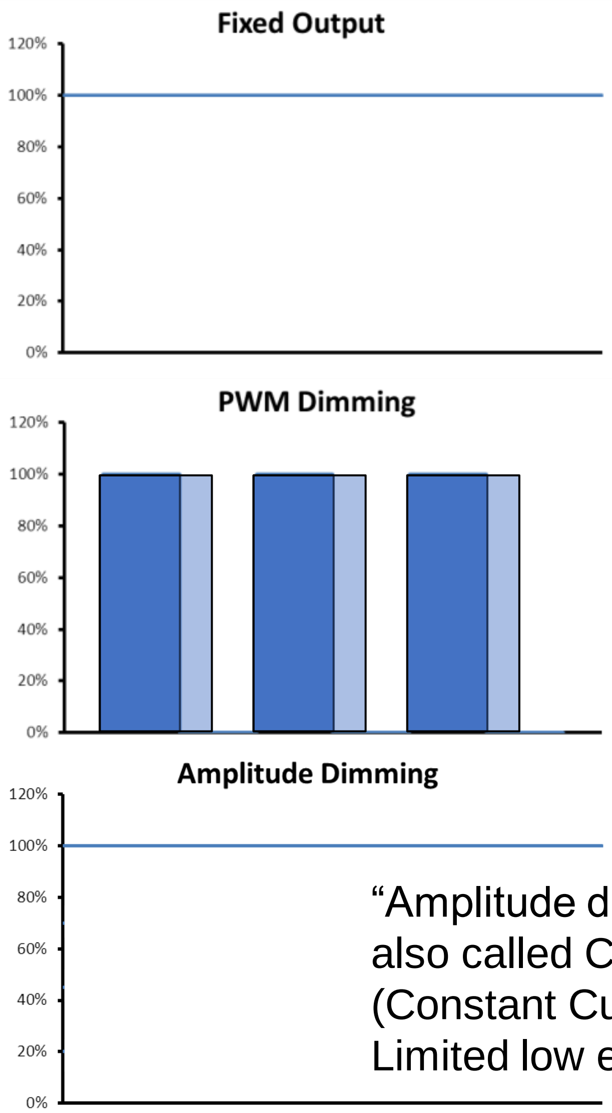
- How stable is the output
- Control method
- Dimming curve
- Ratings
- Compatibility

- Inrush current
- Low End
- Control method
- Lifetime
- Dimming curve
- Radiated or conducted emissions

- Color shift
- Color options (ex. RGB vs RGBA)
- Color Consistency
- Color Temp

Think about it - What exactly does “dimmable” mean?

HOW LEDS ARE DIMMED



Deeper dimming levels

"Amplitude dimming" is
also called CCR
(Constant Current Reduction)
Limited low end due to SOA

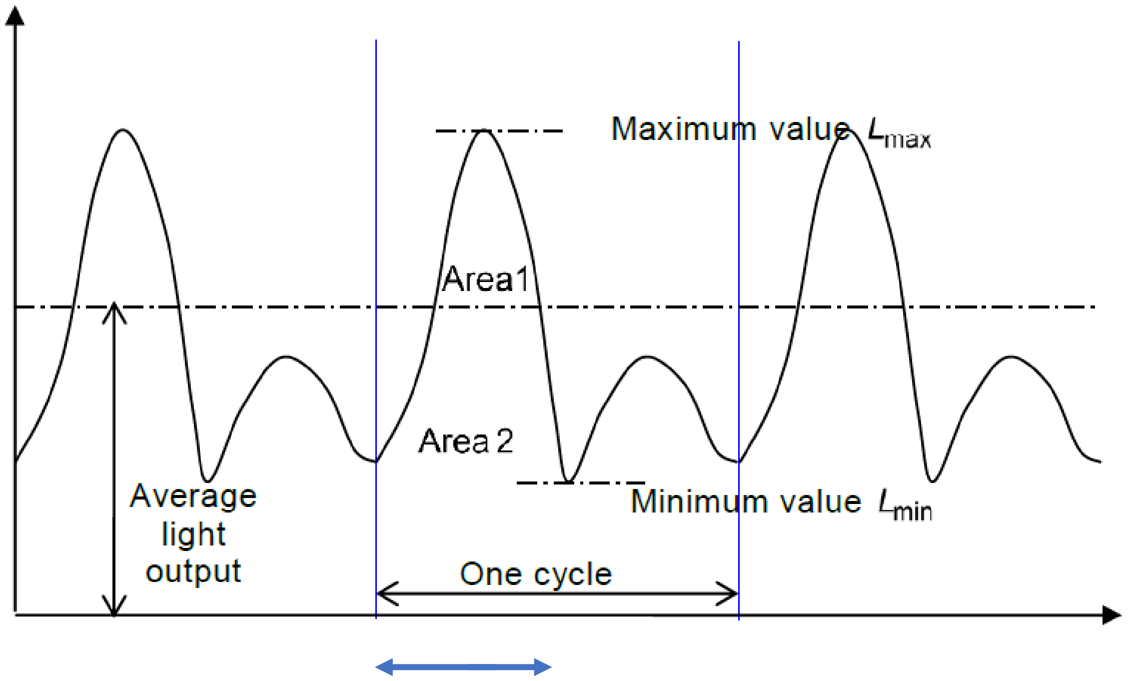
CCR dimming is DC

- No stroboscopic effects
  - Machine interaction
  - Video Interaction
- NO EMI at Driver output/Array
  - Sound studios
  - MRI rooms

DRIVER OUTPUT STABILITY (FLICKER)

- Related to cost/complexity
- Stroboscopic PWM vs. asynchronous (instability)
- Noticeable (120Hz) vs. not noticeable (seen by cameras)
- Driver on board / AC LED differences

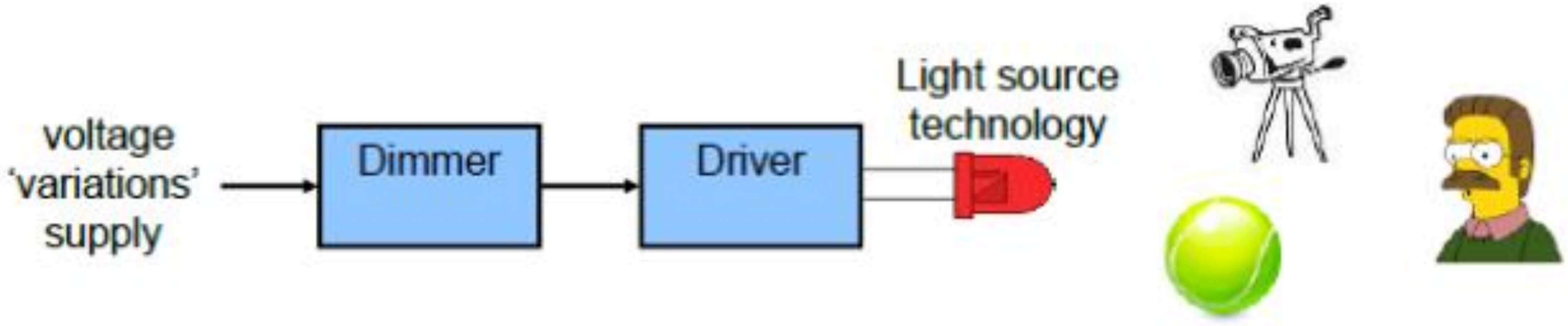
Example of “Driver on Board” LED module



Or One Cycle?

DRIVER OUTPUT STABILITY (FLICKER)

- Very hard to (completely) get rid off
- Very hard to quantify
- Active area of research
  - IEC
  - IEEE
  - NEMA
  - IES …



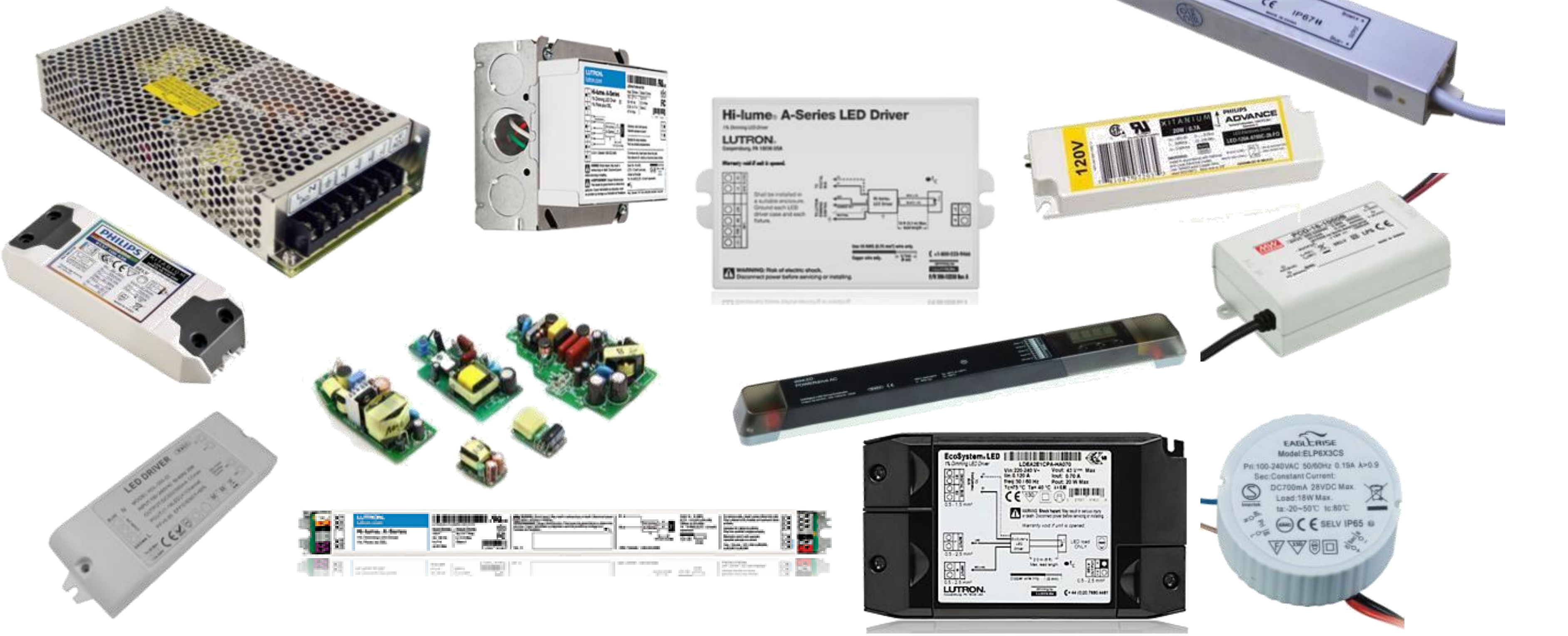
FLICKER INTERFERENCE & SELF SCANNERS

LED phosphor decay time is very fast

Scanner camera picks up a temporal light fluctuation, and processes it to find a moiré pattern: Barcodes not recognized

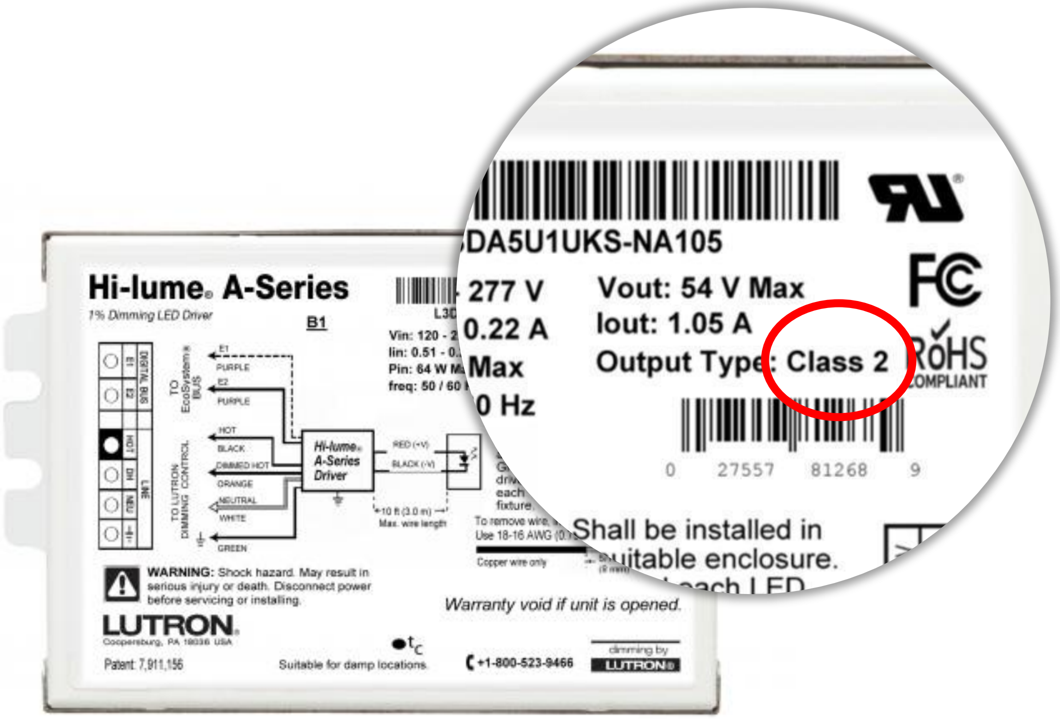
TYPES OF DRIVERS

- Many important decisions to make:
  - Class 2 or non-Class 2?
  - “Listed” or “Recognized”?
  - Constant voltage or constant current?
  - Fixture mounted or remote mounted?
  - Single output or multiple output?

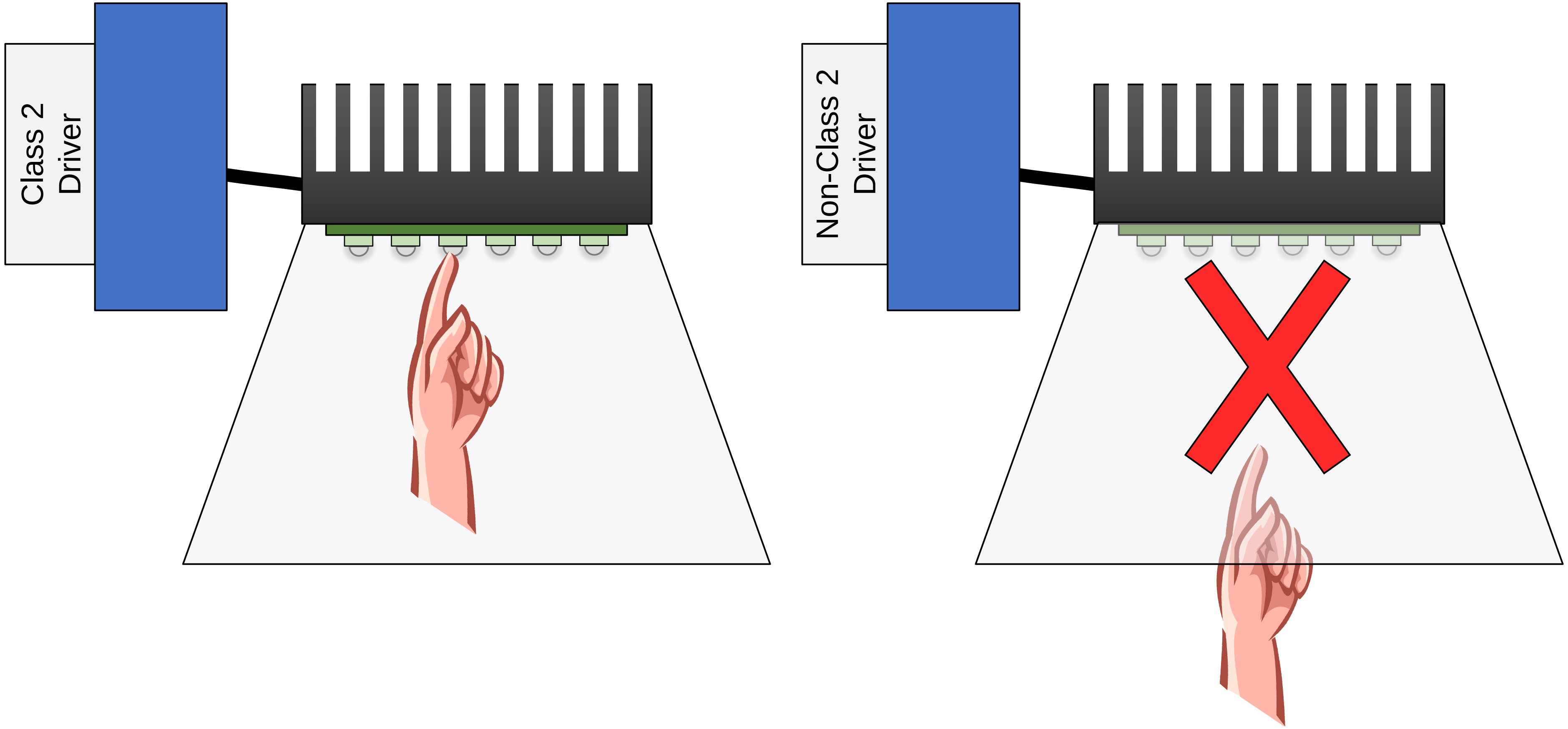


CLASS 2 VS. NON-CLASS 2

- “Class 2 circuits” are defined by the National Electric Code (NEC)
- Defines the wiring and electrical characteristics between a power supply and load
- Meant to minimize the opportunity for fire or electric shock
- Applies only to North America (no direct European/Asian equivalent)
- Limit defined by UL (e.g., UL1310, UL1950)
- Limited to the maximum of:
  - 60V DC
  - 42.4V AC/PWM
  - 100W
- Isolated

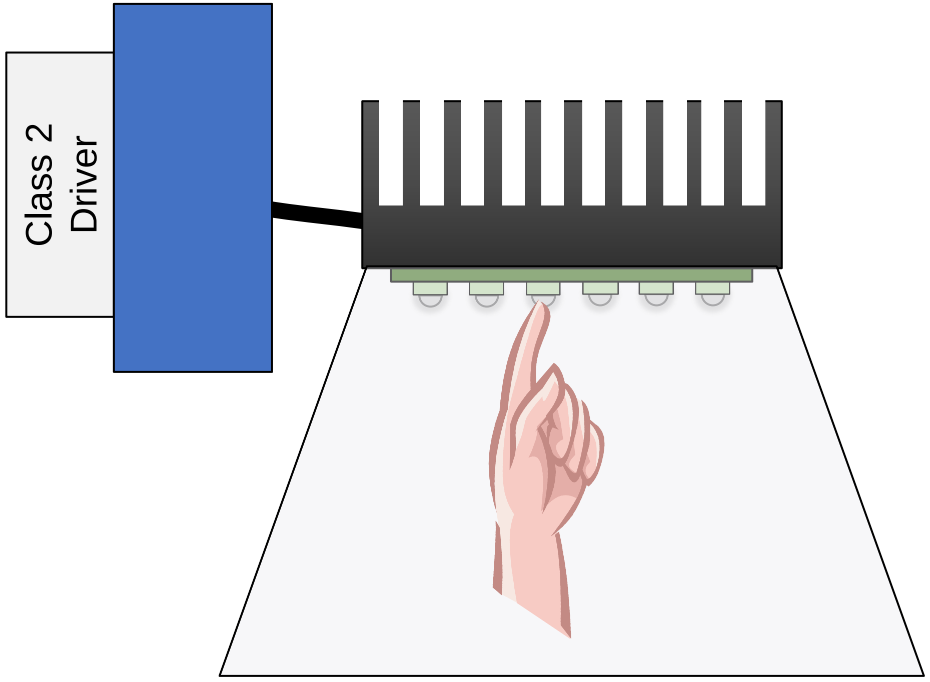


CLASS 2 VS. NON-CLASS 2

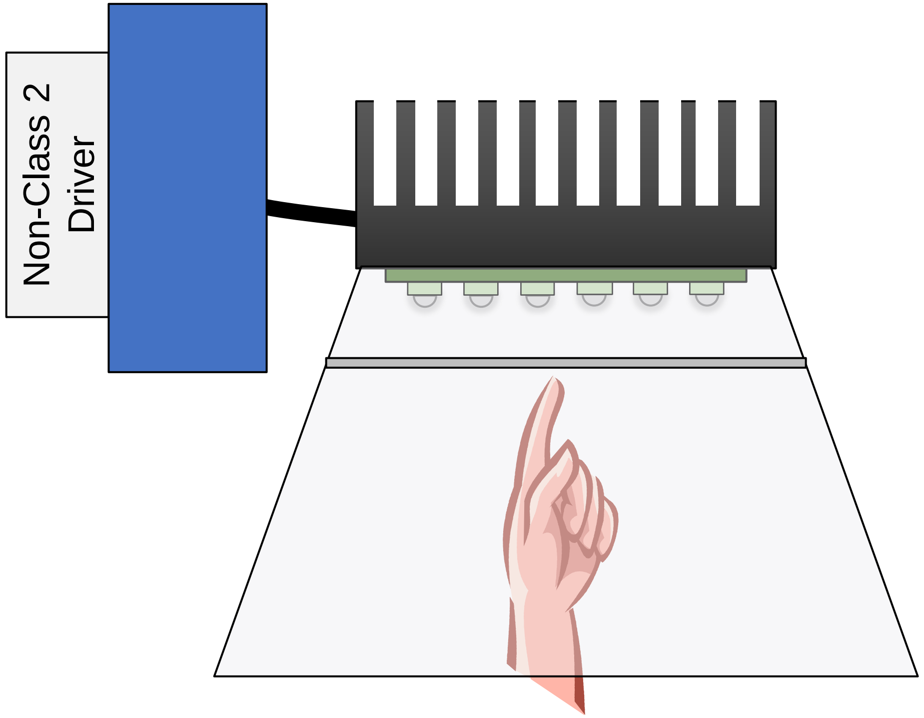


Class 2 Non-Class 2

CLASS 2 VS. NON-CLASS 2



Class 2



Non-Class 2

LISTED VS. RECOGNIZED

- Recognized
  - Intended to be used as a subcomponent of a finished assembly
  - Requires following the provided "Conditions of Acceptability" (mounting, wiring, temperature requirements)
  - May limit options for field replacement

Tested to meet Canadian (CSA) requirements

Tested to meet US (UL) requirements

- Listed
  - Usable as a stand-alone device (not tested as a system)
  - Can be field replaced by electrical equivalents

Tested to meet Canadian (CSA) requirements

Tested to meet US (UL) requirements

TL CLASSIFICATION

- Minimizes problem of field and OEM replaceability and interchangeability
- TL-Rated drivers are UL Listed for installation in the field (in appropriate fixtures)
- Allows OEMs to much more easily substitute different drivers in their designs
  - Driver changes only require a “paperwork exercise” with UL
- Requires certain construction features and standardizes temperature test methods and fault testing criteria

LIGHTING

LED Driver Type TL Program

The LED Driver Type TL Program is intended to assist you in gaining greater market access for your LED drivers. This service is also intended to assist end-product LED Luminaire manufacturers improve their speed-to-market by making it easy to source a compliant LED Driver.

With the LED Lighting industry evolving so quickly, component manufacturers are constantly upgrading their products. Offering a variety of products affords end users the advantage of using components with specific ratings, varying dimming methods, higher efficiencies or efficacies, etc.

Through the flexibility of the UL Recognized Component program, LED Drivers are often designed with varying constructions and are tested in a variety of ways. This flexibility creates a situation where, in most cases, no two LED Drivers are interchangeable without the need for additional safety considerations. UL's Type TL Program takes aim at this situation and creates a set of evaluation and testing guidelines to allow for more standardized LED Driver constructions and ratings. By requiring certain construction features, such as an enclosure and provisions for field wiring, we can reduce the amount of considerations required in the end product. By additionally standardizing Temperature Test methods and fault testing criteria we can further reduce the amount of considerations required in the end product.

By minimizing the end product considerations and opening a path for direct substitution, the TL program helps ensure that your products gain market access in the most efficient way possible. The Type TL evaluation method allows component manufacturers to more easily engage their end users and give them confidence they are using the component that best fits their needs.

By leveraging the collective experience of UL's more than 10,000 employees during product development, you can streamline your overall compliance process. Throughout UL's 99 global laboratory and testing facilities, UL engineers help you seamlessly meet compliance requirements in all the markets you want to reach.

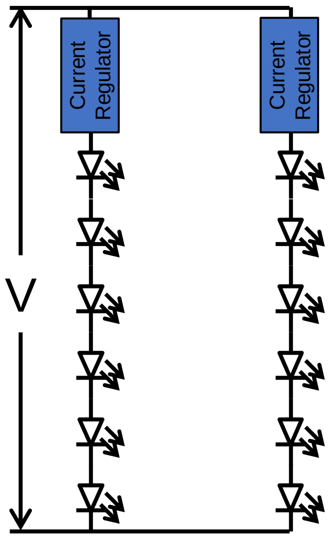
With UL as your certifier you have access to UL's full portfolio of services including:

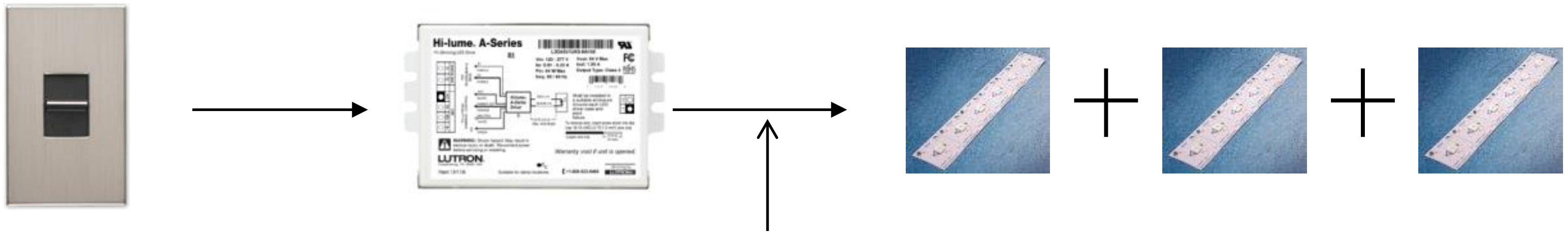
- North American Safety Certification
- Global Market Safety Certification
- EMC Testing
- Environmental and Ingress Protection Evaluations
- Performance Testing

Discover more about how UL is bringing new opportunities to light at www.ul.com/lighting
For more information please contact LightingQuote@ul.com or call 1.877.854.3577

CONSTANT VOLTAGE DRIVERS

- Provides a constant voltage (e.g. 12V or 24V) to the LED module(s)
- Used when the number of luminaires or length is variable and all controlled by one driver (usually external)
- As LED loads are added, power increases
  - The specification of the driver determines power limit
- Most commonly used with strip or cove lights

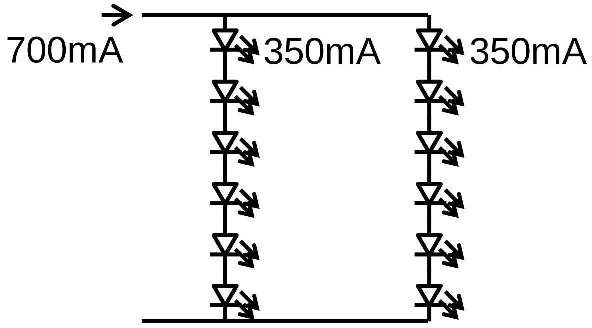


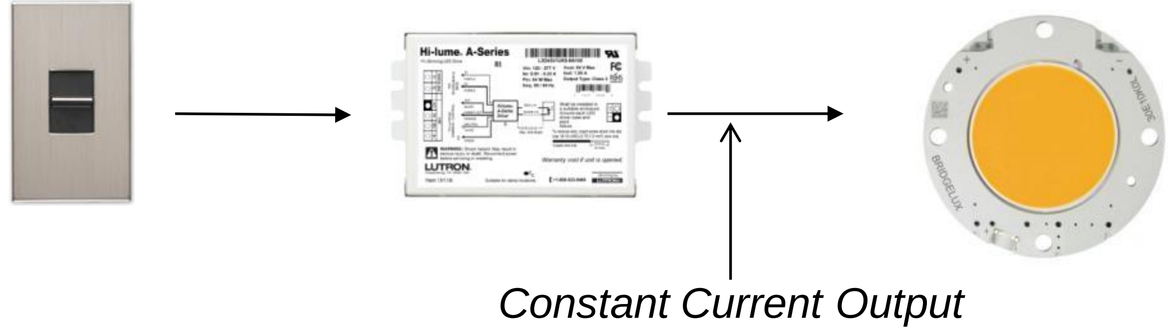


Constant Voltage Output

CONSTANT CURRENT DRIVERS

- Driver provides a constant current to the LED module
- Applies when there is a single LED module paired with a single driver (usually within the luminaire)
- The current output of the driver remains the same regardless of the power of the LED module
- Most commonly used with integral luminaires





