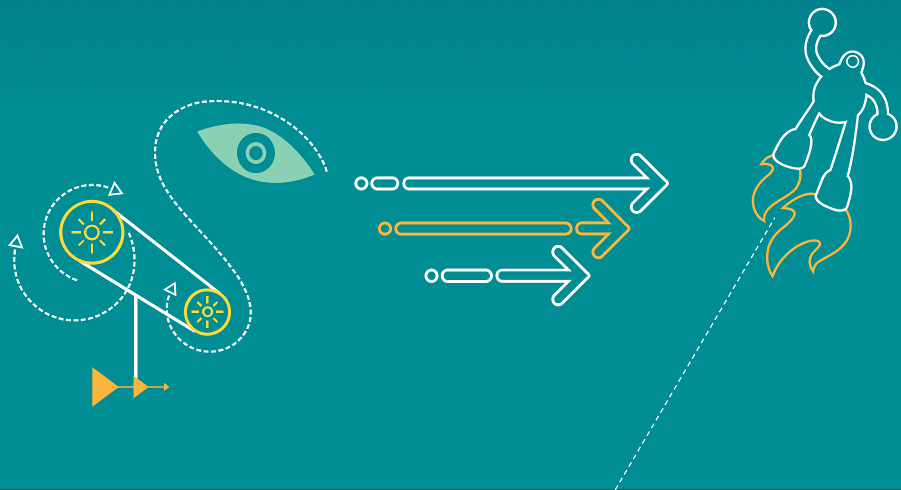
Qualcomm Spectra™ 2xx Deep Dive

Qualcomm Technologies, Inc.



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Revision History

Revision	Date	Description
A	May 2017	Initial release
B	May 2017	Added information on Adaptive bayer filter (ABF) and 2D LUT
C	May 2017	Minor edit to the content slide
D	May 2017	Numerous changes were made to this document; it should be read in its entirety
E	August 2017	Added section on upscaler tuning guidelines
F	August 2017	Added section on Global tone mapping (GTM) Updated slides for upscaler

Contents

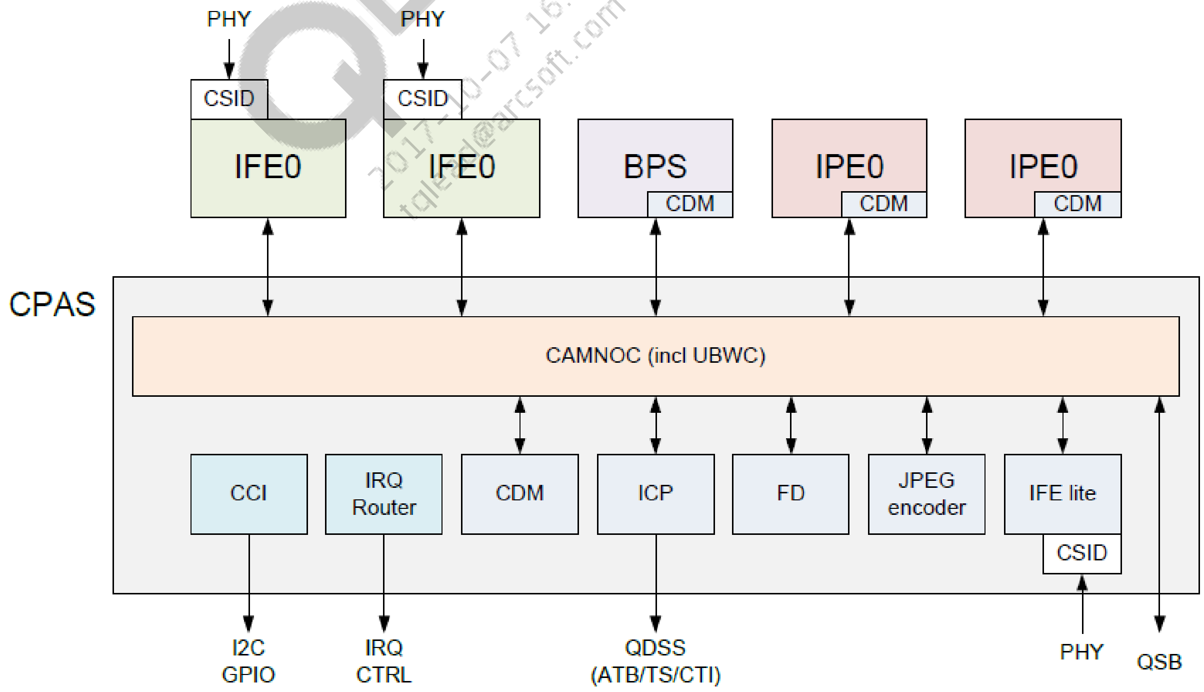
Introduction to Qualcomm Spectra 2xx Components

Objective

- At the end of this presentation, you will have an understanding of the following Qualcomm Spectra 2xx modules, which are the main hardware components for image quality:
  - Image front end (IFE)
  - Bayer processing segment (BPS)
  - Image processing engine (IPE)

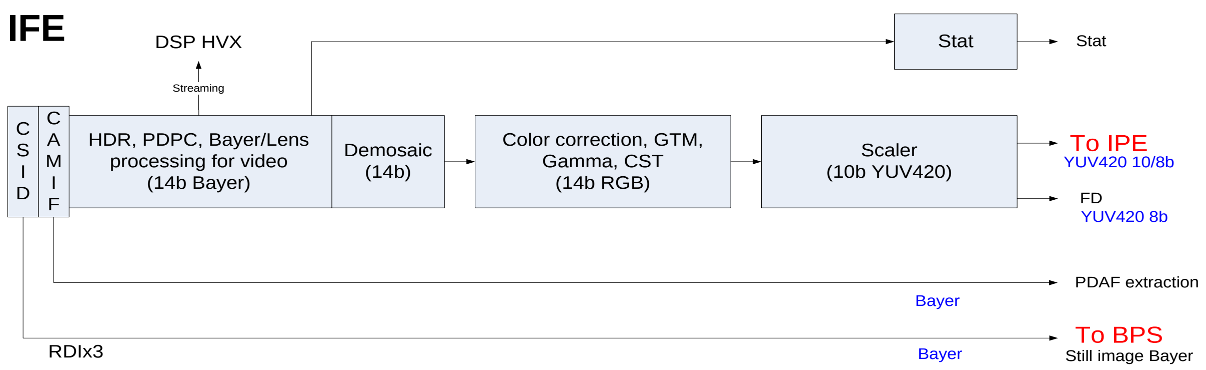
Qualcomm Spectra 2xx Component – Introduction

- This document introduces modules in IFE, BPS and IPE, which are the main hardware components for image quality.
- Qualcomm Spectra 2xx camera subsystem consists of Image Front End (IFE), Bayer processing segment (BPS), Image processing engine (IPE) and Camera peripheral and support (CPAS). The following diagram gives a high level understanding of the subsystem:



Qualcomm Spectra 2xx Component – Introduction (cont.)

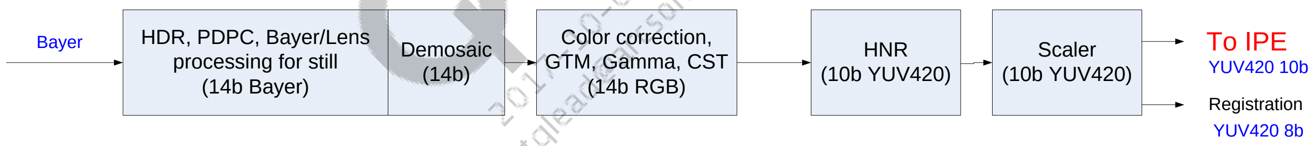
- **Image front-end engine (IFE) x 2**
  - Bayer process for preview/video only
  - Stats for 3A
  - 4 tape-in/out points for HVX streaming
  - Compared to previous chipsets, major luma/color processing modules (that is CAC, LTM, CV, SCE, CS) are moved to IPE
  - Multipass outputs (1:1, 1:4, 1:16) feeding to IPE
  - IFE provides 3 paths for ideal raw dump
    1. From CAMIF (Bayer format)
    2. From Lens shading correction (LSC) output (Bayer format)
    3. From Global tone mapping (GTM) output (RGB14-bit format)
- **IFE-lite x 1**
  - 4 RDI streams (no processing)



Qualcomm Spectra 2xx Component – Introduction (cont.)

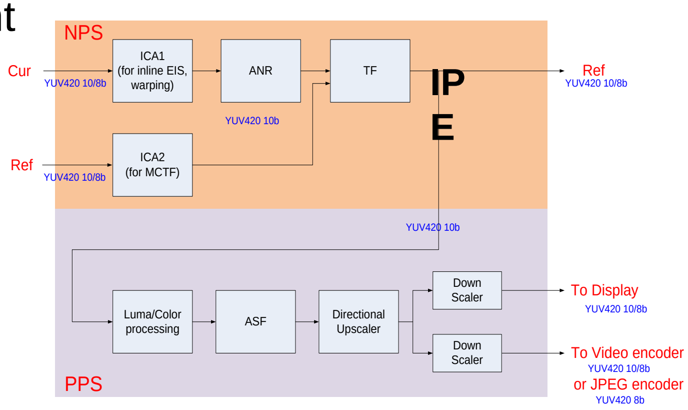
- **BPS × 1**
  - Bayer process and noise reduction for snapshot only
  - Simple stats (BG and HDR Bhist) for special offline processing
  - Multipass outputs (1:1, 1:4, 1:16, 1:64) feeding to IPE

BPS



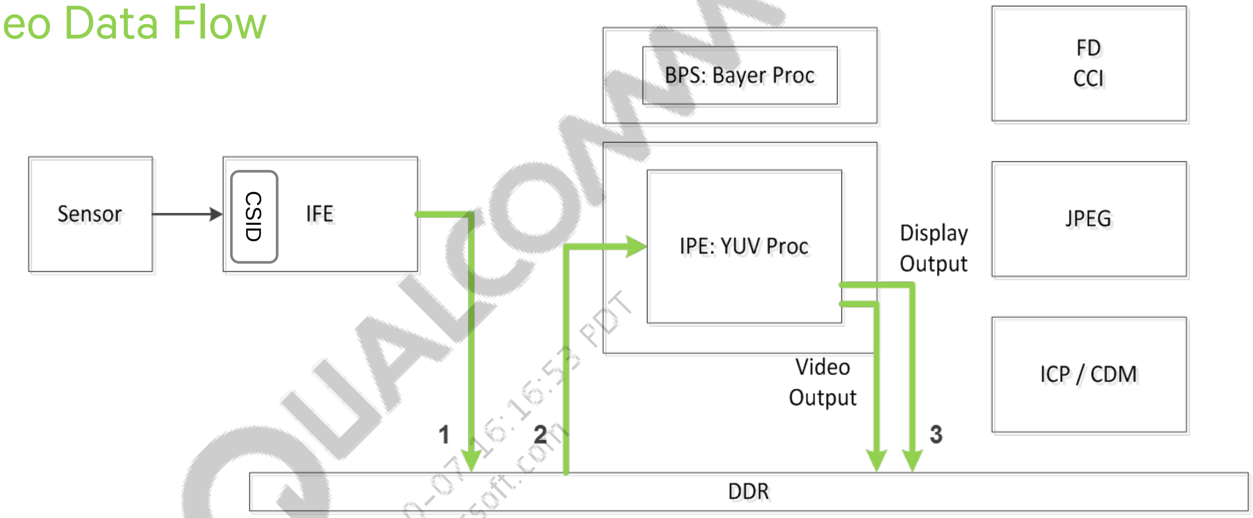
Qualcomm Spectra 2xx Component – Introduction (cont.)

- **IPE × 2**
  - Each IPE consists of 2 parts. Noise processing segment (NPS) and Post processing segment (PPS)
  - NPS
    - ICA1 for inline EIS and image warping
    - ICA2 and Temporal filter (TF) for Motion compensation temporal filtering (MCTF)
    - Advanced noise reduction (ANR) for spatial noise reduction
  - PPS
    - CAC, LTM, 2DLUT, CV, CS, SCE modules for luma/color processing
    - Moving above modules after noise reduction is one of the main changes in Qualcomm Spectra 2xx
    - Adaptive Spatial Filter (ASF) for detail enhancement
    - Scaler (No rotator)
    - Single input multiple outputs (SIMO)

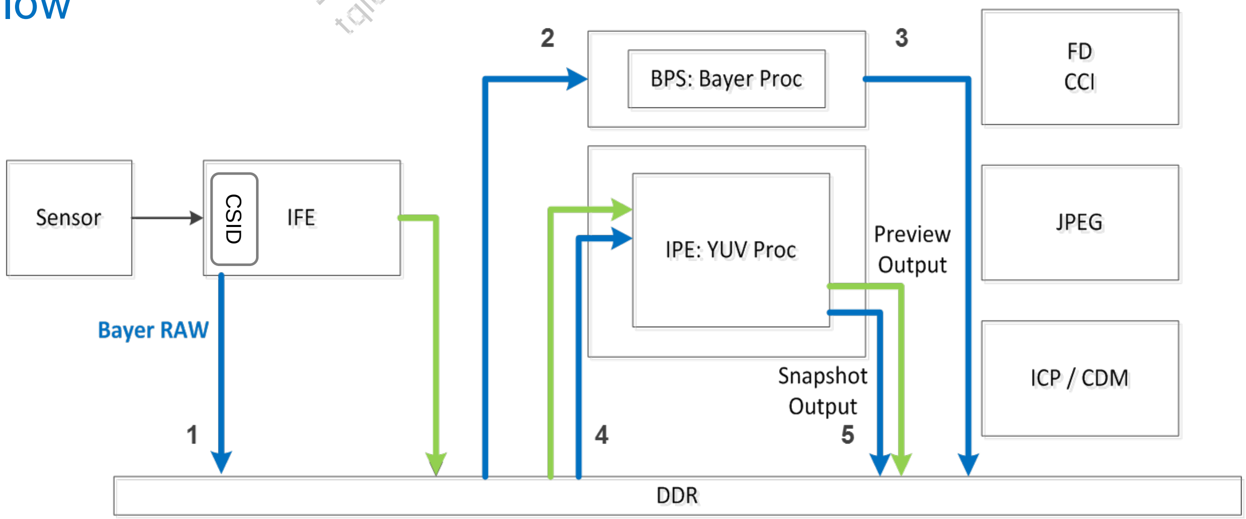


Qualcomm Spectra 2xx Data Flow

- Preview and Video Data Flow



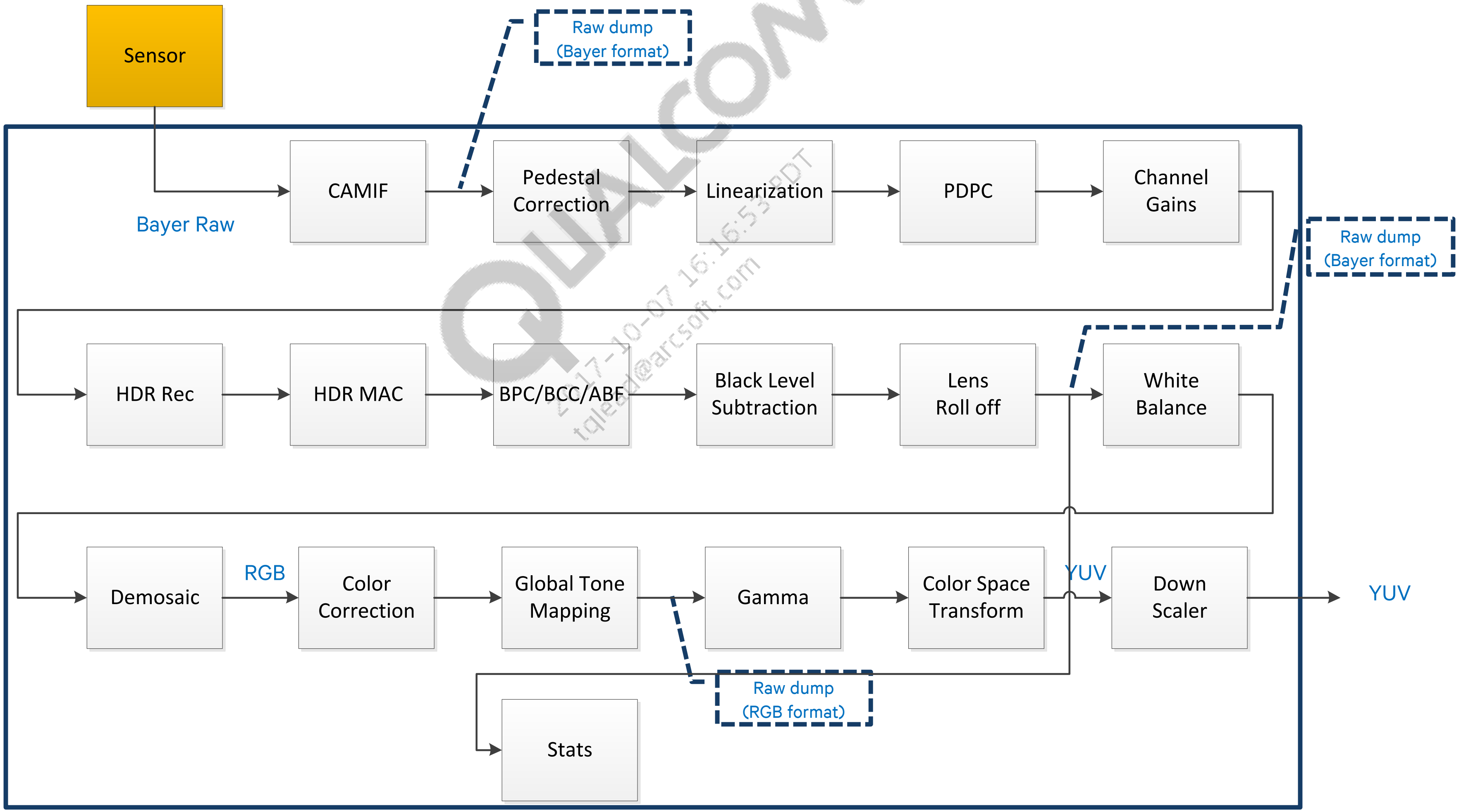
- Snapshot Data Flow



Qualcomm Spectra 2xx Pipeline

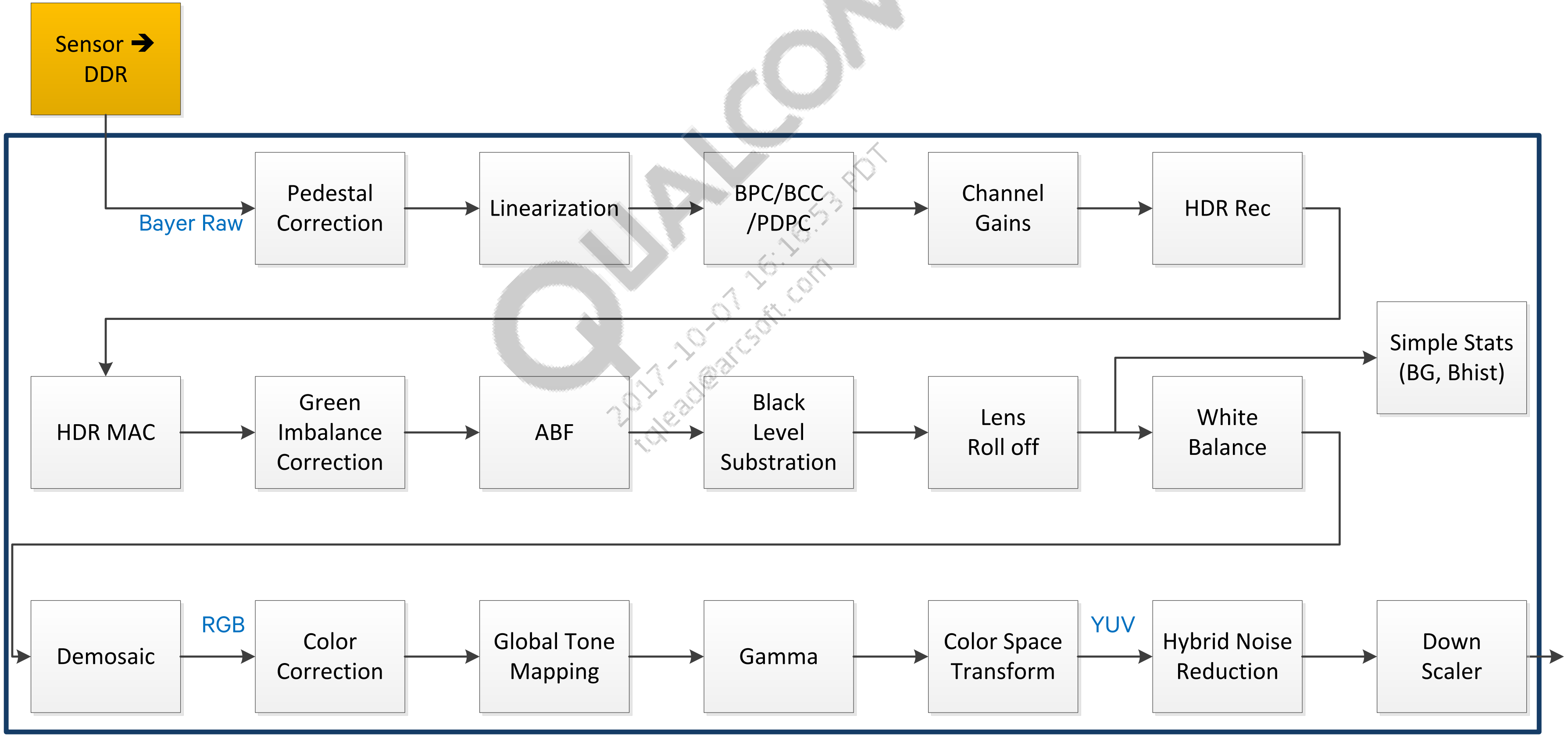
Qualcomm Spectra 2xx Pipeline (Simplified IQ Version)

- IFE



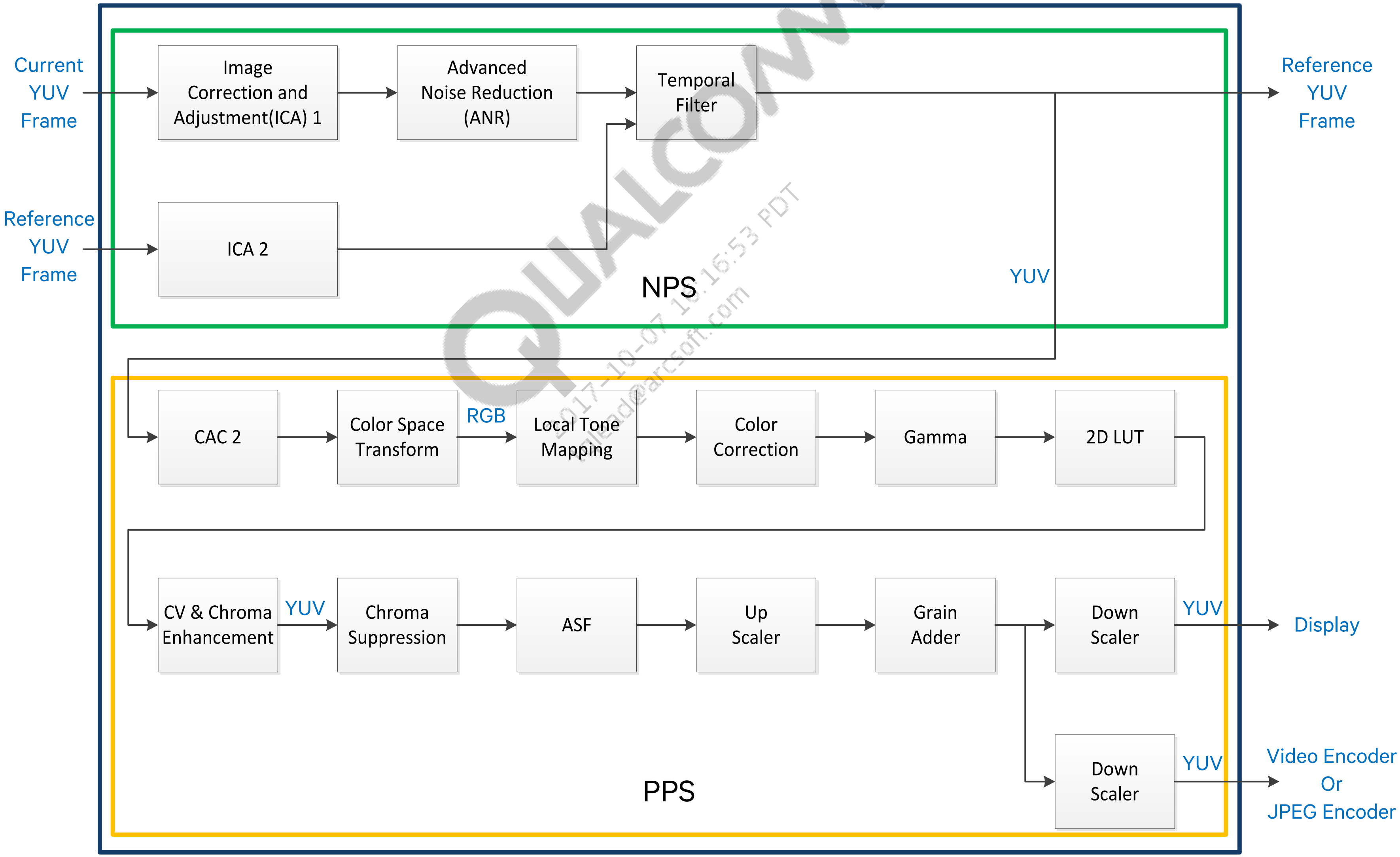
Qualcomm Spectra 2xx Pipeline (Simplified IQ Version) (cont.)

- BPS



Qualcomm Spectra 2xx Pipeline (Simplified IQ Version) (cont.)

- IPE : IPE consists of NPS and PPS



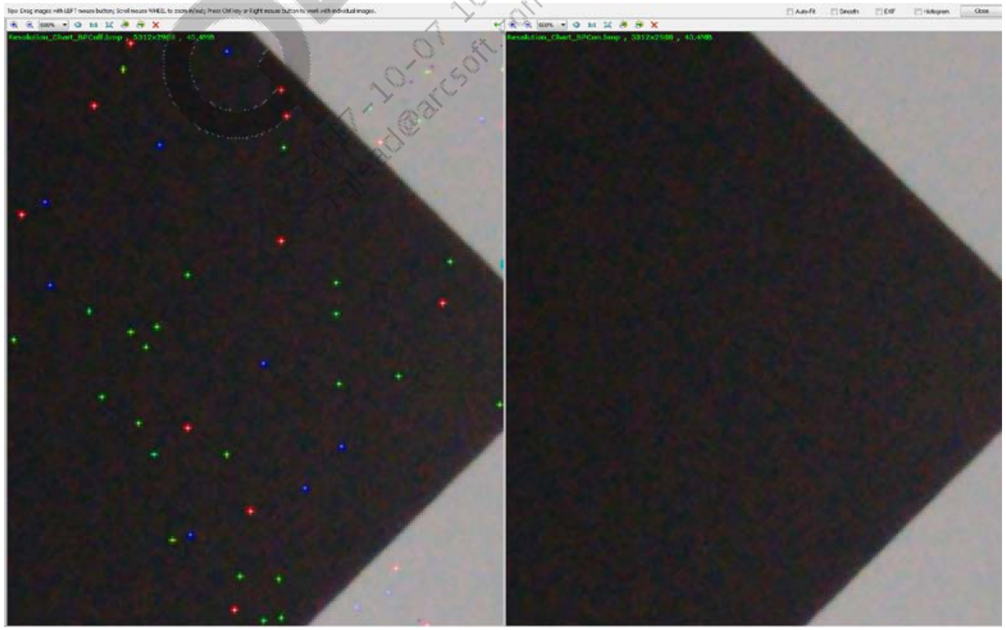
Bad Pixel Correction/Bad Cluster Correction/PD Pixel Correction (BPC/BCC/PDPC)

BPC/BCC/PDPC – Introduction

Problem statement

- Bad pixel correction (BPC)/Bad cluster correction (BCC)
  - A defective pixel is defined as a pixel whose response is noticeably different from the response of the other pixels in the array under dark or uniformly illuminated conditions
  - BPC and BCC modules are designed to remove the defective pixels
  - Supports single and couplet corrections but is not supported for big cluster (for more than 3)

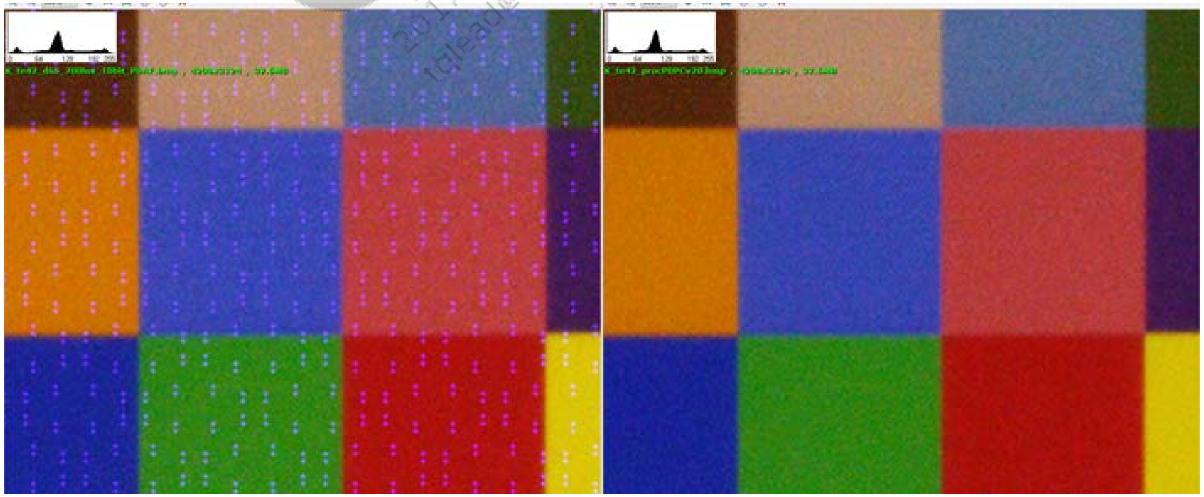
  Examples :



Left : Before BPC/BCC,   Right : After BPC/BCC

BPC/BCC/PDPC – Introduction (cont.)

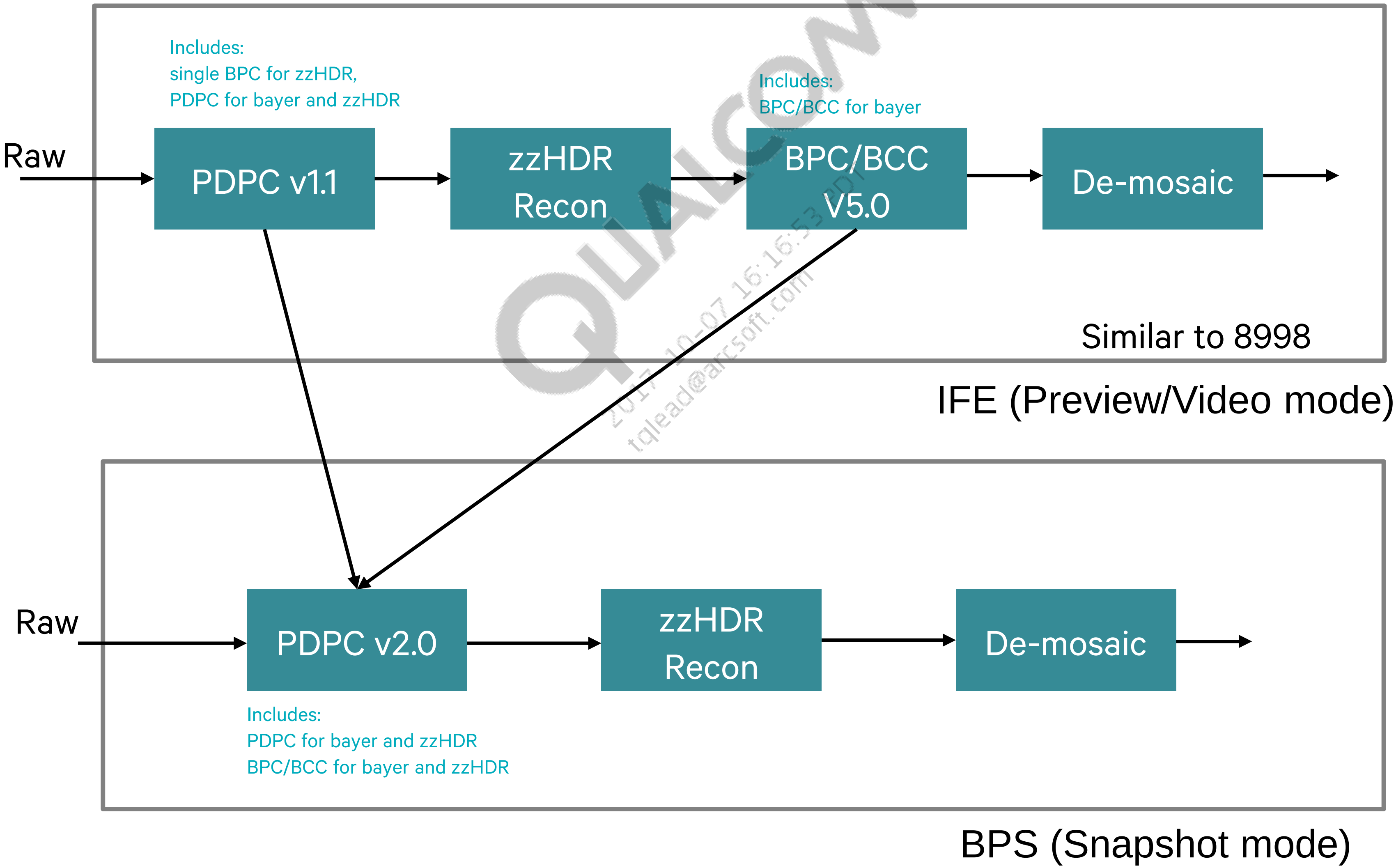
- PD pixel correction (PDPC)
  - Recently, a novel technique called Phase Pixel was introduced into CMOS Sensor to speed up Auto focus. The basic principal of ‘Phase Pixel’ is that a single image is split into two, left and right hand sided halves.
  - PDPC module is designed to correct defective pixels on phase pixel location
  - PD pixels locations are known and the PD pixels can only be on red or blue location but not on a green surface
  - PD pixels are corrected using neighboring pixels
  - Support Bayer pattern and zzHDR (PD pixel on long exposure only)



Left : PDPC Off (PD pixel on blue channel)   Right : After PDPC On

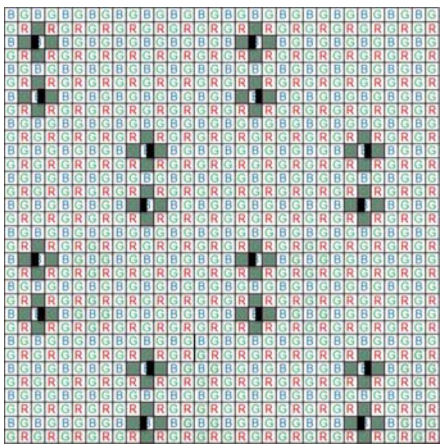
Step 1: Overview of PDPC/BPC Workflow

Block diagram

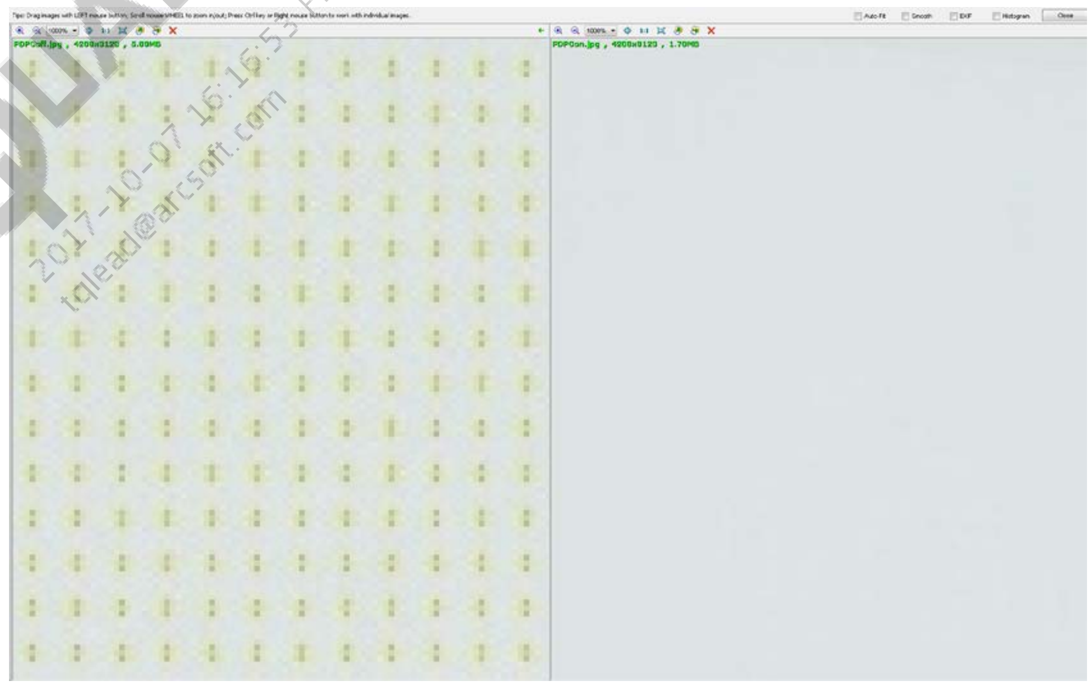


Step 1: Overview of the PD Pixel Correction

- Design wise PD pixel correction part are the same for PDPC v1.1 and PDPC v2.0 module (same as PDPC v1.0 in MSM8998)
- Based on the PDAF pixel location, if current pixel is PDAF pixel, its value is replaced with the corrected value using neighboring pixels



Example of PD pixel locations



PDPC Off PDPC On

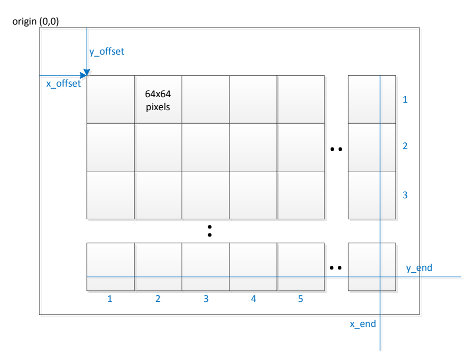
Step 1: Overview of BPC/BCC

- In IFE, with the combination of BPC in PDPC v1.1 and BPC/BCC v5.0 we can run BPC/BCC for zzHDR and bayer
  - BPC/BCC v5.0 is based on the bayer pattern, similar to the BPC/BCC in MSM8996 and MSM8998 bayer mode BPC/BCC
  - Inside PDPC v1.1, a single bad pixel correction is designed for the zzHDR mode
- In BPS, the BPC/BCC part is used in PDPC v2.0 to deal with zzHDR pattern and bayer pattern, the design is similar to MSM8996 and MSM8998, with some improved feature and extra consideration of the zzHDR pattern and PD pixels
- Same channel and cross channel are used for the BPC/BCC to avoid false colors and artifacts
- A pixel is considered a “bad pixel” based on its value :
  - Value is significantly higher than its neighbors → hot pixel
  - Value is significantly lower than its neighbors → cold pixel
- If pixel is identified as bad pixel, its value will be replaced with the corrected value using its neighboring pixels.

