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Technological Trends of LED Backlight Units

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15.1 Introduction

Although CCFLs have been widely used as backlights for TFT-LCDs, other light sources are being investigated extensively. Among them, LEDs are experiencing significant performance improvements, enabling them to be used in relatively small-size displays. For portable devices, the use of white LEDs has become standard. Recently LC-TVs with LED backlights have been commercialized for medium-size devices.

15.2 Structure of LED Backlight Units

There are two types of backlight units as shown in Figure 15.1. One is a side-light type which diffuses the LED light by using a light-guide plate or a cavity. The other is a direct-light type in which LEDs are arranged at the back of the LC panel. LEDs are point light sources in contrast to the line light sources of CCFLs. In order to obtain a uniform distribution of light output, more careful designing of the light-guide plates, diffuser sheets, etc., is required for LED backlight units.

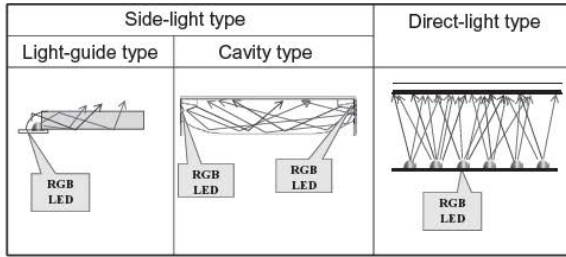


Figure 15.1 Various structures of LED backlights.

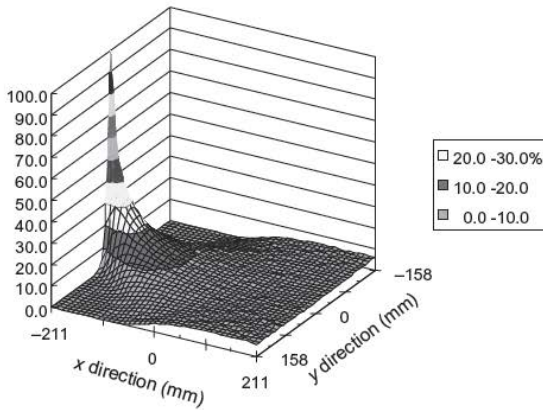


Figure 15.2 Distribution of light output from a light-guide plate type backlight unit when there is one LED light source.

15.3 Design of LED Backlight Units

15.3.1 Light-guide Type LED Backlight Unit

An LED light source package consists of three (R, G and B) LEDs. These packages are arranged linearly at a constant spacing. The LEDs are operated at a constant current. The distribution of light output from a light-guide plate is shown in Figure 15.2 when an LED light source is placed at $x = -211$ mm and $y = 0$. The light intensity decays to 10 % when the travel distance of the light becomes greater than 200 mm. The appearance of the light diffusion in the light-guide plate can be found in Figure 15.3. The light-guide type

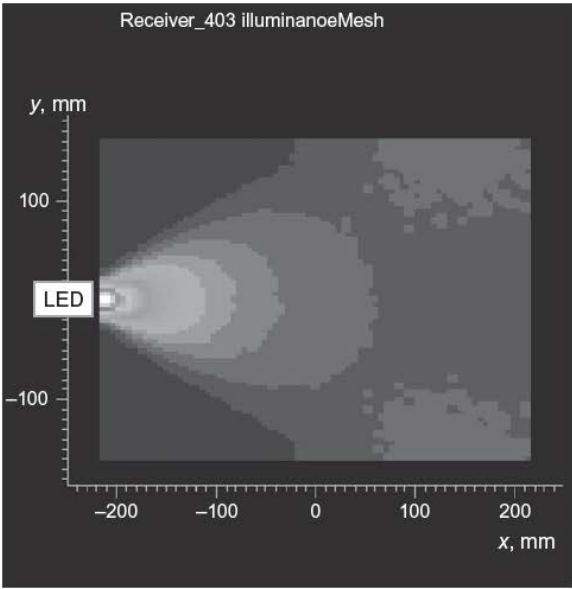


Figure 15.3 Diffusion of LED emission in a light-guide plate.

backlight unit generally utilizes two light-guide plates. The plate closer to the LEDs provides luminance and color uniformity while the second plate changes the point light source to a plane light source.

