

# LEDs for LCD backlighting in Mobile PCs

## Application Note

### Abstract

This application note introduces several LEDs which are particularly well suited for use as a light source for LCD backlighting in mobile PCs.

In addition to the principle construction of backlighting units, an overview of the most important advantages associated with the use of LEDs as a light source is given. Critical parameters and points will be addressed and discussed as well.

Furthermore, the modification of a customary notebook LCD panel is described and the effects relating to the use of LEDs in comparison to cold cathode fluorescent lamps (CCFLs) are shown.

### Introduction

With mobile devices such as notebooks, a battery typically supplies the power for the electrical components.

The operational time is primarily dependent on the capacity (stored energy) of the battery and the average power consumption of the device.

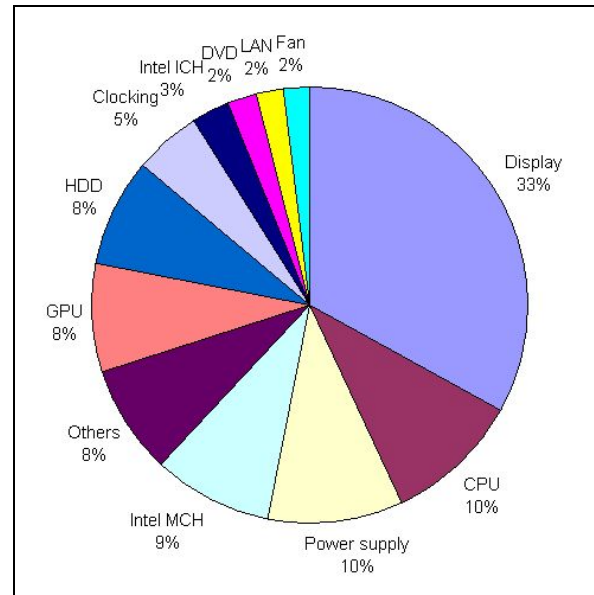
In the end, this means that the greater the energy consumption of the device, the shorter the operating time of the battery.

In order to achieve a longer battery operating time, the power consumption of certain individual components must be reduced.

The following graphic shows an overview of the average power consumption of various functional groups within a notebook.

Investigations regarding potential power savings show that in normal operation, the

LCD display consumes around one third of the battery capacity.



**Figure 1: Overview of the average power consumption of various functional groups in a notebook. Source: Intel**

The remaining components of a notebook require a significantly smaller share.

The processor only becomes disadvantageous under computationally-intensive applications.

Thus, during normal operation, the display is responsible for the greatest consumption of energy.

Current backlighting by means of cold cathode fluorescent lamps (CCFLs) requires around 65 to 70% of the display power. The backlighting therefore contains significant potential for reducing power requirements and thus increasing battery life.

As an alternative light source, LEDs are particularly well suited for backlighting. In addition to many other advantages when

compared to CCFLs, LEDs possess the necessary efficiency for a reduction in electrical power.

## Comparison of LCD backlighting with LEDs and CCFLs as a light source

If one compares current backlighting with CCFLs and novel versions using LEDs as a light source, it can be seen that in addition to the general advantages of LEDs, there is also a system-related potential for improving the construction and design of the LC display.

## CONSTRUCTION OF LCD BACKLIGHTING

In general, LC displays are constructed according to a common scheme. The display consists of an LC panel for the display of information and a backlighting module.

The backlighting primarily consists of one or more light sources, a unit for planar distribution of the light as well as various diffusers and micro-structured prismatic foils which serve to additionally homogenize and increase the brightness.

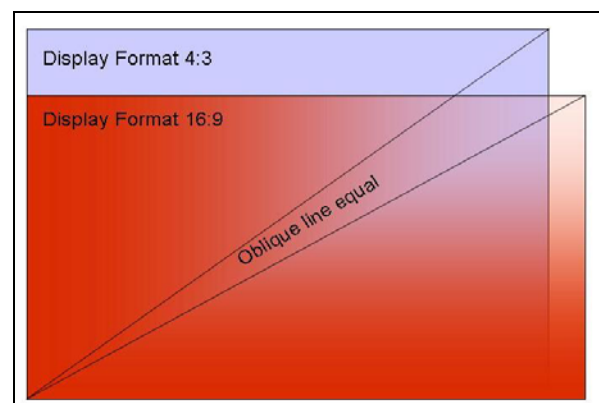
For planar distribution of the light, surface structured light guides of plastic (e.g. PMMA, PC) are predominantly used.

The light is usually coupled from one side and deflected by means of reflection to the emitting surface of the light guide.

The quality of the backlighting and homogeneity of the planar illumination is thus decisively determined by the light guide and its surface structure.

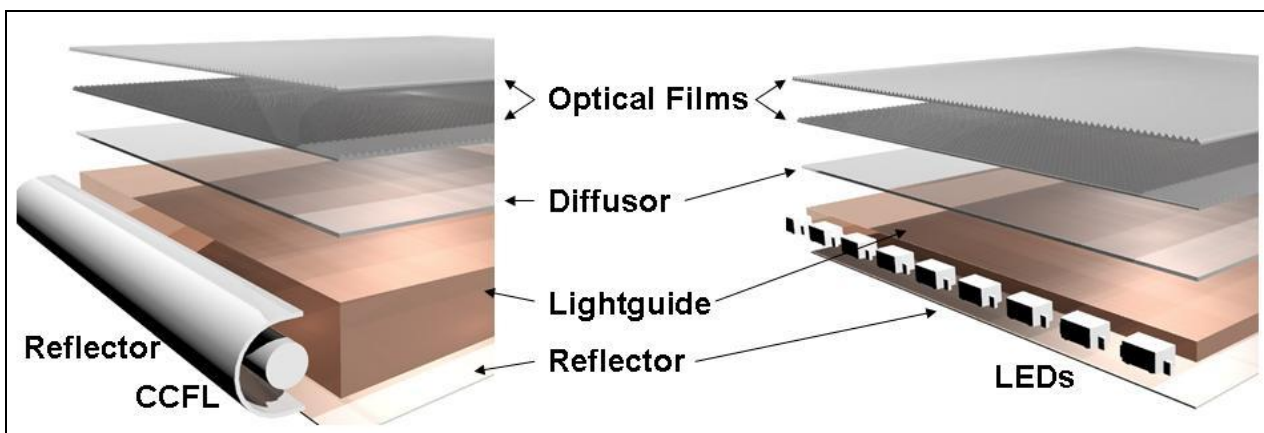
Displays for mobile PCs are typically designed with a brightness of around  $250 \text{ cd/m}^2$  (= nits) with a display size of 12 to 17 inches.

