LEDs, New Light Sources for Display Backlighting

Application Note

Introduction

Because of their low intensity, the use of light emitting diodes (LEDs) as a light source for backlighting was previously limited to use in small displays.
The rapid advancement of semiconductor technology together with new concepts in packaging design has led to a significant increase in LED brightness, so that the use of light emitting diodes in backlighting applications has gained increasing importance. Due to their increased efficiency, LEDs are being used in many new application areas ranging from ever larger display panels to television screens.
The following provides a general overview and comparison of light sources which are currently available for use in backlighting applications, with a focus on the differences between cold cathode fluorescent lamps (CCFL) and LEDs.
Afterwards, the principle construction of backlighting is explained.
In addition, various types of LEDs are shown, along with their possibilities for use and associated challenges relating to the development and implementation of backlighting technology.

Application Areas

Displays, particularly liquid crystal displays (LCDs), come in various sizes from small displays for use in consumer applications up to large LCD displays used in television screens, and have meanwhile established themselves as a standard product for visualization.
In addition to advances in development of LCD panels regarding display size and resolution, one must also concentrate on the other components of the display module (color filter, light medium, lightguides etc.) in order to achieve improvement and optimization of the display.
The primary focus is display backlighting, with emphasis on the light source. With increased display size and information density, the requirements and performance of backlighting also increase; the trend in the area of visualization is generally tending towards photorealistic images (Figure 1).

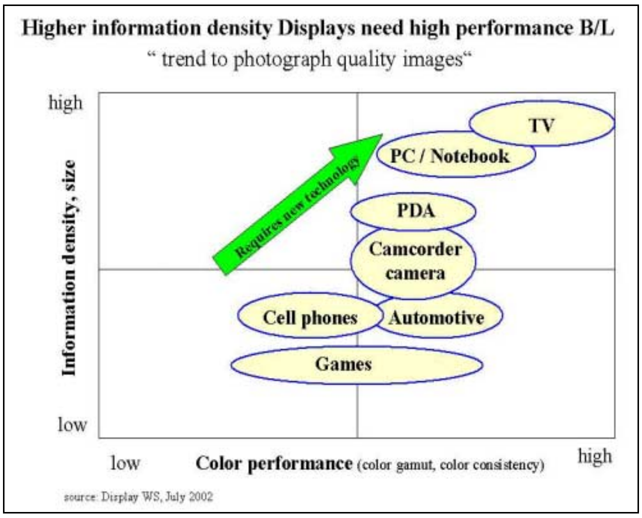

Figure 1: Backlighting performance in relation to information density / display size

Light Sources

At present, fluorescent lamps (CCFLs) prevail as the state of the art for backlighting large displays (larger than 3 inches) when compared to other light sources such as incandescent lamps or electroluminescent film, and offer a cost-effective light source due to their high intensity, long life and availability in various sizes.

Light Sources	Spectrum	Availability	Life Time	Brightness	Dimension	Automotiv Capability
Incandescent Bulb	--	++	-	+	--	--
CCFL	--	+	++	++	++	+
HG Free CCFL	--	+	++	++	++	+
White LED	--	++	++	+	++	++
Color LED	++	++	++	++	++	++
EL-Panel or Foil	--	+	-	-	+	+

Figure 2: Overview and comparison of light sources

CCFLs exhibit two considerable weaknesses, however. First of all, the red component of radiated light is fairly low (Figure 3).

