LED Backlighting for LCDs: Options, Design Considerations, and Benefits

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LED-backlit LCD modules are an increasing subject of interest to save energy and improve the operating life and durability of devices that incorporate LCDs. This White Paper discusses the viewing experience, technologies, and some of the economic considerations when considering integrating an LED-backlit LCD module into a design.

LCD Backlighting: An Introduction

Choosing a backlighting system for a Liquid Crystal Display (LCD) is a major consideration. An LCD's backlighting significantly affects brightness, contrast, and many other aspects of the viewing experience.

Let's begin with a brief overview of how LCDs work. LCDs are comprised of a mix of crystalline material suspended in a liquid medium and sandwiched between two pieces of glass. The light source or backlight is behind the glass and passes through the LCD, an effect similar to shining a light through a translucent material (see Figure 1). The semiconductor switches within an LCD cause the crystalline material to act as a shutter, thereby controlling the light coming through the liquid crystal optical stack. The resulting image corresponds to the electronic data information supplied to the display pixel array, which acts as a variable light valve to pass or inhibit the light through each colored pixel. A plasma television, in contrast, has light emitted from each pixel, similar to a number of individually-switched fluorescent light bulbs.

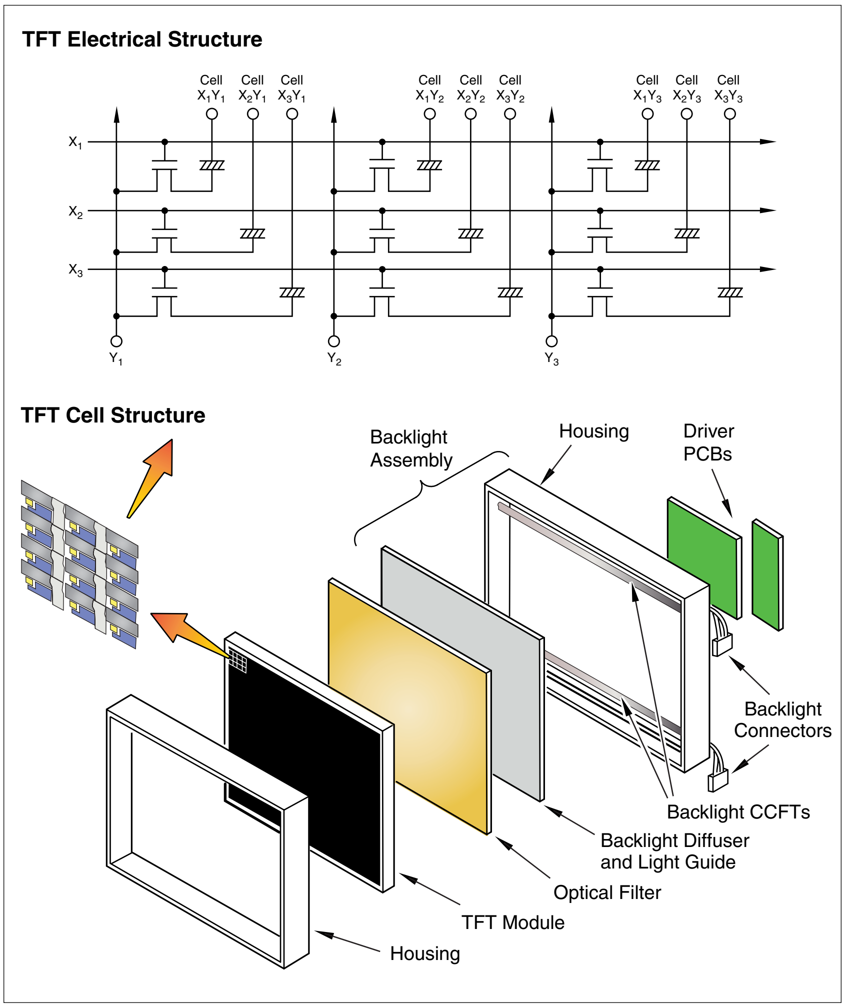


Figure 1: Simplified View of a Typical LCD Module, Showing Backlight Integration

LED versus CCFT Technology

Up until now, the prevalent LCD backlighting technology has been based on the Cold Cathode Fluorescent Tube (CCFT) (see Figure 2). We see fluorescent technology in use everyday in our homes and offices, integrated into overhead florescent lighting, free-standing lamps, under-cabinet lighting, along with other types of arc-based lighting in commercial and industrial lighting standards and applications.

