LEDs for liquid crystal display (LCD) backlighting - Part 2

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Summary: In Part 1 the author described the types and structures of LED LCD backlight units and their relative advantages. This installment concluded with a summary of market requirements for BLUs and a history of how they've driven their development. This second and final installment begins with a close look at recent market trends and technological development and concludes with the key points in the optical design of LED backlights.

Key words: LED LCD backlight, LCD backlight, backlight unit, LED backlight.

19.6 Market trends and technological developments

19.6.1 Market trends
Over the past decade, LEDs have slowly been incorporated into various LCD devices, initially in mobile phones and recently in LCD televisions. Due to a combination of factors, including the fact that OLED development has made less progress than expected, that there has been no significant breakthrough in the technology of other light sources used in LCDs and that the quality of LEDs has been continuously improved, LCDs with an LED BLU have gradually become the best choice for displays. For LCD devices, the quality and features of the light source affect or even directly determine the optical quality and market competitiveness of the LCD products. Several advantages of LEDs solve a few of the outstanding problems with LCDs. It is clear that using an LED inside an LCD has increased the mainstream status of LCDs. A market forecast for large BLUs based on a survey by LED inside published in August 2011 is shown in Fig. 19.4.
A cost forecast based on a survey produced by NPD DisplaySearch for different BLU types for 32-inch high-definition (HD) 60 Hz LCD televisions is shown in Fig. 19.5.\textsuperscript{4}

The high cost of LED BLUs obviously affects the commercial market penetration of LCDs based on LEDs. To reduce costs, television manufacturers have been adopting two-chip LEDs to reduce the number of LEDs. The number of LEDs used per set with a direct-type BLU is expected to be less than in a set with an edge-type BLU.\textsuperscript{4} Figure 19.6 shows a forecast for the number of LED packages per television set.\textsuperscript{17}
Overall the focus of technological development is to produce devices with: a slimmer body; higher quality (in terms of better brightness uniformity, higher brightness, less unevenness, lower color washout and higher color saturation); lighter weight; lower cost; larger size; narrower bezel (for aesthetic reasons and ease of application, e.g. for an LCD video wall); better environmental factors (lower carbon emissions, lower power consumption and less use of non-toxic materials); rapid switching or rapid scanning; wide brightness and contrast adjustment ranges; finer local dimming and more smart functions, for example, auto-adjusting the brightness. However, many of these technologies are conflicting, for example, display size and power consumption or thickness and brightness uniformity for direct-type BLUs. Based on these desired qualities, an ideal BLU can almost be realized with LEDs and LEDs are able to meet the requirements of any application.

For different products and different product positioning, there are different trends in the technological developments. Tables 19.5 and 19.6 respectively list these trends for the different products and product positioning.

**Table 19.5 Technological development trends for different products**

<table>
<thead>
<tr>
<th>Product</th>
<th>Common LED type</th>
<th>Common BLU type</th>
<th>Development trends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile phone</td>
<td>B-LED chip + Y phosphor</td>
<td>Low-power chip</td>
<td>Slimmer, Lighter weight, Narrower bezel, Lower power consumption, Wide brightness adjustment range, Auto-adjust the brightness, Environmentally friendly, Lower cost</td>
</tr>
<tr>
<td>Netbook</td>
<td>B-LED chip + RG phosphors</td>
<td>Medium-power chip</td>
<td></td>
</tr>
<tr>
<td>Notebook</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitor</td>
<td>B-LED chip + Y phosphor</td>
<td>Medium-power chip</td>
<td>Higher quality, Narrower bezel, Lower power consumption, Auto-adjust the brightness, Environmentally friendly, Lower cost</td>
</tr>
<tr>
<td></td>
<td>RGB chips LED</td>
<td>High-power chip</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RGB LED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Television</td>
<td>B-LED chip + Y phosphor</td>
<td>Low-power chip</td>
<td>All</td>
</tr>
<tr>
<td>Large announcement display</td>
<td>RGB LED</td>
<td>Medium-power chip</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-power chip</td>
<td></td>
</tr>
</tbody>
</table>
The current status and the trends in development of LED LCD televisions are discussed below. Table 19.7 shows the status of the technology for LED LCD televisions.

