Qualcomm Technologies, Inc.

Content Adaptive Backlight Design

User Guide

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Revision history

Revision	Date	Description
A	July 2014	Initial release
B	June 2015	Added new parameters to Configurable parameters table
C	July 2016	Numerous changes were made throughout the document; should be read in its entirety
D	February 2017	Updated to conform to QTI standards; no technical content was changed in this document revision
E	March 2017	Additional updates to conform to QTI standards; no technical information was changed in this document revision

Contents

1 Introduction

Content Adaptive Backlight (CABL) is an LCD display enhancement tool that, when enabled, allows device users to reduce power consumption without compromising image brightness. Since backlight is the major consumer of battery power, CABL provides an algorithm that reduces the backlight while boosting image contrast. This compensatory effect ensures a perceived uniform level of brightness for the customer.

1.1 Purpose

Intended for OEMs, this document provides guidelines for enabling CABL on target devices. The CABL operation depends both on hardware and software implementation. As such, the document also includes hardware/software system requirements, detailed information on CABL operation and capability, interface descriptions, and limitations. It assumes OEM familiarity with their specific target as well as target source code architecture.

1.2 Conventions

Function declarations, function names, type declarations, attributes, and code samples appear in a different font, for example, `#include`.

Code variables appear in angle brackets, for example, `<number>`.

Commands to be entered appear in a different font, for example, `copy a:*.* b:`.

Button and key names appear in bold font, for example, click **Save** or press **Enter**.

1.3 Technical assistance

For assistance or clarification on information in this document, submit a case to Qualcomm Technologies, Inc. (QTI) at https://createpoint.qti.qualcomm.com/.

If you do not have access to the CDMATech Support website, register for access or send email to support.cdmatech@qti.qualcomm.com.

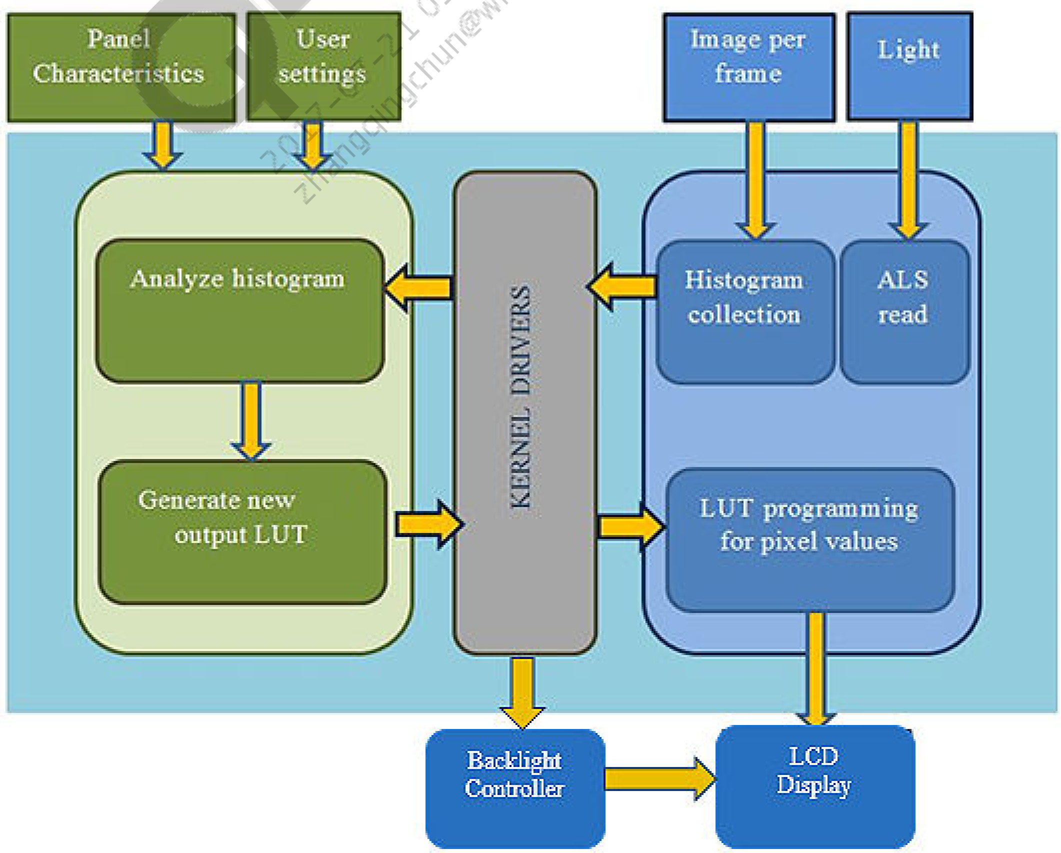
2 CABL design overview

An overview of CABL consists of algorithm operation and capability, hardware and software system requirements, and the effect of each component on CABL operation. CABL operation depends on both hardware and software implementation.