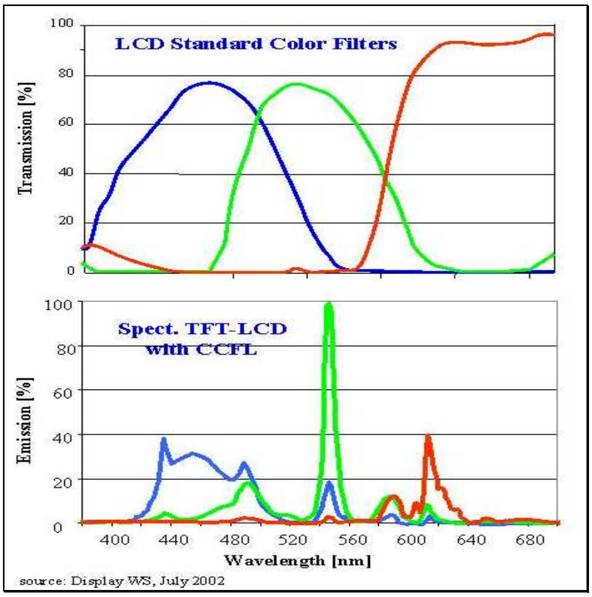

Figure 3: CCFL Spectrum and LCD Color Filter

This means that the display is only able to show a limited color spectrum (color gamut) (Figure 4), and the brilliance of the colors is low.

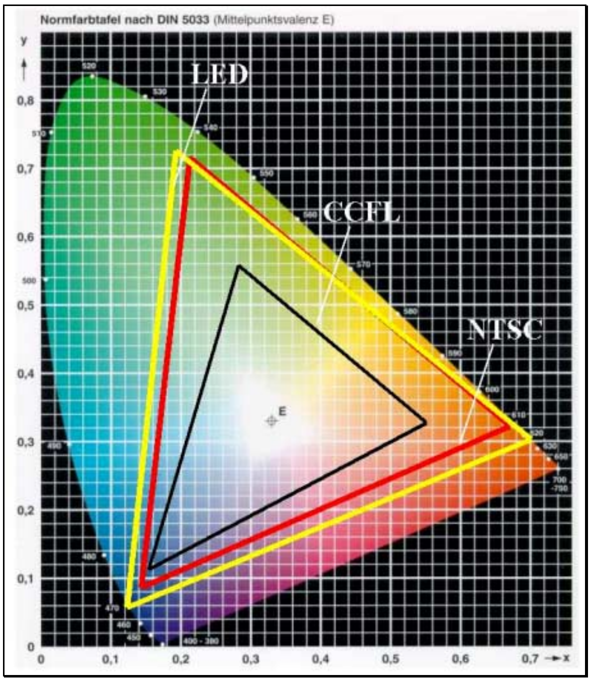

Figure 4: Comparison of color spectrums (NTSC: National Television System Committee)

Secondly, due to the materials and construction employed, fluorescent lamps exhibit a high sensitivity to mechanical stress and vibration.

For these reasons, their use in many application areas such as the automobile industry or air and space technology (avionics) is limited or they cannot be used at all.

In comparison, a significant improvement can be achieved with the use of LEDs, since they can produce a specific light within a narrow spectrum and exhibit a considerably higher level of mechanical stability.

In addition, their lifetime is as great as or greater than that of CCFLs and they can be driven with much simpler control circuitry and at low voltage levels. An additional advantage of LEDs is their short switching time which lies in the range of nanoseconds.

By using a pulsed light source, it is possible to considerably improve the display of moving images on LCDs, since the smearing effect is minimized.

Backlighting

In general, backlighting modules are constructed according to a common scheme.
The module principally consists of one or more light sources, a layer to diffuse the light evenly across the surface, and a micro-prismatic foil which serves to homogenize and increase the brightness.

Diffusion of the light is predominantly accomplished by surface-structured light-guides of plastic (PMMA, Plexiglas, acrylic glass etc.), whereby the light is introduced at the sides and is reflected by the diverting surfaces of the lightguide. The advantage of this variant is the inexpensive, compact and very flat modular construction of the backlight (Figure 5).

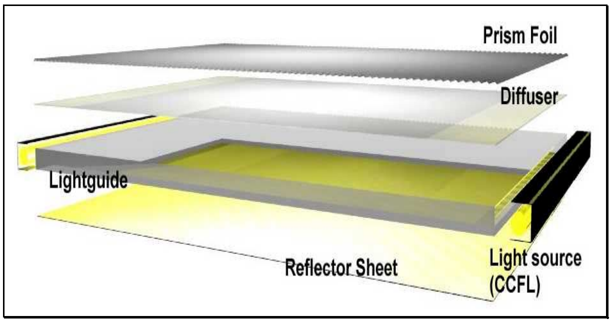

Figure 5: Modular construction with lightguide

Another method of diffusing the light is the use of a reflector box (Figure 6). This approach is primarily driven by higher brightness requirements, in which the use of multiple light sources is unavoidable.