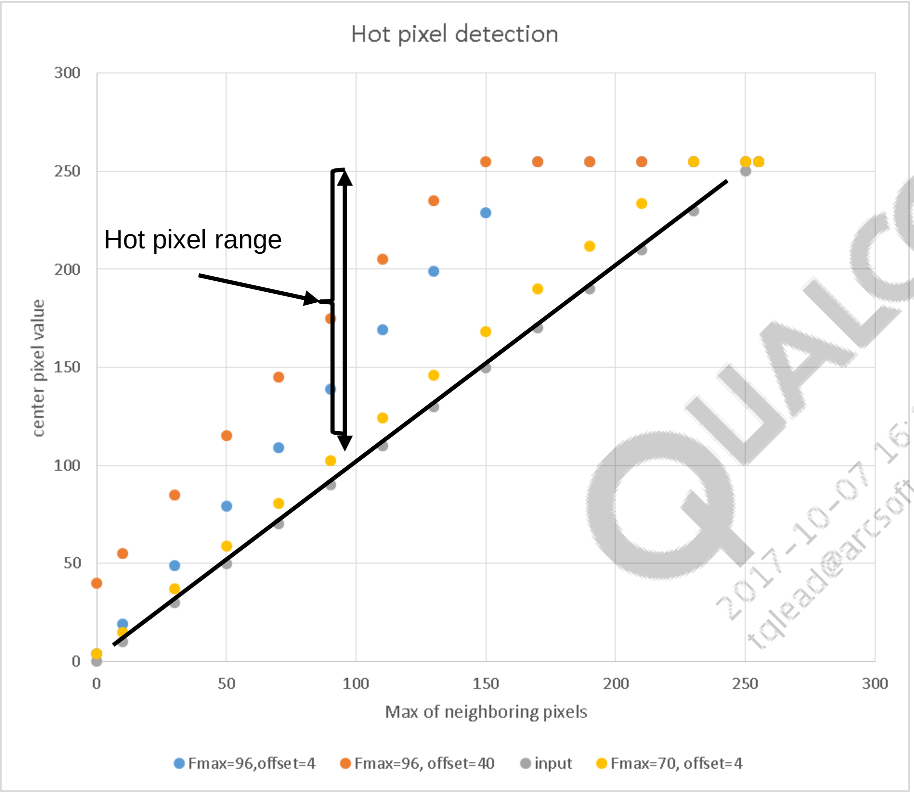
Step 2.1: PD Pixel Correction

- PD pixel correction only requires the PDAF pixel locations, and does not need any tuning parameters
- PDAF pixel pattern is assumed to be periodic across 64×64 pixel blocks
- If the PD pixel repeat block is smaller than 64×64, copy the block to populate it to full 64×64 block
- A 32×64 PDAF_PD_Mask is generated based on PD pixel locations by skipping green pixel locations

Pdaf_global_offset_x	14	PDAF 64×64 pattern global offset x- Pixel offset (0 means first pixel from left)
Pdaf_global_offset_y	14	PDAF 64×64 pattern global offset y- line offset(0 means first line from top
Pdaf_global_offset_y	14	Horizontal PDAF pixel end location +1 (0 means first pixel from left)
Pdaf_y_end	14	Vertical PDAF pixel end location +1 (0 means first line from top)
PDAF_PD_Mask[32*64]	2048*1	PD location 1 bit mask LUT- 0: not PD pixel; 1: PD pixel



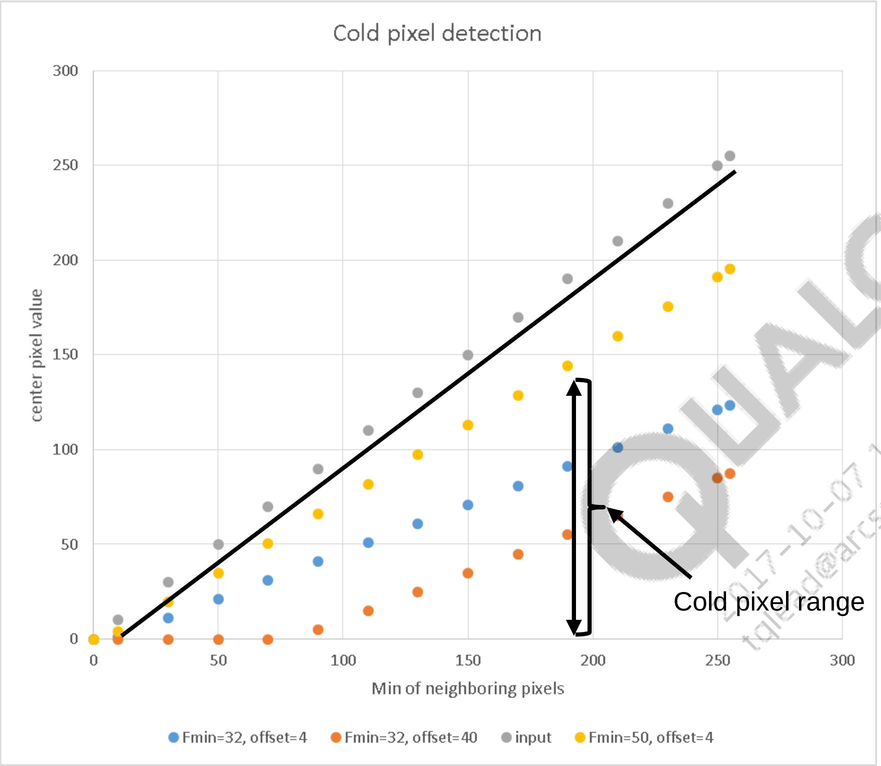
Step 2.2: BPC/BCC Basic Tuning Steps (Hot Pixel)



Larger Fmax → less hot pixel detected
Larger offset → less hot pixel detected
BCC offset is the offset used for detecting clusters

- Parameters to tune: Fmax and BPC offset, BCC offset
  1. Set the parameters to default based on the different lighting conditions
  2. Check whether any bad pixels are missed, for highlight region, lowering Fmax has more impact than lowering offset, for lowlight region, lowering offset has more impact than reducing Fmax
  3. Use the adjusting Fmax, offset settings and compare to the original images without BPC on, check whether there is any resolution loss or false color
  4. Fine tune the Fmax and offset till the resolution loss and false colors are acceptable

Step 2.2: BPC/BCC tuning steps (cold pixel part) Basic tuning



Smaller Fmin → less cold pixel detected
Larger offset → less cold pixel detected
BCC offset is the offset used for detecting clusters

- Parameters to tune: Fmin and BPC offset, BCC offset
  1. Set the parameters to default based on the different lighting conditions
  2. Check whether any bad pixels have been missed, for the highlighted region. Increasing Fmin has more impact than lowering offset. For lowlight region, lowering offset has more impact than adjusting Fmin.
  3. Use the adjusting Fmin offset settings and compare the result with the original images without BPC on. Check whether there is any resolution loss or false color.
  4. Fine tune the Fmin and offset till the resolution loss and false colors are acceptable

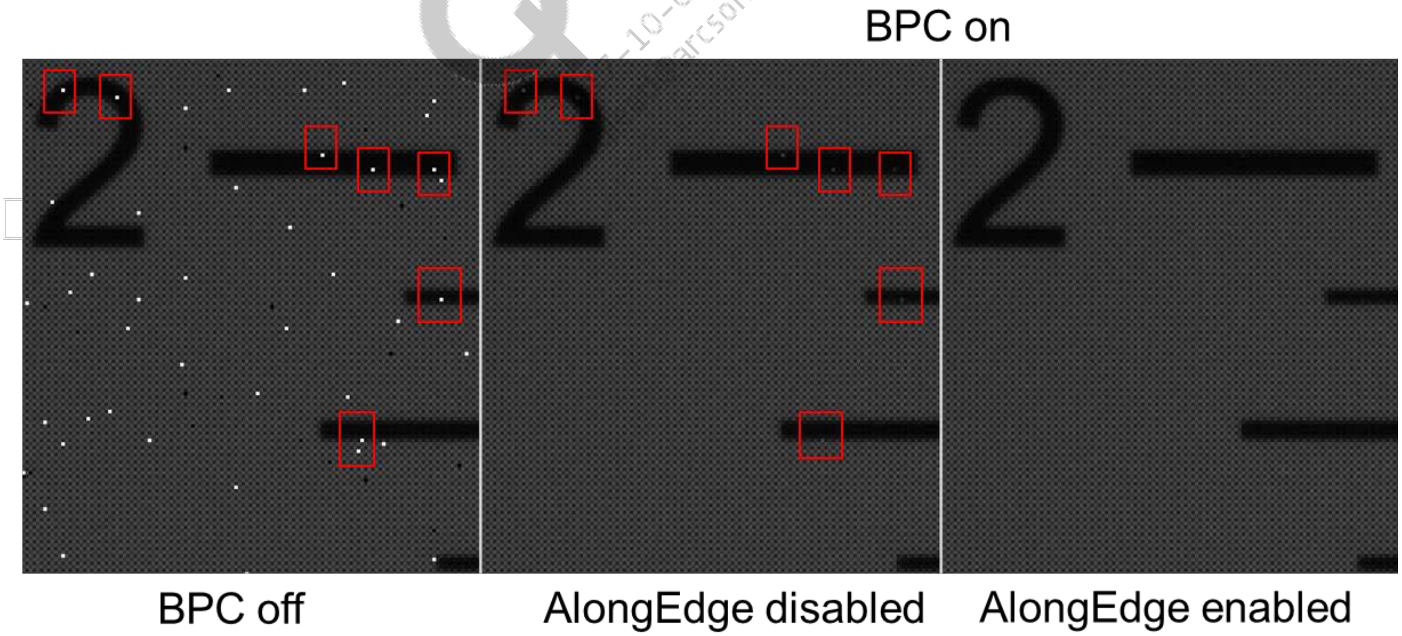
Note: Offset values are shared with hot and cold pixel detections, when adjusting offset, need to double check both hot pixel and cold pixels.

Step 2.3: BPC/BCC Advanced Tuning Steps

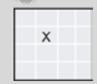
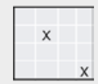
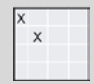
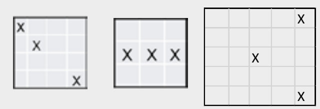
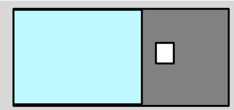
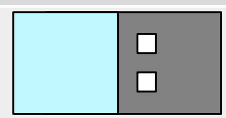
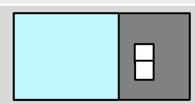
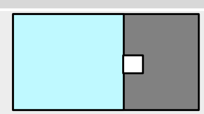
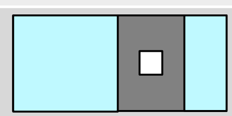
- UsingCrossChannel: Enable/disable the BPC correction from cross-channel.

Note: Detection in cross channel is always on. Default value should be enabled to avoid artifacts.

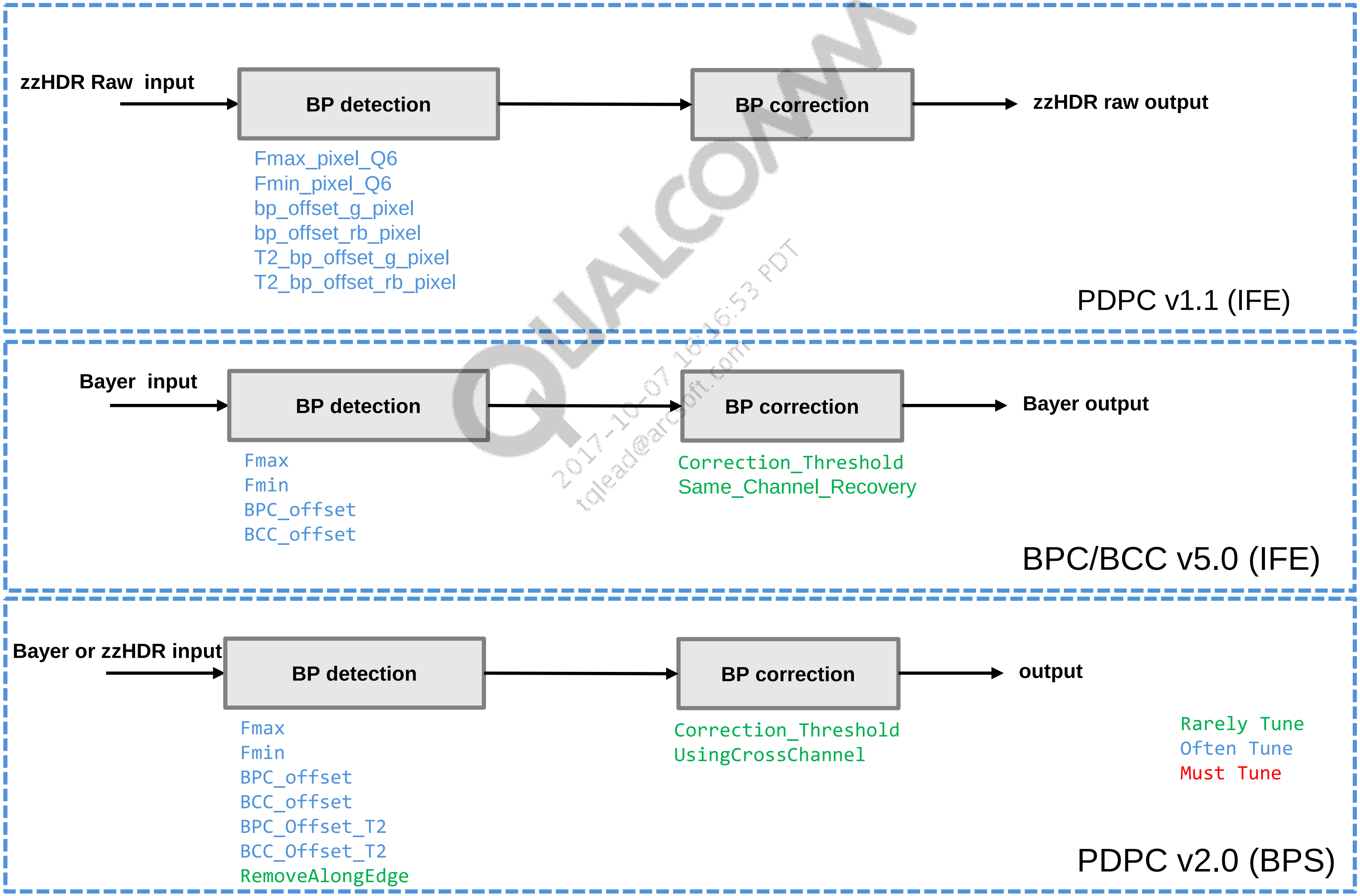
- RemoveAlongEdge: This feature can help for some bad pixels along the edges. But not all the bad pixels along the edge areas, it also has potential of introducing artifacts, we recommend to turn off this feature.



BPC/BCC Supporting Types

Category	Type	Example	
Flat Region	Single		✓
	Same Channel Couplet		✓
	Cross Channel Couplet		✓
	>=3 Cluster		✗
Edge Region	Single along the edge		✓
	SC Couplet along the edge		✗
	CC Couplet along the edge		✓
	Bad Pixel is on the edge or inside the 'transitional edge'		✗
	Bad Pixel is between two edges		✗

Effects of Parameters: Must Tune and Often Tune



Enable/Disable Module in Different Mode for Bad Pixel

- Video mode: Use PDPC v1.1 and BPC/BCC v5.0, one for zzHDR, one for regular bayer
- Snapshot mode: Use PDPC v2.0 which is a merged BPC/BCC for bayer and zzHDR
- PD pixel correction enable/disable: pdaf_pdpc_en in PDPC v1.1 or PDPC v2.0

	Format	PDPC v1.1	BPC/BCC V5.0	PDPC v2.0
Video	Non-HDR	Off	On	
	zzHDR	On	Off	
Snapshot	Non-HDR			On
	zzHDR			On

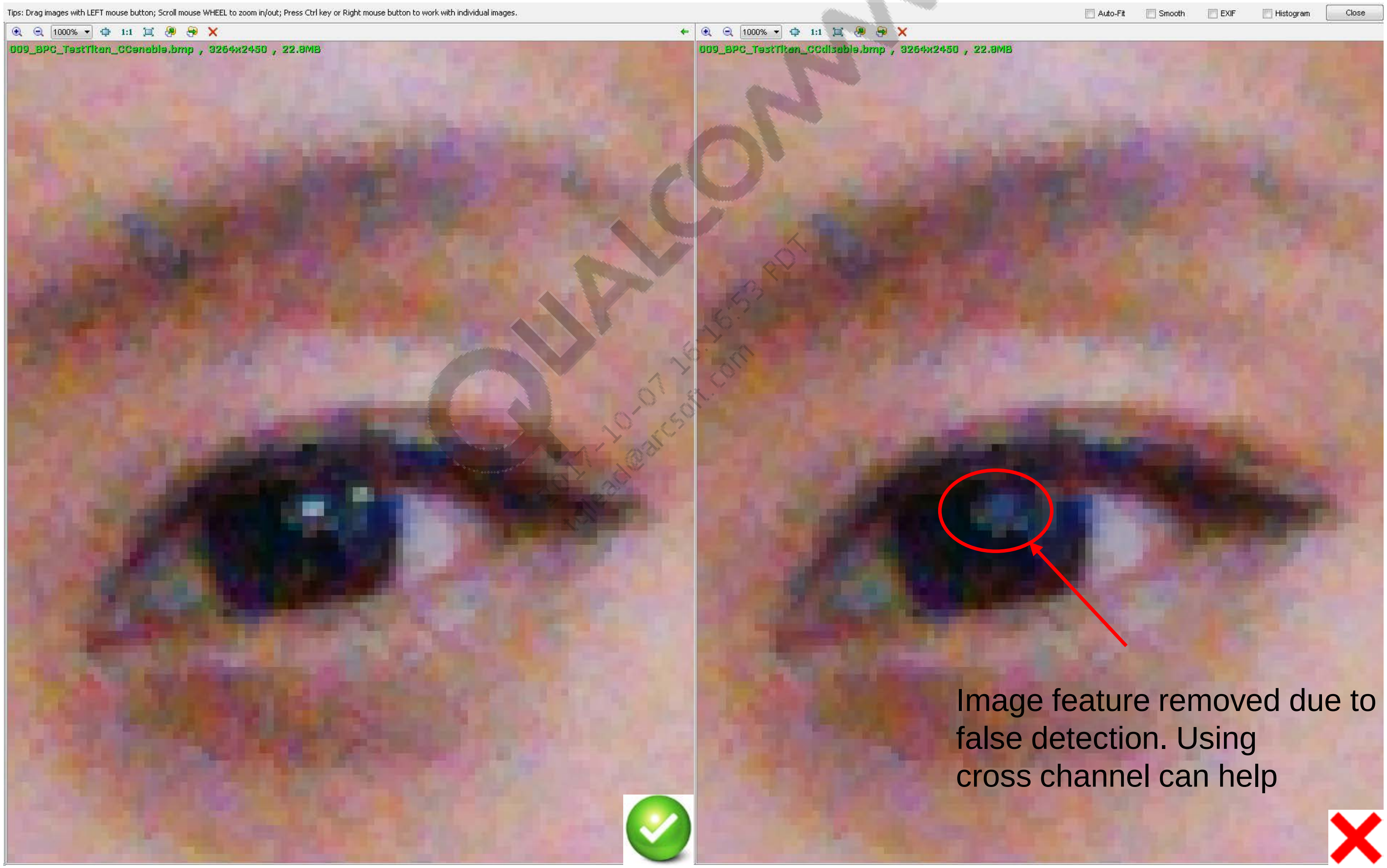
Impact of Fmax/Fmin and Offset

For PDPC v1.1, BPC/BCC v5.0 and PDPC v2.0 behaviors are the same.

Weak setting, Fmax=96

Aggressive setting, Fmax=65

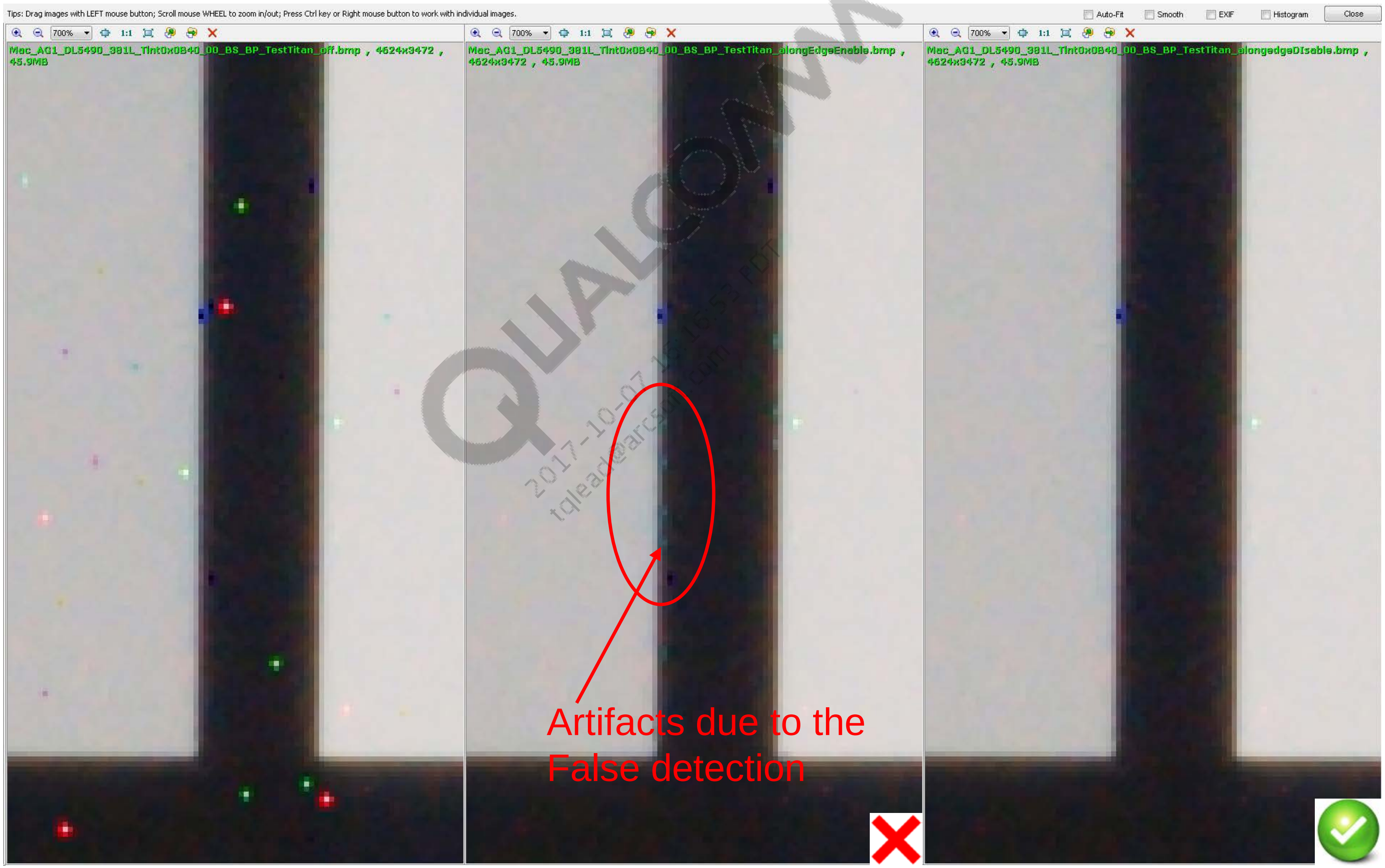
UsingCrossChannel (PDPC v2.0)



UsingCrossChannel=1

UsingCrossChannel=0

RemoveAlongEdge (PDPC v2.0)



Original BPC off

BPC on and RemoveAlongEdge enabled

BPC on and RemoveAlongEdge disabled

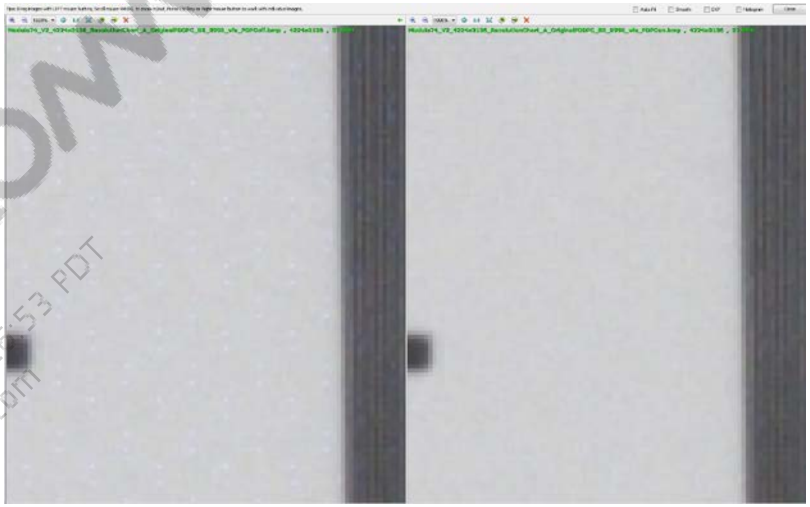
Step 3: How to Coordinate with Other Modules

- PDPC/BPC is the first module that doesn't rely on other modules, while having the impact on all the following modules if not tuned properly
- For other modules tuning, they can turn off the BPC to avoid the negative impact from the un-tuned BPC settings
- For PD sensors, PDPC should always be turned on
- For PDPC/BPC tuning, only enable the basic modules that are needed to have final YUV images
  - Non-HDR: Enable black-level cancelation, AWB, CCM, tone mapping and so on. All the de-noise module and edge enhancement modules need to be turned off, including image quality enhancement module, such as CAC
  - zzHDR: Besides the modules listed in non-HDR mode, also enable the zzHDR recon and tone mapping part

Test Plan for PD Pixel Correction

How to confirm if this module works normally:

1. Take a raw image from a PDAF sensor
2. If we don’t have a PDAF sensor, a simulation on the non-PD sensor can also work
3. Make sure the PD configuration part is correct
4. Check if the PD pixels are being corrected. While the other non-PD pixels are un-touched.
5. Check if there is any artifacts or false color.
6. Make sure the PD locations are configured properly, since there are no tuning parameters available for the PD pixel correction
7. Support PD sensor types:
   a) Non-HDR: PD pixel on red or blue
   b) zzHDR: PD pixel on red or blue, only on long exposure

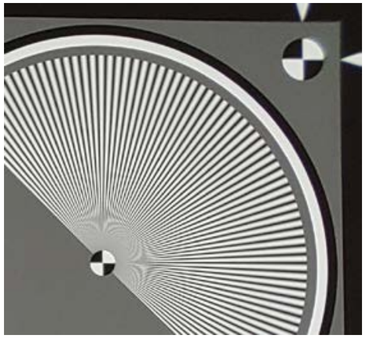


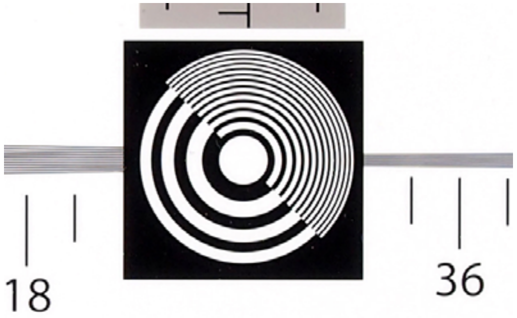
PDPC off
pdaf_pdpc_en=0

PDPC on
pdaf_pdpc_en=1

Test Plan for PD Pixel Correction (cont.)

- How to confirm if this module works normally:
  1. Take raw image from non-HDR and zzHDR sensor
  2. Turn bad pixel detection off and on to check before and after
  3. Check if there is any bad pixels left
  4. Check if there is any significant details loss, if so, reduce the BPC/BCC strength
  5. Check if there is any false color or artifacts that don't exist in BPC off image
  6. Check if there is any feature or small detail loss
  7. Adjust BPC settings till issues are solved or trade-off are acceptable
- Test images
  - Test charts and natural images
  - All light conditions
    - outdoor/indoor/lowlight/very lowlight from 1500lux to 4lux
    - Number of bad pixel is sensitive to lighting conditions, usually low light conditions has more bad pixels
  - High frequency components: trees, small texts, high frequency details

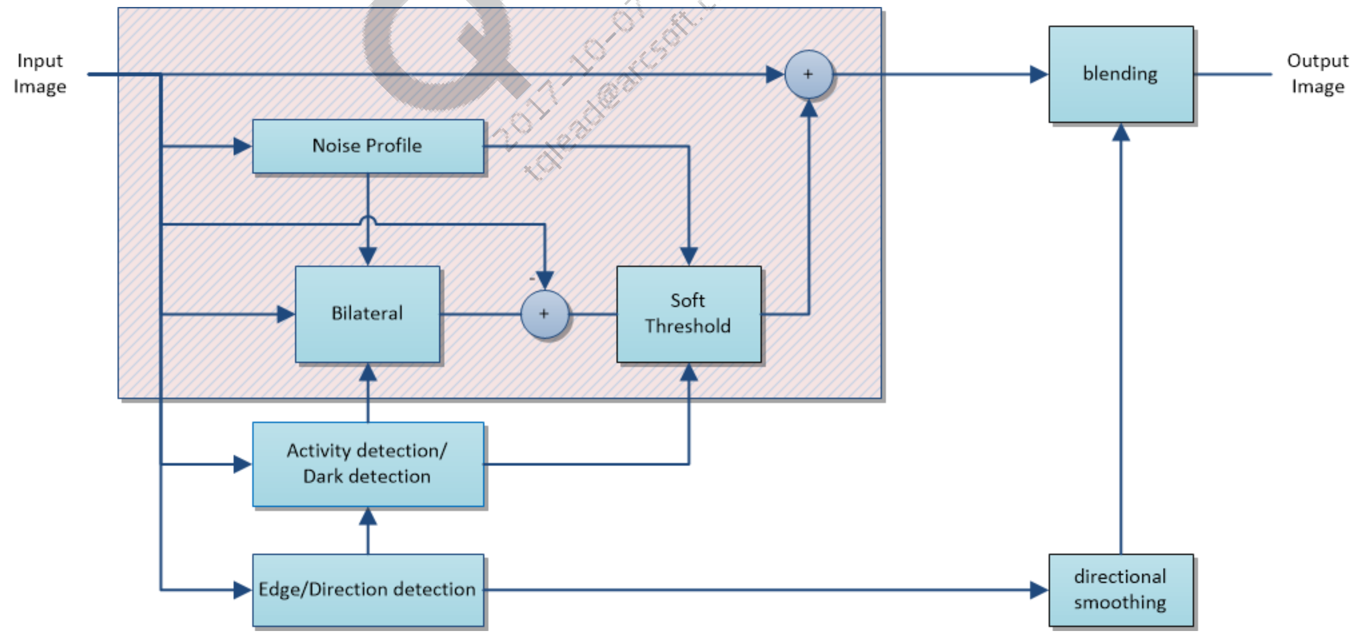




Adaptive Bayer Filter (ABF)

Overview

- Denoising block in Bayer domain
- An updated version of ABF3.4 in IFE and BPS
  - More flexible filtering controls
  - Directional smoothing
  - Dark desaturation and smoothing
  - Denoising strength adjustment based on activity



Tuning Procedure

1. Follow radial and noise profile calibration procedures
   a) Noise profile: **noise_std_lut**
   b) Radial-based adjustment: **radial_noise_prsv_adj** and **radial_edge_softness_adj**
2. Enable desired features in he enable and reserved section
3. Tune important parameters first
   a) Noise preservation: **noise_prsv_base** and **noise_prsv_anchor**
   b) Denoise strength: **denoise_strength**
   c) Edge softness: **edge_softness**
   d) Radial adjustment for noise preservation: **radial_noise_prsv_adj**
   e) Radial adjustment for edge-softness: **radial_edge_softness_adj**
4. Advanced tune different features
   a) Min-Max filter (single BPC) for bad pixel correction or Peak noise reduction (PNR)
   b) Directional smoothing
   c) Activity-based adjustment for filtering
   d) Dark region smoothing and desaturation
   e) Other control knobs

Step 1: Noise Profile and Radial Control Calibrations

- Noise profile: **noise_std_lut**
  - Defines noise level (standard deviation) vs. intensity level
  - Length: 65
  - Min: 0; Max: 512
  - Effect: Higher value stronger noise reduction
  - Calibration: Tool uses MCC chart to calibrate
- Radial adjustment for noise preservation: **radial_noise_prsv_adj**
  - Defines noise preservation adjustment factor vs. radial distance percentage
  - Length: 5
  - Min: 0.0; Max: 1.0
  - Effect: Higher value, more noise preservation
  - Calibration: Tool uses gray chart to calibrate
- Radial adjustment for edge softness: **radial_edge_softness_adj**
  - Defines edge-softness adjustment factor vs. radial distance percentage
  - Length: 5
  - Min: 0; Max: 15.99
  - Effect: Higher value, stronger noise reduction (blurrier result)
  - Calibration: Tool uses gray chart to calibrate

Step 2: Parameters for Enable Controls

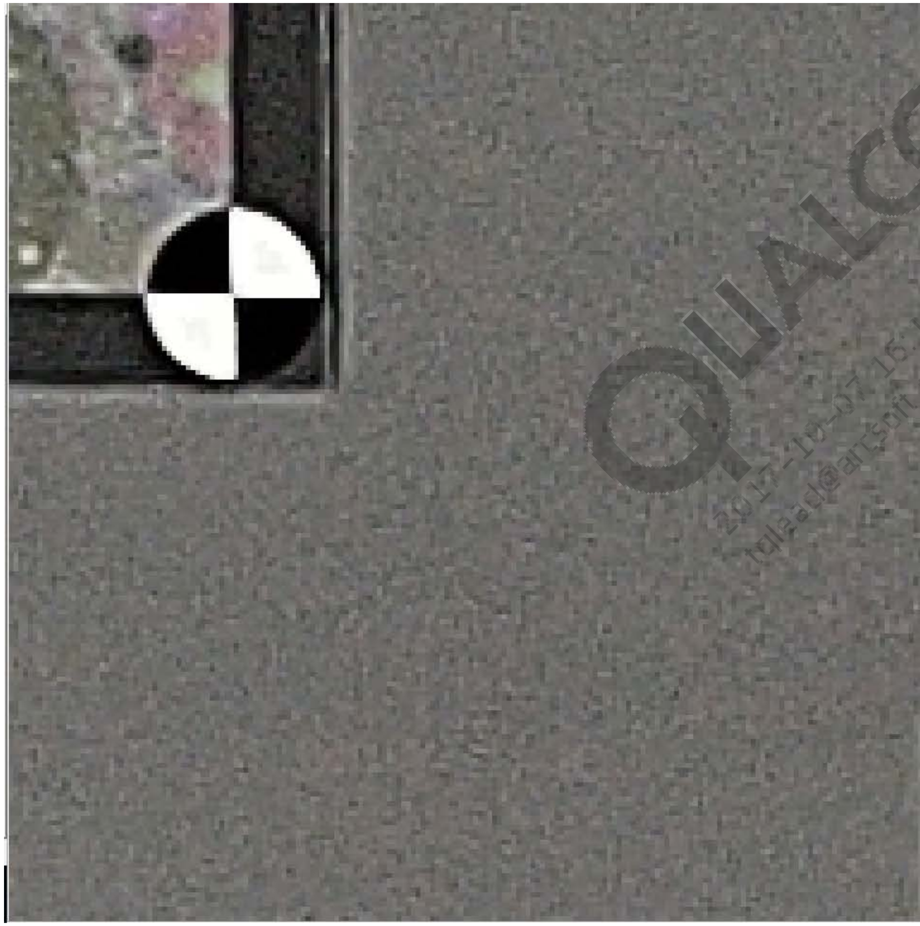
- Parameters in enable section:
  - **bilateral_en**: noise reduction enable
  - **minmax_en**: min-max filter enable
  - **dirsmth_en**: directional smoothing enable
- Parameters in reserve section:
  - **cross_plane_en**: enable Gb and Gr cross-channel filtering
  - **dark_desat_en**: enable dark region desaturation
  - **dark_smooth_en**: enable dark region smoothing
  - **act_adj_en**: enable activity-based filtering adjustment

Step 3.1: Noise Preservation Control

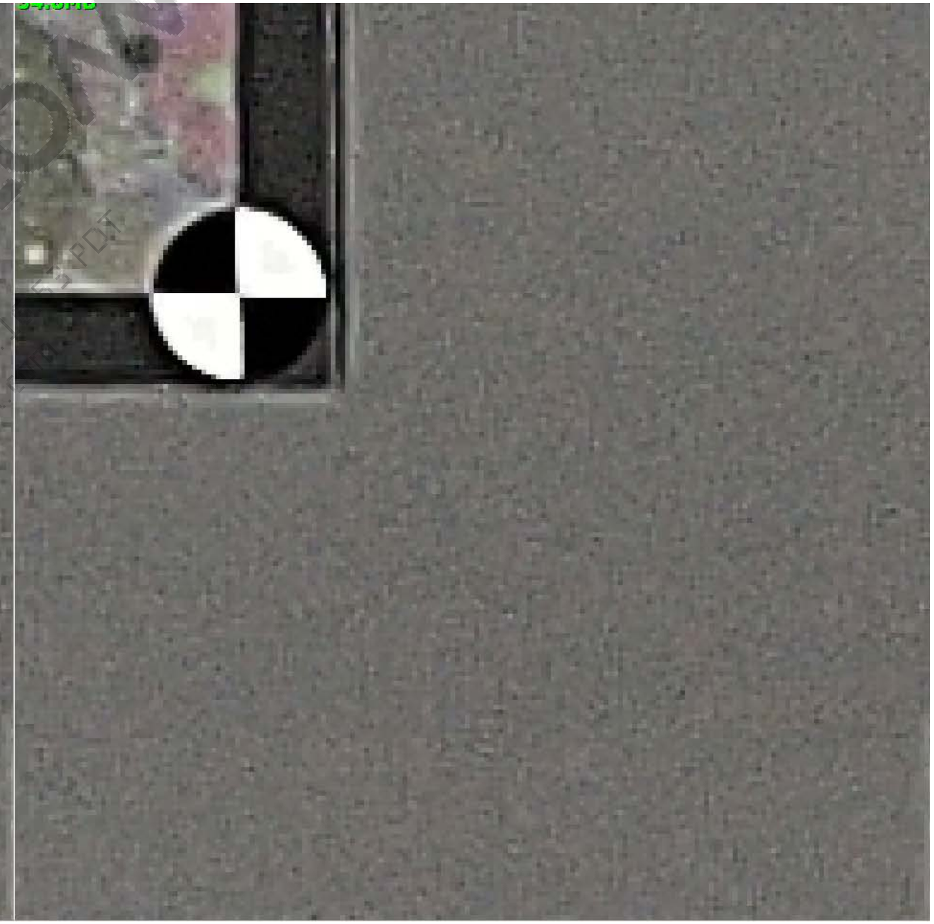
- **noise_prsv_base**
  - Defines the percentile of preserved noise (similar parameter is called “filter_strength” in the previous chipsets)
  - Length: 10 (entry 1-5 for R/B channel, entry 6-10 for Gb/Gr channel)
  - Default: All 0.2 array
  - Min: 0; Max: 1.0
  - Effect: Lower value stronger noise reduction
- **noise_prsv_anchor**
  - Anchor table for **noise_prsv_base**
  - Length: 5
  - Default: [0.0, 0.625, 0.125, 0.800, 1.0] (The first and last entries are fixed)
  - Min: 0; Max:1.0

Step 3.1: Noise Preservation Control (cont.)

