

## The Fundamentals of LED Lighting: What Consumers need to know

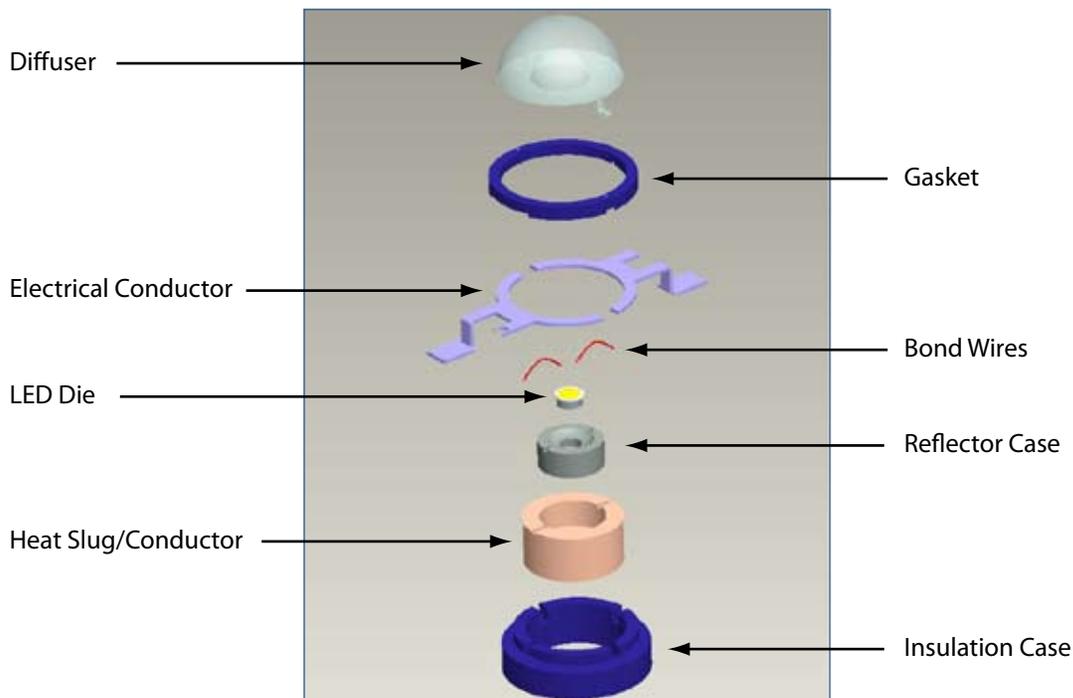
In recent years LED technology has experienced fast growth exponentially. The lighting industry will benefit greatly from such a development. However, such speedy progress in LED technology also produces many questions in the field, which include, but are not limited to, LED color uniformity and dimming.

This paper will address some of the basic issues about LEDs in basic lighting terms.

### ► 1. The Basics of LED

LED stands for Light Emitting Diode. It is a semiconductor diode that radiates light when DC current passes through the LED die. When operated under proper thermal management, LED technology offers several advantages over conventional lighting:

- Compact LED size (on average 15mm in diameter)
- Energy efficient (on average 50 lumens per watt for white light)
- Long lifespan (50,000 hours with less than 30% light depreciation)



(Figure1: LED Components)

An LED can achieve different colors of light (e.g. Amber, Blue, Cyan, Green and Red) by applying different materials onto the die. Similar to a fluorescent lamp, the most common way to achieve white light for an LED is coating a blue LED with yellow phosphor. Different color temperatures (e.g. warm white, cool white) can be achieved by adjusting the composition of phosphor.

LEDs come in two basic categories:

- Indication:  
Low wattage LEDs (lower than 0.2W) used in signs, signals, and indicator lights on electronic equipment. Typically the light output of a single indication LED is below 10 lumens.
- Illumination:  
As the technology advanced in the 1990's, white LEDs and high power LEDs (higher than 1W) made LED illumination feasible. The light output of a single illumination LED ranges from 40 lumens to 150 lumens, depending on the CCT (Correlated Color Temperature) and forward current power.

