Suppressing color breakup in LCDs

An innovative approach significantly improves display performance while simultaneously enhancing the resulting contrast ratio and reducing power consumption.

Field-sequential-color LCDs (FSC-LCDs) potentially offer greater overall light-emission efficiency compared with conventional devices, as well as lower use of power. Their spatial color mixing differs from that of traditional LCDs (which employ color filters) by rapid sequential display of the red, green, and blue (R, G, B) fields for each optical frame. The individual color components are thus perceived separately by the retina, which could degrade the image quality when a relative velocity exists between the object on the screen and the observer’s eyes. This well-known visual artifact, illustrated in Figure 1, is called color breakup (CBU).

CBU-reduction methods have been developed in relation to digital light projectors, for which the field rate is increased to frequencies \(>540\text{Hz}\) or even up to \(1000\text{Hz}\). For LCDs, a number of methods have been proposed, including the insertion of black or monocolor fields, the ‘motion compensation’ technique, and the ‘four color-fields arrangement’ (4-CFA). However, the liquid-crystal (LC) response time at higher field rates (\(>300\text{Hz}\)) and the uncertainties due to the observer’s motion impose strict limitations on the application of these methods to large-size FSC-LCDs. In addition, all of these methods use monocolor fields to generate full-color images and suppress CBU.

Instead, we propose the ‘Stencil-FSC’ method to effectively suppress CBU based on a field rate of only 240Hz (for four subframes), which is achieved using traditional LC response modes. Conventional FSC-LCDs apply three primary-color (RGB) subframes to the same pixels in a time sequence to form a full-color image, as shown in Figure 2(b). If one casually looks at three high-luminance images, CBU will most likely be observed, reducing image clarity. Our idea, based on stenciling, is similar to first painting an undertone on a canvas and then sequentially adding other colors to complete a vivid, colorful image, as illustrated in Figure 2(c). Accordingly, we propose displaying a basic multicolor image on a first subframe, after which the luminance of the other three primary-color images is used to modify the details and render an image in vivid colors. As a consequence, less primary light is seen and CBU is suppressed.

Local color-backlight-dimming technology is used to obtain high luminance and rough colors for the initial subframe image. The LED backlight contribution is calculated using localized control technology to irradiate a low-resolution yet colorful image. Next, an LC cell with high-resolution pixels traces the detailed outline, without using color filters. Finally, a multicolor field image is obtained (see Figure 3).

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Table 1. Comparison of three 32in RGB LED-based LCD TVs.

<table>
<thead>
<tr>
<th>LED-based 32&quot; TV</th>
<th>Full-on LCD</th>
<th>RGB-FSC-LCD</th>
<th>Stencil-FSC-LCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>579:1</td>
<td>442:1</td>
<td>5973:1</td>
</tr>
<tr>
<td>Power (W)</td>
<td>180</td>
<td>67</td>
<td>44</td>
</tr>
<tr>
<td>CBU</td>
<td>None</td>
<td>Serious</td>
<td>Very slight</td>
</tr>
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Figure 3. Simulation results for the first subframe image. (bottom) Color backlight, (middle) minimum LC, and (top) the first subframe images.

Figure 4. (left) Backlight distribution of the first field of the Stencil-FSC-LCD. (right) Demonstration photos of four subframes on a 32in FSC-LCD based on the Stencil-FSC method. (Image ©2007 Microsoft Corporation.)

The Stencil-FSC method was implemented on a 32in Offset-Codebook-mode FSC-LCD with $1366 \times 768$ pixels, as shown in Figure 4 (left). The backlight module was divided into $16 \times 12$ divisions using 1152 ($48 \times 24$) LEDs. In Figure 4 (right) the first subframe picture represents a high-luminance, rough-color image. The other three subframes show low-luminance color details, eventually completing a full-color image.

To capture an image affected by CBU, a digital still camera (Fujifilm-F50) was set up on a moving stage. Figure 5 shows that CBU can be suppressed successfully using the Stencil-FSC method, as illustrated in Figure 5(b) and (d). In addition, the dynamic contrast ratio (CR) was enhanced to 5973:1 for a power consumption of only 44W. The performance of 32in RGB LED-based LCD TVs using full-on, RGB-FSC, and Stencil-FSC technology was measured (see Table 1). These results show the advantage of this approach over the conventional FSC method. Our next step will be to simplify the system to comprise just three or even two multicolor fields, which will be more amenable to commercialization.

In conclusion, the Stencil-FSC method both significantly reduces CBU and increases dynamic CR while reducing power consumption. As such, our proposed FSC-LCD is a very promising development toward the next generation of 'green' LCD TV applications.

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