Example



noise_prsv_base = all 1.0 array



noise_prsv_base = all 0.6 array

Step 3.2: Extra Filtering Strength

- **denoise_strength**
  - Adjust strength according for different channels
  - Length: 4
  - Default: [1.0, 1.0, 1.0, 1.0] ([R, Gr, Gb, B])
  - Min: 0; Max: 1.0
  - Effect: Larger value, stronger noise reduction
  - Suggestion: Tuning is only needed when noise level is different among the channels

Step 3.3: Edge-softness

- **edge_softness**
  - Adjust bilateral filter strength for different channels
  - Length: 4
  - Default: [3.0, 3.0, 3.0, 3.0] ([R, Gr, Gb, B])
  - Min: 0; Max: 15.99
  - Effect: Larger value, stronger noise reduction

Step 3.4: Radial Adjustment

- **radial_noise_prsv_adj**
  - Defines noise preservation adjustment factor vs. radial distance percentage
  - Length: 5
  - Min: 0.0; Max: 1.0
  - Effect: Smaller value, stronger noise reduction

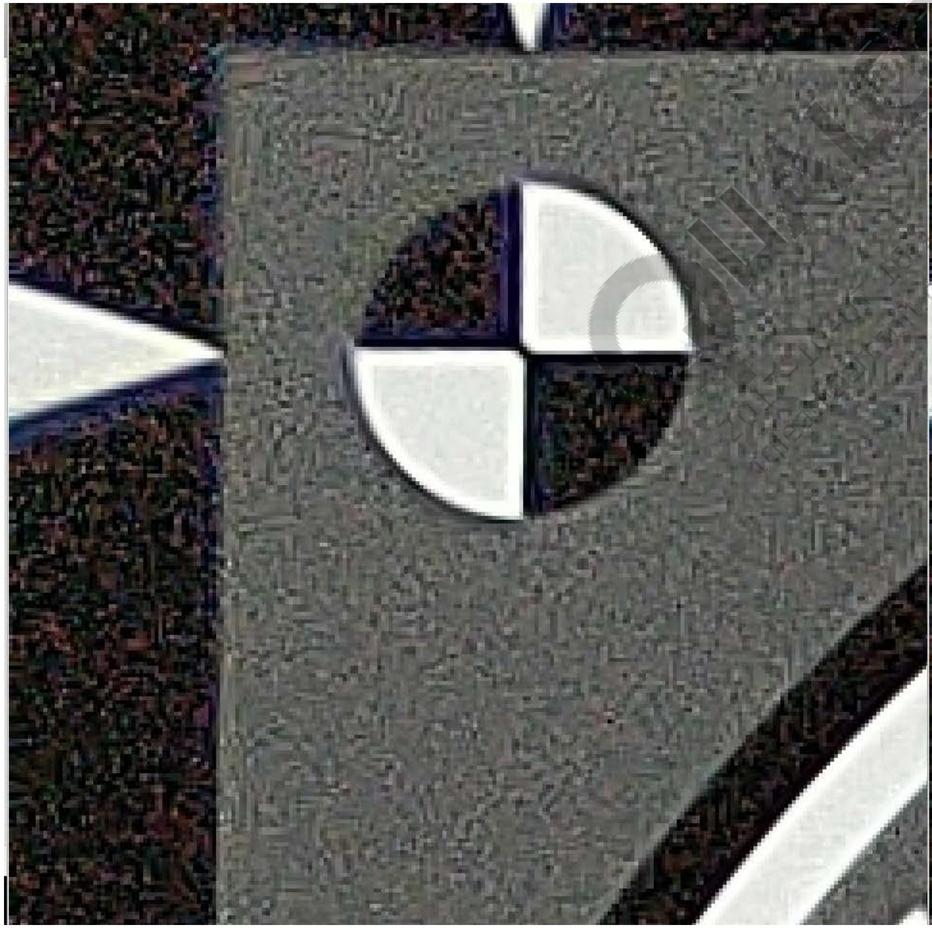
  Examples:
  - radial anchor: [0.0 0.4 0.6 0.8 1.0]
  - setting #1: [1.0000 1.0000 1.0000 1.0000 1.0000]
  - setting #2: [1.0000 0.8750 0.7500 0.6250 0.5000]

- **radial_edge_softness_adj**
  - Defines edge-softness adjustment factor vs. radial distance percentage
  - Length: 5
  - Min: 1.0; Max: 15.99
  - Effect: Larger value, stronger noise reduction

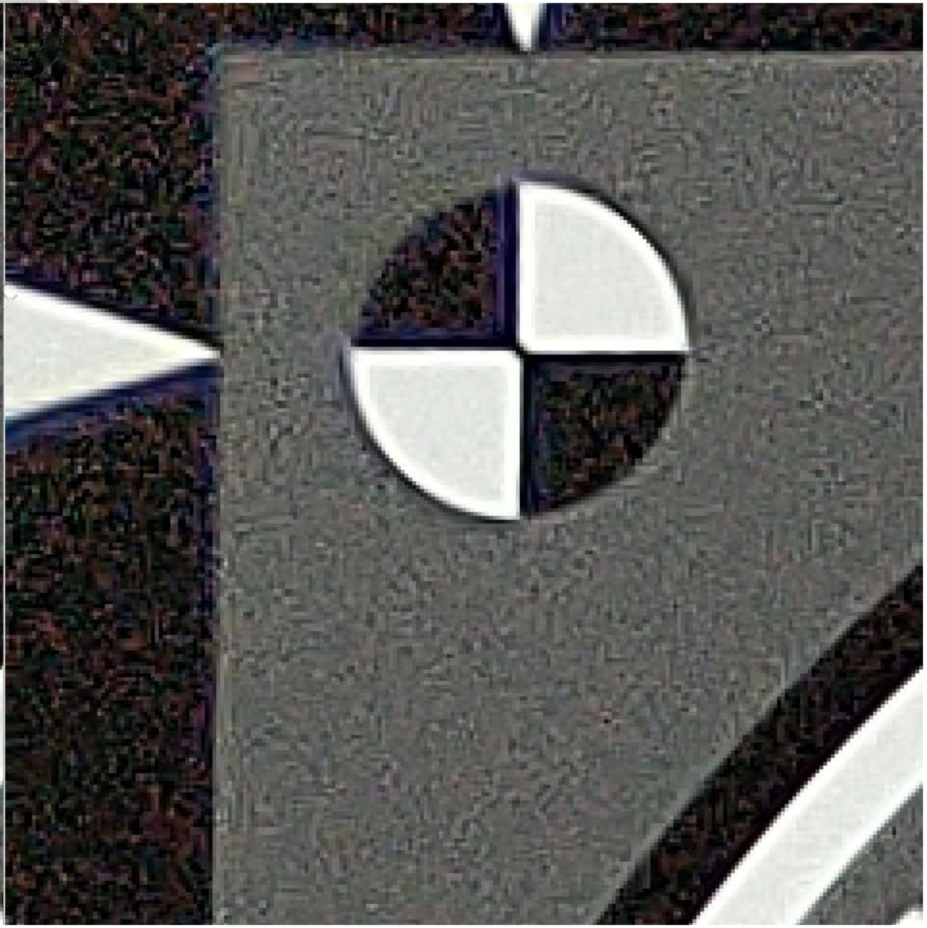
Step 3.4: Radial Adjustment (cont.)

Example of radial adjustment for noise preservation

setting #1: [1.0000 1.0000 1.0000 1.0000 1.0000]
setting #2: [1.0000 0.8750 0.7500 0.6250 0.5000]



Setting #1



Setting #2

How to Coordinate with Other Modules

- ABF is not the main block for denoising in Qualcomm Spectra 2xx
  - ANR + TF for video denoising
  - HNR + ANR for snapshot denoising
  - HNR + ANR + TF for multi-frame denoising
- ABF strength (Bilateral filtering strength) should be set to mild in order to preserve more detail/texture
- Kernel size of ABF is similar to the kernel size of GIC, HNR and first pass of ANR
  - For snapshot, balance is among GIC, HNR and ABF4.0
  - For video, balance is among GIC, ABF3.4 and first pass of ANR
- ABF can be used to balance noise level for different channels
  - **filter_strength**
  - **noise_prsv_base**

How to Coordinate with Other Modules (cont.)

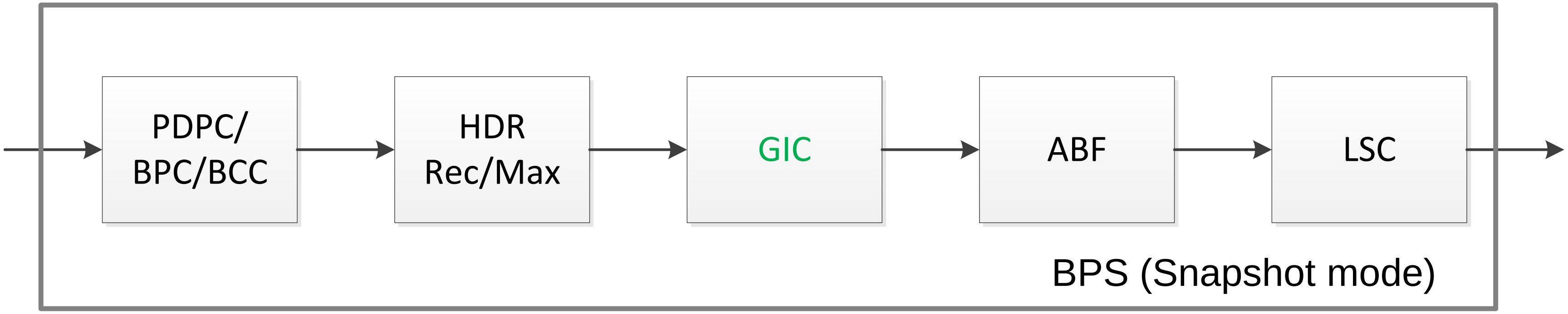
- For special RCCB or RGBW sensor, ABF4.0 could help reduce more noise in the early part of the pipeline
  - **blk_opt**: using Gr and Gb channel in block matching
  - Dark smoothing and dark desaturation
- Directional smoothing should be turned off when one works on an initial spatial tuning
  - Rely on edge alignment in ASF3.0
- Activity based strength adjustment should be turned off during initial spatial tuning
  - Rely on HNR1.0
- Min-Max filter should be off in normal tuning. We should rely on:
  - BPC/BCC/PDPC2.0
  - PNR in GIC

Green Imbalance Correction (GIC)

Green Imbalance Correction (GIC) – Introduction

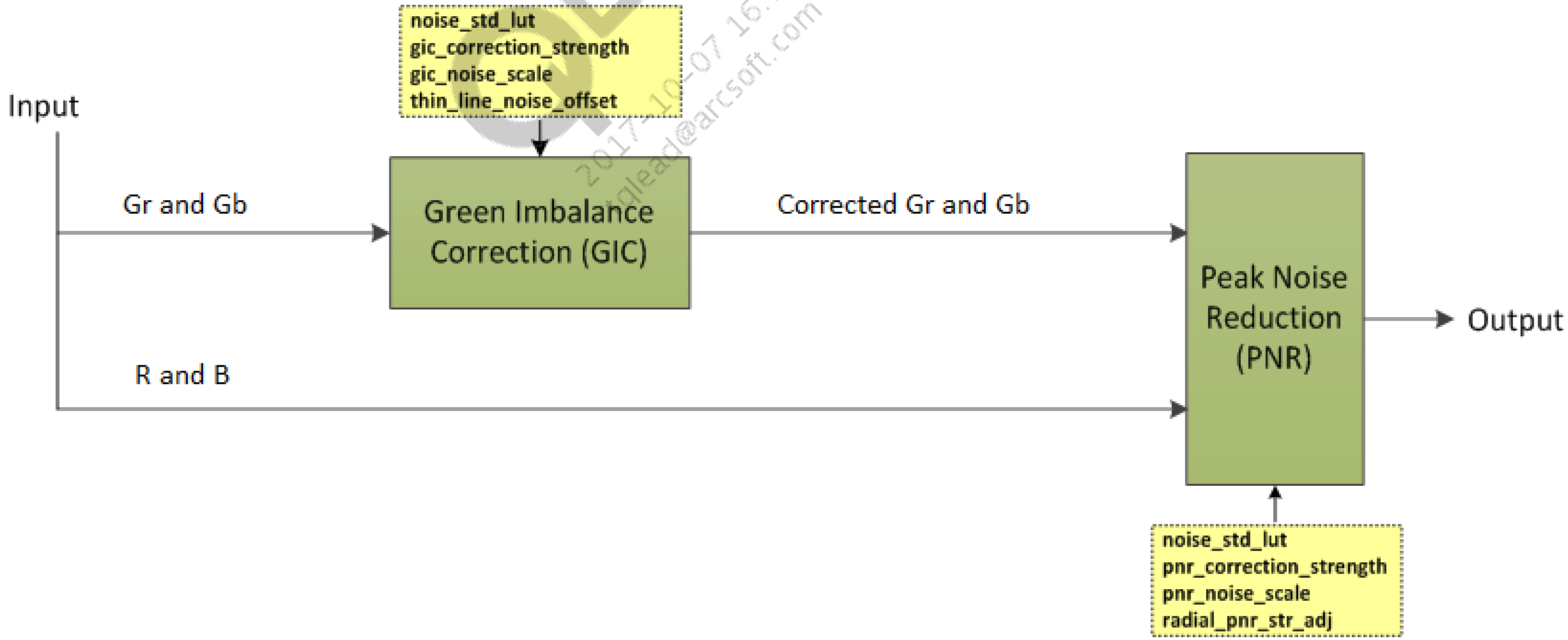
Problem statement

- Some Bayer sensors have local imbalance between Gr and Gb channels and the imbalance becomes more noticeable as the sensor resolution increases recently
- The imbalance cannot be corrected by operations like channel gain and lens roll-off correction. ABF can correct some amount of green imbalance artifacts, but if ABF is set too strong, it may cause significant blurring
- GIC isolates Gr/Gb imbalance from signals and efficiently reduce the local imbalance
- On Qualcomm Spectra 2xx BPS, GIC is applied in Bayer domain and located before ABF and Lens shading correction (LSC) modules



Step 1: Overview

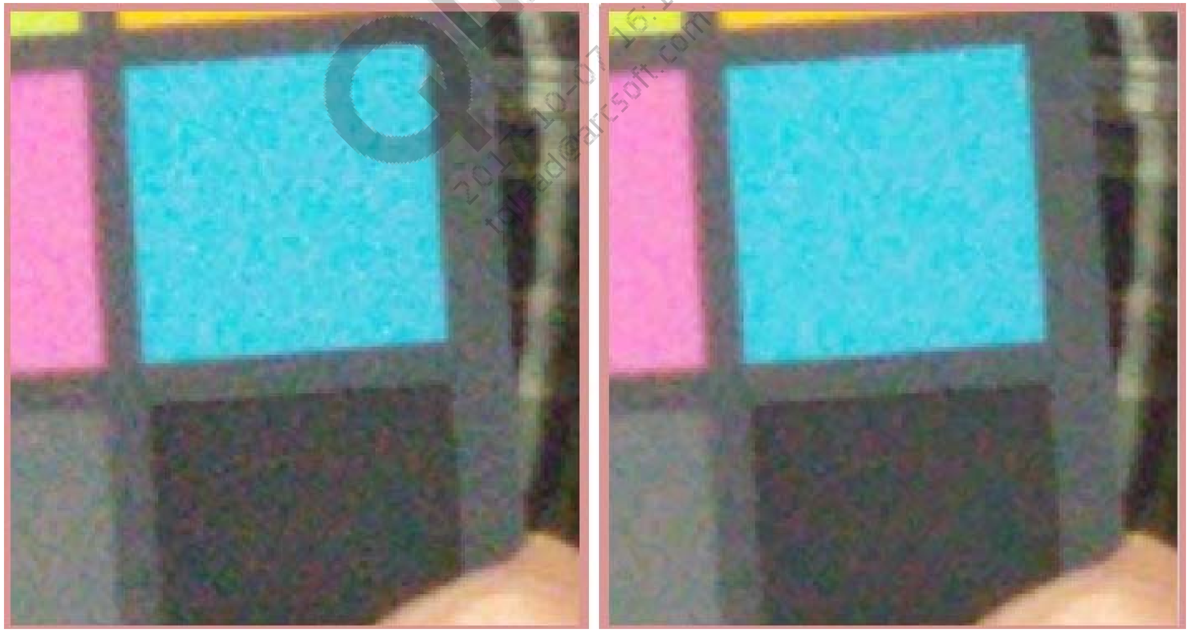
- Qualcomm Spectra 2xx GIC is an update module combined with green imbalance correction and PNR. It is located in BPS, which is used for snapshot processing only
- Imbalance artifacts of Gb and Gr channels are corrected first
- Corrected Gb and Gr channels work with R and B channels for PNR



Step 2: Parameters to Enable Controls

- Parameters in enable section:
  - gic_global_enable: enable/disable entire GIC/PNR module
- Parameters for sub-module enable:
  - enable_gic: enable/disable GIC sub-module
  - enable_pnr: enable/disable PNR sub-module

Examples:

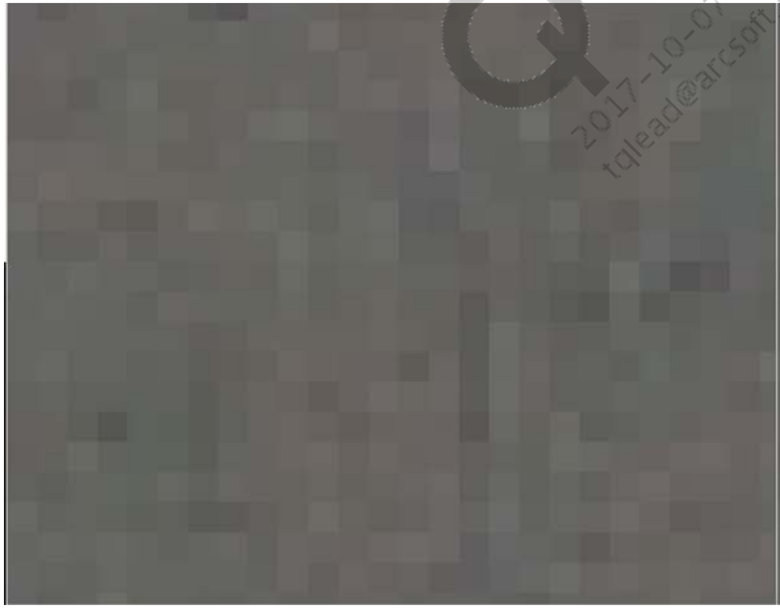


Left: GIC and PNR Off, Right: GIC and PNR On

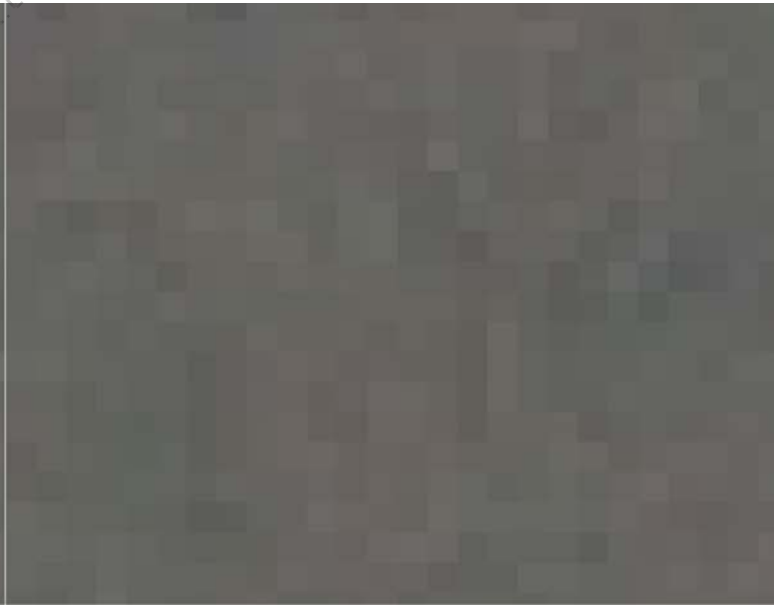
Step 3.1: GIC Correction Strength

- gic_correction_strength
  - Green imbalance correction strength
  - Length: 1
  - Default: 0.6
  - Min: 0; Max:1
  - Effect: lower value results in stronger correction

Examples:



gic_correction_strength = 1.0



gic_correction_strength = 0.6

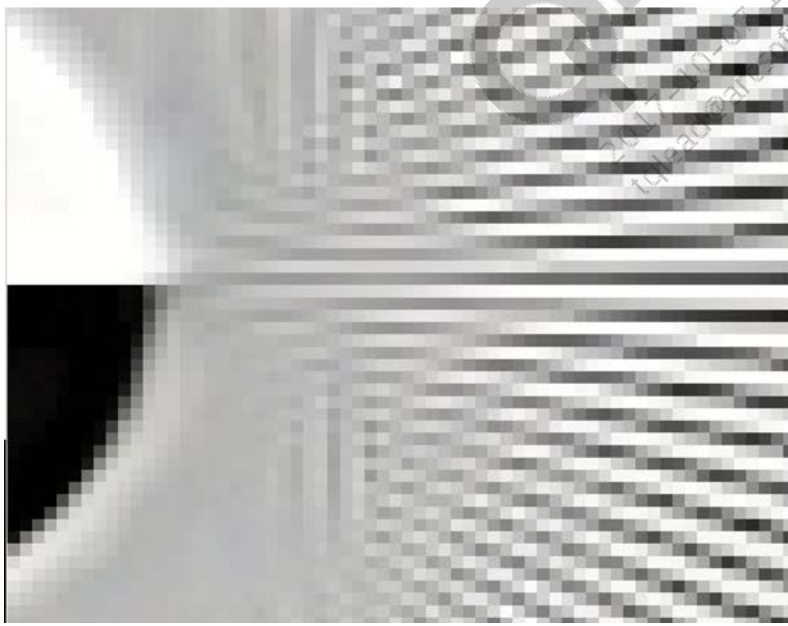
Step 3.2: GIC Noise Scale

- gic_noise_scale
  - Noise scale factor of green imbalance correction which is used for Gb/Gr channel difference clamping
  - Length: 1
  - Default: 1.0
  - Min: 0; Max: 15.98
  - Effect: Higher value results in weaker correction

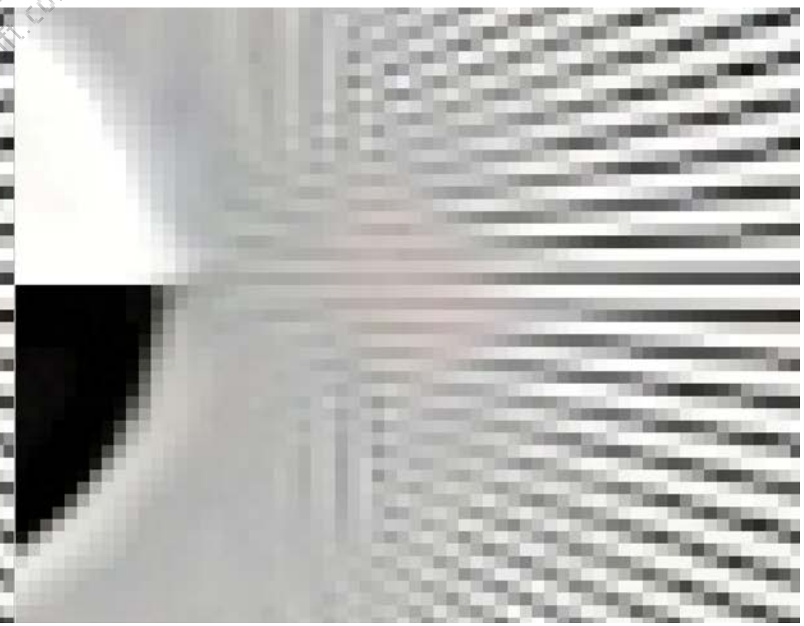
Step 3.2: GIC Thin Line Noise Offset

- thin_line_noise_offset
  - Noise offset of edge and thin line detection
  - Length: 1; Default: 400
  - Min: 0; Max: 16383
  - Effect: Higher value results in weaker thin line detection (thin lines might be impacted by GIC)

Examples:



thin_line_noise_offset = 400



thin_line_noise_offset = 2000

Step 4.1: PNR Correction Strength

- pnr_correction_strength
  - Peak noise reduction strength
  - Length: 1
  - Default: 0.6
  - Min: 0; Max:1
  - Effect: Lower value results in stronger reduction

Examples:

pnr_correction_strength = 1.0 pnr_correction_strength = 0.6

Step 4.2: PNR Noise Scale

- pnr_noise_scale
  - Noise scale factor of PNR for each channel which is used to separate flat region and texture region
  - Length: 4
  - Default: [1.0, 1.0, 1.0, 1.0]
  - Min: 0; Max: 15.98
  - Effect: Higher value, more area could be detected as flat region
  - Suggestion: setting pnr_noise_scale could impact texture region

Advanced Step 5.1: Noise Profile for GIC and PNR

- noise_std_lut
  - Noise profile (standard deviations) vs. local intensity
  - Length: 65
  - Default: calibrated and sharing with ABF4.0
  - Min: 0; Max: 512.0
  - Effect: Higher value results in weaker green imbalance correction and stronger PNR

Advanced Step 5.2: Radial PNR Strength Adjustment

- radial_pnr_str_adj
  - Adjust PNR strength based on radial distance percentage
  - Length: 7
  - Default: 1.0
  - Min: 0; Max: 15.98
  - Effect: Smaller value results in stronger PNR

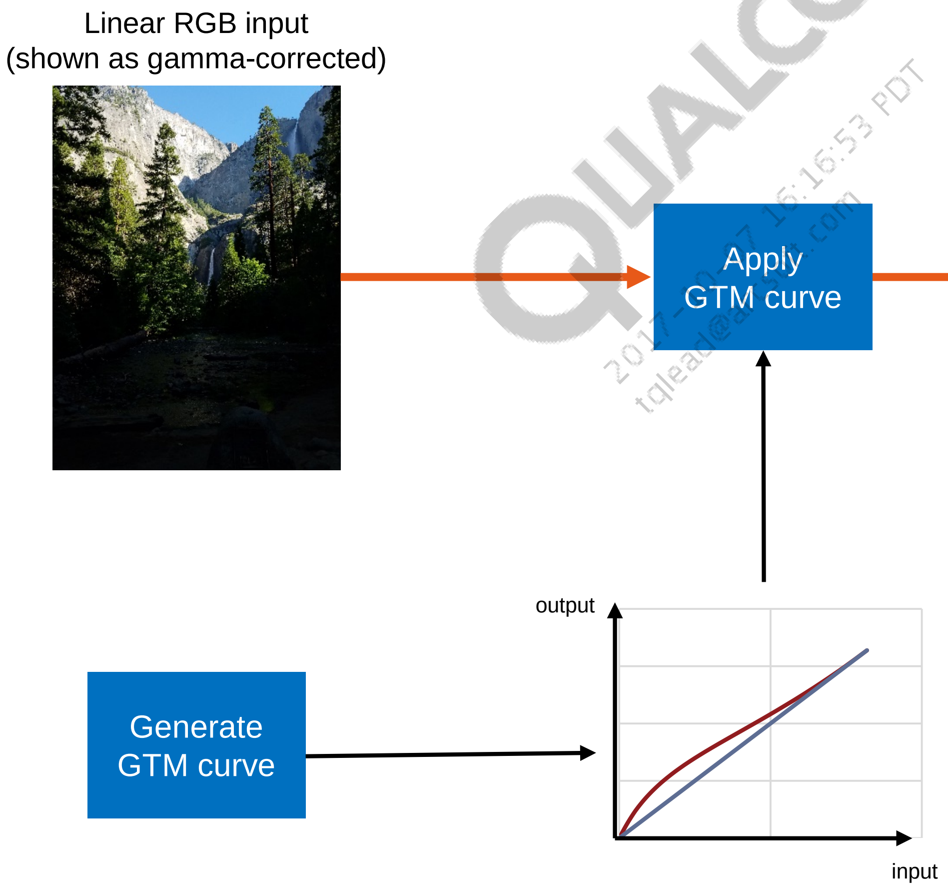
Tuning Procedure

1. Follow radial and noise profile calibration procedures
2. Enable desired features in enable flag section
3. Tuning parameters to reduce green imbalance artifacts
   a) Tuning correction strength: gic_correction_strength
   b) Tuning noise scale: gic_noise_scale
   c) Adjust thin line processing: thin_line_noise_offset
4. Tuning parameters for PNR
   a) Tuning correction strength: pnr_correction_strength
   b) Tuning noise scale: pnr_noise_scale
5. Advanced tuning
   a) Fine tune noise profile: noise_std_lut
   b) PNR radial-base strength adjustment: radial_pnr_str_adj

Global Tone Mapping (GTM)

Introduction

- GTM applies a global tone curve to each pixel to enhance visibility. It is used in HDR or automatic dynamic range compression (ADRC) application to compensate the enhanced image dynamic range.



HDR: GTM/LTM Tuning Image Capture

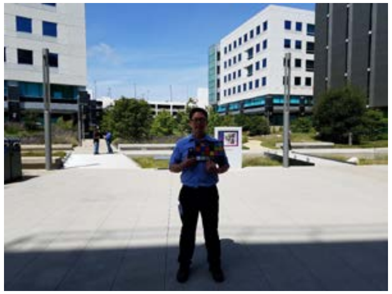
- Capture HDR raw images, covering 6 exposure lux index zones and exposure ratios from 1× to 16×
- For each scene, capture raw images of HDR mode and non-HDR mode
- HDR scenes image content suggestions:
  1. Window scene: Half bright outdoor, half dark indoor, containing a person holding MCC chart by the window, bright outdoor scene through the window.
  2. Shade scene: outdoor scene with half bright sun and half dark shade.
  3. Outdoor texture: A person standing under direct sunlight, holding a texture test chart. There are dark shade on the background.
  4. Backlit scene: A person holding MCC chart under shade with bright background, for example, sky with clouds.

Lux Index	Exp Ratio
100 - 200	1 – 2
200 – 250	2 – 4
250 - 300	4 – 6
300 – 380	6 – 8
380 – 450	8 – 12
450 - 600	12 - 16


1. Window scene

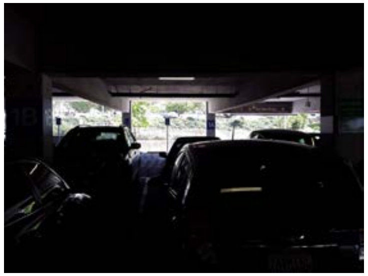

2. Shade scene


3. Outdoor texture


4. Backlit scene

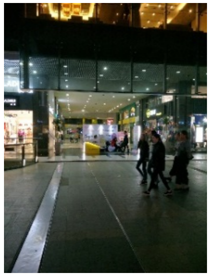
HDR: GTM/LTM Tuning Image Capture (cont.)

5. Garage scene: Inside the parking building with bright outside background
6. Building scene: Buildings with dark shadows
7. Night scene: Building with lights at night
8. Indoor scene: Indoor decoration with small outdoor areas
9. Nature scene: Natural objects including trees, grass, water and buildings, containing highlights and shadows
10. Resolution chart in lab scene. The resolution chart are placed half in the bright side and half in the dark side.
11. Night scene with people's face, shop windows/lights. It would be best if the person can swing the hands or so on to generate some motion.



5. Garage scene

6. Building scene



7. Night scene

8. Indoor scene

9. Nature scene

GTM Tuning Introduction

- GTM tuning is used to generate GTM curve
- GTM curve generation automatically considers LSB or MSB mode
- There are two modes to generate GTM curve: Auto mode and Manual mode, which is controlled by *manual_curve_enable*. Default value is 0 for auto mode.
- GTM tuning table is 2D, triggered by lux_index/gain and exp_ratio, covering low light, normal light, high light regions and 6 exposure ratios
- GTM curves can be tuned for each of lux zone and exposure ratio based on OEMs requirement

GTM Tuning Procedure

- Set all parameters to their default values
- Decide the mode (Manual or Auto)
- For each lux region and exposure ratio, tune GTM parameters so that the middle tone is similar to non-HDR mode
- Auto mode tuning: *a_middletone, middletone_w*

GTM curve is automatically generated based on *a_middletone* and *middletone_w*

- Manual mode tuning: *a_middletone, yratio_base_manual [65]*

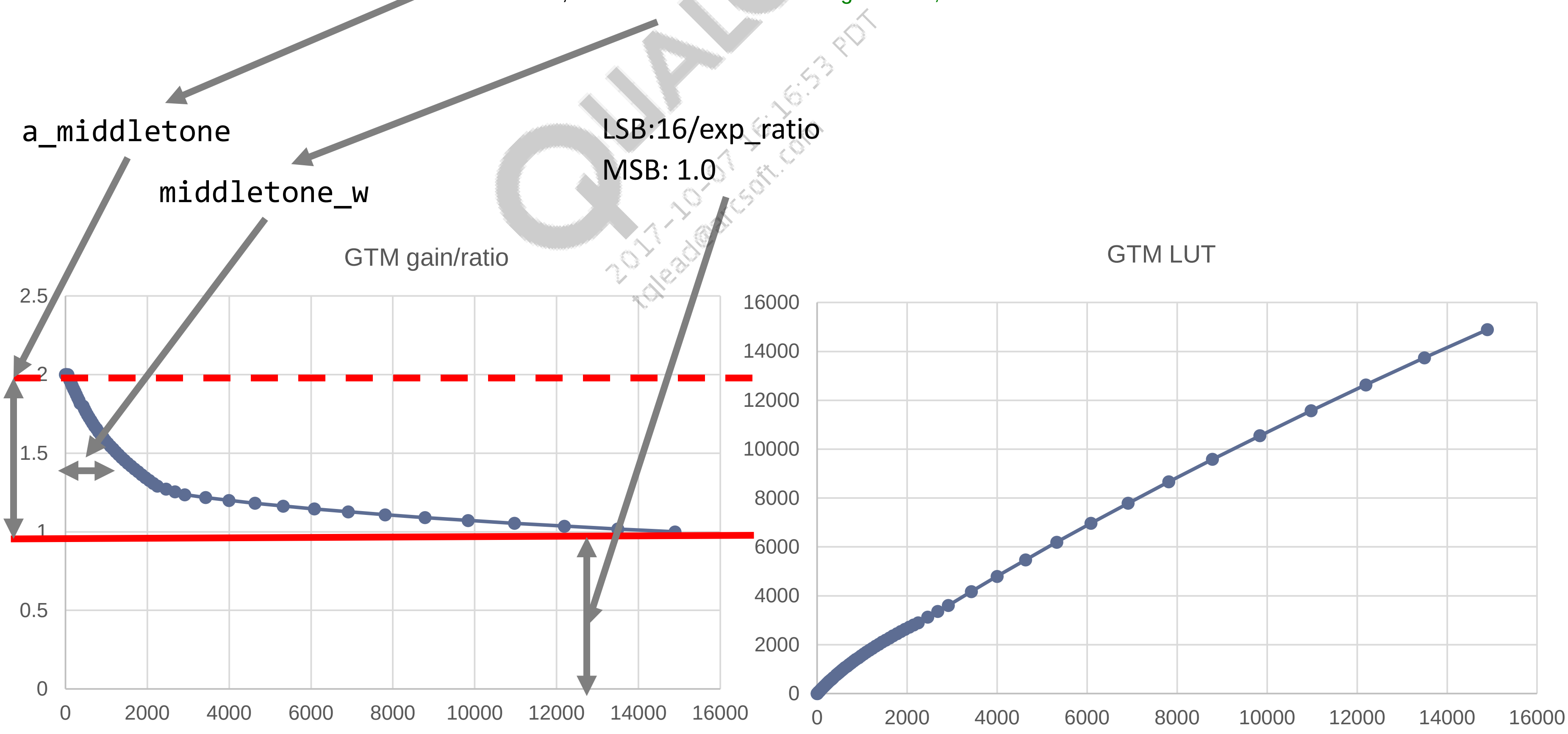
GTM curve is based on *yratio_base_manual*, and adjusted by *a_middletone*

GTM Tuning Procedure (cont.)

- Auto mode tuning

Increasing *a_middletone* and *middletone_w* will increase image brightness.

0.250000f, /* A MiddleTone */ ← range 0.0-1.0, default 0.25
8.00000f, /* MiddleTone W */ ← range 0 – 32, default 8



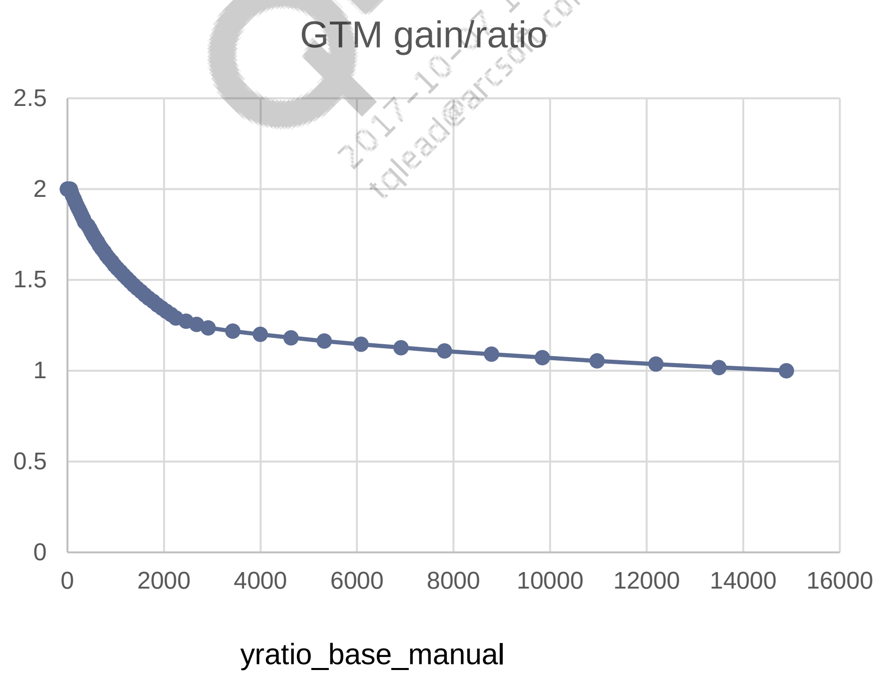
GTM Tuning Procedure (cont.)

- Manual mode tuning

Manual curve *yratio_base_manual* is defined for each lux zone and exposure ratio.

Increasing *a_middletone* will increase image brightness.

```
Yratio_base = a_middletone * yratio_base_manual
```



Hybrid Noise Reduction (HNR)

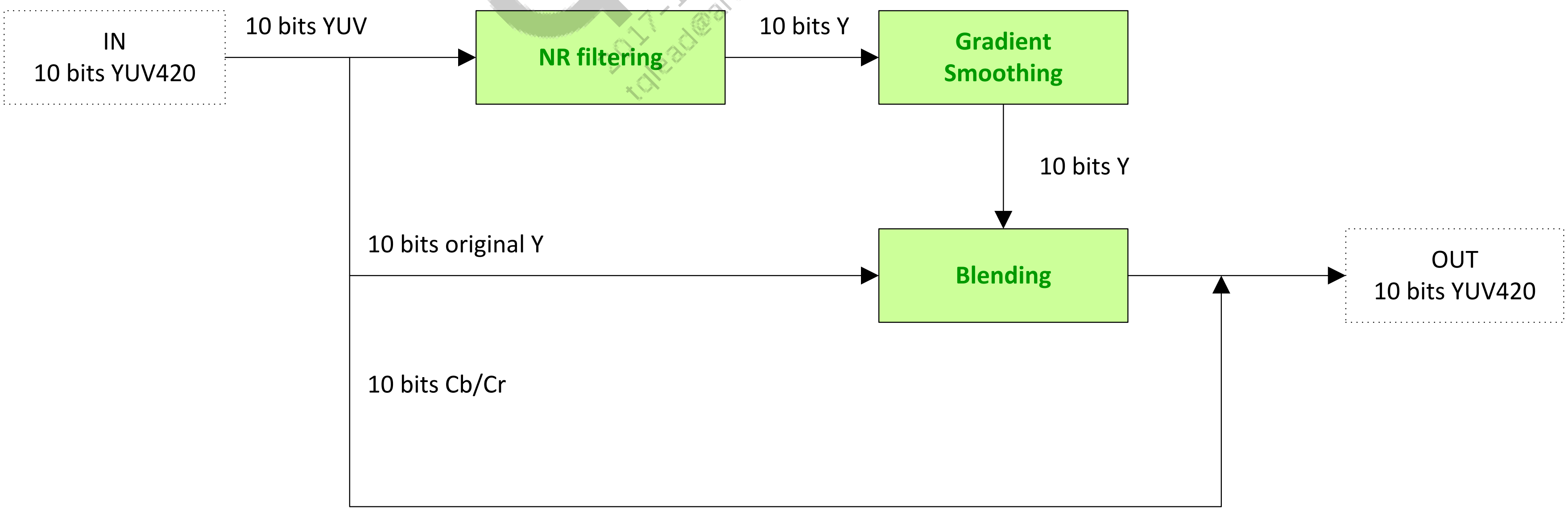
Hybrid Noise Reduction (HNR) – Introduction

Problem statement

- HNR module is a blending architecture to reduce luminance noise but to keep texture details
- HNR is located at the end of BPS, which means it’s available for snapshot only
- The module consists of DCT-based frequency domain noise reduction, gradient smoothing and spatial domain blending
- Unlike conventional spatial domain noise reduction, DCT-based frequency domain takes advantages to distinguish week texture and noise. Using this, HNR reduces noise while preserving edges and texture

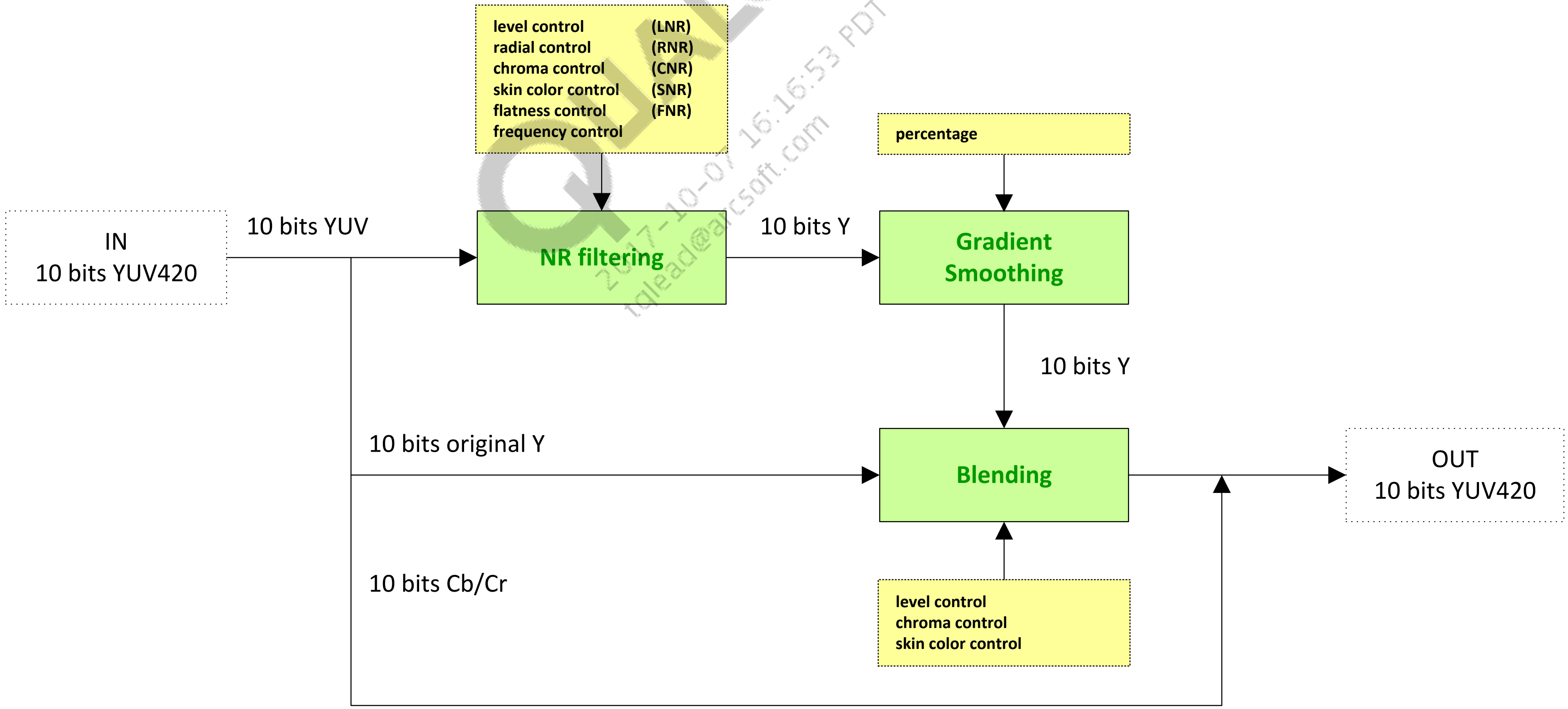
Step 1: Overview

- HNR in BPS
  - Spatial and frequency-domain noise reduction
  - Blending with input image with weighting factors
  - Gradient smoothing for jaggy edge treatment
  - Multiple controls in both noise reduction and blending stages
- Luma noise reduction only
- 10-bit input and 10-bit output



Step 1: Overview (cont.)