FIXTURE MOUNTED VS. REMOTE MOUNTED

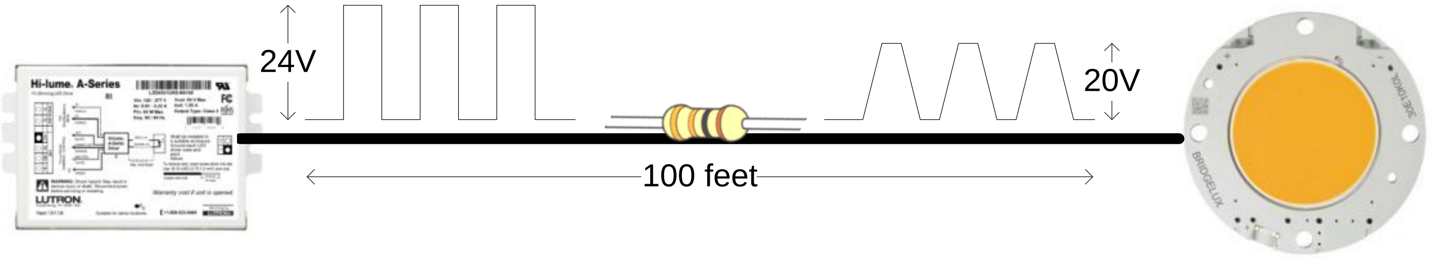
- Most fixtures have drivers mounted in or on them
- Sometimes, the driver is mounted separate from the fixture
  - Reduced EMI/electrical noise
  - Centralized power conversion
  - Wiring/installation convenience
- Wiring details are important
  - Voltage drop
  - Current distortion
  - Should be run separate from mains

Maximum driver–to–LED light engine wire length for **Constant-Current Drivers:**

Wire Gauge	Maximum Lead Length		
	200 mA to 700 mA	710 mA to 1.50 A	1.51 A to 2.10 A
18 AWG (0.75 mm²)	30 ft (9 m)	15 ft (4.5 m)	10 ft (3 m)
16 AWG (1.5 mm²)	35 ft (10.5 m)	25 ft (7.5 m)	15 ft (4.5 m)
14 AWG (2.5 mm²)	50 ft (15 m)	40 ft (12 m)	25 ft (7.5 m)
12 AWG (4.0 mm²)	100 ft (30 m)	60 ft (18 m)	40 ft (12 m)

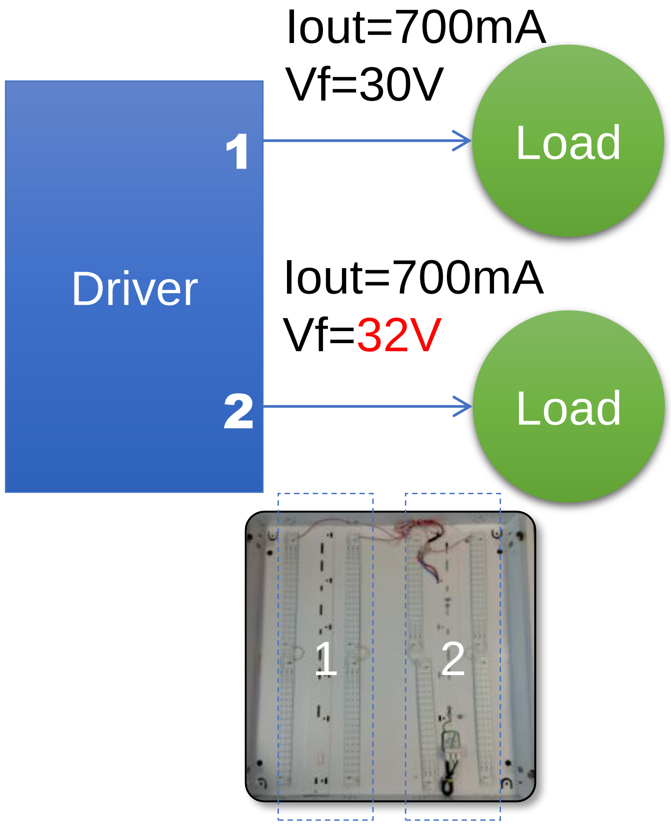
Maximum driver–to–LED light engine wire length for **Constant-Voltage Drivers:**

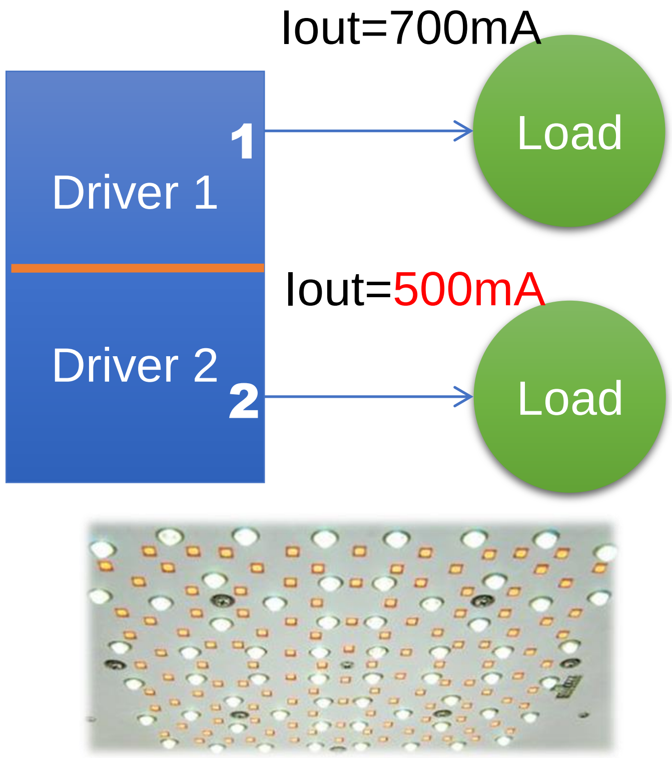
Wire Gauge	Maximum Lead Length		
	10 V to 20 V	20.5 V to 40 V	40.5 V to 60 V
18 AWG (0.75 mm²)	10 ft (3 m)	15 ft (4.5 m)	30 ft (9 m)
16 AWG (1.5 mm²)	15 ft (4.5 m)	25 ft (7.5 m)	50 ft (15 m)
14 AWG (2.5 mm²)	25 ft (7.5 m)	40 ft (12 m)	75 ft (22.5 m)
12 AWG (4.0 mm²)	40 ft (12 m)	60 ft (18 m)	100 ft (30 m)



SINGLE OUTPUT VS. MULTIPLE OUTPUT

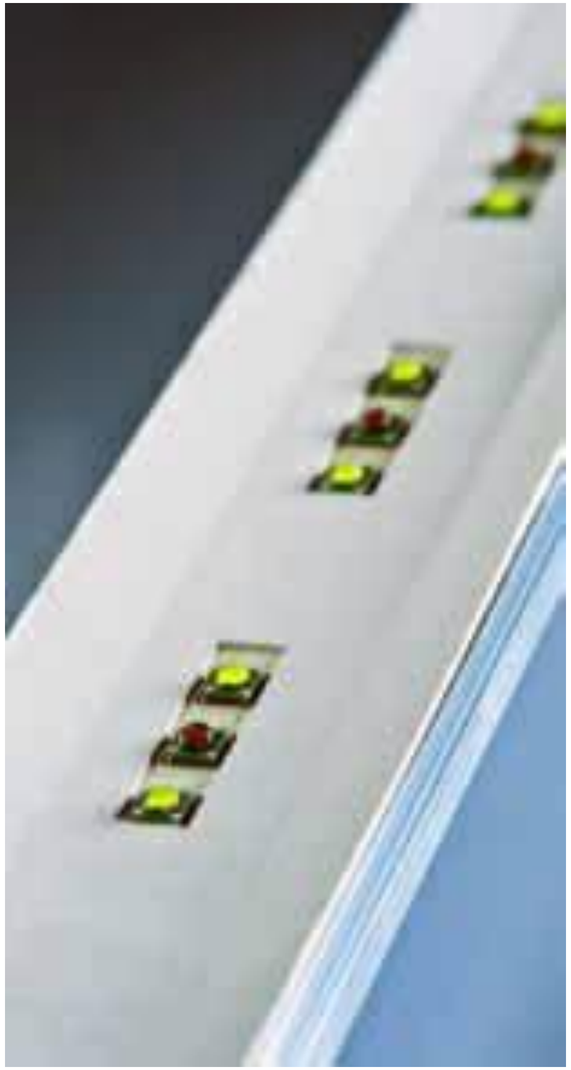
- Single output
  - Simpler, but different currents possible
- Multiple output
  - Better current sharing
  - Lower complexity for multiple loads

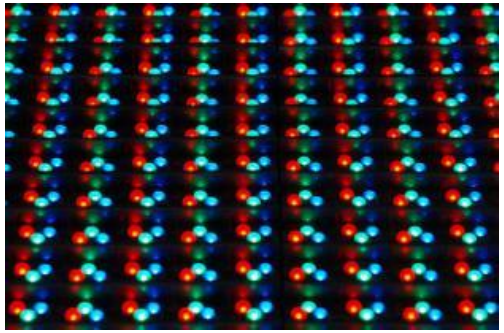




REASONS FOR MULTIPLE OUTPUTS

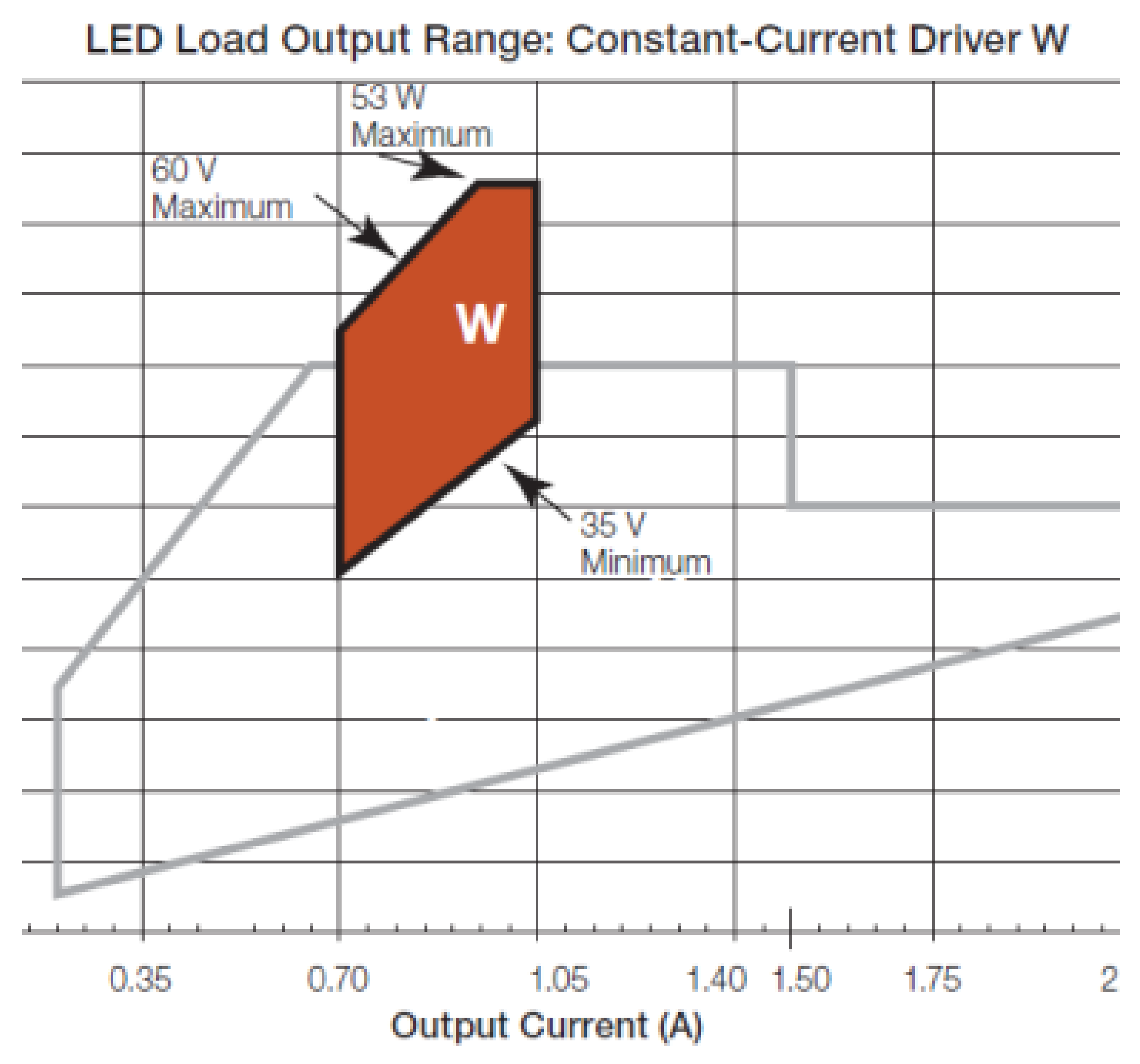
- Color control
  - RGB/RGBA/RGBY
  - Adjustable CCT (tunable white or dim-to-warm)
- Increases in efficiency
  - Higher wattage fixtures at lower currents
  - Adding separate LED (red) to boost efficiency or CRI
- Differing LED forward voltage
- Stay within Class 2 limits





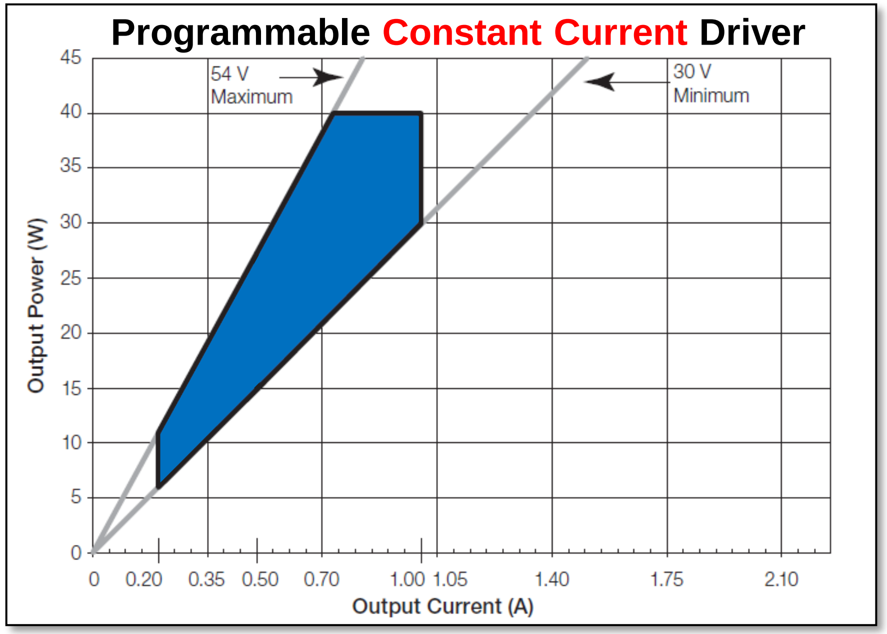
DRIVER OUTPUT PARAMETERS

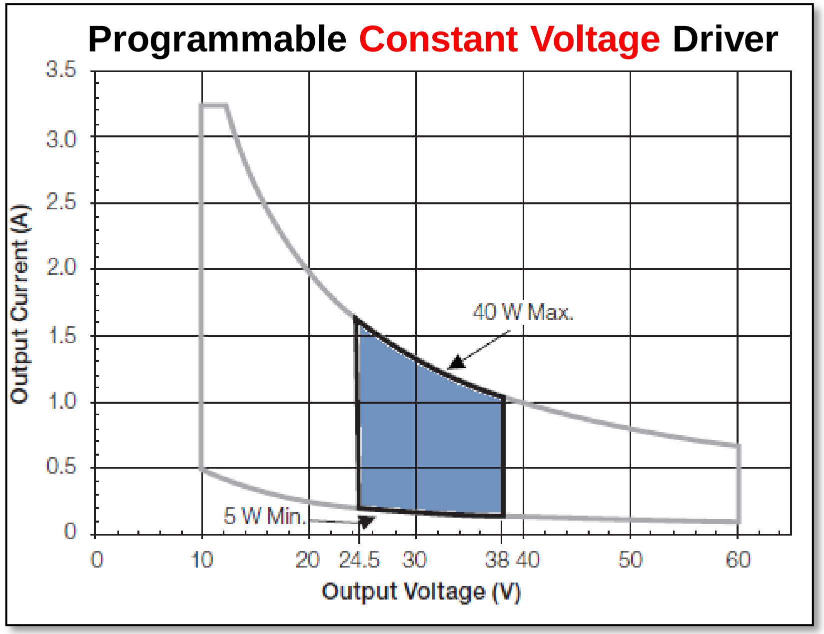
- For efficiency reasons, most drivers are designed to operate over a narrow range of output voltage
- Some drivers offer a “programmable” output current over a limited range
  - Programming may be done via software or hardware (Rset)
  - Leads to operational efficiencies
  - Programmability usually means higher complexity and lower efficiency
- The drivers’ power rating alone does not tell you its supported voltage and/or current!
  - 40W driver: *0.5 amps at 80 volts*
  - 40W driver: *2 amps at 20 volts*
  - 40W driver: *4 amps at 10 volts*



UNDERSTANDING VOLTAGE AND CURRENT

- Fixed output
  - Standard current (CC) or voltage (CV)
  - Maximum and minimum voltage (CV) or current (CC)
- Variable output current
  - Operating “window” of supported voltages and currents
  - Bounded by maximum voltage, current, and power
- Worst case of LED module Forward Voltage MUST be within the driver’s operating area (V_f max is critical!)





EXAMPLE

1. Select LED and determine maximum Forward Voltage and desired Drive Current from datasheet.

   $V_f = 10.1V – 13.1V$

   $I_f = 700mA$

From LED Module Datasheet

Electrical (constant current)							
Module	Drive Current[5]	Forward Voltage[6]			Power Consump-tion[7]	Lumen Output[8] (Typical)	Efficacy (Typical)
	mA	Min	Typ	Max	W	lm	lm/W
400 lm	700	8.2	8.2	9.9	5.7	400	70
	500	7.9	8.1	9.6	4.1	300	74
	350	7.8	7.9	9.4	2.8	220	80
700 lm	1050	8.4	9.2	10.1	9.7	700	72
	700	8.2	8.8	9.9	6.2	500	81
	500	7.9	8.6	9.6	4.3	380	88
	350	7.8	8.4	9.4	2.9	280	95
1000 lm	1050	10.5	12.4	13.5	13.0	1000	77
	700	10.1	11.9	13.1	8.3	720	87
	500	9.8	11.6	12.7	5.8	540	93
	350	9.6	11.4	12.5	4.0	380	96

6. Voltage data based on 20° C to 90° C operating range. For operation outside this range, contact factory.

EXAMPLE

1. Select LED and determine maximum Forward Voltage and desired Drive Current from datasheet.

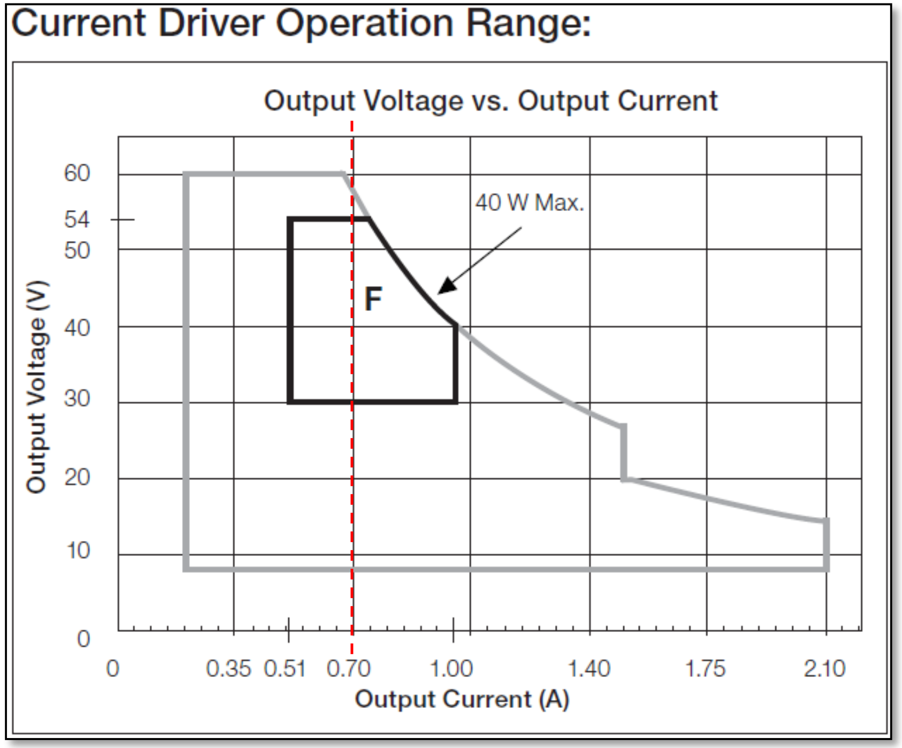
   $V_f = 10.1V – 13.1V$

   $I_f = 700mA$

2. Select driver capable of the desired output current.

   Found.

From LED Driver Datasheet



EXAMPLE

1. Select LED and determine maximum Forward Voltage and desired Drive Current from datasheet.

   $V_f = 10.1V - 13.1V$

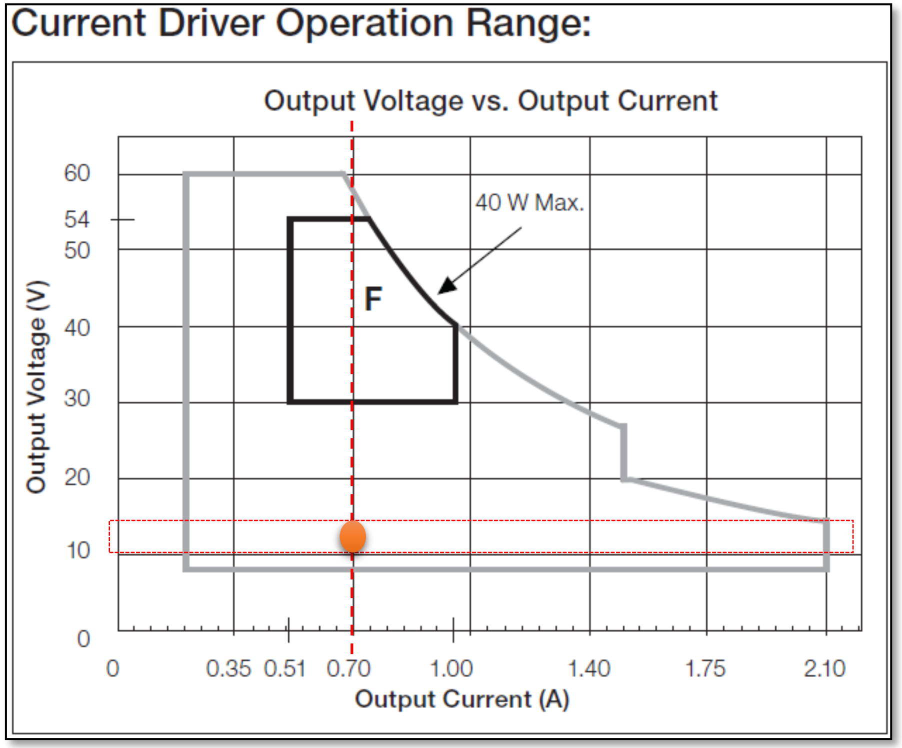
   $I_f = 700mA$

2. Select driver capable of the desired output current.

3. Ensure driver is capable of both MAXIMUM <u>and</u> MINIMUM voltages.

   No. Go back to Step 2.

From LED Driver Datasheet



EXAMPLE

1. Select LED and determine maximum Forward Voltage and desired Drive Current from datasheet.

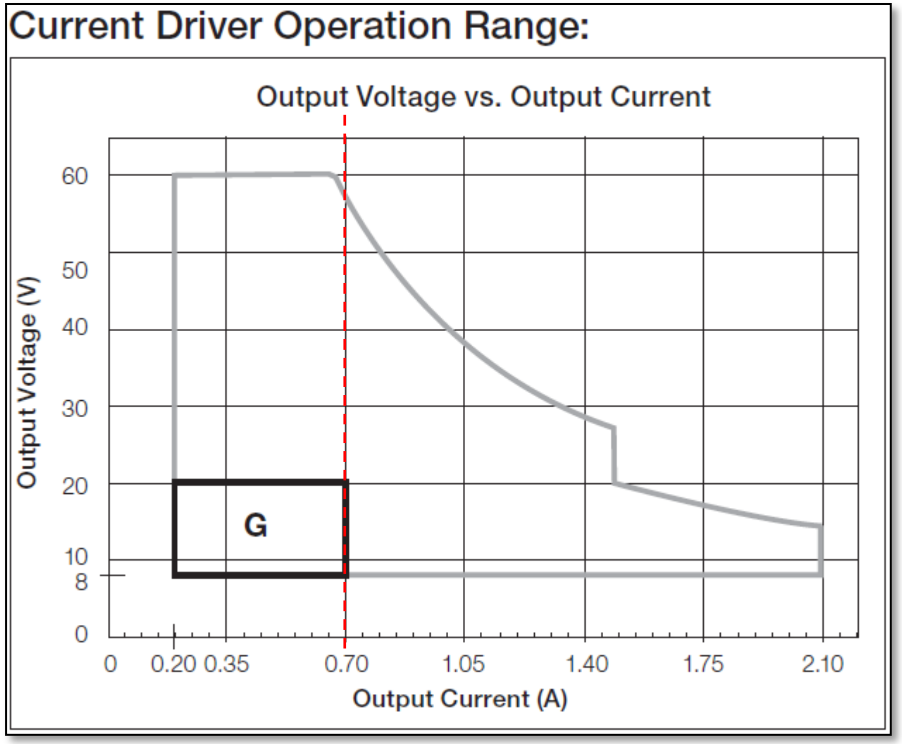
   $V_f = 10.1V – 13.1V$

   $I_f = 700mA$

2. Select driver capable of the desired output current.

   Found, although on the edge (no room to increase current)

From LED Driver Datasheet



EXAMPLE

1. Select LED and determine maximum Forward Voltage and desired Drive Current from datasheet.

   V_f = 10.1V – 13.1V

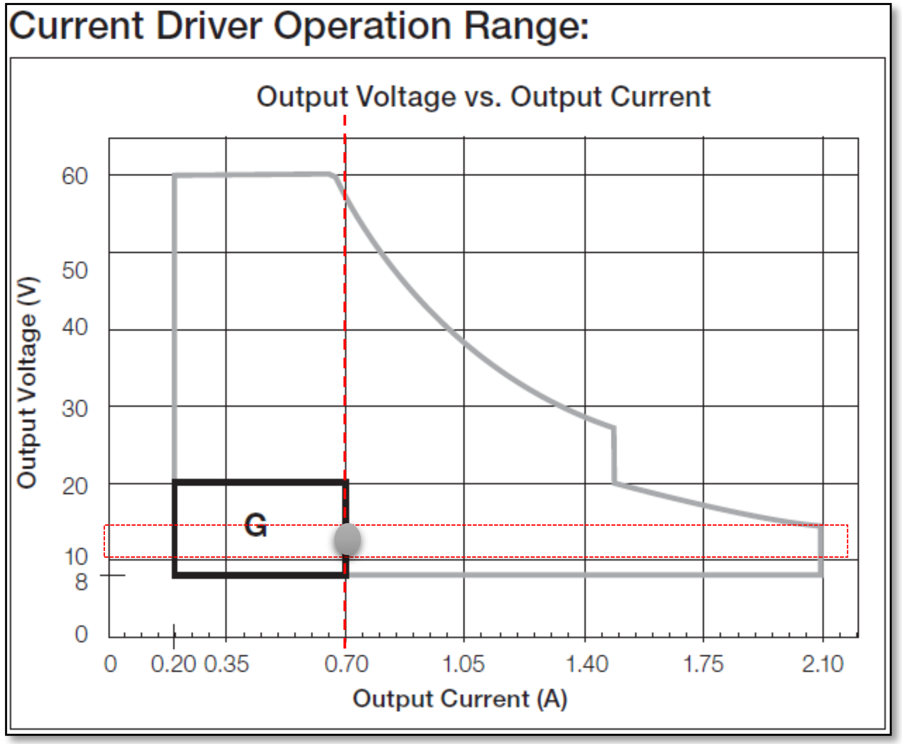
   I_f = 700mA

2. Select driver capable of the desired output current.

3. Ensure driver is capable of both MAXIMUM and MINIMUM voltages.

   Selected LED is well within driver's output voltage range.