CCT of LED	Driving Current		Average Lumens <sup>1</sup>	Efficacy <sup>2</sup>
3000K	350 mA	1.2W	84	70 lm/W
4500K	350 mA	1.2W	96	80 lm/W
6000K	350 mA	1.2W	108	90 lm/W
3000K	700 mA	2.5W	100	40 lm/W
4500K	700 mA	2.5W	110	44 lm/W
6000K	700 mA	2.5W	130	52 lm/W

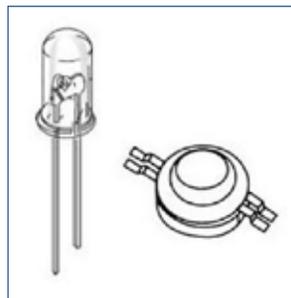


Figure 2: Illustrated is a low power LED typically used for indication (left); and a high power LED typically used for illumination (right). (Not to Scale).

## ► 2. LED Color Temperature & White LED Color Uniformity Issue

CCT is used by the lighting industry to define a warm or cool light source:

*“The correlated color temperature (CCT) describes the relative color appearance of a white light source, indicating whether it appears more yellow/gold or more blue, in terms of the range of available shades of white. CCT is given in Kelvin (SI unit of absolute temperature) and refers to the appearance of a theoretical black body heated to high temperatures. As the black body gets hotter, it turns red, orange, yellow, white, and finally blue. The CCT of a light source is the temperature (in K) at which the heated black body matches the color of the light source in question.”<sup>3</sup>*

Lamps with a CCT rating below 3200K usually are considered warm sources, whereas those with a CCT above 4000K usually are considered cool in appearance. Currently CCT is based on incandescent lamps, but LEDs and CFLs are not incandescent sources. Therefore, LED lamps of equal CCT do not necessarily appear equal.

<sup>1</sup> Different LED manufactures offer LEDs with different light output due to the rapidly changing technology

<sup>2</sup> The efficacy here is just the bare lamp. Usually a fixture efficacy is only 60% of that of the bare lamp

<sup>3</sup> Referred from: Department of Energy web site (<http://www1.eere.energy.gov/buildings/ssl/cct.html>)

## White LED Color Uniformity

As mentioned previously, CCT metrics developed for incandescent sources are not suitable for Phosphor converted white LEDs. There will be variations in color of white even though they are in the same CCT value, depending on:

- Phosphor composition from batch to batch
- Operating junction temperature
- Forward current
- Fixture or cover materials (if used)
- Manufacturing quality

There were field complaints about perceivable individual color variances among the white LEDs. LED manufacturers came up with a so called color “binning” system for different batches of LEDs. As Figure 3 shows, it is actually a range of the “x” and “y” chromaticity coordinate values to define the spectrum of LED.

