Adaptive dimming and adaptive boosting backlight technologies for LCD-TV systems

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Abstract
The limited transmittance of LCD panels can be observed as a waste of energy, leading to a limited brightness. Light leaking through LCD panels driven to black, can be observed as a poor black-level, limiting the contrast ratio.

Adaptive Dimming Backlight technology can be applied to attenuate the backlight luminance, improving local contrast, black-level and saving power.

The optical crosstalk between the controllable backlight segments has a negative impact on the dimming performance, limiting the spatial backlight luminance modulation. Crosstalk Compensation can partly compensate this artifact, enhancing the spatial modulation of the segments.

Adaptive Boosting Backlight technology can be applied to boost the output of the panel over 100%. This improves the local brightness and contrast for a sparkling picture, still saving power.

Crosstalk compensation enables deeper dimming. Deeper dimming improves on contrast and enables more boosting for an even brighter picture. So when these technologies are combined:

- the contrast may increase up to 5 times (CCFL/EEFL).
- the brightness may double and contrast may increase up to 20 times (HCFL).
- Alternatively, for 2D-Dimming the spatial contrast may increase up to a factor of 100 and the temporal contrast may increase to infinite (LED). At the same time, up to 50% average power can be saved!

1. Introduction
LCD-TV systems need to render video and multi-media images with an optimal front-of-screen performance. They have to meet many requirements, like: contrast, brightness, color, flicker, motion portrayal, viewing angle, dissipation and cost.

All these items are directly related to the backlight. LCD-TV's require a high brightness hence these systems typically use direct-lit LCD panels.

The dimming/boosting properties of the existing light sources are listed in next table. The max power range in the table shows the headroom for boosting of the light sources in typical applications. If more light sources are installed, this number increases proportionally. Hence installing more light sources enables more boosting and better X-talk compensation saving more power with better performances.
At the SID2006 exhibition our 1D-Dimming and Boosting backlight concept was shown at the Philips Booth and got a lot of positive feedback. The main benefits are:

- Spatial contrast and brightness enhancement
- Black-level improvement.
- More local dimming and boosting.
- Continuous power reduction

<table>
<thead>
<tr>
<th>Light source</th>
<th>Power range</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>typ</td>
</tr>
<tr>
<td>CCFL</td>
<td>33%</td>
<td>100%</td>
</tr>
<tr>
<td>EEPL</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>HCFL</td>
<td>10%</td>
<td>100%</td>
</tr>
<tr>
<td>high power</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>RGB-LED</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>White-LED</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 1: normalized power range

In this paper we will show the benefits of this technology, and extend the scope to 2D backlights. In a 2D-mode (possibly per R, G and B channel), the spatial dimming and boosting technologies have an even higher impact on contrast improvement and power reduction.

### Overview of the concept

#### 2. Overview of the concept

The ideal backlight level is depending on the R, G and B values of the picture content. If these levels are high, the panel is optimal at the nominal backlight level. But when the RGB levels are low the backlight should be dimmed, to minimize the leakage of the LC. At the same time the RGB levels need to be gained, to preserve the intended brightness. Hence contrast (especially for dark levels) is improved, but clipping for bright levels is introduced. The adaptive backlight algorithm needs to find an optimal compromise.

This rather subjective requirement is difficult to determine, especially in combination with boosting due to the interaction between the two features. Best results are obtained by using histogram analysis. Histograms provide information about the balance between dark and bright pixels in the picture and can be used to predict the amount of clipping as function of the gain.

Preferably the analysis is executed for R, G and B values separately. Common "auto contrast" features for TV-sets are based on analyzing the Y component. But for this feature we willingly introduce some clipping to prevent LC leakage, and need to control this strictly! Hence Y information alone is not sufficient. The basic concept of the total dimming and boosting technology is drawn on the block diagram in figure 1.

The processing is executed in four stages:

- Analyze the picture content to determine the optimal (locally lowest) backlight luminance.
- Calculate and control the required light source levels to meet the optimal boosted light output.
- Construct the actual light profile of the backlight to resolve the dynamic gain.
- Execute the dynamic gain in the RGB-stream to the panel.

### 3. Adaptive Dimming Backlight

To improve the black-level, viewing angle and dissipation of LCD-TV systems, an adaptive dimming backlight technology can be applied. By applying a matching gain to the video-data, the backlight...
can be reduced such that the perceived luminance of images remains the same.

3.1 0D-Dimming
The concept is based on histogram analyzing and is usable for 0D, 1D, 2D and 2D-color implementations. An alternative concept, with a feedback of the clipping error caused by the gain, is often used for 0D implementations since it is cheaper to implement. A gain control unit determines an optimal video gain and backlight attenuation factor, based upon the filtered feedback. Drawback of this method is the worsened temporal control over the clipping error and the unawareness of the bright/dark balance of the picture.

As over time the gain/attenuation factor will change, the backlight luminance will modulate over a range, providing a temporal contrast larger than the nominal contrast. On average image-data, power reduction of more than 20% can be achieved without visible image artifacts.