From LED Driver Datasheet



PERFORMANCE ASPECTS OF DRIVERS: DIMMING

Constant current reduction (CCR) dimming

- Can get to 1% reliably due to improvements in LEDs

Pulse Width Modulation (PWM) dimming

- Allows deeper dimming (<1%)
- Shares current better across parallel strings of LEDs
- "Parasitics" (dynamic resistance) of LEDs are not as critical
- May cause stroboscopic flicker
- Does not provide benefit of "droop" (less efficient)

Hybrid approach

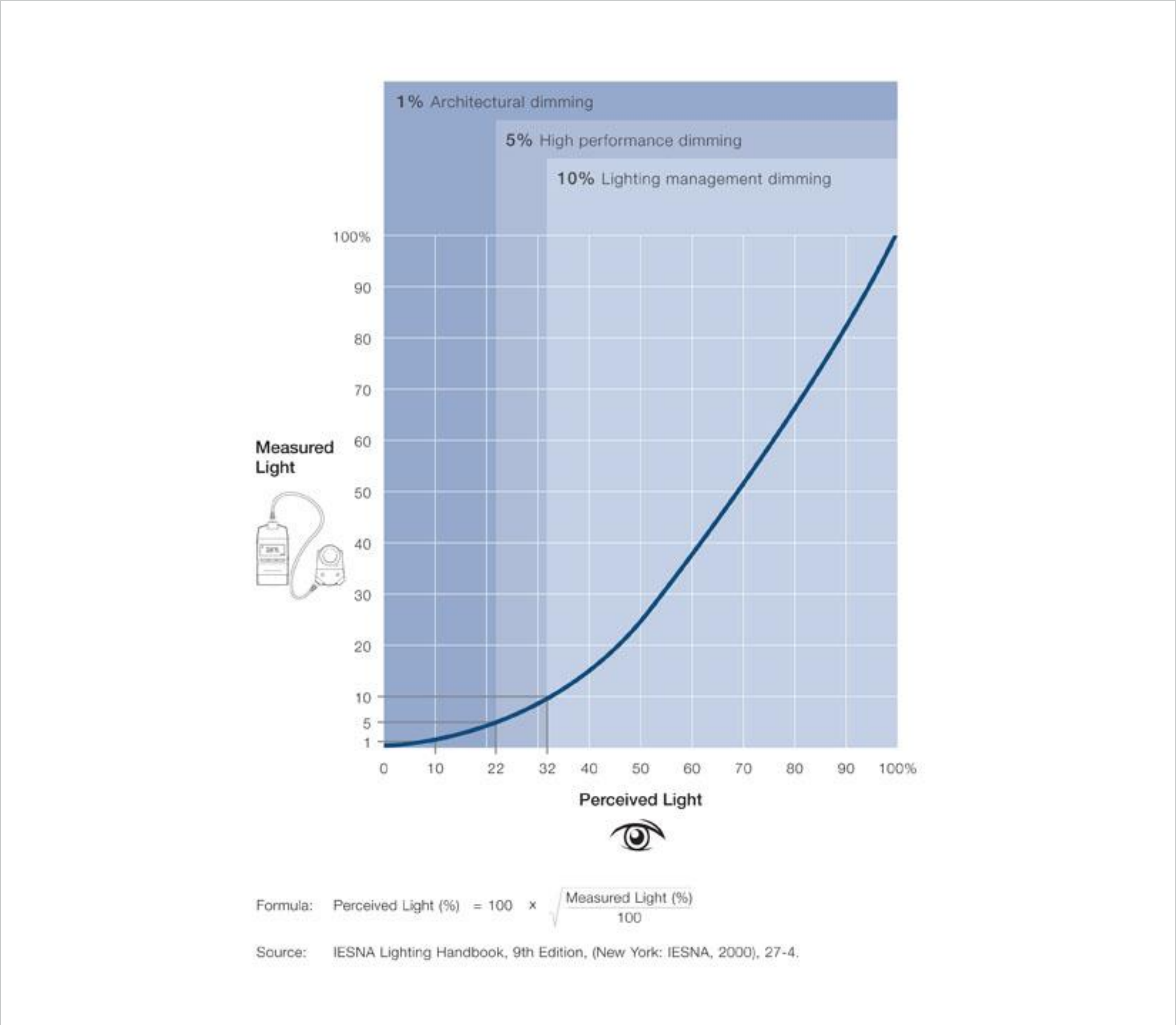
- Manufacturer specific
- Can allow very deep dimming

PERFORMANCE ASPECTS OF DRIVERS: DIMMING

- Needs are driven by the application:
    - Dimming level
    - Dim to warm
    - Flicker

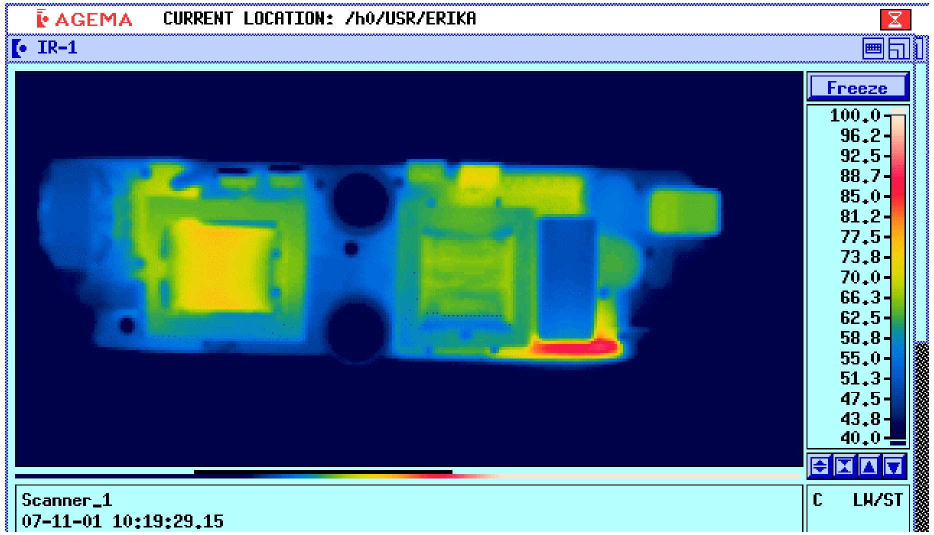
MEASURED VS. PERCEIVED LIGHT

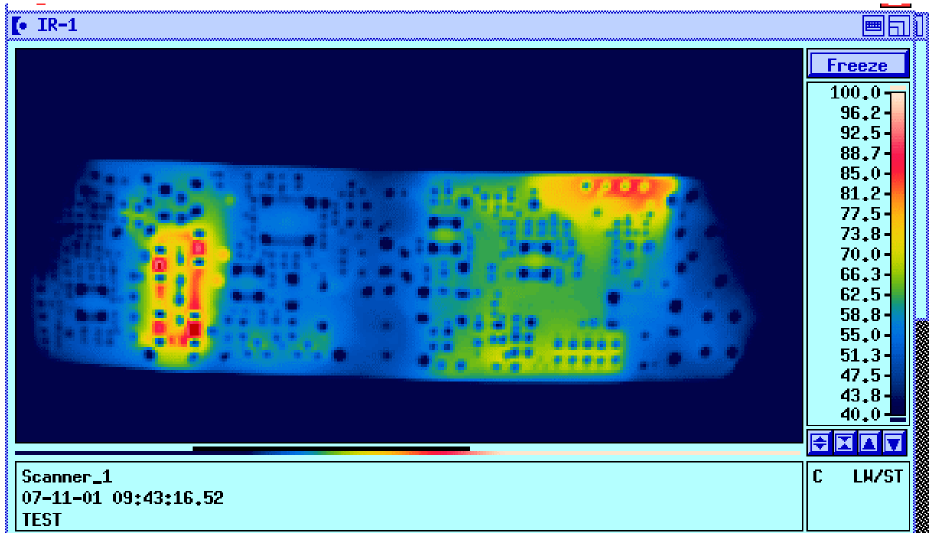
- **Measured light:** the amount of light as shown on a light meter
- **Perceived light:** the amount of light that your eye interprets due to dilation
- **20% measured = 45% perceived**



PERFORMANCE ASPECTS OF DRIVERS: THERMAL

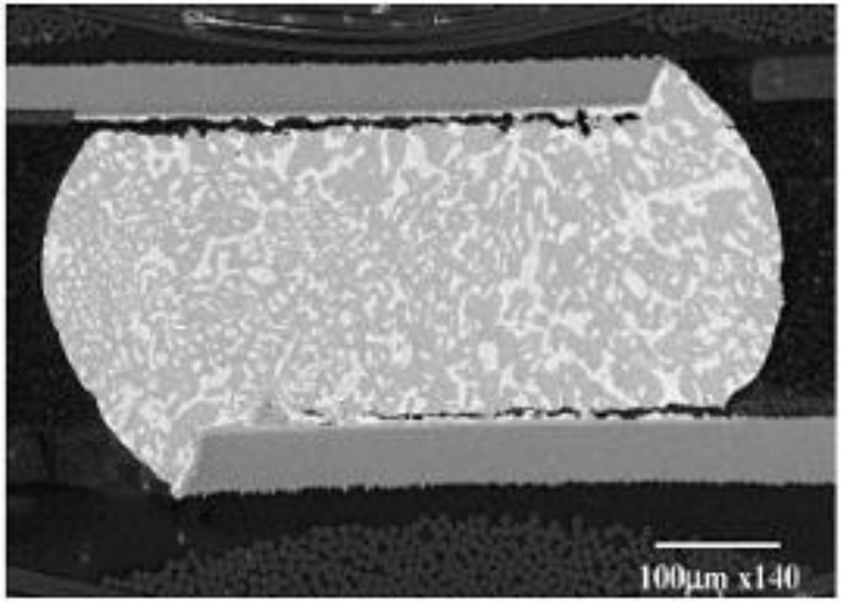
- Less efficiency = hotter temperatures
- Temperature rating methods
  - Calibration point (Tc)
  - UL Conditions of Acceptability (CoA)
  - Ambient
- Implications on lifetime
- De-rating and thermal fold back





PERFORMANCE ASPECTS OF DRIVERS: LIFETIME

- Lifetime (under what conditions?)
  - Switching cycles
  - Temperature / thermal cycle stress
  - Spec point of Tc brings all influences of Ambient and Efficiency to one lifetime prediction
  - Installation details



Solder joint crack due to thermal cycling

PERFORMANCE ASPECTS OF DRIVERS: INRUSH

- LED drivers can have much more substantial inrush than previous technologies at the same wattage
- This can lead to premature failure of any controls connected to them (dimmers OR switches) or false breaker tripping
- Drivers should comply to voluntary NEMA 410 inrush specification
  - http://www.nema.org/Standards/Pages/Performance-Testing-for-Lighting-Controls-and-Switching-Devices-with-Electronic-Drivers-and-Discharge-Ballasts.aspx

Mechanical and electrical wear (high inrush)

Relay contacts 120VAC, 16A 50k cycles

Primarily mechanical wear (no inrush)

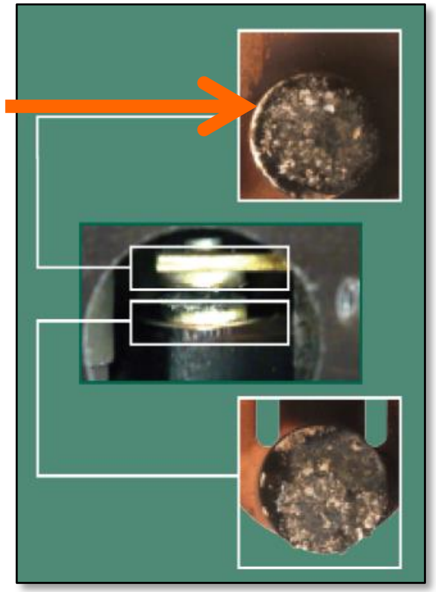


Table 2
Peak Current Requirements

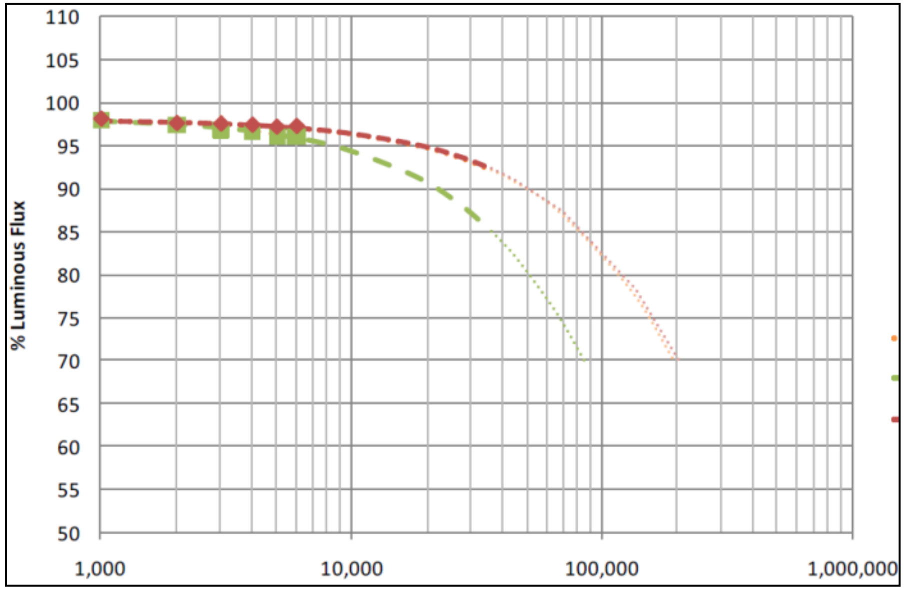
Steady state current (A)	Peak current (A) 120 Vac	Pulse Width 120 Vac (ms) See Note 2	I^2t (A^2 sec) 120 Vac See Note 1	Peak current (A) 277 Vac	Pulse Width 277 Vac (ms) See Note 2	I^2t (A^2 sec) 277 Vac See Note 1
0.5	75	0.34	11	77	0.07	11
1	107	0.48	24	131	0.71	27
2	144	0.70	41	205	0.85	76
3	166	0.89	51	258	0.98	111
5	192	1.20	74	320	1.20	205
8	221	1.25	98	370	1.25	274
10	230	1.50	106	430	1.50	370
12	235	1.80	110	440	1.80	387
15	239	2.00	114	458	2.00	420
16	242	2.10	117	480	2.10	461

NOTES—

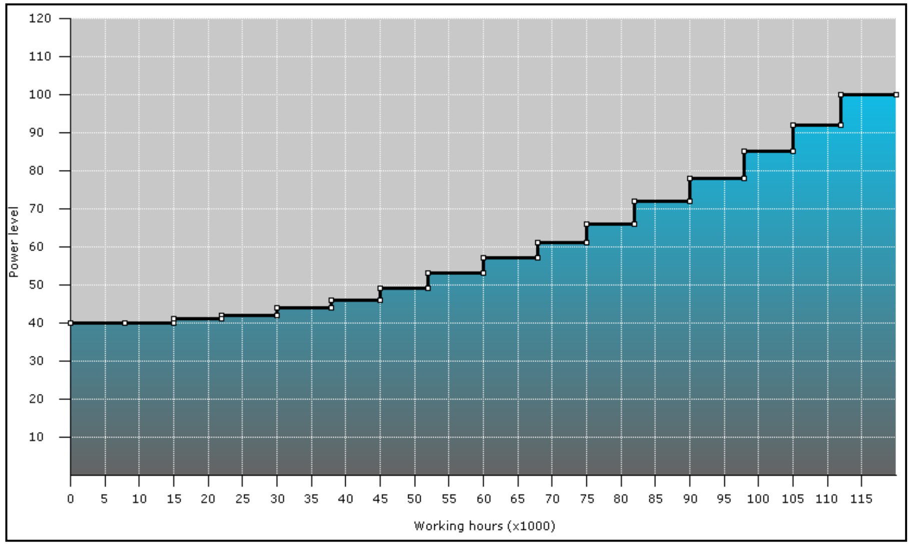
1. The values used to calculate I^2t are the peak current shown in Table 2 and a pulse duration of 2 ms (t).
2. Pulse widths shown in Table 2 are documented in Figures 3 through 14 and will provide adequate performance with electronic devices having pulse widths up to 2 ms, in accordance with ANSI standard C82.11 or ANSI C82.14.

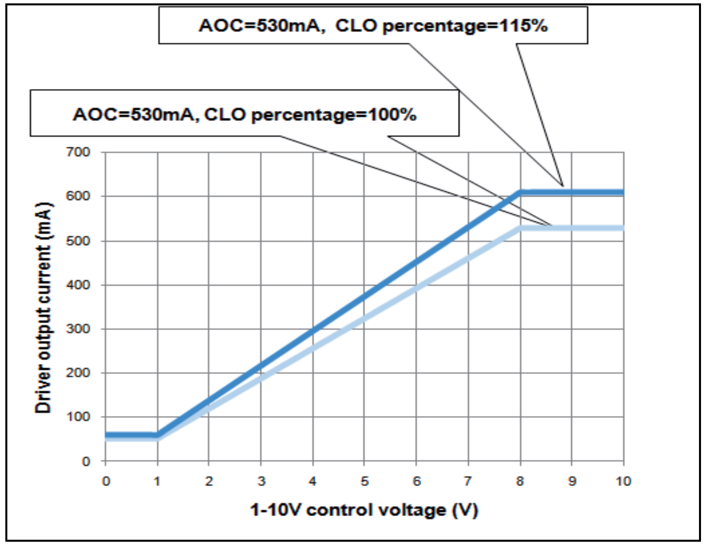
PERFORMANCE ASPECTS OF DRIVERS: ADVANCED FEATURES

- Lumen maintenance
  - Driver must increase current over time



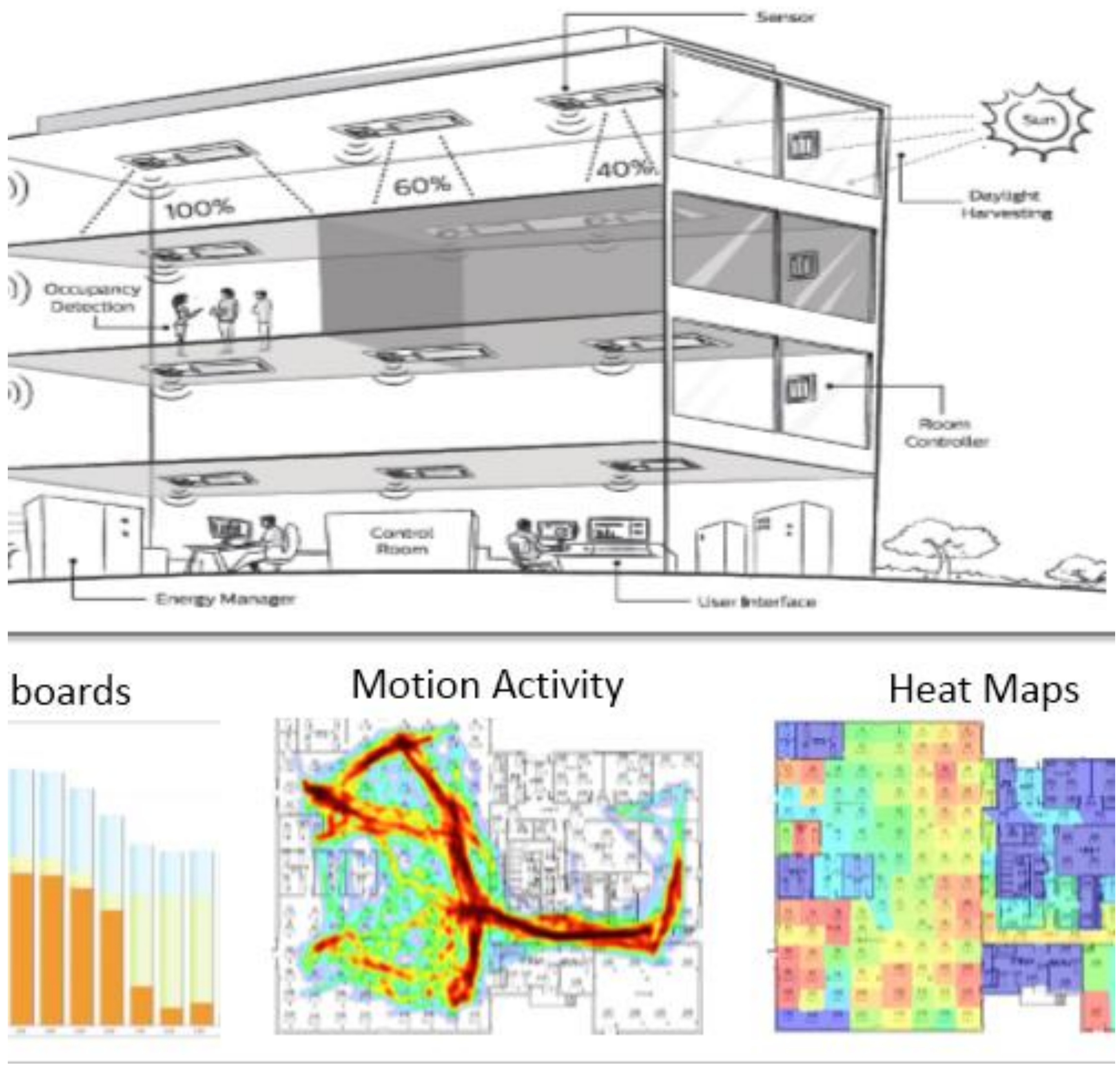
Typical LED lumen depreciation





PERFORMANCE ASPECTS OF DRIVERS:
ADVANCED FEATURES

- Sensor connections
- Logging
- Measurement
- diagnostics



ONE MORE THING: RELIABILITY

- Failure Rate: <0.01% per 1khr (is this based on actual field return data or some wild guess)
- Lifetime: Min 50khrs of life time (under what conditions?); in some cases up to 100khrs of life time
- What does MTBF mean compared to lifetime?
- Drivers designed and tested to incorporate all the lessons learned from traditional ballast experience
- Is it field replaceable?
- Will you still be able to buy it?

Concerns about lifetime and maintenance have been around for a long time. *Credit: Ford Motor Company*

Control of LED

CONTROL TYPES

- Control type refers to the signal and wiring between the control and driver
  - LED screw-in lamps generally use only forward or reverse phase control
  - LED fixtures can use any method
  - The control MUST match the control type needed by the driver!

- Control Options
  - Non-dim
  - Forward Phase
  - Reverse Phase
  - 3 Wire (“fluorescent”)
  - DMX 512
  - 0-10V
  - DALI / digital
  - Wireless

On what type of control does the LED operate?

- 3 Wire Phase Control
- 2 Wire Phase Control
- 0-10V

Analog; really
In 2022!

- DALI
- EcoSystem
- DMX 512
- Wireless (2.4GHz)

Standard
500/1000 Megbits/second
Through Fiber optics

Which picture do you use and why?

NON-DIM CONTROL

- Lowest complexity
- Can be most efficient
- LED are often dimmable, while fluorescent wasn’t
  - Compared to fluorescent, dimming LEDs isn’t as complicated
  - BUT, still can be lowest-cost option
- Limits applications
  - Dimming controls save energy and add value

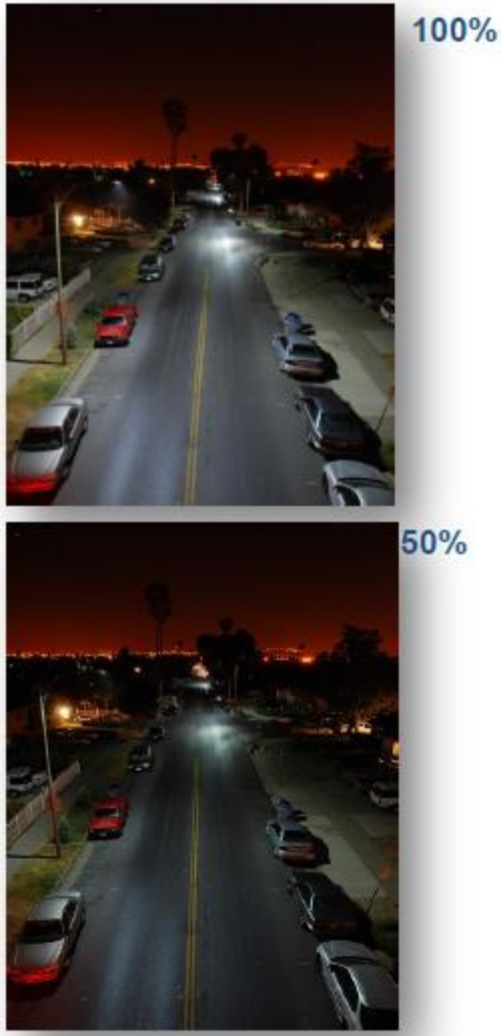
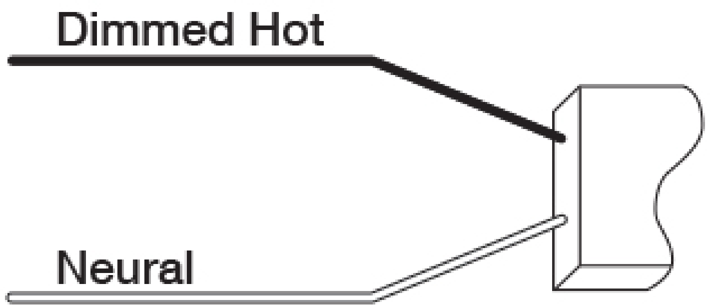


Photo Source: PG&E Emerging Technology/Energy Solutions

Phase Control

Advantages of typical bulbs

- **Easy retrofit**

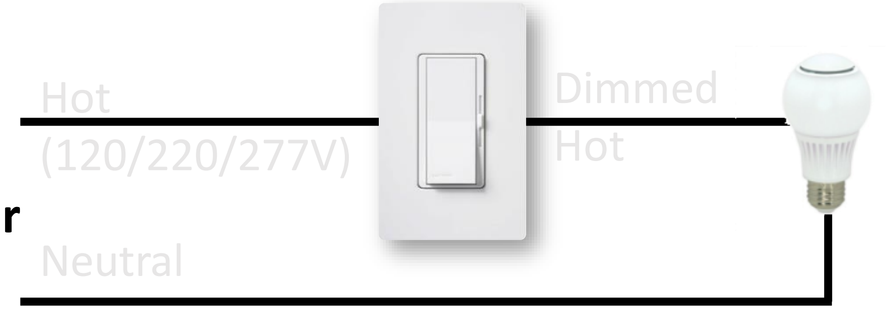


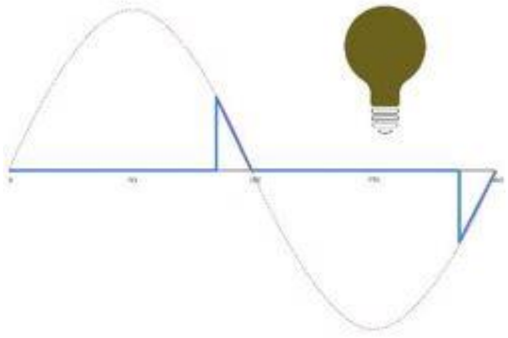
Disadvantages of typical bulbs

- **Light level sensitive to line voltage variation**
- **Audible noise**
- Other performance issues

Forward phase analog (leading edge/triac)

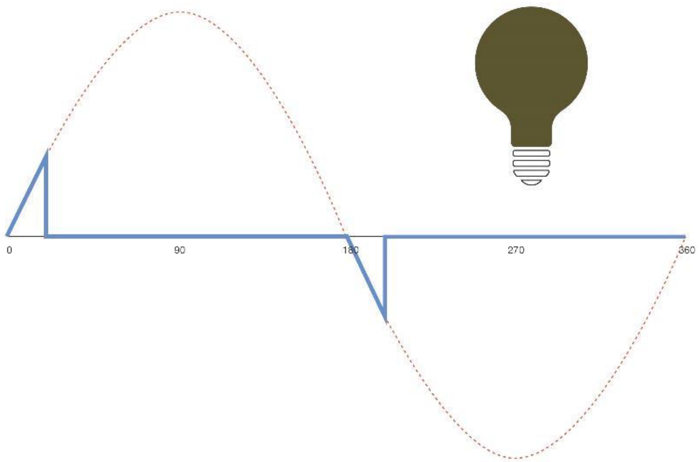
- **Most common dimming method**
- **Designed for incandescent, halogen or magnetic low-voltage (MLV) loads**
- **Installed base of incandescent dimmers not intended for LEDs (performance issues and compatibility problems are likely)**
- **Installed base UL listed for Incandescent, MLV or Halogen, NOT LED**
- **High Inrush, I=Cdv/dt**
- **Dimmer to dimmer interactions**

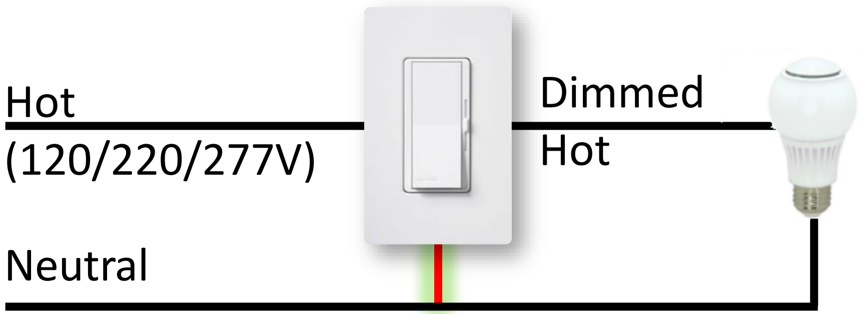




Reverse phase analog (trailing edge)

- **Typically used for** electronic low voltage transformers (typically on track lights)
- **Lower likelihood of acoustic noise**
- **Smaller installed base, usually require a neutral wire**
- **More Expensive dimmer**



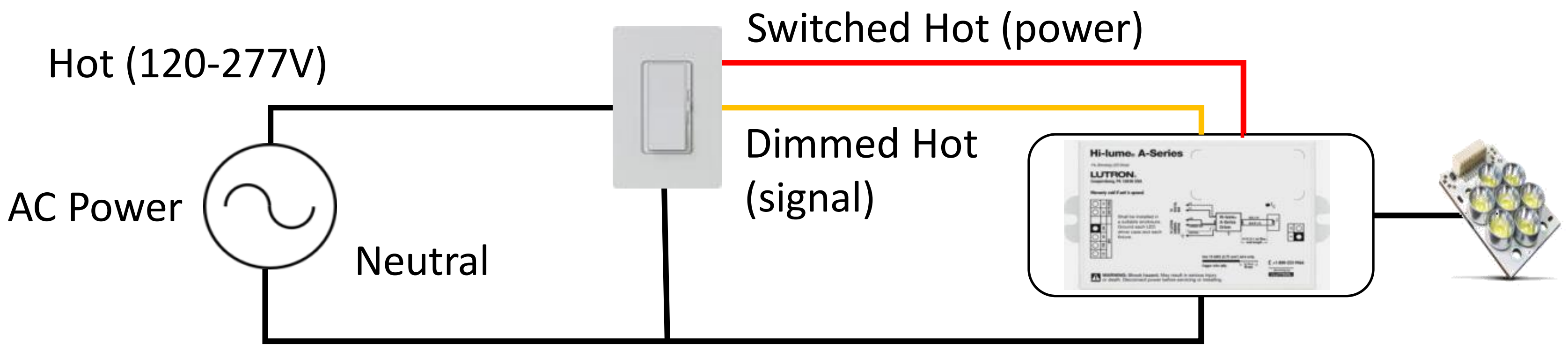


Dimming LED has Challenges

- Only bulbs listed as dimmable can be dimmed (some are not)
- Current installed base of dimmers were designed (and UL listed) for INC and HAL loads
- LEDs installed onto an **existing dimmer** will likely lead to **poor performance**
- Lutron C.L dimmers are specifically designed for this application!