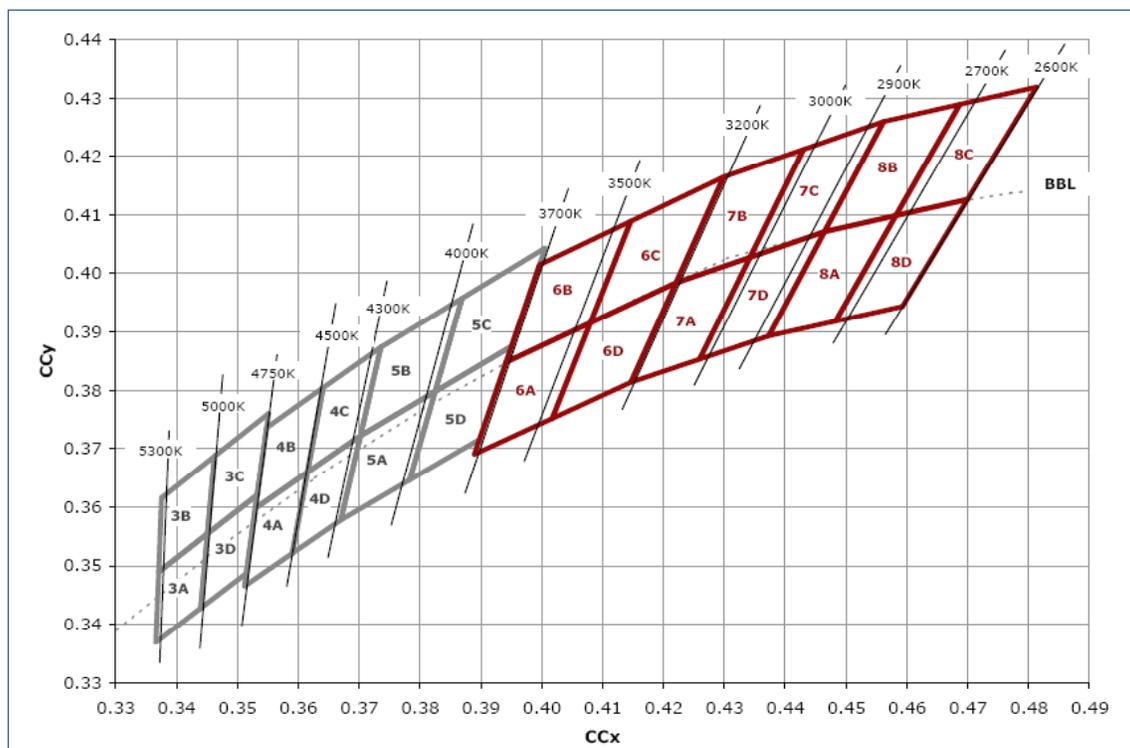


Figure 3: Binning Plot (Source: Cree Specification Sheet)

Usually LED manufacturers supply LEDs that fall into the aggregation of four bins (e.g. the aggregation of 6A, 6B, 6C and 6D in Figure 3). **When WAC specifies LED binning, we require LEDs to fall into one specific bin** (e.g. either 6A, or 6B, or 6C or 6D in Figure 3) **to ensure maximum color uniformity.**

Back to the CCT specification, The U.S. Department of Energy (DOE) just published their Energy Star Qualified LED Fixture requirements. They allow a  $\pm 245\text{K}$  for color variance at 3500K. By comparison, **WAC only allows a  $\pm 100\text{K}$  for color variance at 3500K.**

## Luminaire Requirements

<b>Correlated Color Temperature</b>	The luminaire must have one of the following designated CCT's and fall within the 7-step chromaticity quadrangles as defined in the Appendix.	
	<b>Nominal CCT<sup>1</sup></b>	<b>CCT (K)</b>
	2700K	2725 $\pm$ 145
	3000K	3045 $\pm$ 175
	3500K	3465 $\pm$ 245
	4000K	3985 $\pm$ 275
	4500K	4503 $\pm$ 243
	5000K	5028 $\pm$ 283
	5700K	5665 $\pm$ 355
6500K	6530 $\pm$ 510	
<b>Color Spacial Uniformity</b>	The variation of chromaticity in different directions (i.e. with a change in viewing angle) shall be within 0.004 from the weighted average point or the CIE 1976 (u', v') diagram.	
<b>Color Maintenance</b>	The change of chromaticity over the lifetime of the product shall be with 0.007 on the CIE (u', v') diagram.	
<b>Color Rendering Index (CRI)</b>	Indoor luminaires shall have a minimum CRI of 75.	

Table 1 Energy Star Requirements for Solid State Lighting Luminaire. Ver. 1.1 (Dec.2008)

## ► 3. LED Dimming Technology

Unlike an incandescent lamp, the electronics used to power an LED lighting system are much more complex. An LED driver is required in an LED system, similar to a fluorescent lighting system.

Since the electric current passing through the LED must flow in one direction, DC power must be used. A little fluctuation on the input forward voltage will cause wide variations on the current passing through the diode. The DC power source should be either a constant current or have a current limitation device.

Most constant current drivers are not designed for dimming. Their function is to maintain a constant electric current, leveling any input current fluctuation. This type of driver will not work with existing dimmers. The following information is about 4 major dimming technologies for current lighting system, and they might be suitable for LED dimming.

### 3.1 – Types of Dimming Control

#### a. Two-wire control

A two-wire dimmer switch is the most commonly used control method. There is a single wire between the dimmer and the light source.