<table>
<thead>
<tr>
<th>Product position</th>
<th>Common LED type</th>
<th>Common BLU type</th>
<th>Development trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-grade television</td>
<td>RGB LED</td>
<td>Low-power chip</td>
<td>Direct-type</td>
</tr>
<tr>
<td></td>
<td>B-LED chip + RG phosphor</td>
<td>Medium-power chip</td>
<td>Direct-type</td>
</tr>
<tr>
<td>Medium-grade television</td>
<td>B-LED chip + Y phosphor</td>
<td>Medium-power chip</td>
<td>Edge-type</td>
</tr>
<tr>
<td>Low-grade television</td>
<td>B-LED chip + Y phosphor</td>
<td>High-power chip</td>
<td>Direct-type</td>
</tr>
</tbody>
</table>

Recently, technological developments for LED LCD televisions using an edge-type structure have included:
- reducing the number of LED bars so that they are on one side instead of two sides to lower the cost
- reducing the thickness of the LGPs to reduce the cost, weight and module thickness
- reducing the chromaticity deviation of the LGPs
- using micro-structures with higher efficiency for the LGPs
- using local dimming technology
- changing the packaging from the 5630 type to the longer 7030 type.

For edge-type structures, the technological development of LED LCD televisions mainly focuses on cost and quality.

19.6.2 Advantages and key technologies of LED LCD televisions
Compared with CCFL-type LCDs, LED-type LCDs: 18
- produce images with greater dynamic contrast
- can be extremely slim with some screens less than half an inch (0.92 cm) thick 19
- offer a wider color gamut when an RGB-LED BLU is used 20,21
- produce less environmental pollution on disposal
- have typically 20–30% less power consumption
- are more robust and reliable
• have a non-linear, wider dimming range
• give full and flicker-free dimming at all temperatures down to 5% or lower
• can have a higher image quality
• can realize programmable chromaticity adjustments.

The key technologies used in LED LCD televisions that make them so advantageous include:
• LED spectral and LED light bar design
• good design potential
• thermal design
• optical design of modules
• integration and efficiency of the drive circuit
• local dimming technology.

19.6.3 New display technologies using LEDs: crystal LED displays

In early 2012, Sony Corporation announced that it had developed a next-generation self-luminous display technology called the crystal LED display, and unveiled a 55-inch crystal LED prototype at CES 2012. Each pixel of an ultra-fine RGB color LED chip is directly connected to a light emitter. For 1080 full HD resolution, the total number of LED chips is about 6 million. So far, according to information from Sony Corporation, compared with existing LCDs, the prototype has about 3.5 times the contrast ratio, 1.4 times the color gamut and 10 times faster response time.

(Continued on next page)

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19.7 Optical design

19.7.1 Design factors
According to the specific application requirements, some of the design factors to be considered are:
• diagonal display size
• panel thickness
• luminance
• color gamut
• thermal environment and associated constraints
• power limits
• dynamic contrast
• BLU cost.

19.7.2 Key design considerations
Compared to a CCFL-based BLU, the key design considerations include:
• designing the LED light guide bar to form line-shaped light, as in a CCFL
• for an edge-type structure, designing the micro-structure of the light injection surface of the LGP to diffuse light emitted from the LED chips fully
• for edge-type and direct-type structures, designing the secondary optical parts to diffuse light emitted from a middle- or high-LED chip array fully.

The effect of the micro-structure of the light injection surface of an LGP is shown in Fig. 19.7.
19.7.3 Edge-type BLUs
The optical design considerations for edge-type LED BLUs are listed in Table 19.8.

Table 19.8 Optical design considerations for edge-type LED BLUs
When the white LED light is just coupled into the LGP, the light is more concentrated in front of the LED and then slowly spreads out. This unequal distribution of the light creates a hot spot. Using the estimated length of the color mixing area as a model, the rough length of the hot spot area $L$ for an injection surface without a micro-structure can be written as:

$$L = \frac{(p-w)/2}{\tan \left[ \sin^{-1} \left( \frac{\sin \alpha}{n} \right) \right]}$$

[19.1]
where \( p \) is the LED pitch, \( w \) is the width of the LED emitting area, \( \alpha \) is a half of the half-intensity angle and \( n \) is the LGP index. Schematic diagrams of these parameters and light propagation are shown in Fig. 19.7. This estimated result is very rough. If the selected LEDs are multi-color, the estimated length of the color mixing area is the same as in Eq. 19.1, except that \( p \) is modified to represent the maximum pitch between equal color LEDs.\(^{24}\)

To meet the requirements for a narrow bezel and uniform brightness, the LED hot-spot problem needs to be eliminated, which can be achieved using microstructures such as prisms, pyramids, cylindrical or conventional lenses. These are used on the light injection surface of an LGP to couple and diffuse the light efficiently from the LEDs into the LGP.\(^{7}\)

The secondary optical element is also used to diffuse the light fully to form an approximately linear light source injecting into the LGP.\(^{25}\) A total internal reflection lens has been designed and used to improve the brightness and uniformity of the backlight. The brightness and uniformity were improved by 40% and 83%, respectively, compared with a conventional backlight unit. Furthermore, the technologies used for the LGP and optical films are the same as for a CCFL-type device.

