LED Driver Fundamentals

Outline

- Fundamentals of Electricity
- LEDs as electrical components
- Driver Controls
- Driver Selection
- Standards, Ratings, and Reliability
- Mythbusters

- **Fundamentals of Electricity**

Coulomb

The coulomb (symbol: Q) is the unit for electrical charge

A coulomb is a collection of electrons at a moment in time; by definition 6.241   10^18 electrons

Not to be confused with Avogadro's number which denotes a fixed number of electrons 6.022 10^23

Q = I * S

Ampere

The ampere (symbol: I) is the unit for electrical current

Current is a measure of how many electrons are moving within a circuit.

I = Q / S

I = E / R

Volt

The volt (symbol: V, or E) is the unit for absolute electrical potential and electromotive force.

Volts are what is needed to push electrons around a circuit

Volts are what hurts when you get a shock

$$E = I * R$$

Ohm

The ohm (symbol: R) is the unit for electrical resistance

An ohm is the unit that quantifies what blocks the flow of electricity

$$R = E / I$$

Watt

The watt (symbol: w) is the unit for power (electrical and non electrical)

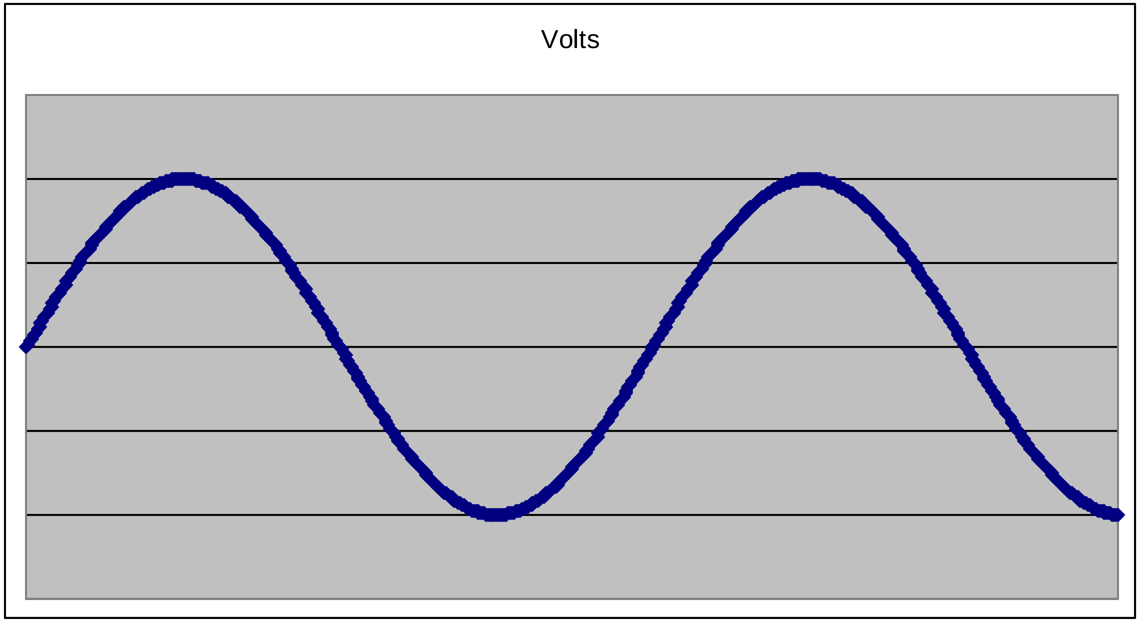
A watt of heat is created when a volt and an amp are consumed