3.2 1D-Dimming
For 1D-Dimming the required luminance level is determined for all segments separately. By definition a segment is the smallest controllable unit of light sources. A 1D-segment is a single HCFL lamp, or a group of CCFL lamps in parallel or a string of LEDs in series. Best results are achieved with horizontal segments since this orientation corresponds with the brightness profile of pictures like landscapes.

To get a set of requested light levels per segment, multiple histograms are generated from each new video frame. The video-data is analyzed based on a histogram of the local video content. These levels are temporarily and spatially filtered, as they should only change gradually, to avoid visible artifacts.

The vertical luminance profiles of the lamps are characterized and stored in a Lookup Table (LUT). These segments can have a sharp segmentation, in which the individual lamps are not influencing their neighbors; however this makes it difficult to achieve a proper homogeneity of the backlight. A smooth segmentation improves the homogeneity, as there are no sharp boundaries between the lamp segments.

The LUT is used to reconstruct the actual light profile of the complete backlight for the given lamp levels. Now for each line of the LC-panel, the backlight level is known. From this level the required gain can be calculated. Due to optical crosstalk between segments, this gain can be different from the value intended by the histogram analyzer, resulting in more clipping errors. Crosstalk compensation will prevent this.

As over time and space the dimming factors will change, the backlight luminance will modulate over
a larger range, providing a larger temporal and spatial contrast, as the difference in luminance between very bright and very dark object becomes bigger! The number of segments is related to the dimming modulation. More segments allow for modulation at a higher resolution, but may also increase cost, as more lamp drivers are required. On average-image data, a power reduction of more than 30% can be achieved without visible image artifacts.

### 2D-Dimming

#### 3.3 2D-Dimming

For this technology also a multiple histogram analysis is used to determine the desired luminance level of each segment, which is typically a group of LEDs. Since 2D segments have more neighbors, crosstalk compensation is even more important to ensure sufficient light output at all positions of the backlight.

As the segments get smaller, the luminance should also be detected at a higher resolution. This increases the chance that a very dark image area coincides with a 2D segment, enabling deeper modulation and providing even more temporal and spatial contrast. For a high-power LED backlight, the number of tiles is typically equal to the number of RGB-LEDs (~100), for low-power LED backlight groups of RGB-LEDs will be used for each tile. On average-image data, a power reduction up to 50% can be achieved without visible image artifacts.

#### 3.4 2D-color Dimming

For this technology a histogram analysis per color is required to determine the desired luminance level of each colored light source per segment (R,G and B LED).

Also RGB-Dimming leads to more complex correction in the RGB-stream. The gain should be executed by a matrix to compensate for the mixing of the varying RGB-light levels in the color filters of the LC-panel.

### 4. 1D and 2D Crosstalk Compensation

The interaction between the segments due to optical crosstalk has a big impact on the overall performance of segmented dimming and boosting. Crosstalk limits the effective spatial backlight modulation (even if compensated for). The compensation will never be perfect and the quality is very much dependent on the properties of the light sources.

An important aspect is the possibility of a light source to be driven above nominal levels (boosting), this way lack of light, due to dimming of a neighboring segment, can be compensated for. Without boosting effective crosstalk compensation is only possible if the requested levels of all surrounding segments are dimmed. If effective crosstalk compensation is not possible, dimming is limited for segments close to a not dimmed segment by a light level modulation limiter as drawn in next Figure 2.

![Figure 2 Example of 1D light level modulation limiter.](image-url)
The limiter reduces overshoot or clipping of the crosstalk compensated light source control levels and/or preserves boosting space for the boosting algorithm.

Crosstalk compensation ensures compensation of the error between the predicted light level in the centre of a segment and the requested light level. As a result the spatial modulation of the backlight profile is amplified. Straightforward linear error compensation will lead to lack of light at the borders of bright segments as indicated in Figure 3. An asymmetrical compensation can prevent this.

![Figure 3 Example of 1D asymmetrical X-talk compensation](image)

**Adaptive Backlight Boosting**

### 5.1 0D-Boosting

After a period of dimming it is allowed to have a period of boosting. Hence long term boosting of static pictures is not possible, mainly due to temperature limitations.

As over time the video gain and attenuation factor will change, the luminance will modulate over a larger range, providing a larger temporal contrast. On average image-data, power reduction of more than 20% can be achieved using dimming & boosting, without visible image artifacts.

### 5.2 1D-Boosting

In essence power boosting is an adaptive multiplication of the luminance levels of the light sources of all segments, while the video gain is not reduced. The power gain is updated each frame proportional to the nominal power of the backlight (non-dimmed) and the power requested by the dimming levels. Only potentially saved power by the 1D-dimming algorithm is used to boost the light output of the panel. So the averaged power per frame time is lower or equal to the nominal power consumption. Hence boosting is also possible for static pictures.

A numeric example: A backlight system with 5 segments dimmed to 20% and 5 segments at 80% saves 50% of its nominal power. Hence all lamps can be boosted with a factor of 2. Thus 5 lamps will run at 40% and 5 at 160%.

The actual power gain is limited to a maximum allowed power gain. This gain is the ratio of the
maximum allowed luminance level of a segment divided by the highest (crosstalk compensated) dimmed luminance level and a user controlled maximum, as there is no need to change a night scene into daylight.