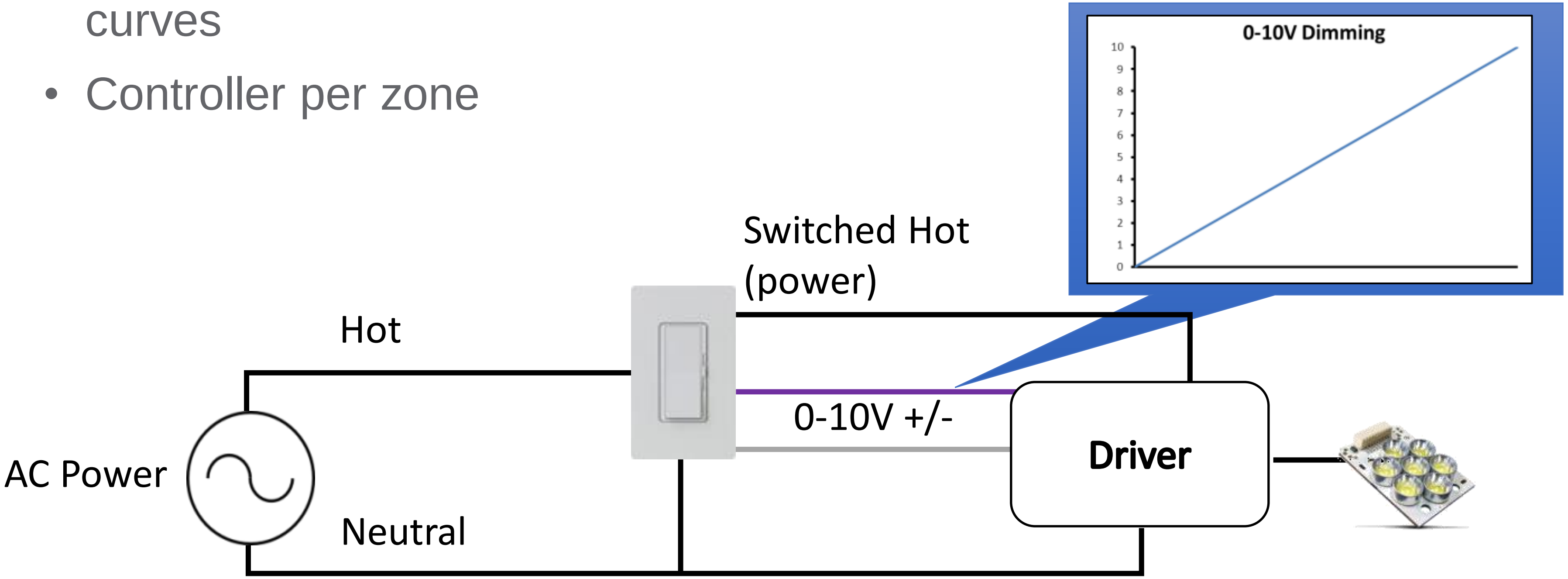
3-WIRE ANALOG CONTROL

- Fluorescent standard, control signal carried separate from power
- Precise, less prone to noise, but requires a third line voltage wire
- Universal voltage, high power factor, multiple control types available



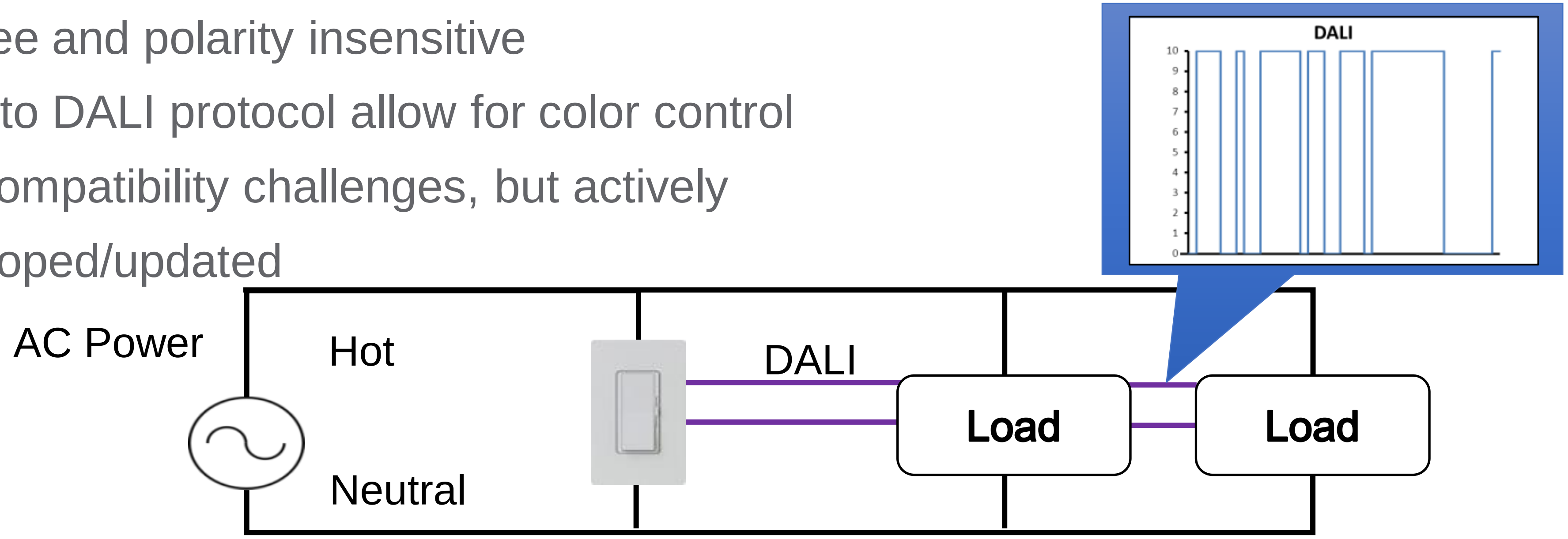
0-10V ANALOG CONTROL

- Analog control standard, low voltage wires run to each fixture in a lighting control zone (sensor group or area)
- For Architectural Lighting, IEC standard 60929 exists for general illumination - dimmer receives current from the driver (ANSI theatrical standard also exists where the dimmer provides current…not cross-compatible!)
- Requires 0-10V low voltage control output AND line voltage switching
- No guarantee of compatibility, performance, or matching dimming curves
- Controller per zone



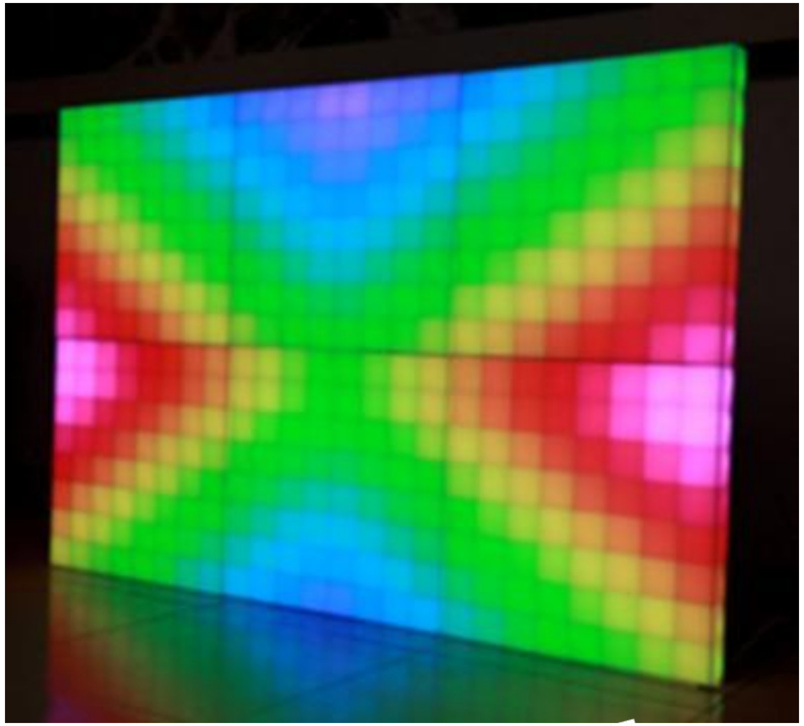
DALI / DIGITAL CONTROL

- DALI allows digital addressing of up to 64 individual ballasts/drivers in fixtures & status feedback
- Preferred method for high-performance dimming
- Many advanced features available (many are manufacturer-specific/proprietary)
- Power wires can be run separate or together with control wires
- Topology free and polarity insensitive
- Extensions to DALI protocol allow for color control
- Still a few compatibility challenges, but actively being developed/updated



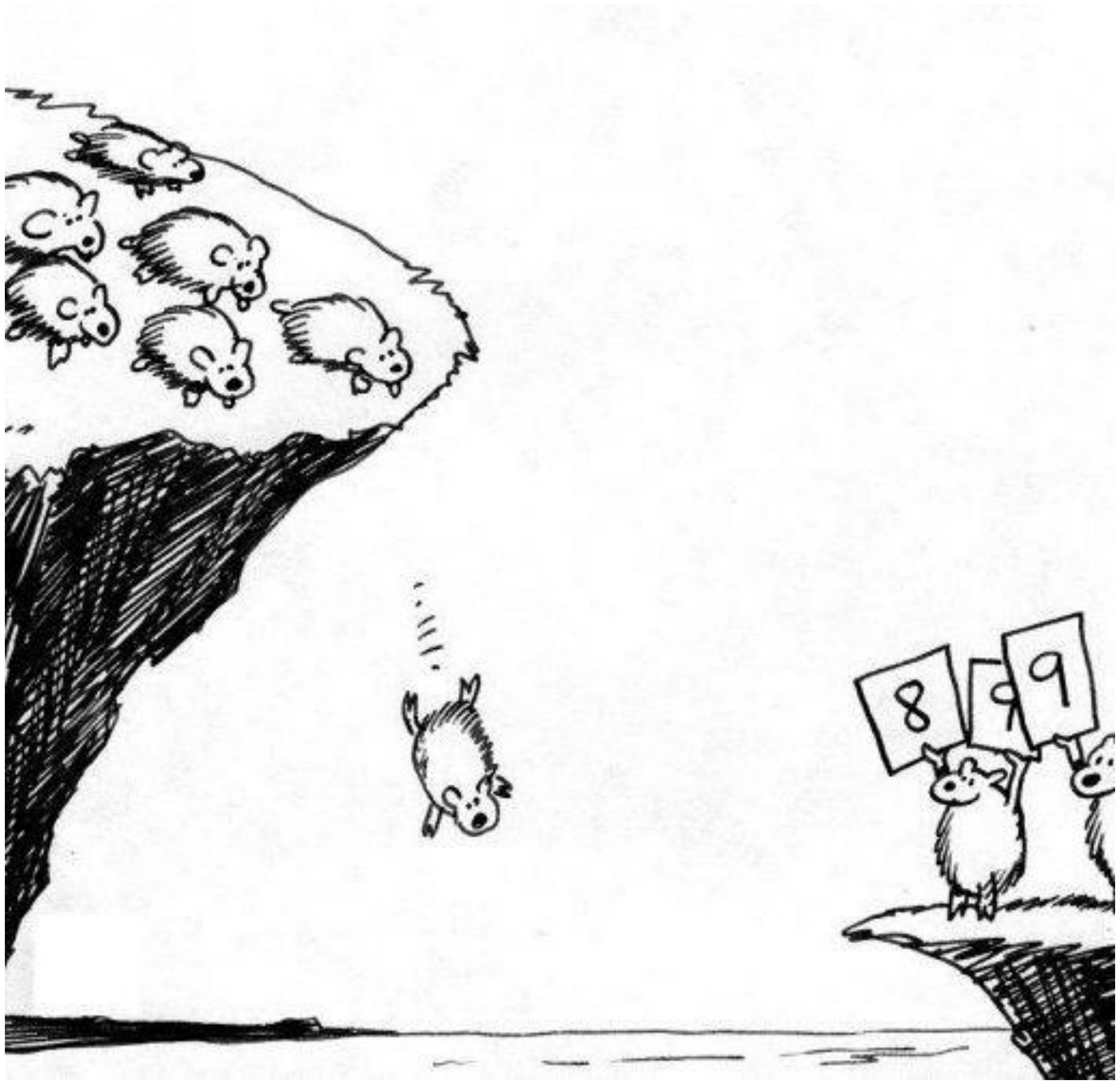
DMX-512 CONTROL

- Popular in theater applications & RGB (Red/Green/Blue) LED control
- 512 Channels per Universe with 0-256 Levels per channel
- Multiple channels for individual color control
- Possible to use for single color general applications
- Complicated wiring for general illumination; daisy chained and terminated
- Often requires an interface and more complex programming and installation



Deep Dive Into 0-10V Control
The De Facto Control Standard

- **Why do we trust fixture manufactures with control methods?**



0-10V Inrush currents

- NEMA has a recommendation NEMA-410 which sets limits on the inrush current for Drivers and ballasts. Here is a section from the NEMA allowable inrush levels vs steady state:

How do you make
A commodity driver?

Table 2
Peak Current Requirements

Steady state current (A)	Peak current (A) 120 Vac	Pulse Width 120 Vac (ms) See Note 2	I^2t (A^2 sec) 120 Vac See Note 1	Peak current (A) 277 Vac	Pulse Width 277 Vac (ms) See Note 2	I^2t (A^2 sec) 277 Vac See Note 1
0.5	75	0.34	11	77	0.07	11
1	107	0.48	24	131	0.71	27
2	144	0.70	41	205	0.85	76
3	166	0.89	51	258	0.98	111
5	192	1.20	74	320	1.20	205
8	221	1.25	98	370	1.25	274
10	230	1.50	106	430	1.50	370
12	235	1.80	110	440	1.80	387
15	239	2.00	114	458	2.00	420
16	242	2.10	117	480	2.10	461

NOTES—

1. The values used to calculate I^2t are the peak current shown in Table 2 and a pulse duration of 2 ms (t).

2. Pulse widths shown in Table 2 are documented in Figures 3 through 14 and will provide adequate performance with electronic devices having pulse widths up to 2 ms, in accordance with ANSI standard C82.11 or ANSI C82.14.

Reality for 0-10V

[redacted] 25W Single Output Switching Power Supply **LPF-25 series**

INPUT	POWER FACTOR (Typ.)	PF>0.97/115VAC, PF>0.95/230VAC, PF>0.92/277VAC at full load (Please refer to "Power Factor Characteristic" curve)								
	EFFICIENCY (Typ.)	84%	85%	86%	86%	86%	86%	86%	87%	86.5%
	AC CURRENT	0.4A / 115VAC 0.25A / 230VAC 0.2A/277VAC								
	INRUSH CURRENT (Typ.)	COLD START 50A(twidth=200µs measured at 50% Ipeak) at 230VAC								
	MAX. No. of PSUs on 16A CIRCUIT BREAKER	4 units (circuit breaker of type B) / 8 units (circuit breaker of type C) at 230VAC								

A 0.2A load has a turn-on inrush of 50A!!!!!!!!! What?

The good news is that this manufacturer gave us the data, most manufacturers simply do not publish the data. Here is their FAQ #6

A6. What is "Inrush Current"? What will we notice?

Ans:

If there are several power supplies turning on at the same time, the dispatching system of AC source may shut off and go into protection mode because of the huge inrush current. It is suggested that these power supplies **start up one by one.**

0-10V Control or is it 10V -0

- Two control methods: ***current sink*** and ***current source***

- The IEC standard for <u>general lighting</u> requires:
  - Control to be the current sink
- The ANSI standard for <u>theatrical lighting</u> requires:
  - Control to be the current source

- You **CANNOT** mix controls, ballasts or drivers from these two standards

- Meeting the standard will ensure compatibility but not performance

0-10V Control

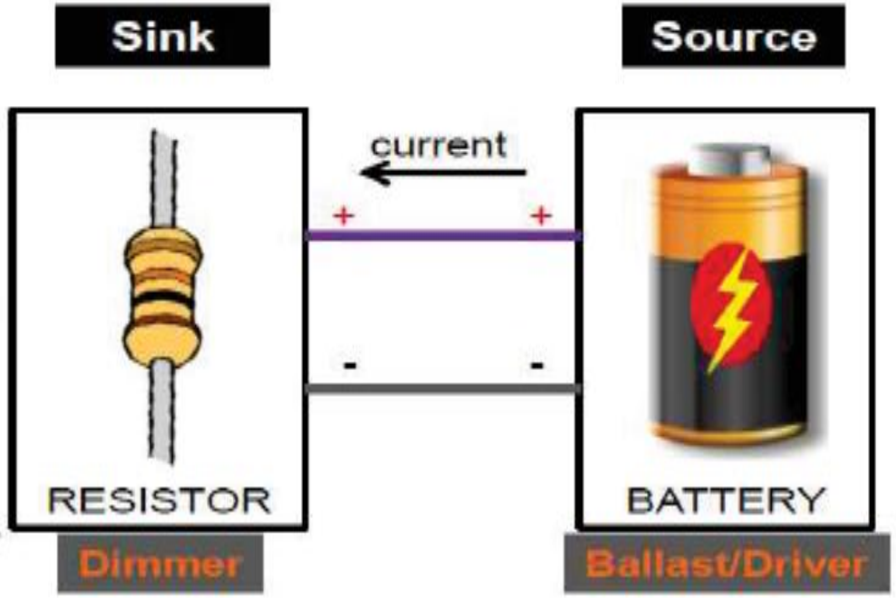
IEC 60929 for General Lighting

•What it defines:

- The ballast/driver sources the current for the 10 Volts (2mA Max)
- The control sinks the current
- **At 10 Volts or above, the lights go to full**
- **At 1 Volt or below, the lights go to their minimum level**

• It does **not** define dimming performance, power performance, lifetime, etc

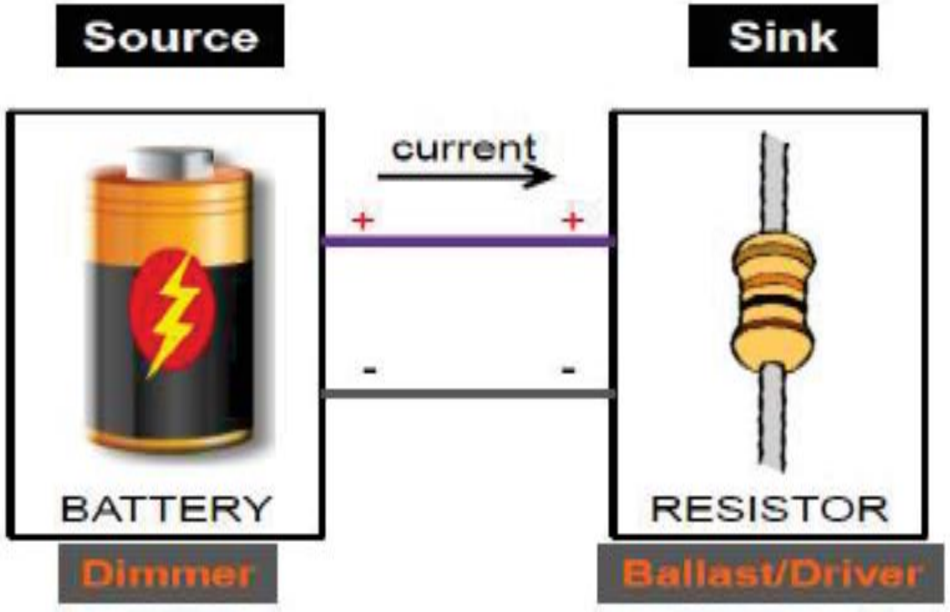
•Each zone is hard wired



0-10V Control

ESTA E1.3 for theatrical lighting

- What it defines:
  - The control sources the current
  - The ballast sinks the current
  - **10V is 100% light**
  - **0V is off**



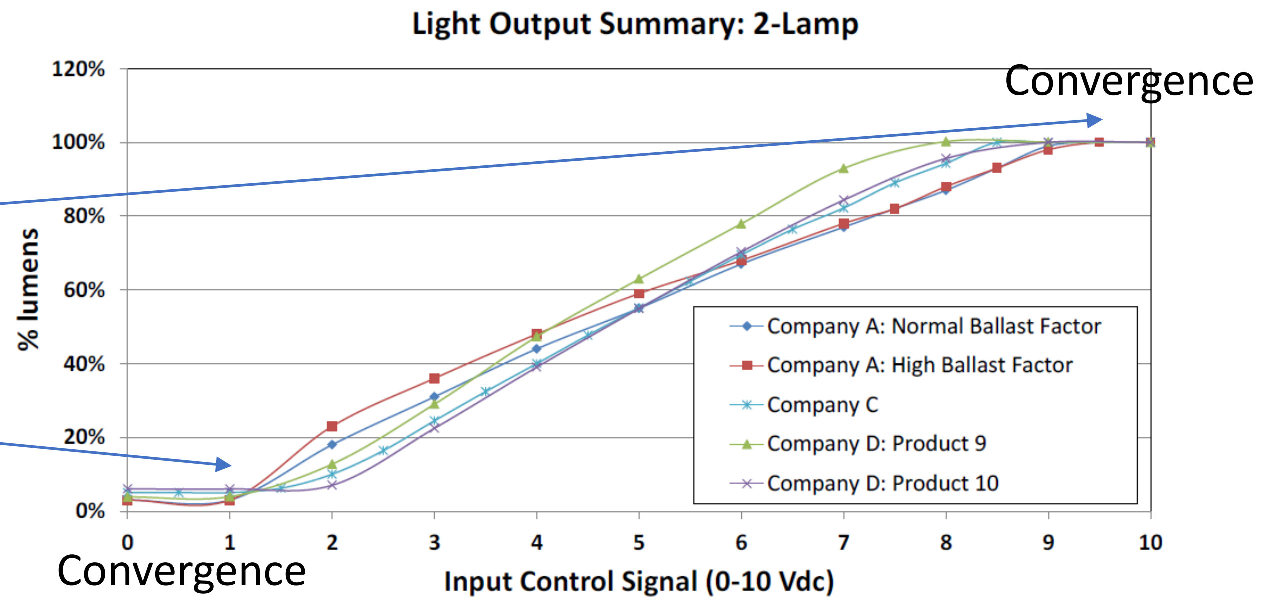
Confusion results from 0-10V LED fixtures that are developed for the theatrical market and are moving into general lighting or the fixture manufacture wants a "free" driver, so removes parts.

0-10V is an open protocol!

- Not so with LED, the fixture is UL listed with the driver. You cannot change out the driver to a different model number as this violates the UL listing and would require retesting the whole fixture at UL or with a UL inspector or using a TL listed driver.
- 0-10V dimming curves are all over the map:

IEC 60929 for General Lighting

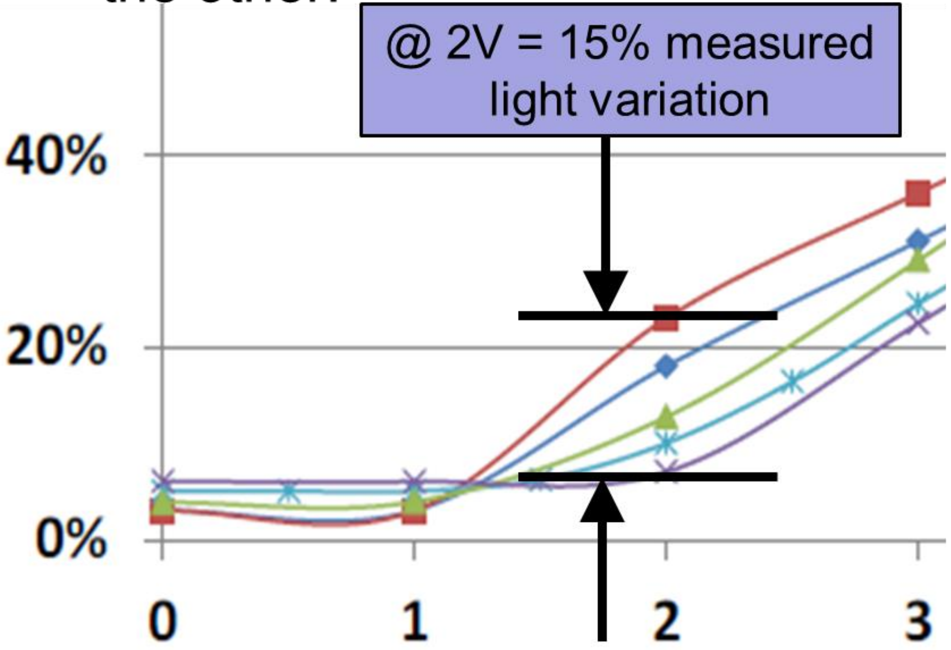
- **At 10 Volts or above, the lights go to full**
- **At 1 Volt or below, the lights go to their minimum level**

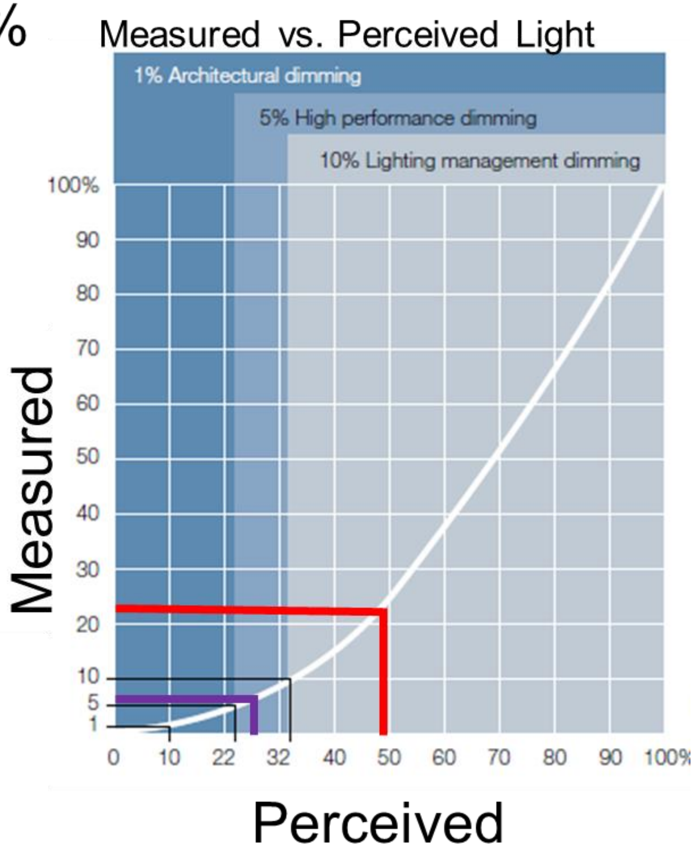


- From SMUD study – July 2013

0-10V How do you fix this?

