Qualcomm Technologies, Inc.

Content Adaptive Backlight Design Guide

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Revision history

Revision	Date	Description
A	Jul 2014	Initial release
B	Jun 2015	Added new configurable parameters to Table 5-1

Contents

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1 Introduction

1.1 Purpose

Content Adaptive Backlight Control (CABL) helps minimize power consumption. CABL operation is highly dependent on both hardware and software implementation. This document provides guidelines for enabling CABL on target devices. It includes hardware/software system requirements, detailed information on CABL operation and capability, interface descriptions, and limitations.

CABL is available on MSM8974, APQ8084, MSM8994, MSM8992, and MSM8996 devices. Readers should be familiar with their specific target as well as source code architecture.

1.2 Conventions

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

Shading indicates content that has been added or changed in this revision of the document.

1.3 Technical assistance

For assistance or clarification on information in this document, submit a case to Qualcomm Technologies, Inc. (QTI) at https://support.cdmatech.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 Overview

This chapter provides an overview of the CABL algorithm, the interdependency between components, and how each component affects CABL operation.

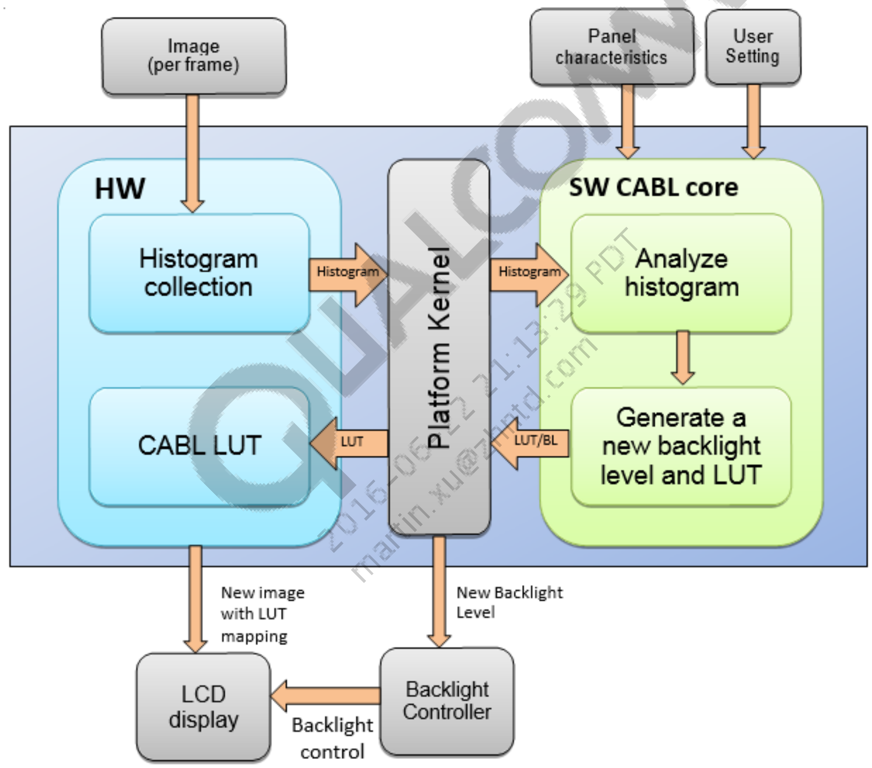

Figure 2-1 CABL block diagram

CABL consists of a software component – SW CABL core – and a hardware component. The inputs for the software CABL core block are:

- Panel characteristics – Including the panel gamma curve and backlight response curve described in Section 3.5
- User settings – OEM-configurable parameters that allow custom settings
- Histogram data – Passed from the hardware histogram collection block to the CABL core block for each frame

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

Based on its inputs, the CABL core generates two outputs for a given frame:

- New backlight level
- CABL Lookup Table (LUT)

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 controls the backlight depending on the image contents. Other backlight control blocks, such as auto brightness control and UI backlight setting (see Section 3.4), 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.

3 System Requirements

This chapter describes CABL hardware and system requirements for achieving optimal power savings while maintaining display quality.

