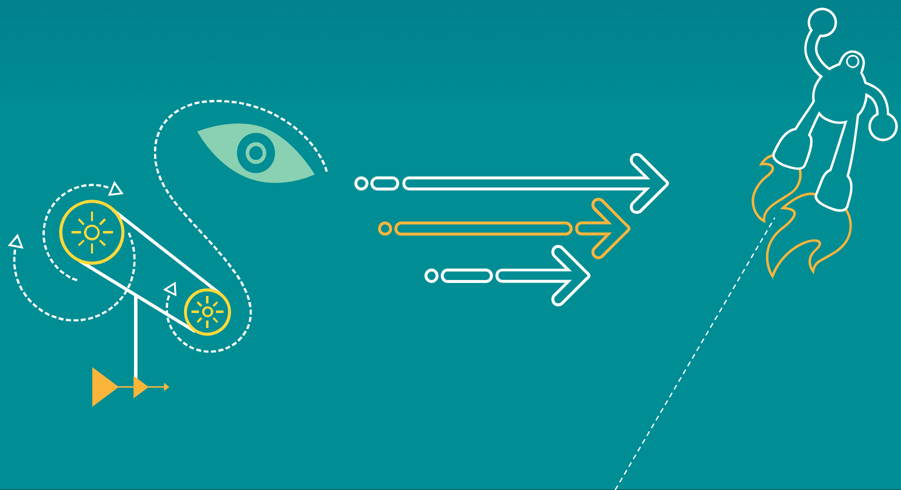
Camera Module Selection and Calibration Data

Qualcomm Technologies, Inc.



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Revision History

Revision	Date	Description
A	March 2011	Initial release
B	May 2012	Updated AWB Calibration Usage
C	May 2012	Minor update made to AWB Calibration Usage
D	November 2012	Added Verification of AWB Calibration and Lens Shading Calibration
E	June 2014	Numerous changes were made to this document; it should read in its entirety
F	August 2014	Minor change to lens shading information
G	October 2014	Updated page 13 and added sample calibration files
H	January 2015	Updated slide 13 and added Lens Sag Calibration slides, slides 23 and 24
J	January 2015	Updated to include calibration files
K	February 2015	Updated slide 13
L	February 2015	Updated attachment files
M	March 2015	Added accurate information for Gr/Gb and additional usage
N	September 2015	Updated slide 10 and added slide 14
P	January 2016	Attached calibration files
R	July 2016	Numerous changes were made to this document; it should read in its entirety

Revision History (cont.)

Revision	Date	Description
T	February 2017	Updated slides 9, and 10
U	April 2017	Added calibration files

Note: There is no Rev. I, O, Q, S, X, or Z per Mil. standards.

Contents

Introduction

Introduction

- Problem – Camera module deviation
  - Camera modules have production variations that cause the response of the camera module to be different from each other even when used in the same external conditions.
    - Lens placement accuracy and, manufacturing tolerances
    - Color and Infrared (IR) filter variations
    - Electro-mechanical tolerances in Auto Focus (AF) actuator
    - Sensor manufacturing design, and so on
- Solution – Module selection and calibration data.
  - Golden and limit module selection
    - Camera color tuning cannot be performed on every produced camera module. Select Golden Module (GM) and limit module for tuning and verifying image quality.
    - GM represents the batch of camera sensor modules from which the other modules can inherit color tuning.
    - GM is not the best module, but standard module that represents entire module's response.
  - Compensation of module deviation with calibration data
    - Image quality tuning to be performed with GM and tuning parameter are adjusted based on calibration data that is programmed in the EEPROM/OTP ROM in each camera module.
    - Module calibration takes care of the module-to-module deviation and ensures acceptable variations for the image quality.

Module Selection for Tuning and Verification

AWB Golden and Limit Module Selection

- Consider selection from N (over 200 from different production line) available modules
- Get Automatic White Balance (AWB) calibration data generated on D65 or TL84 for each module. If the calibration data in the module is not available, see the Calibration Data section and generate calibration data with the following procedures
  - Compute average of R/G and B/G with N available modules

$$Avg(R/G) = \frac{1}{N}\sum_{k=1}^{k=n} R/G_k \qquad Avg(B/G) = \frac{1}{N}\sum_{k=1}^{k=n} B/G_k$$

• K: Modules, 1~N

  - Compute the variation (distance) of each module from this average

$$\Delta R/G = \sqrt{(Avg(R/G) - R/G)^2} \qquad \Delta B/G = \sqrt{(Avg(B/G) - B/G)^2}$$

$$\Delta = \Delta R/G + \Delta B/G$$

• Avg(R/G), Avg(B/G): Average of N modules
• R/G, B/G: Target Module (TM) calibration data

  - Select GM and Limit module
    - GM is the module with the smallest distance from average.
    - Limit module is the module with the largest distance from average among screened-in modules based on module vendor screening specifications.
    - There could be different GM and limit modules based on different light sources.