CABL is a part of the adaptive brightness/backlight adjustment (ABA) framework that includes:

- Content adaptive backlight scaling (CABL) – Reduces power consumption by LCD panels
- Fidelity optimized signal scaling (FOSS) – Reduces power consumption by OLED panels
- Sunlight visibility improvement (SVI) – Improves the visual experience outdoors

ABA shares the hardware block with different software-implemented core algorithms, shown by the figure below.



Inputs for CABL software algorithm

Following are the inputs for CABL software algorithm:

- Panel characteristics – Includes the panel gamma curve and backlight response curve
- User settings – Includes OEM-configurable parameters that allow custom settings
- Histogram data – Data passed from the hardware histogram collection block to the CABL core block for each frame

NOTE Panel characteristics and user settings are initialized when CABL is started.

The histogram data is transferred to the CABL core and analyzed. A new backlight scaling factor, which is ≤ 100%, is generated and applied to the original backlight to yield a lower backlight level. The new backlight level is passed to the backlight controller while the CABL LUT values are sent to the hardware registers. To compensate for the lowered backlight level, the CABL core generates a CABL LUT for tone reproduction to make an image brighter than the original. This new image is sent to the LCD panel. When the new image generated by the CABL LUT is displayed on the LCD panel, the new backlight level, which is darker than the original level, is applied so that the final output image appears normal.

CABL output generation

CABL software algorithm generates the following two outputs for a given frame:

- New backlight level
- CABL Lookup Table (LUT)

CABL algorithm process

CABL software algorithm process is a follows::

- Histogram data transferred to the CABL core and analyzed
- New backlight scaling factor, which is ≤ 100%, generated and applied to the original backlight to yield a lower backlight level
- Backlight level passed to the backlight controller while CABL LUT values are sent to the hardware registers. (To compensate for the lowered backlight level, the CABL core generates a CABL LUT for tone reproduction to make an image brighter than the original)
- Image sent to the LCD panel, and when generated by the CABL LUT to display on panel, a new backlight level, darker than the original level, is applied so that the final output image appears normal

CABL controls the backlight depending on the image contents. Other backlight control blocks, such as auto brightness control and UI backlight setting, are based on ambient light sensor output. The auto brightness control block determines a backlight level at which a user can comfortably view the display in a given environment based on output from the ambient light sensor. From this level set by auto brightness control, CABL determines how much it can optimally reduce the backlight depending on the display content. Auto brightness control does not conflict with CABL.

RELATED INFORMATION

"Backlight scaling factor and remapping curve" on page 8
"LCD gamma table curve measurement" on page 9

3 CABL system requirements

Hardware and software requirements for CABL are configured to ensure optimal power savings while maintaining display brightness. For optimal performance, important guidelines for each setting should be followed.

3.1 Number of backlight levels

A minimum of 256 differentiable backlight levels are needed for the backlight control system, including the hardware LCD panel. The software kernel driver must support 256 differentiable levels.

If the system does not meet this requirement, the backlight change may be noticeable to human eye, even for adjacent levels and may cause screen flickering on certain images.

3.2 Luminance difference for adjacent backlight levels

The brightness difference for any adjacent backlight levels should not exceed 1% of the maximum luminance measured from the white test image. For example, if the maximum luminance of the device with the white test image is 400 cd/m2, the luminance difference between any adjacent backlight levels should not exceed 4 cd/m2. The luminance can be validated using a spectroradiometer, such as the Photo Research SpectraScan® PR-655 or any similar device capable of measuring the display luminance accurately.