- Noise reduction controls: Level, radial, chroma, skin, flatness and, frequency
- Blending controls: Level, chroma, skin
- Gradient smoothing: Percentage

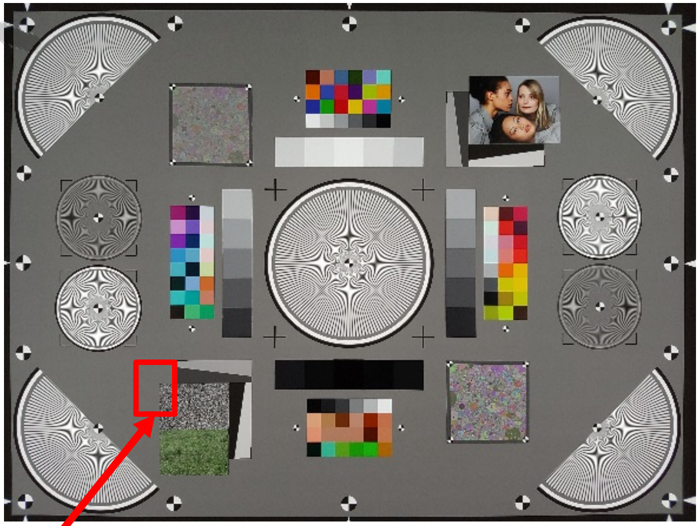


Step 2: Parameters to Enable Controls

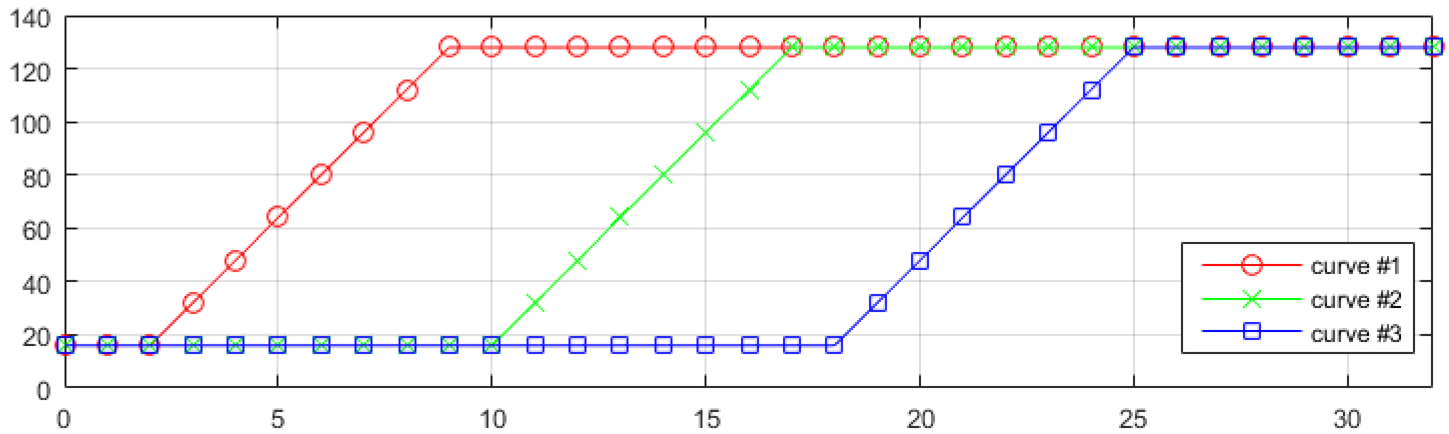
- Parameters in the Enable section:
  - hnr_nr_enable: noise reduction enable
  - hnr_blend_enable: noise blending enable
- Parameters in the Reserve section:
  - lnr_en: level-based noise reduction enable
  - rnr_en: radial-based noise reduction enable
  - cnr_enable: chroma-based noise reduction enable
  - snr_enable: skin-color based noise reduction enable
  - fd_snr_enable: face detection assisted SNR enable
  - fnr_enable: flatness control enable
  - lpf3_en: gradient smoothing enable
  - blend_cnr_en: chroma-based blending enable
  - blend_snr_en: skin-color based blending enable

Step 3.1: Noise Reduction Strength

- flitering_nr_gain_arr
  - Description: Overall strength of HNR
  - Length: 33
  - Default: All 128 array
  - Min: 0; Max:128
  - Effect: Lower value stronger noise reduction
  - Calibration: Tool uses MCC chart to calibrate
  - Suggestion: Piece-wise smooth curve



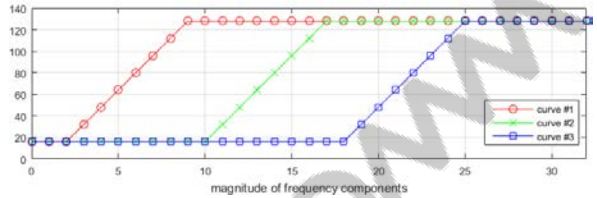
Examples:



High frequency **low frequency**

Step 3.1: Noise Reduction Strength (cont.)

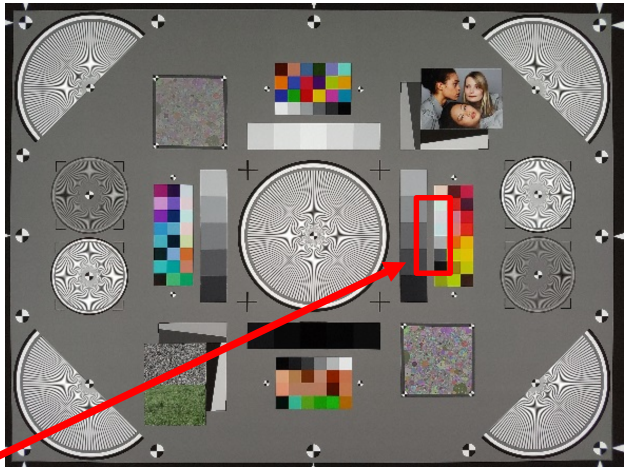
- flitering_nr_gain_arr

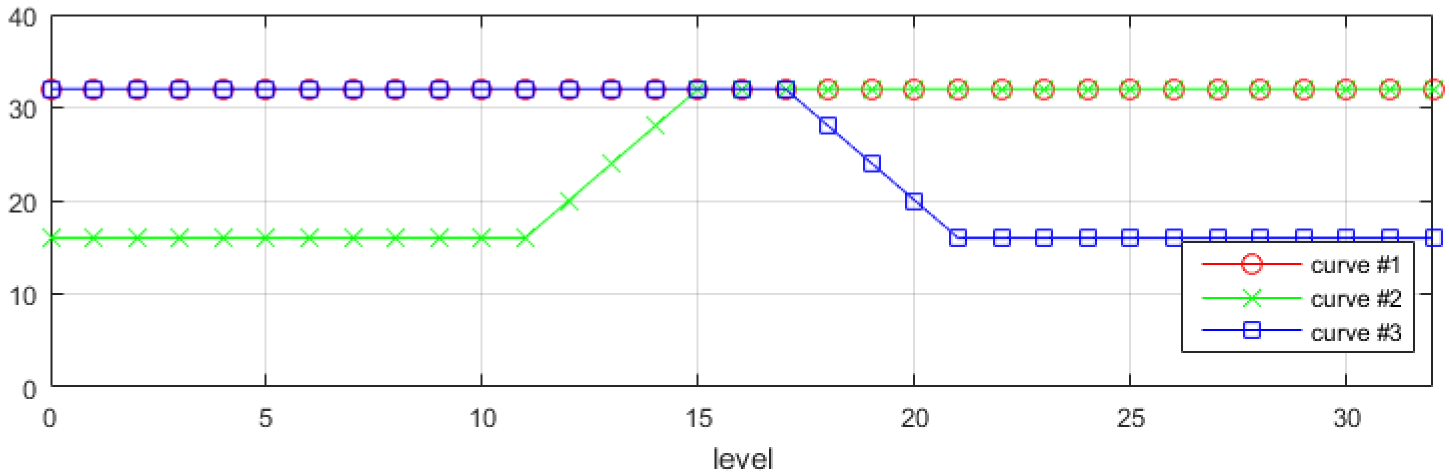


Curve #1	Curve #2	Curve #3

Step 3.2: Level-Based Noise Reduction Adjustment

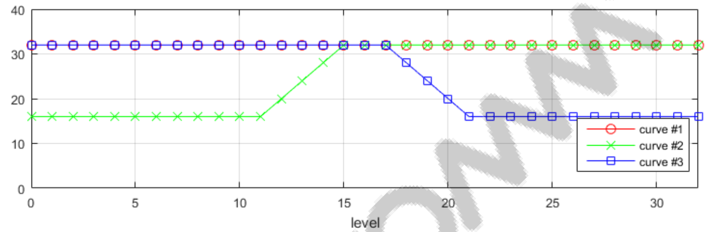
- lnr_gain_arr
  - Description: Adjust strength according to intensity level
  - Length: 33
  - Default: All 32 array
  - Min: 0; Max: 32
  - Effect: Lower value stronger noise reduction
  - Calibration: None
  - Suggestion: Piece-wise smooth curve
  - Examples:





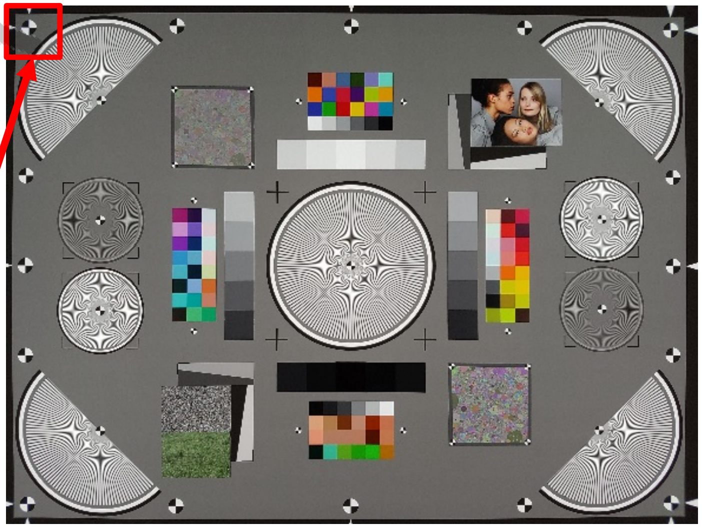
Step 3.2: Level-Based Noise Reduction Adjustment (cont.)

- lnr_gain_arr



Step 3.3: Radial-Based Noise Reduction Adjustment

- radial_noise_prsv_adj
  - Description: Adjust strength based on radial distance
  - Length: 7
  - Default: All 1.0 array
  - Min: 0; Max:1.0
  - Effect: Lower value stronger noise reduction
  - Calibration: Tool uses flat-field image
  - Suggestion: Monotonically decreasing



Examples:

- radial anchor: [0.0 0.2 0.3 0.4 0.6 0.8 1.0]
- setting #1: [1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000]
- setting #2: [1.0000 1.0000 0.9375 0.8750 0.7500 0.6250 0.5000]

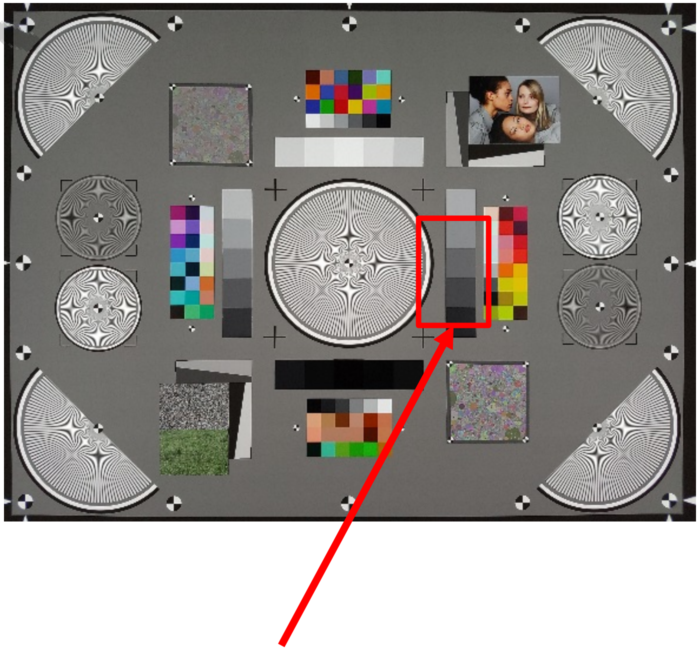
Step 3.3: Radial-Based Noise Reduction Adjustment (cont.)

- radial_noise_prsv_adj

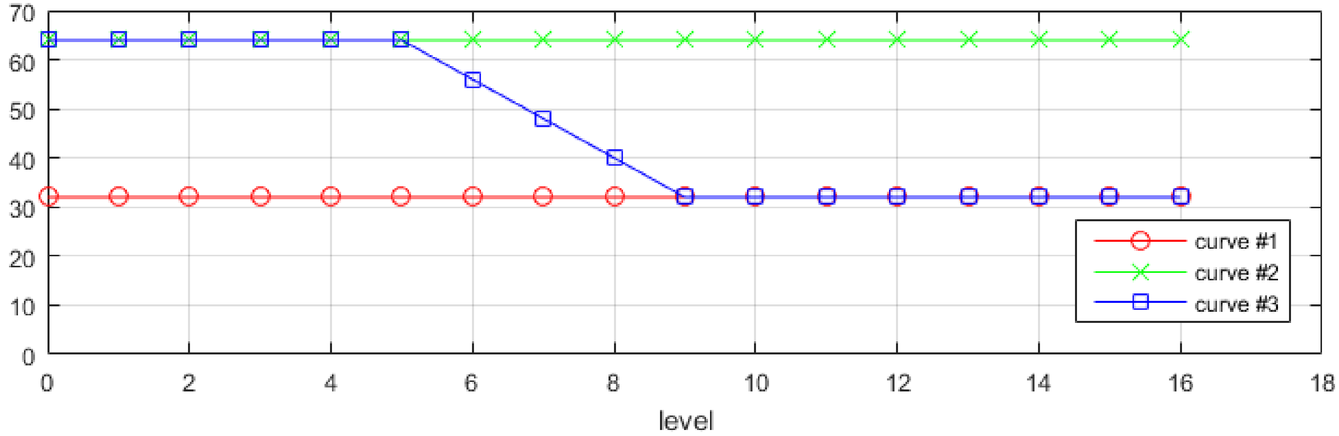
Setting #1: [1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000]
Setting #2: [1.0000 1.0000 0.9375 0.8750 0.7500 0.6250 0.5000]

Step 3.4: Level-Based Noise Blending Adjustment

- blend_lnr_gain_arr
  - Description: Blending weight of input luma channel
  - Length:17
  - Default: All 32 array
  - Min: 0; Max: 255
  - Effect: Higher value noisier output
  - Calibration: None
  - Suggestion: U shape curve to preserve more details on both dark and highlight regions.

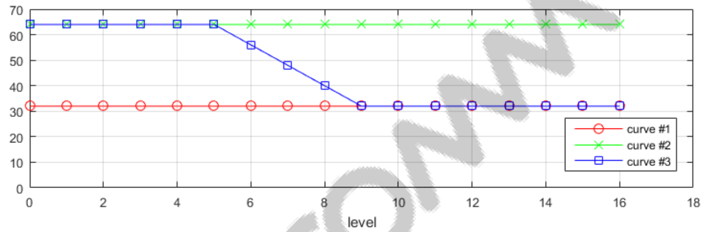


Examples:

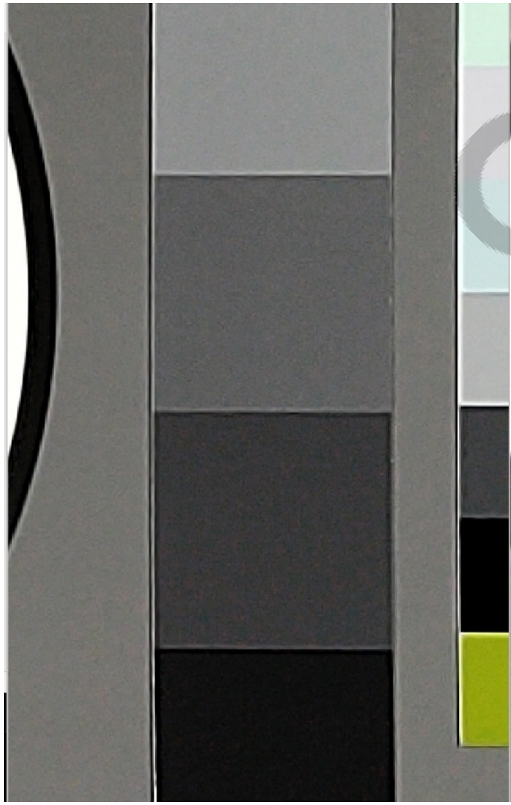


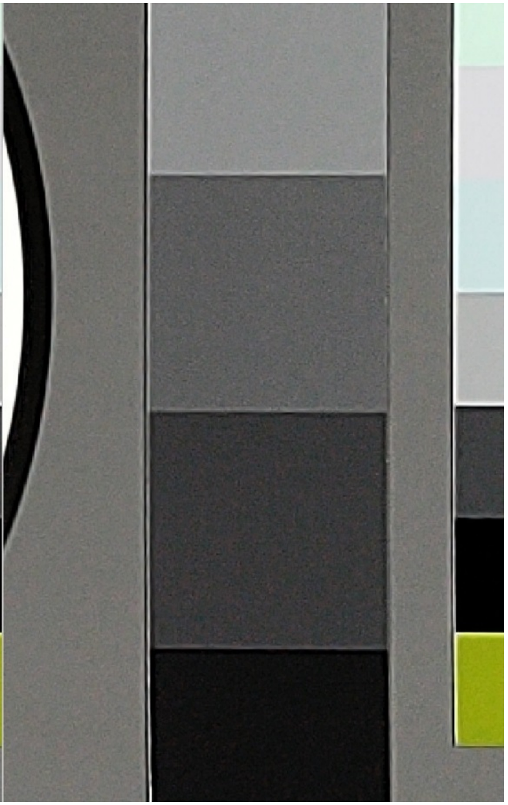
Step 3.4: Level-Based Noise Blending Adjustment (cont.)

- blend_lnr_gain_arr



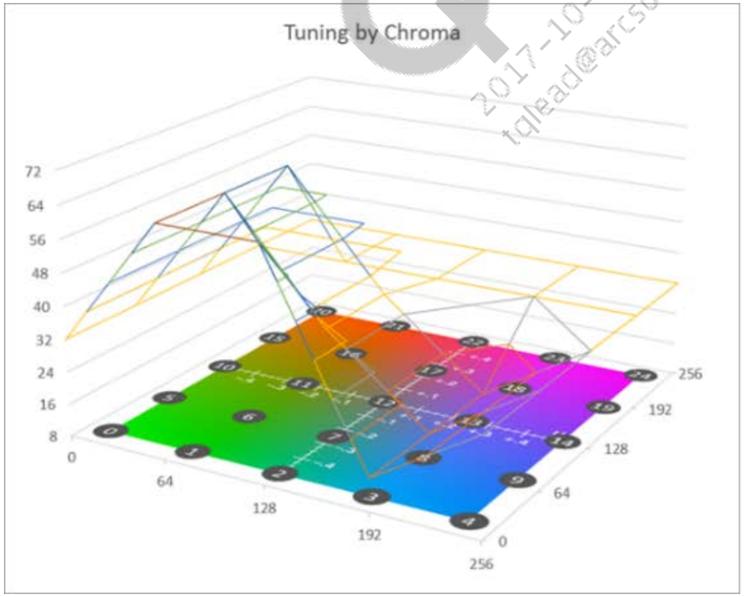
Curve #1 | **Curve #2** | **Curve #3**

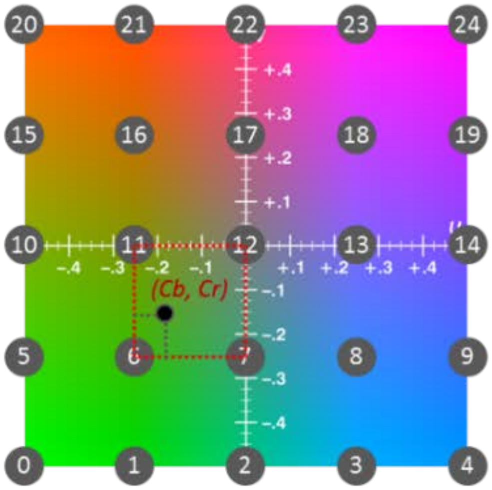




Step 4.1: Chorma-Based Noise Reduction Strength Adjustment

- cnr_gain_arr:
  - Description: Partition UV plane to 4×4 mesh with 25 points
  - Length: 25
  - Default: All 32 array (disabled)
  - Min: 0; Max: 32
  - Effect: Lower value stronger noise reduction
  - Calibration: None

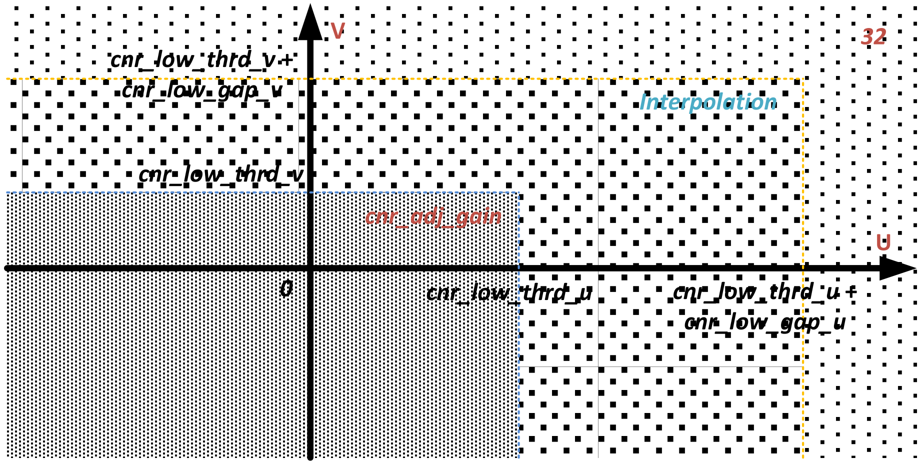




Step 4.1: Chorma-Based Noise Reduction Strength Adjustment (cont.)

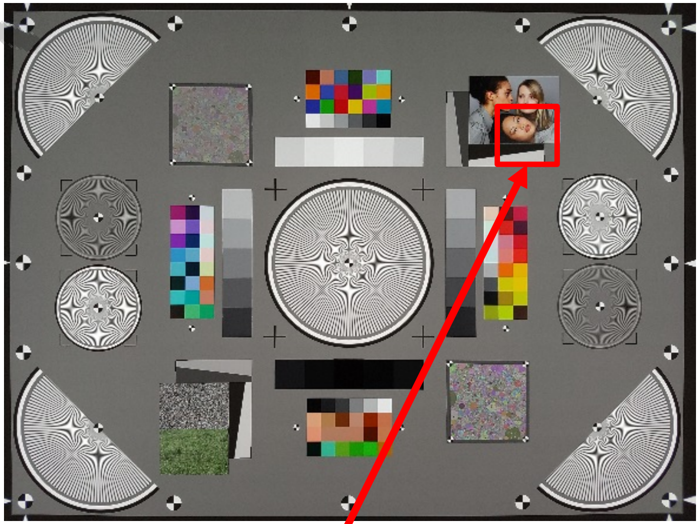
- Parameter list
  - Define chroma region for adjustment with: cnr_low_thrd_u & cnr_low_thrd_v
  - Define interpolated region with: cnr_low_gap_u & cnr_low_gap_v
  - Adjust noise reduction strength with: cnr_adj_gain
- Blending weight of input luma channel

name	length	default	min	max	higher value	lower value
cnr_low_thrd_u(v)	1	2	-128	127	Impact more region	Impact less region
cnr_low_gap_u(v)	1	1	0	7	Larger interpolated region	Smaller interpolated region
cnr_adj_gain	1	32	0	32	Noisier output	Smoother output

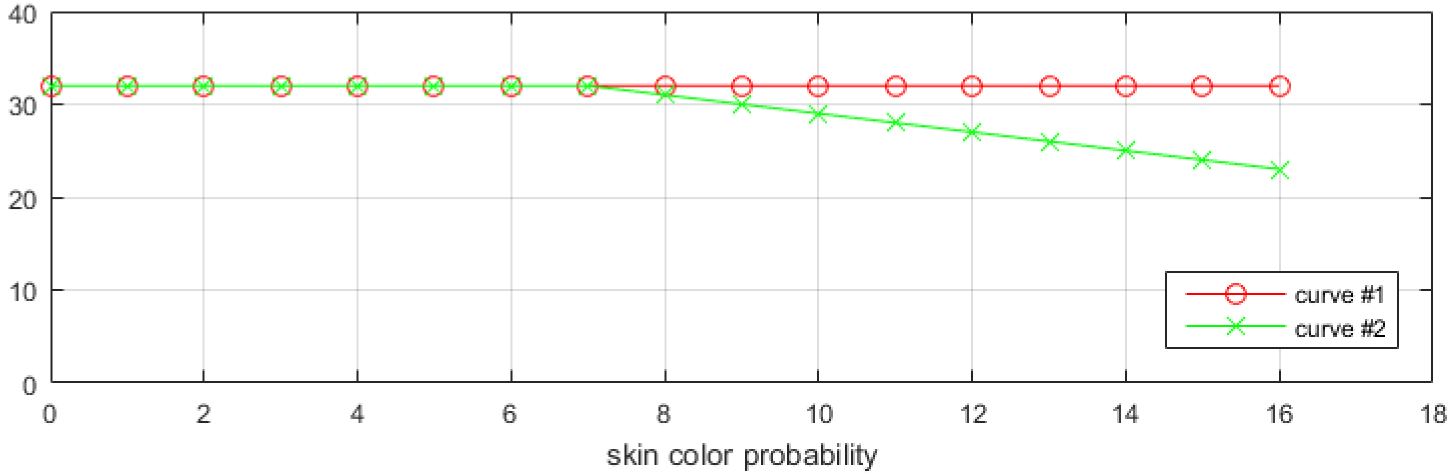


Step 4.2: Skin-Color Based Noise Reduction Strength Adjustment

- snr_gain_arr
  - Description: Adjust noise reduction strength based on skin color
  - Length:17
  - Default: All 32 array (disabled)
  - Min: 0; Max: 32
  - Effect: Lower value cleaner flat regions
  - Calibration: None
  - Suggestion: Using mild adjustment

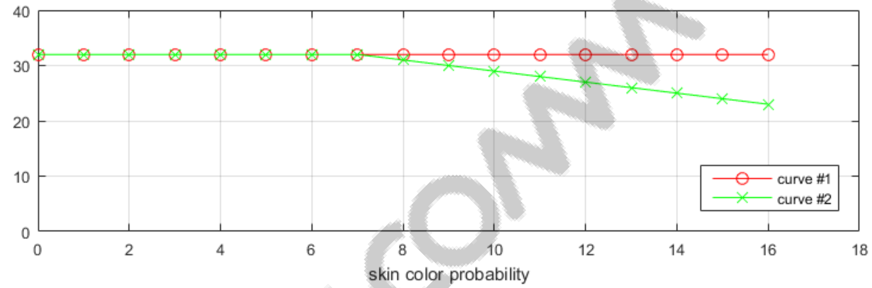


Examples:



Step 4.2: Adjust Noise Reduction Strength in Flat Regions

- snr_gain_arr

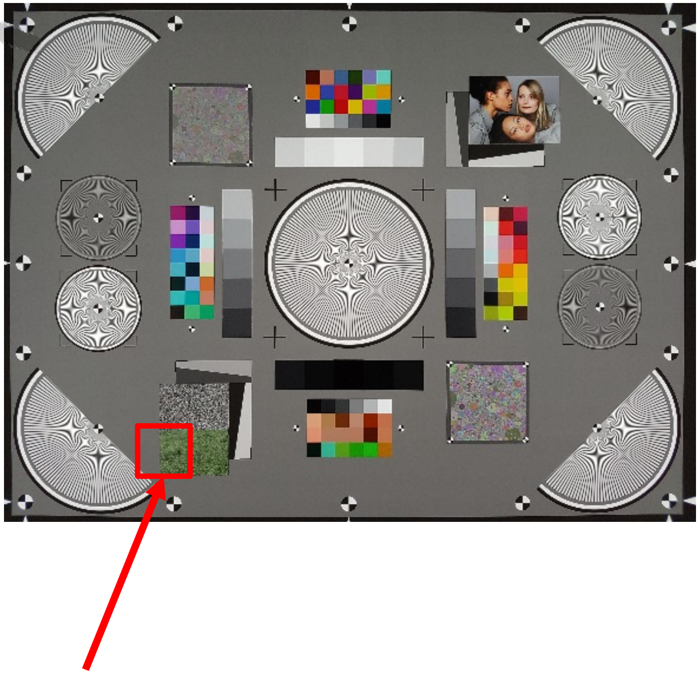


curve #1

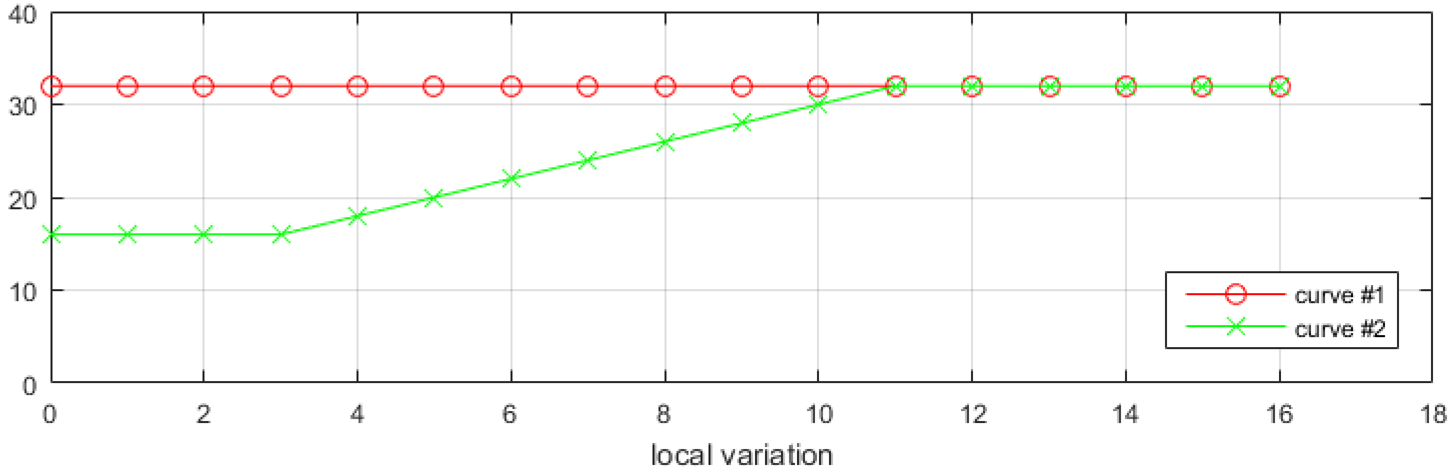
curve #2

Step 4.2: Adjust Noise Reduction Strength in Flat Regions (cont.)

- fnr_gain_arr
  - Adjust noise reduction strength based on local variations.
  - Length:17
  - Default: All 32 array (disabled)
  - Min: 0; Max: 32
  - Effect: Lower value cleaner flat regions
  - Calibration: None
  - Suggestion: Using mild adjustment

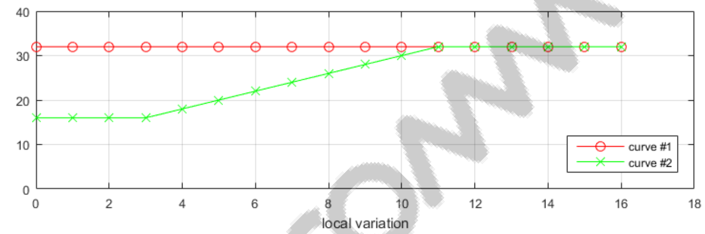


Examples:



Step 4.2: Adjust Noise Reduction Strength in Flat Regions (cont.)

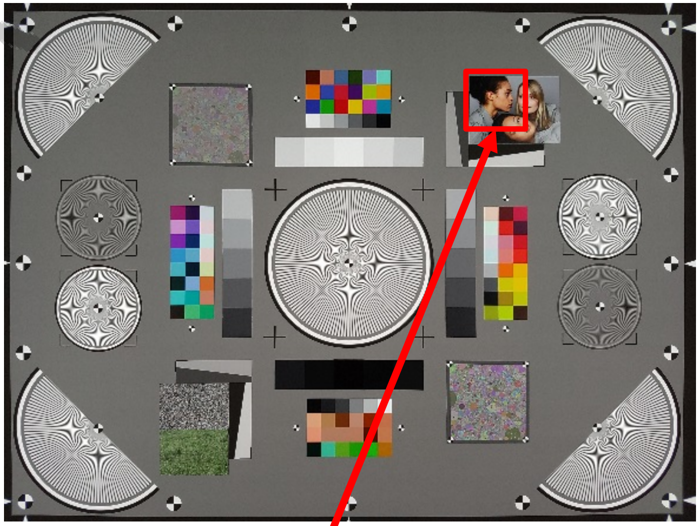
- fnr_gain_arr

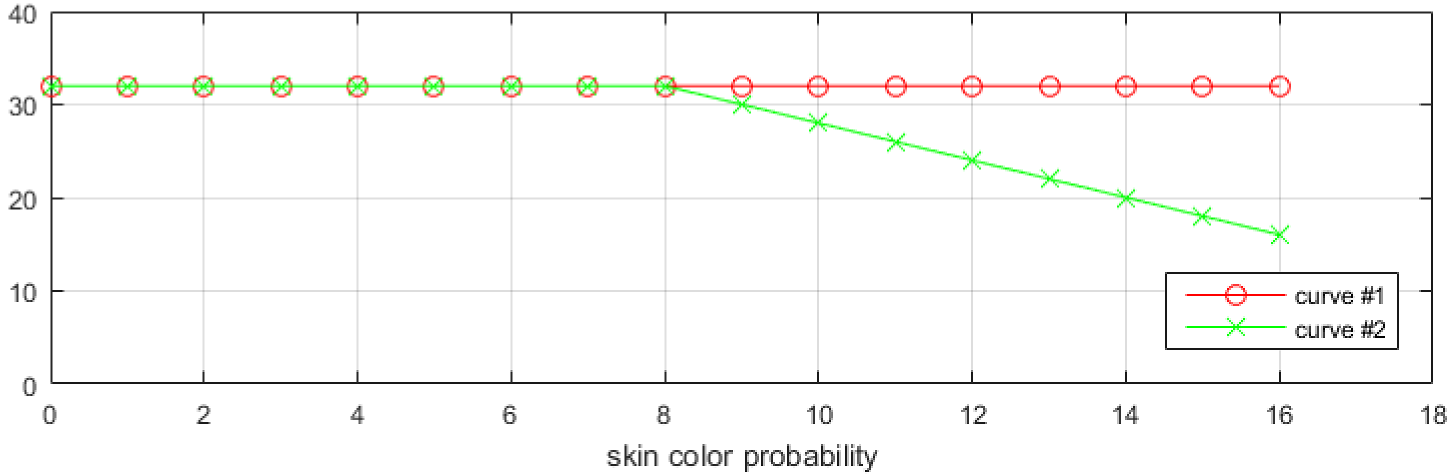


Step 4.3: Skin-Color Based Blending Adjustment

- blend_snr_gain_arr
  - Description: Blending weight of input luma channel
  - Length:17
  - Default: All 32 array (disabled)
  - Min: 0; Max: 32
  - Effect: Lower value smoother skin region
  - Calibration: None

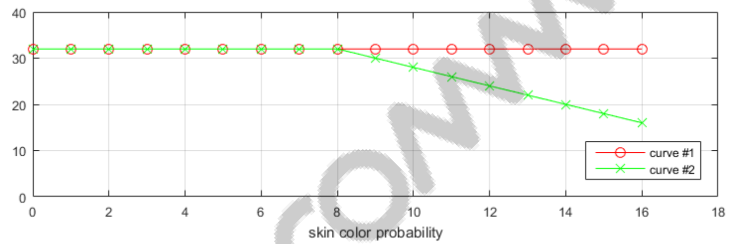
Examples:





Step 4.3: Skin-Color Based Blending Adjustment (cont.)