To illuminate the electro-optical image generated within the LCD using CCFTs, light is spread over the back of the glass structure all at once via a light guide. The light guide is a structure used to uniformly distribute the light toward the area that requires illumination and hides the light source. Between the light guide and LCD is a diffuser that helps to even out the illumination.

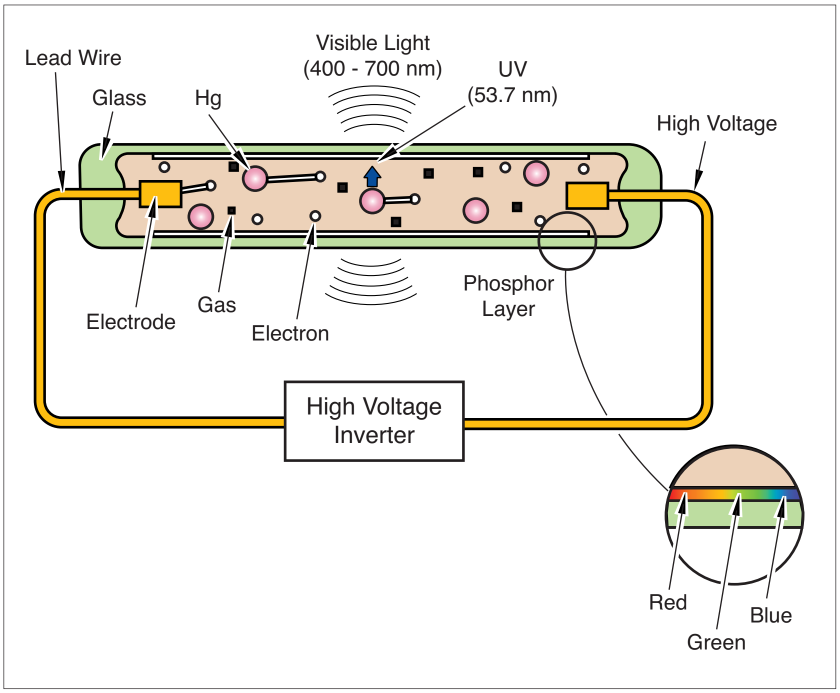
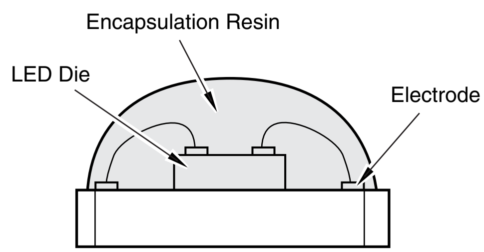


Figure 2: Anatomy of a CCFT: A high voltage source strikes an arc through a noble gas medium modulated by mercury, generating ultraviolet radiation. This radiation is absorbed and converted to visible light by the phosphor coating of the tube.

A Light Emitting Diode (LED) is a semiconductor device that produces light when current is passed in one direction. Light is produced from the energy conversion that occurs in the LED structure, much like a tiny light bulb (see Figure 3). However, due to their semiconductor-based structure, LED lights are much more rugged and damage-resistant than ordinary light bulbs and fluorescent tubes.



LED Cross Section

Figure 3: Typical LED for backlighting: Light is emitted from the die and is diffused by the encapsulation resin.

Design Considerations

There are number of factors to consider when looking at the option of CCFTs versus LEDs in use for backlighting. If the display will be used in a rugged environment with temperature extremes, harsh ambient elements, vibration, or where the dreaded “drop test” applies, then there are many advantages to consider with LEDs. The overall construction of the CCFT contains glass and other aspects that make it less hardy that its LED counterpart. LEDs are free of glass and other small, breakable parts, (see Figure 2 and Figure 3).

One key issue to consider is the operating life of CCFTs in extreme environments, especially in cold conditions. An LED backlight can operate at the lower temperatures and last much longer. By contrast, a CCFT’s operating life is limited in these conditions by several factors:

Low Temperature Effects: Operating CCFTs between 10°C and 50°C has no effect on life. Starting and operating a CCFT below 10°C greatly shortens its life. At 0°C, a CCFT will last approximately 1,000 hours, as compared with a standard minimum operating life of 50,000 hours for an LED. (see Figure 4).