$P = I * E$

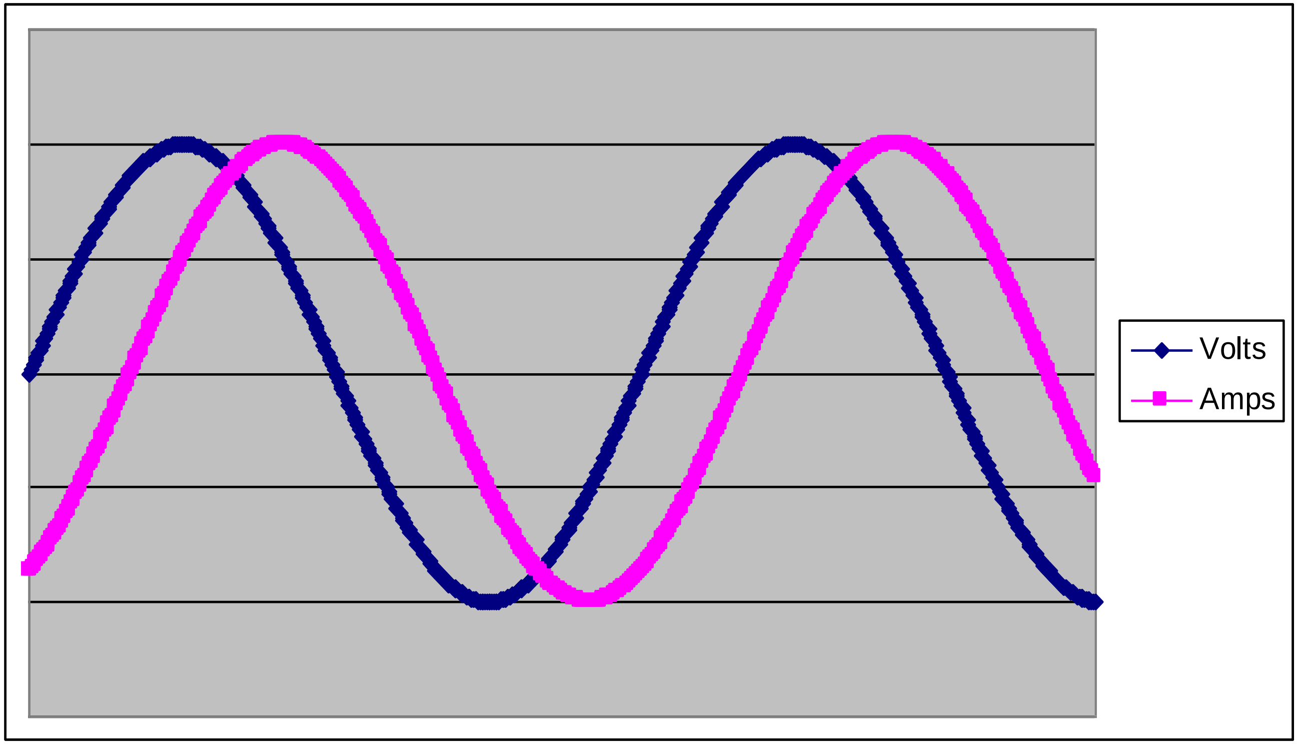
$P = I^2 * R$

$P = E^2 / R$

AC waveform – V & I in sync
Power FACTOR = 1.00
1 Volt * Amp = 1 Watt

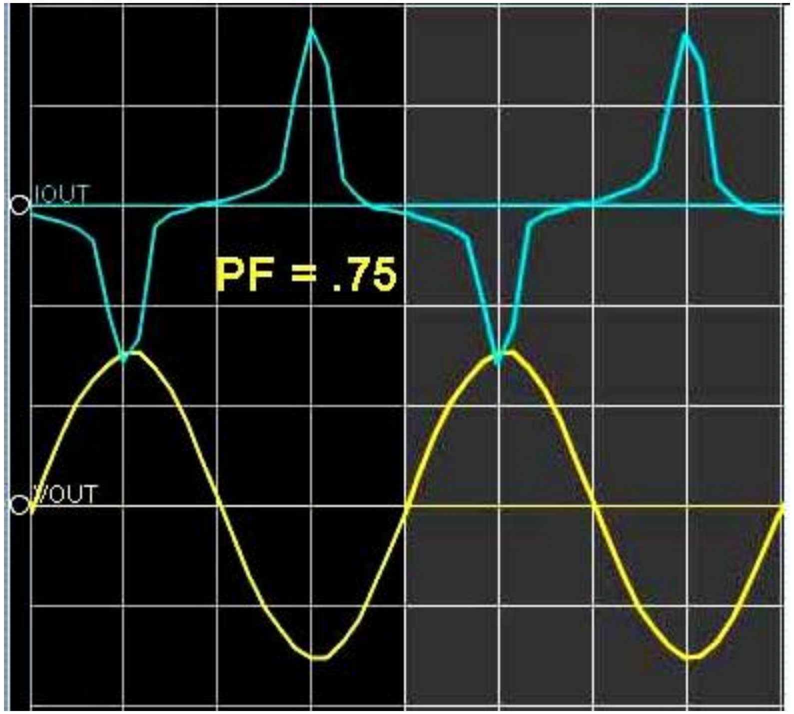


AC waveform – V & I not in sync
Power FACTOR = 0.75
Volt * Amp NOT Watt



Total Harmonic Distortion

- creates audible noise
- creates radio interference
- V and I can still be in sync



Power efficiency

Power efficiency is defined as the output power (Vdc * Idc) divided by the input REAL power (watts ac) and NOT apparent power (VA)

Can not be reliably measured with a volt meter alone, but needs a scope or a specialized power meter

Crest factor

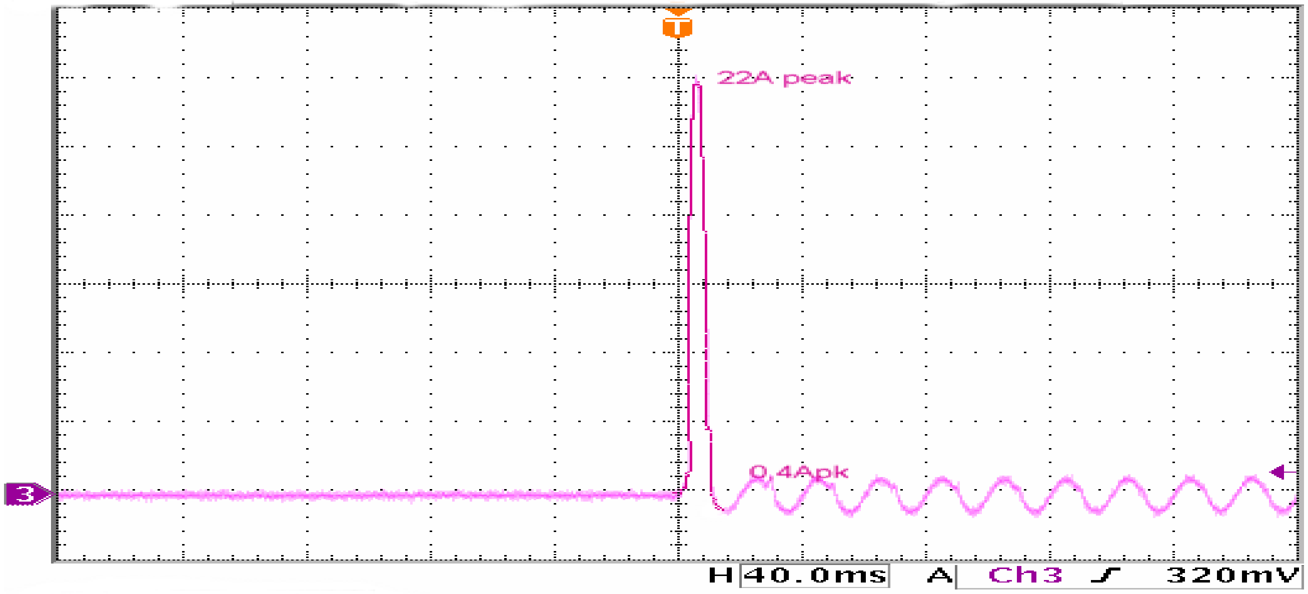
The crest factor is roughly defined as the peak amplitude of a waveform divided by its root-mean-square (RMS) value.

Crest factor is sometimes incorrectly referred to as ripple current.

An excessive crest factor will lead to lumen losses

Inrush Current

Inrush is the peak AC input current used when a power supply is first turned on and can be many times greater than the average current consumed



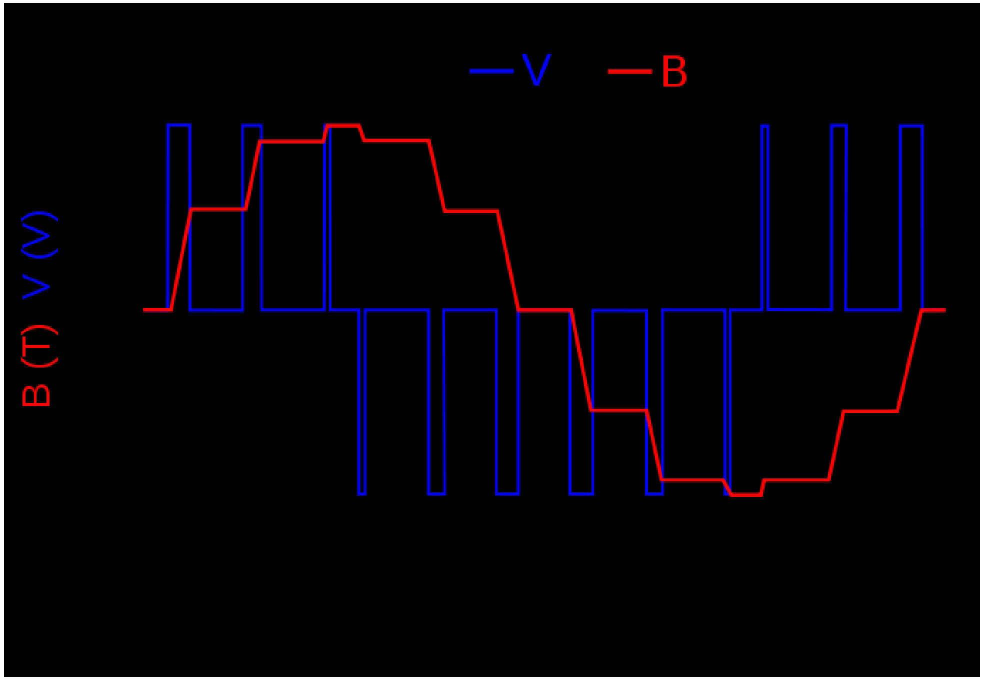
Hot Swap / Outrush Current

Outrush current is defined as the peak current energizing the LED load and normally applied when the driver is still connected to an AC input i.e. hot swap

Outrush contributes to LED stress and premature aging if the current used exceeds the manufacturers maximum rating

Pulse Width Modulation (PWM)

Pulse width modulation is the creation of an analog or AC waveform from a DC source. Very high crest factor.