- blend_snr_gain_arr

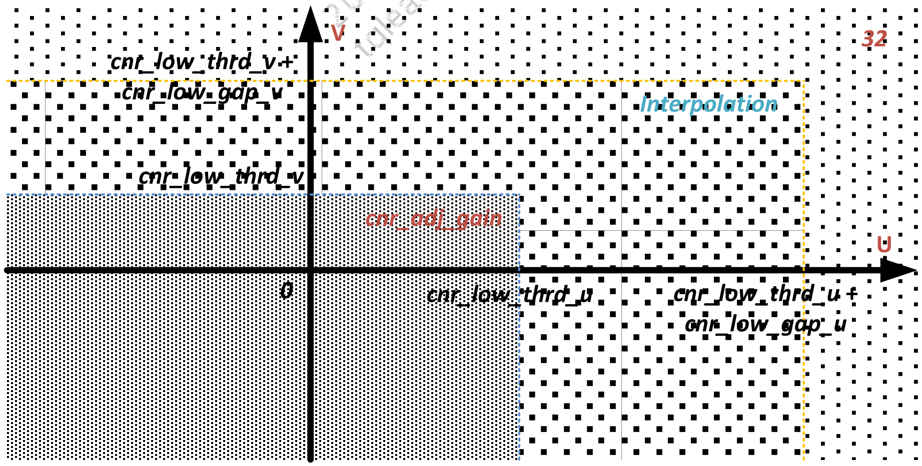


curve #1 **curve #2**

Step 4.4: Chroma-Based Blending Adjustment

- blend_cnr_adj_gain
  - Blending weight of input luma channel based on defined regions
  - Sharing the region definition with noise reduction stage
  - Length: 1
  - Default: 32
  - Min: 0; Max: 63
  - Effect: Lower value smoother output in defined chroma regions

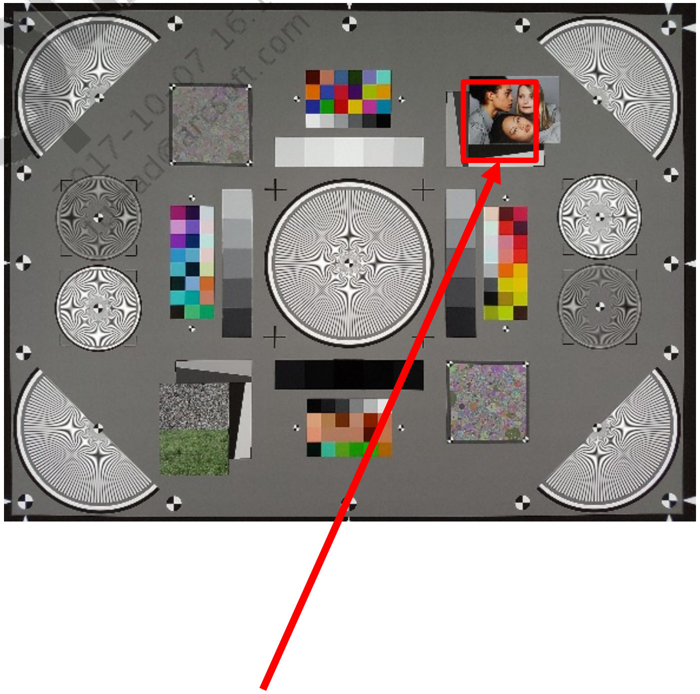
Examples:



Step 4.5: Reducing Jaggy Artifacts Along Edges

- lpf3_percent
  - Controls threshold for smoothing
  - Length:1
  - Default: 16
  - Min: 0; Max: 255
  - Effect: Higher value smoother edges
  - Calibration: None

Examples:

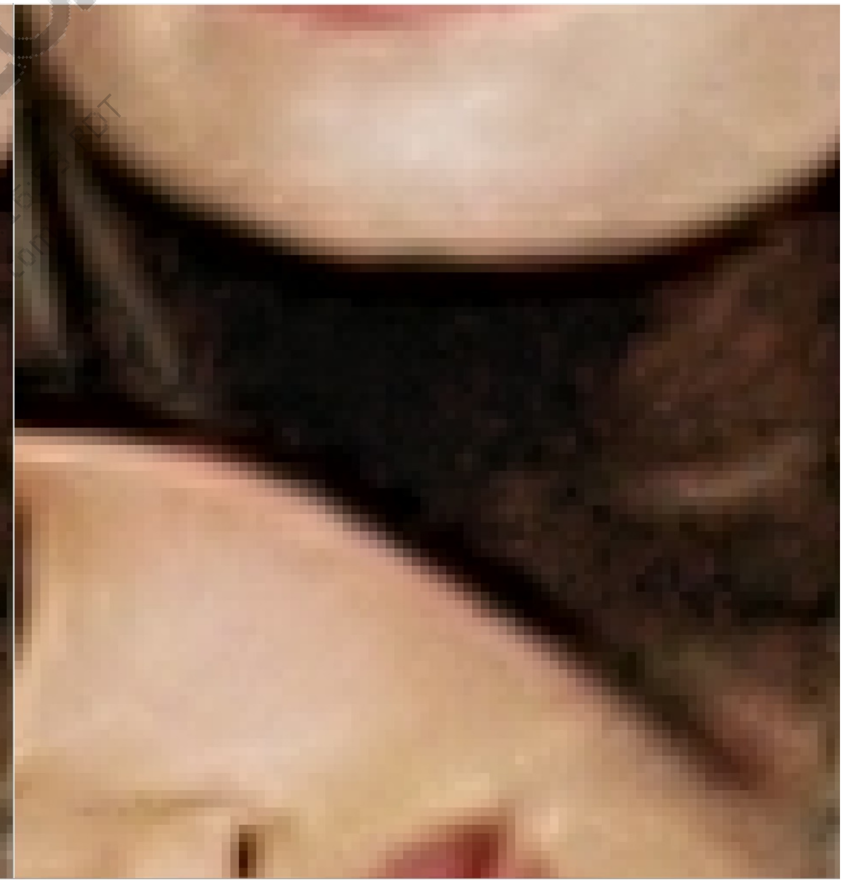


Step 4.5: Reducing Jaggy Artifacts Along Edges (cont.)

- lpf3_percent

lpf3 off

lpf3_percent = 64



Step 5.1: Adjust Skin Color Definition

- Parameter list for adjusting skin color
  - skin_hue_min
  - skin_hue_max
  - skin_y_min
  - skin_y_max
  - skin_saturation_min_y_max
  - skin_saturation_max_y_max
  - skin_saturation_min_y_min
  - skin_saturation_max_y_min
  - skin_boundary_probability
  - skin_percent
  - skin_non_skin_to_skin_q_ratio

Step 5.2: Facial Areas Adjustment

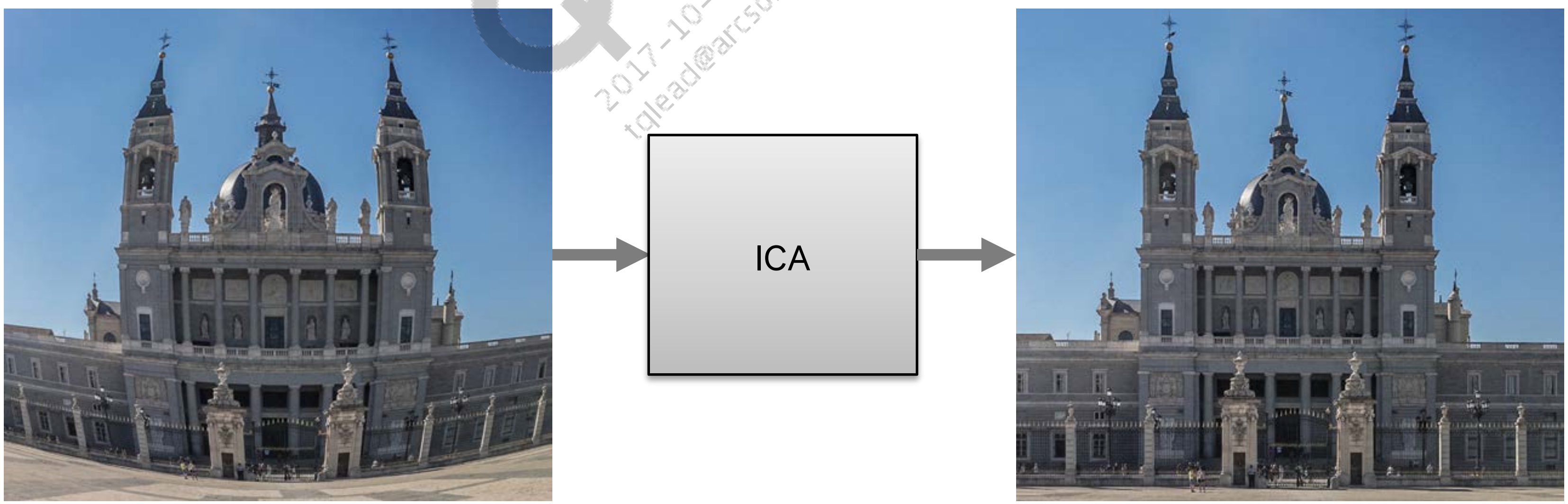
- face_boundary
  - Lower bond factor for facial areas detected by face detection
  - Length: 1
  - Default: 1.2
  - Min: 0; Max: 8
  - Effect: Lower value smaller facial areas
- face_transition
  - Lower bond factor for facial areas detected by face detection
  - Length: 1
  - Default: 2.0
  - Min: 0; Max: 8
  - Effect: Larger value larger transition areas
- face_boundary ≤ face_transition

Image Correction and Adjustment (ICA)

Image Correction and Adjustment (ICA) – Introduction

Problem statement

- Image Correction and Adjustment (ICA) module is a hardware unit which is mainly used for correction of geometric distortions caused by camera lens and movement
- The ICA HW unit should act as a low-power real-time warping engine inline to IPE. Typical use-cases are Lens distortion correction (LDC) and Electronic image stabilization (EIS)
- It should also support image alignment in order to allow Motion compensated temporal filter (MCTF)

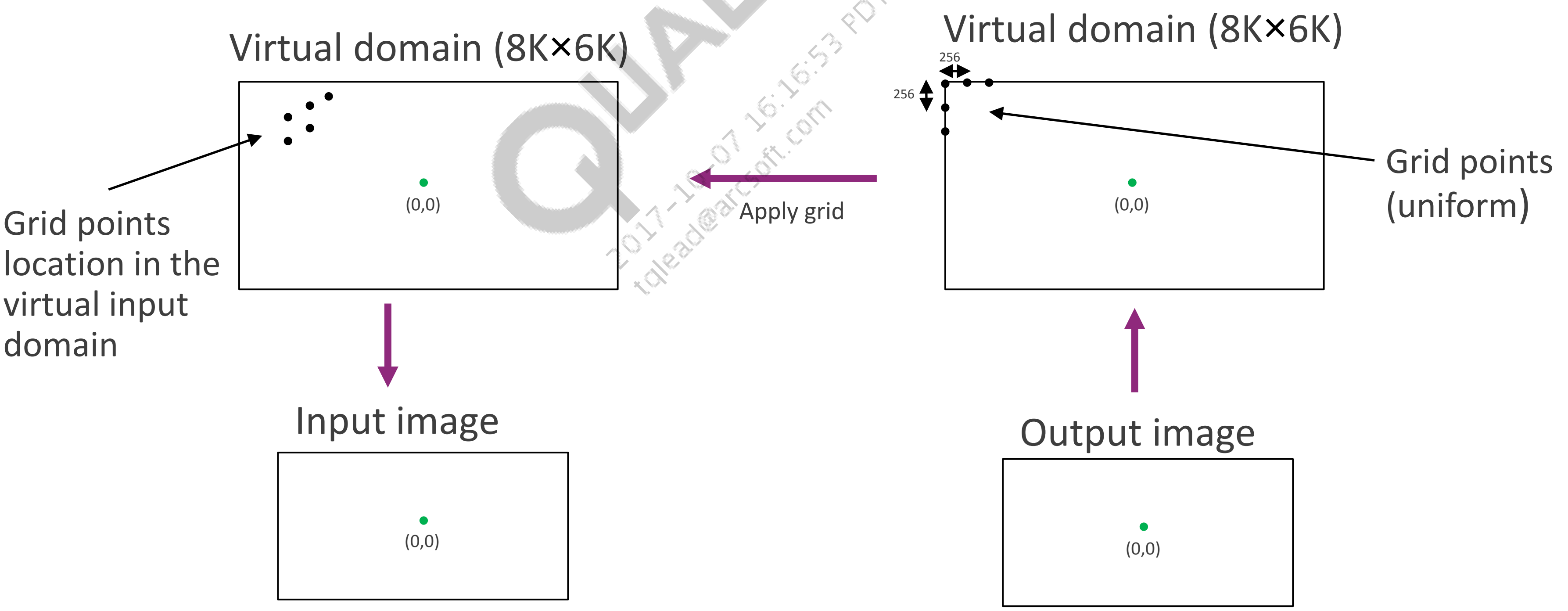


Input - Distorted

Output - Undistorted

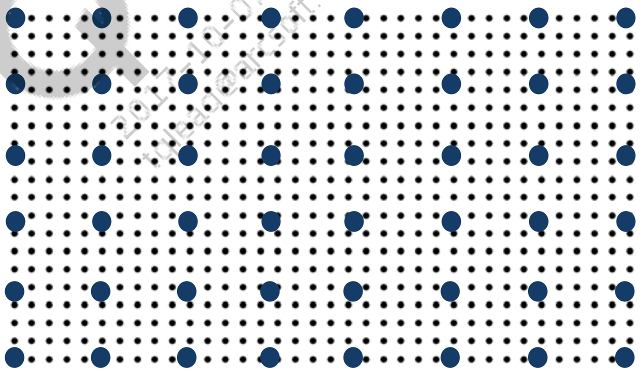
Step 1: Grid Transform

- Grid samples do not depend on the resolution
  - Received and applied in “virtual domain” (8K×6K)
  - Origins (0,0) are at the center



Step 1: Grid Transform (cont.)

- Grid transform can be used to apply a general transformation
- Essentially a warp map and each sample contains explicit mapping of output to input coordinate, both are in the virtual domain
  - The virtual domain is defined by 17 bits for X and 17 bits for Y
- It consists of a sparse uniform grid (33 by 25 samples) over the output image:
  - Intermediate coordinates calculated by the hardware using bi-cubic interpolation:



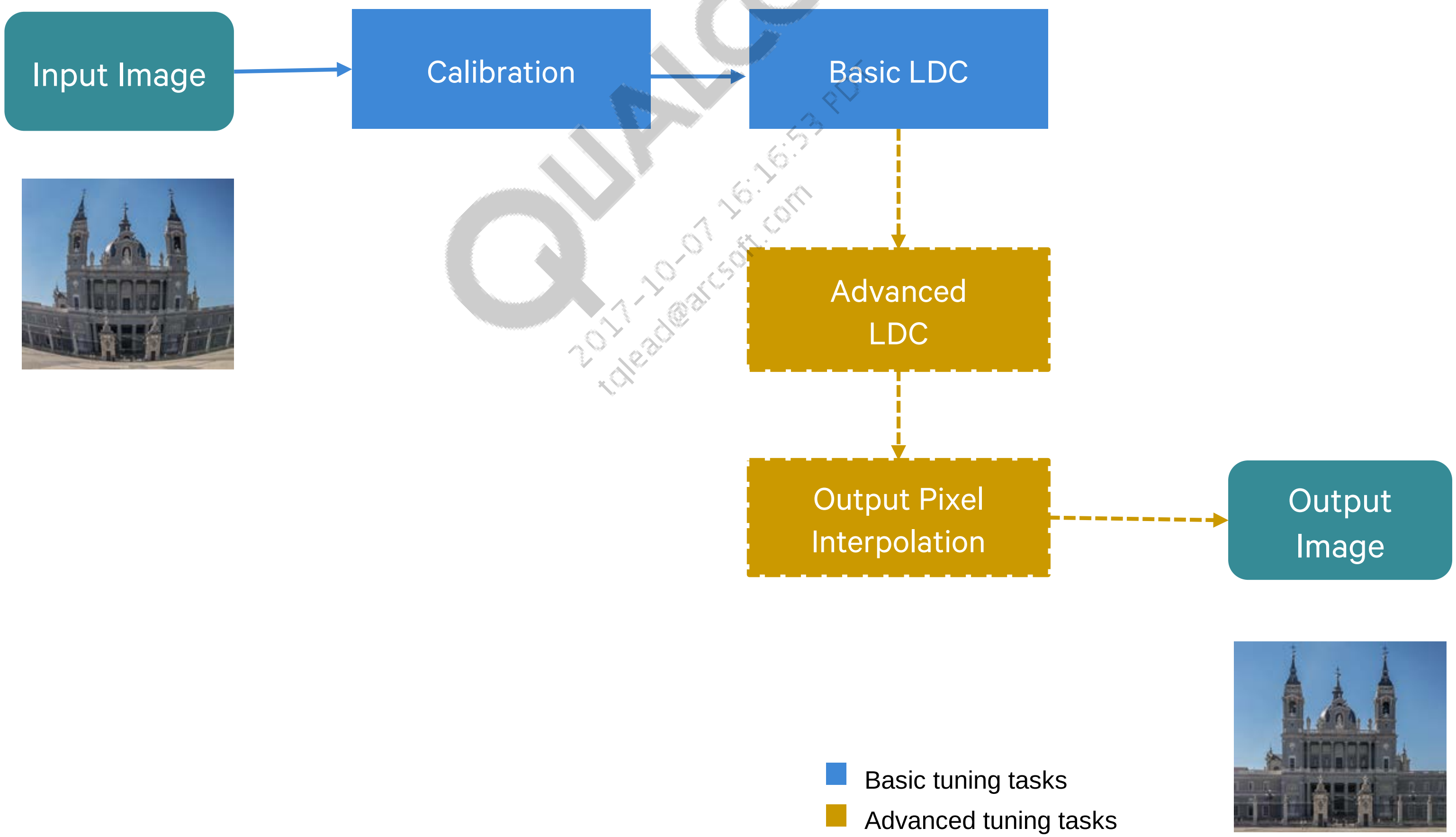
- Enable via CTC_TRANSFORM_GRID_ENABLE parameter
  - (CTC : Coordinate transform calculator)

Output Pixel Interpolation

- Output pixels are generated via interpolation
  - Luma – Two interpolation options
    - Configurable 4×4 symmetric kernel
      - Defined by setting Y_INTERPOLATION_TYPE parameter to 0
      - Interpolation kernel is defined by OPG LUT (symmetric with 32 phases)
    - Native bi-linear interpolation
      - Defined by setting Y_INTERPOLATION_TYPE parameter to 1
  - Chroma
    - Bi-linear interpolation

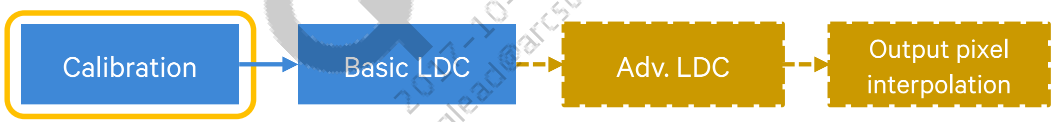
Step 2: LDC Tuning Flow Diagram

- The following diagram describes the LDC tuning flow:

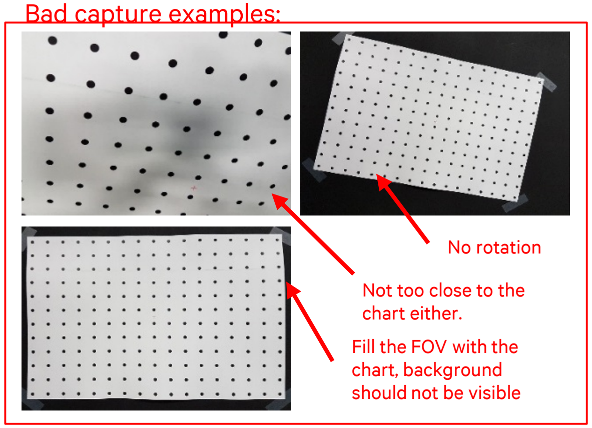


Step 3.1.1: Calibration

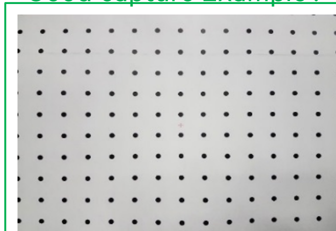
- For LDC calibration, a dot chart is required
  - Capture requirement
    - Light can be D65, TL84, D50 and should be around 400 lux
    - Using a tripod, the camera position should be parallel and aligned (not rotated) with the chart
    - Set camera to use minimum gain (to reduce noise) and set exposure so that there will be no flicker from light source
    - Chart should cover the entire FOV or little more : Image should include only the chart
    - Make sure that the captured image has no motion blur and AF focused



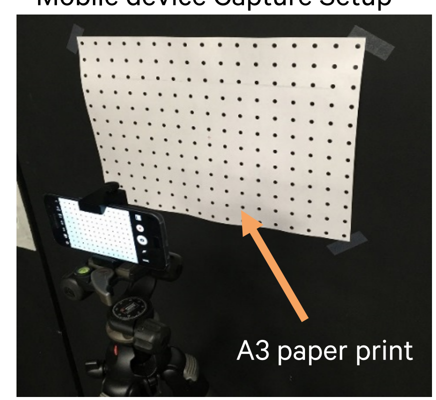
Bad capture examples:



Good capture Example :



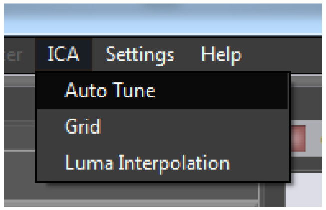
Mobile device Capture Setup



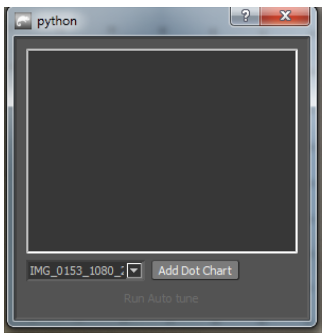
* LDC tuning should be done per every camera, i.e. different tuning for front /rare, or between tele and wide…

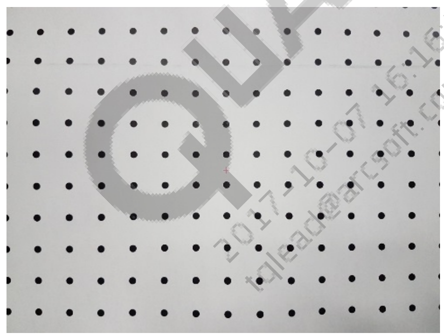
Step 3.1.2: Calibration

- Use Auto Tune option from the ICA menu

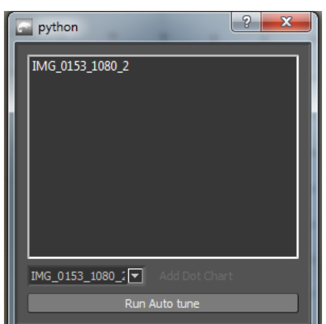


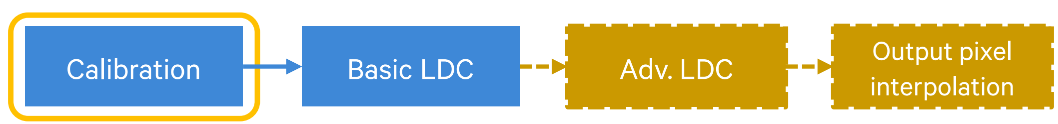
- Select the dot chat image captured





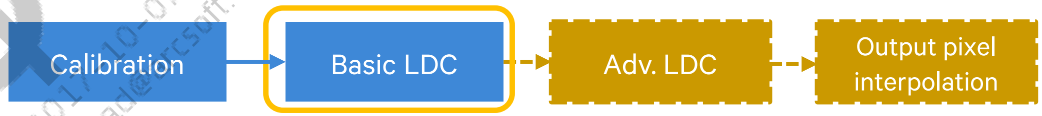
- Run Auto Tune to calibrate automatically

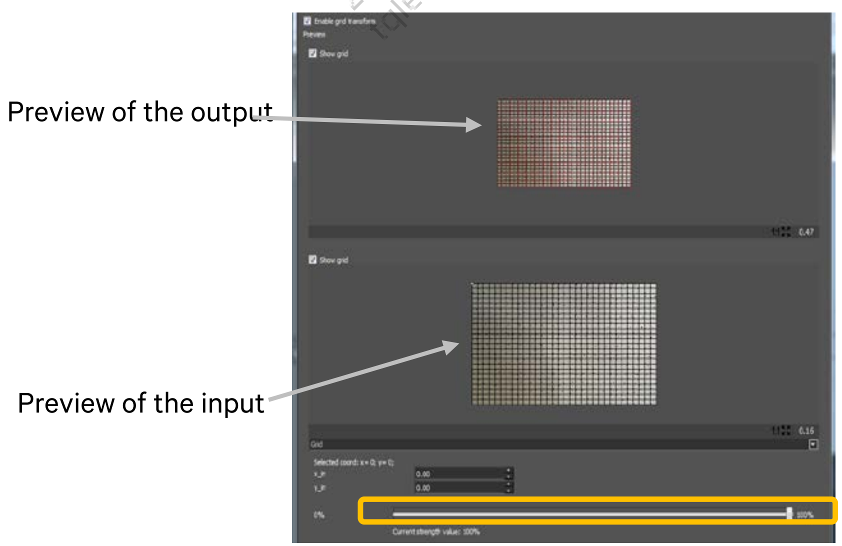




Step 3.2.1: Basic LDC

- Correction Strength
  - Background
    - ICA LDC calibration corrects the image to full undistorted reference with 100% strength
    - A tuning engineer may choose to keep some of the distortion and lower the Correction Strength
  - Tuning Flow
    - Select Grid from the ICA menu
    - Use the Correction Strength slider(yellow box below) to adjust the strength of the effect
    - Access the impact from the preview of the output, then process and examine impact on an image





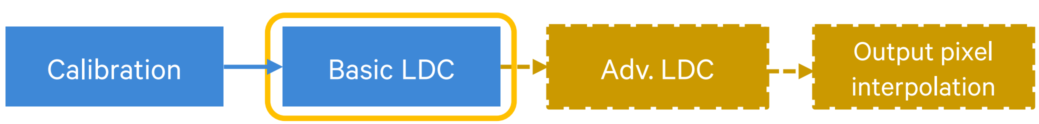
Step 3.2.2: Basic LDC

- The effect of Correction Strength

LDC disabled

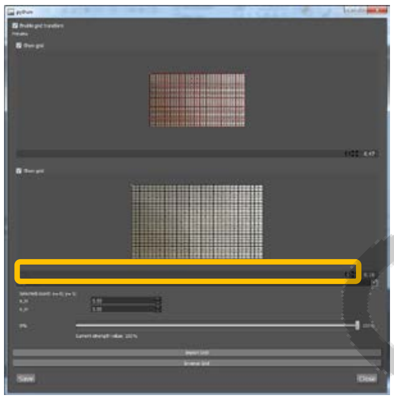
Strength 50%

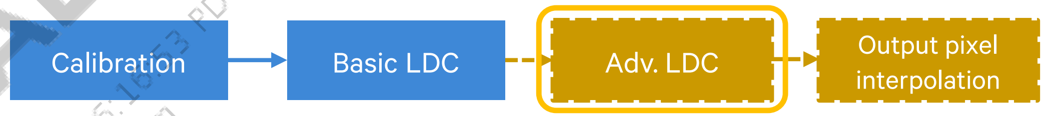
Strength 100%



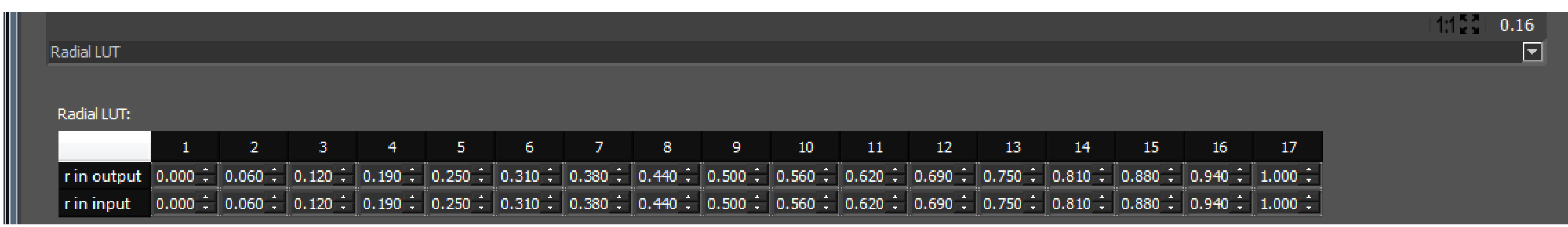
Step 3.3.1: Advanced LDC

If a radial correction function or LUT are available, they can be used as well by changing the tuning mode





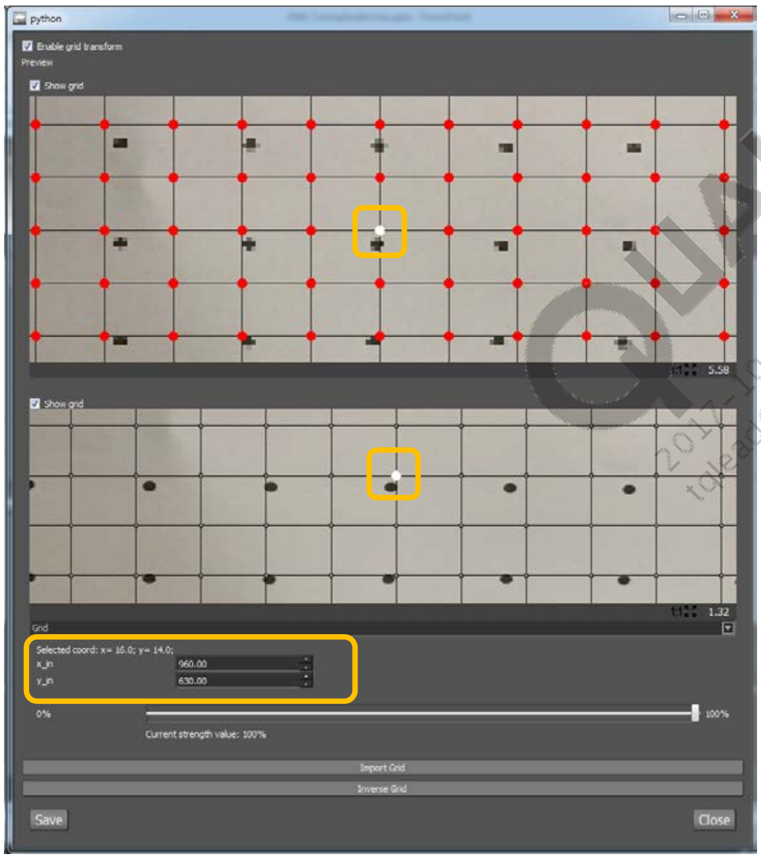
Tuning mode

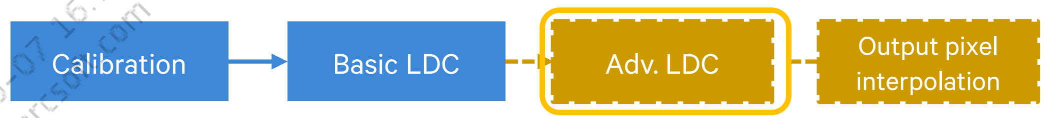


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
r in output	0.000	0.060	0.120	0.190	0.250	0.310	0.380	0.440	0.500	0.560	0.620	0.690	0.750	0.810	0.880	0.940	1.000
r in input	0.000	0.060	0.120	0.190	0.250	0.310	0.380	0.440	0.500	0.560	0.620	0.690	0.750	0.810	0.880	0.940	1.000

Step 3.3.2: Advanced LDC

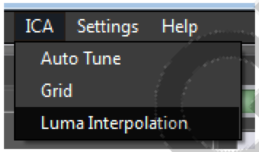
- Each grid sample also can be adjusted individually using the Grid Tuning Mode by selecting a grid point and changing its mapped coordinates

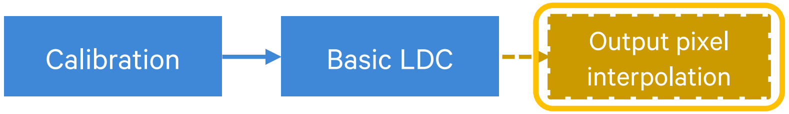


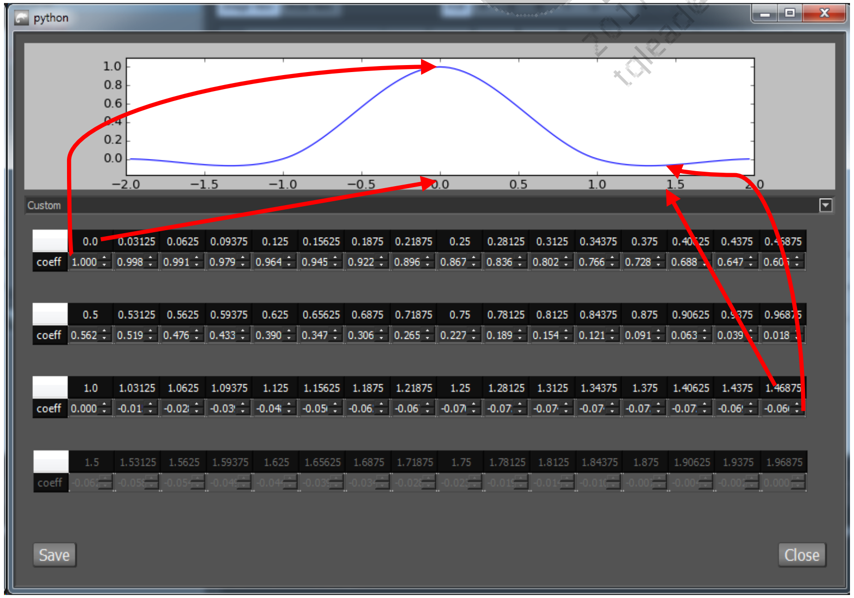


Step 3.4.1: Output Pixel Interpolation

- Output pixel interpolation can be used to compensate some resolution degrade after warping engine processing
  - Recommend not to enable at the beginning of projects since it affects overall sharpness and luma noise level
- The pixel interpolation kernel can be customized by selecting Luma Interpolation from ICA menu
- The kernel can be defined directly in Custom mode (bi-cubic or bilinear)



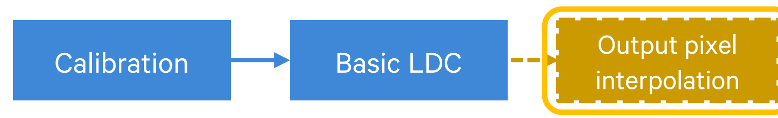




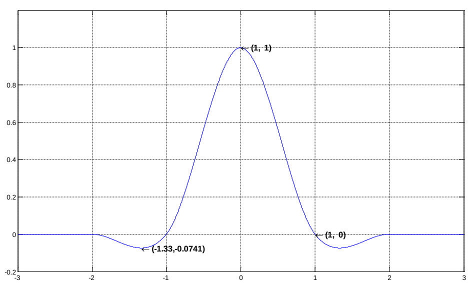
Step 3.4.1: Output Pixel Interpolation (cont.)

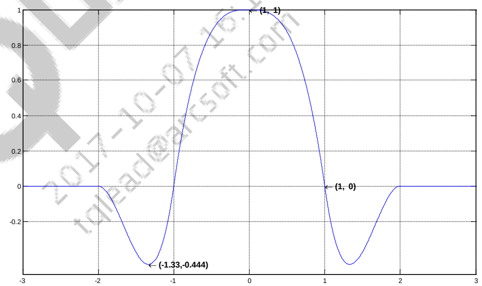
- 4 × 4 Kernel example
  - Consider the following formula for kernel selection with two parameters B and C

$$k(x) = \frac{1}{6}\begin{cases} (12-9B-6C)|x|^3 + (-18+12B+6C)|x|^2 + (6-2B) & |x|<1 \\ (-B-6C)|x|^3 + (6B+30C)|x|^2 + (-12B-48C)|x| + (8B+24C) & 1 \le |x| < 2 \\ 0 & otherwise \end{cases}$$



  - B = 0, C = 0.5 (Bi-cubic)
  - B = 0, C = 3





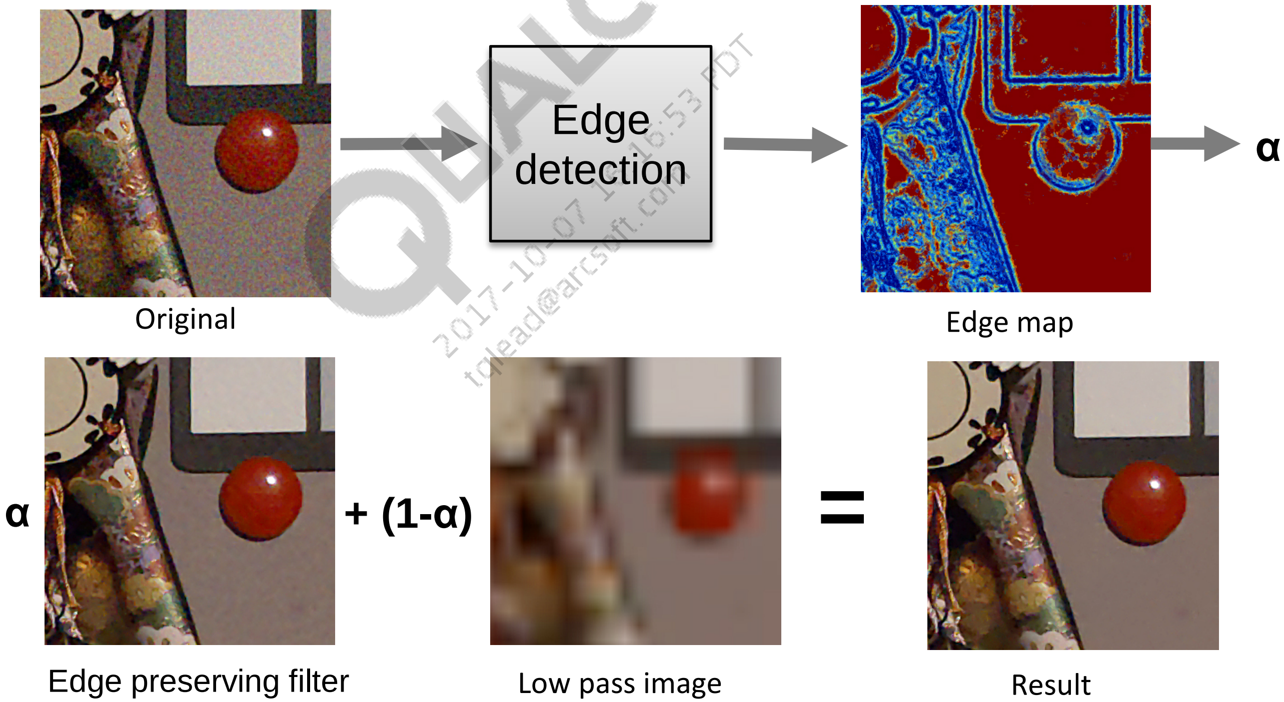
Step 4: How to Coordinate with Other Modules

- ICA LDC should be tuned first in IPE
- Sharpening should be done at a later stage. It is not recommended to use ICA Luma Interpolation function for sharpening, instead it is suggested to use ASF
  - Snapshot case, use of the Luma Interpolation function would break current luma noise level which is already tuned
  - Preview and video case, use of the Luma Interpolation function would affect inputs of multi frame temporal filtering block

Advanced Noise Reduction (ANR)

Advanced Noise Reduction - Background

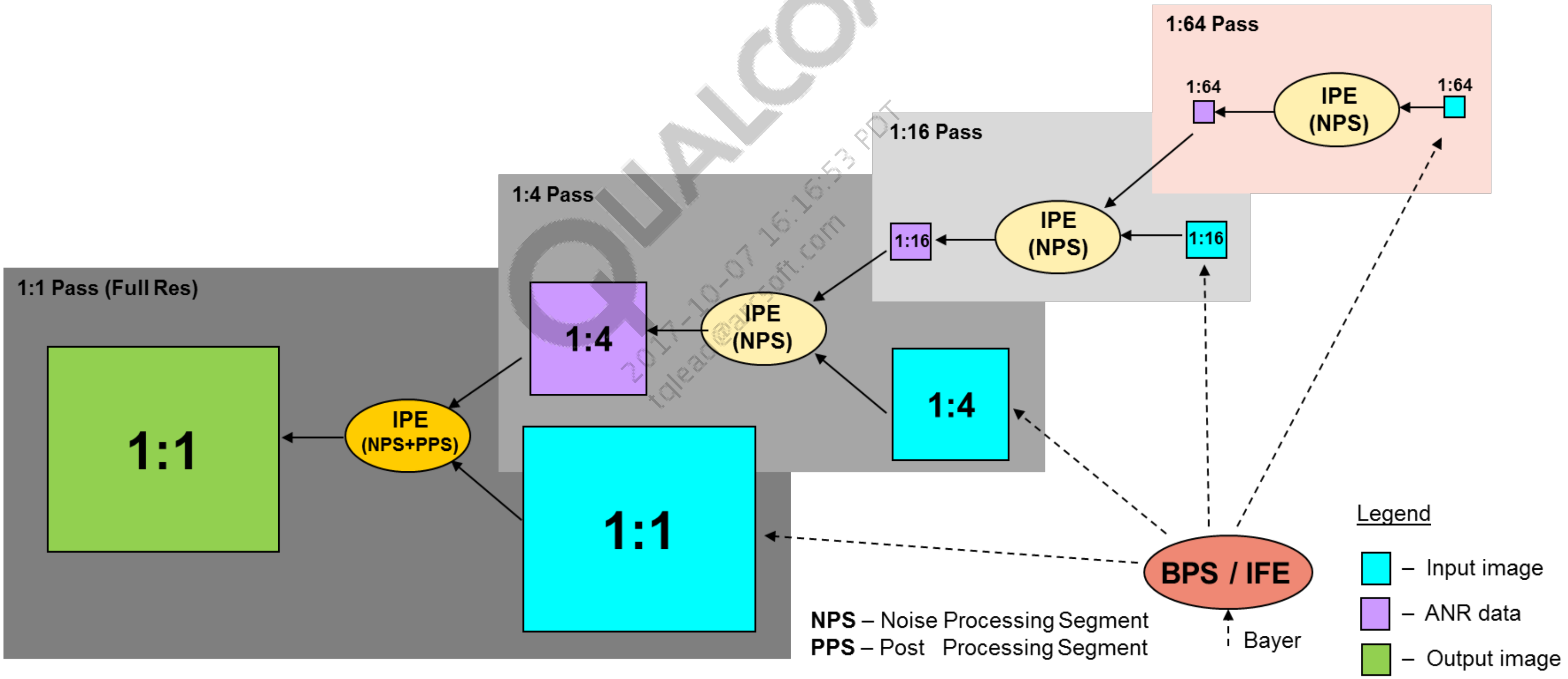
- Advanced noise filtering
- Multi pass spatial noise filtering
- Located in NPS of IPE, which means it's available for both video and snapshot