Mercury Depletion: Ionization will eventually exhaust the mercury in the tubes, reducing light output. Operation below 10°C will accelerate this function. The glass will also absorb mercury, reducing its transparency.

Operating Angle: If the display is operated for a considerable portion of its life off-axis, the mercury can “pool” in an area of the CCFT, causing the display to appear brighter in one area.

Phosphor Poisoning: Mercury is absorbed by the phosphor coating on the CCFT, reducing the output efficiency of the lamp. Operation below 10°C will accelerate this function. Poor arc maintenance of the bulb will also reduce phosphor life.

Electrode Depletion: Attempting to strike and operate the CCFT at a voltage below its stable point will cause the arc to sputter, eroding the electrodes. This stable point will vary with temperature, but operation below 10°C causes the strike voltage and stable point to rise dramatically.

Another key issue to consider is operating voltage. CCFTs require inverters to

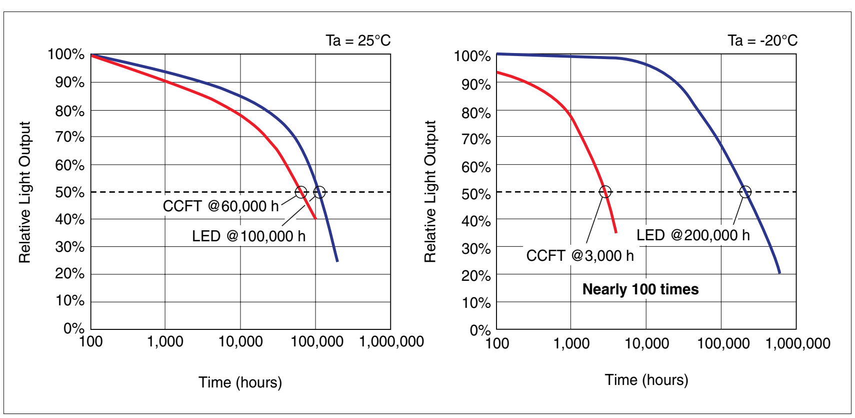


Figure 4: Left - Operating Life Comparison - Room Temperature; Right - Operating Life Comparison - Low Temperature

produce the high voltage alternating current (AC) they require to start the current flowing ("strike" the arc) between their electrodes. Most inverters have feedback circuits that ramp up the applied AC voltage to roughly four times the operating voltage during start up. This high voltage causes the arc within the tube to strike, allowing the mercury to ionize, releasing electrons from the molecules. Once ionized, the voltage drops to a nominal level, which can vary greatly – anywhere from several hundred volts to a few thousand volts – the level of which is set by the requirements of the tube. The total wattage rating of the inverter is critical; larger length and diameter CCFTs require higher wattages.

It is difficult to completely dim a CCFL, since the arc within the CCFT will "quench" (or go out), requiring the CCFT to be re-struck. Repeated quenching and re-striking the arc is detrimental to the CCFT; the eroding effect on the electrodes is greater than that of a "sputtering" or unstable arc.

By comparison, LEDs operate with a much lower voltage (4 - 32 Volts) and are driven by controlled current drivers (20 – 150 mA) rather than voltage sources. This usually takes the form of an LED driver IC utilizing the inductor/Schottky diode pumping method, incorporating a feedback system to monitor output current. Driver output frequency can be from 0.5 - 3 MHz and efficiencies are up to 92%, depending on usage. The driver IC handles the DC to DC conversion, and these ICs typically include an input for a PWM dimming signal. Dimming is achieved by varying the duty cycle of the PWM.

Thermal design considerations are very important. In an enclosure, an electronic device generating heat requires careful heat management. LEDs are more sensitive to damage from overheating than CCFTs, so it is necessary to dissipate this operating heat as efficiently as possible. Ineffective heat management can drastically reduce the operational life of an LED backlight, and subsequently the LCD product.

Parameter	CCFT Backlight	LED Backlight
Dimming Ratio	(25%) to 100% Dependending on Inverter design	Extremely wide (<1% to 100%)
Electrical Noise	Strike: 1,000 to 15,000 Vrms Driving: 600 Vrms (50 - 60 kHz)	DC 32 V
Safety (Hazardous Material)	Hg in CCFT	Safe (No hazardous materials)
Mechanical Shock	Weak (CCFT)	Strong (No glass to break)

Table 1: Technology Comparison

LED Backlighting Arrangement

Depending on the type of application, an LED backlighting scheme can be either the on-edge or the flat array type. Each has its advantages, depending on the performance required and the constraints that are placed on the economics of the product.