Spatial Power Boosting can be combined with the temporal 0D-Booster.

As over time and space the video gain and backlight attenuation factor will change, the luminance will modulate over a larger range, providing a larger temporal an spatial contrast, as the difference in luminance between very bright and very dark object increases. On average image-data, power reduction of more than 25% can be achieved using dimming and boosting, without visible image artifacts.

5.3 2D-(Color)-Boosting

Again the basic concepts for 2D and 1D are the same. However boosting capabilities for LED backlights are in practice restricted by the power limitations of the individual LED and not by the total power consumption of the backlight.

So to preserve headroom for boosting the overshoot of the X-talk compensation should be restricted by the spatial modulation limiter as discussed in paragraph 4.

As the lamp segments get smaller, the backlight luminance can modulate over a larger range, providing even more temporal and spatial contrast. On average image-data, a power reduction up to 50% can be achieved using dimming and boosting, without visible image artifacts.

System requirements

6. System requirements

This set of enhancement algorithms puts some extra, specific requirements towards the applied lamps. The lamps must have an operating range of preferably 30 to 150% for 0D addressable backlights, up to 10 to 200% for 1D and up to 0 to 300% for 2D.

6.1 Conventional CCFL/EEFL Backlight

Conventional CCFL and EEFL can support either some level of scanning backlight, or some level of dimming backlight, as they have a limited dimming range and no fast switching characteristics.

Using conventional CCFL and EEFL a 32” LCD panel requires about 16 lamps, to provide 600 Cd/m2 front-of-screen light output. The lamps typically can dim down to 30%, but have almost no support for boosting backlight, as they cannot be driven beyond their nominal current setting.

6.2 HCFL Backlight

Philips Lighting Aptura HCFL meets all the requirements. It can support a combination of Scanning, 1D-Dimming and Boosting backlight. HCFL can create up to 5 times more light per lamp than conventional CCFL lamps. Using these lamps, a conventional 32” LCD backlight requires only 8 lamps and can still provide 600 Cd/m2 front-of-screen light output.

6.3 LED Backlight

NXP low-power LEDs are ideal devices to support 2D-colour Dimming backlight, as they provide small segments at a high resolution.

With the current LED technology the cost are still high, but as technology progresses these cost are coming down very fast.

Unfortunately LEDs cannot be driven at a much higher power to support real boosting if the number of LEDs is limited to the lowest number (cost) for nominal light output.
6.4 **Display Processing** Requirements
To support Adaptive Dimming and Boosting backlight features, some processing is required. As the algorithms are adaptive to the video input, the video-data needs to be analyzed. This analysis is required as **input** to the display processing algorithms. The dimming algorithm also requires video processing, as the backlight dimming needs to be compensated for with video gain.

The most cost-effective solution would be to integrate these features into the TCON chip, which is an already existing component in the video path, taking care of the **interface** towards the display drivers, as well as the overdrive processing to enhance motion portrayal.

6.5 **Display Companion Chip**
However to make these features timely available for any display module maker, an alternative solution is defined: the Display Companion Chip. This **chip** enables a large set of display and backlight specific features. It is to be used as a front-end of existing (commodity) TCON chips. Hence, it can be seamlessly integrated in existing products and combined with proprietary **IP** or specific LCD panel properties. There is no need to redesign existing TCON devices.

NXP is currently developing this device to make the adaptive backlight solution available to all display module makers as well as LCD-TV set makers.

**Conclusions**
7. **Conclusions**
The perceived Contrast and Brightness can be enhanced significantly by a combination of backlight dimming and boosting technology. The lamps of a backlight can be driven in a way that they generate less light at dark locations and more light at bright locations (temporal and spatial), with a corresponding video-gain compensating for it.

The algorithms can control either: 0D, 1D, 2D or 2D-color addressable backlights, ranging from cost-effective to high performance solutions for TV and **monitor** applications.

8. **References**

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Pierre de Greef (Dutch), born in 1963, is a System Architect at NXP Semiconductors, the semiconductor company founded by Philips. His responsibilities include defining algorithms and system architectures for Picture Quality enhancement, used in flat screen TV as well as mobile
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Hendriek Groot Hulze (Dutch), born in 1969, started working for Philips Semiconductors in 1996. Currently he is working for NXP Semiconductors, the semiconductor company founded by Philips, as a senior design engineer. As analogue designer he started developing proto-CRT-monitors to promote ICs like deflection-controllers and video-amplifiers. His field of work switched from large to small signal, from analogue to digital, from CRT to LCD and from small to large screens. A constant was the field of application, namely displays. This way Hendriek developed himself into an expert on picture quality with a broad scope on technologies. He is responsible for the development of innovative algorithms to improve picture quality for LCD-panels in TVs. His main goal is to optimize the total system performance of the LC and the backlight with LEDs. Hendriek studied Electronics at the Polytechnic school in Eindhoven (NL) where he graduated in two main subjects: Analogue and Digital IC-design. He can be reached at hendriek.groot.hulze@nxp.com