Listed below are some examples of applications of LED edge-type BLUs. A 19-inch LCD monitor with a six-lead MULTILED\(^{®}\), the LRTB G6SG, was developed by OSRAM Opto Semiconductors.\(^{26}\) It uses a light bar with 77 LEDs and an LED pitch of 5 mm instead of some of the CCFLs. Only two of the CCFLs were replaced and the rest of the design (housing, light guide, optical films, etc.) remained unchanged. It only requires a passive cooling system of ventilation slots in the housing and the MCPCBs were mounted on thin heat sinks. Due to the continuous increasing LED brightness, a smaller number of LEDs are needed and the heat generated is relatively reduced.

![Figure 19.8 Edge-type LED BLU with high-power side-emitting white Luxeon™ LEDs.\(^{27}\)](image)

Using high-power LEDs for larger LCD BLUs has clear advantages over small LEDs. Philips Lumileds Lighting Company developed an edge-type LED BLU with high-power side-emitting white Luxeon™ LEDs.\(^{27,28}\) The schematic construction is shown in Fig. 19.8. The light from the side-emitting LEDs is coupled into an LGP with an optical incoupling efficiency of 82%. This BLU has the advantages of a thin design and high coupling efficiency.

Consider a commercial 7-inch BLU in which the lighting area is 145.8 mm × 82.2 mm and the LGP thickness is 0.6 mm. The optical specifications and materials used are listed in Tables 19.9 and 19.10, respectively. Here \( L_{\text{min}} \) and \( L_{\text{max}} \) are the measured minimum and maximum luminance for the nine points shown in Fig. 19.9.

![Figure 19.9 Optical specifications for a commercial example of a 7-inch BLU](image)
Table 19.10 Materials used in a commercial example of a 7-inch BLU

<table>
<thead>
<tr>
<th>Part</th>
<th>Quantity</th>
<th>Part model (supplier)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDs</td>
<td>7 pieces x 2 strings</td>
<td>NSSW206 (NICHIA)</td>
</tr>
<tr>
<td>MCPCB</td>
<td>1</td>
<td>AL-5052 (CS Aluminium)</td>
</tr>
<tr>
<td>Reflector sheet</td>
<td>1</td>
<td>RW188 (Kimoto)</td>
</tr>
<tr>
<td>Light guide plate</td>
<td>1</td>
<td>Idemitsu LC-1500 (PC material) (Green Point)</td>
</tr>
<tr>
<td>Diffuser</td>
<td>1</td>
<td>BS-04(188) (Keiwa)</td>
</tr>
<tr>
<td>Prism sheet (horizontal)</td>
<td>1</td>
<td>BEF III-T 90/50 (3M)</td>
</tr>
<tr>
<td>Reflective polar</td>
<td>1</td>
<td>DBEF-D400 (3M)</td>
</tr>
</tbody>
</table>

H and W are measured in the vertical and horizontal directions, respectively. To avoid the hot spot area, the lighting area begins at 3 mm away from the incident surface. The optical design considerations for this example are shown in Table 19.11.

Consider a commercial example of a 46-inch BLU. The requirements are specified in Table 19.12. The optical measured positions are shown in Fig. 19.10.

19.7.4 Direct-type BLUs
Compared with a CCFL-based BLU, the most important point of optical design for an LED-based BLU is designing the secondary optical parts to diffuse the light emitted from the medium- or high-power LED chip arrays fully.
**Figure 19.9 Measured positions for the 7-inch BLU**