- With various 0-10V products set at 2V the measured output varies 15%
- One Fixture is TWICE as bright as the other!

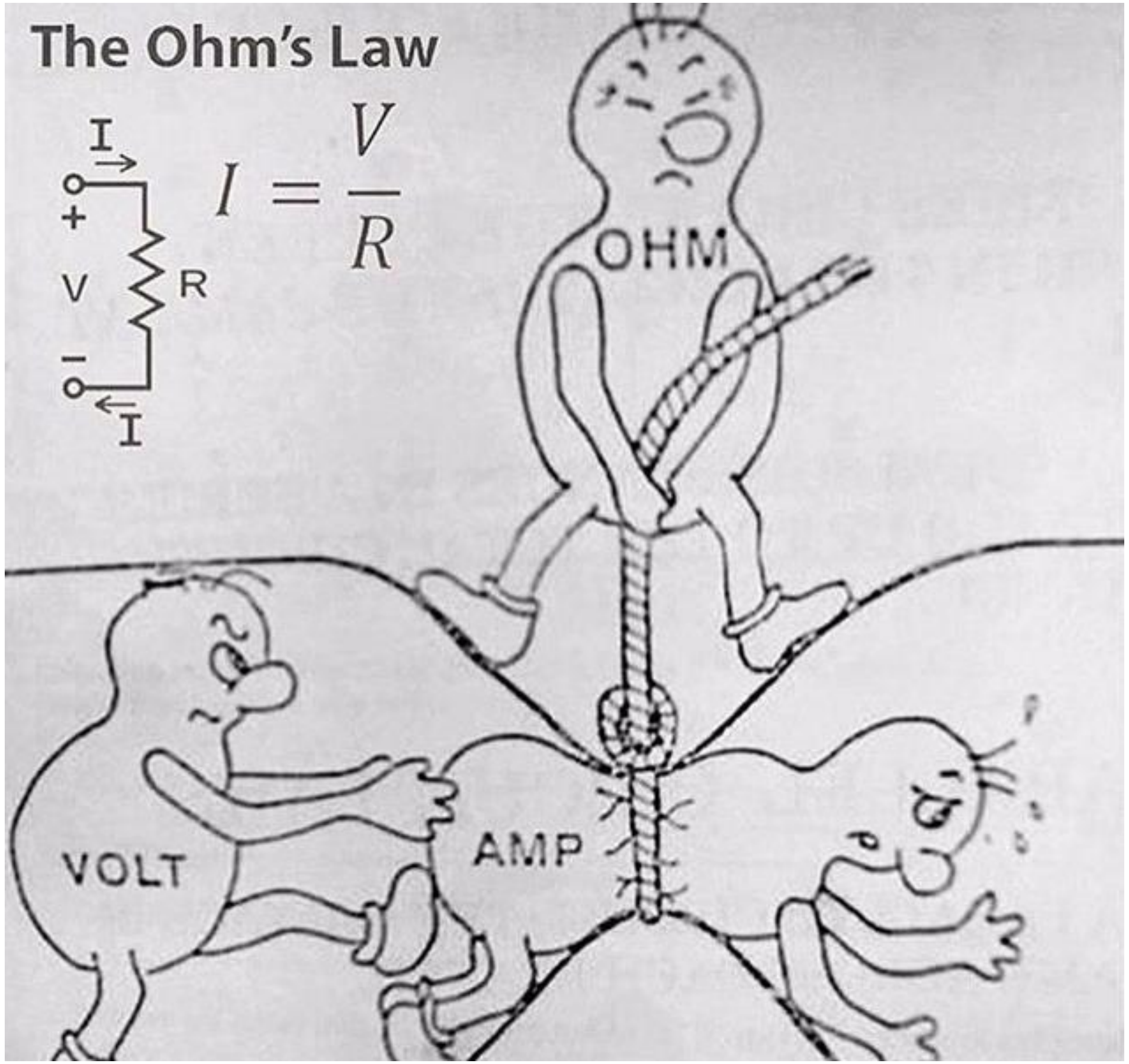




25 % difference in perceived light or **RED** is twice as bright as **PURPLE** at 2V

Ever Heard of Ohm's Law?

- Any given length of wire has Resistance along the length.
- As we force the current through the wire, some voltage is lost
- If we start out with only 10V and lighting level is proportional to voltage, what happens along the wire?

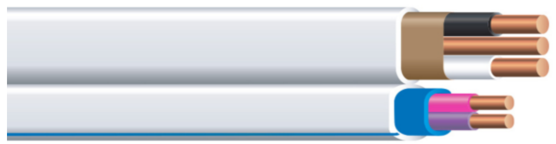


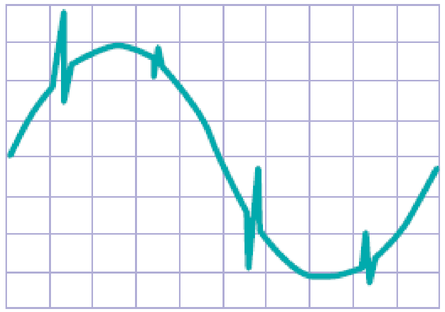
0-10V long wire length issues

More later why this was installed with the wrong control method

0-10V wiring Trends

- What happens if 0-10V signal wires run with power wires?
    - Coupled interference
    - Potential miswires
- Would you do this with speaker wire?





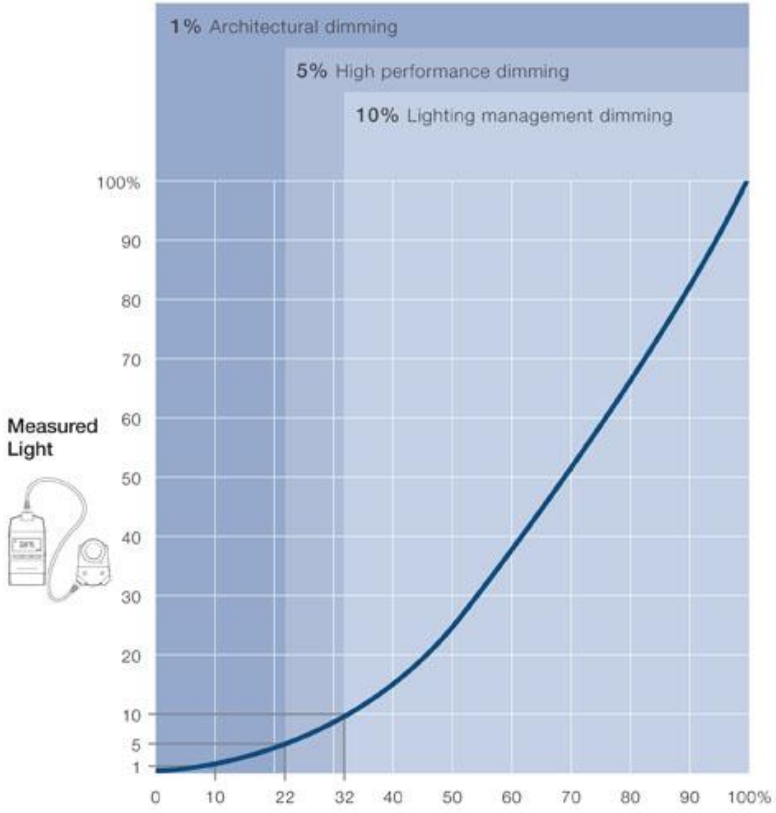
Linear or Logarithmic control?

Linear vs. Logarithmic Dimming

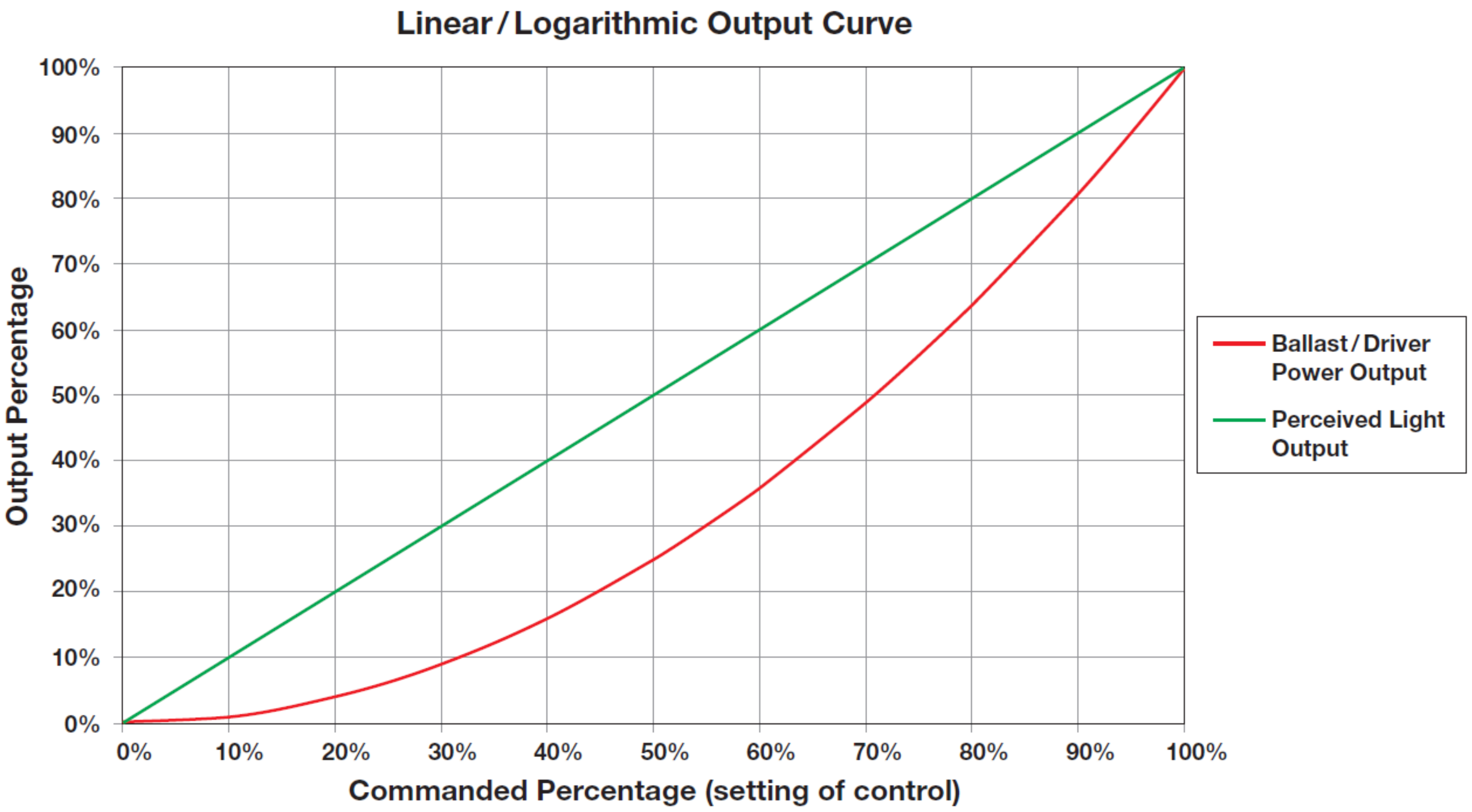
Linear vs. Logarithmic describes two different things:

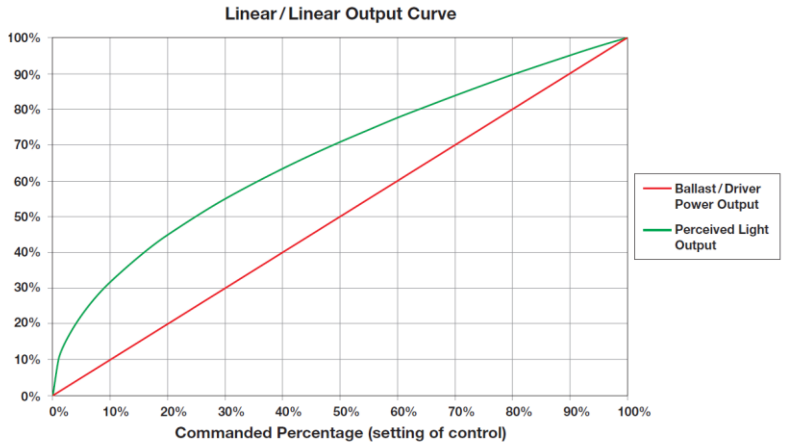
1. For the control, it is the shape of the curve plotted using the commanded % of light from the system against the output voltage on the 0-10 V line.
2. For the ballast / driver, it is the shape of the curve plotted by 0-10 V voltage vs. light output

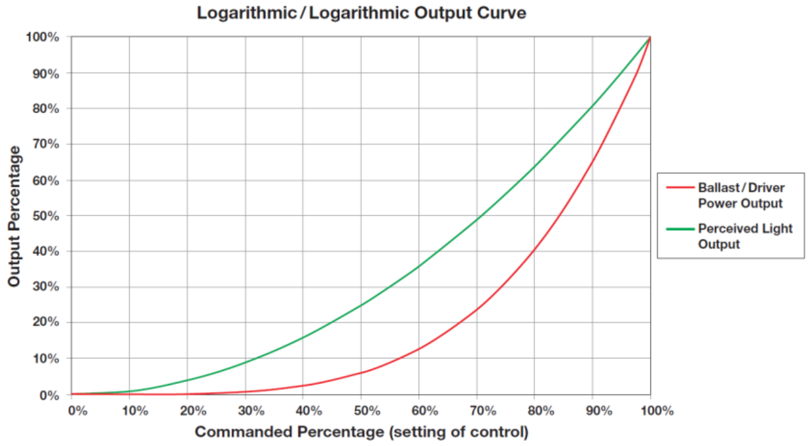
This concept is used to allow for compensation between measured and perceived light (Figure 3). This relationship is due to the changes in the human eye as the light level decreases. The dilation of the pupil allows more light to enter the eye so that the measured light level could be 10% but the light level perceived by the eye would be around 32%.



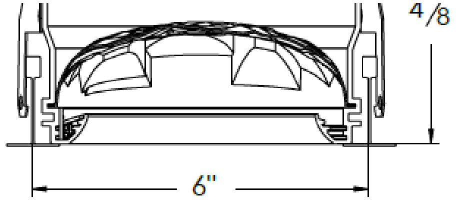
Linear/Log Combinations







Typical 0-10V fixture specification sheet



A+ Capable options indicated by this color background.

Ordering

Example: CHSL 6X4 G9 80CRI 35K 2000LM WVE 1SD DARK 120 ZT

CHSL	6X4				
Series	**Size**	**Ceiling Trim**	**LED Color Rendering**	**LED Color Temp**	**LED Output[2]**
CHSL	**6X4** 6"X4'	**DF[1]** Tegular tee slot	**80CRI** 80+ CRI	**27K** 2700K	**1000LM** 1000 Lumens
		G9 9/16" inverted tee	**90CRI** 90+ CRI	**30K** 3000K	**1500LM** 1500 Lumens
		G15 15/16" inverted tee		**35K** 3500K	**2000LM** 2000 Lumens
				40K 4000K	**2500LM** 2500 Lumens
				50K 5000K	**3000LM** 3000 Lumens
				65K 6500K	**3500LM** 3500 Lumens
					4000LM 4000 Lumens

Texture	**Directional Gradient**	**Minimum Dimming Level**	**Voltage**	**Emergency Options**	**Control Input**	**Options**
MNML Minimalist	**1SD[3]** Side	**DARK[4]** Constant Current, Dimming to < 1%	**120** 120V	**E10WCP[6]** 10-watt emergency battery pack	**ZT** 0-10V	**CP[8]** Chicago plenum
WVE Weave	(see page 2)	**MIN1[5]** Constant Current, Dimming to 1%	**277** 277V	**EMG[6,7]** Emergency generator power	**NLIGHT** nLight enabled	**PWS** 6' pre-wire, 3/8" diameter, 18 gauge
PYR Pyramid			**347** 347V		**NLTAIR2** nLight Air	
					DALI DALI	
					DMX DMX512/RDM	
					ECOD Lutron Hi-Lume Digital driver	

Notes

1. Available for 9/16" grid only.

7. EMG option requires a connection to existing powered nLight network. Power is provided from a separate nLight fixture

Sink, Source, Linear, logarithmic, current?

Installation using 0-10V vs. Digital control

COOPER LIGHTING - METALUX® energy solutions

DESCRIPTION

The SkyRidge™ transforms ambient lighting by perfectly blending a refined

Catalog #		Type

Controls

Equipped standard with a 0-10V continuous dimming driver that works with any standard 0-10V control/dimmer. Dimming range is 5% to 100%; varies by control device. Combine with energy-

ORDERING INFORMATION

SAMPLE NUMBER: 24SR-LD1-48-C-UNV-L835-CD1-U

Rating
Blank=Standard
ATW-SW4= Chicago Rated [7]

Series [9]
24SR=2' x 4' SkyRidge Series

Air
[Blank]=Standard
A=Air (Vented) [8]

Lamp Type
LD1=LED 1.0

Stock Lumen Outputs
39=3900 Lumens
48=4800 Lumens

MTO Lumen Outputs [5]
29=2900 Lumens [6]
34=3400 Lumens
45=4500 Lumens
53=5300 Lumens
59=5900 Lumens
64=6400 Lumens

Reflector
C=Curved (Standard)
S=Straight

Optics
Blank=Standard

Voltage [1]
347V=347 Volt
UNV=Universal Voltage
120-277

Options
Emergency
EL=Emergency Installed, 700 Lumens [4]
EL14=Emergency Installed, 1400 Lumens [2, 4]
EL10W=Emergency Installed, 10 Watts [10]
CCT
L830=3000K
L835=3500K
L840=4000K
Flex
Multiple Configurations Available

Driver Type
CD=0-10V Dimming Driver (Standard)
SD=Step-Dim Driver [13]
5LTD=Fifth Light (DALI) Driver [3]

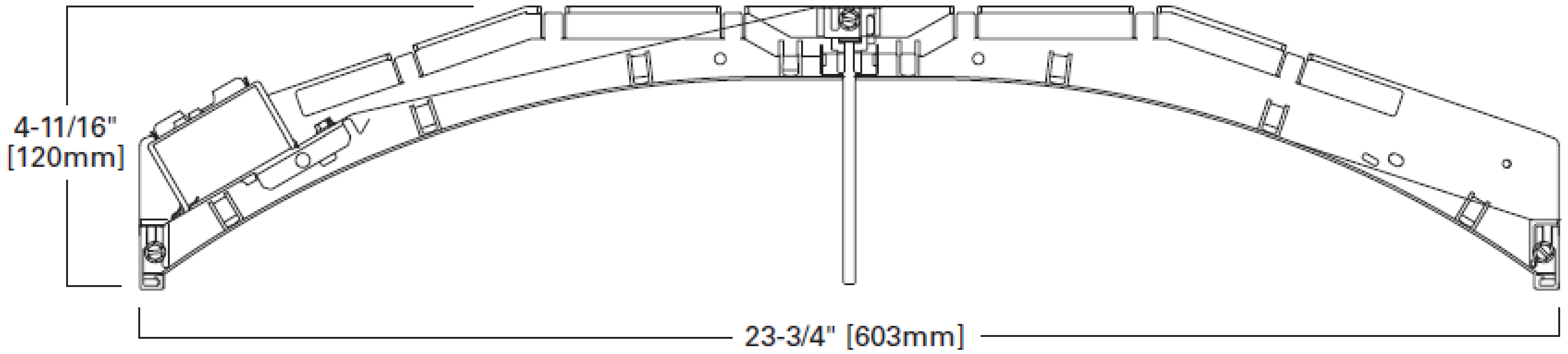
Number of Drivers
1=1 Driver

SkyTrim [11]
PG=Primary Green
SO=Storaro Orange
PL=Pearl
BR=Belladonna Rose
MR=Medium Red
ST=Straw
CC=Custom [12]

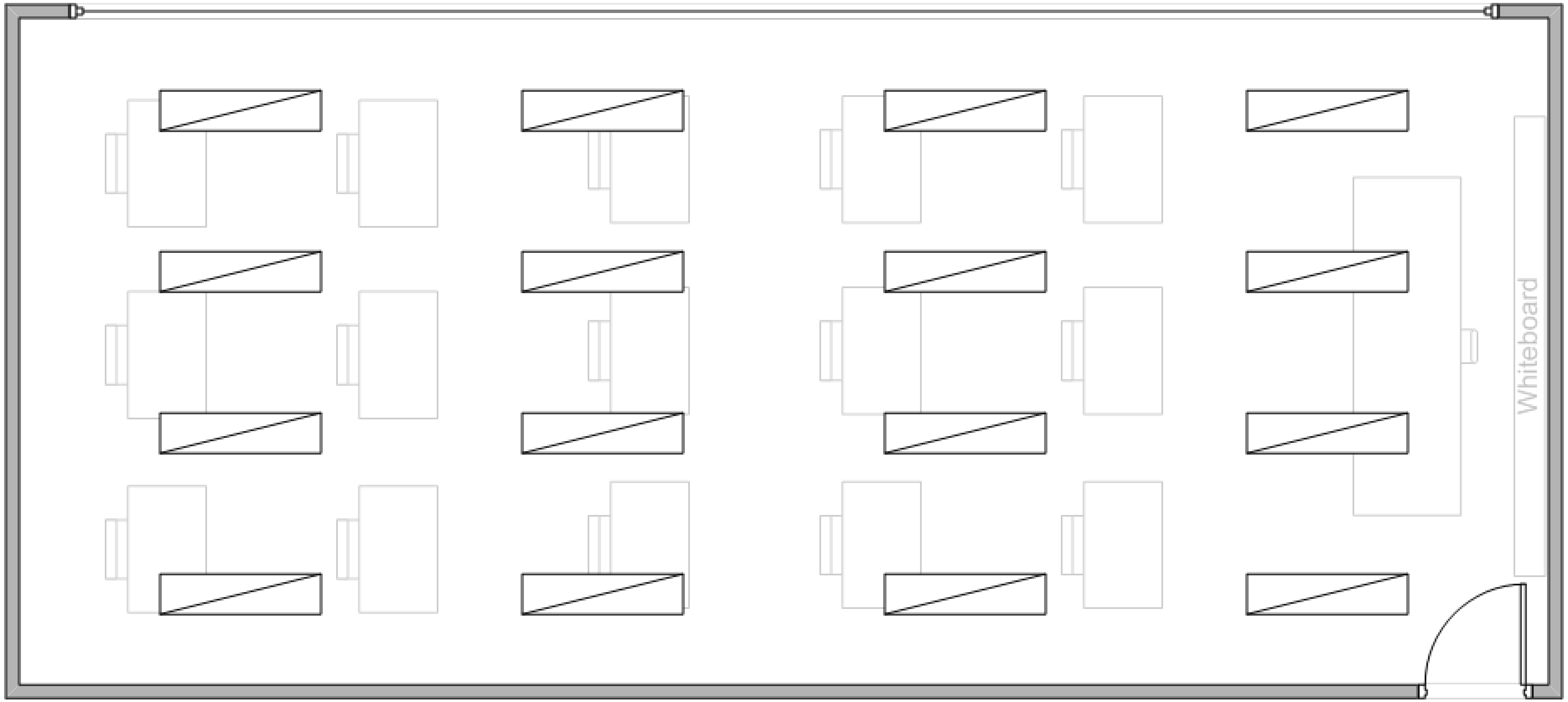
Packaging
U=Unit Pack
PALC=Job Pack, in carton

ACCESSORIES
T3A END E.Q. BRACKET PARTS BAG (Standard with fixture)
DF-24-W=2' x 4' Drywall Frame Kit

CURVED



Create Zoning for 0-10V



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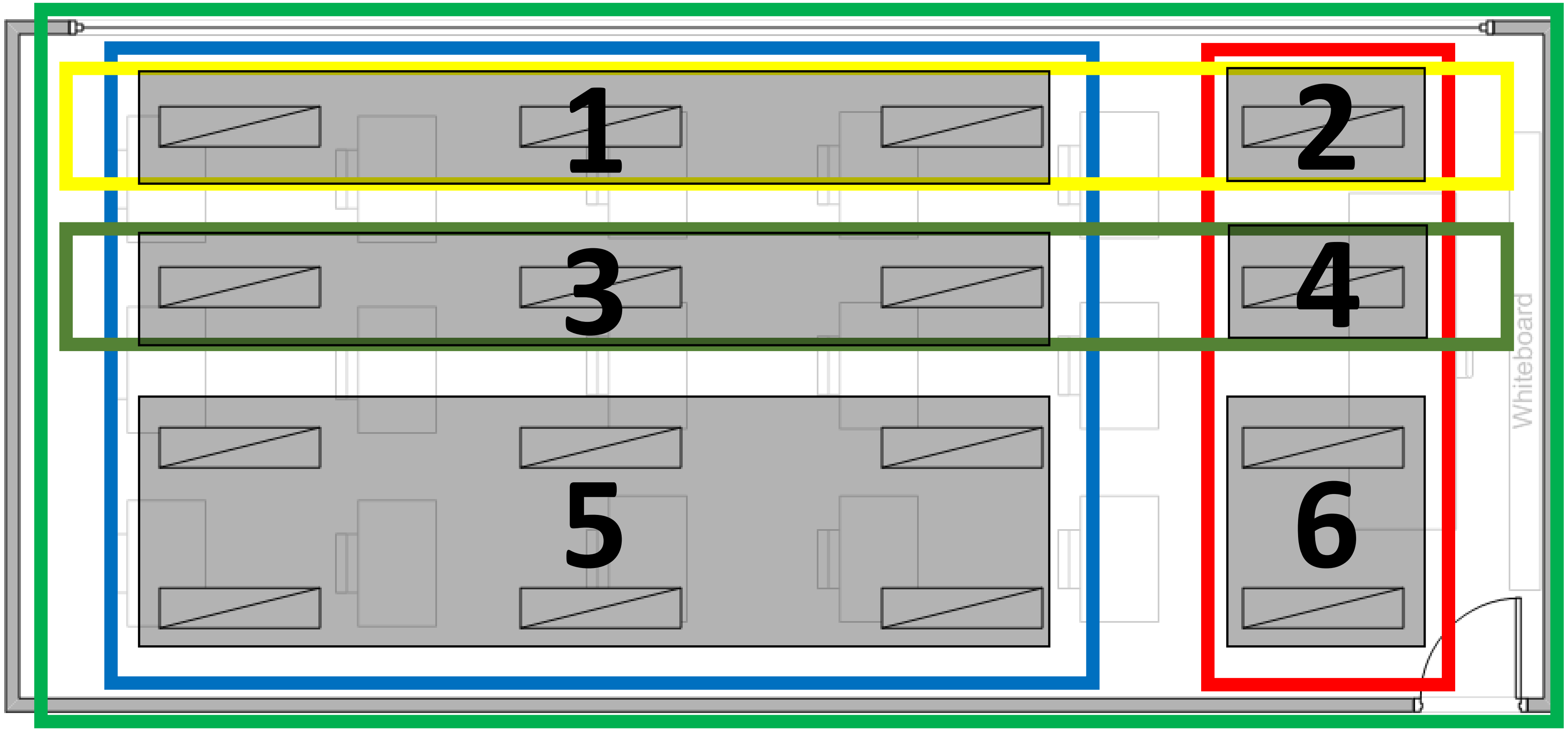
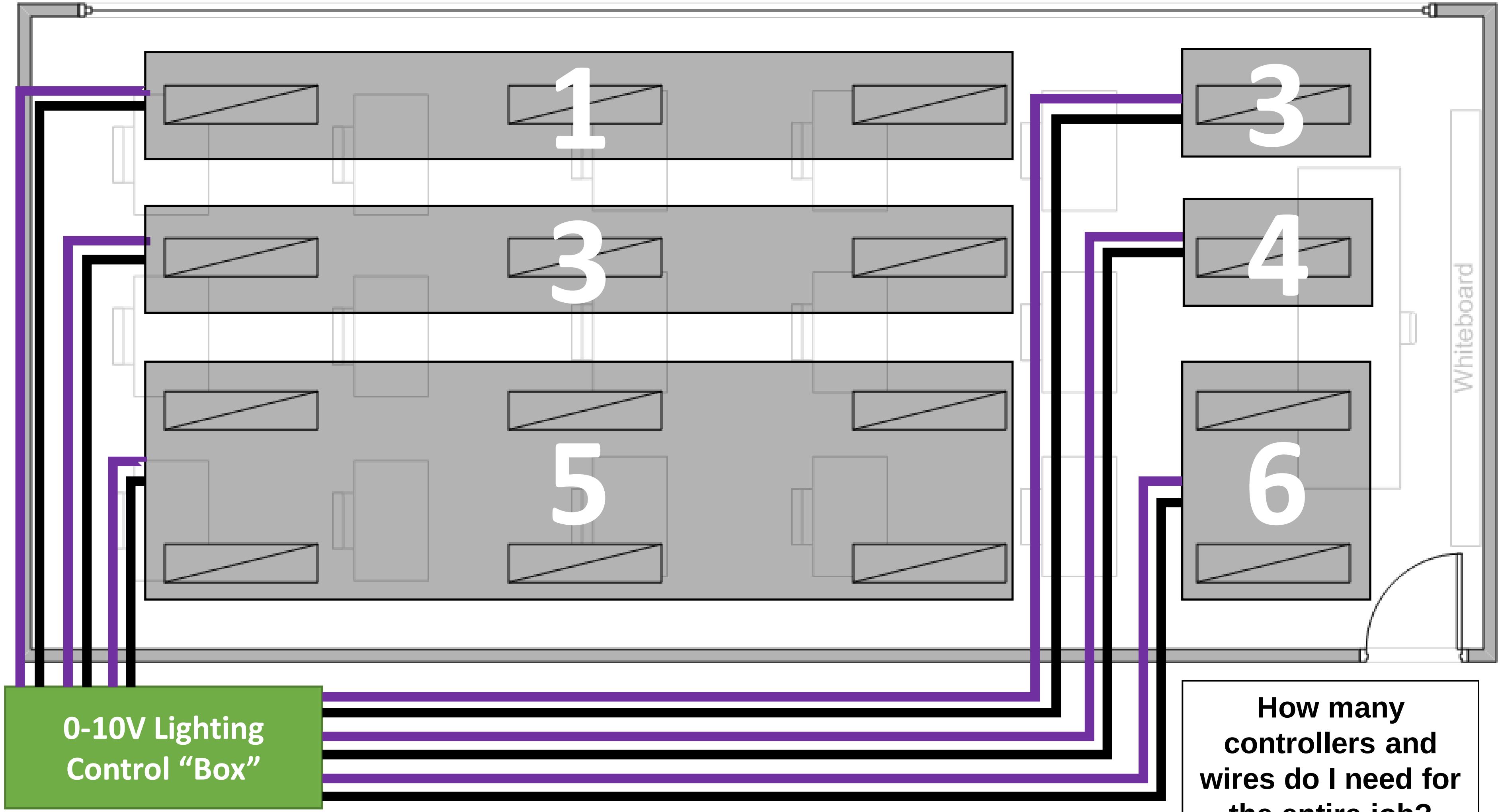


Occupancy | Personal Control Zone | Personal Control Zone | Daylight Zone 1 | Daylight Zone

0-10V control and wiring details



How many controllers and wires do I need for the entire job?