Recently, a trend away from the previous standard 4:3 format to a 16:9 or 16:10 format can be observed.



**Figure 3: Preferred display formats**

The new format has the advantage that it corresponds to the natural human field of vision and also to the display format of film. In addition, the shorter display height makes it easier to achieve a homogeneous illumination, since the light must not be directed and distributed over a greater distance.



**Figure 2: Principle backlighting construction**

The somewhat longer display side also allows more light to be provided and coupled to the light guide.

Changing to the new formats also has a slight disadvantage: For the same diagonal, the area is around 11% or 6% (16:10) smaller.

## GENERAL BENEFITS OF LEDs VS. CCFLs FOR USE IN MOBILE PCs

The general advantages of LEDs over CCFLs are due to the packaging technology and/or the physical characteristics of the semiconductor, such as:

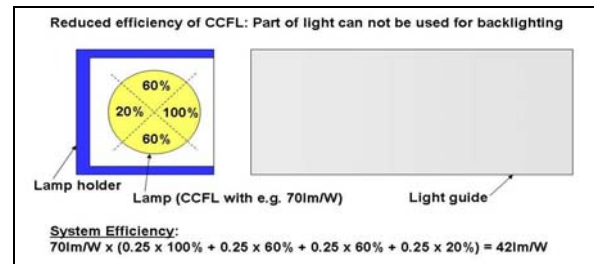
- Lower power consumption  
→ extended battery life
- LED life time
- Vibration and shock resistant
- Scalability
- RoHS compliant  
(mercury free, lead free)
- Temperature range (-40 → 85°C)
- Luminance uniformity & color gamut equal or higher
- Low voltage DC (low EMI, no inverter)
- Instant light on and off (< 100 ns)
- Easy LED driving & unlimited dimming
- Direct CCFL replacement possible, no additional system cost

If one compares the pure efficiency levels of both technologies, it can be shown that all together, a greater luminous flux is provided by the CCFL than by the LEDs for the same power.

In practice, however, the entire luminous flux of the CCFL cannot be used for backlighting, since due to the construction, only a fraction of the light can be coupled to the light guide from the side.

The real efficiency of the CCFL is thus considerably lower.

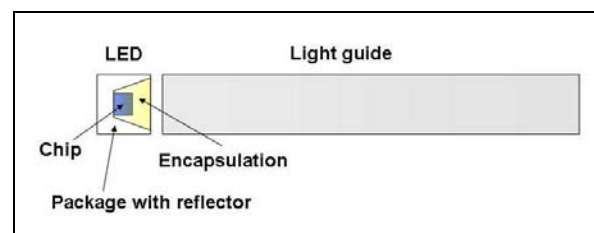
For a CCFL with an optical efficiency of 70 lm/W, for example, this means that in the system, a real efficiency of only 42 lm/W can be used.



**Figure 4: System efficiency of CCFL**

In comparison, an efficiency of 50 lm/W and more can be achieved nowadays with white LEDs.

With the construction of the specified single-sided radiation in the system, nearly 100% of the luminous flux can be used for backlighting.



**Figure 5: Setup and alignment of LEDs**

The currently available white LEDs are already more efficient and fulfill the requirements regarding display brightness and reduced power consumption as well.

Furthermore, a continuous improvement in efficiency can be expected from advancements in semiconductor technology.

## ADDITIONAL CONCEALED ATTRIBUTES OF LEDs FOR IMPROVING SETUP AND DESIGN OF LCD MODULES

In addition to the general positive characteristics, there are further features of LEDs which are advantageous for the construction and design of the LCD module.

### SETUP - REDUCED THICKNESS AND WEIGHT

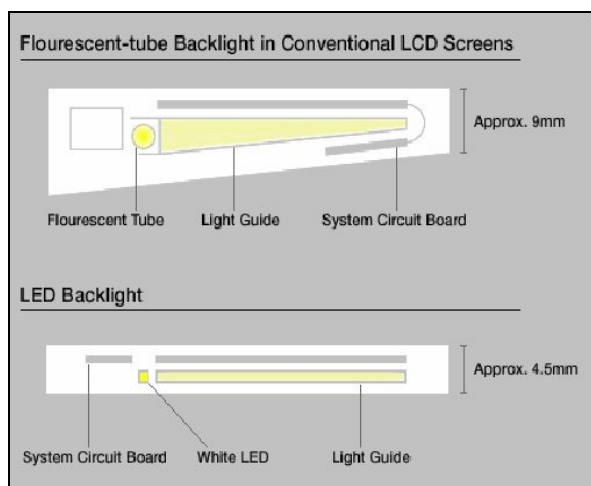
In addition to the housing, the thickness and weight of LCD modules is primarily determined by the light guide used for backlighting.