In using the edge-lit method, the light source is placed slightly behind the edge of the LCD panel. The backlight array may be mounted on one, two, or all four edges, dependent upon the size of the display and amount of light required. The light is captured by a light guide that spreads it evenly across the back of the LCD. The light guide is similar to a wedge of plastic that directs the light across, and then perpendicular to, the flat surface (see Figure 6).

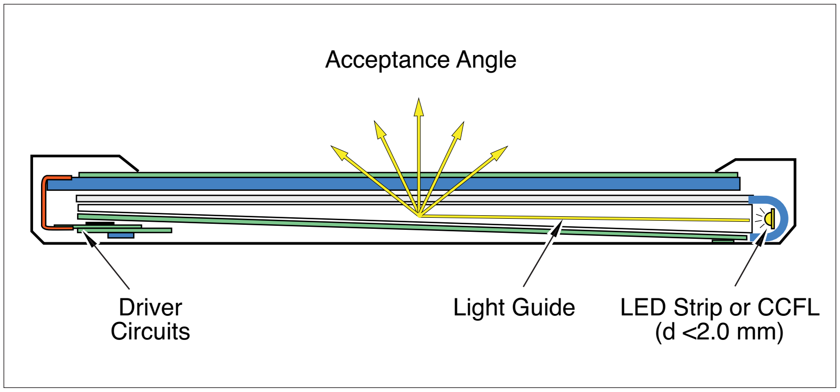


Figure 6: Edge-lighting an LCD Module with a Light Guide

If the display is lit by LEDs on the edge(s), the result can be a pleasingly-thin product profile that also delivers a significant reduction in power consumption as compared to a CCFT-backlit LCD. Using strips of LEDs to light the edge is also lower in cost than a large flat array (see Figure 7).

Edge-lit solutions also provide an excellent cost-over-performance ratio that becomes very attractive when absolute top performance from the module is not required. Modern modules provide excellent brightness and contrast ratios; so although edge lighting the module creates some compromises in ultimate contrast when compared with array-lit panels, the resulting ultra-slim product often becomes worth the compromise.

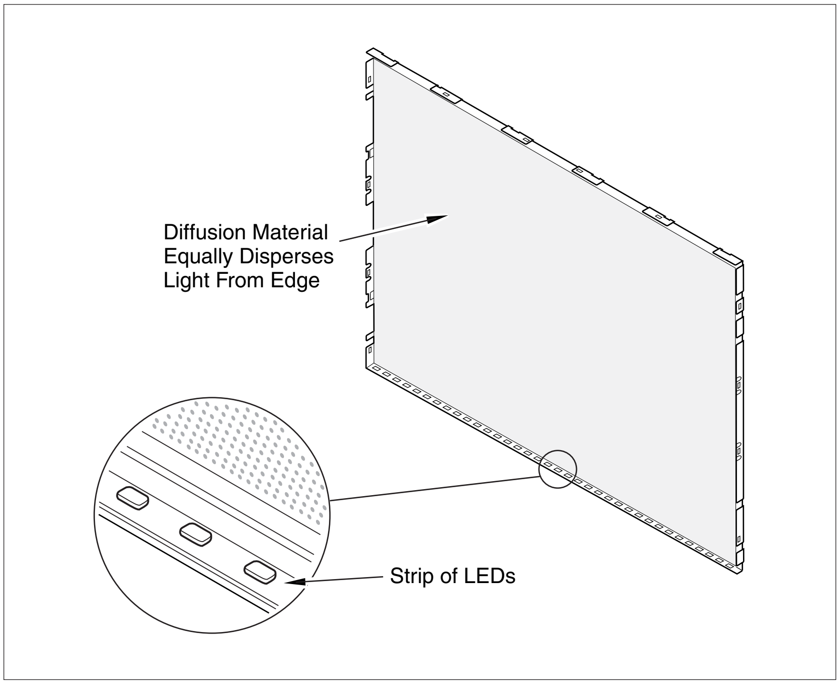


Figure 7: Edge-lit LCD Example

If the LEDs are placed in a flat array across the flat surface of the rear side of the LCD, local dimming (and lighting) is possible (see Figure 8 and 9). The LEDs are arranged in an array or grid configuration in order to tailor light penetration in various areas of the LCD pattern. All or part of the array can be darkened or brightly lit, which allows the dark portions of a movie or image to look as it was intended. The blacks will be true black and the grays will be much more distinguishable. This method and execution is frequently seen in TV panels.