3.1 Number of backlight levels

A minimum of 150 differentiable backlight levels are needed for the backlight control system, including the hardware LCD panel. It is strongly recommended that the device have 256 differentiable backlight levels. 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 eyes, even for adjacent levels. This 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/m^2, the luminance difference between any adjacent backlight levels should not exceed 4 cd/m^2.

If the system does not meet this requirement, the backlight change might be noticeable to human eyes, even for adjacent levels. This 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.

Backlight latency can be affected by the backlight control blocks in the software kernel driver and hardware backlight controller, as shown in Section 3.3.1.

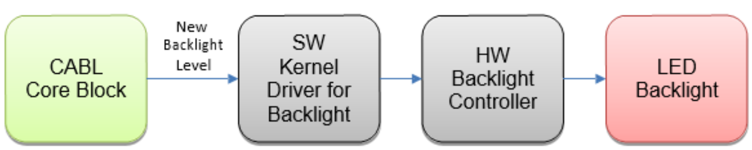

Figure 3-1 CABL and backlight control system

The backlight control system for CABL should not have any blocks in software and hardware causing major delays.

3.3.1 Design considerations

- Backlight settling time – Hardware component

  The backlight controller/driver should settle to its new backlight level within 1/5 of the frame time.

- Gradual backlight control mechanism – Hardware/software component

  If the backlight controller/driver employs a software or hardware gradual backlight mechanism, this mechanism must be disabled when CABL changes the backlight.

  Gradual backlight refers to the gradual changing of the backlight level over a period of time. It provides a more pleasant visual experience and eliminates flashing effects when the backlight level must be changed substantially ie. using an ambient backlight controller when the user moves from outdoors to indoors.

  A typical gradual backlight mechanism can take up to a few hundred milliseconds to switch backlight level, which interferes with CABL operation.

- CABL thread and callback latency priority – Software component

  Ensure that the CABL computational thread is executed with sufficient priority and completed within half a frame time. Failure to meet this requirement could result in frame delay, which could cause a visual artifact.

  Latency of the callback function for the hardware histogram collection block should be minimized (less than 1 ms) for CABL to process the contents frame-by-frame.

3.4 Backlight scaling factor and remapping curve

The backlight scaling factor generated by the CABL core is applied to the original backlight level, which should be linear to the luminance output. To use a backlight remapping block that makes the user backlight setting nonlinear to the luminance output (typically implemented in the form of backlight-PWM curve):

1. Use the customized backlight remapping table as the Backlight Response Table in Section 3.5.2. In this way, the luminance can be maintained well for different content, but more conservative power savings may result.
2. Keep the Backlight Response Table in Section 3.5.2 as 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 case, but there may be potential luminance losses.

   An example of a backlight remapping curve is shown in Figure 3-2.

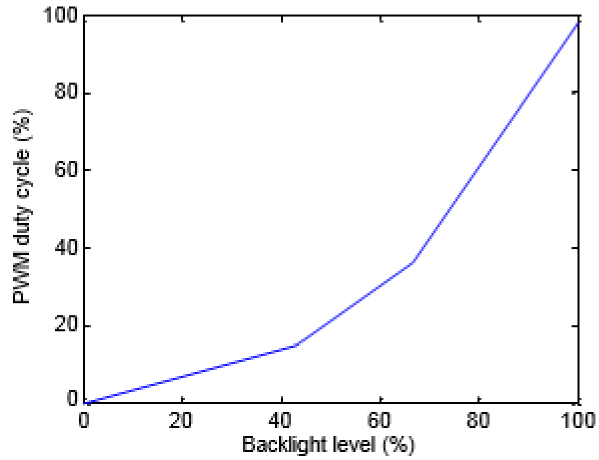

Figure 3-2 Backlight remapping curve example

3.5 LCD characteristics

To achieve optimal power performance and visual quality from CABL, measure the display panel characteristic curves 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 Gamma table

The gamma table holds LCD matrix transmission information, shown in Figure 3-3.