The properties of the light guide such as its dimensions and form are in turn, determined and influenced by the light source used.

This means that the smaller the light source is, and the more directly the light can be supplied, the thinner the light guide can be formed and the less weight it will have.

With CCFLs as a light source, the thickness is predefined by the minimum size of the lamp holder (reflector). A further reduction is not possible, since otherwise an insufficient amount of light is coupled and the system efficiency is reduced.

The total thickness of LCDs with a CCFL light source is typically less than 1 cm.



**Figure 6: Comparison of thickness**

With LEDs as a light source, the thickness of the light guide is predetermined by the height of the LED package or more precisely, by the light opening.

Depending on the type of LED used, the thickness of the light guide can be reduced to that of the foil ( $\geq 0.6$  mm).

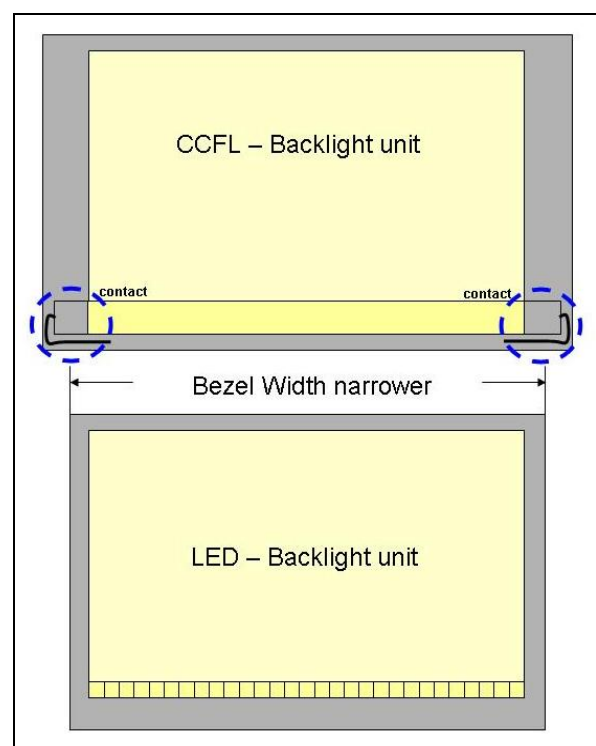
The construction of displays with LED light sources can therefore be kept considerably thinner and lighter. The total display thickness can be limited to a few millimeters (2 - 4 mm).

## DESIGN - NARROW BEZEL

The influence of the light source can also be seen with LCD design and the thickness of the housing.

Since the electrical contacts of the CCFLs are at the ends of the tube and these do not produce any light, the display width must correspond to the effective illuminated length of the lamps. As a result, the LC panel must be extended on both sides to accommodate the contacts of the CCFL.

For the LCD module, this means that the panel bezel requires a certain width at the edges.



**Figure 7: Comparison of panel bezels**

In contrast, LEDs can be arranged such that they are flush with the edge of the LC panel. In most cases, they are placed somewhat inwards, due to their radiation angle, in order to prevent excess illumination at the corners.

For the same display size, LEDs permit a housing with a narrower frame to be designed, in comparison to CCFLs.

## LEDs for LCD Backlighting in Notebooks

From the numerous types of LEDs available, essentially only miniature packages with minimal dimensions are suitable for backlighting of LCDs in mobile PCs.

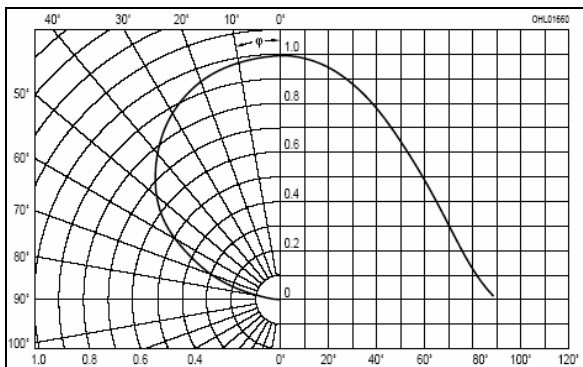
In this case, the radiation mainly occurs to the side, whereby nearly the entire light can be coupled and distributed in the light guide.

Currently, there are two white LEDs from the OSRAM OS product portfolio which are particularly well suited in fulfilling the given requirements as a light source for mobile devices and can be used for backlighting.

Both LEDs are of the type "Micro SIDELED<sup>®</sup>" and mainly differ in size and radiation characteristics.



**Figure 8: Micro SIDELED<sup>®</sup> LW Y1SG, 0.8 mm**



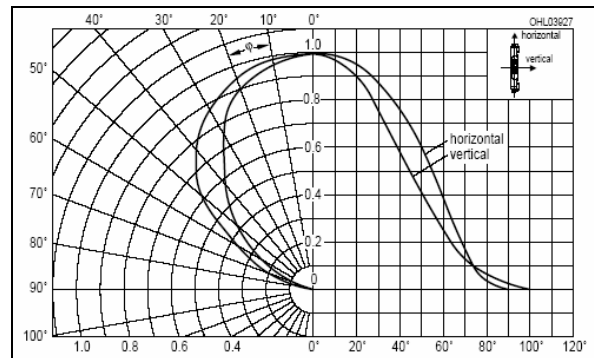
**Figure 9: Micro SIDELED<sup>®</sup> LW Y1SG radiation characteristics**

The larger LED, designated LW Y1SG, has a component height of 0.8 mm, a maximum luminous intensity of 1.4 cd @ 20 mA and shows Lambertian emission characteristics.

The smaller LW Y3SG has a height of 0.6 mm, a maximum intensity of 1.6 cd @ 20 mA and radiates the light within a smaller angle, both horizontally (110°) and vertically (90°).