Specifier insists on digital dimming

COOPER LIGHTING - METALUX®

energy solutions

DESCRIPTION

The SkyRidge™ transforms ambient lighting by perfectly blending a refined

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Stock Lumen Outputs
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C=Curved (Standard)
S=Straight

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347V=347 Volt
UNV=Universal Voltage 120-277

Options
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EL14=Emergency Installed, 1400 Lumens (2), (4)
EL10W=Emergency Installed, 10 Watts (10)
CCT
L830=3000K
L835=3500K
L840=4000K
Flex
Multiple Configurations Available

Driver Type
CD=0-10V Dimming Driver (Standard)
~~**SD**=Step-Dim Driver (10)~~
5LTD=Fifth Light (DALI) Driver (3)

Number of Drivers
1=1 Driver

SkyTrim (11)
PG=Primary Green
SO=Storaro Orange
PL=Pearl
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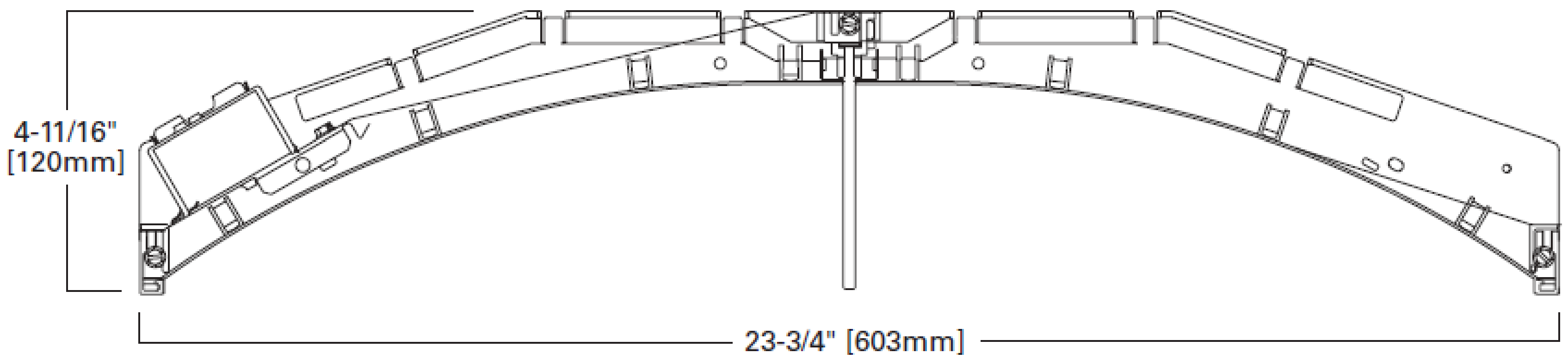
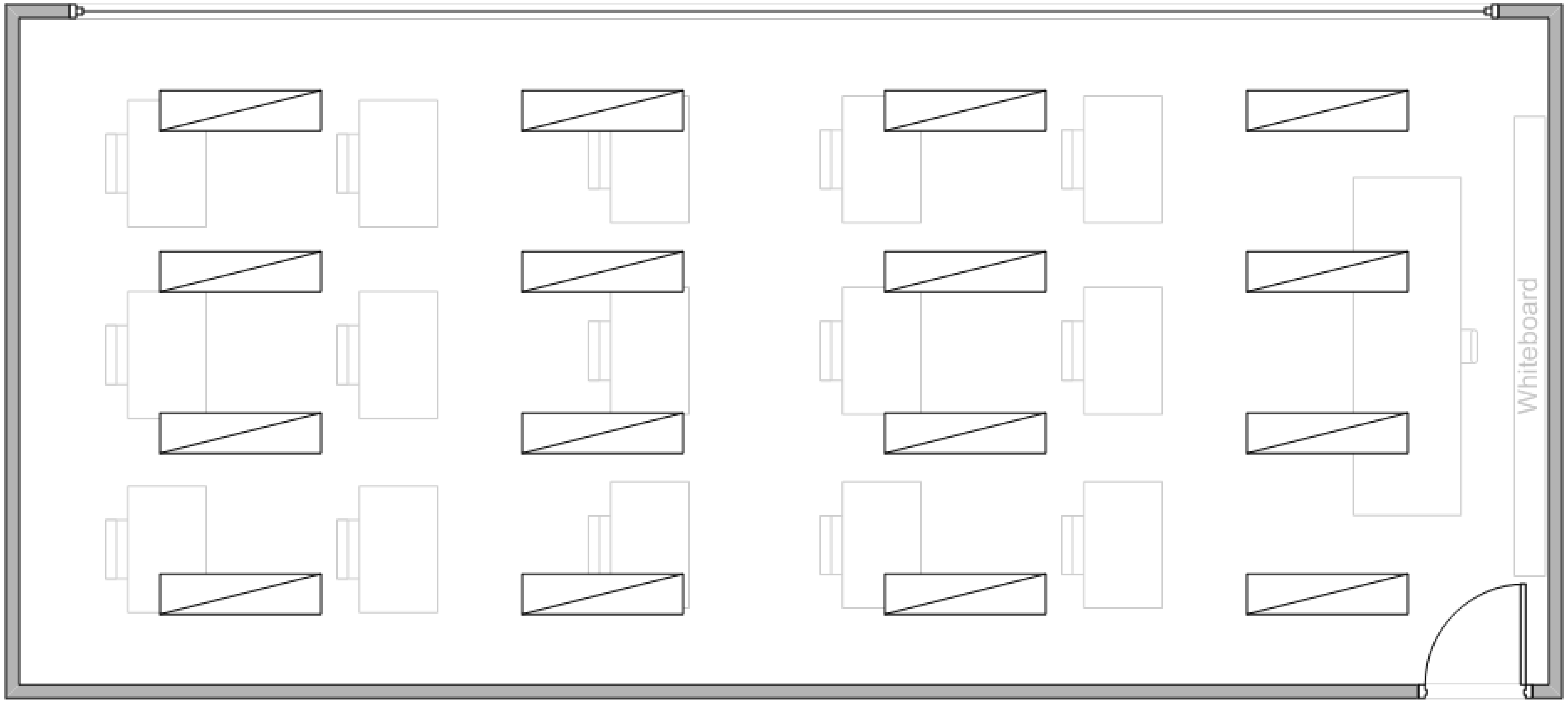
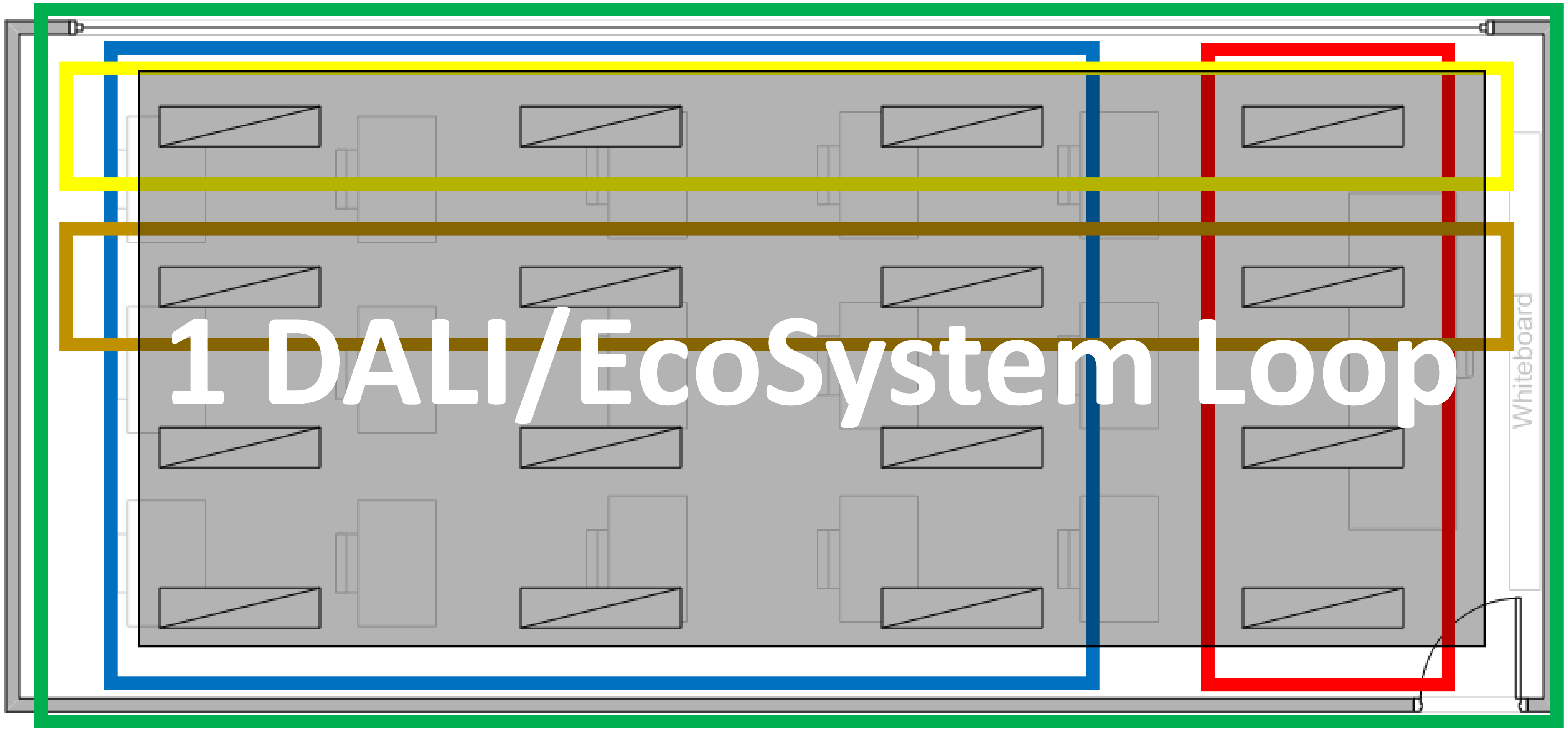
CURVED



Create Zoning for Digital DALI/Ecosystem



Designing with Digital



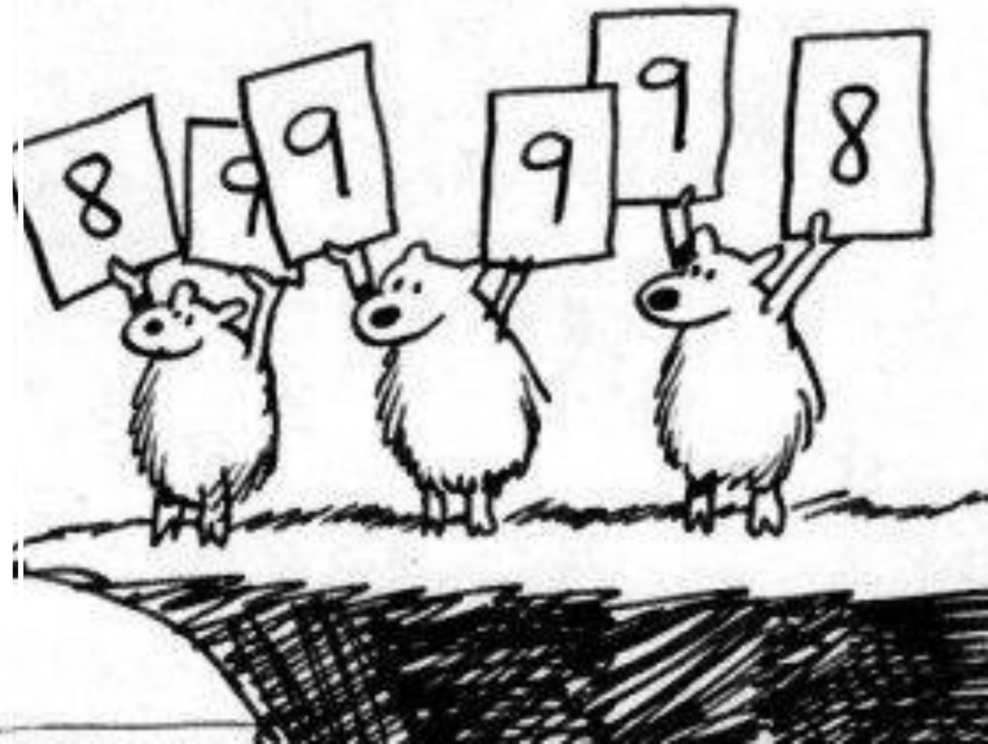
Occupancy | Daylight Zone | Daylight Zone 2 | Personal Control Zone 1 | Personal Control Zone

0-10V (ANALOG) VS. DALI (DIGITAL)

	DALI	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
Guaranteed compatibility between controls + drivers	Usually	No
Driver feedback	Extensive	No
BMS integration	Fixture by fixture information	Generally circuit level information (depends on amount of control interfaces)

0-10V conclusion

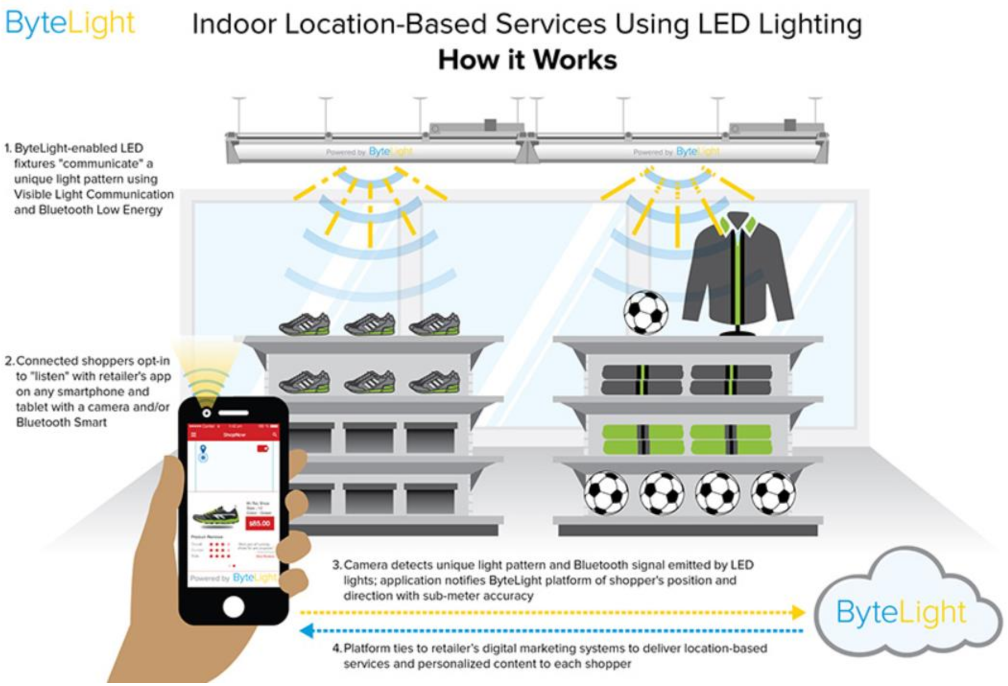
- Analog control method not suited for precise control, especially tunable white or full spectrum
- Requires more control gear
- Wire runs and wire handling critical for performance
- Hard wired zoning; requires rewire for zone changes
- Can never find all the required parameters
- Prone to wiring mistakes

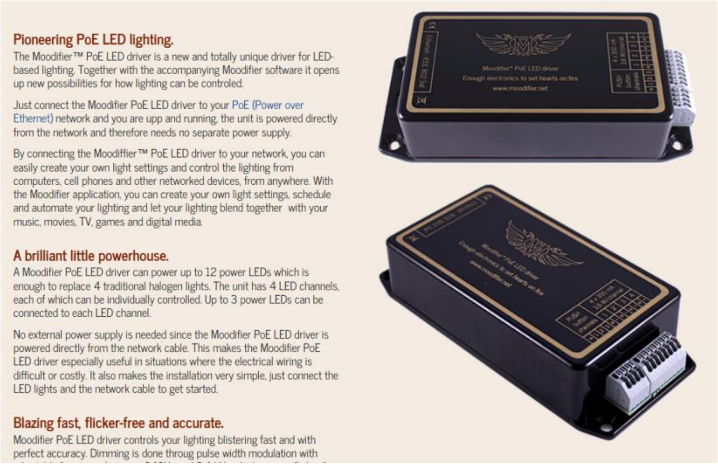


FUTURE CONTROL TECHNOLOGY

- Power over Ethernet / DC grid?
- Wireless control
- Indoor positioning

- In the end: Functionality is determined by the DRIVER!





Summary

Load Type Matrix

	Forward Phase	Symmetric Forward Phase	Reverse Phase	Switching	3-Wire	0-10V	DALI	EcoSystem	DMX
	Phase Control								
Incandescent / Halogen									
Magnetic Low Voltage (MLV)									
Electric Low Voltage (ELV)									
LED Driver (bulb)									
LED Driver (fixture)									
Ballast									
	Analog Control						Digital Control		

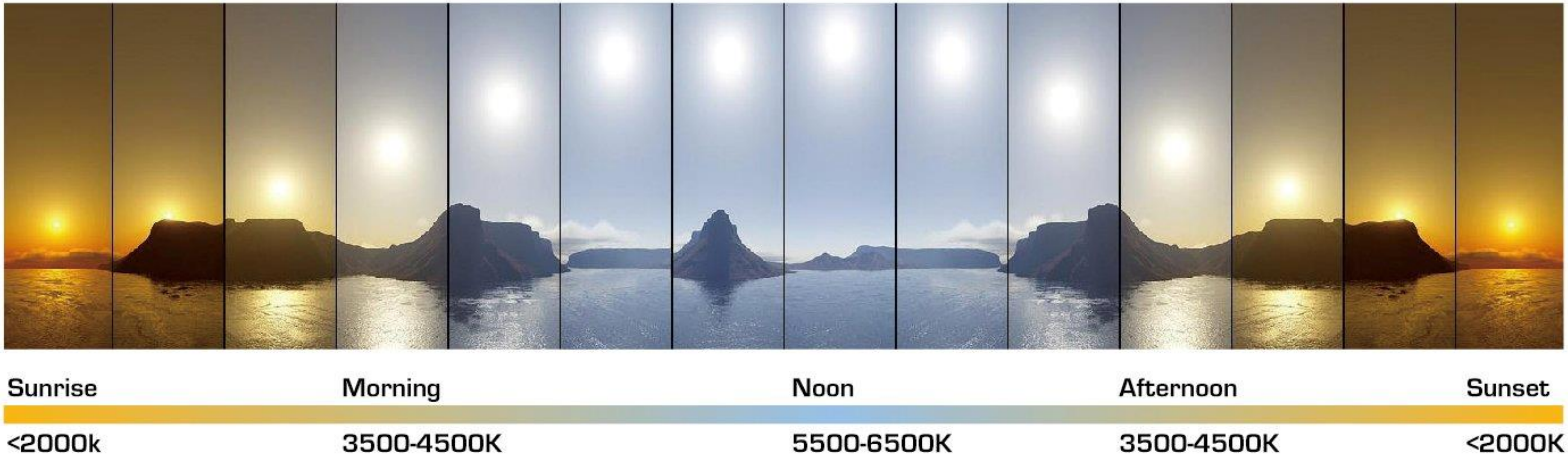
Load Type Matrix

	Analog Control						Digital Control		
	Phase Control						Digital Control		
	Forward Phase	Symmetric Forward Phase	Reverse Phase	Switching	3-Wire	0-10V	DALI	EcoSystem	DMX
Incandescent / Halogen	●	●	●	●					
Magnetic Low Voltage (MLV)		●		●					
Electric Low Voltage (ELV)			●	●					
LED Driver (bulb)	●	●	●	●					
LED Driver (fixture)	●	●		●	●	●	●	●	●
Ballast	●	●		●	●	●	●	●	

New Applications for LED

- Everyone is pushing LED
- New applications are being developed
- Lots of hype, some really don’t work
- How can you reduce risk with the right kind of control
- Ever heard of Tunable White?

Tunable White LED



CIE Chromaticity Diagram

The Black Body Curve

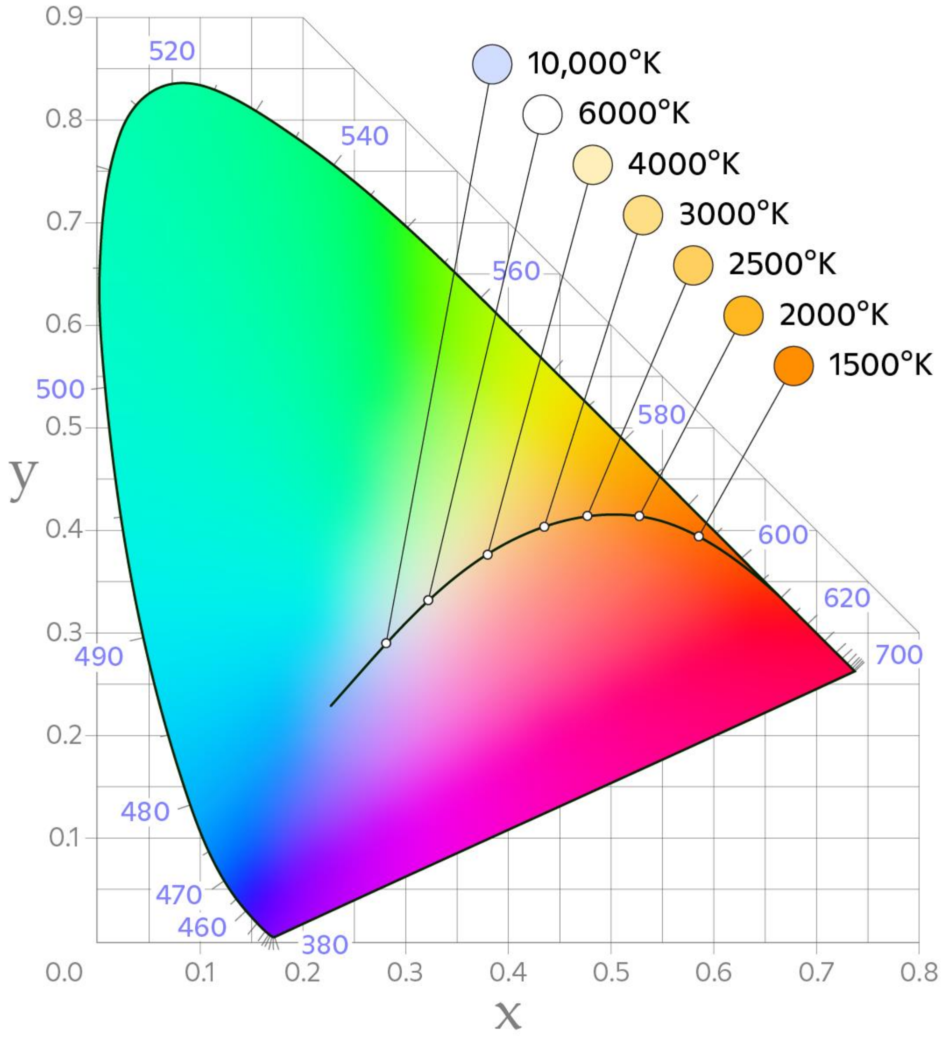
- Black Bodies are naturally black substances that emit various levels of white light when heated to specific temperatures in degrees Kelvin (K)
- The Black Body curve represents the total range of naturally occurring white light.
- Common examples of black bodies are light bulb filaments, candles and Heated Nails!.