Lens Shading Golden and Limit Module Selection

1. Consider selection from N (over 200 from different production line) available modules
2. Get Lens Shading Calibration (LSC) data generated on D65 or TL84 for each module. If calibration data in the module is not available, see the Calibration Data section and generate calibration data by the following procedures
   a) Compute average of each grid point (17 × 13) in four channels with N available modules

$$R[i,j]=\frac{1}{N}\sum_{k=1}^{N}R_k[i,j] \qquad Gr[i,j]=\frac{1}{N}\sum_{k=1}^{N}Gr_k[i,j]$$

$$Gb[i,j]=\frac{1}{N}\sum_{k=1}^{N}Gb_k[i,j] \qquad B[i,j]=\frac{1}{N}\sum_{k=1}^{N}B_k[i,j]$$

- K: Modules, 1~N
- [I,J]: grid point, 17 × 13

   b) Compute the variation (distance) of each module from this average

$$\Delta R_k=\sqrt{\sum_{i,j}\left(R[i.j]-R_k[i.j]\right)^2} \qquad \Delta Gr_k=\sqrt{\sum_{i,j}\left(Gr[i.j]-Gr_k[i.j]\right)^2}$$

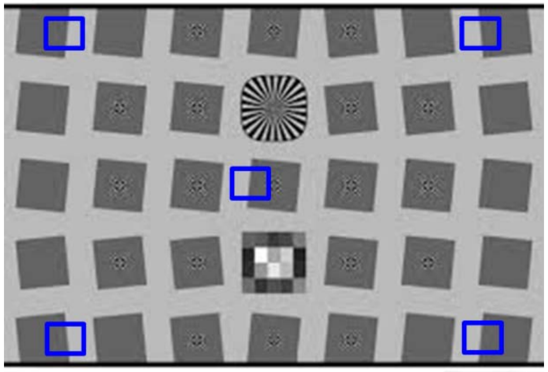
$$\Delta Gb_k=\sqrt{\sum_{i,j}\left(Gb[i.j]-Gb_k[i.j]\right)^2} \qquad \Delta B_k=\sqrt{\sum_{i,j}\left(B[i.j]-B_k[i.j]\right)^2}$$

$$\Delta_k=\Delta R_k+\Delta Gr_k+\Delta Gb_k+\Delta B_k$$

- R/Gr/Gb/B[i,j] – Average of grid value
- R_k/Gr_k/Gb_k/B_k[i,j] – TM's grid value
- K: Modules, 1~N
- [I,J]: grid point, 17 × 13

   c) Select GM and limit module
   - GM is the module with the smallest distance from average
   - Limit module is the module with the largest distance from average among screened-in modules based on module vendor screening spec
   - There could be different GM and limit modules based on different light sources.

AF Golden and Limit Module Selection



1. Capture an SFR test chart image with 100% FOV.
2. Measure the MTF50, spatial frequency at which contrast is at 50% (that is, using IMATEST) from center and four corner regions of the test chart as shown.
3. Golden and Limit module selection
   - Golden module selection for auto focus is based on the following set of criteria:
     - The center MTF measured at must meet or exceed top 7.0% percentile at both INF and 10 cm distances. Top 7.0% may be calculated from the random selection of 40 modules that have passed MTF test requirement of the module manufacturer.
     - The MTF at the outermost four corners must meet or exceed 60% of center the MTF.
   - Limit module is the module with the highest difference in MTF50 based on the center and the four-corner regions within the set of screened-in modules based on module vendor screening specification.
4. MTF reporting method
   - Report the MTF50 from all the modules evaluated for golden module selection (example, 40 modules).
   - The MTF50 is to be measured values at both INF and 10 cm distances.
   - Send the captured raw images used for the MTF50.

Calibration Data

Calibration Data Overview

- Example of format and memory map in EEPROM/OTP ROM
- AWB calibration
  - Parameters
  - Procedure
  - Usage
  - Verification
- AF calibration
  - Parameters
  - Procedure
  - Usage
  - Verification
- LSC
  - Parameters
  - Procedure
  - Usage
  - Verification

Example of Format and Memory Map in EEPROM/OTP ROM

Item	Data Content	Sizes (bytes)
Vendor Code	Vendor ID	1
Version	Calibration Tools version	1
Calibration Data	Calibration Data	3
Module information	Module ID 1	2
Module information	Module ID 2	2
D65 AWB R/Gr	R/Gr Ratio (D65)	2
D65 AWB B/Gr	B/Gr Ratio (D65)	2
D65 AWB Gb/Gr	Gb/Gr Ratio (D65)	2
TL84 AWB R/Gr	R/Gr Ratio (TL84)	2
TL84 AWB B/Gr	B/Gr Ratio (TL84)	2
TL84 AWB Gb/Gr	Gb/Gr Ratio (TL84)	2
A light AWB R/Gr	R/Gr Ratio (A)	2
A light AWB B/Gr	B/Gr Ratio (A)	2
A light AWB Gb/Gr	Gb/Gr Ratio (A)	2
Check Sum	Check sum	2
AF Infinity Position	Facing downwards	2
AF Macro Position	facing upwards	2
AF Initial current	AF Initial current	2
AF Infinity Position – lens sag	Facing forwards	2
AF Infinity Position – lens sag	Facing up	2
Check Sum	Check sum	2
D50 Sensor Response Data	LSC	1768
Check Sum	Check sum	2
TL84 Sensor Response Data	LSC	1768
Check Sum	Check sum	2
A Sensor Response Data	LSC	1768
Check Sum	Check sum	2
Total Check Sum	Check sum	2
Total Size		5349