Outline: Sections

- **LEDs as electrical components**

LEDs as Electrical Components

(L)ight (E)mitting (D)iode

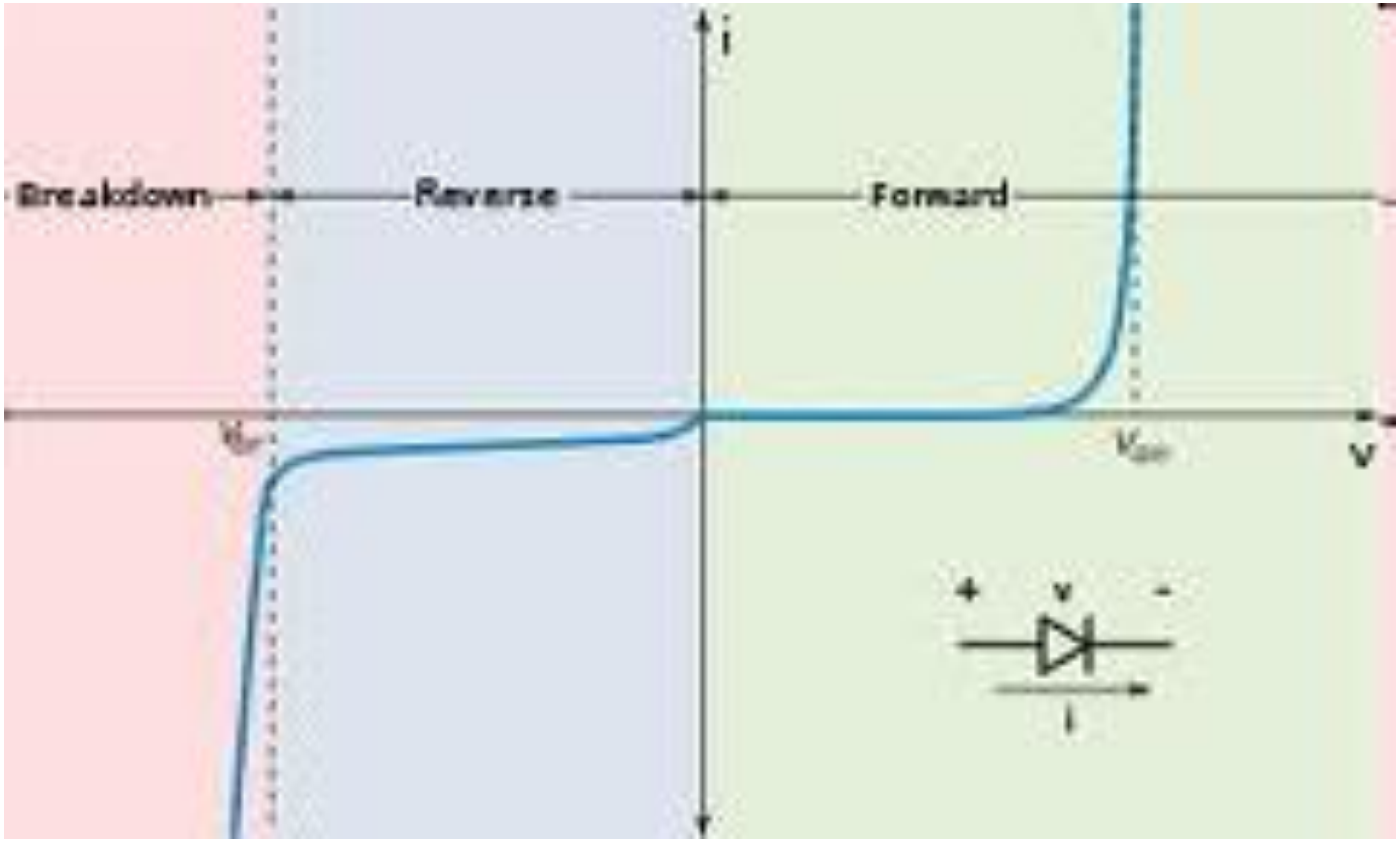
As its name implies, the LED functions as a diode

Diodes are formed from semiconductor which is loosely defined as a material that allows current flow easier in one direction than another

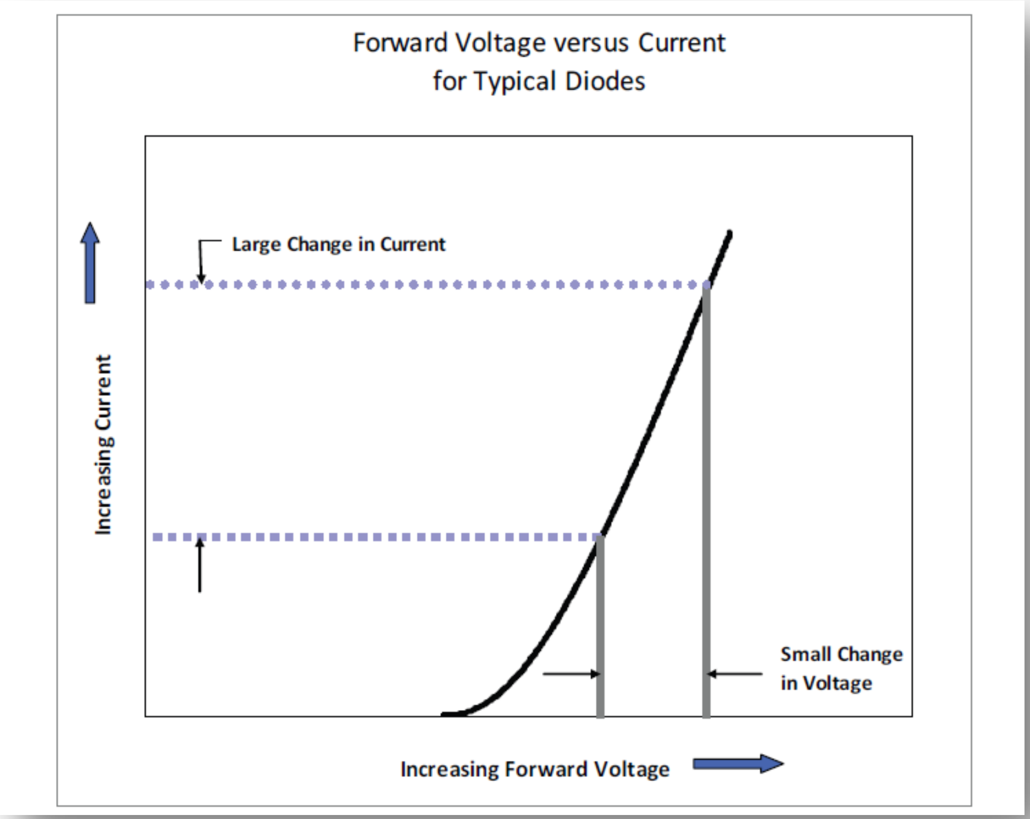
Once the voltage bandgap is exceed, current flows easier in a diode. The bandgap is allows electrons to flow easier when it is “forward biased”