15.3.2 Cavity-type LED Backlight Unit

R, G and B rays are mixed in the cavity rather than in the light-guide plate. One of the features of the cavity-type backlight unit is its low weight. Also loss of light is less since, for the light-guide type, the light has to experience entering into and exiting from the plates twice; each of these processes has an associated optical loss. Also there are higher chances of reflection at the side walls for the light-guide plates.

The distribution of light output from the cavity-type backlight unit is shown in Figure 15.4. The decay of light intensity is more gradual than that of Figure 15.2. Figure 15.5 is an example of light-output distribution of the cavity type when LEDs are placed only at the bottom side. It can be seen that the luminance is uniform in the horizontal direction. By providing LEDs at both the top and bottom sides, vertical uniformity can be obtained (Figure 15.6).

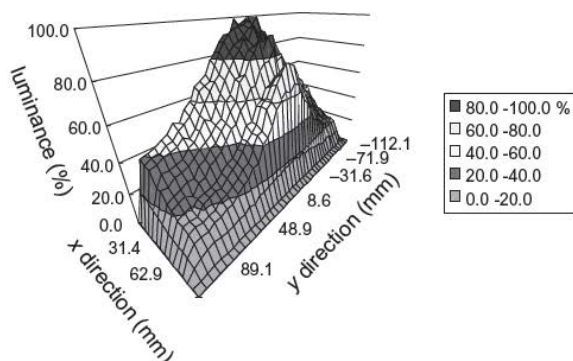
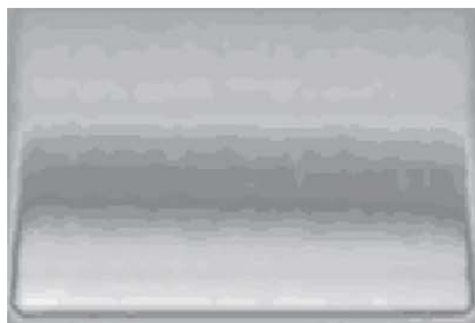


Figure 15.4 Distribution of light output from a cavity-type backlight unit when there is one LED light source.



LEDs

Figure 15.5 Luminance distribution of a cavity-type backlight; LEDs are placed at the bottom side.

15.3.3 Direct-light Type LED Backlight Unit

The direct-light type uses LEDs at the back of the LC panel. Loss of light is the smallest among the various types shown in Figure 15.1, but it is relatively difficult to achieve luminance and color uniformity. This is due to shorter paths of the light trajectories. For a light-guide plate, the light propagates a long distance along the plate surface and the optical path lengths become even longer by a factor of the refractive index of the plate. Also for the cavity

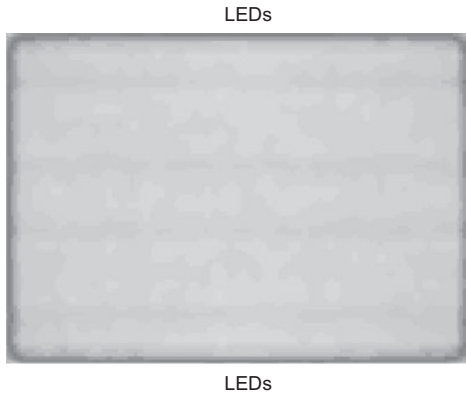


Figure 15.6 Luminance distribution of a cavity-type backlight; LEDs are placed at both the top and bottom sides.

type, the light experiences multiple reflections, thus the optical paths are longer compared to those of the direct-light type.

For the side-light type, mixing of the colors is attained by the long optical path. This mechanism is not applicable to the direct-light type in which optical paths are approximately equal to the thickness of the backlight unit. The direct-light type therefore requires a different design such as inserting diffusive sheets between the light source and the LC panel. Figure 15.7 shows how the light diffuses with respect to the distance from the LEDs. At 10mm above the LEDs, a circle of radius 22mm is irradiated. The radius increases to 83mm at a distance 50mm from the LEDs. By overlapping the luminous regions, appropriate mixing of colors can be attained.