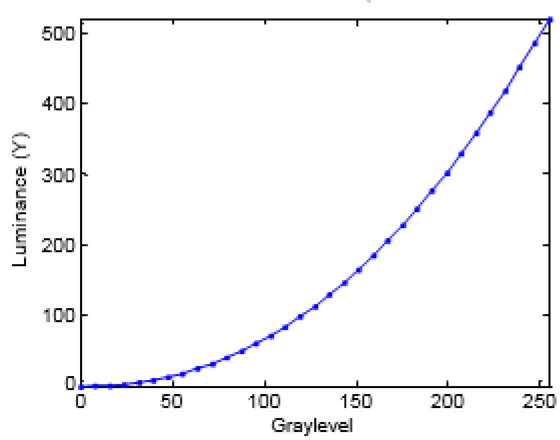

Figure 3-3 Gamma curve characterization example

The gamma curve measurement procedures are as follows:

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. Figure 3-3 shows a gamma characteristic curve for 33 gray level measurement points.
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.

3.5.2 Backlight response table

The backlight response table 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 described below.

For OEMs not using their own backlight remapping curve, the backlight response typically shows a linear curve, as in Figure 3-4. Since the default response table already has the linear curve in the OEM file, OEMs that do not use their own backlight remapping do not need to update the backlight response table.

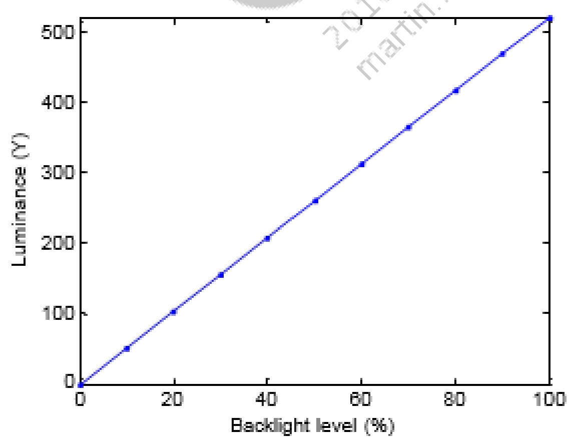

Figure 3-4 Backlight vs luminance measurement example

The backlight response table measurement procedures are as follows:

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. Figure 3-4 shows 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.

4 Limitations

This chapter discusses limitations that clearly define the scope of the CABL scheme. Note that the effectiveness of the CABL scheme in power optimization can be significantly affected by many factors. To achieve efficient power consumption while maintaining good display quality, all requirements described in Chapter 3 should be met. If some of these conditions are not met, the user may experience suboptimal performance.

4.1 Panel type

CABL is designed to support backlit panels. AMOLED/OLED type panels are not supported.

4.2 Frame delay

Based on currently available histogram data, the CABL core algorithm calculates a new backlight level and CABL LUT and applies them to one or two frames after. It is assumed that the next one or two frames are closely correlated to the current frame. If there is a scene change between the current and the next one or two frames, the temporal filter smooths the transition.

4.3 Power savings content dependency

Backlight power saving is defined as the difference between backlight power consumed with and without CABL.

Power savings are highly dependent on image content. For example, if dark scenes are continually shown on the display without any bright area, significant backlight power savings ie. more than 50%, can be achieved with a some CABL configurations. On the other hand, if the screen only shows very 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.

4.4 Quality degradation

In most usage cases, users will not see noticeable quality issues while running CABL. However, there might be some corner cases in which users can see a certain degree of quality degradation, such as a noticeable backlight change or a certain luminance loss in bright areas. This results from the tradeoff between power savings and visual quality. For certain display content, e.g., UI, use a higher quality setting of CABL and/or tune the CABL control parameters to remove or reduce quality degradation.

5 Configurable Parameters

This chapter describes configurable parameters that control visual quality and power savings.

Table 5-1 Configurable parameters

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

Parameter	XML ID name	Description
reserved_param_WST	CABLWindowSizeThreshold	Lower bound of transition window in temporal filter
reserved_param_FCT	CABLFilterCoefficientThreshold	Lower bound of coefficient of history information in temporal filter
reserved_param_BDF	CABLBackLightReductionFactor	Factor reducing the speed of the backlight change
reserved_param_BSTHC	CABLBackLightStepSizeHighCorrelation	Backlight change delta allowed when frames are similar
reserved_param_SCT	CABLSceneCorrelationThreshold	Correlation value beyond which frames are considered similar
reserved_param_SCD	CABLSceneChangeThreshold	Correlation value below which the scene is considered to have changed

5.1 CABL OEM file

Configurable parameters are stored in an on-device file that can override the default parameters. To define configurable parameters:

- For MSM8974 and older targets, override the parameters in `abl_oem.c`. Overwrite the defined defaults and recompile.
- For APQ8084 and newer targets, use an XML file framework to provide parameters to the CABL algorithm.