For this level of control and capability, a greater number of LEDs are also required, which will increase product cost as compared to the edge lighting technique. To achieve the desired effect, the number of LEDs required can be in the hundreds. Product development time may also be a factor. All of the LEDs must have a similar output and a similar color temperature to achieve a uniform look. This requires more attention during product development than using the edge-lit method.

Currently, the local dimming method is primarily employed in high-end LCD TVs. It is likely that the method will become more prevalent in the consumer space, as well as in industrial applications such as medical equipment (e.g., MRI or CAT scan), air traffic control and other applications where viewing an incredibly-precise image is essential.

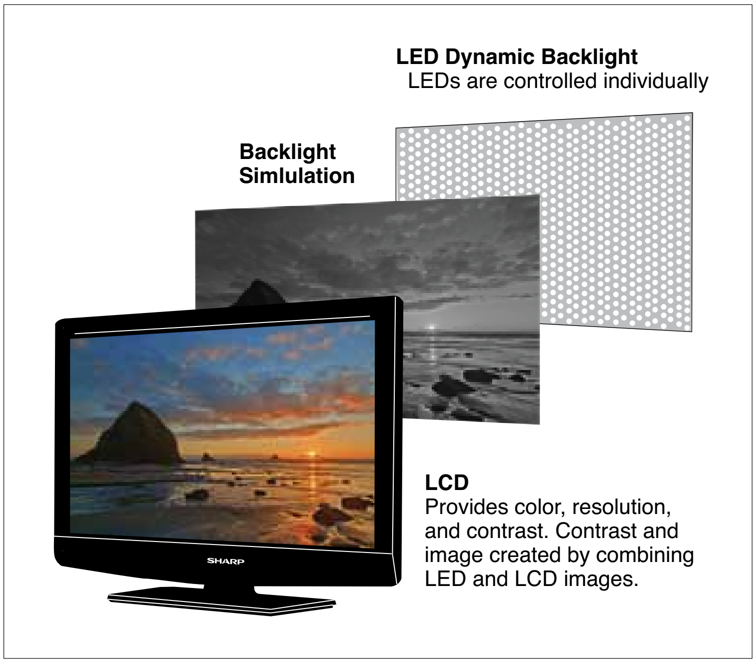


Figure 8: High-end LCD TV Incorporating Local Dimming in a Dynamically-controlled Backlight