- Module information
  - Customer can add more detail module information.
- AWB calibration data
  - Customer can use 1–3 illuminants.
  - Three illuminants are recommended for better adjustment.
  - 2 bytes for each calibration value.
  - 18 bytes for all three illuminants.
- AF calibration data
  - Infinite down, macro up, start current
  - Infinite forward/up – for lens sag
  - 10 bytes for all parameters
- LSC data
  - Using tintless correction.
    - Use one illuminant, TL84.
  - Using discrete lens shading correction.
    - Three illuminants are recommended.
    - 1768 (17 × 13 13 × 4 4 × 2) bytes for one illuminant cal.
    - If LED illuminant (not bulb type) is used for cal, then only one calibration data value is enough.
- A calibration sample, which is generated by the calibration dll, is available on the Attachments tab.

AWB Calibration – Light Sources

- Light sources for white balance calibration:
  - Quartz tungsten halogen lamp is used to generate type A light. A relatively accurate D50 can be generated by filtering tungsten halogen. The selected lamp supports a lifespan of at least 4000 hours of continuous operation. A diffuser with relatively uniform transmittance is used. The lamp has a DC-regulated output in order that the output is stabilized within 1%. With some due diligence, the list of lamp manufacturers that meet these criteria may be quickly narrowed.

AWB Calibration – Parameters

- The following values are obtained for AWB calibration data in each calibration illuminant.
  - R/Gr
  - B/Gr
  - Gb/Gr

AWB Calibration – Procedures

1. Pick a stable light source of a known color temperature as calibration light.
   - If one illuminant is available, the recommended illuminant is:
     - In the 4000 K – 5000 K range, Fluorescent (TL84 or CW) or D50 (DNP viewer).
   - If two illuminants are available, the recommended illuminants are:
     - High CCT – > 5000 K; Day light source (D65 or D50).
     - Low CCT – < 3000 K; A is preferred.
   - If three illuminants are available, the recommended illuminants are :
     - High CCT – > 5000 K; Day light source (D65 or D50).
     - Mid CCT – approximately 4000 K; Fluorescent (TL84 or CW) is preferred.
     - Low CCT – < 3000 K, A is preferred.
2. Illuminate sensor module with this calibration light.
3. Cover the module with a diffuser so that a flat field image can be taken.
4. Adjust sensor gain and exposure time so that brightness of G channel should be in 190-210 for 8-bit scale.
5. Capture RAW image.
6. Generate R/Gr, B/Gr, and Gb/Gr calibration data by using the calibration tool with RAW image input and proper input parameters (see Calibration Tool section).
7. Place the following three parameters (R/Gr, B/Gr, Gb/Gr) into the EEPROM/OTP ROM of the camera module.

AWB Calibration – Usage

1. Read calibration data from EEPROM/OTP ROM.
2. Read GM calibration data from the Chromatix™ header.
3. Compute calibration adjustment factor for R/Gr, B/Gr, and Gb/Gr
   - Compute ratio between TM/GM
4. Apply the calibration factor to all AWB reference points and all manual WB gains
   - If one illuminant (Fluorescent (TL84 or CW) or D50) is available
     - Apply the adjustment factor to all reference points
     - Apply the inverse of the adjustment factor to all manual WB gains and LED WB gains
   - If two illuminants are available (Day (D65 or D50), A)
     - Apply the high CCT (Day light source) correction factor to D75, D65, D50, NOON, and Custom_D reference points
     - Apply low CCT (A) correction factor to A/U30/H and Custom_A reference points
     - Compute average of high and low CCT correction factors and apply to mid CCT illuminants, such as TL84, CW, and Custom_F
     - Apply the inverse of correction factor to the manual WB gains and LED WB gain according to CCT
   - If three illuminants (Day (D65 or D50), Fluorescent (TL84 or CW), A) are available
     - Apply high CCT (Day) correction factor to D75, D65, D50, NOON, and Custom_D reference points
     - Apply mid CCT (Fluorescent) correction factor to CW, TL84, and Custom_F reference points
     - Apply low CCT (A) correction factor to A/U30/H and Custom_A reference points
     - Apply the inverse of correction factor to the manual WB gains and LED WB gain according to CCT

AWB Calibration – Usage (cont.)

