

XEC-LCD White Paper

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Gradual improvements in battery technology have not kept pace with the power consumption demands of the latest handheld electronic devices. Especially, LCD display plays an important role; it usually occupies ~1/3 or even more of the total power consumptions. Hardware designers are using advanced power-saving techniques to help minimize integrated circuit and system power consumption. Yet these techniques will not yield significant power savings without intelligent energy conservation software to exploit them effectively.

Freescale Semiconductor's eXtreme Energy Conservation (XEC) technology is a multi-phase, multi-generational project to develop advanced power-saving software for Freescale handset platforms. LCD power conservation is a key aspect. Based on advanced runtime performance algorithms, XEC-LCD uses a standardized software framework that supports multiple platforms; it runs as system software with operating systems.

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1 XEC-LCD Introduction

1.1 Overview

Freescall's eXtreme Energy Conservation (XEC) targeted for LCD panel displays is a comprehensive ready-to-use energy saving solution with the system intelligence and connections to exploit board-level power-saving features effectively in order to provide potentially longer battery life than competitor solutions. XEC-LCD is optimized for Freescall's handset platforms and is delivered as part of the customized operating system (OS) software provided with a chipset's OS board support package. Because XEC-LCD will run on various platforms with different display panels, and is designed to take advantage of each chipset's particular features, energy savings will vary by use cases.

XEC-LCD mainly covers two aspects concerning about the LCD displays power consumption. XEC-AA means power conservation based on ambient environment. XEC-DLS means power conservation based on dynamically luminance scaling, which suites for the full screen video playback use case.

1.2 Definitions, Acronyms, and Abbreviations

Table 1. Definitions, Acronyms, and Abbreviations

Term/Acronym	Definition
AA	Ambient Aware
API	Applications Programming Interface
BL	Back light
BLAR	Back Light Auto Regulation
BSP	Board Support Package
CSC	Color Space Conversion
DLS	Dynamic Luminance Scaling
IPU	Image Processing Unit
LCD	Liquid Crystal Display
OS	Operating System (software)
RGB	Red-Green-Blue (color format)
XEC	eXtreme Energy Conservation
YUV	Luminance-Chrominance-Chrominance (color format)
PMIC	Power Management Integrated Circuit

2 XEC-LCD Solutions

2.1 XEC-LCD Background

2.1.1 Transmissive Panel Characteristics

Transmissive LCD has a transparent rear polarizer that allows the backlight to go through. It works best in low light environment conditions with the backlight on continuously. In a high light condition, in order to get a better view experience, image contrast enhancement may be needed. The common methods include increasing the backlight increment or pixel luminance/contrast enhancement.

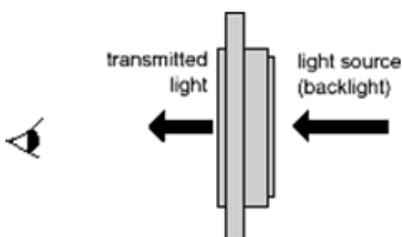


Figure 1. Transmissive LCD Prototype

The view experience is related to pixel luminance and backlight transparency. It works on the principle:

$$L(x) = t(x) \uparrow * b \downarrow$$

- L is user observed luminance, t is transmissivity of pixel, and b is backlight level. We can get t(x) by measuring the characters of the display panel.
- Dimming the backlight while scaling up the t(x) to maintain the L(x) is the principle of XEC-LCD, so to achieve the power saving goal.

The transparencies vary on different panels. By measuring the light intensity under different backlight level, we can get the panel characteristics. The relationship between Y to lux can be set as $\text{lux} = A * Y^B$, B is the power coefficient. The typical value of B is from 1.8 to 2.2.



Figure 2. Screen Lux vs Y Value

2.1.2 Backlight Control Module

Usually the backlight is assembled by a LED array, and its intensity is linear to the driving current. For different panels, the backlight intensity is controlled in different ways. Some panels are driven by PMICs with constant current for the backlight module; others are driven by the PWM duty cycle to adjust the screen brightness.

2.1.3 XEC-LCD Scheme

XEC-LCD technology is based on the principle between backlight and pixel luminance, which generates observer's view image.