LEDs as Electrical Components

Diode V * I curve

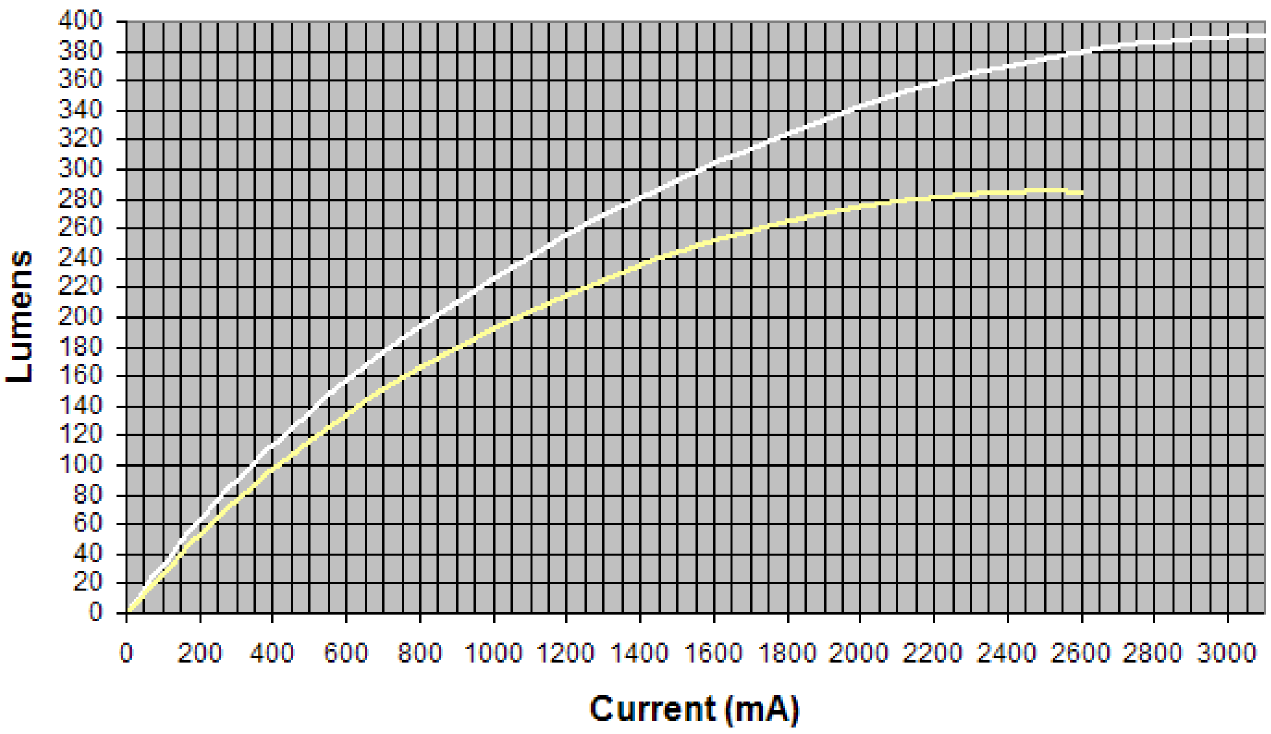


Impact of a Small Voltage Change



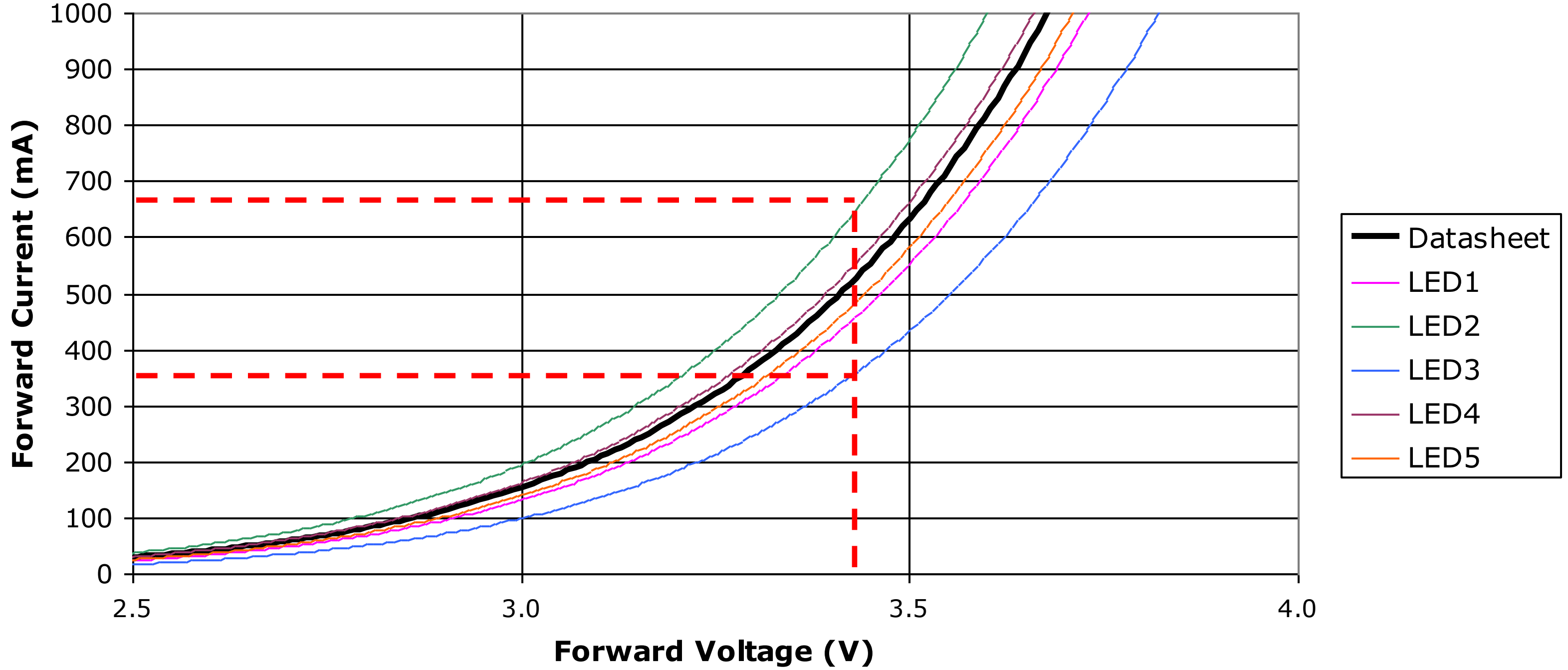
LEDs as Electrical Components

Lumens vs Current



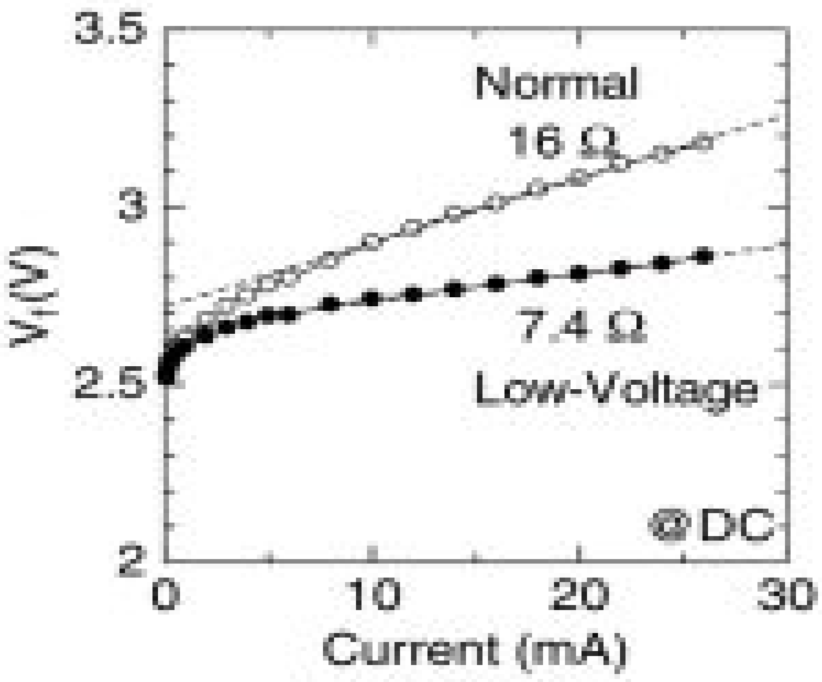
LEDs as Electrical Components

Voltage Variations in High Brightness LEDs



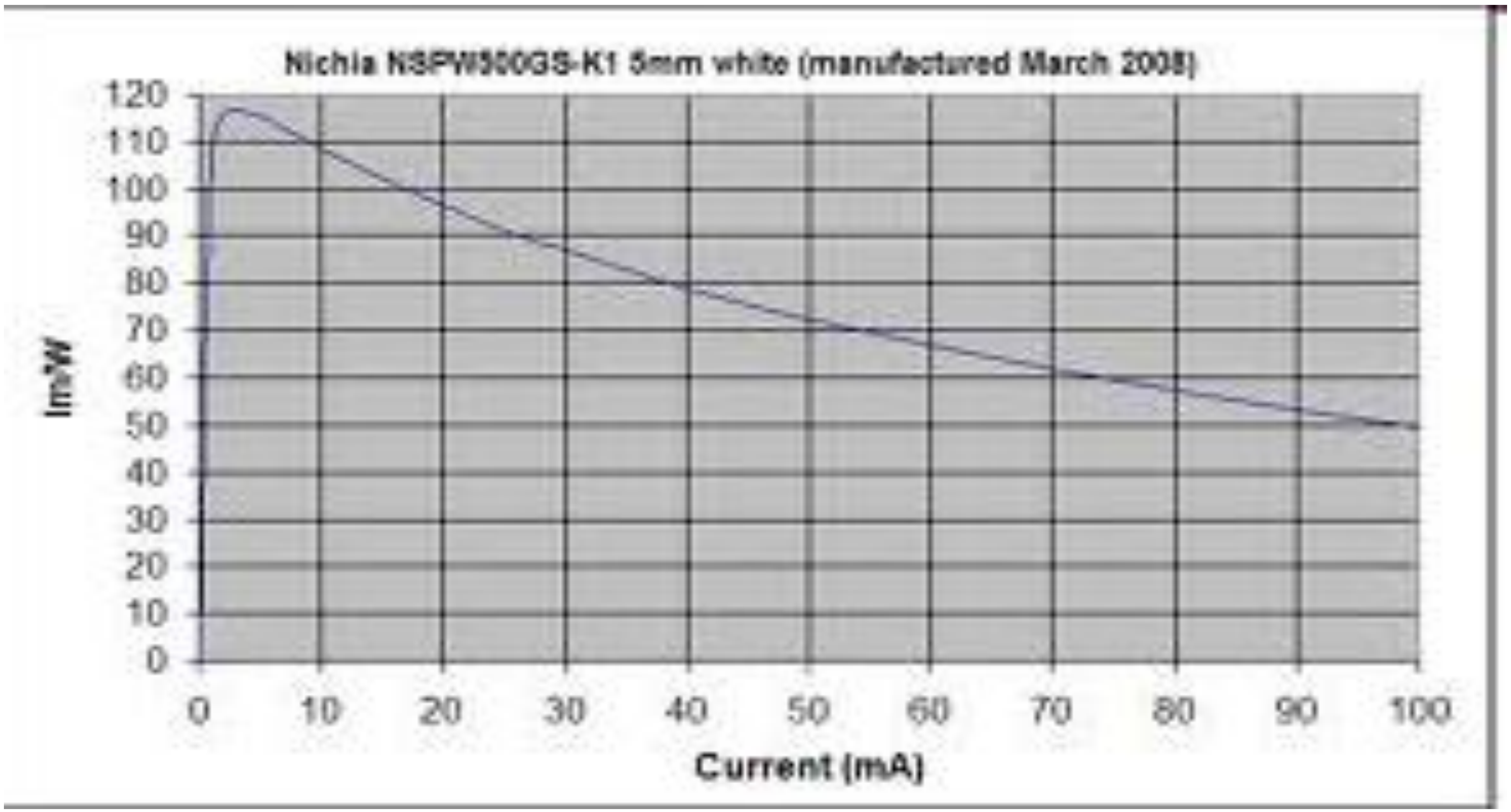