5. Apply the calibration factor to the channel imbalance parameter.
   - When BGGR or BGRG – gr_over_gb
   - When RGGB or GRBG – 1/gr_over_gb
6. Apply the calibration factor to the tuning parameter, ref_b_bg_tl84, for Bayer AWB (heuristic for purple sky prevention).
   - Use the same adjustment factor that is used for TL84 reference point adjustment.
7. Apply the calibration factor to the tuning parameter, awb_misleading_color_zones
   - If one illuminant (Fluorescent (Currently TL84 is used) or Day (Currently D50 is used)) is available, apply the calibration factor to:
     - `awb_misleading_color_zones[i].detect_zone.rg_center`
     - `awb_misleading_color_zones[i].detect_zone.bg_center`

AWB Calibration – Usage (cont.)

- If two illuminants (A and Day (Currently D50 is used)) are available
  - Apply the Day (D50) calibration factor to: `awb_misleading_color_zones[i].detect_zone.rg_center` and `awb_misleading_color_zones[i].detect_zone.bg_center`, if `awb_reserved_data.reserved_int[i+20]` is 0.
  - Apply the A calibration factor to: `awb_misleading_color_zones[i].detect_zone.rg_center` and `awb_misleading_color_zones[i].detect_zone.bg_center`, if `awb_reserved_data.reserved_int[i+20]` is 2.
  - Compute average of high and low CCT calibration factor and apply it to: `awb_misleading_color_zones[i].detect_zone.rg_center` and `awb_misleading_color_zones[i].detect_zone.bg_center`, if `awb_reserved_data.reserved_int[i+20]` is 1.

AWB Calibration – Usage (cont.)

- If three illuminants (Day (Currently D50 is used), Fluorescent (Currently TL84 is used) and A) are available
  - Apply the Day (D50) calibration factor to: `awb_misleading_color_zones[i].detect_zone.rg_center` and `awb_misleading_color_zones[i].detect_zone.bg_center`, if `awb_reserved_data.reserved_int[i+20]` is 0.
  - Apply the Fluorescent (TL84) calibration factor to: `awb_misleading_color_zones[i].detect_zone.rg_center` and `awb_misleading_color_zones[i].detect_zone.bg_center`, if `awb_reserved_data.reserved_int[i+20]` is 1.
  - Apply the A calibration factor to: `awb_misleading_color_zones[i].detect_zone.rg_center` and `awb_misleading_color_zones[i].detect_zone.bg_center`, if `awb_reserved_data.reserved_int[i+20]` is 2.

Note: i ~ [0, MISLEADING_COLOR_ZONE_NUM]

AWB Calibration – Usage (cont.)

8. Apply the calibration factor to the tuning parameter, `awb_extended_outdoor_heuristic`
   - Apply the Day (Currently D50 is used) calibration factor to:
     - `awb_extended_outdoor_heuristic.awb_outdoor_green_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_bright_blue_sky_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_not_enough_stat_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_blue_ground_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_cloud_sky_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_blue_sky_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_fog_sky_adjust.detection_zone[i].rg(bg)_center`
     - `awb_extended_outdoor_heuristic.awb_outdoor_green_detect_adjust.detection_zone[i].rg(bg)_center`

Note: i ~ [0, DETECT_ZONE_NUM]

AWB Calibration – Usage (cont.)

9. Apply the calibration factor to the tuning parameter, awb_single_color_tracking
   - Apply the Day (Currently D50 is used) calibration factor to:
     - `awb_single_color_tracking.awb_single_color_detect[k].detection_zone[i].rg(bg)_center`

- Refer to the following files and functions for usage examples in source code:
  - File – \mm-camera\mm-camera2\media-controller\modules\sensors\eeprom\libs\eeprom_util\eeprom_util.c
    - Function – eeprom_whitebalance_calibration
  - File – \mm-camera\mm-camera2\media-controller\modules\sensors\eeprom\libs\...
    - Function – XXX_format_wbdata
      - Set wbc >gr_over_gb according to Bayer pattern and calibration data.
        - For "BGGR" and "GBRG" of bayer pattern, Gb/Gr of stored calibration data wbc >gr_over_gb = awb_gr_over_gb;
        - For "RGGB" and "GRBG" bayer pattern, Gb/Gr of stored calibration data wbc >gr_over_gb = 1.0f/awb_gr_over_gb;