**Figure 10: Micro SIDELED<sup>®</sup> LW Y3SG, 0.6 mm**



**Figure 11: Micro SIDELED<sup>®</sup> LW Y3SG radiation characteristics**

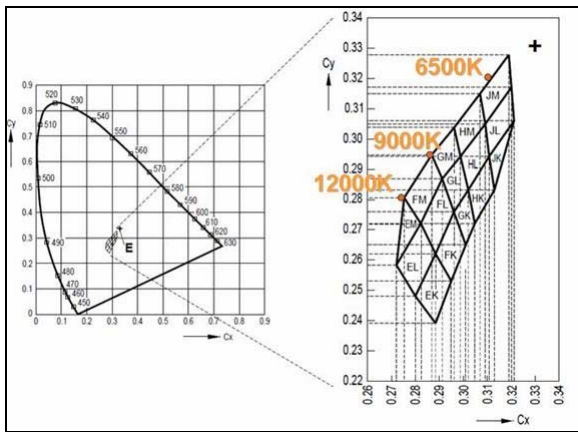
Since the light is radiated to the side with the aid of a reflector, the Micro SIDELED<sup>®</sup> is ideal for the backlighting of LCD panels, particularly for notebook applications.

Currently, it is already being used as a standard product for backlighting of small LCDs used in mobile phones, digital cameras and other consumer electronic products, for example.

As with all available LEDs, the Micro SIDELED<sup>®</sup> is sorted into various groups or bins after production. The brightness, color coordinates of the white point and the forward voltage are used as selection criteria for this type of LED.

The limits for the classification of the individual white groups are thus very narrowly defined.





**Figure 12: White groups of the Micro SIDELED®**

As can be seen from Figure 13, several shades of white are obtainable.

The lower white groups (> 9000 K) show a somewhat bluish appearance; in the upper group, the white takes on a more yellowish appearance (touch).

Delivery of the Micro SIDELED® generally occurs by means of a taped reel which only contains one brightness group and one white group.

Since OSRAM-OS continually makes improvements to the luminous intensity of LEDs, please check the individual data sheets of the LED types for further details and the latest performance data ([www.osram-os.com](http://www.osram-os.com)).

## LED CHARACTERISTICS RELATED TO BACKLIGHT OPERATION

Since semiconductor diodes are used for creation of light in LEDs, the specific characteristics which are relevant for usage in backlighting should be more closely considered and observed.

### Thermal considerations

In general, in order to maintain reliability and optimal performance, the junction temperature of the Micro SIDELEDs® should not exceed the allowable maximum of 95°C. If necessary, suitable thermal management should be adapted for the LED module.

Basically, LED warming originates from two sources, whereby one is external in origin (existing ambient temperature) and the other from internal activities (current dependent power losses).

The result is that not all operational conditions are suitable or permitted for a particular ambient temperature.

In the corresponding data sheets, the maximum allowable currents for DC operation and various pulse loads are given for two ambient temperatures ( $T_A = 25^\circ\text{C}$  and  $T_A = 85^\circ\text{C}$ ).

For all cases in between, the maximum operating conditions can be estimated by interpolation of the curves.

### Influence of junction temperature

Basically, the maximum allowable junction temperature should not be exceeded, since this can lead to irreversible damage to the LED and spontaneous failure.

Due to the fundamental physical interdependencies which arise with the operation of light emitting diodes, changes in the junction temperature  $T_J$  within the allowable temperature range have an effect on several LED parameters.

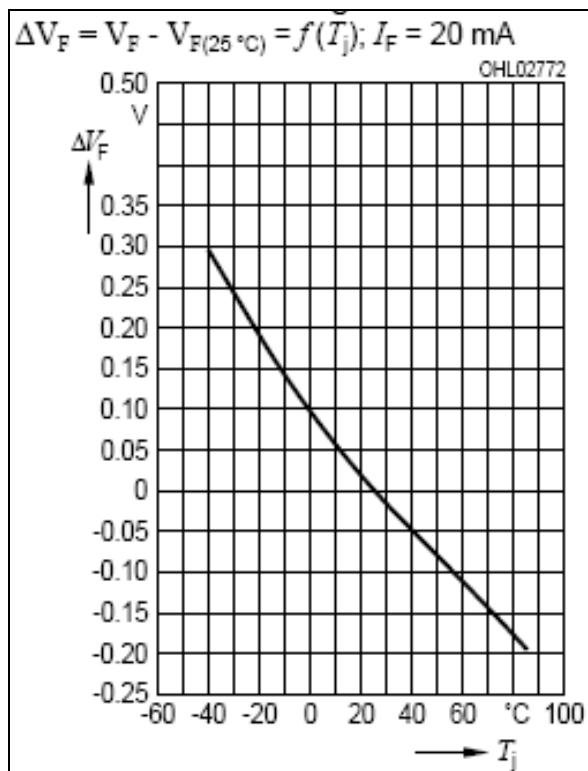
The forward voltage, luminous flux, wavelength (color) and lifetime of the LED are all influenced by the junction temperature.

Depending on the given requirements, this can also have an effect on the backlighting.