15.4 Requirements for Backlight Units

Requirements for the backlight units are determined by LCD modules and the products in which they are used. Among various items, the following requirements are of particular importance.

15.4.1 Luminance

The required backlight luminance is determined by the transmission of the LC panel. The luminous flux of each R, G and B LED is measured under a predetermined current level. The luminance fluctuates for each LED after

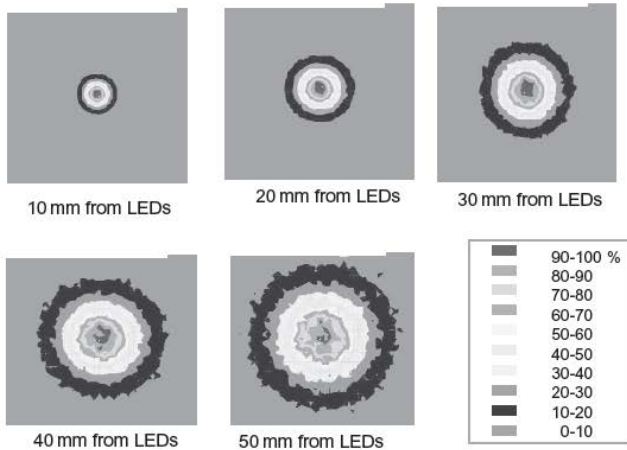


Figure 15.7 Diffusion of LED light; the vertical and horizontal sizes of the background squares are both 175 mm.

manufacture and hence suitable LEDs have to be selected before they are shipped to customers. Data of the average and lowest values should be accompanied when the LEDs are shipped.

15.4.2 Luminance Uniformity

The luminance uniformity of the backlight unit is defined by

$$\text{luminance uniformity} = (\text{maximum luminance}) / (\text{minimum luminance}),$$

where the maximum and minimum luminance are obtained by dividing the LCD screen into nine regions as shown in Figure 15.8, and measuring the luminance values at the centers of the regions (a)–(e). European standards divide the screen into 25 regions to obtain a more accurate value of uniformity.

15.4.3 Emission Spectra

Emission spectra also fluctuate for each LED after manufacture and hence suitable LEDs have to be selected. The measurement of the spectra is done under a predetermined current level and temperature. Data of the center, lowest and highest wavelengths should be accompanied with the shipment.

(a)		(b)
	(c)	
(d)		(e)

Figure 15.8 Measuring points for evaluating luminance uniformity.

15.4.4 Width of Spectrum

The width of the emission spectrum is also affected by the manufacturing process and the structure of LEDs. The HWHM (half-width at half-maximum) value should be specified.

15.4.5 Chromaticity and Color Gamut

The output colors are determined by the combination of the emission spectra of the LEDs and the transmission spectra of the color filters. The required CIE chromaticity coordinates of white, R, G and B for the LCD modules are specified by the customers. The color gamut can be expressed quantitatively by the area of a triangle made by RGB colors on the CIE1931 (x, y) chromaticity diagram. For more accurate expression, CIE1976 UCS (u', v') chromaticity coordinates should be employed. The CIE1976 allocates higher weights for R and B compared with CIE1931, more accurately matching the perception characteristics of the human eyes. For example, a typical CCFL has a CIE1931 area which is 73 % of the NTSC area, but a CIE1976 area is 83 % of NTSC. A typical LED backlight has a CIE1931 area which is 103 % of NTSC and a CIE 1976 area which is 115 % of NTSC.

15.4.6 Temperature Dependence

Emission spectra depend on the operating temperatures of LEDs. The dependence should be specified in terms of nm/°C.