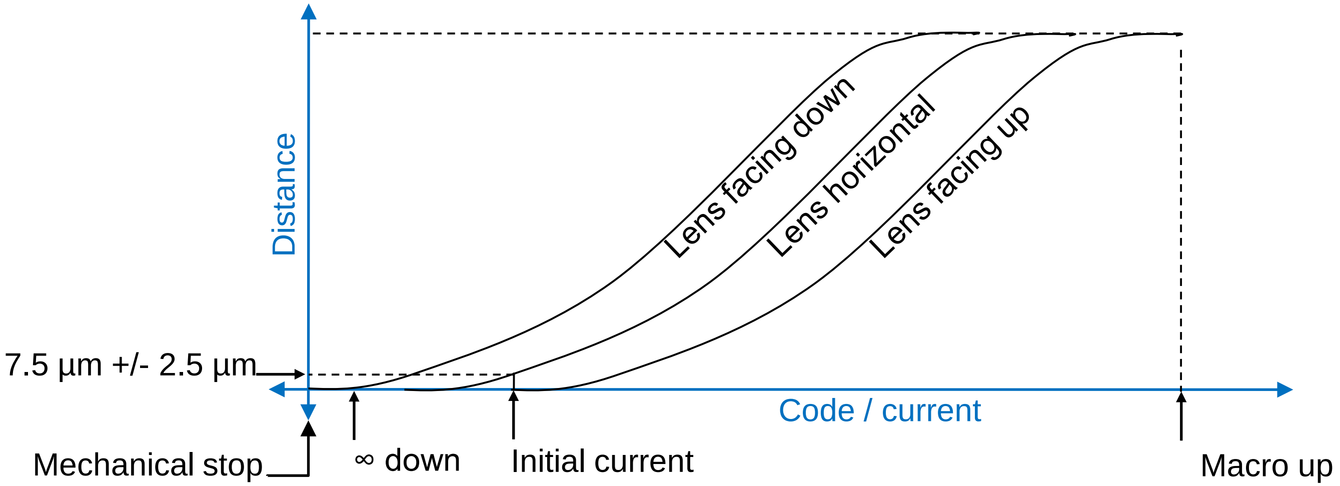
Note: k ~ [0, NUM_SPECIAL_COLOR_DETECT] and i ~ [0, DETECT_ZONE_NUM]

AWB Calibration – Verification

1. Capture JPEG using GM under Fluorescent (TL84 or CW) lighting condition using MWB for gray chart.
   - Measure R/G and B/G of the center portion of the image (1/8 × 1/8 to 1/4 × 1/4) by using the Chromatix tool.
2. Capture JPEG using TM under Fluorescent (TL84 or CW, which should be the same light source from the step #1.) lighting condition using MWB for gray chart.
   - No OTP CAL data applied
   - Measure R/G and B/G of the center portion of the image (1/8 × 1/8 to 1/4 × 1/4).
   - Error1rg = (TM R/G)/(GM R/G)
   - Error1bg = (TM B/G)/(GM B/G)
3. Capture JPEG using TM under TL84 lighting condition using MWB for gray chart.
   - OTP CAL data applied
   - Measure R/G and B/G of the center portion of the image (1/8 × 1/8 to 1/4 × 1/4)
   - Error2rg = (TM R/G)/(GM R/G)
   - Error2bg = (TM B/G)/(GM B/G)
4. Verify that Error2 < Error1 and Error2 < 5%
5. Repeat steps 1-4 using D65 or D50 light source (or what is used to set MWB for daylight) and daylight manual WB.

AF Calibration – Parameters

- DAC code value to move lens from infinity side mechanical stop to target distance focus positions for:
  - Infinity position DAC code
    - Direction – Lens facing downwards
    - Focus distance – Hyperfocal distance, infinity (H cm)
  - Macro position DAC code
    - Direction – Lens facing upwards
    - Focus distance – 10 cm
  - Initial current DAC code
    - Direction – Horizontal orientation
    - Value to start moving the lens from Infinity to 7.5 µm ± 2.5 µm



AF Calibration – Procedures

- Infinity down (H cm)
  1. Place target (Large ISO chart) H (Hyperfocal distance) cm from the camera lens.
  2. Move/focus lens from mechanical stop to best focus using infinity to macro direction movements with the lens facing downwards.
  3. Store DAC value.
- Macro up (10 cm)
  1. Place target (small ISO chart) 10 cm from the camera lens.
  2. Move/focus lens from mechanical stop to best focus using infinity to macro direction movements with the lens facing upwards.
  3. Store DAC value.
- Initial current
  1. Measure using laser or distance metering system and apply code to driver to get lens to move from mechanical stop to near macro (7.5 µm ± 2.5 µm) direction in the horizontal orientation.
  2. Store DAC value.

AF Calibration – Usage

1. Read infinity DAC and macro DAC calibration data and set region_params[1].code_per_step.
2. Read start current DAC calibration data and set region_params[0].code_per_step.

- Refer to the following files and functions for usage examples in source code.
  - File – \mm-camera\mm-camera2\media-controller\modules\sensors\eeprom\libs\eeprom_util\eeprom_util.c
    - Function – eeprom_autofocus_calibration
  - File – \mm-camera\mm-camera2\media-controller\modules\sensors\eeprom\libs\...
    - Function – XXX_format_afdata

AF Calibration – Verify

1. Determine the target distance and the module orientation used by the module manufacturer for AF calibration (example, 1.5 m face-down, and 10 cm face-up).
2. Using a Macbeth Color Checker (MCC) chart (or other test chart) with the same target distance and the module orientation, perform Touch AF and capture logs.
3. The final lens position in units of DAC must match the calibration data within ±20 DAC.
   - For instance, if the AF calibration data for 1.5 m face-up is 110 DAC, then Touch AF performed with an MCC, 1.5 m face-up should be between 90 and 130 DAC.