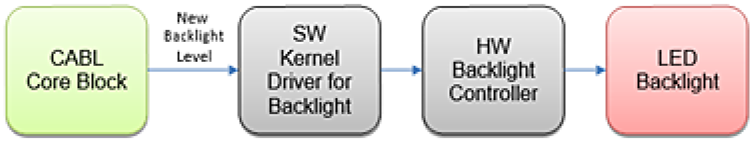
If the system does not meet this requirement, the backlight change might be noticeable to human eyes, even for adjacent levels and may cause screen flickering on certain images.

3.3 Backlight latency

Backlight latency is the time required for the system to change the backlight to its new level once CABL sets the new backlight level. If backlight latency is too long (beyond one period of refresh rate), this causes the backlight to be out of sync with the CABL hardware block. Visual quality degradation may occur due to the mismatch between the LUT and the backlight.

The CABL algorithm runs on a frame-by-frame basis. Therefore, backlight latency should be short enough to allow backlight changes quickly for each frame. The typical total latency should be below 5 ms.

As shown in the figure below, backlight latency can be affected by the backlight control blocks in the software kernel driver and hardware backlight controller.



Any blocks in software or hardware within the backlight control system for CABL can cause major delays.

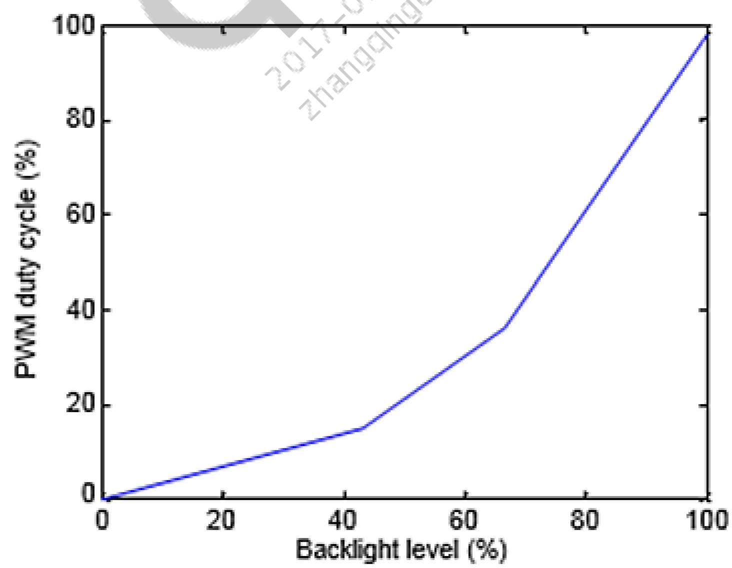
NOTE Any other component active in the gradual backlight control mechanism must be disabled when CABL is enabled. For example, **Auto Backlight Control** using **Ambient Light Sensor**.

3.4 Backlight scaling factor and remapping curve

The backlight scaling factor generated by the software CABL core is applied to the original backlight level, which should be linear to the luminance output. The following steps describe how to use a backlight remapping block that makes the user backlight setting nonlinear to the luminance output (typically implemented in the form of a backlight-PWM curve as shown in the figure.

1. Use the customized remapping table as the backlight response table. In this way, the luminance can be sustained for different content while maintaining conservative power savings.
2. Keep the backlight response table as the default (linear), and apply the CABL output backlight scaling factor on top of the backlight remapping block.

   The power savings could be more aggressive than the linear mapping table reveals. However, as the backlight remapping curve figure shows, there may be potential luminance losses.



RELATED INFORMATION

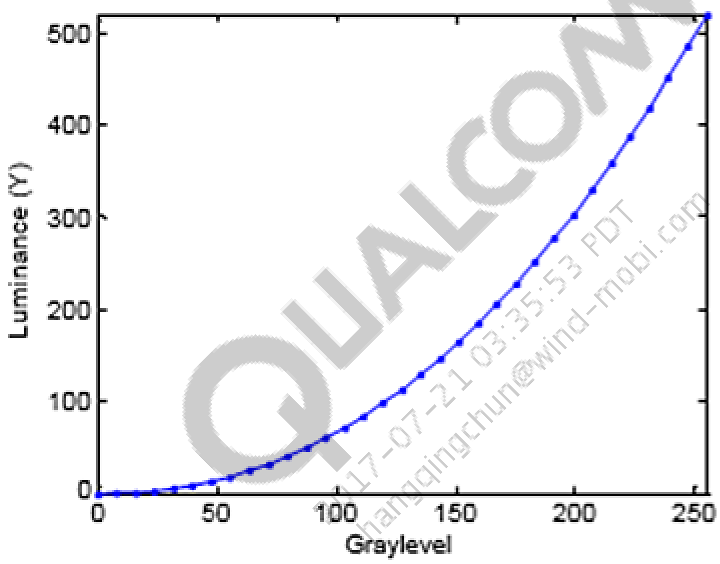
"Backlight response table measurement" on page 10
"CABL design overview" on page 5
"LCD gamma table curve measurement" on page 9