15.4.7 Lifetime

Lifetime is defined by the time when the luminance is reduced to a half of the initial value. CCFLs have a life of 50000 hours. The lifetime of LEDs depends on the operating current, temperature and ambient humidity, making it difficult to measure. Since the luminous efficiency of LEDs is lower

than those of CCFLs, the operating temperatures of LEDs are generally higher. In addition, LED backlight units have a closed structure in order to admit LED light into the light-guide plate. The structure increases the temperature rise, leading to further shortening of the life. Also the lenses of LEDs are degraded by high temperature and humidity.

15.5 Technical Trends of LED Backlights

Backlights for cell phones once used inorganic EL. However, since their operating frequency is within the audible range, their luminous efficacy is low and their color representation is limited, inorganic EL has been replaced by white-emitting LEDs since the beginning of 2000. For medium-size LCDs, the backlight unit is not simply a light source; it also contributes to picture quality improvements including widening of the color gamut, reduction of motion blur and obtaining higher dark-room contrast. These improvements are attained mainly by the introduction of three-color (RGB) LED backlights. LCDs with LED backlights have been commercialized by Mitsubishi, NEC, Sony and other companies since 2002.

15.5.1 Wider Color Gamut

Figure 15.9 compares the emission spectra of a CCFL and an RGB-LED package. The LED has more intense spectra in the red region. Also it emits only pure R, G and B, providing high color purity. The color gamuts of a CCFL and an RGB-LED are compared in Figure 15.10. These have, respectively, 72 % and 103 % area with respect to the NTSC triangle.

15.5.2 Improvement of Emission Characteristics under Low Ambient Temperature

The temperature dependences of luminance and ignition voltage are illustrated in Figure 15.11 for a CCFL and an LED. For a CCFL, which utilizes mercury, the luminance is reduced to 20 % when the temperature is lowered from 25°C to -20°C. If the luminance of the backlight unit should be kept within $\pm 20\%$, then the CCFL temperature should not fall below 10°C. Also an ignition voltage one and a half times higher is required for the temperature variation from 25°C to -20°C. For LEDs the luminance and operating voltage are, much less dependent on the ambient temperature. For a range in temperature from -40°C to +85°C, luminance and operating voltage variations are kept within $\pm 20\%$ of the values at 25°C.

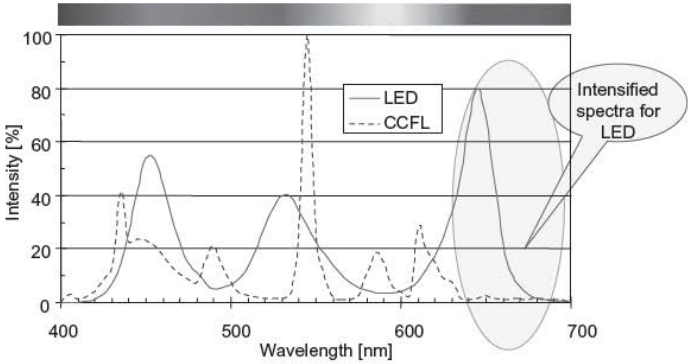


Figure 15.9 Emission spectra of a CCFL and an RGB-LED.

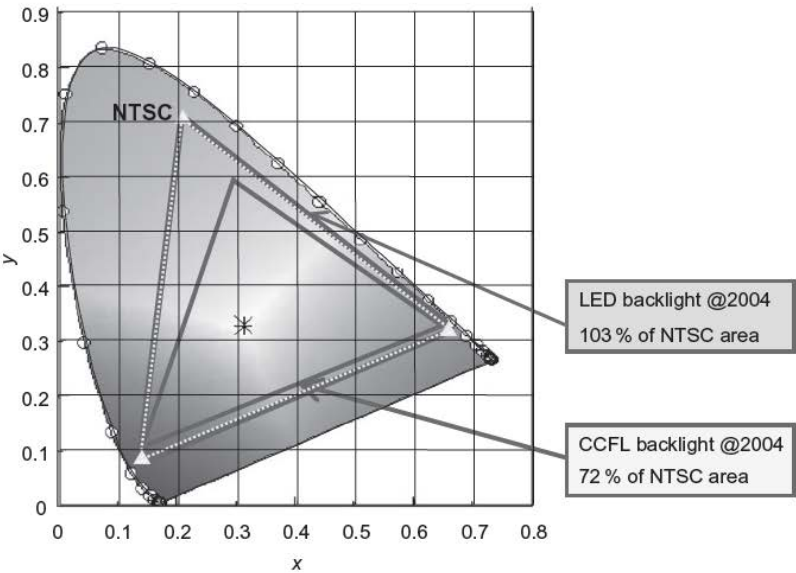


Figure 15.10 CIE chromaticity values for a CCFL and an RGB-LED.