- @ Vf = 3.4V; current can range from 350mA to 675mA
- Result is relative LED brightness from 100% to 165%!
- Constant voltage operation is NOT recommended

LED single die performance (VI)

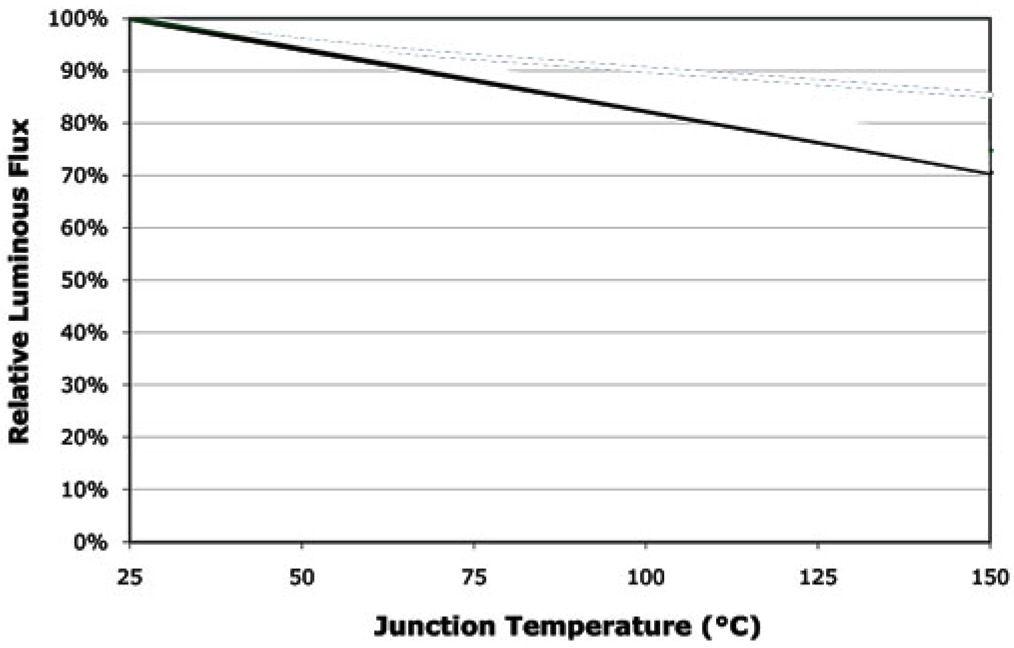


LEDs as Electrical Components

Single Die Current Density



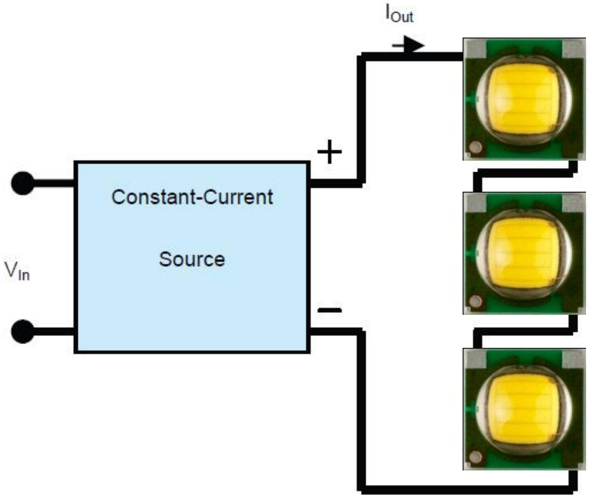
Lumens vs Temperature



Driver Controls and Selection

- A Simple Fixture:

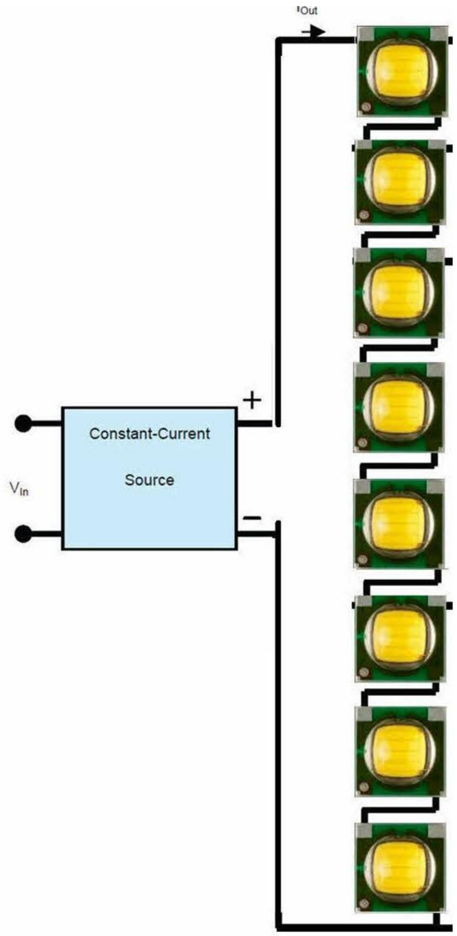
- Most lumenaires require multiple LEDs
- LEDs typically connected in series
- All LEDs will see the same current
- Voltage requirement increases as LEDs are added to the string



Driver Controls and Selection

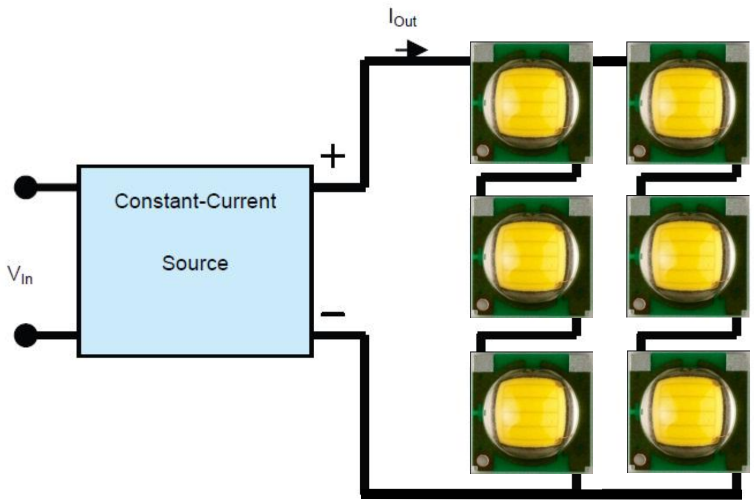
Driver Selection Example

- Assume 8 Cree X-PG LEDs
  - 350mA / LED
  - 3.3VDC / LED
  - 1.2W / LED
- Voltage required:
  - 8 x 3.3V = 26.4V
- Power required:
  - 8 x 1.2W = 9.6W
- LED12W-36-C0350



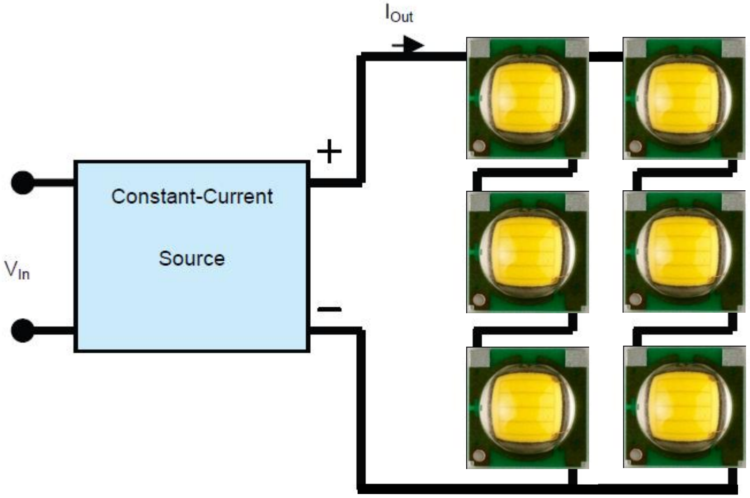
LEDs in Parallel

- Advantages
  - If one LED opens, other string stays lit
  - Reduces required voltage
- Disadvantages
  - Current is shared and can lead to "current hogging"



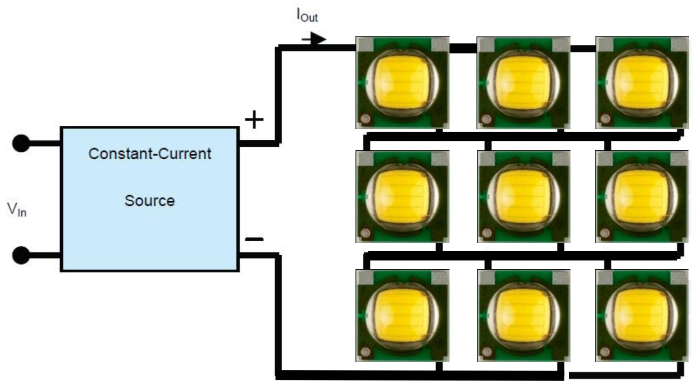
LEDs in Parallel

- Failure modes
  - Short
    - Balance of LEDs remain lit
    - String with short draws more current
  - Open
    - Half of fixture goes dark
- Remaining string sees more current



Driver Controls and Selection

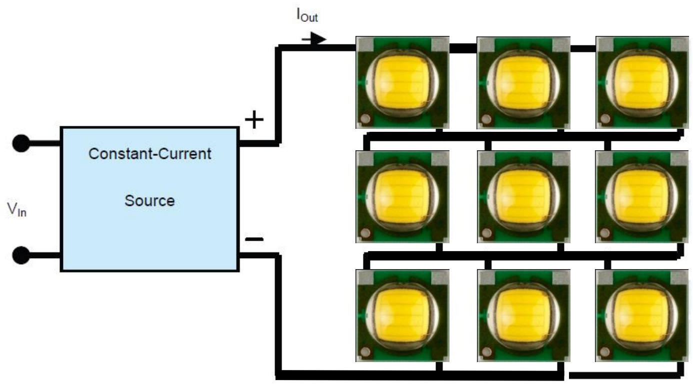
- LEDs in Matrix
  - Advantages
    - Improves fault tolerance
    - If one LED opens, other LEDs stay lit
    - Reduces required voltage
  - Disadvantages
    - Current is shared and can lead to “current hogging”



Driver Controls and Selection

LEDs in Matrix

- Failure modes
  - Short
    - One row of LEDs goes dark
  - Open
    - Other LEDs stay lit
    - Remaining LEDs in that row see more current