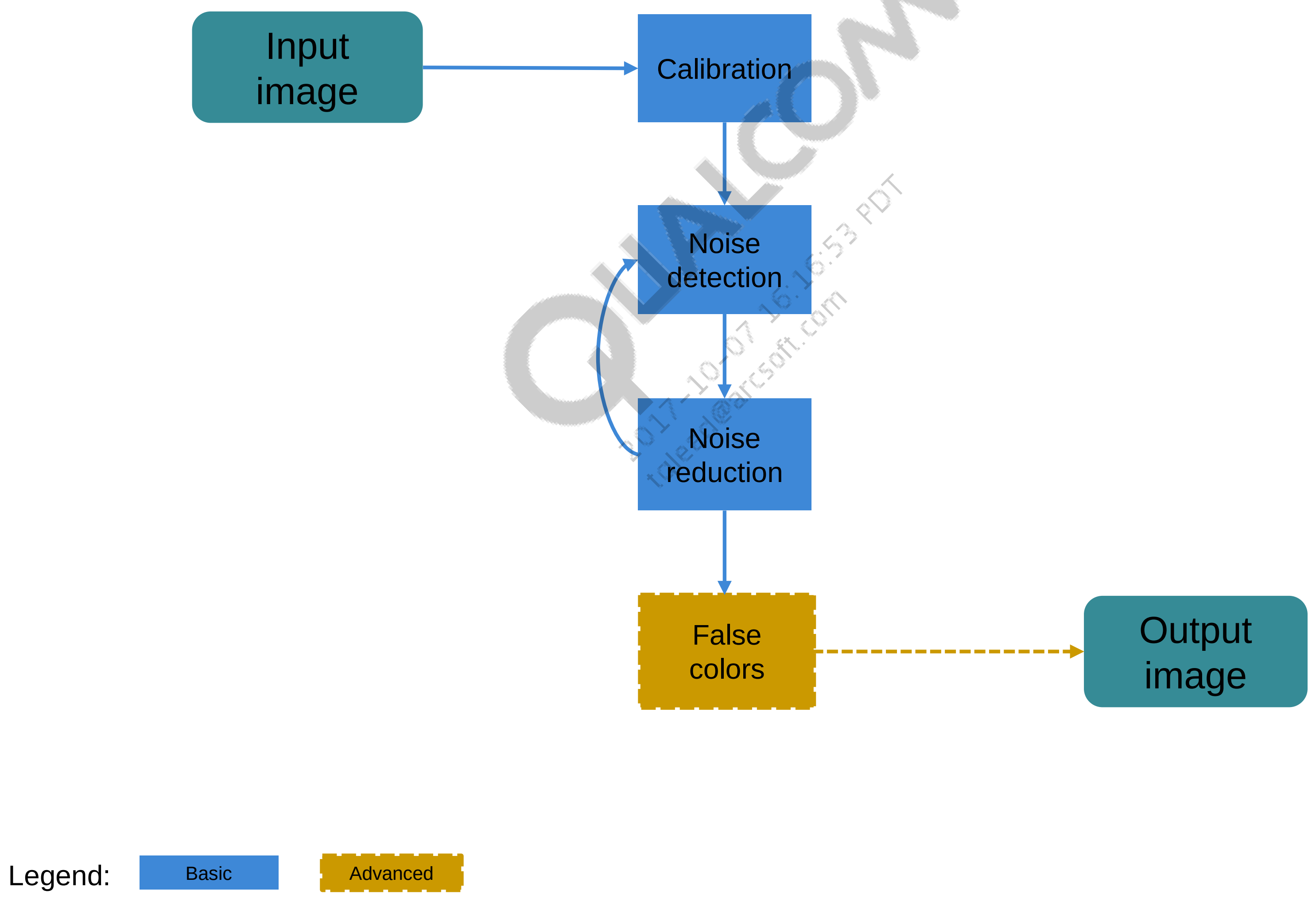
- α is determined for each pixel according to the edge map

Advanced Noise Reduction - Overview

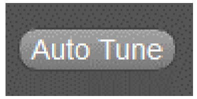
- General Processing Flow



Tuning Flow Diagram

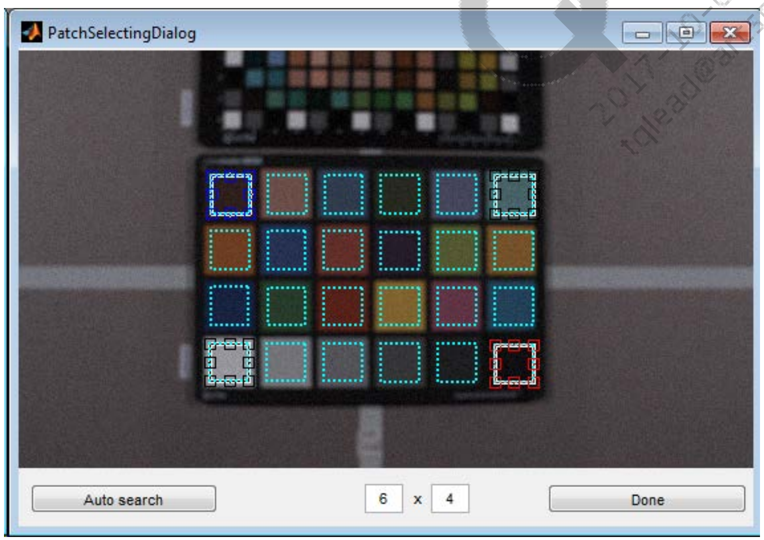


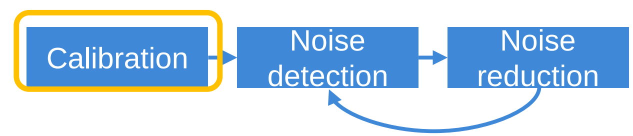
Calibration – Steps

1. Use Auto Tune 

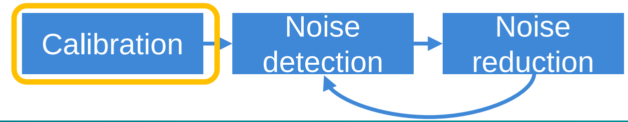
2. Select 1 flat field image and at least 1 MCC
3. Click Run AutoTune and wait until patch selection dialog opens

   Make sure that the MCC patches are properly selected and covers ~80% of each patch and is center aligned. If not, correct it by dragging them to fit
4. Click Done
5. Examine the result on a “natural scene” image

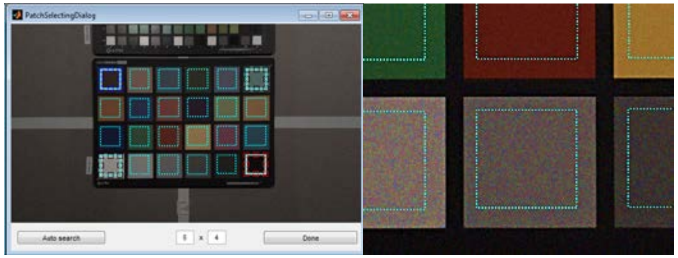




Calibration Troubleshooting

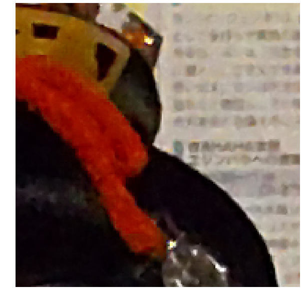


- Example of a good calibration



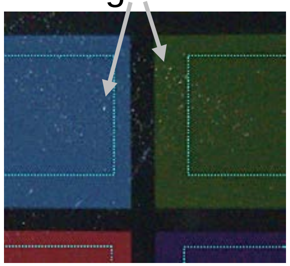
NO ANR

Good calibration result



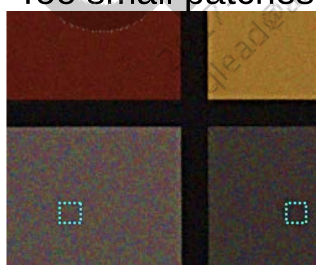
- Example of a bad calibration
  - In most of the cases, bad MCC(s) input will result in over filtration

Damaged MCC

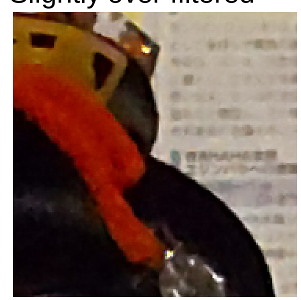


Or

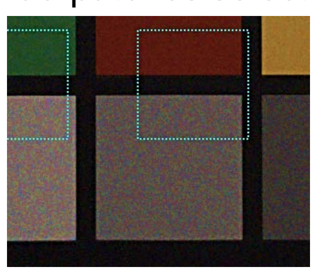
Too small patches



Slightly over filtered

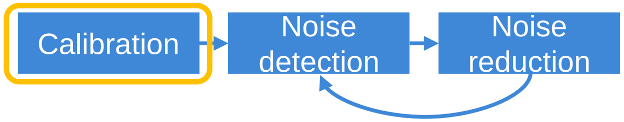


Bad patches selection



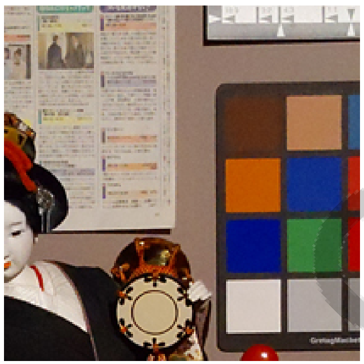
Heavily over filtered

Calibration Troubleshooting (cont.)

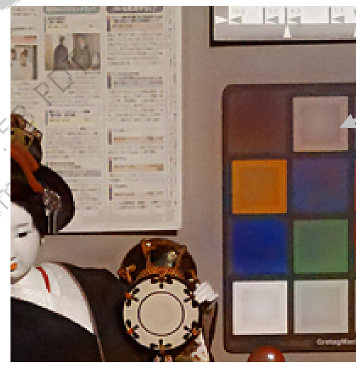


- Inaccurate flat field image may result radial noise patches and heavily effect calibration noise detection, especially in low frequencies

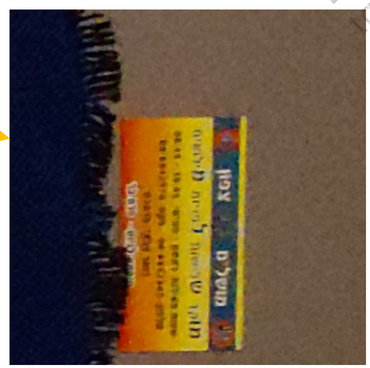
Calibration result using accurate flat field image



Calibration result using defected flat field image

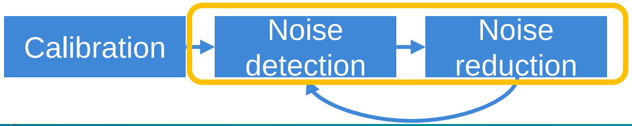


Halos

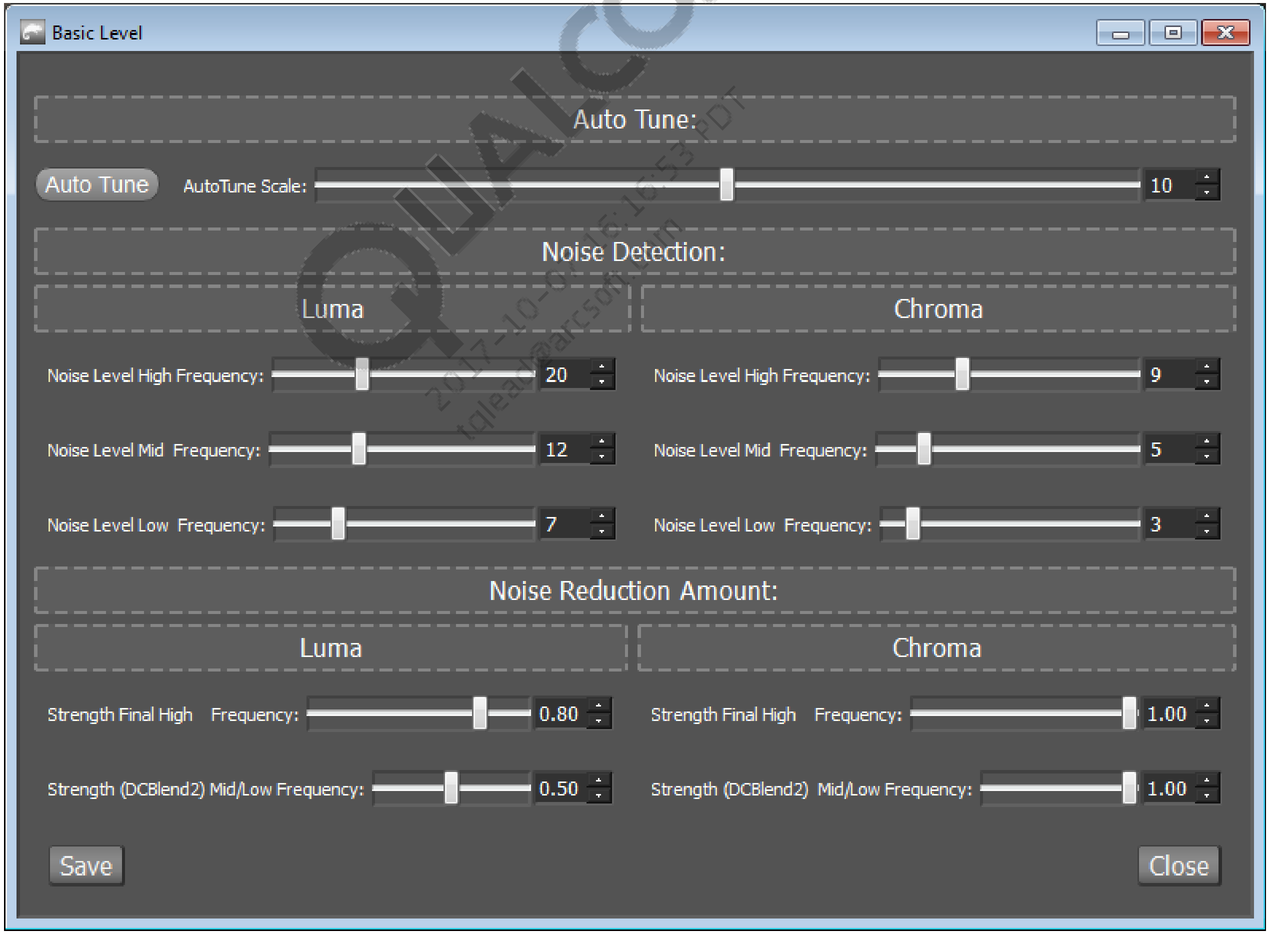


Noise in image corners

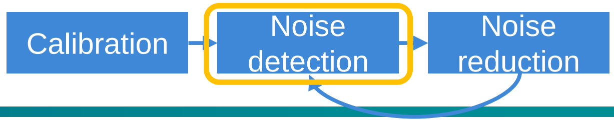
Tuning Steps – Basic Level



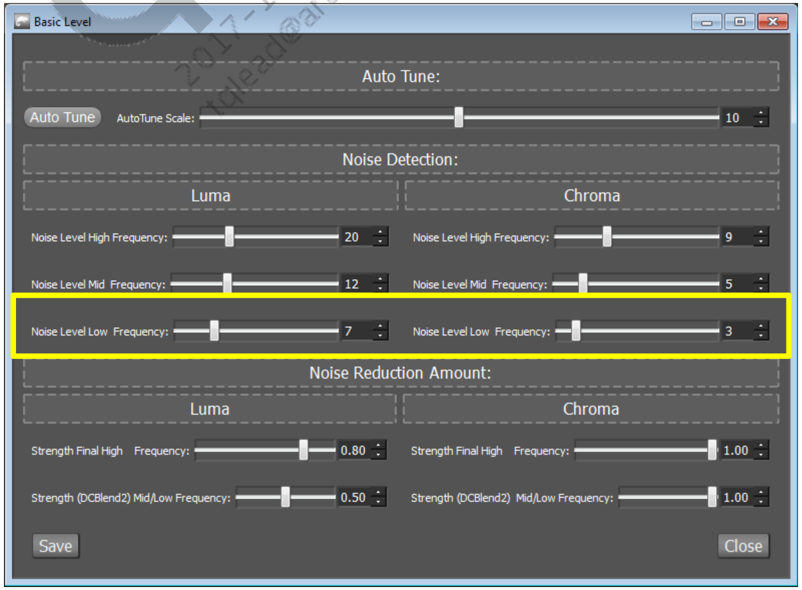
- Tune on “natural scene” image
- Applicable only after calibration
- After each change, click Save and then click Process



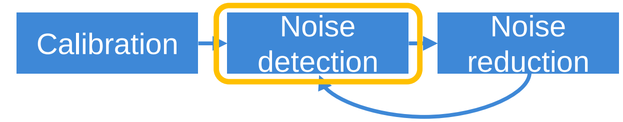
Tuning Steps – Basic Level (cont.)



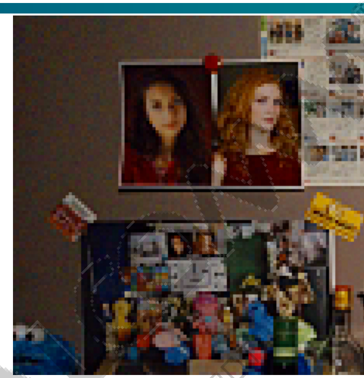
- Noise detection
  - Separates details from noise at each frequency range
    - Higher value (more details are interpreted as noise) = “eaten” edges, more filtering
    - Lower value (more noise is interpreted as details) = Noisier images, noise patches
  - Flow – 1st step
    - Select **DC16** image in the viewer
    - Adjust if required, Noise Level Low Frequency (Luma and Chroma) to achieve a **noise-free** edge preserved DC16 image



Tuning Steps – Basic Level (cont.)



NO ANR



Details loss

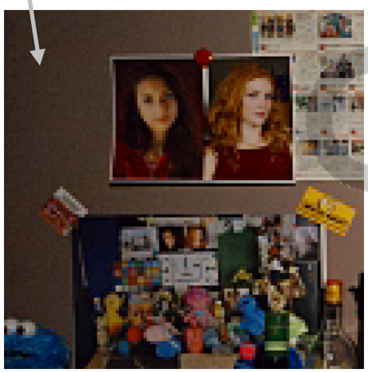
Noisy flat areas

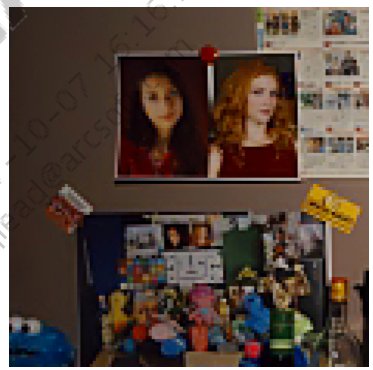
Too low

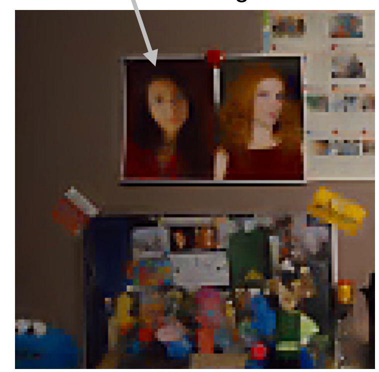
Good

Too high

*Noise level **low***
Frequency
luma

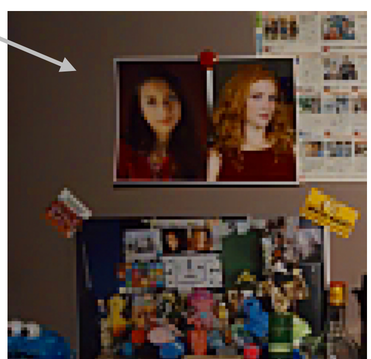


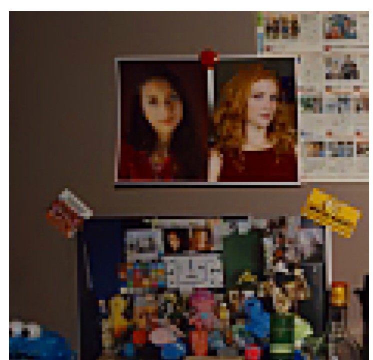


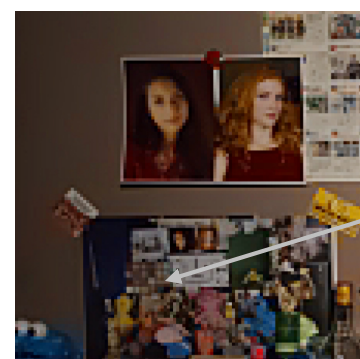


Chroma noise

*Noise level **low***
Frequency
chroma

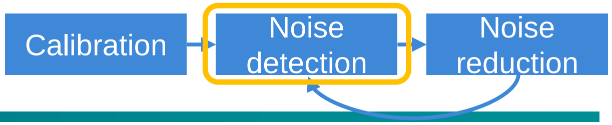




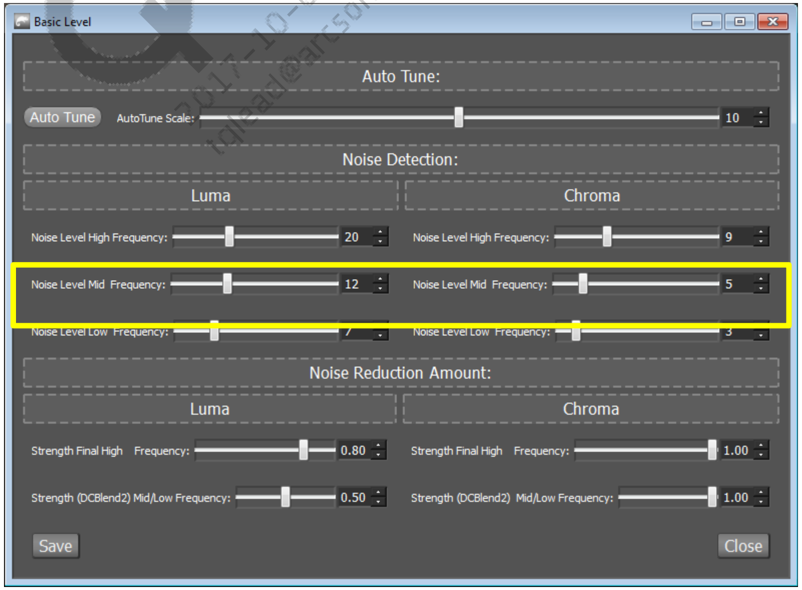


Desaturated color details

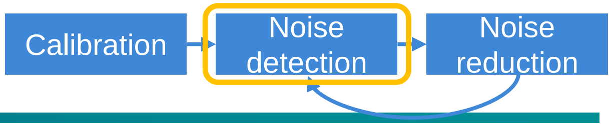
Tuning Steps – Basic Level (cont.)



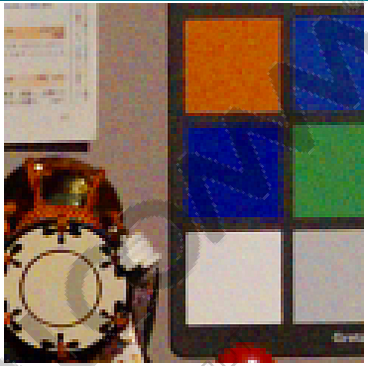
- Noise detection
  - Separates details from noise at each frequency range
    - Higher value (more details are interpreted as noise) = “eaten” edges, more filtering
    - Lower value (more noise is interpreted as details) = Noisier images, noise patches
  - Flow – 2nd step
    - Select **DC4** image in the viewer
    - Adjust if required, Noise Level Mid Frequency (Luma and Chroma) to achieve a **noise-free** edge preserved DC4 image



Tuning Steps – Basic Level (cont.)



NO ANR



Noisy flat areas

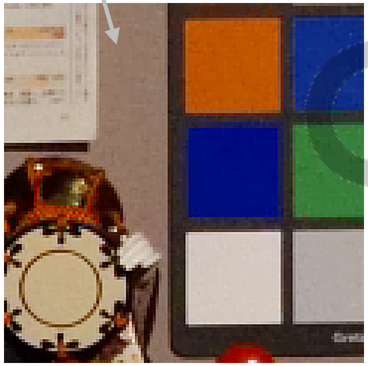
Too low

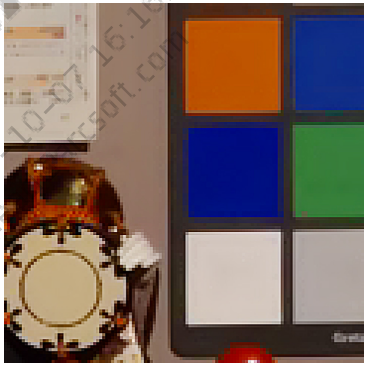
Good

Details loss

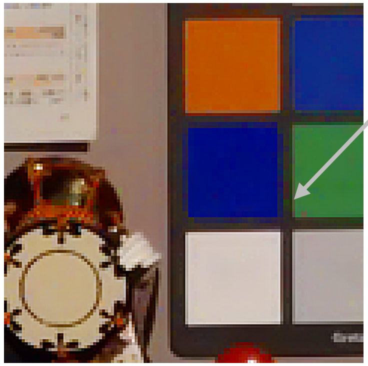
Too high

*Noise level **mid***
Frequency
luma

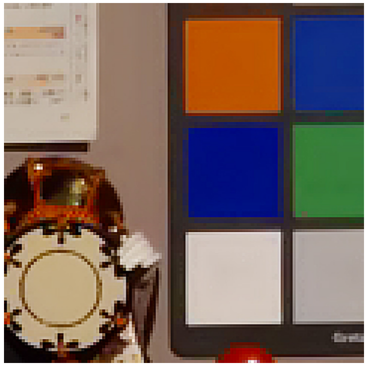


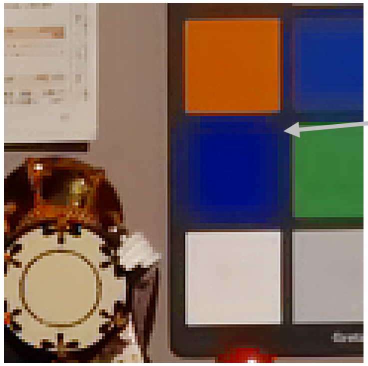


*Noise level **mid***
Frequency
chroma



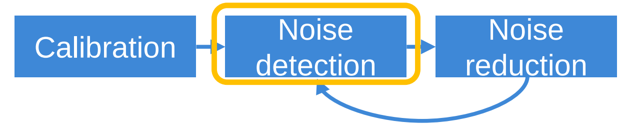
Chroma noise



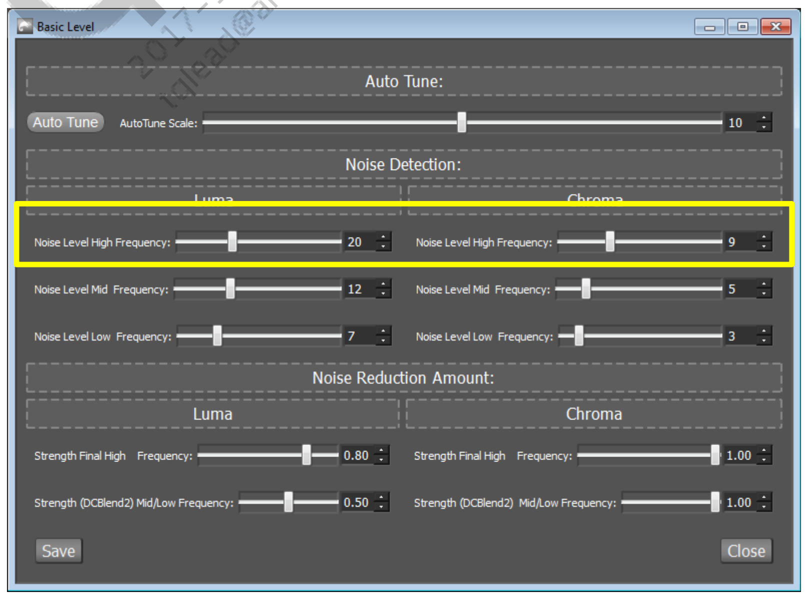


Color bleeding

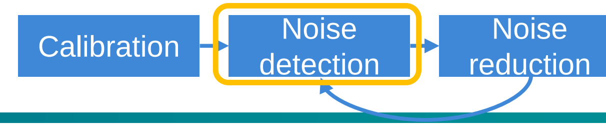
Tuning Steps – Basic Level (cont.)



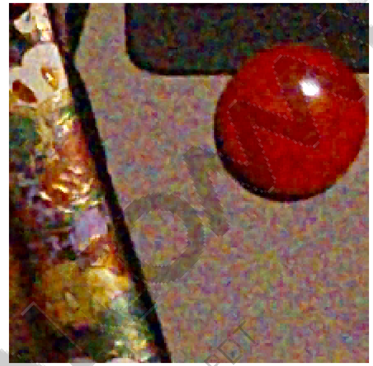
- Noise detection
  - Separates details from noise at each frequency range
    - Higher value (more details are interpreted as noise) = “eaten” edges, more filtering
    - Lower value (more noise is interpreted as details) = Noisier images, noise patches
  - Flow – 3rd step
    - Select Full image in the viewer
    - Adjust, if required, Noise Level High Frequency (Luma and Chroma) to achieve a good compromise between high frequency noise patches to fine texture details retention (in image part close to image center)



Tuning Steps – Basic Level (cont.)



NO ANR

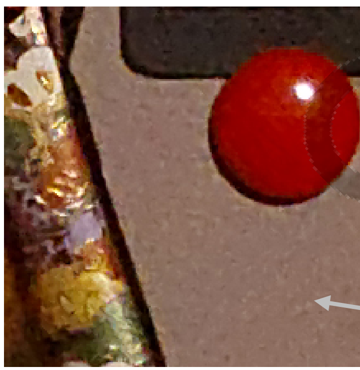


Too low

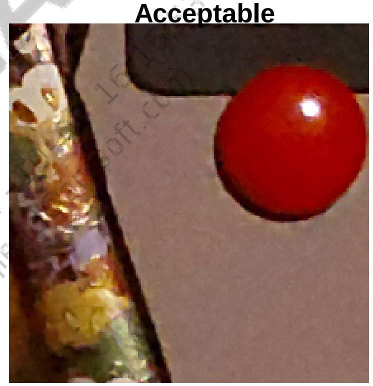
Acceptable

Too high

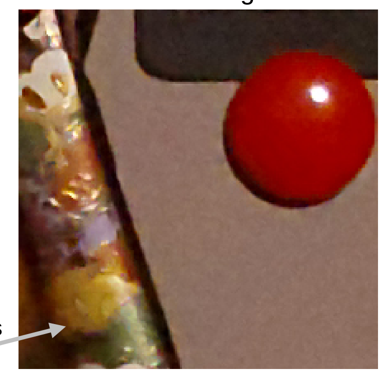
Noise level ***high***
Frequency
luma



Noisy flat areas, dots

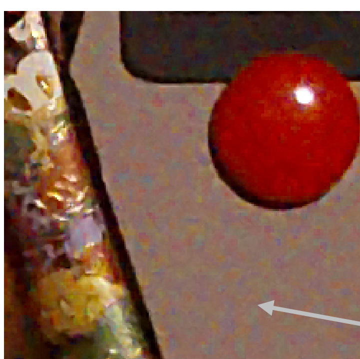


Details loss

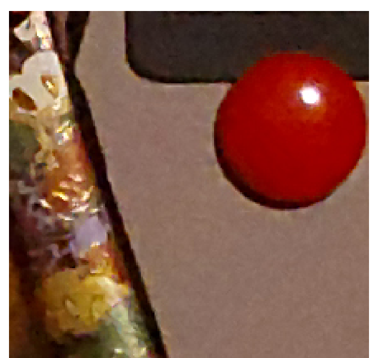


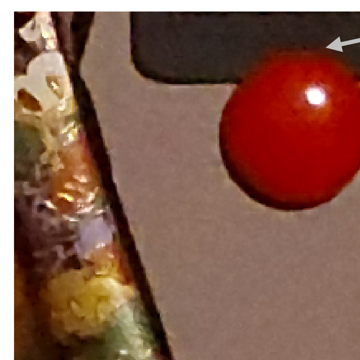
Color bleeding

Noise level ***high***
Frequency
chroma

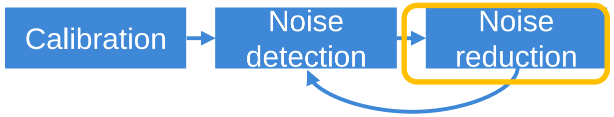


Chroma noise





Tuning Steps – Basic Level (cont.)



- Noise reduction amount
  - Defines the amount of blend between original image to filtered
    - Higher value (blend more) = softer image
    - Lower value (blend less) = more granular and noisy image
  - Flow
    - It is suggested to keep Chroma section in noise reduction amount sliders at max. value
    - Adjust Strength (DCBlend2) mid/low frequency slider to achieve
      - Clean image on flat areas
      - Retained low contrast textures in flat areas
      - Desired mid frequency granularity
    - Adjust Strength final high frequency slider to achieve*
      - Clean image but leaving desired high frequency granularity
      - Texture retention and continuity
      - Reduce harsh transition between flat and not flat areas
    - The tuning engineer may go back to Noise detection section according to tuning flavor
      - For example, maybe after lowering Strength final high frequency, increase Noise level high frequency

* Available only for stills

Tuning Steps – Basic Level (cont.)

Calibration → Noise detection → Noise reduction

NO ANR

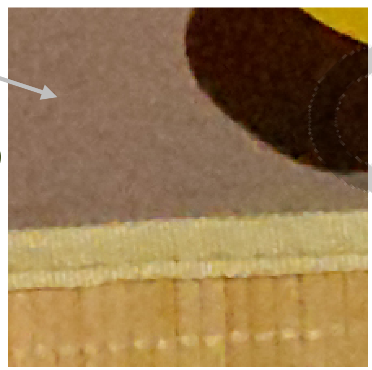
Low value

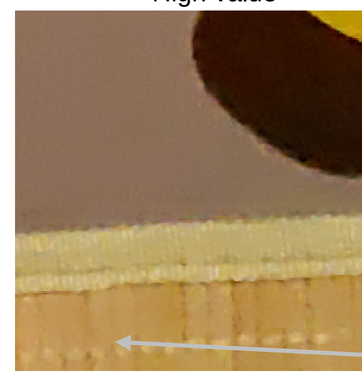
Mid value

High value

High "mid freq" granularity

Strength (DCBlend2) mid/low frequency luma

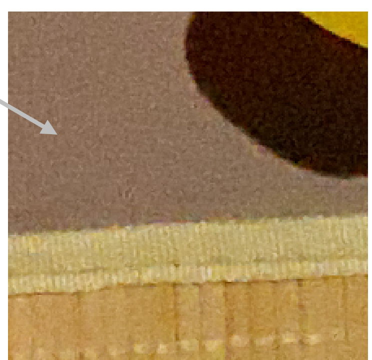


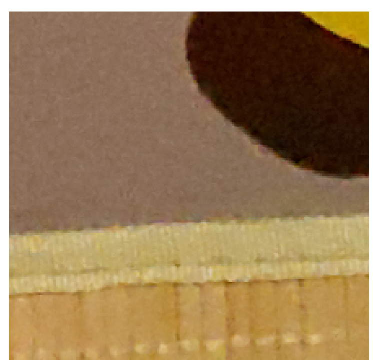


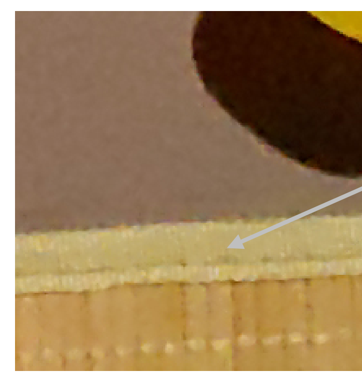
Low contrast texture loss

High "high freq" granularity

Strength final high Frequency luma







Fine texture loss

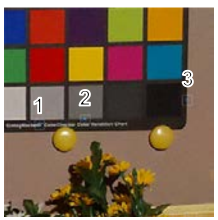
Advanced Tuning Steps – False Colors

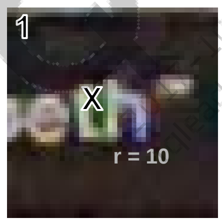
- Background
  - Chroma noise is harder to clean on edges due to high luma derivatives
  - False colors have two mechanisms cascaded to correct this issue (effects only chroma channels)
    - Grey Edge Treatment: Detects strong edge which should be with low chromaticity (“grey edge”) and adjust chroma filter Base Functions to filter it
    - Chroma Edge Treatment: Performs median filter on “grey edges” and on areas without details that have color noise

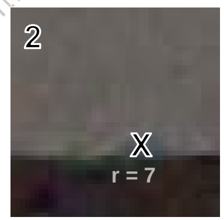
  - Tuning flow recommendation
    - Disable Chroma edge treatment for all passes
    - Tune Grey edge treatment for DC4 then for FULL, bypass for other passes
    - Tune Chroma edge treatment. Start tuning with FULL. Only if needed, carefully tune DC4. Bypass for other passes

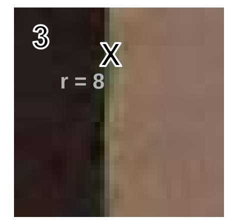
Advanced Tuning Steps – False Colors (cont.)

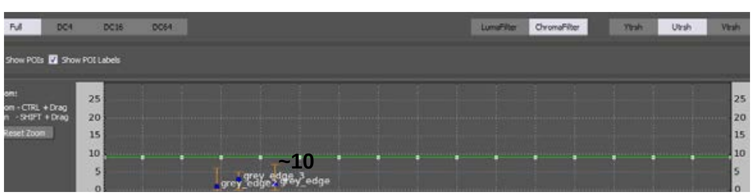
- Grey edge treatment – Tuning
  - In a “natural scene” image find several regions where there is an obvious strong grey edge with chroma noise along the edge and place POIs on them
    - It is suggested to have a small color checker inside the “natural scene” for debug
  - For each of these points
    - Write down the high value of derivative distribution for Y, U and V displayed in Base Functions of Chroma Filter for DC4 and Full
    - Measure and write down the chroma radius (intensity) of the noise in DC4 and Full











Advanced Tuning Steps – False Colors (cont.)

- Tune for DC4 and Full
  - Chromaticity Threshold
    - Start: Fill the low observation of chroma radius (example: 7)
    - End: Fill the high observation of chroma radius (example: 10)
  - Enable enable_grey_treatment_thr_modification
  - Threshold modification target
    - Y: Fill Y high value of derivative distribution (example: 140)
    - U: Fill U high value of derivative distribution (example: 10)
    - V: Fill V high value of derivative distribution (example: 10)
  - For Full only: enable_grey_treatment_isotropic_filter_blend
- Examine the impact on “natural scene” and on some other representative images if applicable. Start with DC4 then go to Full
  - Detect less: Decrease Chromaticity Threshold or increase Y max derivative threshold
  - Detect more: Increase Chromaticity Threshold or decrease Y max derivative threshold
  - Try to find a good compromise between preserved color edges (e.g. mcc patches corners in “natural scene”) to clean grey edges. Prefer the conservative approach (preserve color edges and details) because additional reduction might be possible using Chroma Edge Treatment

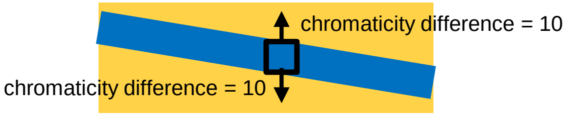
Advanced Tuning Steps – False Colors (cont.)

- Grey edge treatment – parameters
  - Chromaticity threshold
    - A pixel with chromaticity higher than End won't be a candidate for grey edge; lower than Start will be a full confident candidate and interpolation between start and End
  - Y max derivative threshold
    - A pixel with Y derivative lower than Start won't be a candidate for grey edge; higher than End will be a full candidate and interpolation between start and End
  - A pixel will be detected as grey edge only if it was marked as a candidate in Chromaticity threshold and Y max derivative threshold
  - Enable_grey_treatment_thr_modification
    - Enables increasing Chroma Filter thresholds in base functions
    - Y, U, V: will be increased to these values correspondingly (according to confidence)
  - Enable_grey_treatment_isotropic_filter
    - Blends pixel's chroma with chroma isotropic filtered pixel according to confidence of grey edge detection
  - Enable_grey_treatment_dcblend2_chroma_modification
    - Blends pixel's chroma with chroma filtered lowpass image pixel according to confidence of grey edge detection

Advanced Tuning Steps – False Colors (cont.)

- Chromaticity threshold and Y max derivative threshold
  - Grey edge detection – similar to Grey Treatment section above. Pixels detected as grey edge will be filtered with a median filter. This detection overrides Detail Corner Sensitivity Y/UV and Detail Chromaticity Minority Th
- Detail corner sensitivity Y/UV
  - Higher value (more local details identified) = less filtering
  - Lower value (less local details identified) = more filtering
- Detail chromaticity minority th
  - If a pixel is located on a strip between two other colors, performing median may smear the pixel
  - If the chromaticity difference in both directions is higher or equal than this value - median won't be applied

Example



If *Detail Chromaticity Minority th* == 8 then this pixel won't pass median filter

Advanced Tuning Steps – False Colors (cont.)