AF Calibration for Lens Sag Compensation (Open-Loop VCM Only)

- Parameters
  - Infinity position facing forward DAC code
    - Direction – Lens facing forwards.
    - Focus distance – Hyperfocal distance, infinity (H cm) (the same distance as for measuring the infinity down DAC).
  - Infinity position facing up DAC code
    - Direction – Lens facing up.
    - Focus distance – Hyperfocal distance, infinity (H cm) (the same distance as for measuring the infinity down DAC).
- Procedures
  - Infinity forwards (H cm)
    1. Place target (Large ISO chart) H (Hyperfocal distance) cm from the camera lens.
    2. Move/focus lens from mechanical stop to best focus using infinity to macro direction movements with the lens facing forwards.
    3. Store DAC value.
  - Infinity up (H cm)
    1. Place target (Large ISO chart) H (Hyperfocal distance) cm from the camera lens.
    2. Move/focus lens from mechanical stop to best focus using infinity to macro direction movements with the lens facing up.
    3. Store DAC value.

AF Calibration for Lens Sag Compensation (Open-Loop VCM Only) (cont.)

- Usage
  - This information is only used for open-loop VCM for lens position deviation when the orientations are different.
  - Combines accelerometer gravity data and the OTP lens sag compensation data to compensate the different lens position for the same distance due to orientation changes.
- Verification
  - Similar to other AF calibration data verification.

Note: Infinity down DAC value is recommended to be in the linear region of the VCM.
This feature is important for depth-assisted AF.

LSC – Parameters

- 17 × 13 table normalized sensor response data for each channel in each calibration illuminant.
  - D65/D50 sensor response data.
  - TL84 sensor response data.
  - A sensor response data.
- 17 × 13 grid size is recommended for all versions of lens shading hardware blocks.
  - Using 2 bytes for response data of each grid.
    - Total size – 17 × 13 13 × 4 (channel) × 2 (bytes) = 1768 bytes.

LSC – Procedures

1. Pick a stable light source of a known color temperature as the calibration light.
   - Using Tintless Correction
     - Use one illuminant, TL84 fluorescent type bulb.
   - Using Discrete Lens Shading
     - If one illuminant is available, the recommended illuminant is:
       - D50 (DNP viewer)
     - If two illuminants are available, the recommended illuminants are:
       - High CCT – >5000 K; D65 is preferred (non-LED and non-fluorescent type bulb)
       - Low CCT – <3000 K; A is preferred (non-LED and non-fluorescent type bulb)
     - If three illuminants are available, recommended illuminants are:
       - High CCT – >5000 K; D65 is preferred (non-LED and non-fluorescent type bulb)
       - Mid CCT – Approximately 4000 K; TL84 fluorescent type bulb is preferred
       - Low CCT – <3000 K, A is preferred (non-LED and non-fluorescent type bulb)
2. Illuminate sensor module with this calibration light.
3. Cover the module with a diffuser so a flat field image can be taken.
4. Adjust sensor gain and exposure time so the brightness of the G channel is in the 190–210 range for 8-bit scale (For the measurement, Qualcomm Technologies, Inc. (QTI) recommends customers to use center RoI by 25%.).
5. Capture RAW image.
6. Generate LSC data by using the calibration tool with inputting a RAW image and setting proper input parameters (see Calibration Tool section).
7. Place 17 × 13 calibration data into EEPROM/OTP ROM in the camera module.

LSC – Usage

1. Read calibration data from EEPROM/OTP ROM.
2. Read golden module calibration data from Chromatix header.
3. Compute calibration adjustment factor for each grid point.
   - Golden module [Channel][i]/Target module[Channel][i] in each illuminant (i = 17 × 13).
4. Apply the calibration factor to the lens shading table for all illuminants.
   - If one illuminant (D50) is available:
     - Apply the adjustment factor of D50 to all of the lens shading table.
   - If two illuminants are available (D65, A):
     - Apply the high CCT (D65) adjustment factor to the D65 lens shading table.
     - Apply the low CCT (A) adjustment factor to the A lens shading table.
     - Compute the average of the high and low CCT adjustment factors and apply to the TL84 lens shading table.
   - If three illuminants (D65, TL84, A) are available:
     - Apply the high CCT (D65) adjustment factor to the D65 lens shading table.
     - Apply the mid CCT (TL84) adjustment factor to the TL84 lens shading table.
     - Apply the low CCT (A) adjustment factor to the A lens shading table.

LSC – Usage (cont.)