Outline

- **Driver controls**

Driver Controls and Selection

Driver Controls and Selection

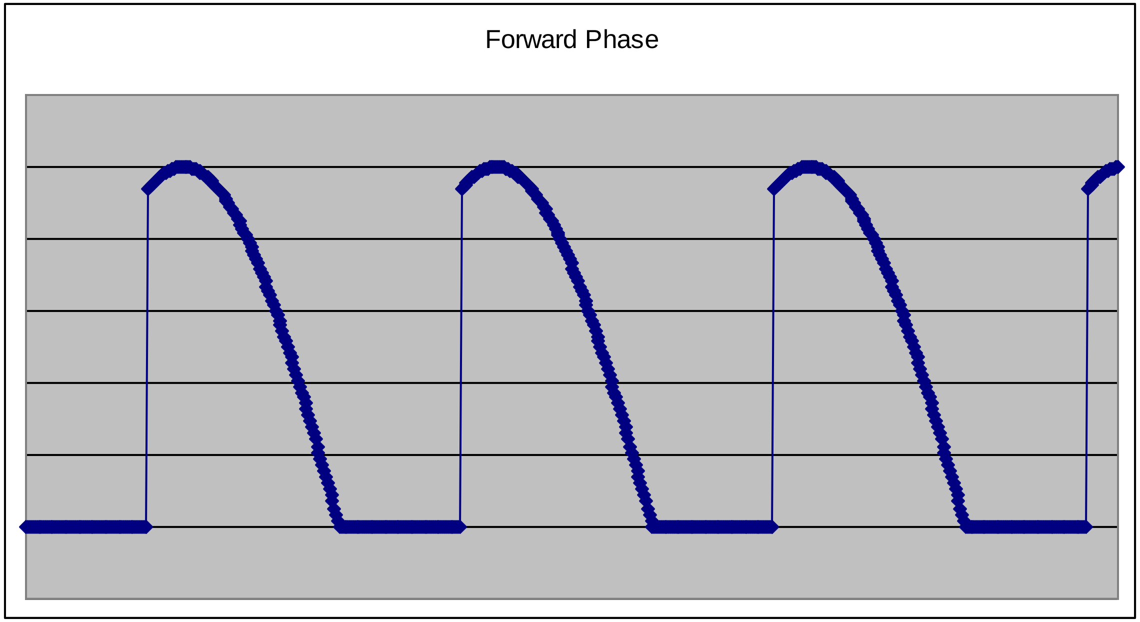
- LED Fixtures / Lighting Engines:
  - Comprised of one to many LEDs
  - Infinite combinations of series and/or parallel LEDs – unlike HID or FL
  - Variety of possible LED drive currents, ranging from 200 mA to 4000 mA
  - Must know the specification of the Light Engine to pick the correct driver – Most important will be the minimum and maximum DC voltage and the output current
  - Most are designed to be Constant-current driven

Driver Selection

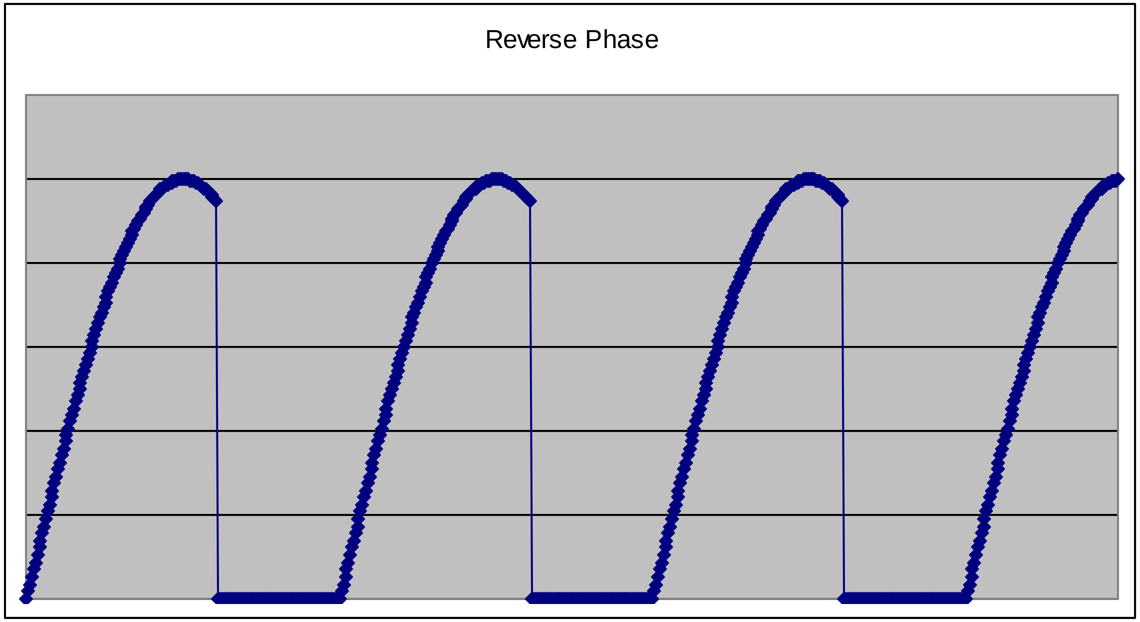
Dimming Drivers

- Two control methods for dimming in lighting
  - Line-voltage dimming
    - aka Phase cut or Triac dimming
    - Commonly used for incandescent lamps
    - uncommon method for LED dimming
  - 0-10V (2 wire)
    - Common protocol used with fluorescent dimming
    - Widely available controls

Forward Phase Triac Dimming



Reverse Phase IGBT Dimming



Driver Controls and Selection

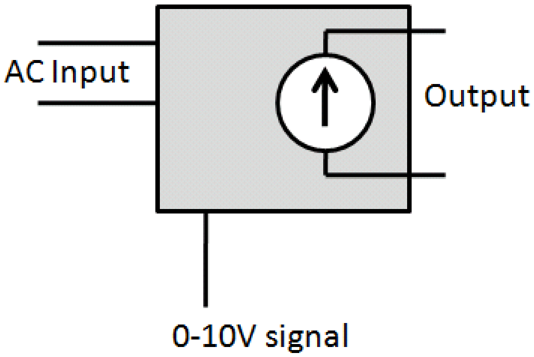
Triac dimming mainly associated with indoor Products, but some applications have been reported outdoor

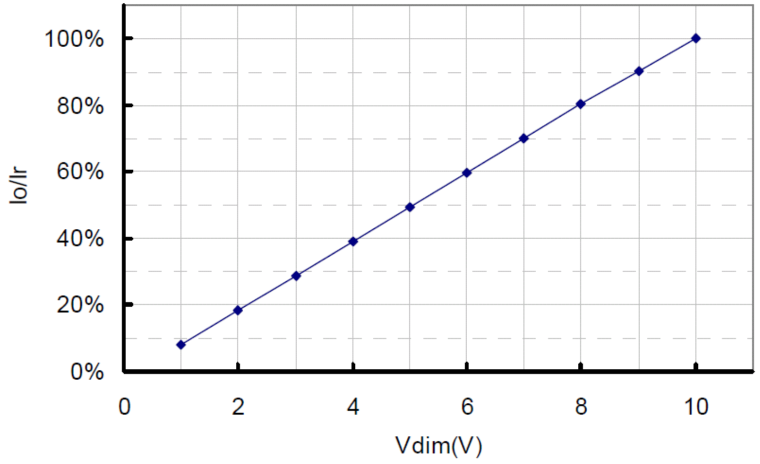
Triac compatible drivers are less efficient than low voltage dimming drivers 85% vs 89%-94%

Driver Controls and Selection

Dimming (0-10V)

- An controlled voltage is applied to connection on the lighting driver.
- 10V provides full power
- Output current scales linearly with the applied voltage.





Outline

➢ **Driver Selection**

Driver Selection

How to select the proper driver?