### Influence on forward voltage $V_F$ and luminous flux $\Phi_v$

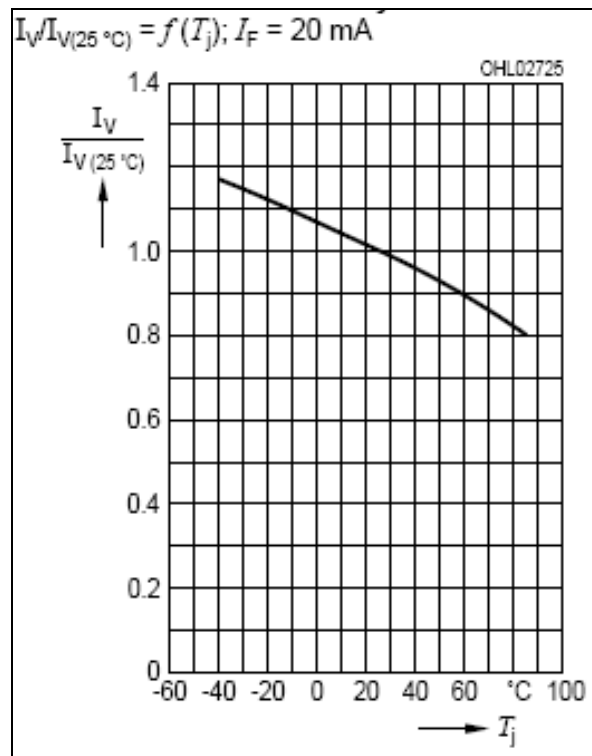
For LEDs, an increase in junction temperature leads to a decrease in the forward voltage  $V_F$  (Figure 13), as well as a reduction in luminous intensity  $I_v$  (Figure 14).

The changes which arise are reversible. That is, the output values return to their original level when the temperature change is reversed.



**Figure 13: Relative forward voltage vs. junction temperature (e.g. LW Y3SG)**

For use in backlighting, this means that the lower the junction temperature  $T_J$ , the greater the light output will be. On the other hand, this means that the display will become darker as the junction temperature in the LCD panel rises.



**Figure 14: Relative luminous flux vs. junction temperature (e.g. LW Y3SG)**

*Chromaticity coordinates (x/y color coordinates)*

The influence on the chromaticity coordinates by a change in junction temperature appears as a reversible shift in the output values.

The amount of the shift can be calculated by means of the respective temperature coefficients (Table 1).

Temperature coefficient [ $10^{-3}/K$ ]	
<b><math>TC_x</math></b> $I_f = 20 \text{ mA}, -10 < T < 100^\circ\text{C}$	-0.2
<b><math>TC_y</math></b> $I_f = 20 \text{ mA}, -10 < T < 100^\circ\text{C}$	-0.2

**Table 1: Typical temperature coefficients of the color coordinates x and y of the LW Y1SG**

An increase in temperature to  $40^\circ\text{C}$ , for example, leads to a shift in the color coordinates of -0.008 in this case.

The shift leads to a minimal change in appearance and can also have an influence on the backlighting, depending on the given requirements.

Depending on the requirements, it must be determined if this shift can be tolerated, or that appropriate measures can be taken to avoid or at least compensate for temperature related effects.

#### Reliability and lifetime

With regard to aging, reliability and performance, driving LEDs at their maximum allowable junction temperature is generally not recommended. With increasing temperature, a decrease in the lifetime can be observed.

Conditions	Median Lifetime	Unit
$I_F = 15 \text{ mA}$ $T_A = 25^\circ\text{C}$	>50,000	Operating hours

**Table 2: Exemplary median lifetime for typical brightness group (e.g. LW Y3SG)**

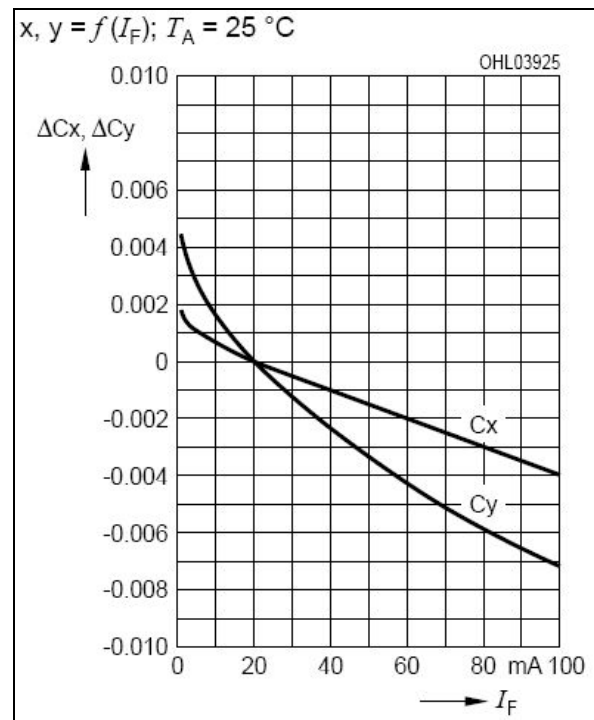
#### Electrical considerations

As with all white LEDs in which white light is created by means of a blue semiconductor die and phosphor conversion, the white Micro SIDELEDs® show a dependency of the chromaticity coordinates on the forward current applied (Figure 15).

This has the effect that a change in forward current also causes a shift in the chromaticity or xy color coordinates. Relating to the output chromaticity coordinates at the grouping current ( $I_F = 20\text{mA}$ ), a reduction in current leads to a slight shift in the yellow direction and an increase in the blue direction.