- Final lens shading table

$$\text{Chromatix LSC}[i, \text{channel}, n] = \text{Chromatix LSC}[i, \text{channel}, n] \times \frac{GM[i]}{TM[i]}$$

  - i – Illuminant table
  - Channel – Corresponds to R, B, Gr, or Gb
  - N – Table entry (17 × 13)
  - GM[i] – EEPROM LS calibration data of GM
  - TM[i] – EEPROM LS calibration data of TM
- Refer to the following files and functions for usage examples in source code:
  - File – \mm-camera\mm-camera2\media-controller\modules\sensors\eeprom\libs\eeprom_util\eeprom_util.c
    - Function – eeprom_lensshading_calibration
  - File – \mm-camera\mm-camera2\media-controller\modules\sensors\eeprom\libs\...
    - Function – XXX_format_lscdata

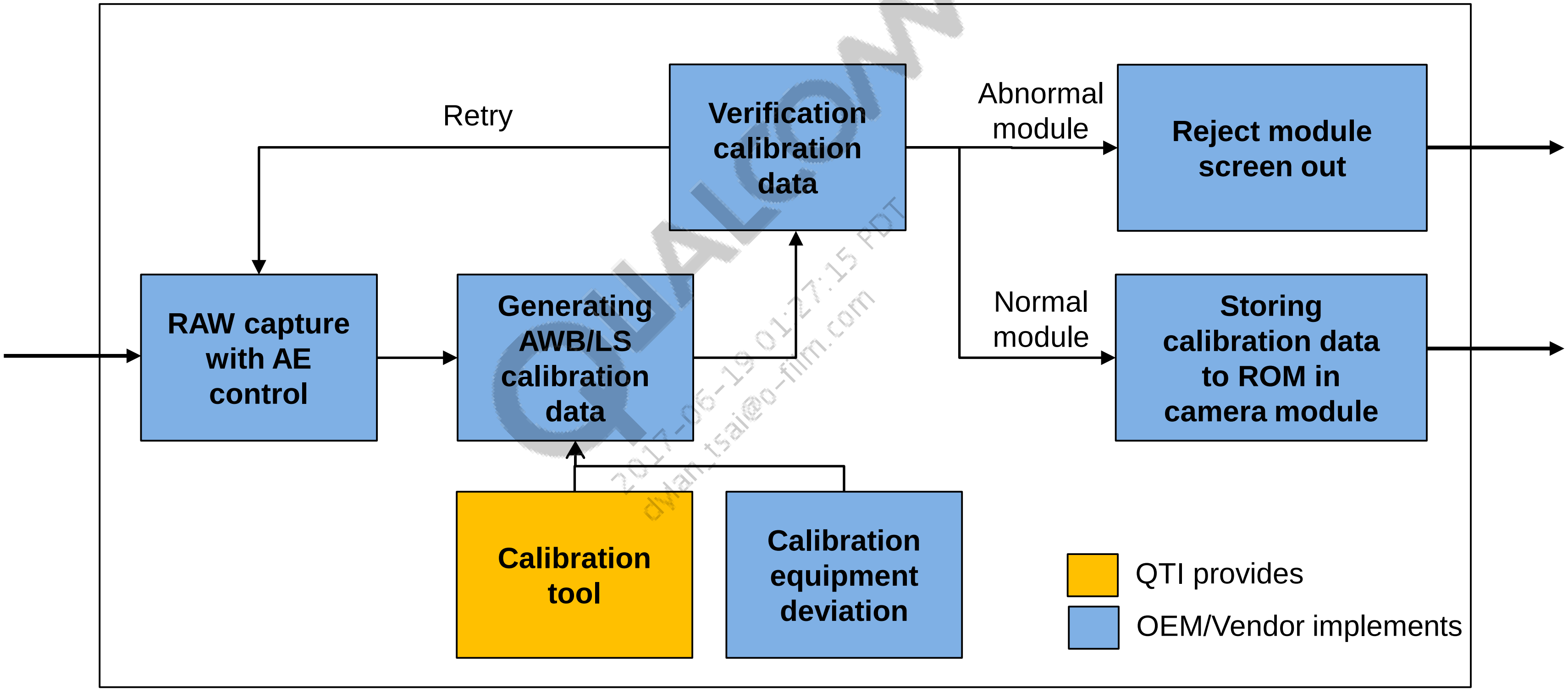
LSC – Verification

1. Capture lens shading test images using a DNP viewer and diffuser for
   - Capture images with GM (LSC tuned)
   - Target module + calibration adjustment
   - Target module + no calibration adjustment
2. Test the numerical specification for lens shading with each image
3. Test results of the GM and target module + calibration adjustment images should pass
4. Verify that lens shading performance of the target module + calibration adjustment image shows an improvement over the target module + no calibration adjustment image
   - The lens shading limit sample should be good for TM in this verification so that significant improvement is visible

Calibration Tool

Calibration Tool Usage on the Camera Module Production Line

- Example structure of application on camera module production line



- QTI provides the calibration tool – Source code (See Attachments tab).
- Customer/module vendor can implement camera module production tool using the calibration tool (source code).
- Calibration equipment deviation and verification calibration data are optional.