Artic Sky: 10,000°K

Incandescent: 3000°K

Sunrise: 2000°K

Candlelight: 1500°K

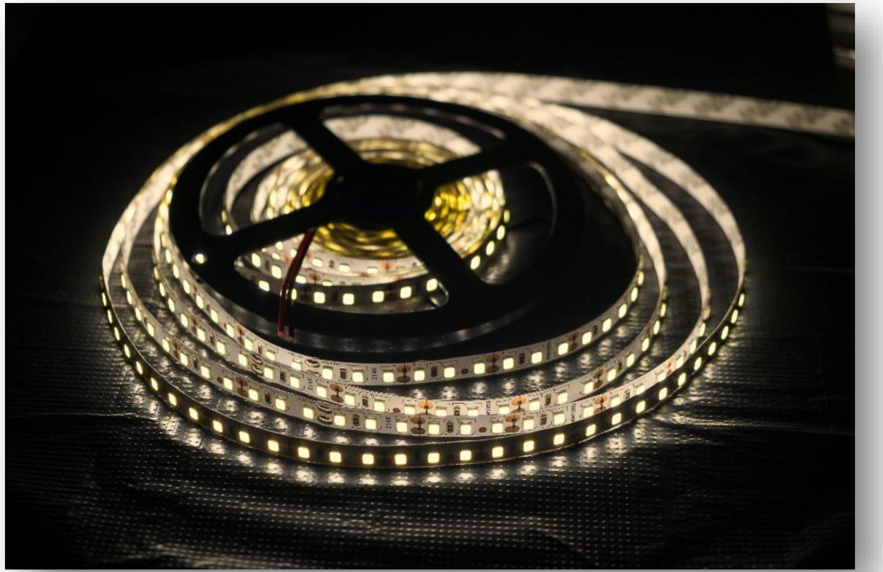


Tunable White

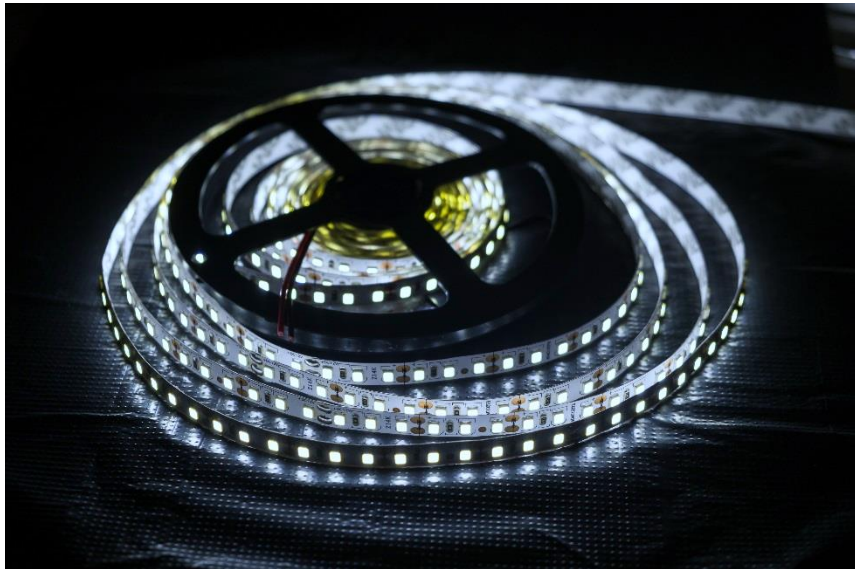
Tunable White:

any CCT at any intensity

Warm



Cool

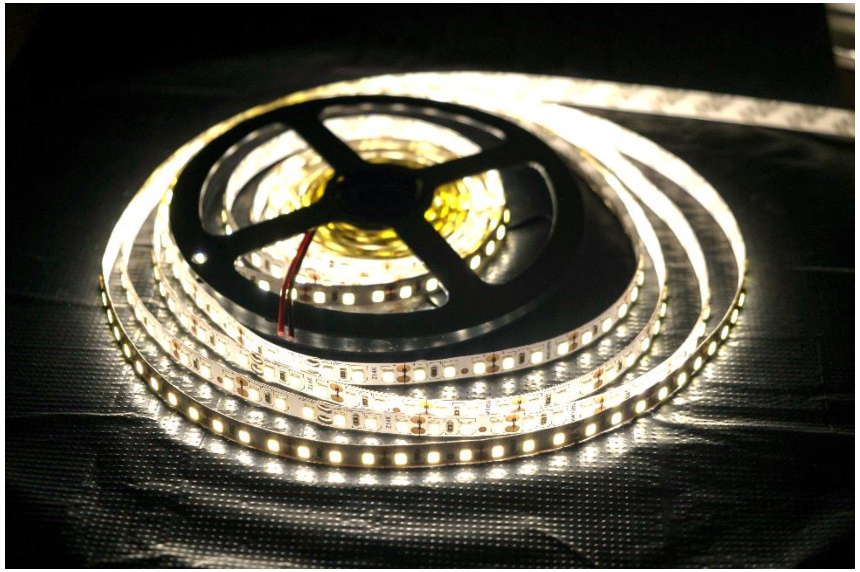


Perceived light is additive

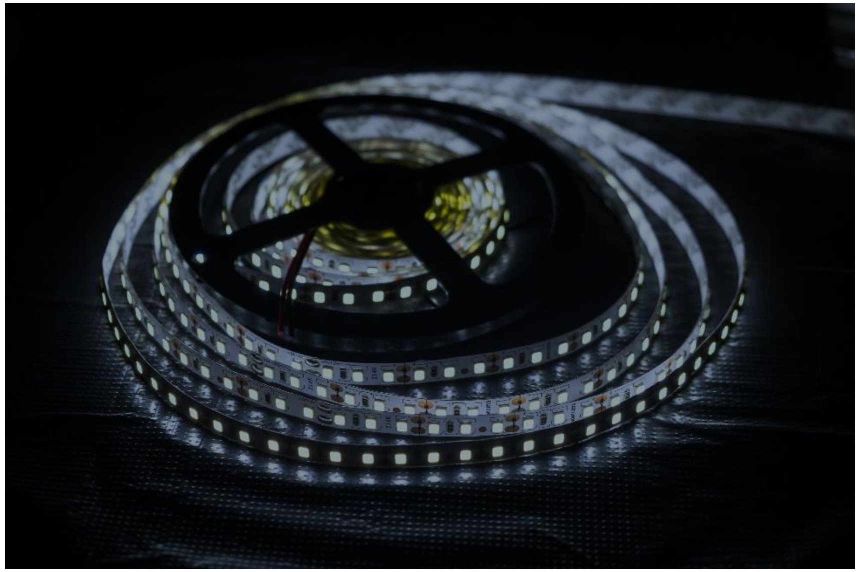
Tunable White:

any CCT at any intensity

Warm



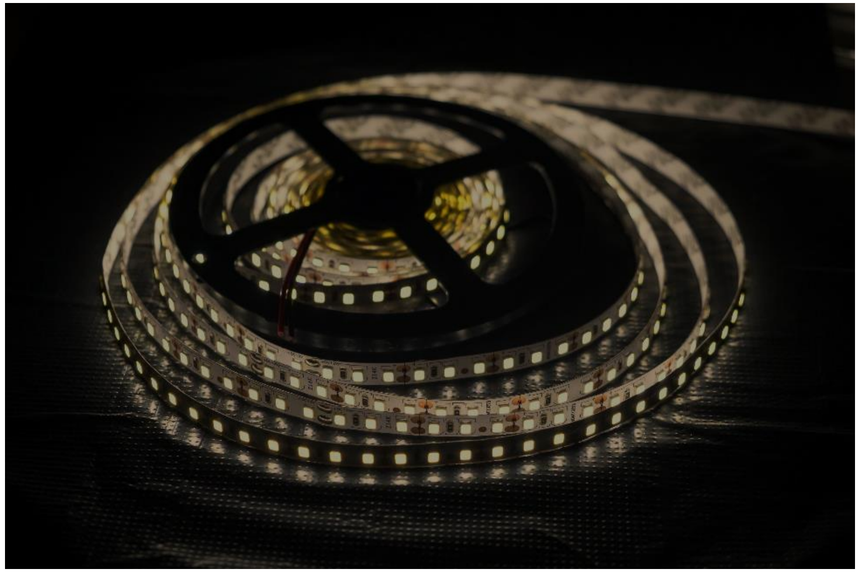
Cool



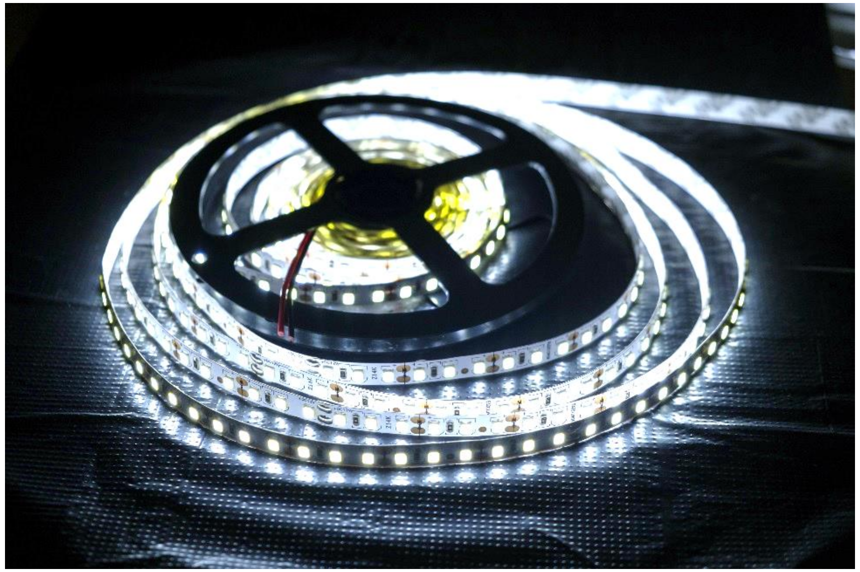
Combined: Warm Output

Tunable White:
any CCT at any intensity

Warm



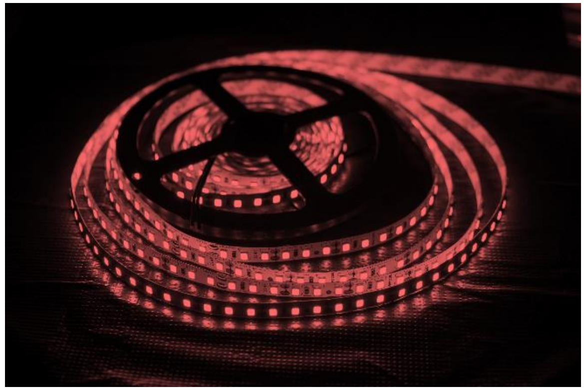
Cool



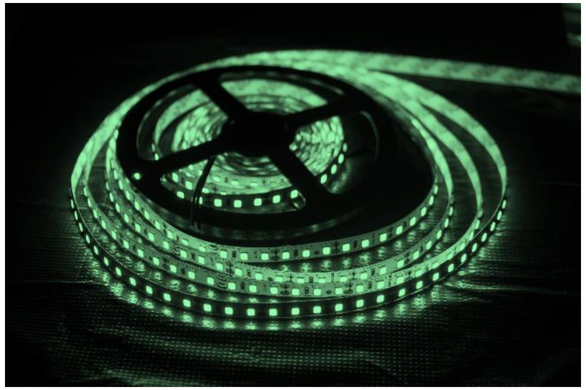
Combined: Cool Output

Tunable White:
any CCT at any intensity

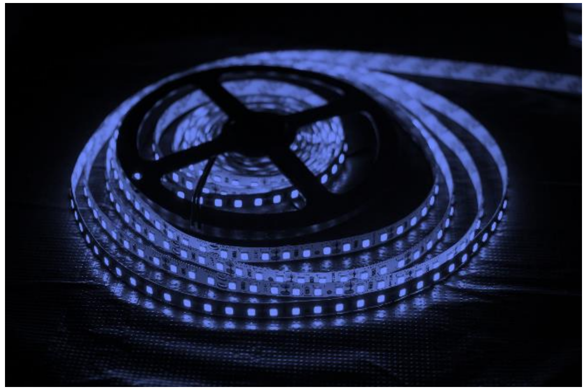
Red



Green

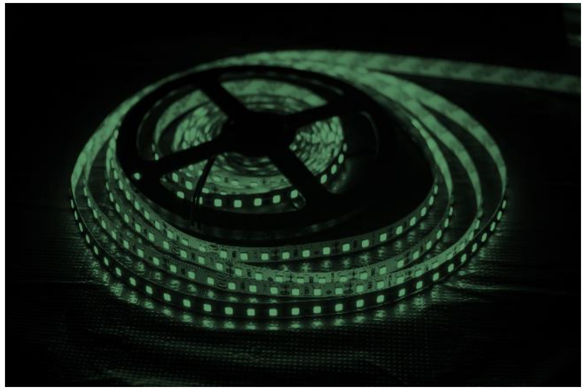


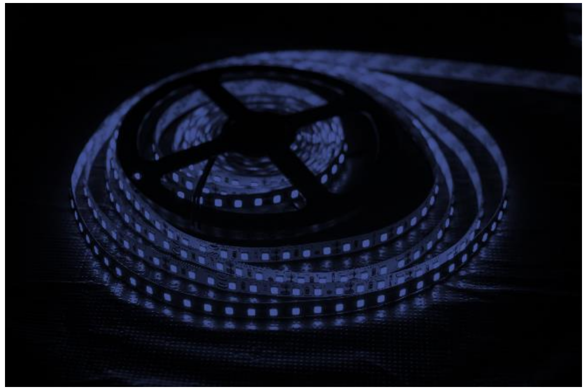
Blue



Tunable White:
any CCT at any intensity

Red | Green | Blue



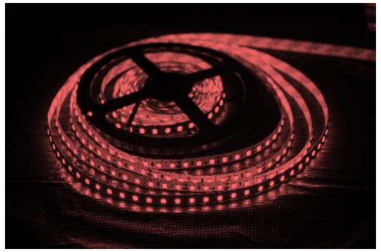
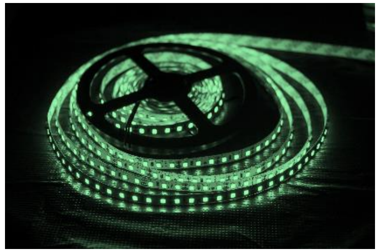
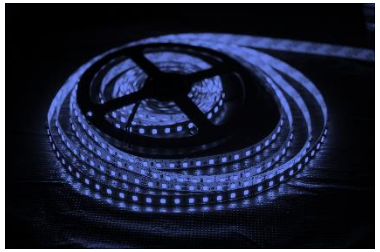


Combined: Warm Output

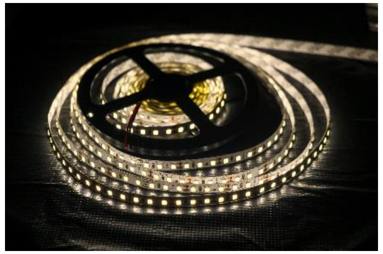
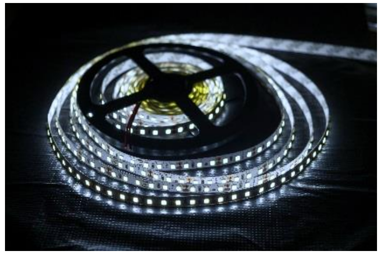
Tunable White:

any CCT at any intensity

Red Green Blue

Warm Cool

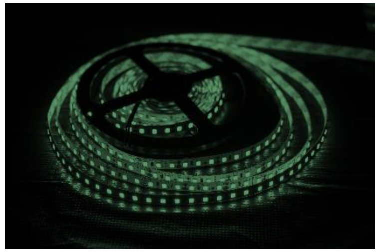



Tunable White:

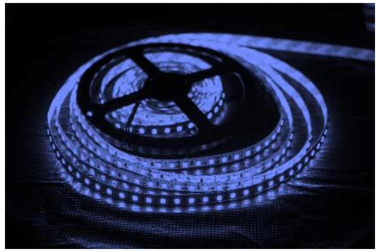
any CCT at any intensity

Red

Green



Blue

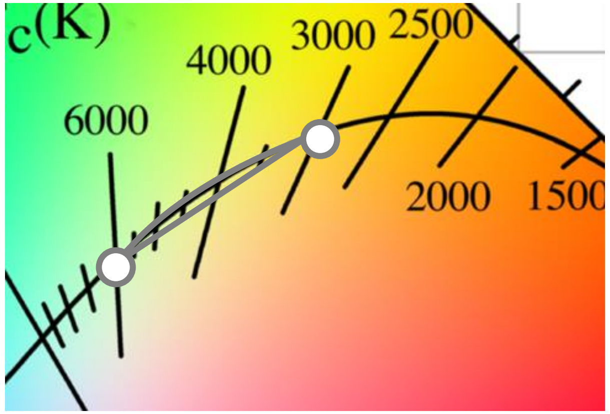


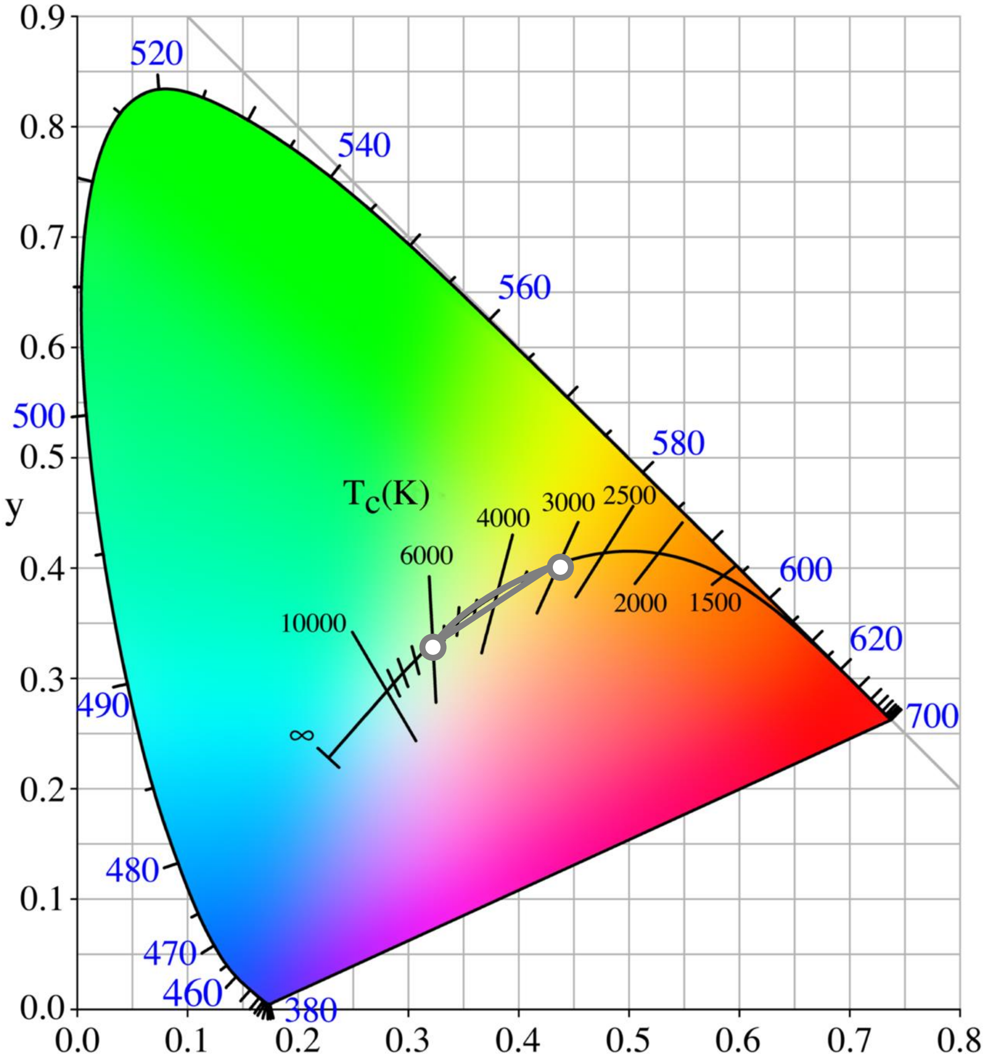
Warm

Cool

Combined: Cool Output

Tunable white typically uses 2 sets of white LED’s



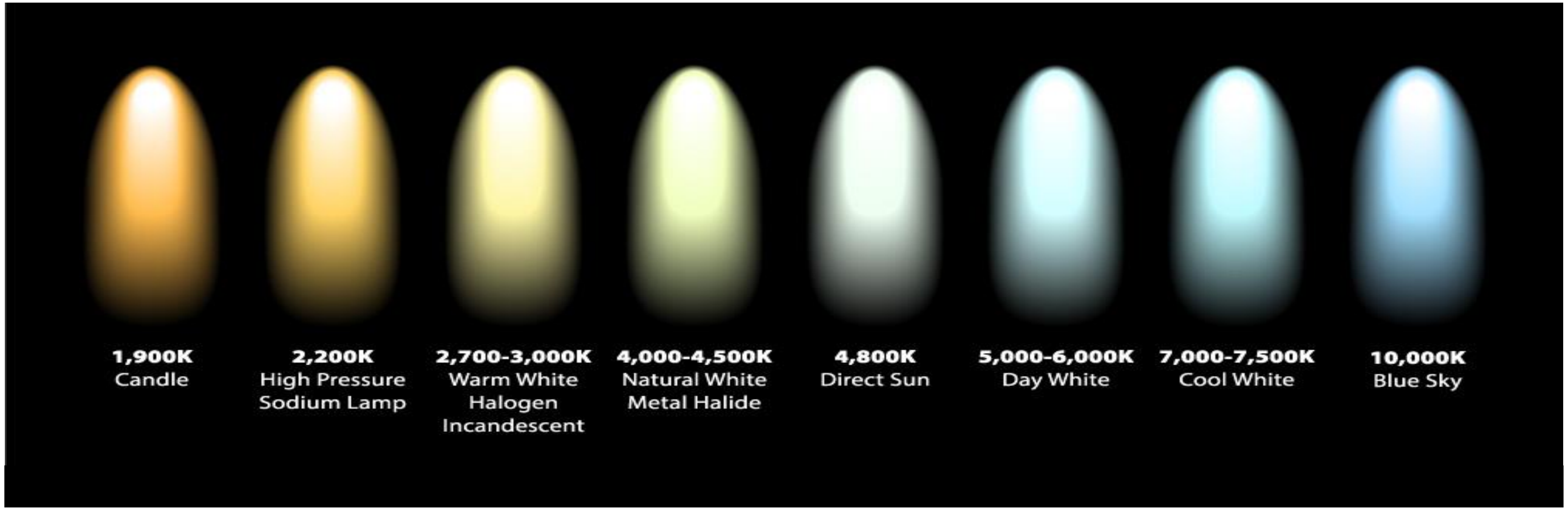


Oops! We dropped below the black body curve, so the constructed light may have a pink tinge!

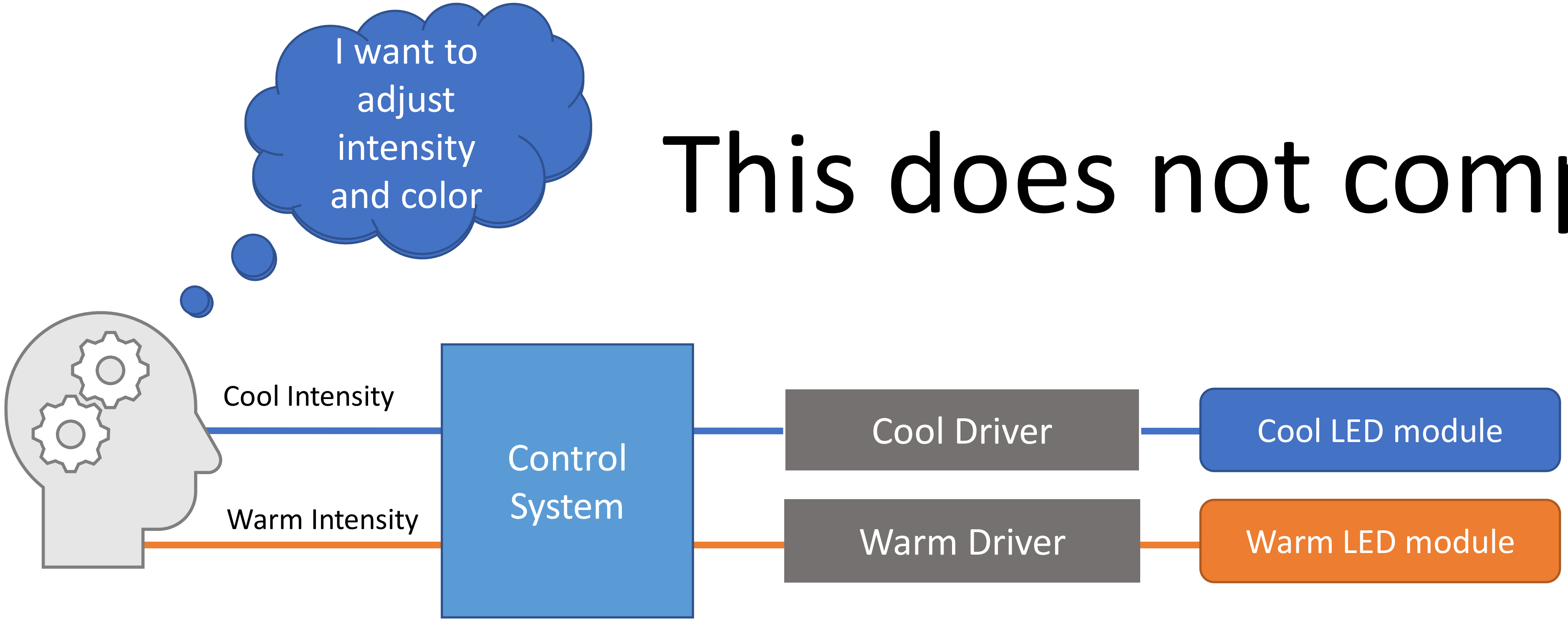
Tunable White Control

There are 2 common ways of achieving tunable white:

1 Warm/Cool intensity control
2 Intensity and CCT control



Warm/Cool

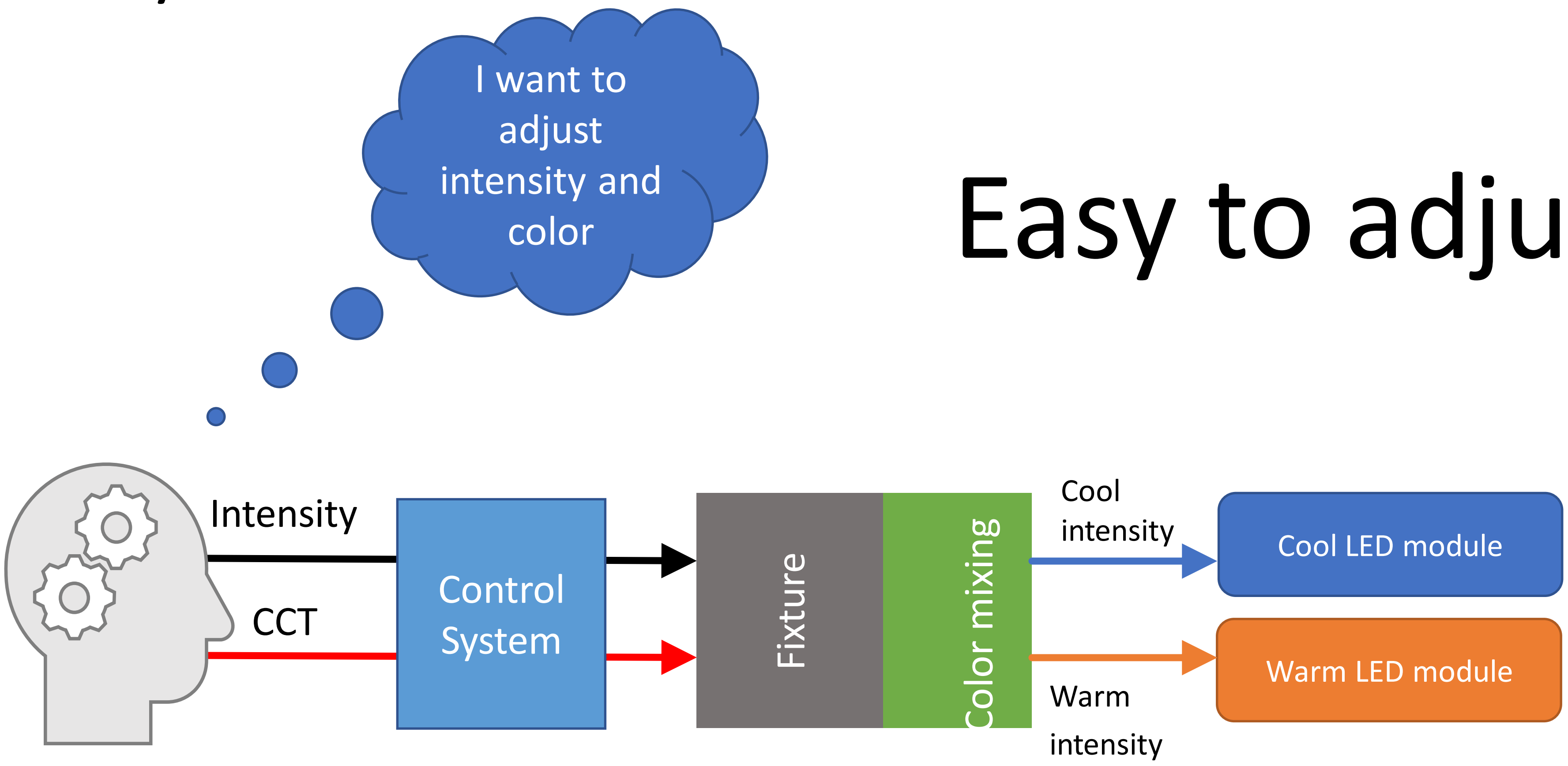


This does not compute!

Remember the cooler CCT LEDs tend to be more efficient, so they do not dim the same!!!!