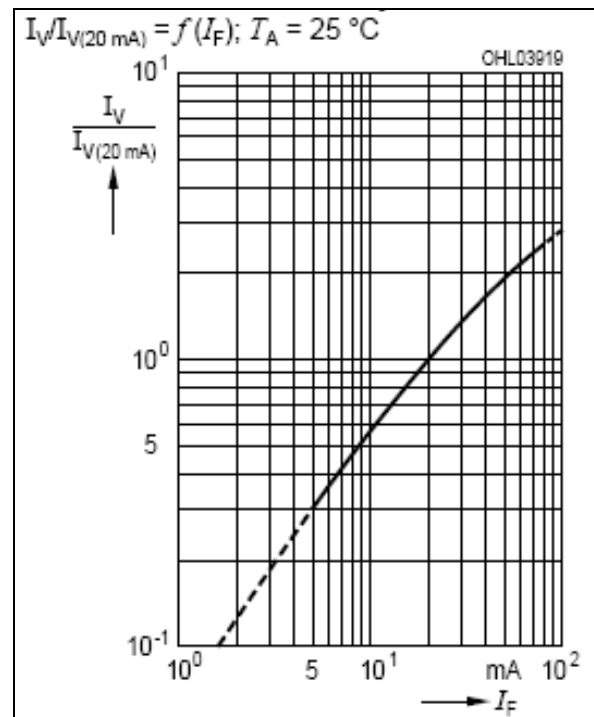
Finally, this can mean a change in the color appearance for the backlighting. Particular attention must be given when dimming the LEDs (see also the application note "Dimming InGaN").

Furthermore, the brightness of an LED does not linearly rise or fall with respect to forward current, due to the physical characteristics of the semiconductor diode.



**Figure 15: Chromaticity coordinate shift vs. forward current (e.g. LW Y3SG)**

As a result, the forward current must be significantly raised if the luminous flux is to be doubled from a specific value. This effect can also be seen in the following diagram (Figure 16).



**Figure 16: Relative luminous flux vs. forward current IF (e.g. LW Y3SG)**



Since the LEDs are usually driven with a constant high current, it is recommended that when developing the control circuitry, care should be taken that a function for pulse width modulation (PWM) is included.

The PWM function offers the distinct advantage that the brightness can be dimmed to any desired level and at the same time, the chromaticity coordinates can be held constant, since the current level remains constant and only the pulse width changes.

## Challenges linked with LEDs

In addition to the many advantages, certain design challenges also arise with the use of LEDs.

These are primarily based on the fact that the LEDs are nearly point light sources in which a homogeneous area should be illuminated or backlit.

### COMPLEXITY OF OPTICAL PATH

In contrast to CCFLs which emit their light nearly homogeneously over their entire length, the light of LEDs is positionally limited and is emitted as a point with a predefined radiation angle.

For backlighting, this means that the light is emitted as several points along the side of the light guide and must be homogeneously distributed at that location.

A homogeneous mixing through the radiation angle first requires that a particular distance is maintained.



**Figure 17: LED arrangement and mixing area**

The size of the mixing area required depends on the distance between LEDs and the radiation angle.

In the example shown above, the radiation angle of the LEDs is  $120^\circ$  and the distance between LEDs is 10 mm. As can be seen in the image, the light distribution first becomes homogeneous at a distance of 7 mm. Within the first 7 mm, dark, non-illuminated areas are displayed.

For backlighting, this means that in the end, the light guide must be extended by this mixing area.

If the light guide were made smaller, brighter points of light - so-called hot spots - would be displayed at the edge of the display.

A reduction of the mixing area can only be achieved with a smaller offset between LEDs and/or a larger radiation angle.

The size of the radiation angle itself is again limited by the limit angle of total reflection at the light guide.

A further way to minimize the mixing area is offered by the light guide itself. Through an additional structuring of the surface at the coupling side, the light can already be diffused at the input. This can be achieved with imprinted prisms or lens formations, for example. This is also associated with additional costs, however.

Generally, it can be said that the LED offset must be less than 7 mm in order to keep the mixing area less than 5 mm.

### INTERACTION OF VARIOUS PARAMETERS DISTANCE – NUMBER – POWER – COSTS

Through the LED offset itself, other parameters are influenced and visa versa. Thus, the offset determines the minimum LED count required for a certain display size.

On the other hand, the LED count determines the power budget for a particular brightness group, which has a decisive influence on the operational time of the battery.

In addition, the LED count also determines the costs for illumination.

For the LED backlighting, this means that ultimately, one cannot optimize individual parameters; an optimization must take place with respect to the entire design.

The following Table 3 shows this type of optimization for several display diagonals, whereby the additional focus is a minimum LED count.

#### CONSISTENT LIGHT AND COLOR ACROSS SCREEN

Due to the positional arrangement when using LEDs, one must pay particular attention to a uniform appearance with respect to light and color throughout the display.

In order to achieve a uniformly bright white screen, the LEDs used should theoretically possess nearly identical brightness and chromaticity coordinates.

In practice, however, it suffices that the LEDs all lie within one brightness or chromaticity group. The reason is that the group limits are typically chosen such that deviations within the group cannot be recognized or perceived by the human eye.

A construction with LEDs from different brightness groups and/or chromaticity groups should therefore be avoided.

A change can lead to non-homogeneity and differing color impressions within the display. Figure 17 shows such an example. With this prototype, LEDs of the same brightness group but differing white groups were arbitrarily employed. As can be seen in the image, a spotty total color impression is shown.

LCD diagonal	12.1"	14.1"	15"	15.4" wide	17" wide
Length	261 mm	286 mm	304 mm	331 mm	382 mm
Width	199 mm	214 mm	228 mm	207 mm	245 mm
LED pitch	6.5 mm	6.0 mm	5.7 mm	6.2 mm	5.3 mm
Mixing distance	4.6 mm	4.3 mm	4.0 mm	4.4 mm	3.7 mm
LED number	40	47	53	53	72
LED power @ 200 nits	2.3 W	2.7 W	3.1 W	3.1 W	4.2 W
LED power @ 60 nits	0.5 W	0.6 W	0.7 W	0.7 W	1.0 W
Calculation based on luminous intensity of typ. 1400 mcd per LED					

Table 3: LCD Size — LED Distance – Mixing Area – LED Number – LED Power

## Example of a LED backlight

For demonstration purposes and in the course of a study, a customary notebook with a 15.4 inch LCD panel was modified with white LED backlighting.