With this method, the light sources are directly built into the reflector box, and radiate the light in all directions.
The reflector box serves to mix and homogenize the light. The advantage of this approach is the significantly higher brightness of the backlight. This can only be accomplished with a greater module depth, however.

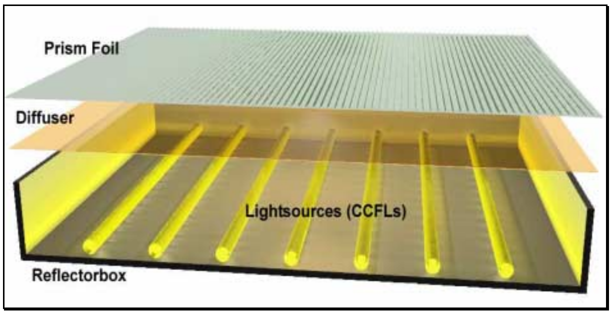

Figure 6: Modular construction with reflector box

Depending on brightness requirements and conditions, a combination of both variants may be employed.

LEDs for Backlighting

For use as a light source for backlighting, LEDs roughly fall into three categories – single-color, multi-color and white.

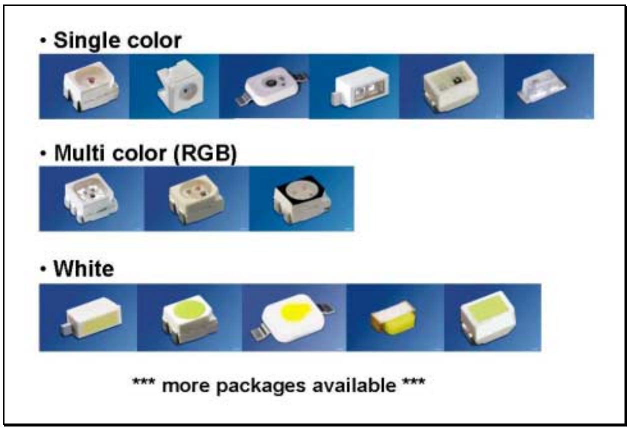

Figure 7: LED groups with examples

For displays with a monochromatic backlight, all of the LEDs in the three groups are equally well suited, and show no particular specialty.

For backlighting of multi-colored displays, however, the three groups exhibit individual advantages and disadvantages with respect to each other and also when compared to CCFLs (Figure 8).

The most significant advantage of single and multi-color LEDs as opposed to white LEDs and CCFLs is the decidedly larger color gamut available for the display and the individually selectable white point, as well as providing the potential for sequential backlighting.

LED Group	Advantages	Disadvantages
SINGLE COLOR	♦ Increased color gamut ♦ White point adjustment ♦ High brightness ♦ Small & large packages available ♦ High driving conditions possible ♦ Sequential color potential	♦ Large mixing & compensation area ♦ Various chip degrading
MULTI COLOR	♦ Increased color gamut ♦ White point adjustment ♦ Color mixing inside LED ♦ Small compensation area ♦ Sequential color potential	♦ Limited number of packages ♦ Various chip degrading ♦ More complex layout
WHITE	♦ Small compensation area ♦ Small & large packages available ♦ Simple control circuit	♦ Color gamut like CCFL ♦ Fixed white point ♦ No sequential color potential

Figure 8: Advantages and disadvantages of the three LED groups

Backlighting (RGB) with single-color LEDs presents a particular disadvantage, however.
Because of the alternating arrangement of the individual colors, additional space is required for color mixing, where the size of the mixing area is dependent on the distance between two LEDs of the same color and their emission angle (Figure 9).

Beyond this area, homogeneous, mixed light is available for illuminating the display.

For modules with lightguides, this means that the surface of the lightguide must be enlarged, or for reflector boxes, the depth must be increased.