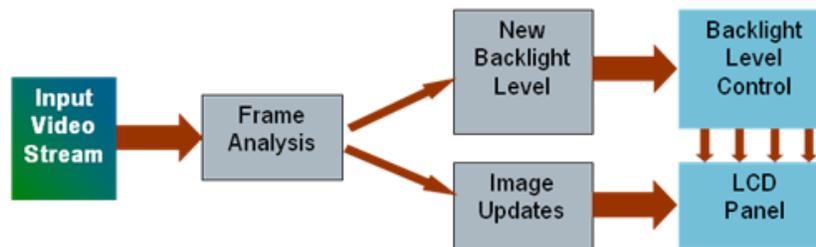


Figure 3. Basic Scheme for XEC-LCD Technology

2.2 XEC-AA

XEC-AA is a common feature that is already supported by many mobile devices. It needs an on-board light sensor aware to the ambient environment. The CPU will get the actual luminance of environment from time to time and tune the backlight accordingly.

Commonly there is a look up table as per the typical environment brightness, such as outdoors, indoors, office with light, etc. backlight would be set with the value stored in the LUT corresponding to the environment lux.

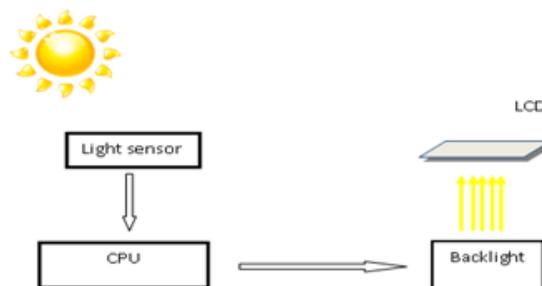


Figure 4. XEC-AA Basic Scheme

2.3 XEC-DLS

The principle of dynamic backlight scaling is to save power by dimming the backlight while compensating the luminance by scaling up the Y component of images, so the user can perceive similar levels of intensity with negligible image degradation. It employs in an efficient way for the hardware image processing unit

(IPU) to implement hardware assisted image compensation. This method is called XEC-DLS (Extreme Energy Conservation-Dynamic Luminance Scaling).

The approach is based on frame-by-frame distortion histogram analysis on YUV image format. Each pixel is used to compute the luminance histograms of the pre-processed image. The distortion histogram computed takes into account the amount of saturated pixels for a given α scaling factor. The scaling factor is also applied to the luma (Y) component of the image in order to maintain a target luminance.

2.3.1 XEC-DLS Data Flow

Data processing flow is as shown in Figure 5.

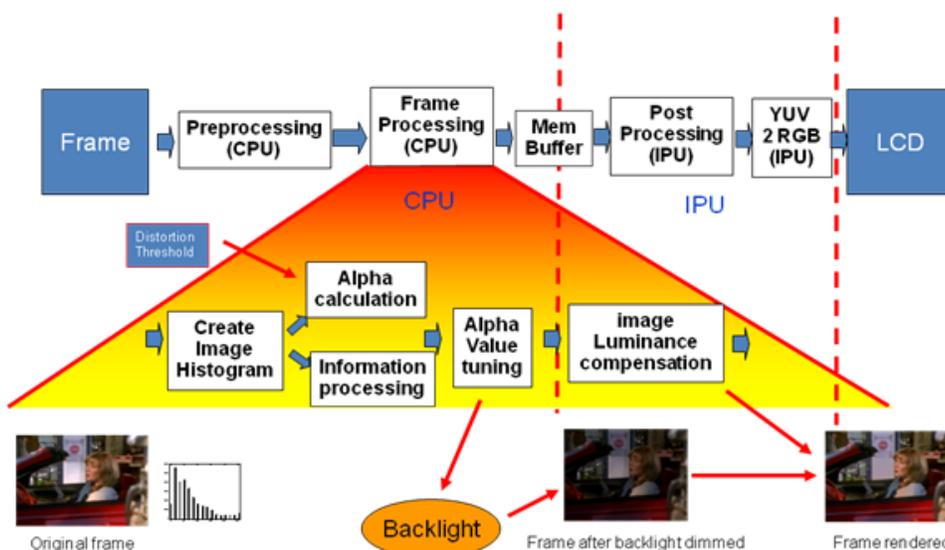


Figure 5. DLS Processing Flow

On CPU side, video content analysis and alpha calculation are the main tasks. Each frame is taken into account. The distortion threshold determines the washout percentage of the Y value. The processing of CPU should be fast and effective. The video frame ratio is ~30 frames per second, and the XEC-DLS processing should be done as soon as possible to achieve the real time playback.