**Table 19.11 Optical design considerations for a commercial example of a 7-inch BLU**

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection and configuration of LED type</td>
<td>White top-view-type LED, NF5W036C, is used. Two strings of LED strips are arranged on the long side.</td>
</tr>
<tr>
<td>Diffusing light emitted from LED chips</td>
<td>There is no micro-structure on the light injection surface of the LGP.</td>
</tr>
<tr>
<td>LGP geometry, physical properties and process</td>
<td>A flat-shaped PMMA LGP is used and fabricated by injection molding.</td>
</tr>
<tr>
<td>Selection of the extraction patterns and design of the extraction pattern density on the bottom surface of the LGP</td>
<td>The extraction pattern structure is fabricated by etching. It is designed according to previous experience and software tools.</td>
</tr>
<tr>
<td>Injection molding or flat panel cutting</td>
<td>The LGP is fabricated by injection molding.</td>
</tr>
<tr>
<td>Selection and disposition of optical films</td>
<td>Selection and disposition of optical films will affect the viewing angle, efficiency, optical quality and cost.</td>
</tr>
<tr>
<td>Chromaticity uniformity</td>
<td>LEDs from different color bins cannot be used on the same MCPCB.</td>
</tr>
<tr>
<td>With or without local dimming</td>
<td>Local dimming is not used.</td>
</tr>
</tbody>
</table>

**Table 19.12 Requirements specification for a commercial example of a 46-inch BLU**

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td>LED bar arrangement Bottom (single side)</td>
</tr>
<tr>
<td></td>
<td>Package type top-view, 5630</td>
</tr>
<tr>
<td></td>
<td>LED phosphor RG or YAG</td>
</tr>
<tr>
<td>LGP</td>
<td>Thickness 3 mm</td>
</tr>
<tr>
<td>Optical films</td>
<td>Reflector sheet 1 piece</td>
</tr>
<tr>
<td></td>
<td>Diffuser plate 1 piece</td>
</tr>
<tr>
<td></td>
<td>Prism sheet 1 piece</td>
</tr>
<tr>
<td>Optical specification</td>
<td>Brightness 6900 cd/m²</td>
</tr>
<tr>
<td></td>
<td>Luminance uniformity Minimum 75%, typical 80%</td>
</tr>
<tr>
<td></td>
<td>Chromaticity uniformity Δx=0.015, Δy=0.016</td>
</tr>
<tr>
<td></td>
<td>Chromaticity shifting Δx=0.003, Δy=0.003</td>
</tr>
<tr>
<td>Power</td>
<td>LED electric power 63 W</td>
</tr>
</tbody>
</table>
If low-power LEDs are adopted, the structure is generally simple and does not have secondary optical parts. The estimated thickness of the light-mixed cavity $H$ can be written as:

$$H = \frac{(p - w)}{2} \tan \alpha$$

where $p$ is the maximum pitch between equal color LEDs, $w$ is the width of the LED emitting area and $\alpha$ is a half of the half-intensity angle. For the optical design of direct-type BLUs with medium- or high-power LEDs, the main considerations are listed in Table 19.13.

*Table 19.13 Optical design considerations for a direct-type LED BLU*
Some application examples of specific LED direct-type BLUs now follows. Consider a 23-inch direct-type BLU based on 72 high-power side-emitting RGB Luxeon™ LEDs consisting of two strips of 36 LEDs each. The LED pitch is 12 mm. The variance of the brightness profile of the resulting backlight as a function of the spacing between the two strips is shown in Fig. 19.11(b) with the spacing ranging from 50 mm to 120 mm.
For RGB LED BLUs, the color uniformity is a relevant performance parameter. The measured color uniformity for this BLU as a function of LED pitch is shown in Fig. 19.12. The upper and lower curves show results for a random placement of LEDs from R, G and B batches of LEDs (called unselected LEDs) and individual LEDs selected based on optimizing the flux for color uniformity (called selected LEDs), respectively. Comparing with the unselected LEDs, the color non-uniformity of the selected LEDs was reduced by approximately half.

By using LED selection, RGB LED light sources can easily be used for a BLU with higher color uniformity. A 32-inch LCD television based on high-power Golden DRAGON® ARGUS® LEDs, which are a Golden DRAGON® combined with a wide radiating ARGUS® lens, has been designed and manufactured. Figure 19.13 shows the arrangement of the RGGB LED clusters with a reflector cover foil. The ARGUS® lens deflects the light emitted from the chip to give a flat homogeneous distribution.
For optimum color homogeneity, a compact cluster arrangement is adopted. This BLU, used with a reflector box with an inner height of 35 mm, consists of 41 RGGB LED clusters mounted on an MCPCB. A hexagonal arrangement of the clusters with a pitch of 82 mm between cluster centers was used. For the thermal design, the RGGB LED clusters were mounted on a 2-mm-thick metal plate, without active cooling. The NTSC color gamut of the complete LCD television was up to 105%.

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