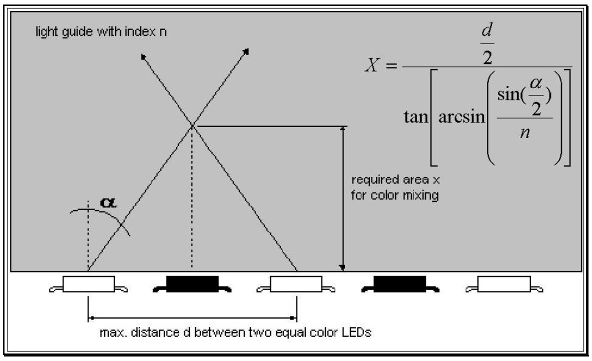

Figure 9: Estimation of the mixing area

With an LED spacing of 10 mm and a color sequence of "blue-green-red-green-blue", an additional mixing area of around 28 mm is required (Figure 10).

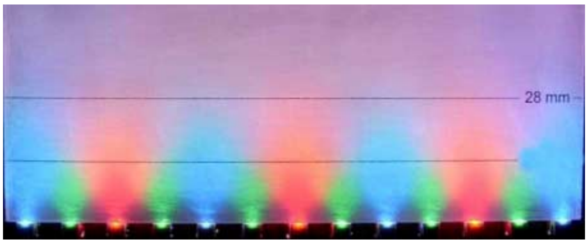

Figure 10: Mixing area for single-color LEDs with an LED spacing of 10 mm.

In contrast, the color mixing already takes place within the package for multi-color and white LEDs.
A much smaller area is necessary to compensate for the emission characteristics in this case. For the same LED spacing, only an area of around 7 mm is required (Figure 11).

Figure 11: Compensation area for multi-color and white LEDs (LED spacing 10 mm)

In general, white LEDs are well suited for backlighting applications.
In part, this is due to the availability of various packaging styles ranging from microcomponents to high power LEDs, and is also due to the relative simplicity of driving the LEDs at low voltage levels.

Based on the principle used for creating white light (Figure 12), a display with a limited color gamut and specific white point can be achieved, as is the case with CCFLs.

The principle is based on luminescence conversion, where a portion of the blue light of the semiconductor chip is converted into yellow light by means of a converter (phosphor).

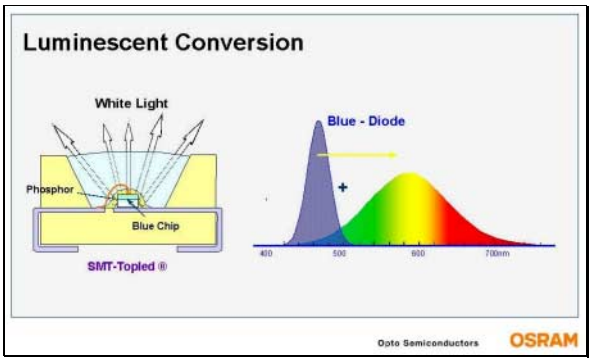

Figure 12: Principle for creating white light

By mixing blue and yellow light, white light can be obtained; the color coordinates (white point) are determined by the ratio of blue to yellow.

Generally speaking, among the three groups, the multi-colored LEDs emerge as the best choice for color display backlighting. Because several different colored semiconductor chips are incorporated into a single housing, the optical as well as design-related mechanical preferences of the other LED groups can be combined together.

In spite of the more complex drive circuitry required, multi-colored LEDs are the recommend light source for backlighting full-color displays.

Construction of LED Backlighting

The challenge when creating LED backlighting is to obtain a homogeneously illuminated surface, in spite of the fact that LEDs act as a point light source with a conical radiation pattern.

Similar to the backlighting of CCFLs, LED modules are based on two principle arrangements regarding the LC panel.

In the first variant – direct backlighting, the LEDs are arranged such that their light directly illuminates the back surface of the LC panel (Figure 13).