3.5 LCD characteristics

To achieve optimal power performance and visual quality from CABL, measure the display panel characteristic curve and store the measurement data in the designated code area. If this data is not provided, the CABL algorithm uses default values defined in the code. The default gamma table has a curve with a gamma value of 2.2 and the default brightness table has the unity linear mapping.

3.5.1 LCD gamma table curve measurement

The gamma table below holds LCD matrix transmission information. The table shows a gamma characteristic curve for 33 gray level measurement points.



The following steps describe the gamma curve measurement procedure:

1. Maximize the backlight level.
2. Change the pixel values from 0 to the maximum value, e.g., R=G=B=255 for 24-bit display bit depth. Use 33 gray levels for this measurement.
3. Measure the luminance level of display using an instrument such as a spectrophotometer, e.g., PhotoResearch PR655, for each gray level.
4. Normalize the luminance measurement data with its maximum value, and convert to 10-bit scale value with the maximum value mapped to 1024. Rescale the gray level pixel values to a 10-bit scale.
5. Store the numbers in the CABL OEM file. The arrays for the luminance measurement data and the gray levels are `oem_gamma_luminance` and `oem_gamma_grayscale`, respectively.

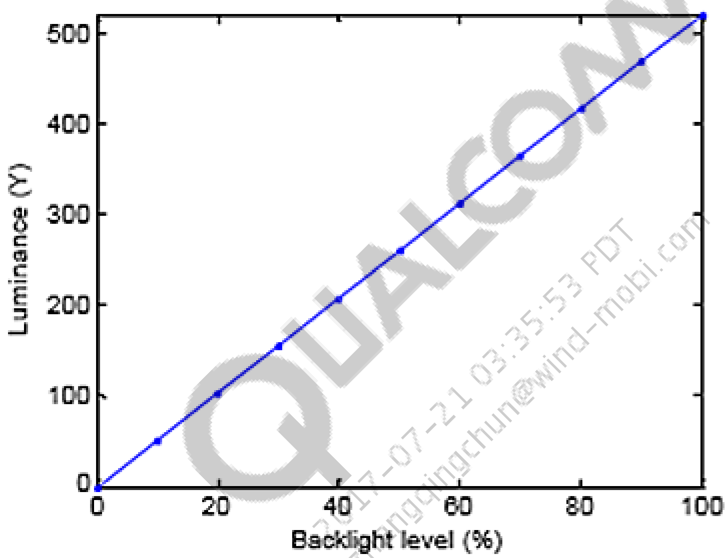
RELATED INFORMATION

"Backlight scaling factor and remapping curve" on page 8
"CABL design overview" on page 5

3.5.2 Backlight response table measurement

The backlight response table shown below holds the panel characteristic curve for the display brightness as a function of backlight level. OEMs using any type of backlight remapping curve in their system can derive this table from the backlight remapping curve. The table can also be generated from the measurement procedure.

For OEMs not using their own backlight remapping curve, the backlight response typically shows a linear curve. Since the default response table already has the linear curve in the CABL config file, OEMs that do not use their own backlight remapping do not need to update the backlight response table.



To generate a response table from the measurement procedure, follow these steps:

1. Display a white color patch that has the maximum pixel value, e.g., R=G=B=255 for 24-bit display bit depth, for the entire display panel.
2. While displaying the white color patch on the panel, change the backlight level. Use at least 11 levels from 0% to 100% of backlight levels.
3. Measure the luminance level of display, e.g., using a spectrometer, for each backlight level. In the figure above, notice a brightness curve that is generated based on 11 measurement points.
4. Normalize the luminance measurement data with its maximum value and convert to 10-bit scale numbers with the maximum value mapped to 1024. Rescale the backlight level to 10-bit scale numbers, mapping 100% backlight to 1024.
5. Store the numbers in the CABL OEM file. The arrays for the luminance measurement data and the backlight level are `oem_blresponse_luminance` and `oem_blresponse_bl`, respectively.