- Neighbors isotropic detail sensitivity
  - Local details identification according to neighbors detail detection
  - Higher value (fewer neighbors required to be counted as details) = less filtering
  - Lower value (more neighbors required to be counted as details) = more filtering
- Neighbors directional detail sensitivity
  - Similar to Neighbors isotropic detail sensitivity but median still may be performed on directions that not detected as detail
  - It is suggested to set this value lower than Neighbors isotropic detail sensitivity
- Bilateral decision minimal size
  - If “flat length” on any direction is higher or equal to this value, a bilateral filter will be performed instead of median. In this case bilateral filter is generally preferable to median since it is using averaging

How to Coordinate with other Modules

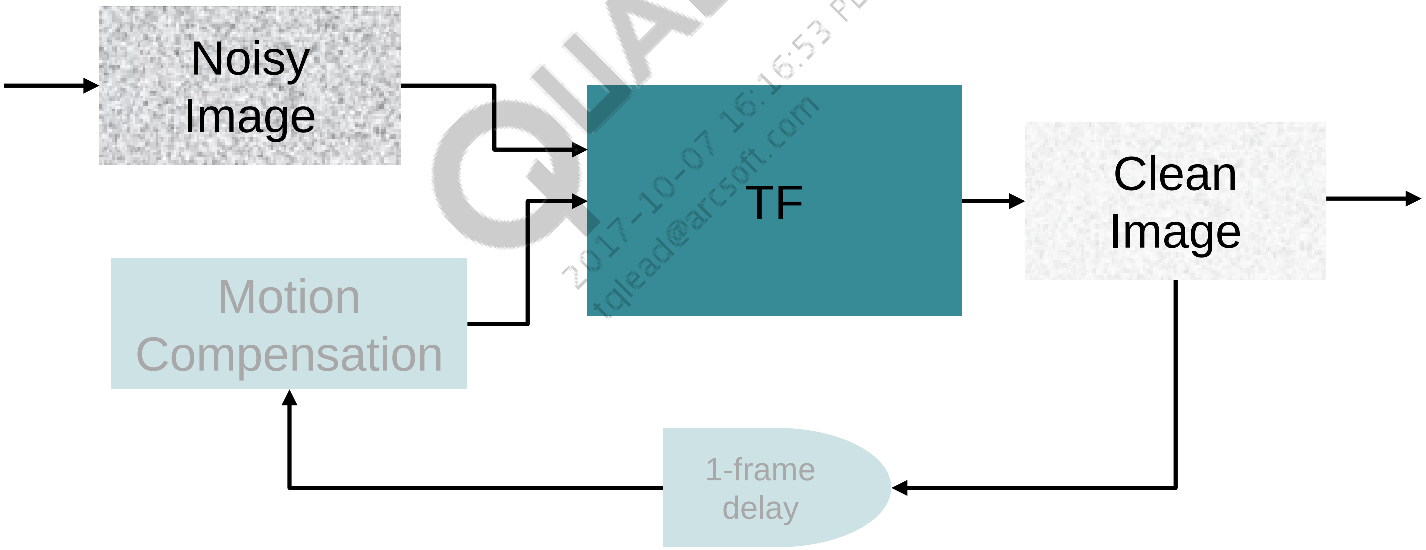
- Mention when to tune the module
  - For example, Temporal filter (TF) should be tuned after ANR
  - Also, units which should be turned on/off during tuning (example: In case of TF tuning mention the units for CCM on, ASF and so on)
- Other module influence
  - Mention other modules which when changed require some tuning or full re-calibration (depending on the change and their impact)

Temporal Filter (TF)

Temporal Filter – Background

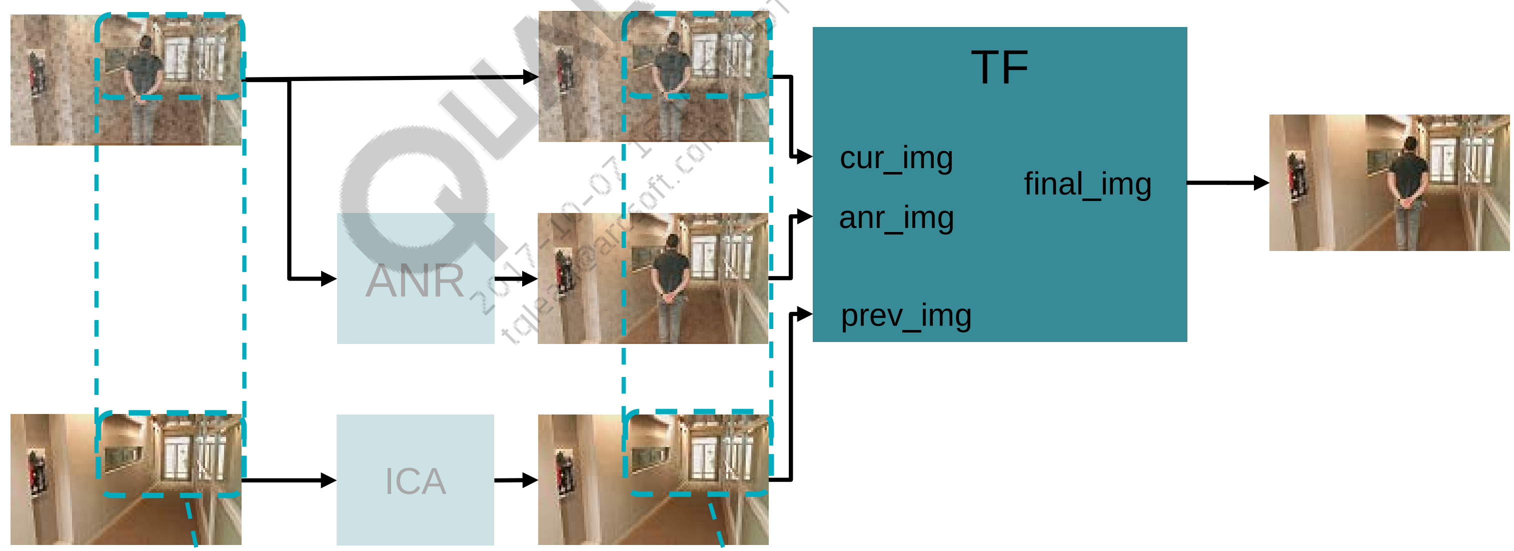
TF

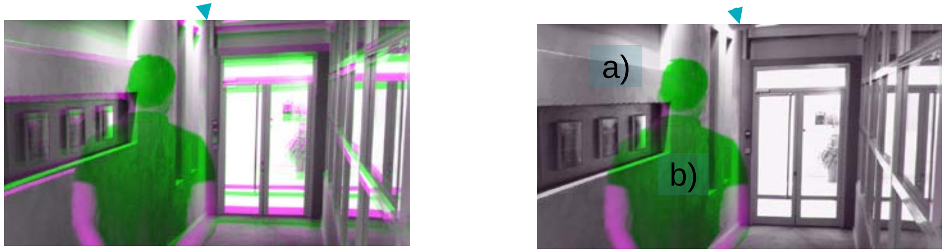
- Temporal noise filtering
  - Works on each video frame
  - Blends current frame with previous frame



Temporal Filter – Background (cont.)

- Blending between input images
  a) Normal operation: blend cur_img with prev_img
     (previous frame is warped to align it with current frame)
  b) Local motion: blend cur_img with anr_img

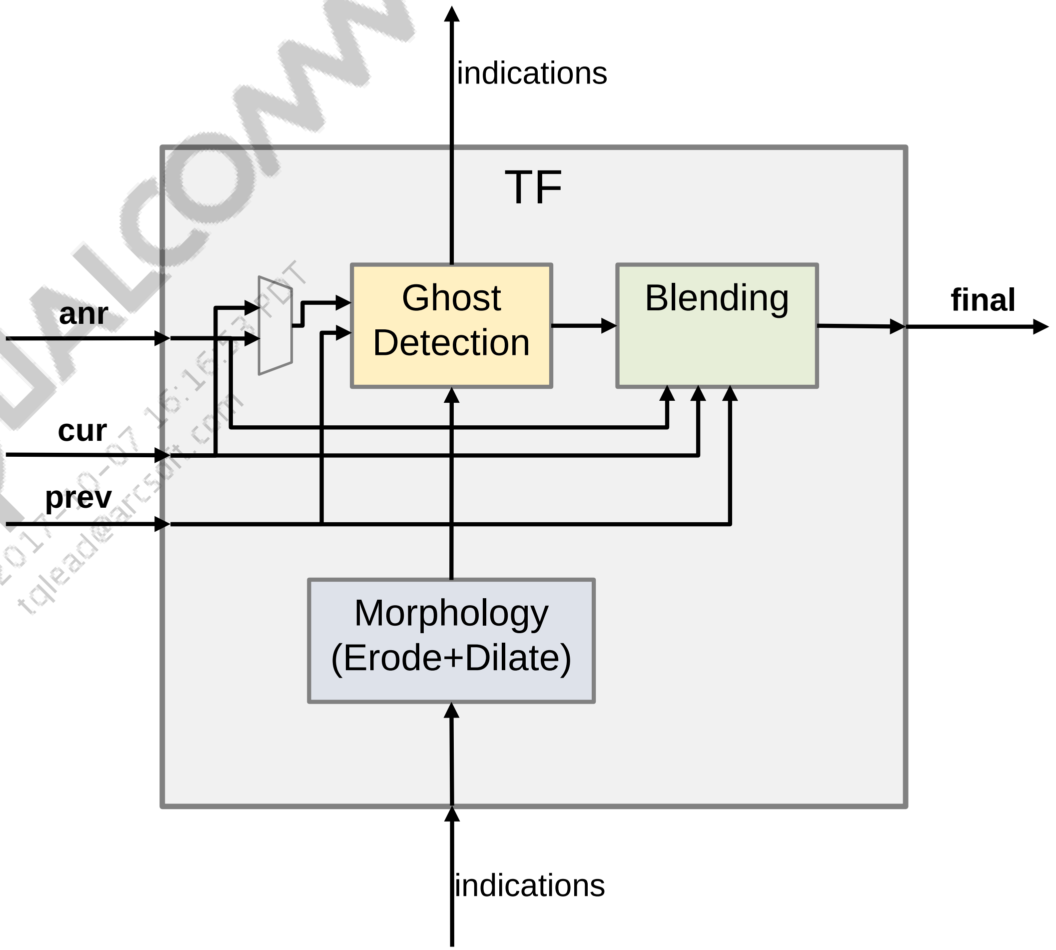




<u>Image alignment, color-coded:</u>
- Gray: similar pixel values (a)
- Color: different pixel values (b)

Overview

- TF block diagram
  - Ghost detection
  - Blending
- Inputs
  - **cur** = current image
  - **anr** = ANR output
  - **prev** = previous image
    (after temporal filtering)
- Output
  - **final** = TF output



Overview (cont.)

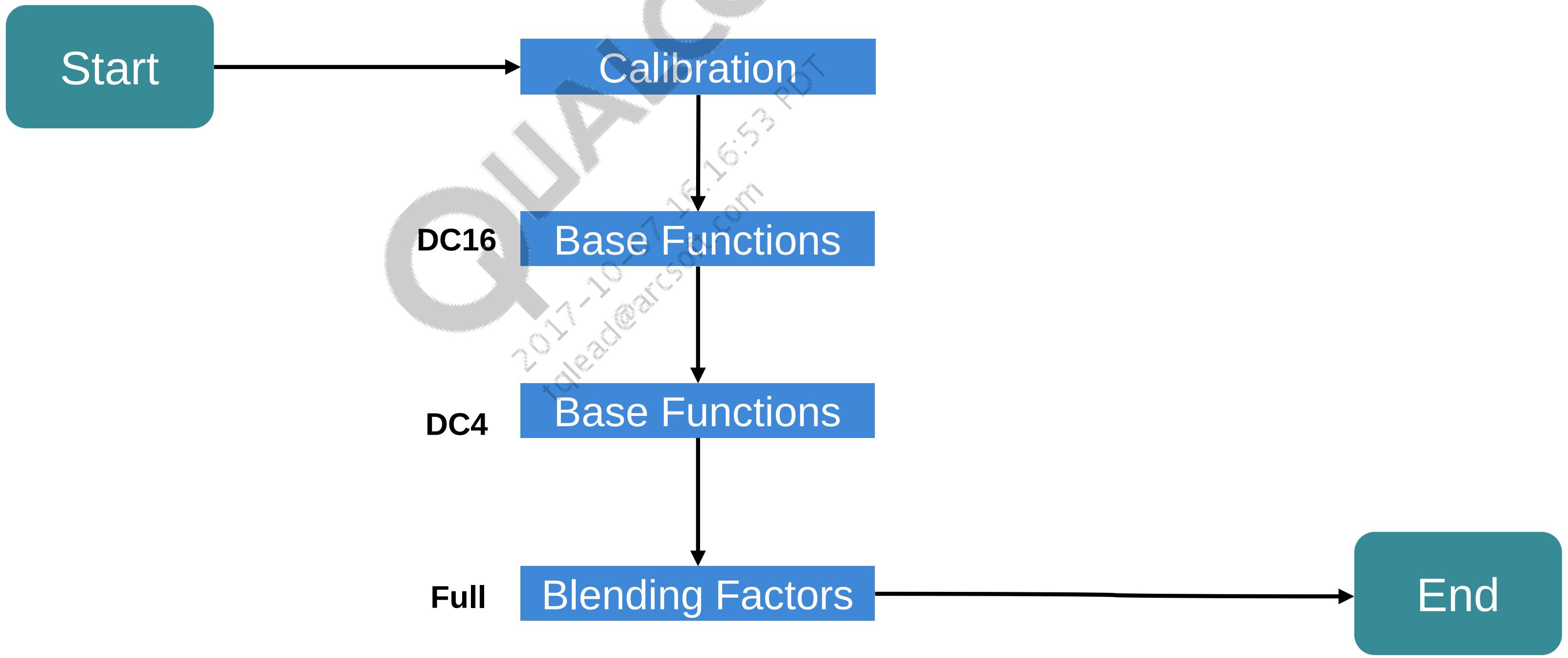
- TF parts
  - Ghost detection
    - Calculates temporal Filtering strength (FS)
    - If current and previous images have different content → FS=0
      - Otherwise, objects in video would appear twice (“ghosts”)
    - If current and previous images have same content → FS=63 (maximum)
      - High filtering strength ensures maximal noise reduction
  - Blending
    - **final** = α_1 * **prev** + (1 - α_1) * **cur_spatial**
      - α_1 (temporal blending factor) is a tunable function of FS
      - When FS = 0, $\alpha_1 = 0$
      - When FS = 63, α_1 is maximal
      - $\alpha_{1,max}$ is big → cleaner output, but slow convergence
      - $\alpha_{1,max}$ is small → faster convergence, but noise reduction is weaker
    - **cur_spatial** = α_2 * **anr** + (1 - α_2) * **cur**
      - α_2 (spatial blending factor) is a tunable function of FS
      - When FS = 0, α_2 is maximal
      - When FS = 63, α_2 is minimal
      - $\alpha_{2,min}$ is big → less noise in output, but details may be degraded
      - $\alpha_{2,min}$ is small → more details are preserved in output, but less noise reduction

Overview (cont.)

- Multi-scale operation
  - 3 scales: 1:16, 1:4, 1:1
  - Indications are passed from coarser scales to finer scales
  - 1:16 and 1:4 scales: only ghost detection
  - 1:1 scale: normally, only blending
    - Turn on 1:1 Ghost Detection for higher-quality processing, higher power consumption

Tuning flow Diagram

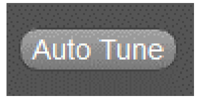
- Where applicable, use tuning tabs in order: DC16 → DC4 → Full



Legend: Basic

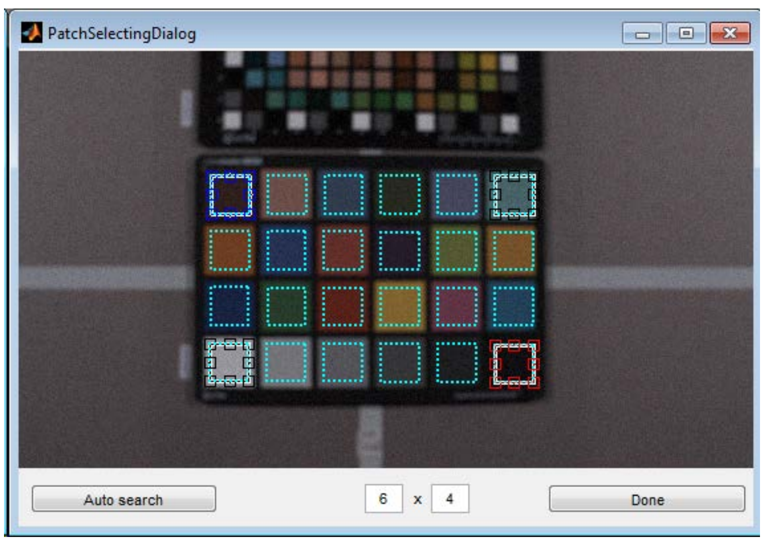
Calibration - Steps

Calibration → Base Functions → Blending Factors

1. Click Auto Tune 

2. Select 1 flat field video and at least 1 MCC
3. Click Run AutoTune and wait until patch selection dialog opens

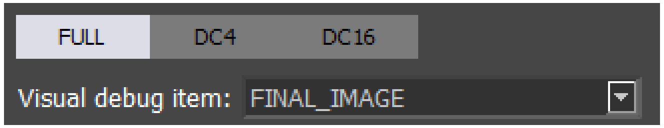
   Make sure that the MCC patches are properly selected and covers ~80% of each patch and is center aligned. If not, correct it by dragging them to fit
4. Click Done
   - If it fails, try again with smaller patches (~70%)
5. Examine the result on a motionless "Natural scene" video



Calibration Troubleshooting

Calibration → Base Functions → Blending Factors

- Look at frame 5 or later (ignore at least 5 first frames)



- Compare final images of frame 0 and frame 5
  - Frame 5 should have less noise

Frame 0

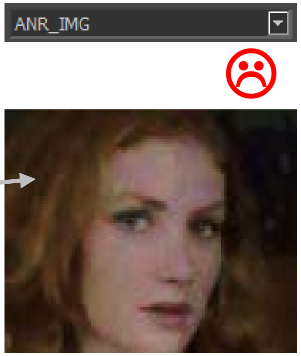
Noise

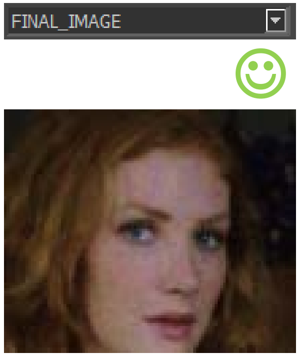
Less noise

Frame 5

- For frame 5, compare ANR image and final image
  - Final image should have less noise and more details

Washed out details

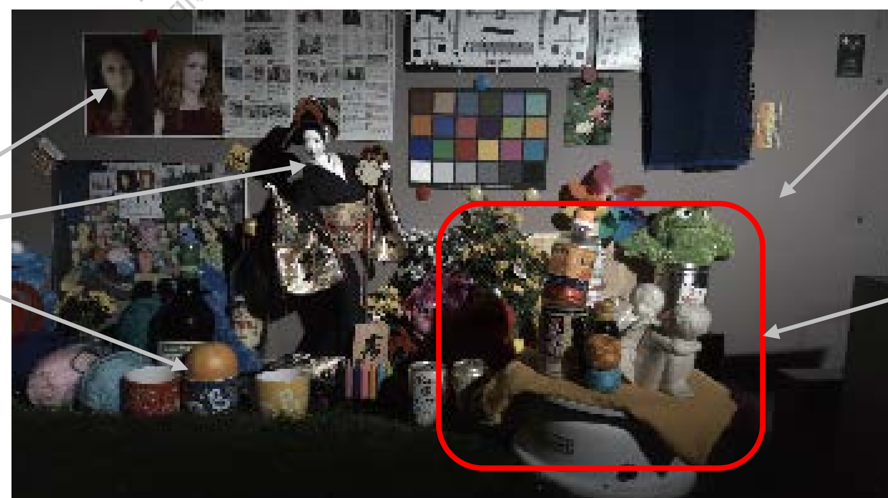




Basic Tuning Steps

Calibration → Base Functions → Blending Factors

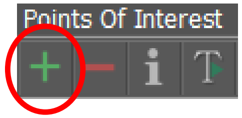
- Tune on video with a moving object
  - Camera should be fixed (use tripod)
  - The moving object (for example, face) should be ~1/3 the size of the frame
  - No changes in lighting
- Applicable only after calibration
- Look at video frame 5 or later (ignore first 5 frames)
- Use Points of interest (POI) to check tuning for:
  - Areas of uniform color
  - Stationary objects
  - Moving objects

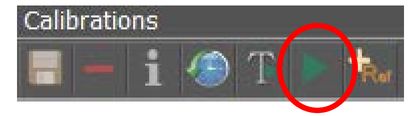


Basic Tuning Steps (cont.)

Calibration → Base Functions → Blending Factors

- Using Points of interest (POI)
  - Use the dedicated controls
  - Place POIs for stationary objects and moving objects
  - Each POI has a resizable square region around it
  - After placing POIs, process the image

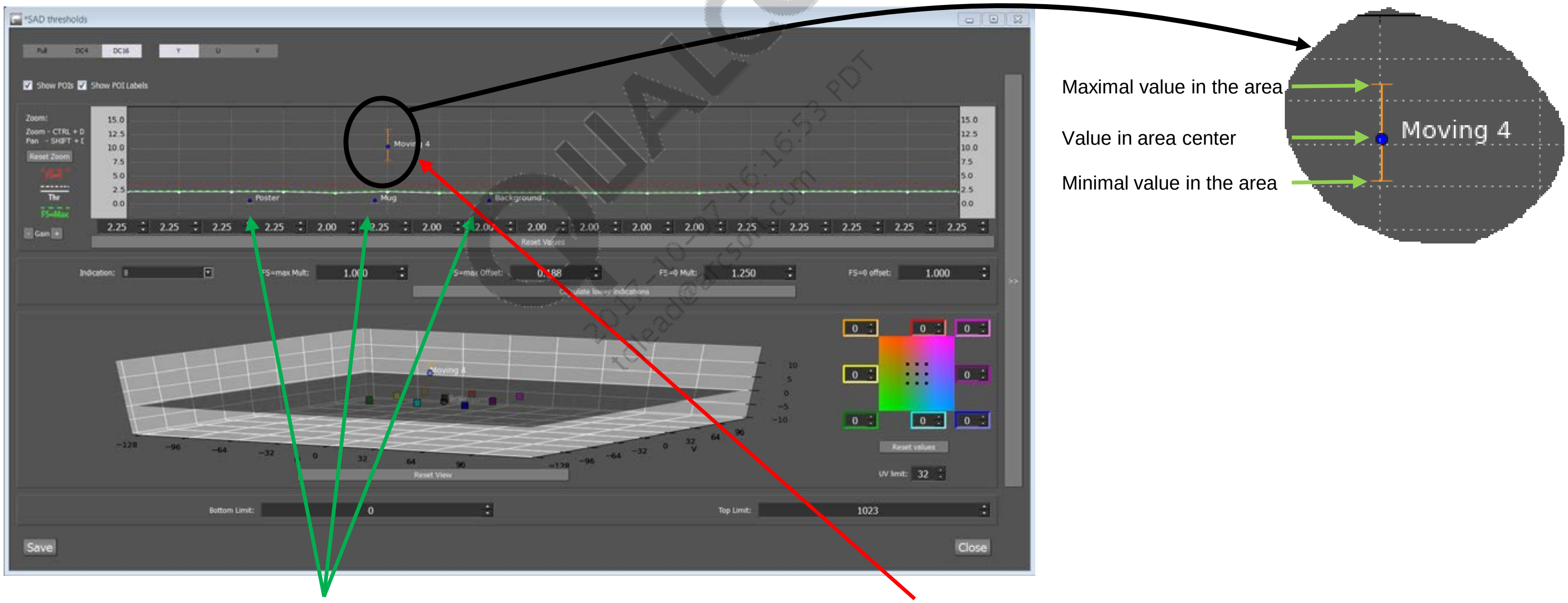




Tuning Steps – Base Functions

Calibration → **Base Functions** → Blending Factors

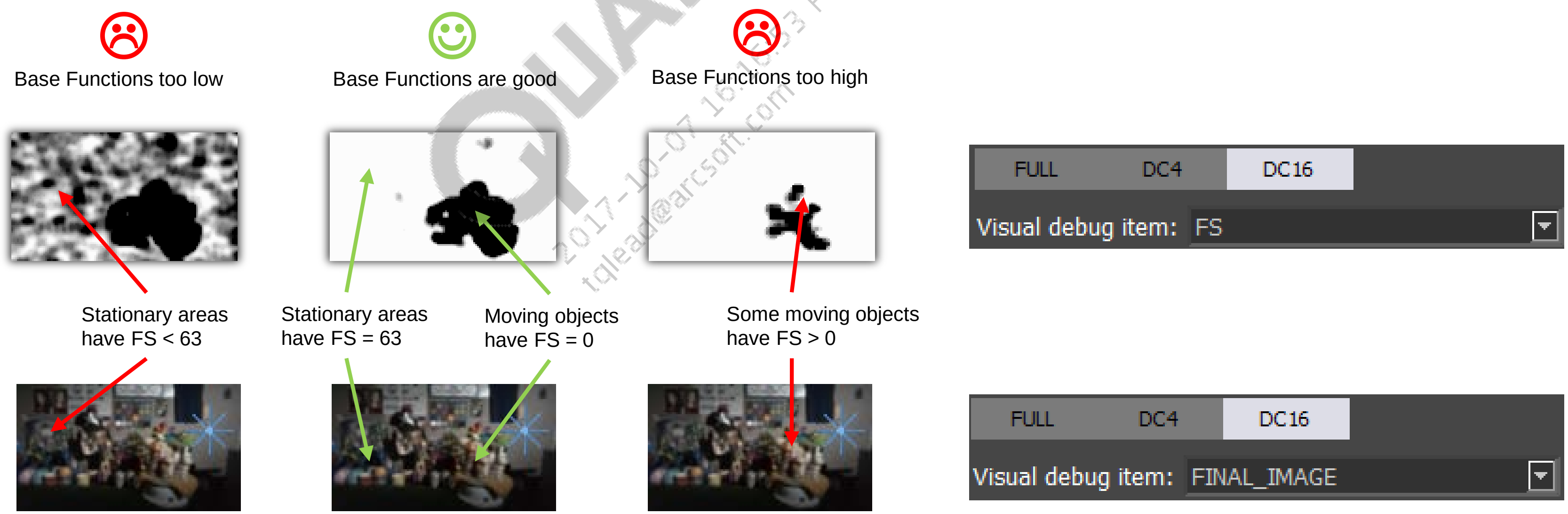
- Base functions separate noise from details
  - Use - Gain + controls to move the red and green lines together
  - POIs for moving objects → values of statistics should be above the red line



  - POIs for stationary objects → values of statistics should be below the green line
  - If it is not possible, do a compromise and check quality

Tuning Steps – Base Functions (cont.)

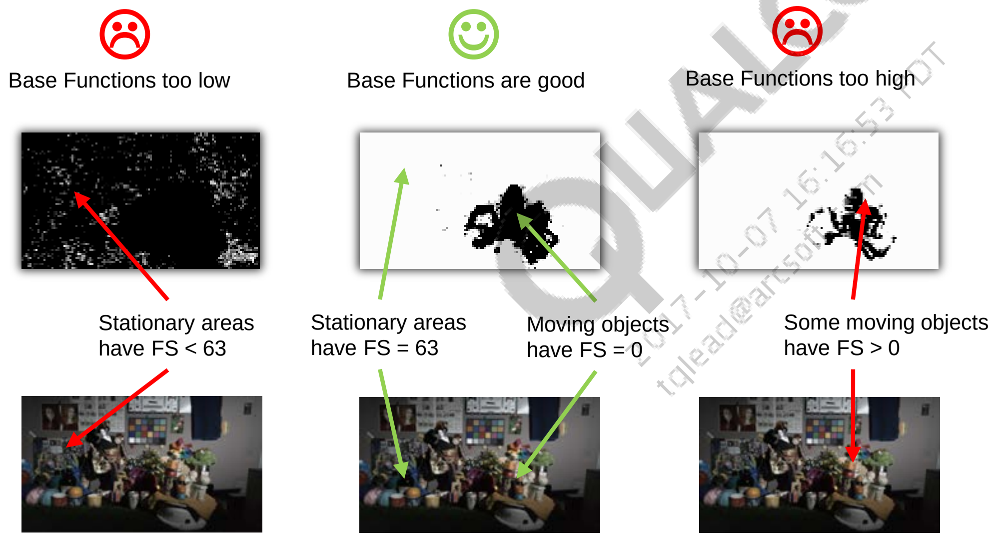
- Start tuning with DC16
- To assess quality of tuning, look at Filtering strength (FS)
  - Moving objects should have FS = 0 (black)
  - Stationary objects should have FS = 63 (white)

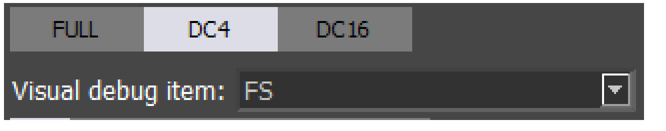


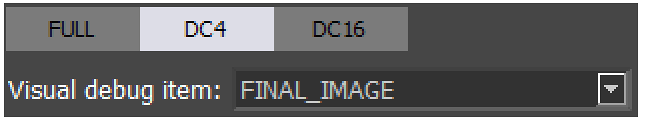
Tuning Steps – Base Functions (cont.)

Calibration → Base Functions → Blending Factors

- After DC16 is good, tune DC4
  - Moving objects should have FS = 0 (black)
  - Stationary objects should have FS = 63 (white)





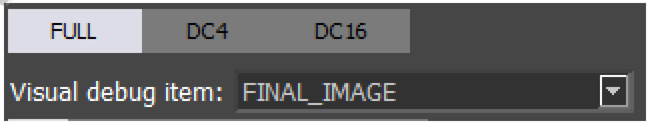


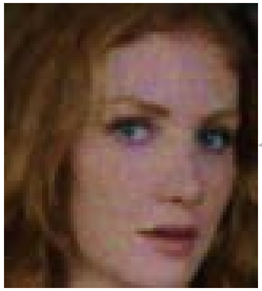
- Do not tune base functions for full pass

Tuning Steps – Base Functions (cont.)

Calibration → **Base Functions** → Blending Factors

- If unsure whether FS is good, look at final image
  - In the final image, problems are harder to spot
  - Choose FULL Pass
  - Choose video frame 5 or later (ignore the first 5 frames)



	Base Functions too low	Base Functions are good	Base Functions too high
Stationary			? 
Moving	? 		

Details washed out

Unnatural colors

For stationary objects, no quality degradation

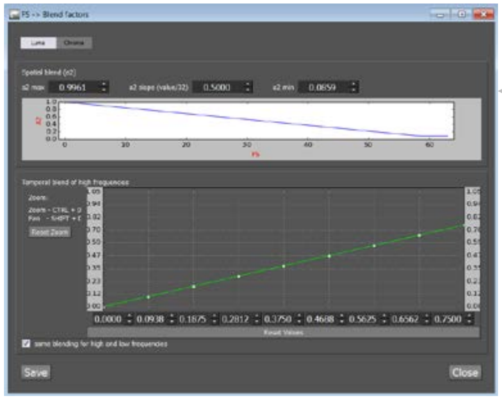
For moving objects, no quality degradation

“Ghosts” (faint copies of objects)

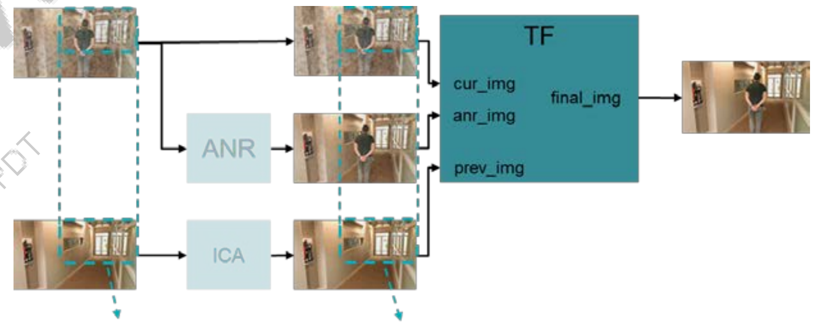
Tuning Steps – Blending Factors

Calibration → Base Functions → **Blending Factors**

- Blending factors control the strength of TF



Spatial Blend tuning



- Spatial Blend provides synergy between ANR and TF
  - a2 max: should be almost 100%
    - Lower values restore fine details on moving objects
  - a2 min: amount of spatial denoising to add to temporal denoising
    - For weak noise, use 0%
    - For very noisy videos, up to 70% may be necessary
    - Higher for Chroma than for Luma

Tuning Steps – Blending Factors (cont.)

- Spatial blend tuning
  - Choose FULL Pass
  - Choose video frame 5 or later (ignore first 5 frames)
- *a2 max* tuning – affects moving objects

Noise

a2 max too low | a2 max is good | a2 max too high

Local motion

Washed out details

- *a2 min* tuning – affects stationary objects

a2 min too low | a2 min is good | a2 min too high

Stationary

Washed out details

Noise

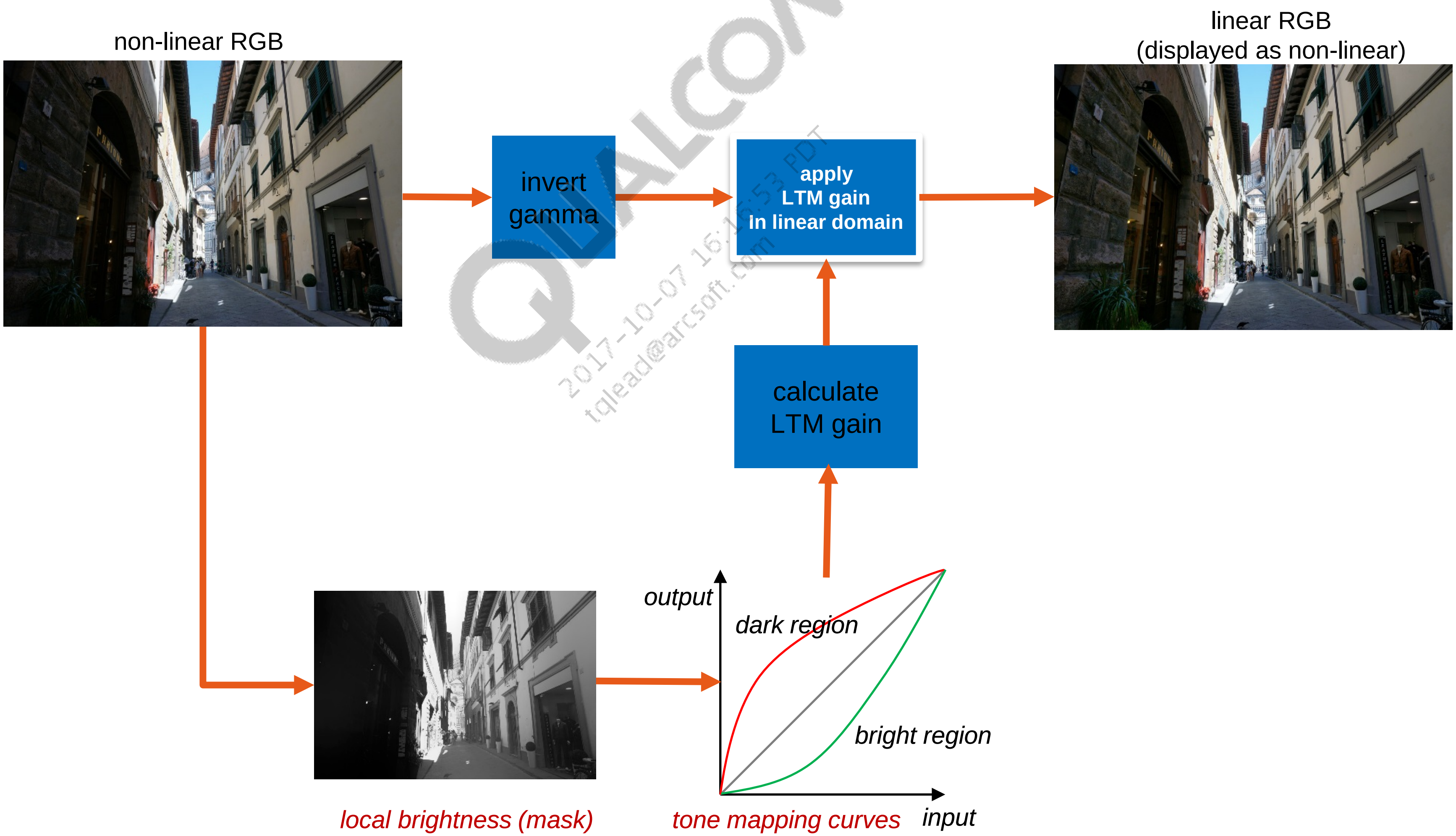
How to Coordinate with Other Modules

- Mention when to tune the module
  - TF should be tuned after ANR
  - During TF tuning, units should be turned on:
    - CAC
    - CCM
    - ASF
    - GLUT
    - 2D LUT
    - Chroma suppression
    - Skin color enhancement
    - GRA
    - M/N DS
- Other module influence
  - ANR – if tuning changes, re-tune TF blending factors

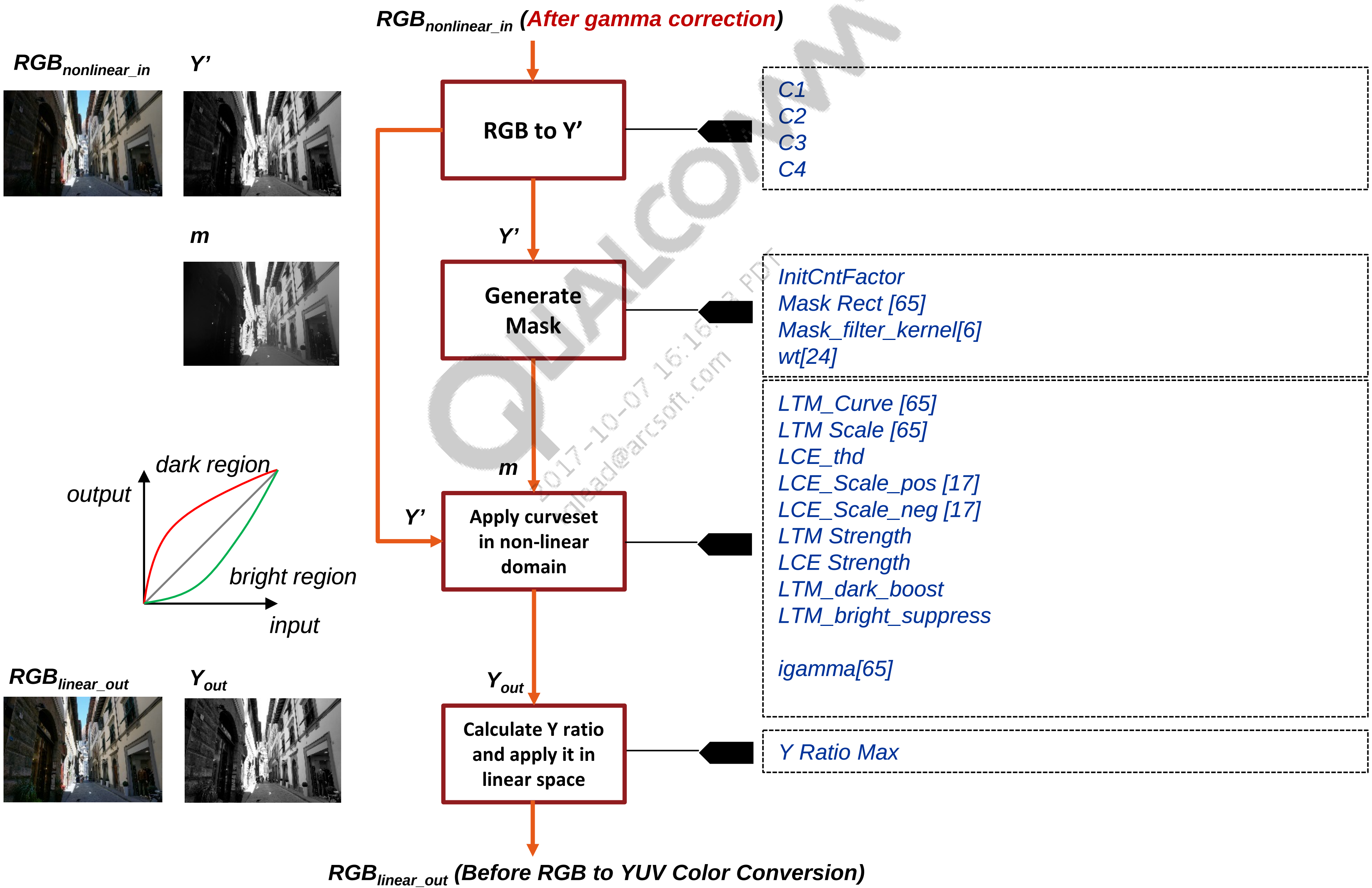
Local Tone Mapping (LTM)

What is LTM

- LTM applies tone mapping gain to each pixel depending on the local brightness to enhance visibility.