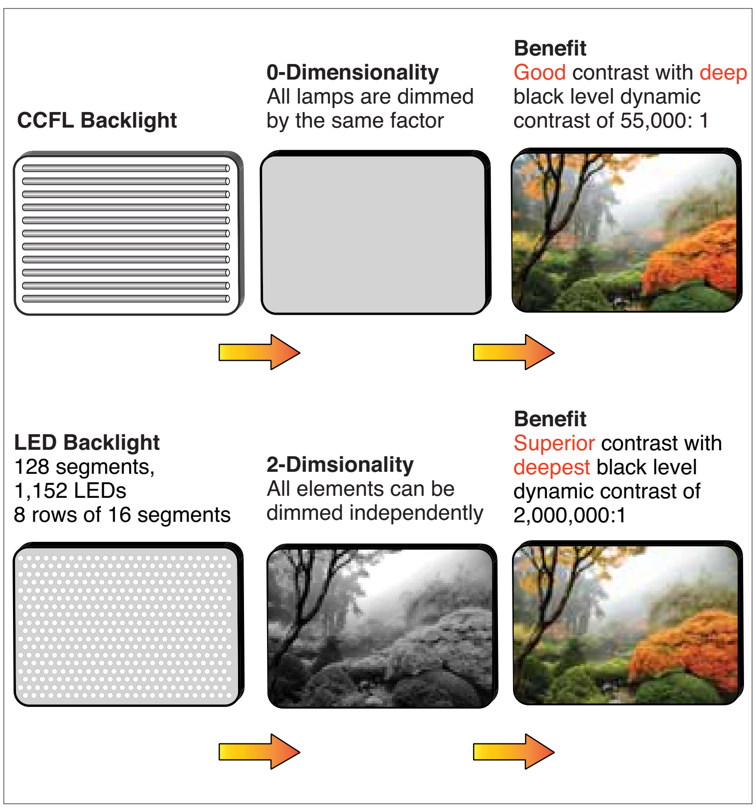


Figure 9: Dynamic Backlighting Comparison - CCFT vs. LED

LED Type and Color

White LEDs and Red/Green/Blue (RGB tricolor) LEDs are the two color options used for LED backlighting. The white LED is an economical preference for many cost-conscious applications such as notebooks and PC monitors. Most, if not all, mobile and handheld LCD-based products such as this use white LEDs. This “white” color is sometimes known as “pseudo-white”: the white LED is actually a blue LED combined with yellow phosphor to produce a light that is white in appearance. The term ‘pseudo-white’ was coined to differentiate these LEDs from those that use separate R, G, and B emitters to create white light.

If an RGB LED is used, the light can be controlled to produce different temperatures of white light. High-end monitors and televisions usually use RGB LEDs to produce images with richer, truer color palates. One method of RGB lighting uses two green LEDs next to a red and blue. This approach allows great contrast and a richer, more accurate color palate.

The use of RGB LEDs for backlighting can provide a color spectrum that closely follows the color filtering in the LCD pixel itself. This method provides a type of band-pass filter that can be adjusted so that the color component allows only a small, designated portion of the spectrum to pass through the LCD. Additionally, the RGB output of each LED can be individually tailored for a color spectrum output that will produce the most vivid colors. This helps to improve the colorimetery of the display.

To be fair, wide-gamut CCFT backlighting has also improved in color rendering in recent years. There are many current LCD models, ranging from cheap TN-displays to color proofing S-IPS or S-PVA panels, which have wide-gamut CCFTs. These increase the representation of the NTSC color specification.

The “Eco” Side of LED Technology

LEDs are being widely recognized for their environmental benefits as compared to CCFT lighting. First, as mentioned, power consumption is far lower with an LED. They are also rather simplistic in structure; unlike an incandescent bulb, they have no filament that will burn out. This, and other durability factors, leads to less frequent need for product replacement – and, in turn, fewer non-functioning products going to the landfill prior to reaching their expected operating life. Unlike CCFTs, LEDs contain no mercury or other toxic components. This eliminates significant concern about their handling and eventual disposal.

In general, consumer demand will continue to lead product manufacturers toward development of the most environmentally-friendly products possible. In the case of LED backlighting, the technology incorporates a great number of benefits, environmental and otherwise, that the manufacturer can tout as competitive product advantages.

Industrial Applications for LED Lighting

Applications that make the best use of LED backlighting technology are those that are sensitive to power consumption. For instance, mobile LCD-based products that run from battery power must allow for a minimum operating battery life in the device to make them useful. The LED backlight facilitates this goal.

Surface-mount LEDs are also very rugged and allow products to be handled more freely and without fear of damage. Cell phones, PDAs, personal navigation devices, and a great number of other handheld monitors and devices need to be able to withstand being dropped or mishandled. Industrialized versions need to withstand much more harsh abuse in their environments. LEDs allow for a very robust design of handheld and mobile products since they are smaller in size and more solid in construction than the glass tube-based CCFT. As mentioned previously, temperature extremes are less of a problem for the LED-based backlight, as well. This is an important feature in many industrial-grade products.

LEDs deliver added value in many industry-specific applications. One example is medical equipment. Use of LEDs reduces radio frequency (RF) noise. This is literally vital when patient monitors and similar instruments require data channels free of Electromagnetic Interference (EMI). Using CCFT-based products requires shielding of other sensitive equipment in order to avoid problems with EMI.

A dramatic example of LED superiority over that of gas-discharge lighting is in that of industrial large-area lighting; for instance, landscape, street, and lot lighting. LEDs are more efficient than gas-discharge lighting, provide a more pleasant light and last longer. Also, because their light does not contain any UV component, LEDs do not attract insects.

Summary

LCD displays and televisions have become increasingly ubiquitous, and it can be expected that they will continue to show up in more and more products and applications. As technology continues to improve, it behooves us to consider what new advances will become available to save energy and improve the operating life and durability of devices that incorporate LCDs.

It follows that LED backlighting will continue to take a more prominent role and will likely become the standard for LCD backlighting. Though this may be impacted somewhat by product cost and economy of scale as compared to CCFTs, LED displays are also quickly becoming more accessible in price.

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