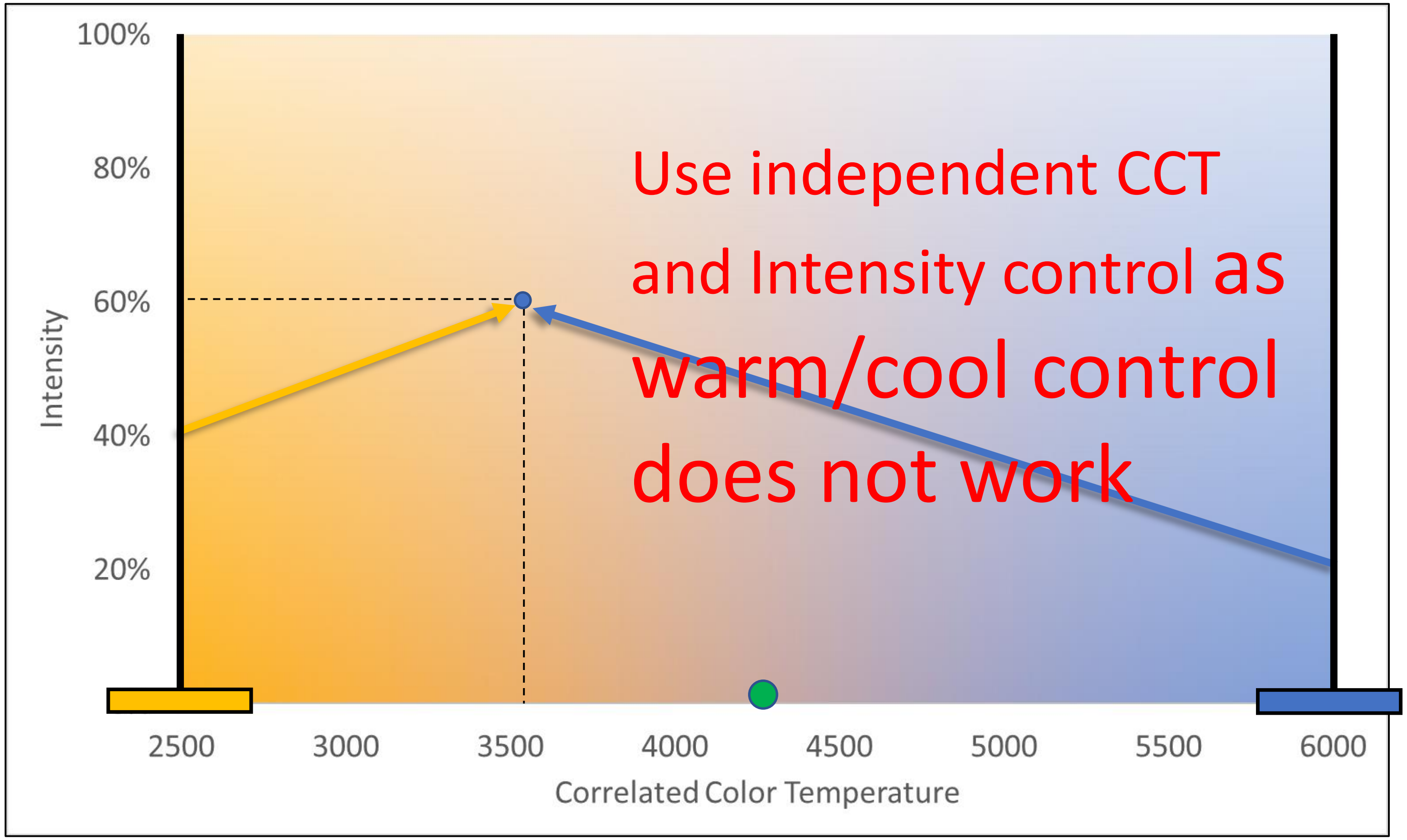
Intensity/CCT

Easy to adjust



Let’s play the Tunable White Game!

http://lutron-tunablewhite.azurewebsites.net/prototype.html



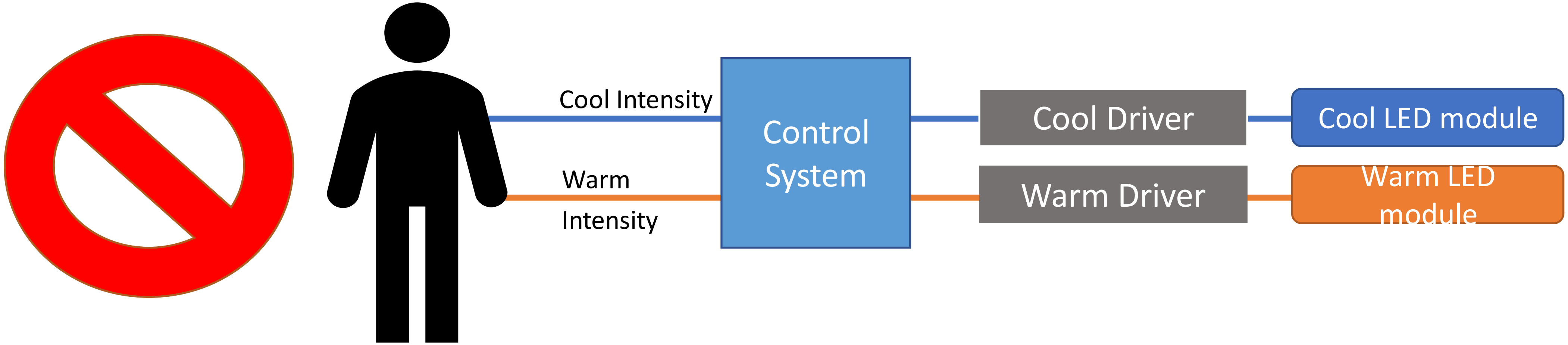
Intensity/CCT Control:
a positive user experience

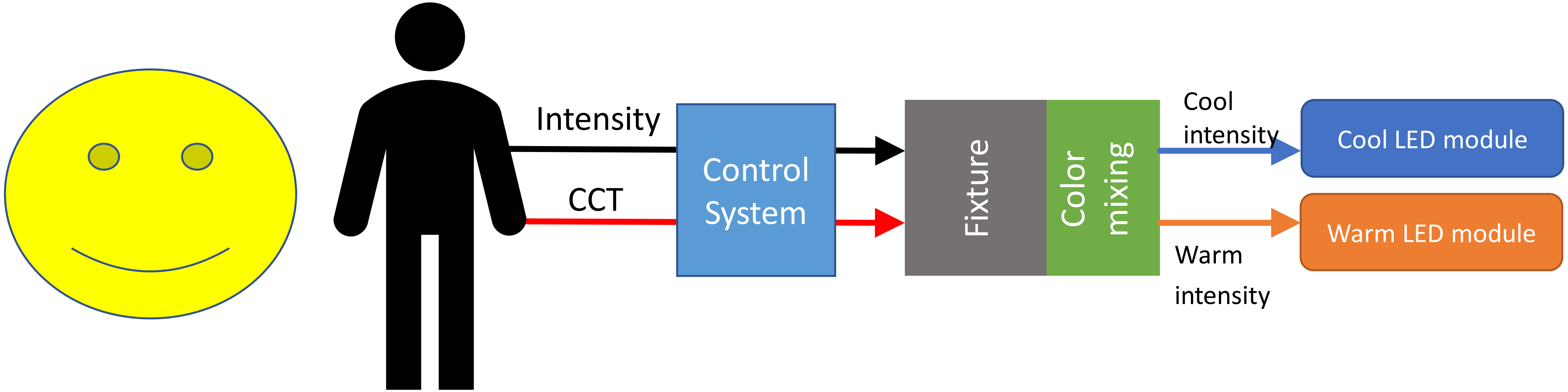
Independent Control of Intensity/CCT

Daylight dimming is possible

Timeclock

Design decisions can greatly affect the system capabilities and cost to install and commission.

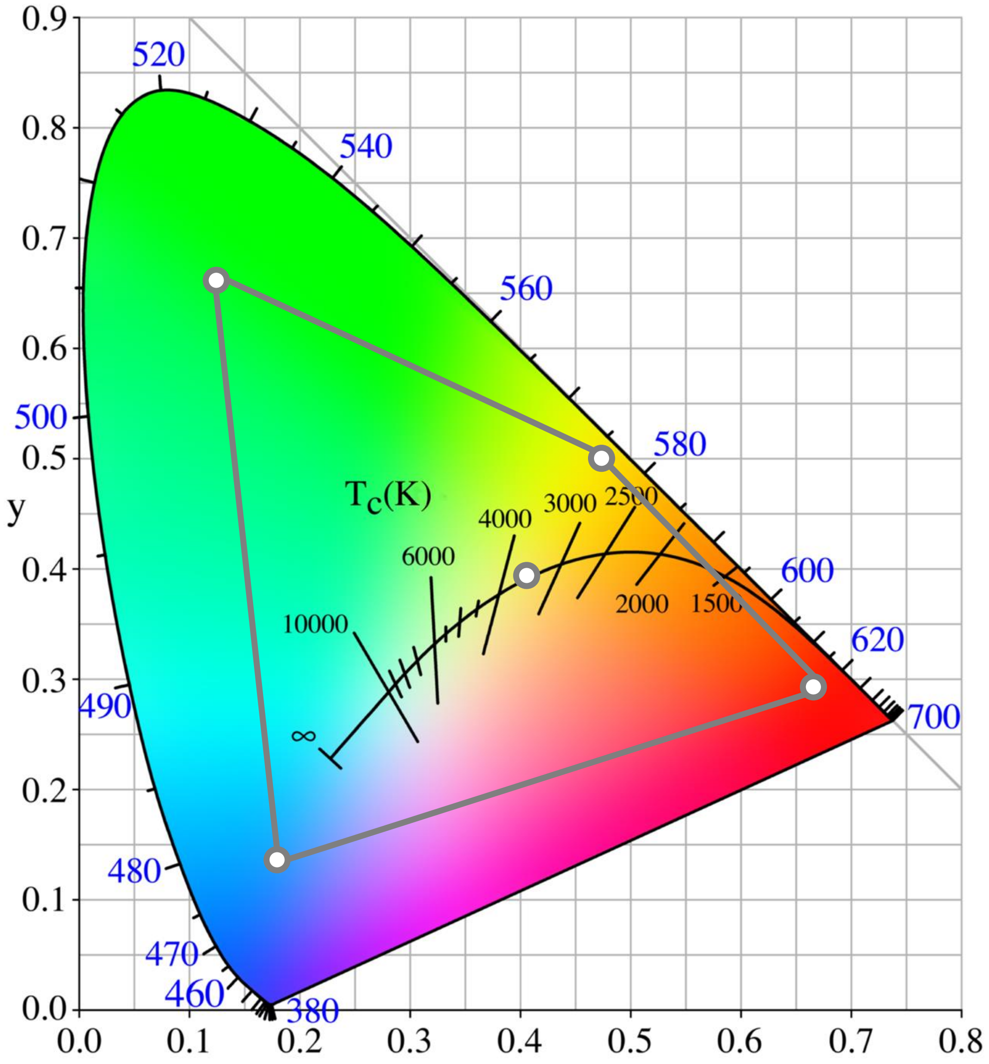




Full Spectrum Control

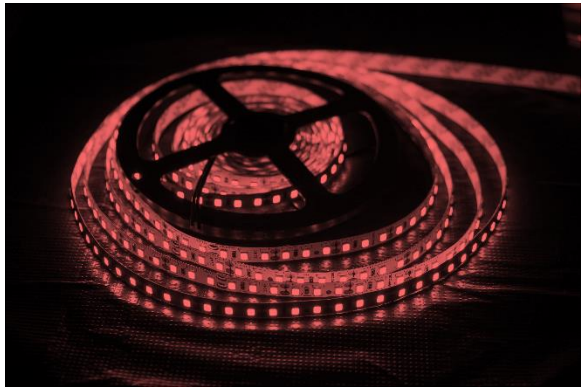
Full spectrum control

- Requires multiple LEDs
- Fixture can operate anywhere in the Gamut
- ultimate **flexibility but** with ultimate **complexity unless system has curated content**
- **Common control methods**
  - **0-10V**
  - **EcoSystem/DALI**
  - **Wireless**
  - **DMX-512**

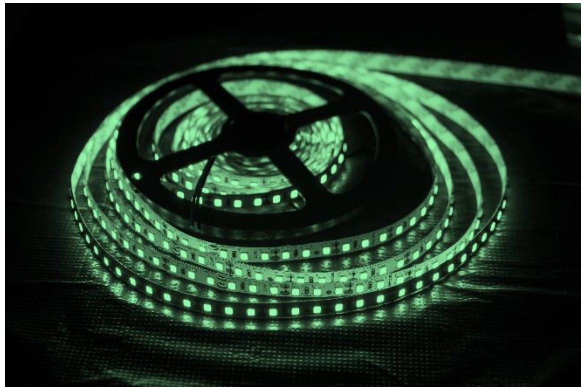


Full Spectrum Control:
RGB Fixtures

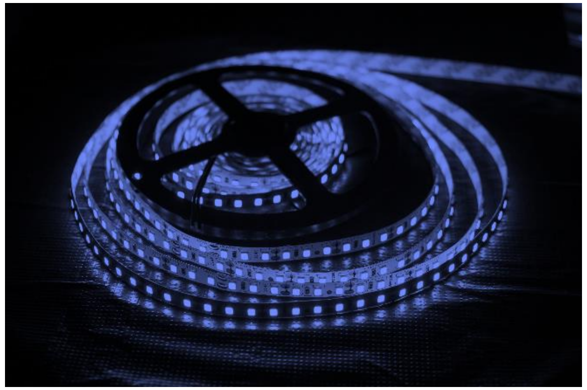
Red



Green



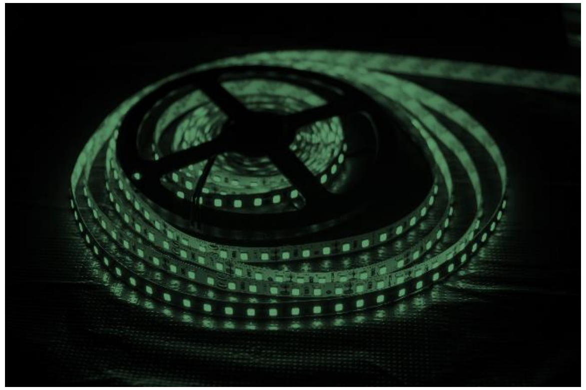
Blue



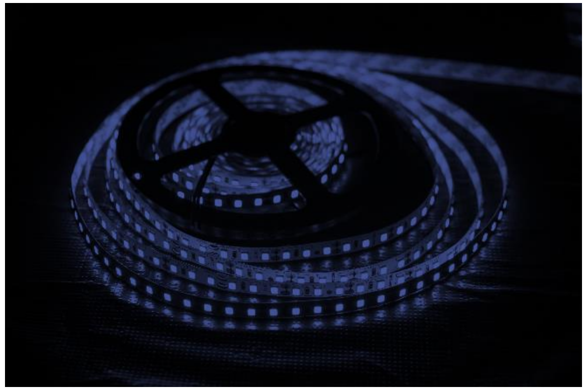
Full Spectrum Control:
RGB Fixtures

Red

Green



Blue

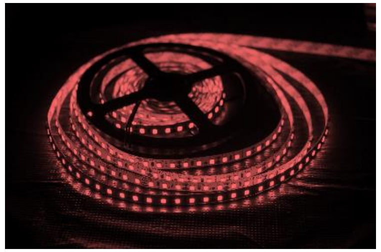


Combined: Orange/very warm white; what intensity?

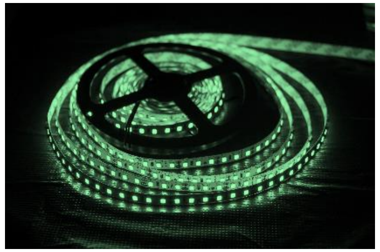
Full Spectrum Control:

RGBW Fixtures

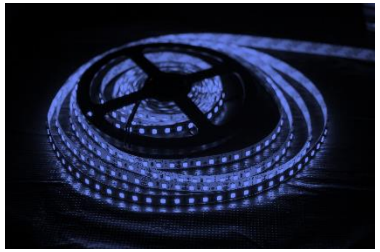
Red



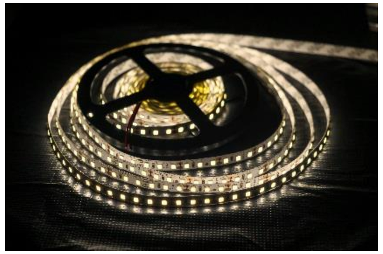
Green



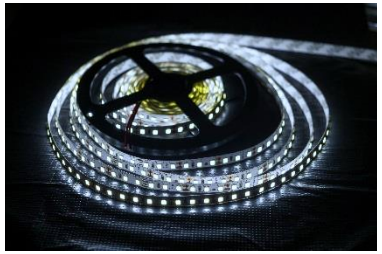
Blue



Warm



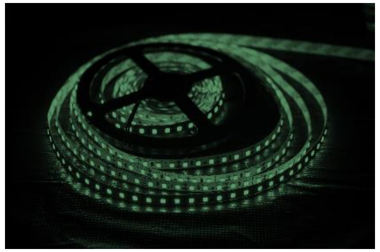
Cool



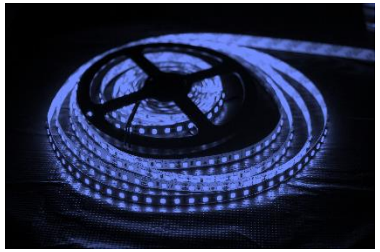
Full Spectrum Control:
RGBW Fixtures

Red

Green



Blue



Warm

Cool

Combined: Very Cool Output; what intensity?

Steps for a Successful System

Use the following questions to match expectations with performance:

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

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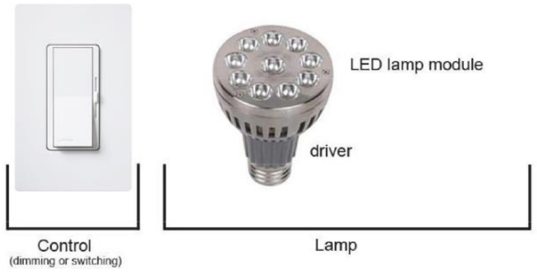
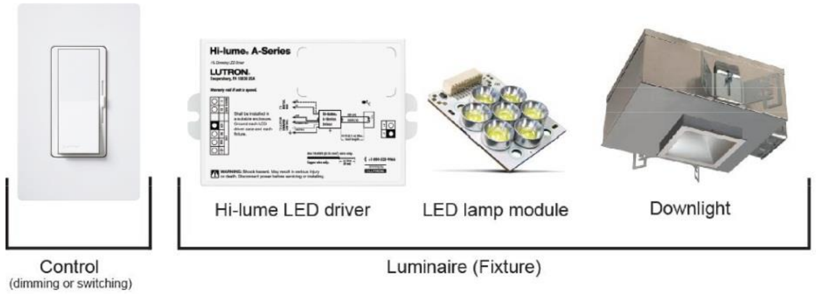
LEDs@lutron.com

www.lutron.com/LED

What type of LED product am I using?

- LED Bulbs (LEDi's)
  - Designed to replace standard incandescent or screw-in CFL bulbs
  - Edison base sockets
  - Integral drivers which determine dimming performance (if dimmable)





- LED Fixtures
  - Variable in purpose (cove lights, down lights, 2x2, etc.)
  - Usually have an external driver
  - Some fixtures have multiple driver options to support different control technologies and applications

    (dim vs. non-dim, 0-10V vs. DALI)

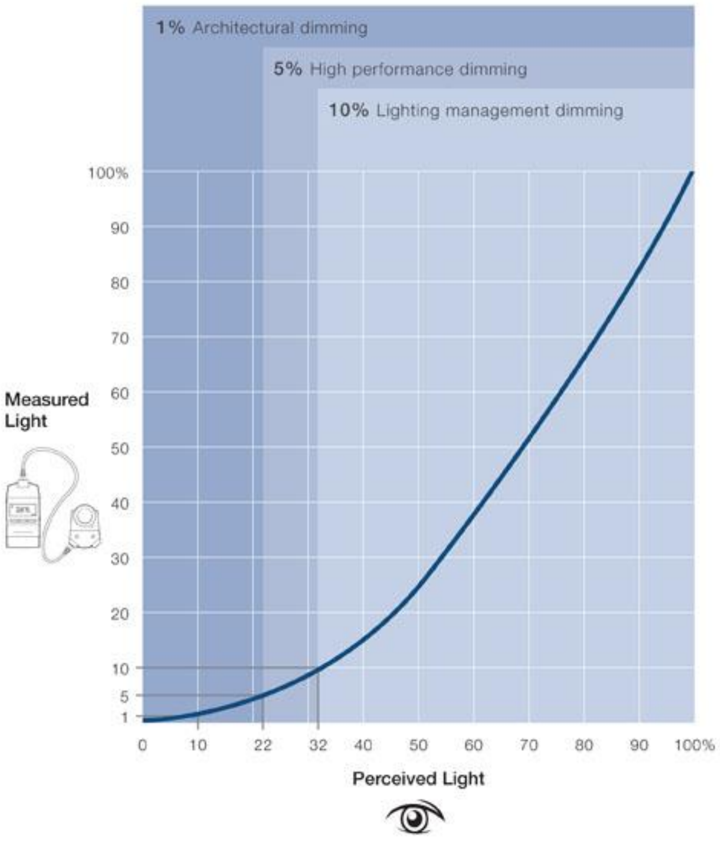
What is the dimming range of the fixture?

- Dimming range varies greatly
  - Some may dim only to 50%, others to 1%
  - Screw-in tend to have lower performance
    - Incandescent lamps dim to below 1%
      - (orange filament glow)

- Select a dimming range suitable for your application
  - 20% dimming: suitable for a lobby, atrium, office, etc.
  - 1% dimming: necessary for a restaurant, media room, etc.

- Measured light vs. perceived light
  - Use caution when comparing and selecting products
  - Not all manufacturers use the same standard

What is the dimming range of the fixture?



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

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

- Difference between measured and 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**

What is the dimming performance of the product?

- May not be given in the spec or literature
- What to watch out for:
  - <u>Flicker</u>
    - The unexpected modulation of light level
  - <u>Pop-on</u>
    - The level the light is at when it is turned off is the level it should return to when it is turned back on
  - <u>Drop-out</u>
    - The light should only turn off when the switch is turned off.
    -
  - <u>Dead-travel</u>
    - Adjusting the control without a corresponding change in light level
  - <u>Audible Noise</u>

ORDERING INFORMATION Lead times will vary depending on options selected. Consult with your sales representative. **Example:** 2TL4 46L RW A19 D50 LP835 N100

2TL4	46L				D50			
Series	**Lumens**	**Door**	**Lens**	**Voltage**	**Wattage**	**Color temperature**	**Control**	**Options**
2TL4 Recessed LED	46L 4600 lumens [1]	FW Flush aluminum, white RW Regressed aluminum, white	A12 #12 pattern acrylic A19 #19 pattern acrylic, 0.156" thick MWS Matte white .040 thick MPL Micro Prism SWL Satin white	(blank) MVOLT (120-277V) 347 347V [2]	D50 50W [3,4]	LP830 82 CRI, 3000 K [5] LP835 82 CRI, 3500 K LP840 82 CRI, 4000 K LP850 82 CRI, 5000 K [5]	NX Dimming, no nLight BLD Bi-level dimming N80 nLight with 80% (L80) lumen management N80EMG nLight with 80% (L80) lumen management for use with generator supply EM power N100 nLight without lumen management N100EMG nLight without lumen management for use with generator supply EM power	EL14L 1400-lumen emergency battery

Screw in LED troubleshooting

- Often adding a resistive load can temporarily solve problems
  - Dimmer underloaded
  - LED interacting with other circuits
- Is the LED actually dimmable
- What type of phase control is required to dim the LED
- Try different manufacturers LED
- Use SSL-7 dimmer and LED

SSL-7

NEMA SSL-7 Scope

- Designed as an *interface* standard for compatibility
  - Sets criteria for LLEs (LED Light Engine, a.k.a. lamps) and dimmers
  - Provides a specified *minimum* level of operation when SSL-7 compliant products are used together
- "Compatibility" means:
  - Reliability of the dimmer and LLE are not affected by combining them
  - Dimming behavior meets or exceeds specified functionality

What is good dimming performance?

Dimmer + Driver + LED Light Engine = Performance

- How stable is the output
- Control method
- Dimming curve
- Ratings
- Compatibility

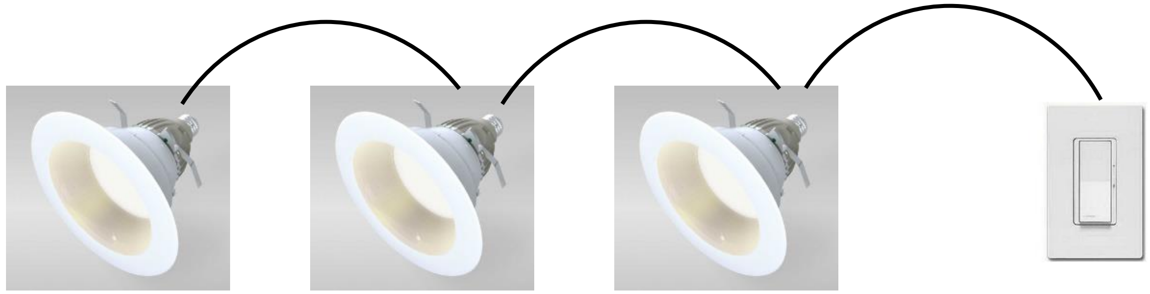
- Inrush current
- Low End
- Control method
- Lifetime
- Dimming curve
- Radiated or conducted emissions

- Color shift
- Color options (ex. RGB vs RGBA)
- Color Consistency
- Color Temp

Think about it - What exactly does “dimmable” mean?

How many LEDs can be connected to a phase dimmer?

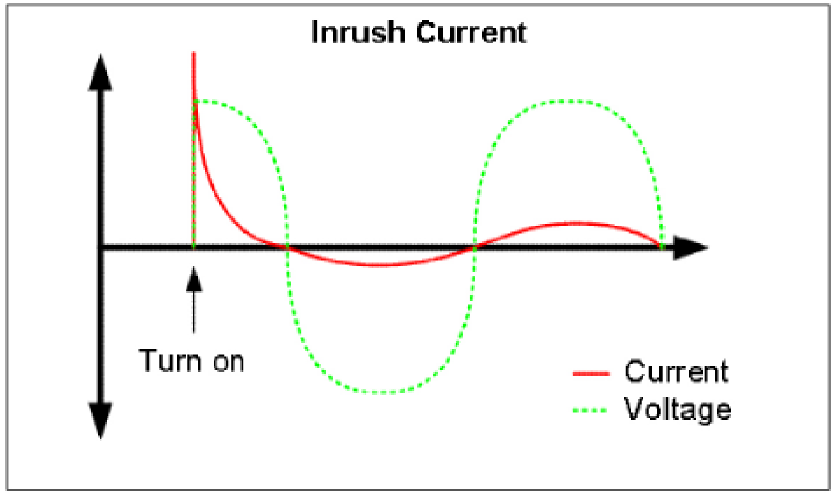
- Minimum number of lamps
  - Dimmer / driver performance may suffer with too little load
  - Most incandescent dimmers require a 25 – 40 watt minimum

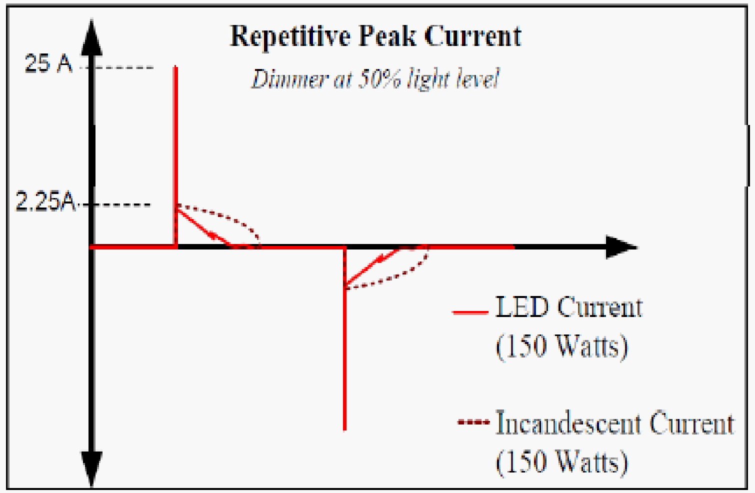


- Maximum number of lamps
  - The simple calculation is wrong
    - 600 watt dimmer / 10 watt LED = 60 LEDs per dimmer: WRONG!
  - Start-up inrush and repetitive current increases draw

How many LEDs can be connected to a dimmer?

- Start-up inrush and repetitive current
  - Lutron testing has shown a 10 watt LED is similar to a 100w incandescent (in terms of max current , NOT power used)
  - This means, a 600 watt dimmer can safely support roughly six LED lamps (typically between 7 and 20 watts)
  - *Note: Only applies to phase control products*





On what type of control does the LED operate?

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

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

Analog, tends to be imprecise

Digital, Precise

Summary

Use the following questions to match expectations with performance:

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