RELATED INFORMATION

"Backlight scaling factor and remapping curve" on page 8

4 Configurable parameters

The OEM may configure specific parameters to control visual quality and power savings. To enable CABL, add the property `ro.qualcomm.cabl=2` to `system/build.prop`.

4.1 Configure CABL parameters using XML

CABL parameters can be configured using an XML file based on the panel characteristics and user preference. CABL parameters can be configured only after enabling the CABL feature. The XML interface is not enabled by default. The steps below describe how to enable the CABL interface.

1. Navigate to the `/system/build.prop` file.
2. Add the following lines in the file:

```
config.cabl.xml=1
config.cabl.path=<path_to_XML_file_on_device>
```

If the XML file is not found, the CABL falls back to the default parameters. A checklist to verify whether each requirement has been satisfied to achieve optimal power savings and visual quality from CABL is described in the Design Checklist.

NOTE Verify that the parameters have been parsed and configured correctly by adding the property `config.cabl.xml.print=1` to `/system/build.prop` and print the parsed values in logcat.

RELATED INFORMATION

“Configurable parameters” on page 11
“Panel characteristic parameters” on page 11
“Design checklist” on page 15

4.2 Panel characteristic parameters

The gamma curve and backlight response curve are defined as follows:

- Gamma curve parameters:
  - The two tables, `GammaResponseTableGrayScale` and `GammaResponseTableLuminance` contain the grayscale values for which luminance values are measured for the display gamma curve. The grayscale values should be rescaled to 0 to 1024. The measured luminance values should also be normalized to the range of 0 to 1024 with the maximum value mapped to 1024. The length of these two tables should be same (represented by `GammaResponseTableLength`).
- Backlight response curve parameters:

  - The tables `BackLightResponseValueTable` and `BackLightResponseLumaValues` contain the backlight level for which luminance values are measured for the display backlight response curve. The backlight values should be rescaled to 0 to 1024. The measured luminance values should also be normalized to the range of 0 to 1024 with the maximum value mapped to 1024. The length of these two tables should be same (represented by`BackLightResponseTableLength`).

RELATED INFORMATION

“LCD gamma table curve measurement” on page 9
“Configure CABL parameters using XML” on page 11

4.3 Visual quality and power savings control parameters

Parameter settings are used to maximize power savings while optimizing the coordination of backlight levels, backlight change speeds, pixel distortion, and scaling.

- `CABLBackLightMinRatio` – Determines the minimum level of backlight scaling factor.
  - A lower value can reduce the backlight level further and yield higher power savings for dark-tone images. However, an excessively low ratio can lead to lower visual quality, for example, a long transition period or flickering when input content changes from dark to bright. It can have different values for each of three quality levels.
- `CABLBackLightMaxRatio` – Determines the maximum level of backlight scaling factor.
  - The default value is 1024, which sets the maximum backlight scaling factor at 100%. If this parameter is set to lower than 1024, CABL always reduces the backlight, thus guaranteeing a certain percentage of power savings even for a full white image. The parameter can have different values for each of three quality levels.
- `CABLPixelDistortion` – Determines the number of pixels that could have been impacted by the `CABL_LUT` for a given frame.
  - A higher value can yield higher power savings. However, an excessively high distortion level can lead to lower visual quality, for example, luminance loss or contrast degradation for certain images at white area. The parameter can have different values for each of three quality levels.
- `CABLBackLightStepSize` – Controls the backlight change speed.
  - The number is used internally to determine other associated parameters to set the final backlight change speed. A higher number yields a fast backlight change speed. The parameter can have different values for each of three quality levels.
- `CABLBackLightMinValue` – The threshold below which CABL does not reduce its backlight level further.
- `CABLBackLightMaxValue` – The maximum brightness level the OS supports for sanitizing the original brightness level, typically 255 for Android.

RELATED INFORMATION

“Configurable parameters table” on page 12

4.4 Configurable parameters table

There are 16 OEM-configurable parameters.