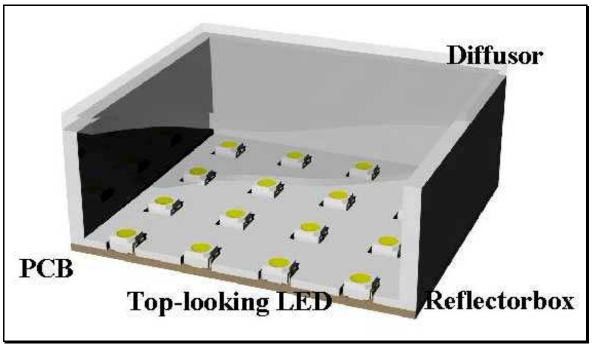

Figure 13: Direct backlighting scheme

The homogeneous illumination of the display surface is achieved by the regular spacing of LEDs and the corresponding depth of the reflector box. The depth of the reflector box is primarily dependent on the LED spacing and the emission angle of the LEDs.

For an initial estimate of the reflector depth for SMT-LEDs without lenses, 1.5 – 2 times the LED spacing can usually be used. This depth provides a good homogeneous illumination.
Further homogenization can be achieved by use of various diffusers and/or special brightness enhancement foils (BEFs). With a clever combination of the various foils, the depth can be reduced.

Typically, direct backlighting is preferred for modules with high brightness requirements (>500 cd/m²), medium size and limited space characteristics (x/y direction).

With the second method – indirect backlighting, the light is deflected or reflected onto the back surface of the panel, usually in combination with a lightguide (Figure 14).

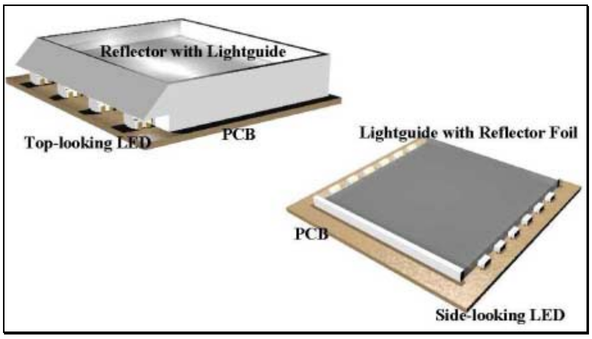

Figure 14: Indirect backlighting scheme

The uniform distribution of light is achieved by special microstructures (microlenses, V-shaped grooves) or dispersion points on the surface of the lightguide. The arrangement of the structure conforms to the position and offset of the LEDs and must be individually calculated for each configuration.

With the use of lightguides, many designs are possible, from the simplest version with a planar lightguide and one-sided LED arrangement (Figure 15), to a lightguide with angled deflector surfaces (Figure 16), angled input coupling areas (Figure 17) and individual LED arrangements.

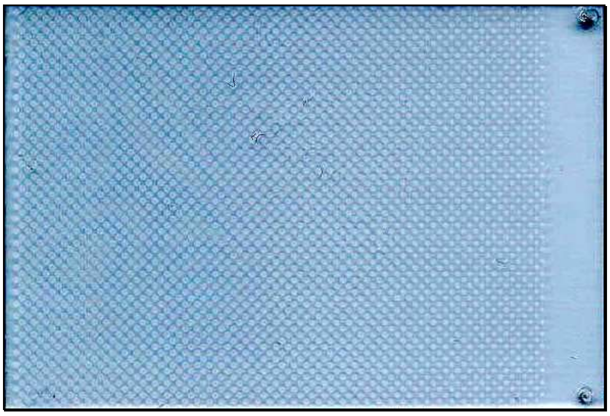

Figure 15: Planar lightguide with microstructure and compensation area, structure becomes thicker from left to right, LED positioned at right

Figure 16: Lightguide with structure, 2 LEDs located under the angled deflector surfaces

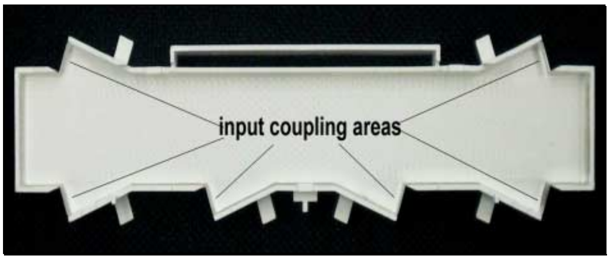

Figure 17: Lightguide with structure, 6 LEDs located at the angled input coupling areas

LED Backlighting for a 10.4” TFC-LC Display

The requirements for the model construction of a white backlight for a 10.4 inch TFT display are twofold: first of all, a brightness of 600-1000 cd/m² on the display surface with a transmission of 7.5 % is required. Secondly, backlight should not be larger than the size of the display itself (x/y direction).