- Line voltage
- Load
- CC / CV
- Dimming
- UL Class 2 under 60v (42v Canada)
- Power Factor
- Size
- Life rating
- Warranty
- Multi-channel / Customs
- IP Rating
- Customer support
- Exceed 60v = Class 1
- LVLE =< 60v in Canada (<150/V)
- UL8750

Driver Selection

Line Voltage:

- US line voltages 120/208/240/277/480
  - 120 & 277 are common
- Canadian voltages = 120/240/277/347
- Typical European line voltages = 220/230/240
- Japanese line voltages = 100/200
- Tolerances are   10%
- Typical competitive drivers are 100-240 (nominal)
  - Some manufacturers de-rate 240V drivers to operate at 277V
  - These will run hot at 277V
  - This WILL lead to shortened lifetimes
- Make sure drivers you specify for 277V nominal operation are rated to operate up to 305V without any de-rating
- Most all drivers are 100-277V Nominal
- Use step-down transformer for 480V or 347V applications
- DC drivers are available for battery backed / solar applications

Driver Selection

- **Define the load**
  - Constant-Current or Constant-Voltage
  - Maximum load possible
  - Allowable LED maximum voltage

Driver Controls and Selection

Dimming Drivers

- Choose the operational mode

- Reduce output DC current
  - This is the simplest method
  - Used by CC drivers

- Pulse width modulation (PWM)
  - This keeps the peak current the same but switches the output on & off quickly, thereby reducing average current
  - Used by CV drivers

Driver Controls and Selection

Dimming Drivers

- 0-10V dimming with 3-wire flexibility
  - Offers additional option of potentiometer dimming
- CC Drivers control output current
- CV Drivers PWM output voltage

Driver Controls and Selection

Power Factor

- Three basic flavors…
  - High Power Factor (HPF) = >90%
  - Power Factor Corrected (PFC)= 80%-90%
  - Normal Power Factor (NPF) = <80%, (typically in the 50-60% range)

- Lower PF device will draw more current

Driver Controls and Selection

Why Care About Power Factor?

- **Affects number of fixtures that can be loaded on a branch circuit (e.g. 20A/120V circuit)**

	HPF	NPF
Driver input watts	120	120
Power Factor	0.91	0.50
Input Current	1.1	2.0
Max # of Fixtures	14	8

Driver Controls and Selection

Driver Size

- Driver has to fit within the fixture
- Why are some drivers larger than others?
  - Bigger components run cooler
  - Small components run hotter
  - Larger drivers run cooler
  - Smaller drivers run hotter
- More heat = shorter life
- Less heat = longer life

UL Class 2

- **Is a safety classification based on maximum possible output voltage**
  - US std =60VDC max
  - Canada std = 42.4VDC max

Catalog watts	Constant Current or Voltage	0-10V Dimming?	Output Current (mA) (range if CV)	Output Voltage (VDC) (range if CC)	Catalog Number	Nominal Input Voltage (VAC)	Max Output Power (Watts)	Expected Life (hours)	Efficiency	Ambient Operating Temp Range (°C) min	Ambient Operating Temp Range (°C) max	Power Factor (min)	Typically in Stock
12	C	N	250	24-48	LED12W-48-C0250	100-277	12	87,000	85%	-30	+60	0.94	
			350	18-36	LED12W-36-C0350		12.6		84%				•
			500	12-24	LED12W-24-C0500		12		84%				•
			700	8-16	LED12W-16-C0700		11.2		83%				
			800	8-16	LED12W-16-C0800		12.8		83%				•
			1000	6-12	LED12W-12-C1000		12		83%				•
	V	N	500-1000	12	LED12W-12	100-277	12		83%	-30	+60	0.94	•
			400-800	16	LED12W-16		12.8		83%				
			250-500	24	LED12W-24		12		84%				•
			175-350	36	LED12W-36		12.6		84%				
			125-250	48	LED12W-48		12		85%				

Class 2: US/Canada US Only

Standards, Ratings, and MTBF

UL Low Voltage Limited Energy

- Is a safety classification based on maximum possible output voltage combined with limiting current
  - US std =60VDC max
  - Canada std = 60VDC max
  - Maximum current is 150/V
  - For example, at 60v max, the circuit must be limited to =< 2.5 amps
- It is a method of meeting Canadian requirements and maximizing driver single channel power
- The input and output must be galvanically isolated

Standards, Ratings, and MTBF

Life Ratings and MTBF

- Many driver manufacturers claim an MTBF of 100,000 hours to match the LED life claims

- An MTBF of 100,000 hours means:
  - A population of 10 units will experience a failure every 10,000 operating hours.
  - A population of 100 units will experience a failure every 1000 hours.
  - A population of 1000 units will experience a failure every 100 hours

- Many Driver manufacturers have a history of producing computer power supplies

- MTBF is a common metric in the IT world

- This is not a reliable indicator of expected lifetime

Standards, Ratings, and MTBF

How is longer life achieved?

- **A key element determining life is the choice of and stress on electrolytic capacitors**
  - Use premium capacitor parts
    - i.e., costlier than standard capacitors
  - Use driver circuits designed to operate capacitors at 50-80% of capacity
    - i.e., larger than what's needed to get by
- The result:
  - Driver will run cooler
  - Driver will last longer
  - Many driver manufacturers will offer a 5 year warranty

Standards, Ratings, and MTBF

Protection

- **Output Over-Voltage:**
  - **Protects driver in the event a light engine is connected that requires more voltage than driver can deliver,**
    - e.g. driver range is 18-36 volts but OEM connects 48V light engine.
    - Driver will cycle on and off.
- **Output Over-Current:**
  - **Protects driver in the event a light engine is connected that requires more current than driver can deliver**
    - e.g. driver is set to produce 350 mA but load attempts to draw 700 mA.
    - Driver will lockout
- **Output Short Circuit:**
  - Protects driver if somebody shorts output leads

Standards, Ratings, and MTBF

Additional Protection

- Over Temperature Protection:
  - Shuts down driver when a specific temperature is exceeded
    - usually 105 C-115 C.
    - Helps to show when driver is misapplied in application.

- Lighting Protection: Self explanatory
  - Most drivers above 100W have this as standard
  - Surge suppressors are a viable option

Standards, Ratings, and MTBF

IP Ratings

- Ingress protection is a measure of resistance to solids and liquids.

- IPxy levels describe:
  - X protection against solids
  - Y protection against liquids

- Higher IP Numbers offer Greater Protection
  - IP 65 is considered damp location
  - IP 67 is considered weatherproof

Standards, Ratings, and MTBF

IP Ratings

X: Protection against solids

0	No special protection
1	Protected against solid objects up to 50 mm, e.g. accidental touch by persons hands.
2	Protected against solid objects up to 12 mm, e.g. persons fingers.
3	Protected against solid objects over 2.5 mm (tools and wires).
4	Protected against solid objects over 1 mm (tools, wires, and small wires).
5	Protected against dust limited ingress (no harmful effects).
6	Totally protected against dust.

Y: Protection against liquids

0	No protection.
1	Protection against vertically falling drops of water e.g. condensation.
2	Protection against direct sprays of water up to 15^{o} from the vertical.
3	Protected against direct sprays of water up to 60^{o} from the vertical.
4	Protection against water sprayed from all directions - limited ingress permitted.
5	Protected against low pressure jets of water from all directions - limited ingress (no harmful effects).
6	Protected against temporary flooding of water, e.g. for use on ship decks - limited ingress permitted.
7	Protected against the effect of immersion to 1 meter.
8	Protects against long periods of immersion under pressure.

Example: IP67

Total protected against dust and protected against immersion between 15cm and 1m.

Outline

- ➢Mythbusters

Mythbuster Demonstration

Parallel circuit operation and current hogging