XML ID name	Description
`GammaResponseTableGrayScale`	Grayscale values for which luminance values are measured for display gamma curve
`GammaResponseTableLuminance`	Luminance value measured at each grayscale level in `oem_gamma_grayscale[]`
`GammaResponseTableLength`	Number of measurement points for the gamma curve
`CABLBackLightMinRatio`	Lower bound of the backlight change for a given original backlight level
`CABLBackLightMaxRatio`	Upper bound of the backlight change for a given original backlight level
`CABLPixelDistortion`	Number (percentage) of pixels to be saturated by `CABL_LUT`
`CABLBackLightStepSize`	Speed of the backlight change
`CABLBackLightMinValue`	Threshold of backlight level below which CABL core block does not reduce the backlight
`BackLightResponseValueTable`	Backlight level for which luminance values are measured for the display backlight response curve
`BackLightResponseLumaValues`	Luminance value measured at each backlight level in `oem_blresponse_bl[]`
`BackLightResponseTableLength`	Number of measurement points for the backlight response curve
`CABLBackLightMaxValue`	Maximum brightness level the OS supports for sanitizing the original brightness level, typically 255 for Android
`CABLSoftClippingSlope`	Transition slope to avoid hard clipping at the bright end of LUT
`CABLLutType`	Type of LUT applied, e.g., `OPTIMIZED_LUMINANCE_FIDELITY`, `HIGH_LUMINANCE`, etc.
`CABLWindowSizeThreshold`	Lower bound of transition window in temporal filter
`CABLFilterCoefficientThreshold`	Lower bound of coefficient of history information in temporal filter

RELATED INFORMATION

“Visual quality and power savings control parameters” on page 12
“Configure CABL parameters using XML” on page 11

5 Limitations

Limitations can (and do) affect CABL, and the efficiency of CABL in power optimization can be significantly changed by many factors.

5.1 Global effect

Because it is a global tone adjustment algorithm, CABL affects the entire frame. The algorithm cannot perform enhancement or reduce pixel intensity only for a part of the displayed content. If you observe flickers with CABL enabled, contact QTI support.

RELATED INFORMATION

"Technical assistance" on page 4

5.2 Temporal effect

CABL is a per-histogram processing algorithm and a software feature, it impacts the temporal LUT difference and software frame delay, respectively. This implies that image brightness changes may be noticeable when the LUT convergence is not yet completed.

5.3 Frame delay

Based on currently available histogram data, the ABA algorithm calculates a new backlight level and LUT and applies them to in next frame. It is assumed that the next frame is closely correlated to the current frame. If there is a scene change between the current and the next frame, the temporal filter smoothens the transition.

5.4 Content dependency

Power savings with CABL (the difference between backlight power consumed with and without CABL) is highly dependent on the image content. For example, a dark scene without any bright area has significant backlight power savings, that is, more than 50%. On the other hand, if the screen only shows bright scenes, the power savings may be very low or negligible.

It is possible to achieve 10% to 30% backlight power savings for a typical video clip.

NOTE Power-saving results are empirical values based on the QTI reference platform. Results vary from platform to platform.

A Design checklist

Use the following checklist to verify whether each requirement has been satisfied to achieve optimal power savings and visual quality from CABL.

	Item	Description	OEM confirmation
1	Number of backlight levels	Does the number of backlight levels meet the minimum requirement (at least 150 levels, or 256 levels of backlight is highly recommended) in hardware?	-
2	Luminance difference for adjacent backlight levels	Does the luminance difference between any adjacent backlight levels exceed 1% of the maximum luminance level of the device measured with the white test image?	-
3	Backlight latency	Is the backlight latency short enough for the frame-based CABL process? For the frame rate 60 fps, the backlight latency should be kept below 5 ms.	-
4	Display panel characterization	Are the panel characteristic curves properly measured and correctly stored in the CABL OEM file?	-

RELATED INFORMATION

"Number of backlight levels" on page 7
"Luminance difference for adjacent backlight levels" on page 7
"Backlight latency" on page 7
"LCD characteristics" on page 9

B Acronyms and terms

Acronym or term	Definition
CABL	Content adaptive backlight control
ABA	Adaptive brightness/backlight adjustment
FOSS	Fidelity optimized signal scaling
SVI	Sunlight visibility improvement
LUT	Lookup table