In this process, all original components such as the light guide, foils and filters were retained. The existing CCFL, reflector and control circuitry were removed after measuring the light intensity, homogeneity and color space.

As a light source, a light bar of 50 LEDs of type LW Y3SG with a brightness of 1400 mcd @ 20 mA, was mounted on a 0.2 mm thick flexible PCB.

The LEDs were arranged in 5 strings, each with 10 LEDs and wired in parallel. Typically, the circuit is designed such that the supply voltage does not exceed 50 V.

The LED light bar therefore has total power consumption of 3 W.

During construction of the LED bar, particular care was taken to ensure that all LEDs were soldered onto the board in a straight line and parallel to the PCB surface, and that no LEDs were tipped or rotated on the PCB.

Afterwards, the modified display was measured. It was shown that in comparison to the previous CCFL backlighting, the display with the LEDs produced a brighter (200 nits) and more homogeneous illumination.

If one were to use a light guide specially designed for the LEDs with an optimized coupling structure and appropriate dot distribution instead of the existing light guide, an additional improvement with regard to brightness and homogeneity is possible.

Regarding the aspect of "power consumption", a comparison showed that the LED backlight had a significantly lower energy consumption than the CCFL display at the same brightness.

This was particularly true at a display brightness of 60 nits. Here, the power loss was less than half as much (~60%). For the power supply, this means that the operational time of the battery increased by around one hour.