5.1.1 CABL parameter XML framework

1. To use XML file parsing instead of the default values present in the source, set the following properties in `/system/build.prop`:

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

2. Configurable parameters and XML tag IDs are listed in Table 5-1. Tag IDs are needed when creating the XML document and should match those given in Table 5-1. Reserved parameters (`reserved_param_*`) are typically for fine-tuned adjustments from the algorithm developer. Use the default parameters given.
3. Note the following about the XML file:
   - The root node is named Group and has an attribute named id, which is set to 'CABLConfiguration', e.g., `<Group id='CABLConfiguration'>`
   - Each CABL-configurable parameter is defined as a child node of the root node, with the node name being the XML tag ID listed in Table 5-1, e.g., `<CABLPixelDistortion>` for the parameter `oem_pixel_distortion`

- Each parameter has an attribute named units, which may take the values 'int', 'uint', 'long', or 'double', e.g., <CABLPixelDistortion units='uint'>150 100 100</CABLPixelDistortion>

4. 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.

5.2 Panel characteristic parameters

See Section 3.5.1 for display gamma curve measurement procedures.

- Gamma curve:
  - oem_gamma_grayscale[] and oem_gamma_luminance[]– The array oem_gamma_grayscale[] contains 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, and recorded by the array oem_gamma_luminance[]. Both arrays should be the same length.

    oem_length_gamma_lut – The number of the elements of the arrays of oem_gamma_grayscale[] and oem_gamma_luminance[].
- BL response curve:
  - oem_blresponse_bl[] and oem_blresponse_luminance[]– The array oem_blresponse_bl[] contains the backlight level for which luminance values are measured for the display BL 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, and recorded by the array oem_blresponse_luminance[]. Both arrays should be the same length.
  - oem_length_blresponse_lut – The number of the elements of the arrays of oem_blresponse_grayscale[] and oem_blresponse_luminance[].

5.3 Visual quality and power savings control parameters

- oem_bl_min_ratio – 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, e.g., long transition period or flickering when input content changes from dark to bright. oem_bl_min_ratio can have different values for each of three quality levels.
- oem_bl_max_ratio – Determines the maximum level of backlight scaling factor. The default value is 1024, which sets the maximum backlight scaling factor at 100%. If oem_bl_max_ratio 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. oem_bl_max_ratio can have different values for each of three quality levels.
- oem_pixel_distortion – Determines the number of pixels that could have been impacted by the CABL_LUT for a given frame. A higher oem_bl_pixel_distortion can yield higher power savings. However, an excessively high distortion level can lead to lower visual quality, e.g., luminance loss or contrast degradation for certain images at white area. oem_bl_pixel_distortion can have different values for each of three quality levels.

- `oem_bl_change_speed` – Controls the backlight change speed. The number is used internally to determine other associated parameters to finally set the backlight change speed. A higher number yields a fast backlight change speed. `oem_bl_change_speed` can have different values for each of three quality levels.
- `oem_bl_min_level` – The threshold below which CABL does not reduce its backlight level further.
- `bl_max_level` – The maximum brightness level the OS supports for sanitizing the original brightness level, typically 255 for Android.

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? See Section 3.1	
2	Luminance difference for adjacent BL levels	Does the luminance difference between any adjacent BL levels exceed 1% of the maximum luminance level of the device measured with the white test image? See Section 3.2	
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. See Section 3.3	
4	Gradual backlight control mechanism	Does the backlight control system have any gradual backlight mechanism in software and hardware, and can it be disabled? See Section 3.3.1	
5	CABL thread priority and callback latency	Is the CABL thread priority set high enough to update the backlight and CABL algorithm per frame without any delay? See Section 3.3.1	
6	Display panel characterization	Are the panel characteristic curves properly measured and correctly stored in the CABL OEM file? See Section 3.5	