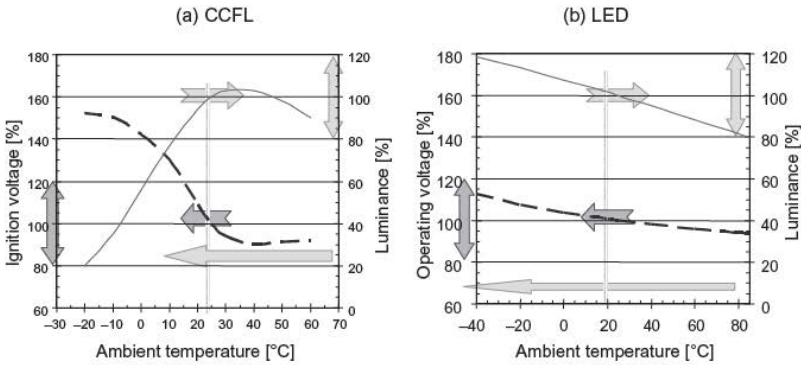


Figure 15.11 Temperature dependences of CCFL and LED characteristics.

15.5.3 Extension of Lifetime

The lifetime of an LED backlight unit is determined by the multiplication of LED emission degradation and optical component transmission degradation. For CCFLs, the life is reduced by too high and also too low temperatures. For LEDs, on the other hand, a low ambient temperature results in higher luminance at a constant current. This allows a reduction of the operating current which, in turn, reduces the LED temperature. As a result, the life is extended.

15.5.4 Picture Quality Improvement of Moving Images

Blinking backlights and local dimming techniques have been introduced to improve picture quality. The techniques require that the LEDs are switched on and off within 0.1 ms, which can easily be attained. Because of these advancements, a wider use of LED backlights is expected.

15.6 Applications of LED Backlights

15.6.1 For Moving Images

Moving pictures can best be shown on a CRT because of the short emission time of a pixel of the order of 1 μ s. The LCD emission time is typically 17 ms (when the blinking backlight technique is not used), which is too long for obtaining the CRT-like images. The picture quality of LCDs can be improved by adopting the blinking backlight or a high frame frequency drive.

15.6.2 For Color Expression

The gamut of sRGB is approximately 72 % that of NTSC. To attain the Adobe RGB gamut, which is wider than that of sRGB, the use of LED backlights is necessary. In order to express all the colors found in nature, the image input device, image storage, image transmission, etc., also have to be improved.

In the field of medical electronics including film-less X-ray photography, it is essential to express images with stable white and blue colors. The RGB-LED backlight can adjust the white and blue colors arbitrarily for medical use. Luminance, color, temperature, etc., can be stabilized by a feedback loop of the output emission of LEDs.

15.7 Conclusions

The remaining issues for the development of LED backlight units are given below.

Cost reduction: Considering the additional costs of drivers and cooling fans, the cost of LED backlight units is appreciably higher than that of CCFL backlight units. A reduction in the cost of LEDs – as well as a reduction in the number of LEDs in a backlight unit – is necessary.

Lower power consumption: LEDs consume about twice as much power as CCFLs, indicating the need to improve the light emitting efficiency. Also losses arising from mixing the RGB light should be reduced.

Color non-uniformity: Color non-uniformity can be improved by reducing the distances between the R, G and B LEDs, although the heat dissipation becomes worse. Mixing of colors can alternatively be done by appropriately designing the backlight optics.

By improving LEDs and LED backlight unit structures, LEDs will be adopted not only for high-end LCD monitors, but for car electronics and home-use TVs.