Calibration Tool API

- LensCorrectionLib – External function in the tool. (see Attachments tab)
  - The function generates AWB and LSC data based on the following input information:

Input parameters	Type	Contents
pImage	Char *	RAW image (8-bit format RAW)
nWidth	int	X resolution of RAW image
nHeight	int	Y resolution of RAW image
CFA_pattern	int	Bayer pattern #define RGGB_PATTERN 0 #define GRBG_PATTERN 1 #define BGGR_PATTERN 2 #define GBRG_PATTERN 3
R_black_offset, Gr_black_offset, Gb_black_offset, B_black_offset	short	Black level for each channel, 8-bit scale
bMode9x7	Bool	0 – 17 × 13 1 – 9 × 7

Output parameter	Type	Contents

pCalData	CalibrationDataStruct	AWB and LSC data
		unsigned short int * R_LSC; // R channel LS data
		unsigned short int * Gr_LSC; // Gr channel LS data
		unsigned short int * Gb_LSC; // Gb channel LS data
		unsigned short int * B_LSC; // B channel LS data
		unsigned short int * AWB; //AWB calibration data

Calibration Tool API (cont.)

- Reference program for generating calibration data (see Attachments tab)
  - Entry point is _tmain(int argc, _TCHAR* argv[])
  - Sequence
    1. Set RAW image resolution
    2. Set RAW format (Raw_8Bit, Raw_10bit_Packed, Raw_10bit_Unpacked, Raw_12bit_Unpacked)
    3. Convert RAW image format to 8-bit format
    4. Crop RAW image (left/right, top/bottom)
    5. Call the LensCorrectionLib function in the tool with parameters
    6. Write AWB and lens shading data to the file
       (Production line tool can use output data directly instead of using file)

Verification of Calibration Data

- AWB calibration data verification
  - Ratio of calibration data between GM and TM should be in threshold
    - 0.75 < R/G Cal ratio = (TM R/G)/(GM R/G) < 1.25
    - 0.75 < B/G Cal ratio = (TM B/G)/(GM B/G) < 1.25
    - 0.95 < Gb/Gr Cal ratio = (TM Gb/Gr)/(GM Gb/Gr) < 1.05
      (Criteria can be adjusted based on module vendor specification)
- LSC data verification
  - The ratio of the calibration data between GM and TM in each grid point should be in threshold
    - 0.75 ≤ Cal ratio in each grid point = (TM Cal data [i])/(GM Cal data [i]) ≤ 1.25
      (Adjust the criteria based on Module Vendor Spec)
  - Smooth curve and no fluctuation in the calibration data
    - There should be no fluctuation in both the H and V calibration data curves
    - Calibration data curves for all the four channels R, Gr, Gb, and B should be smooth
    - For each internal (non-boundary) grid point data, TM Cal data [i] should be within [Max × 120%, Min × 80%], where Max/Min are the max and min values of its eight neighboring points and i is calibration grid point (17 × 13)

Calibration Equipment Deviation

Deviation in Production Line

- In camera module manufacturing, several production lines may experience calibration equipment deviations.
- The same type/model of light box is used for WB calibration, but each one deviates from the ideal value.
- Compensation for this deviation is aspired to such that complete WB calibration produces results as if no deviation in the calibration units ever existed.
- One golden calibration unit must be used to determine the adjustment factor between the golden unit and the manufacturing line's deviation.
- Knowing this deviation allows the calibration method to compensate and still achieve good calibration values for all camera modules that may be produced in different production lines.

Light Box Deviation Inclusion to WB Calibration Data

- Add a step prior to starting WB calibration to use a different or slightly deviated color temperature light box. This extra step determines the deviation of new or different light boxes compared to the golden unit light box. Performed once per calibration line.
  1. Measure R/G and B/G deviation between both light boxes using a good sample module
  2. Calculate the production line adjustment factor and store the values in the calibration tool for all modules that will be produced in this production line
     - Light_box_adjustment_R/G = Golden_LB_R/G / Line_LB_R/G
     - Light_box_adjustment_B/G = Golden_LB_B/G / Line_LB_B/G
  3. Adjust the calibration data generated by the calibration tool with the production line adjustment factor
     - Adjusted R/Gr = R/Gr × Light_box_adjustment_R/G
     - Adjusted B/Gr = B/Gr × Light_box_adjustment_B/G

References

Title	Number
Qualcomm Technologies, Inc.	
Multimedia Driver Development and Bringup Guide - Camera	80-NU323-2

Acronym or term	Definition
AF	Auto Focus
AWB	Automatic White Balance
GM	Golden Module
IR	Infrared
LSC	Lens Shading Calibration
MCC	Macbeth Color Checker
OTP	One-Time Programmable
VCM	Virtual Contiguous Memory

Questions?

https://createpoint.qti.qualcomm.com