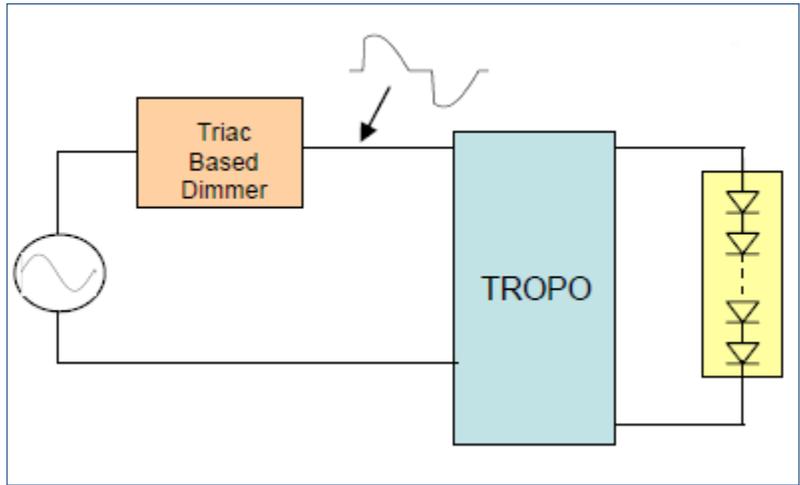


Figure 4: The wiring indication for 2-wire control system applied for an LED lighting system<sup>4</sup>

### b. Three wire control

Most fluorescent light is controlled by this type of technology, because the power required of the ballast should not influence the dimming effect of the light source. Among the 3 wires, one is used to provide power to the light source as long as it is turned on, and the other 2 wires provide control signals to the light in order to set the brightness level<sup>5</sup>.

Currently, only a few LED products in the marketplace use the technology mentioned above. The reason is due to the electrical characteristics of the LED:

- LEDs should be powered by DC voltage and current to protect the LED from fluctuation in electric current which could damage the LED and lower its performance
- Most LED constant current drivers do not have the capability to directly accept the output voltage from dimmer

### c. 0 ~ 10V control

This is an analog control that sets the voltage to the light source between 0V and 10V. It is also exactly specified by IEC standard 60929<sup>5</sup>.

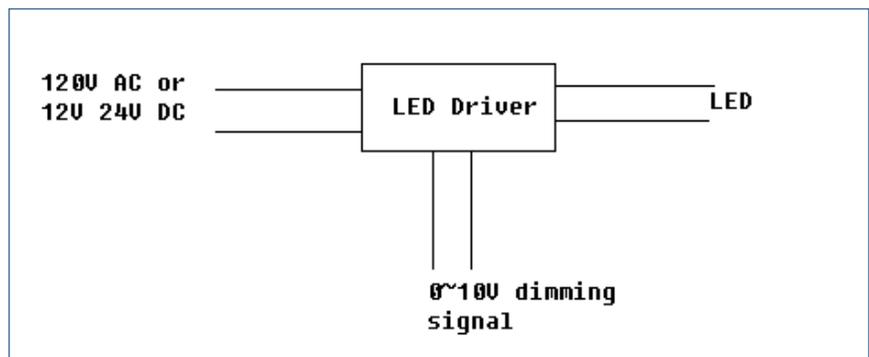


Figure 5. 0~10V dimming wiring schematic

<sup>4</sup> [http://www.roallivingenergy.com/pdf/TROPO DataSheet%20rev%20B.pdf](http://www.roallivingenergy.com/pdf/TROPO%20DataSheet%20rev%20B.pdf)

<sup>5</sup> Amanda Beebe, Controlling consumer expectations of LED lighting: why dimming is so important. LEDs magazine, 04/09

#### d. Digital Control

- DALI: the full name is Digital Addressable Lighting Interface, a control standard which emerged from Europe. This standard allows digital control of separate fixtures:

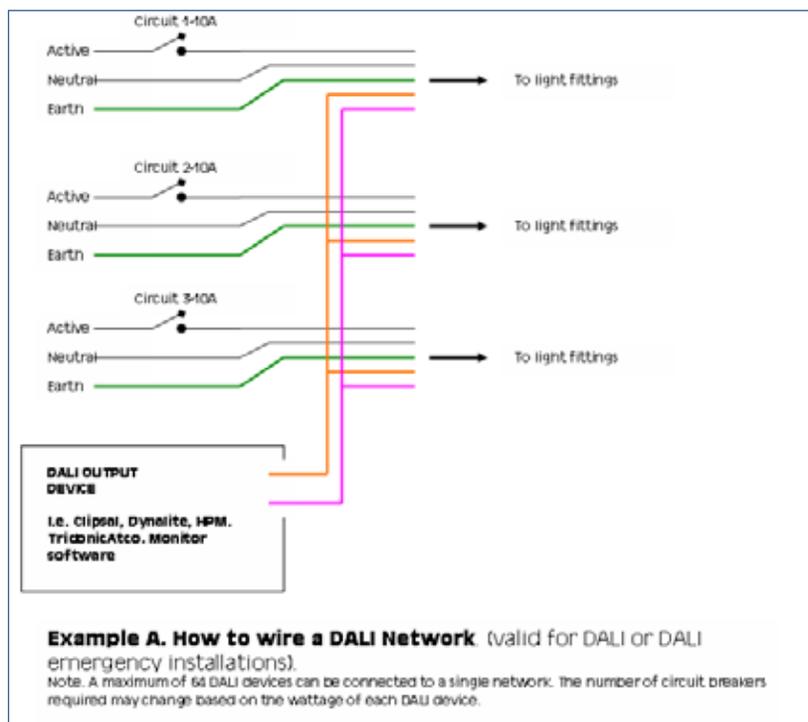


Figure 6. Wiring indication for DALI system  
([http://macolighting.com/images/stories/DALI\\_wiring.PNG](http://macolighting.com/images/stories/DALI_wiring.PNG))

- DMX: this is from theater lighting control, and multiple channels of light (both color and intensity) can be controlled by this type of control technology <sup>5</sup>.



Figure 7. DMX Lighting system

The methods mentioned above, 0~10V, DALI, and DMX, are the most common approaches for LED dimming. However, a low voltage dimming signal must be fed into the DC power supply separately, which makes it very difficult for residential retrofit dimming applications.

### 3.2 – Current Market Observations & Trends On LED Dimming

When a manufacturer claims their products are dimmable, their products are likely to use dimmable driver technology. However, more and more customers require dimming technology to use the 2-wire or 3-wire control method. For example in the residential applications where the tradition lighting system has already been installed with a traditional dimmer ( such as Triac incandescent dimmer or electrical low voltage dimmer, ELV) and all the power lines are buried inside the wall, it is very inconvenient to install a new lighting system which needs two additional signal lines for dimming.

Some driver manufacturers and chip manufacturers have already proposed dimmable driver solutions based on the 2-wire or 3-wire dimmer control technology. Lutron released their Hi-Lume dimmable driver, and we also find other companies offering 2-wire dimmable drivers. Several chip manufacturers have started supplying component level dimming solutions as well.

### 3.3 – WAC Proposed LED Dimming Solutions

As mentioned above, currently most residential spaces where incandescent lighting systems have already been installed use a 2-wire control method. If we want to use LED lighting fixtures in a retrofit application, we need a 2-wire dimming solution. We need to find a proper way to dim WAC LED lighting systems based on available solutions provided by either the driver or the chip manufacturer.

All of the dimming solutions are under development and we plan on using these dimming solutions in our latest LED offerings.

	<p><b>WAC LEDme™ track head:</b>  <i>ELV dimmer is recommended, dimming range is from 100% to 1%</i></p>
	<p><b>WAC LEDme™ pendant:</b>  <b>Dimming from 100% to 15% or better</b>  <i>- Optimal dimming with (ELV) dimmer</i>  <i>- Dimming for SOLORAIL™/DUORAIL™ is recommended with electronic transformer</i></p>
	<p><b>WAC LEDme™ Button Light and Drivers:</b>  <i>WAC dimmable puck light driver is recommended for product dimming, dimming range is from 100% to 15%</i></p>
	<p><b>WAC INVISILED™:</b>  <i>ELV dimmer</i></p>



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