Furthermore, the backlight should not be sensitive to vibration and have a lifetime greater than 10,000 hours, for possible use in industrial and aerospace applications.
Because of the high brightness requirements and display size, direct backlighting with a reflector box offers the only solution.

The resulting module (Figure 18) consists of 336 LEDs based on the white PowerTOPLED with a background brightness of 710 mcd at a current of 30 mA. Since an LED spacing of 10 mm was selected, the resulting reflector height is 18 mm. The height of the entire module (reflector and PCB) is 20 mm.

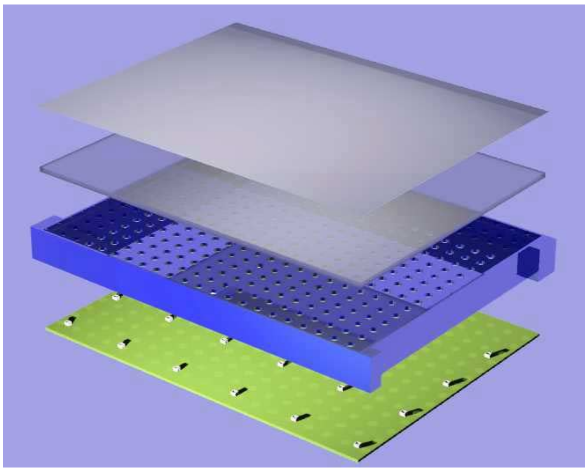

Figure 18: Backlighting module for a 10.4" backlight

The module circuitry was designed to be operated at 20 V and 2.5 A.

LED Backlighting for a 17” TFT-LC Display

For demonstration purposes and in the course of a feasibility study, a 17-inch TFT-LCD monitor was retrofitted with RGB LED backlighting, using the original monitor housing.
In addition, a typical brightness in the range of 200-250 cd/m² was assumed.
The principle construction of the LED backlight (**Figure 19**) is based on indirect lighting.

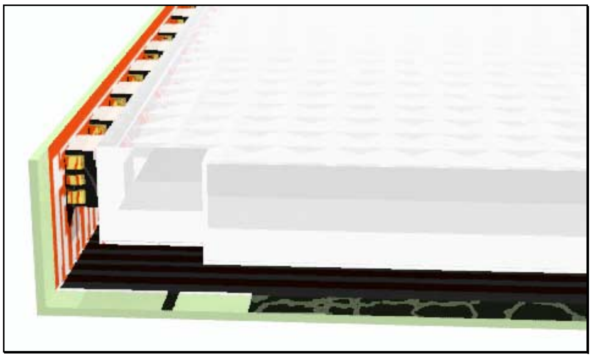

Figure 19: Principle LED backlighting of a 17" LCD

The multi-color LEDs (2x50 pieces, 6-lead MULTILED LATB G66x) were side-mounted with direct contact to the upper and lower sides of a lightguide.
To provide better heat dissipation, the LEDs were mounted on a combination consisting of a flexible PCB and an aluminum base plate. By spacing the LEDs close together, the compensation area could be reduced to a few millimeters, so that the original LCD frame could still be used.

The brightness of the modified monitor (**Figure 20**) was measured with a light density camera and amounted to 220 cd/m² at a light intensity of 620 lm for the LEDs and a specified white point of 0.33/0.33.

Figure 20: 17” TFT-LCD with RGB backlighting

Summary:

New generation LEDs exhibit high performance regarding their use in LC display backlighting.
Through the combination of new chip technology and various packaging designs from miniature to high-power packages, LEDs can be used in many application areas, and fulfill the associated brightness requirements.

In the area of color management and the displayable color space (~120% NTSC), LEDs clearly surpass the customarily used CCFLs and in addition, are insensitive to mechanical stress and vibration.

The many advantages of LEDs and their continual further development in the areas of efficiency and output intensity make them even more attractive for use as a light source for backlighting; in many application areas, they have already established themselves as a standard.

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