2.3.2 XEC-DLS Application

XEC-DLS could be interpolated to the multimedia framework before rendering the frame to LCD without violating the whole streaming. But due to the limitation that the backlight module for LCD display cannot be controlled by blocks, XEC-DLS is applied in full screen video playback cases.

One advantage of XEC-DLS is that it is easy to be ported onto various platforms as an independent library, without concerning about the operation system and frameworks.

Figure 6 shows a chart that displays how the XEC-DLS is interpolated into the current multimedia framework. All that XEC-DLS needs are the video frame information. It will analyze the frame data, and based on the processing result, it is determined if the CSC parameters and backlight level need to be updated. The content of the video frame keeps unchanged.

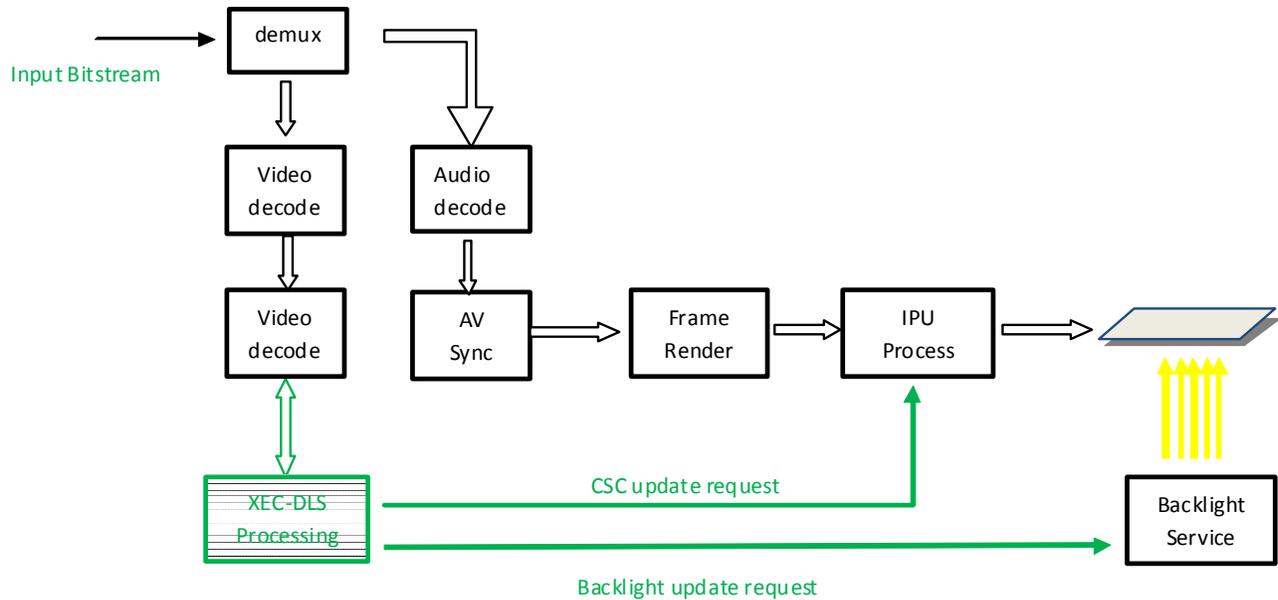


Figure 6. Multimedia Framework Calling XEC-DLS Library

For most of the LCD displays, RGB data format is accepted. The video frame needs to be converted from YUV format to RGB format. This could be done in either software or hardware. On Freescale i.Mx platform, it is performed by IPU sub-modules. The parameters for YUV to RGB conversion are as below:

$$R = (1.164 \times (Y - 16)) + (1.596 \times (Cr - 128))$$

$$G = (1.164 \times (Y - 16)) - (0.392 \times (Cb - 128)) - (0.813 \times (Cr - 128))$$