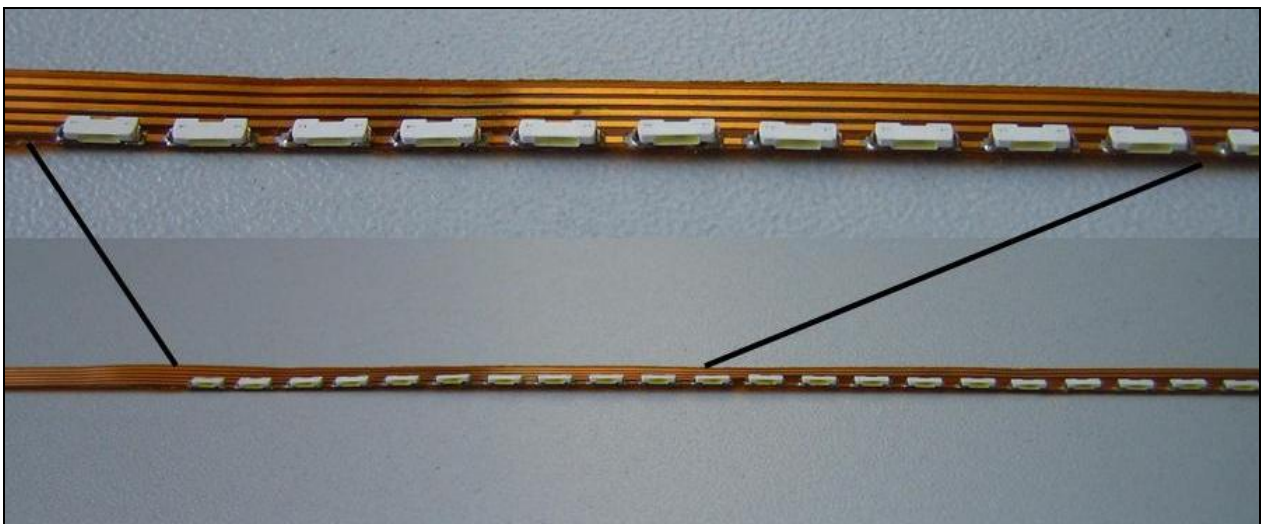


Figure 18: Setup LED light bar

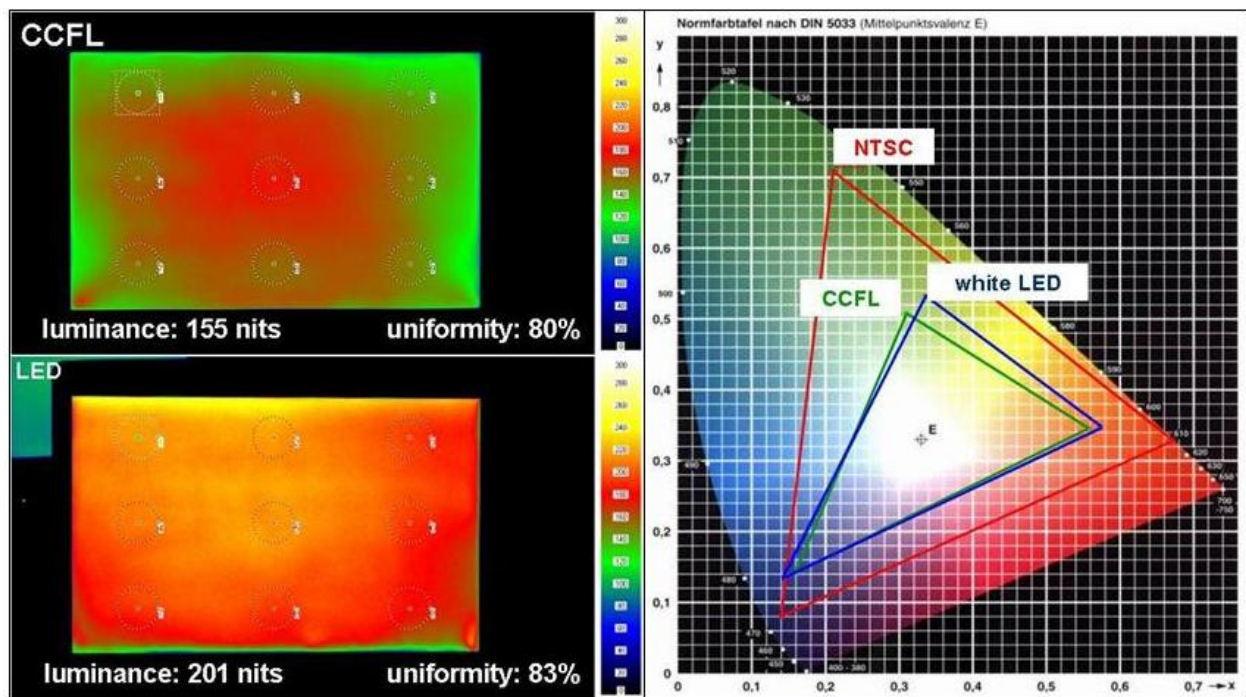


Figure 19: Comparison of Luminance, uniformity and color gamut

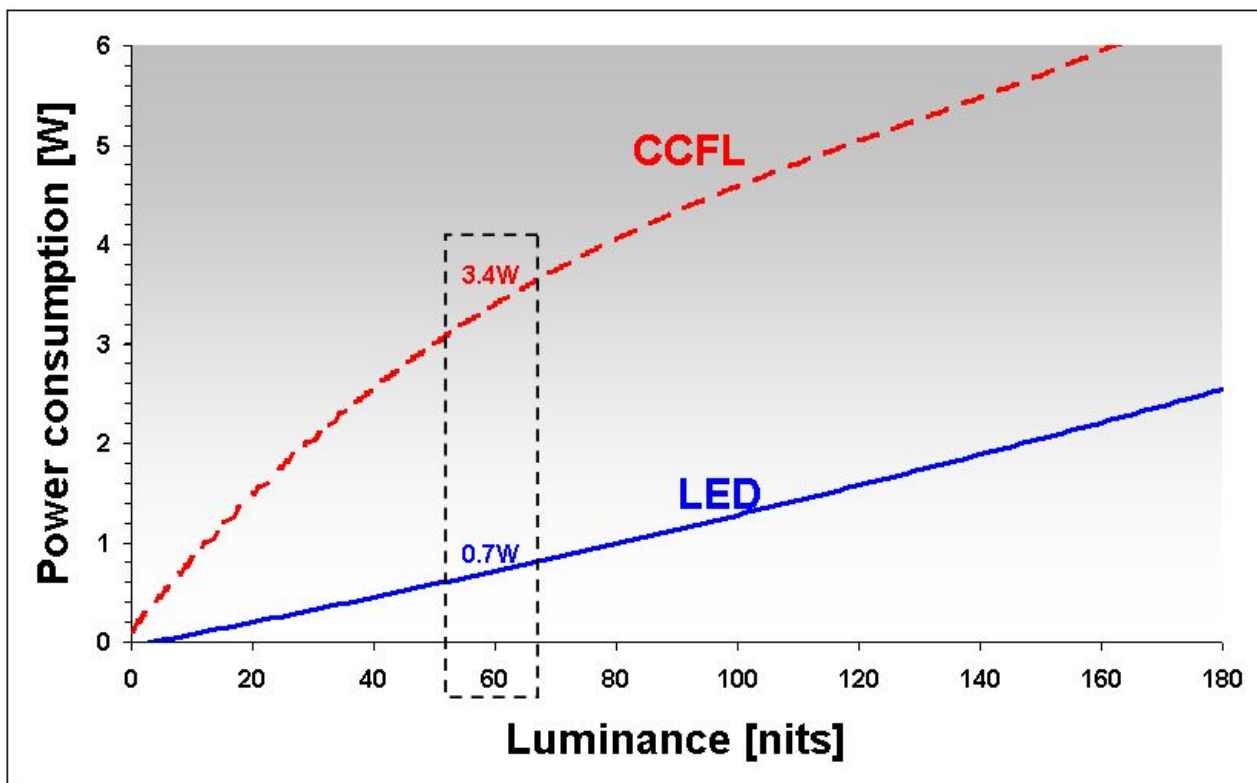


Figure 20: Comparison of power consumption of CCFL vs. LED 15.4 inch backlights



A visual comparison of the different LCDs also shows the advantages of the LED backlighting. Due to its improved color space, the image has more detail and is altogether more plastic in appearance.

LCDs with white LED backlighting already surpass the customary CCFL technology with regard to color range, homogeneity and brightness.

With regards to color space, a significantly greater breadth can be achieved with an LED solution based on the individual colors red, green and blue. The control circuitry and equalization of this RGB solution is indeed a bit more complex; it would be easier to extend or exceed the NTSC color space.

## Conclusion

As the modified notebook with the 15.4 inch LCD panel shows, today OSRAM OS provides already with the LED LW Y3SG a highly-efficient LED solution which can immediately replace the customary CCFL backlighting technology without additional system costs.

In addition to material conditions and mechanical advantages over CCFLs such as being mercury/lead free and vibration/shock resistant, the LEDs also fulfill the requirements of lower energy consumption which increases the operational time of the battery.

With the availability of fast LCD panels, an LED RGB backlight solution will additionally permit sequential color operation. In connection with this, a further improvement in efficiency by a factor of 4 must be achieved.

The use of LEDs as a light source for backlighting has established itself as a standard in many application areas due to their many advantages and continuous further development in the areas of efficiency and greater light output. In the future, they will also be used in mobile PCs such as notebooks, tablet PCs PDAs e-books etc.



**Figure 21: Comparison of phenotype**



## Appendix



**Don't forget:** LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

[www.ledlightforyou.com](http://www.ledlightforyou.com)

Authors: Andreas Stich

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