$$B = (1.164 \times (Y - 16)) + (2.017 \times (Cb - 128))$$

With XEC-DLS enabled, the updated CSC formula would be:

$$R = \alpha \times 1.164 \times (Y - 16) + 1.596 \times (Cr - 128)$$

$$G = \alpha \times 1.164 \times (Y - 16) - (0.392 \times (Cb - 128)) - (0.813 \times (Cr - 128))$$

$$B = \alpha \times 1.164 \times (Y - 16) + 2.017 \times (Cb - 128)$$

α is the scaling factor calculated based on the video content and goal distortion ratio. If α is larger than 1 (and for most cases it is), some pixels with large Y value would wash out, which means that scaled Y would exceed the threshold of luminance ranges. Those Y values would be cut down and cause distortions on the image view. It is the compromise for power saving benefit. But with the backlight dimming, the image quality seems in an equivalent level with negligible degradation. [Figure 7](#) how the image looks with luminance compensation and backlight dimming.



Figure 7. Image Processed with Luminance Compensation and Backlight Dimming

As the figure depicts, though the backlight is dimmed, the image quality is maintained in a high level. For most cases, the power saved is ~30% in display side, with less than 5% pixels washed out.

Figure 8 shows the backlight and luminance scaling on a typical video clip. The backlight is provided by the PWM. The duty cycle is 100% and the scaling factor of luminance is 1 in normal video playback. The backlight is dimmed and smoothed based on the video content. The darker the frame is, the more power will be saved.

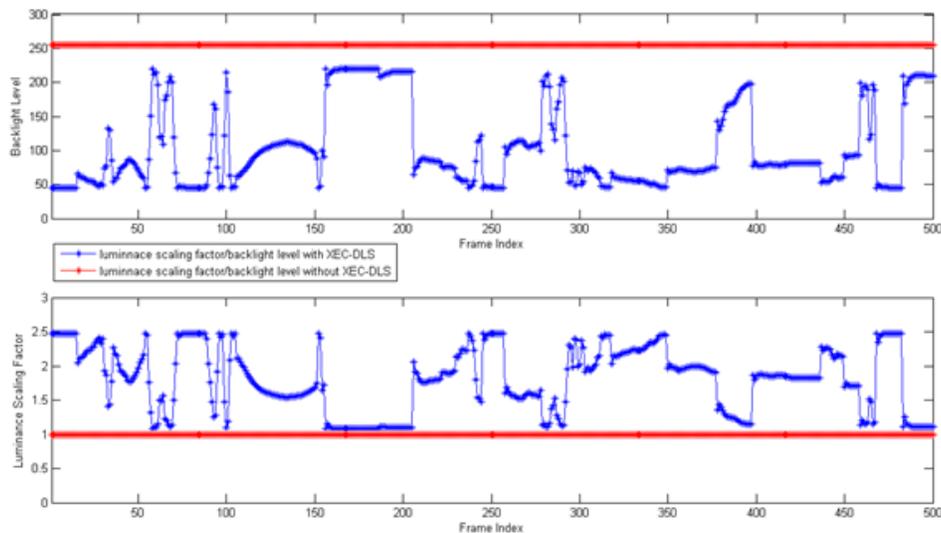


Figure 8. Backlight and Luminance Scaling Factor Changes

To get a better view experience, the backlight should be able to be controlled in small steps, less than 4% is preferred.

Now, the XEC-DLS solution has been carried out on Freescale i.Mx5x series platform as a released feature.

3 System Benefits

As a power saving solution, XEC-LCD could provide longer battery life for handset devices. From CPU side, there is additional real-time computation effort that will cause less than 20 mW extra power consumption, but it is negligible as compared with about 30% power reduction on LCD backlight module (typical power consumption of LCD backlight is 500 mW ~ 1 W).

This technology can be used in full screen video playback without caring about the video encoding format and frame resolution. It can easily be used under any multimedia frameworks without violating the current streaming.

Freescale's XEC technology is architected to be extensible for future enhanced generations and easily deployable across multiple hardware platforms and operating system software. It is ready for use now.

4 Revision History

Table 2 provides a revision history for this white paper.

Table 2. Document Revision History

Rev. Number	Date	Substantive Change(s)
0	04/2011	Initial release.

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