LTM Processing Overview



HDR: GTM/LTM Tuning Image Capture

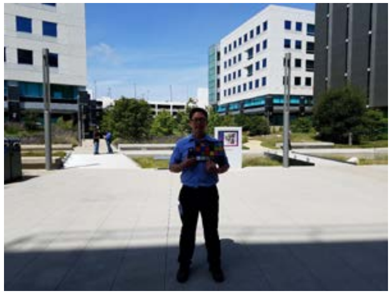
- Capture HDR raw images, covering 6 exposure lux index zones and exposure ratios from 1× to 16×
- For each scene, capture raw of HDR mode and non-HDR mode
- HDR scenes image content suggestions:
  1. Window scene: half bright outdoor, half dark indoor, containing a person holding MCC chart by the window, bright outdoor scene through the window.
  2. Shade Scene: outdoor scene with half bright sun and half dark shade.
  3. Outdoor texture: a person standing under direct sunlight, holding a texture test chart. There are dark shade on the background.
  4. Backlit scene: a person holding MCC chart under shade with bright background, e.g. sky with clouds.

Lux Index	Exp Ratio
100 - 200	1 – 2
200 – 250	2 – 4
250 - 300	4 – 6
300 – 380	6 – 8
380 – 450	8 – 12
450 - 600	12 - 16

1. Window scene

2. Shade scene

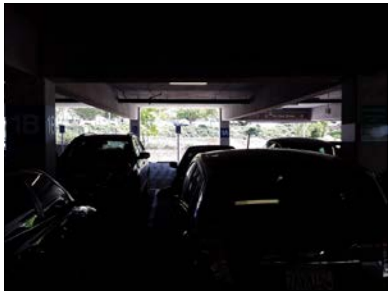
3. Outdoor texture



4. Backlit scene

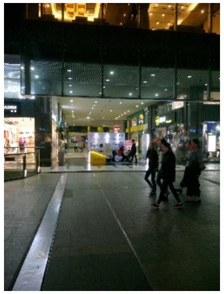
HDR: GTM/LTM Tuning Image Capture

5. Garage scene: inside the parking building with bright outside background.
6. Building scene: buildings with dark shadows.
7. Night scene: building with lights at night.
8. Indoor scene: indoor decoration with small outdoor areas
9. Nature scene: natural objects including trees, grass, water and buildings, containing highlights and shadows.
10. Resolution chart in lab scene. The resolution chart are placed half in the bright side and half in the dark side.
11. Night scene with people face, shop windows/lights. It would be best if the person can swing the hands or so on to generate some motion.



5. Garage scene

6. Building scene



7. Night scene

8. Indoor scene

9. Nature scene

Overview of LTM Tuning

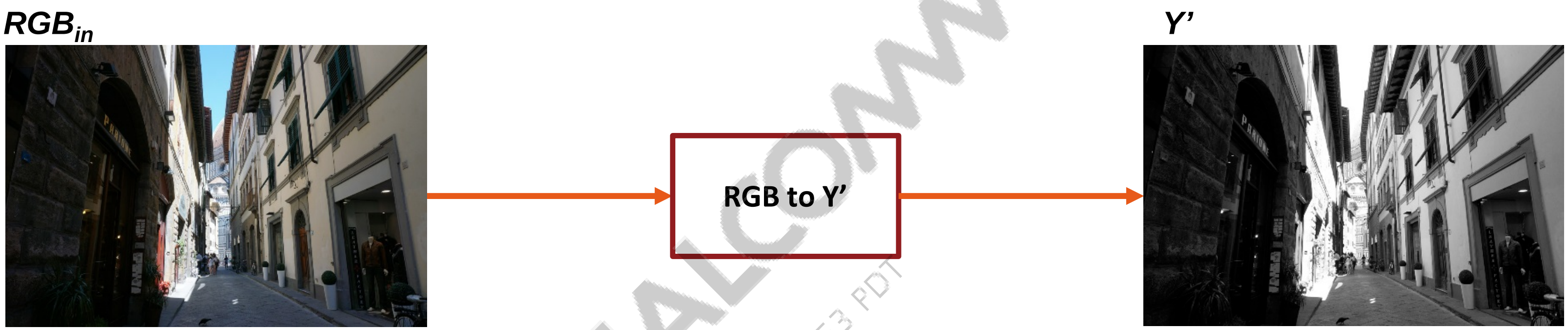
- Set all parameters to default values.
- For each region, tune *LTM_dark_boost*, *LTM_bright_suppress*, *LTM_strength*, and *LCE_strength*.
  - If users need more dark boost, increase *LTM_dark_boost*.
  - If users need more highlight suppression, increase *LTM_bright_suppress*.
  - If users need stronger LTM effect, increase *LTM_strength*.
  - If users need stronger LCE effect, increase *LCE_strength*.
  - Users should check if the noise level is acceptable as increasing dark boost.

Parameter name	Range	Default value	Larger value means
LTM_dark_boost	[0.0, 4.0]	1.0	More dark boost
LTM_bright_suppress	[0.0, 4.0]	1.0	More highlight suppression
LTM_strength	[0,0, 4.0]	1.0-1.5 for bright 1.0 for normal <0.5 for lowlight>	Stronger LTM effect
LCE_strength	[0.0, 4.0]	1.0	Stronger local contrast

Overview of LTM Tuning (cont.)

- If users need to fine tune specific range of tone, tune *LTM_curve* and *LTM_scale*
- If users need to fine tune local contrast, tune *LCE_scale_pos* and *LCE_scale_neg* respectively for positive and negative contrast
- If there is exposure oscillation issue, tune *Local Tone Strength* and *Local Tone Contrast*

LTM Mask Creating : RGB to Y’



$$Y' = \textcolor{blue}{C1} \times R_{in} + \textcolor{blue}{C2} \times G_{in} + \textcolor{blue}{C3} \times B_{in} + \textcolor{blue}{C4} \times max(R_{in}, G_{in}, B_{in})$$

- C1,C2,C3,C4
  - Description: weights of R/G/B/MAX(R,G,B) contribute to Y
  - Bit depth : float
  - Length : 1
  - Default : 0.125,0.25,0.125,0.5
  - Min and Max : 0, 1.0f
  - Conversion : Q6

Note:

- (*C1* + *C2* + *C3* + *C4*) must be between 1.0 and 1.1 to keep Y’ similar to Y
- It is suggested to use following parameters: C1=C3=0.125,C2=0.25, C3=0.5,
- Decrease *C1*, *C2*, *C3* and increase *C4* → increase Y’ → increase suppression in color saturated regions
- The effect of these parameters is more significant in darker regions.

LTM Mask Creating : Effect of C4

Figure 1
(C1, C2, C3, C4) = (0.299, 0.587, 0.114, 0)

Figure 2
(C1, C2, C3, C4) = (0.125, 0.250, 0.125, 0.5)

More suppression compared with Figure 1

Note:

- Decrease *C1*, *C2*, *C3* and increase *C4* → increase *Y'* if the difference between maximum and minimum of R_{in}, G_{in}, B_{in} is big enough, and then increase *m (mask)*
- According to *LTM_Curve* and *LTM_Scale* settings, increase *m* → more suppression

LTM mask creating : Generate Mask

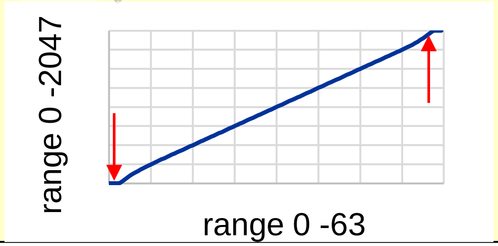
Collecting Data

Y'

1. Collect regional statistics inside hardware
2. Processed local statistics can be used to generate local density representation
3. Use $2^{\textit{InitCntFactor}}$ as initial pixel count for each region
4. Create mask value on fly for each pixel

Generate *mask*

Apply mapping curve ***Mask Rect*** on each grid



m

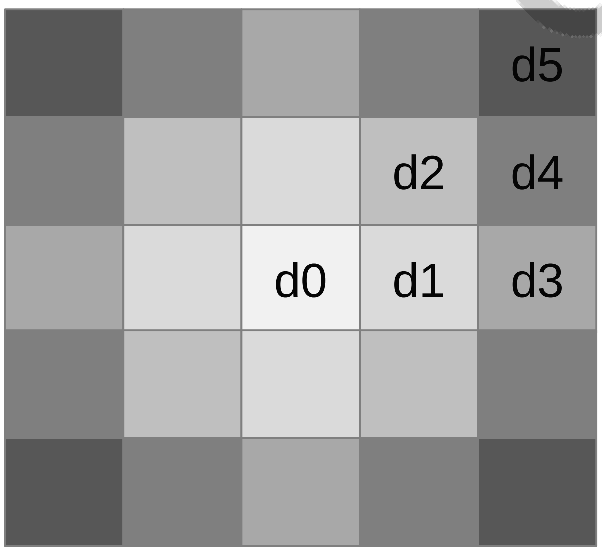
Note:

- Decrease left side of *Mask Rect* → increase dark boost
- Increase right side of *Mask Rect* → increase highlight suppression
- In suggested use case, Mask Rect curve does not change from frame to frame..

LTM Mask Creating : Mask Filter Kernel

- n mean 2^(n-1), when n=0, it means 0
- 5 core coefficients that will be replicated to fill 5×5 matrix
  Min and Max : d0: 1-6; d1: 0-5; d2: 0-4; d3: 0-3; d4: 0-2; d5: 0-1
  default value: 5,3,3,2,2,1
- Reducing the center coefficient helps to smooth mask and increase micro-halo along edges. It reduces potential contrast reverse issue and improve boundary of boosted thin area.

Mask Filter Kernel



Example:

sum = 2^(d0-1)*1 + 2^(d1-1)*4 + 2^(d2-1)*4
+ 2^(d3-1)*4 + 2^(d4-1)*8 + 2^(d5-1)*4
= 2^(5-1)*1 + 2^(3-1)*4 + 2^(3-1)*4
+ 2^(2-1)*4 + 2^(2-1)*8 + 2^(1-1)*4
= 76

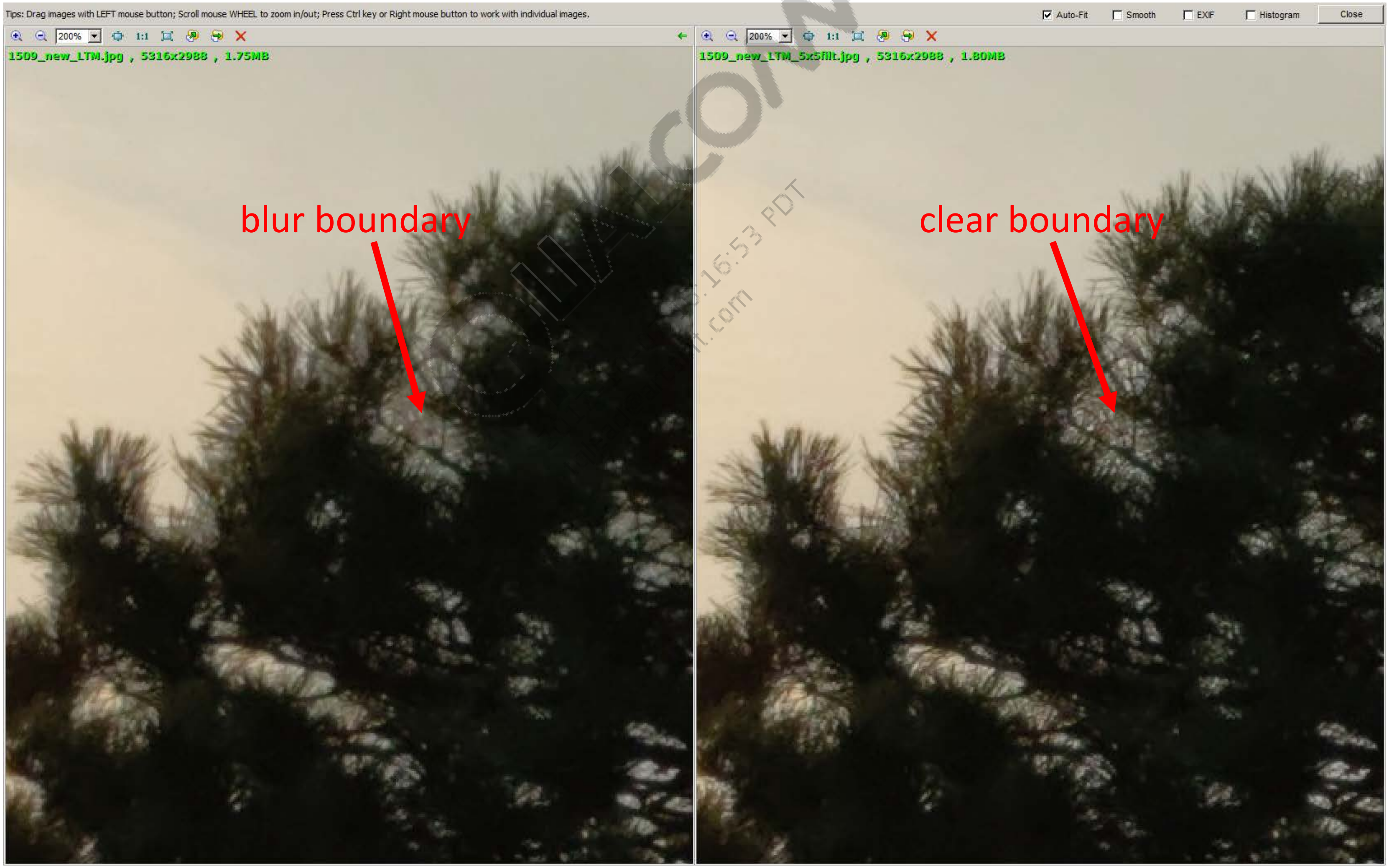
Mask_filter_scale = (2<16)/sum = 862

mask_filter_shift = 16

Use Mask Filter to Improve Boundary of Boosted Thin Area

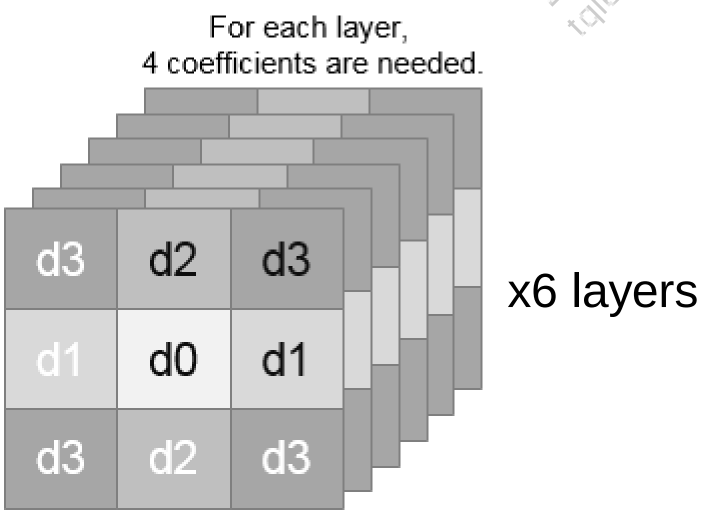
Before improvement

After improvement



LTM Mask Creating : Wt [24]

- This is part of advanced user mode. Also, with mask filtering feature, it is less needed. It is recommended to use default setting.
- 3D kernel has 3x3x11(layer) = 99 coefficients
- Considering symmetric across layers and at each layer, 4 coefficients are needed on each layer and totally 6 layers are needed. So, totally 24 coefficients need to be defined. Data range 0 -255.
- Increasing neighboring coefficients (d1,d2,d3) increases smoothing of center region's statistics with neighboring regions'.
- Increasing outer layer coefficients reduces the barrier to generate mask across different intensities. On the contrary, it may introduce halo.




```
Word16u weight[24] = {
255, 179, 179, 125,
128, 90, 90, 63,
64, 45, 45, 31,
16, 11, 11, 8,
2, 2, 2, 1,
0, 0, 0, 0
};           // 8u,
24=2x2x6
```


LTM Mask Creating: Other Parameters and LUTs

- bin_init_cnt
  - Description: stat bin initialization value, n means 2^n
  - Length: 1
  - Default:
  - Min and Max: 0 to 8
- mask_rect_curve[65]
  - Description: mask rectification curve
  - Bit depth: 12u
  - Length: 65

  Note: recommend not to adjust

Curve Set: LTM_curve/LTM_scale/LCE_scale_pos/LCE_scale_neg

`ltm_curve[65]`

- Description: local tone map curve
- Bit depth: 12u
- Length: 65
- Default: –
- Min and Max: 0 to 4095

`ltm_scale[65]`

- Description: local tone map scale curve
- Bit depth: 12s
- Length: 65
- Default: –

Min and Max: -2048 to 2047

`lce_scale_pos/neg[17]`

- Description: local contrast enhancement curve for positive/negative portion
- Bit depth: 12s (use positive side)
- Length: 2x17
- Default: –
- Min and Max: 0 to 2047

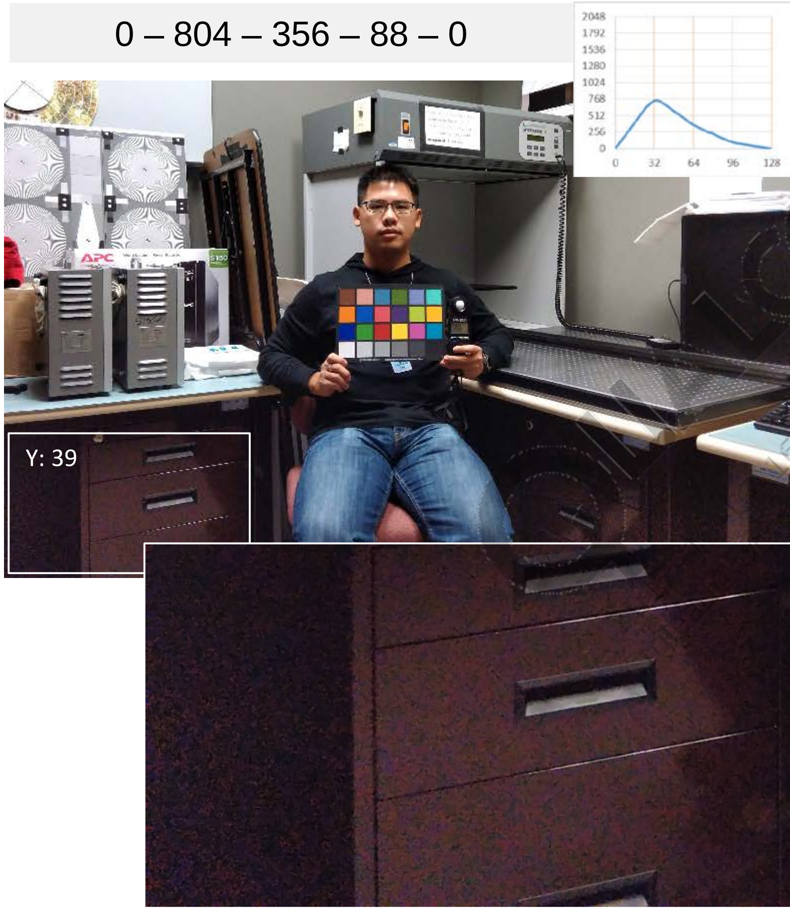
LCE Curves (65 LUT)

`lce_scale_pos/neg[17]`

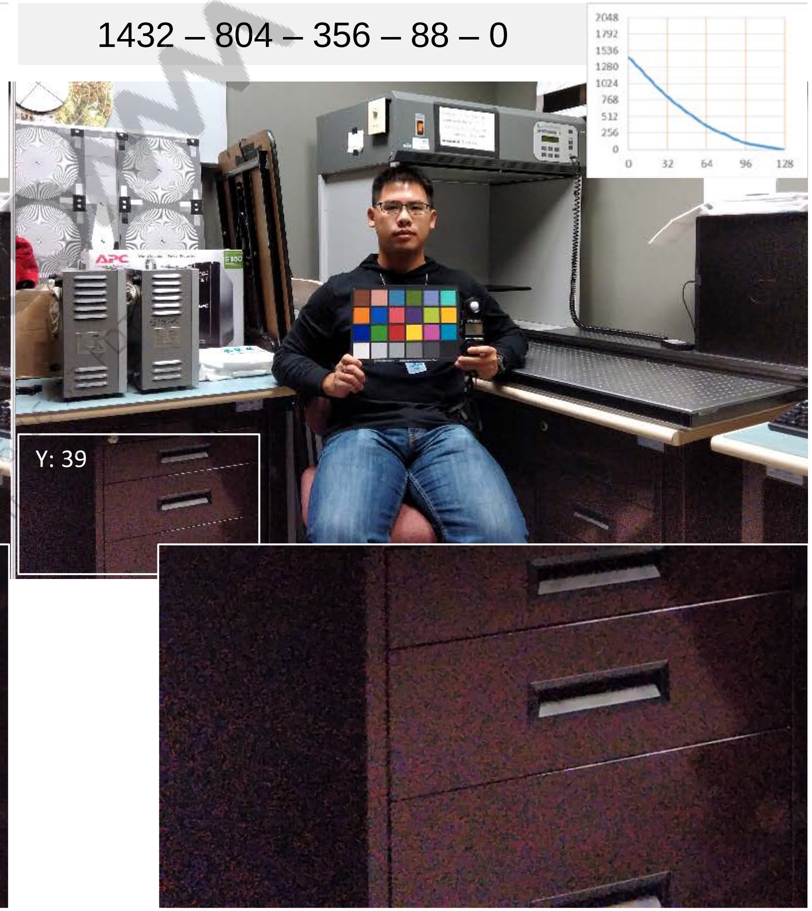
- Description: local contrast enhancement curve for positive/negative portion
- Bit depth: 12s
- Length: 2x17
- Default: –
- Min and Max: 0 to 2047

Effect of LCE Scale

0 – 804 – 356 – 88 – 0



1432 – 804 – 356 – 88 – 0



Note:

- LTM could control tone mapping and local tone enhancement strength separately
- In indoor/dark scenes, lower ***LCE Scale*** value at the beginning of LUT could reduce local tone enhancement effect in dark regions, and therefore keep luma noise low.

LA Curve

`la_curve[65]`

- Description: luma adaptation curve
- Bit depth: 12u
- Length: 65
- Default:–
- Min and Max: 0 to 4095

LA Curve (cont.)

- Titan LTM has a LA curve that can be applied to non-linear Y'. It is a global tone operation.
- Currently, as Titan pipeline has GTM module, it is not needed in normal use case (including ADRC and zzHDR).
- For low light scenes, LA curve can be activated depends on histogram analysis. It can serve as a supplemental option to AEC.

original

only LTM, LA_curve is off

LTM on, LA_curve is on

Software Aided Parameters

- LTM_strength
  - Description: overall scaling factor that will applied to ltm_scale curve
  - Bit depth : float
  - Length : 1
  - Default :
  - Min and Max : 0.0 to 4.0
- LCE_strength
  - Description: overall scaling factor that will applied to lce_scale curve
  - Bit depth : float
  - Length : 1
  - Default :
  - Min and Max : 0.0 to 4.0

Note:

- *LTM_Scale* = *LTM_Scale* × *LTM_Strength* / 256
- *LCE_Scale* = *LCE_Scale* × *LCE_Strength* / 256

Effect of LTM_Strength

LTM_Strength – 128 (0.5x)

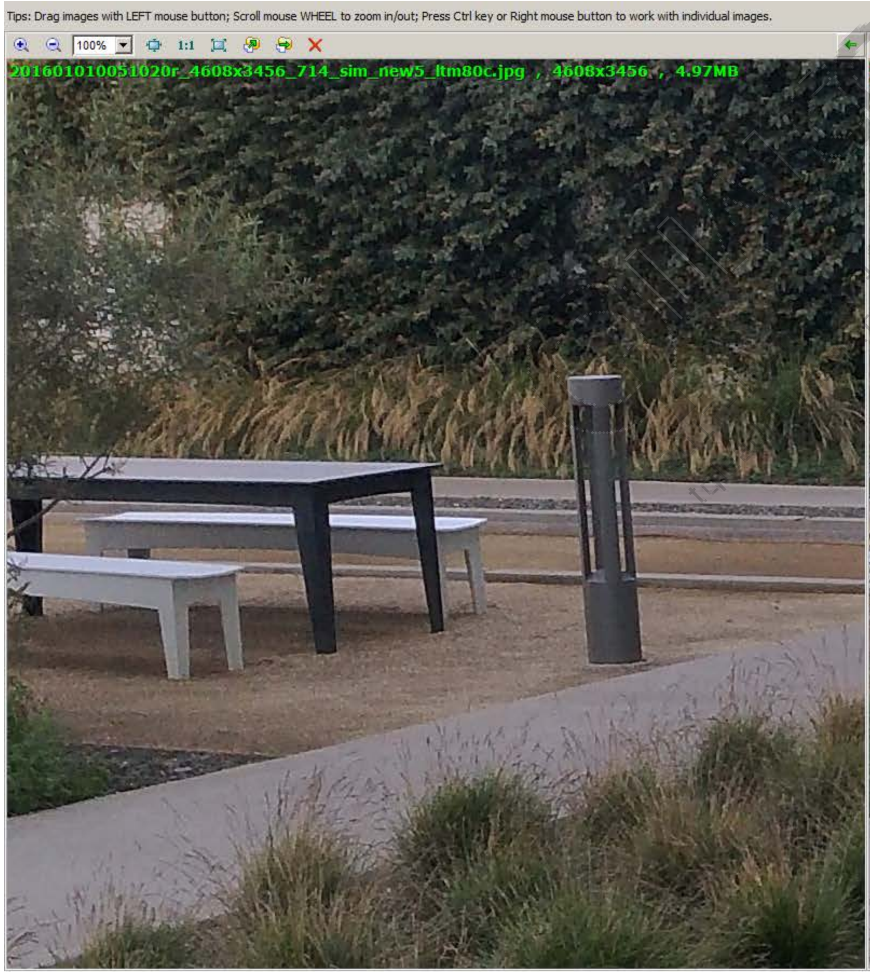
LTM_Strength – 256 (1x)

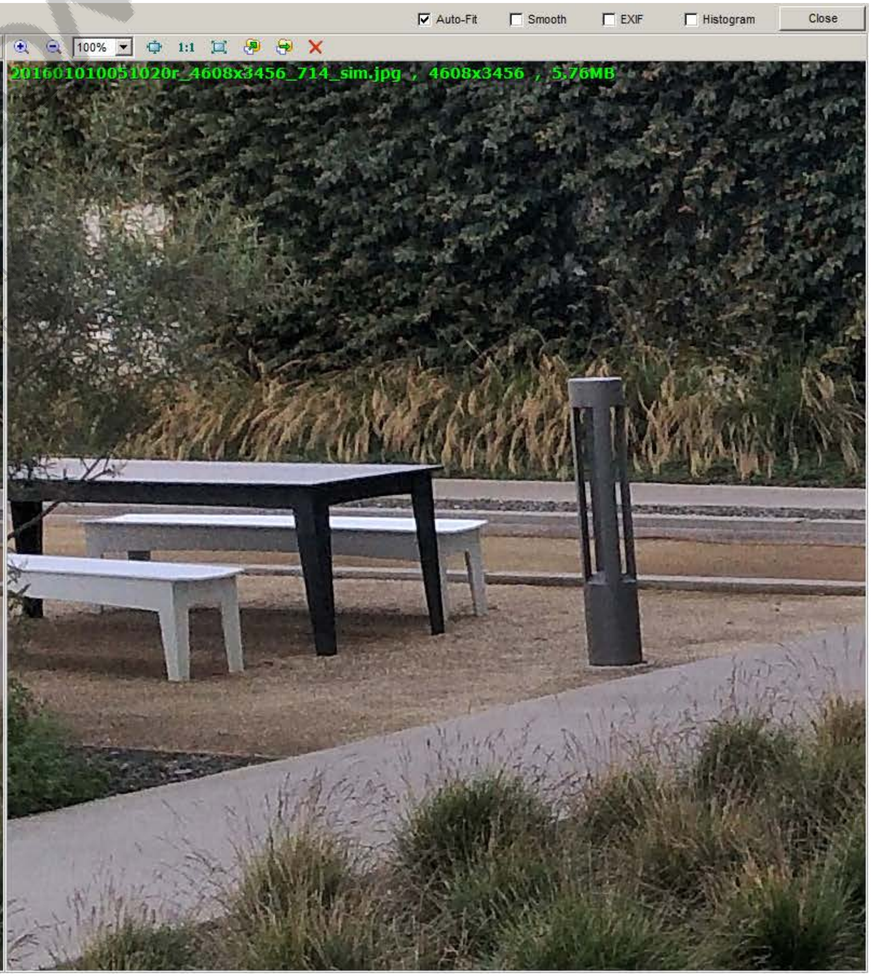
LTM_Strength – 512 (2x)

Effect of LCE_Strength

LCE_Strength – weak

LCE_Strength – strong





Software Aided Parameters

- *LTM_dark_boost*
  - Update lower portion of *LTM_scale* to control the dark boost of LTM
  - Data range – [0.0, 4.0]
  - Default value – 1.0
  - To tune:
    - Increase to boost dark region.
- *LTM_bright_suppress*
  - Update higher portion of *LTM_scale* to control the highlight suppression of LTM
  - Data range – [0.0, 4.0]
  - Default value – 1.0
  - To tune:
    - Increase to suppress highlight region.

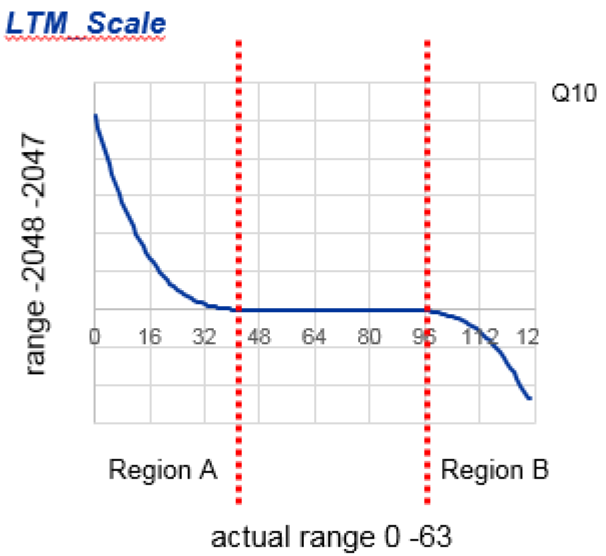
Apply Curves – Software Aided Parameter

1. Dark boost (*LTM_dark_boost*) and highlight suppression *LTM_bright_suppress* on *LTM_Scale*

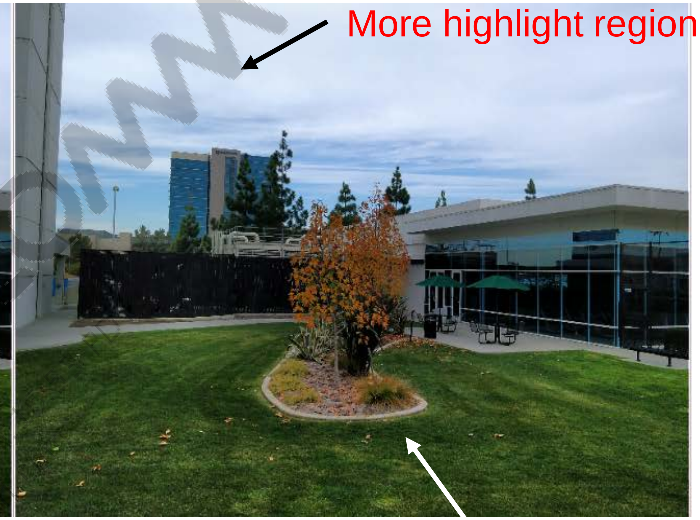
   [Region A]
   LTM_Scale = *LTM_Scale* × *LTM_dark_boost*
   [Region B]
   LTM_Scale = *LTM_Scale* × *LTM_bright_suppress*

2. *LTM strength* on *LTM_Scale* and *LCE_strength* on *LCE_scale*

   LTM_Scale = *LTM_Scale* × *LTM_Strength* / 256
   LCE_Scale = *LCE_Scale* × *LCE_Strength* / 256



Effect of LTM_dark_boost and LTM_bright_suppress

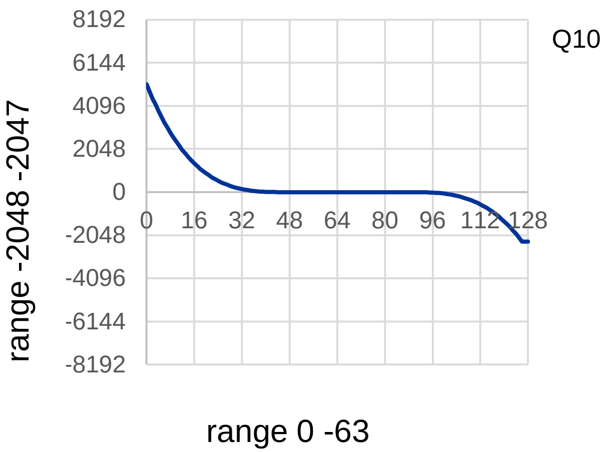


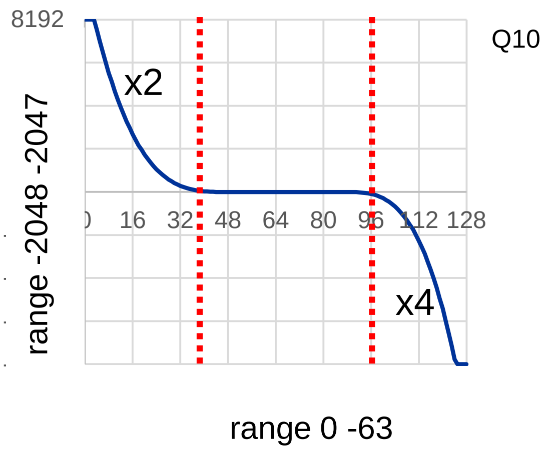
More highlight region suppression

More dark region boost

LTM_dark_boost: 1.0 LTM_bright_suppress: 1.0

LTM_dark_boost: 2.0 LTM_bright_suppress: 4.0





Y Ratio Maximum

- Y ratio maximum
  - Control the maximum gain applied on a pixel
  - Data range – [0, 16.0]
  - Default value – 16.0
  - To tune:
    - It is recommended to keep the default value.

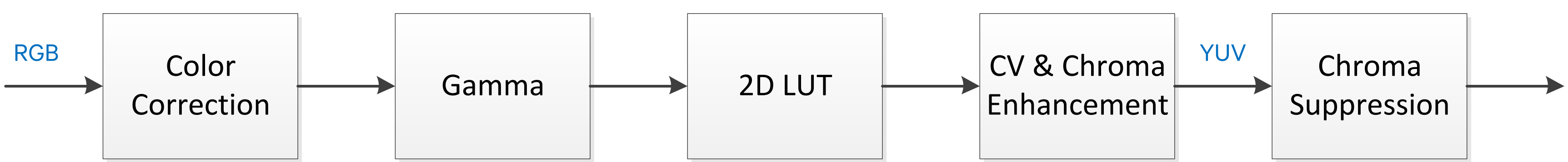
2D LUT

2D LUT - Background

- Goals of color tuning:
  - Render colors accurately, pass color fidelity tests
  - Render visually pleasant colors (e.g. blue sky, green grass)
- Common color tuning modules:
  - Color correction (CC): For overall color optimization
  - Color conversion (CV): For saturation adjustment
  - Skin color enhancement (SCE): For fine tuning of skin tone (or another color)
  - Memory color enhancement (MCE): For increasing saturation of red, green or blue colors
- Limitations of common modules:
  - Tuning one color affects other colors
  - Enhance chroma without considering luma values (may produce obtrusive enhancement)
  - Some modules (SCE, MCE) are not flexible, hard to tune

2D LUT – Overview

- Use 2D LUT module to fine tune a specific color without affecting other colors
- 2D LUT specifics:
  - Located in PPS, at the end of RGB domain
  - Pipeline order: CC → gamma → 2D LUT → CV → Chroma suppression → SCE
  - Module in/out are RGB values, but use HSL (hue, saturation, lightness) color space inside module
  - Enhance specific colors without affecting others
  - Can adjust hue and saturation based on L (lightness) value
  - Can limit the Y (luma) value changes due to enhancement
- Advantages
  - Local color adjustment on the hue-saturation plane
  - Very easy and intuitive color adjustment



Tuning Procedure Overview

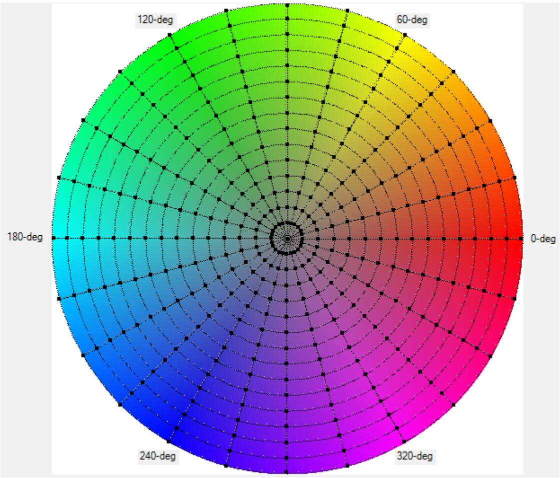
1. Tune CC and gamma before tuning 2D LUT
2. Set 1D knee points in lut_1d_h[25], lut_1d_s[16], based on the colors that need adjustment
3. For each of the colors that need adjustment
   a) Get the HSL values of current and target colors
   b) Set 2D delta hue and saturation LUTs lut_2d_h[24][16], lut_2d_s[24][16] accordingly
   c) Make sure delta LUTs are smooth and within range
4. Set L boundary points (l_boundary_start_a, l_boundary_start_b, l_boundary_end_a, l_boundary_end_b), if needed, so that the color adjustment is only for the defined brightness range
5. Set Y_blend_factor based on the preference of luma preservation vs color enhancement

Step 1. Set 1D Knee Points

Based on the colors that need adjustment, set 1D knee points in lut_1d_h[25], lut_1d_s[16] (reserved parameters, rarely tune)

Related parameters

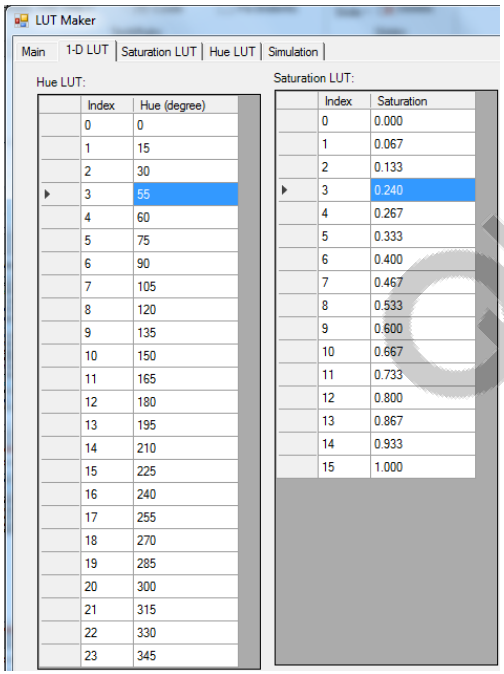
- lut_1d_h[25], lut_1d_s[16] define the sampling in the hue/saturation plane, that is, which hue/saturation to adjust (see the hue/saturation color wheel below)
- lut_1d_h[25] represents hue angle
  - Default value: [0,15,30,45,60,75,90,105,120,135,150,165,180,195,210,225,240,255, 270,285, 300,315,330,345,360] , i.e. evenly spaced from 0-360 degree
  - Must have Lut_1d_h[0] = 0 degree, Lut_1d_h[24] = 360 degree
  - Must have: LUT are always programmed in ascending order, and no two entries can be equal
- lut_1d_s[16] represent saturation
  - Default value: [0.0625,0.125,0.1875,0.25,0.3125,0.375, 0.4375,0.5,0.5625,0.625,0.6875,0.75,0.8125,0.875, 0.9375,1.0], evenly spaced
  - Must have: LUT are always programmed in ascending order, and no two entries can be equal
  - Must have Lut_1d_s[15] = 1.0



Step 1. Set 1D Knee Points (cont.)

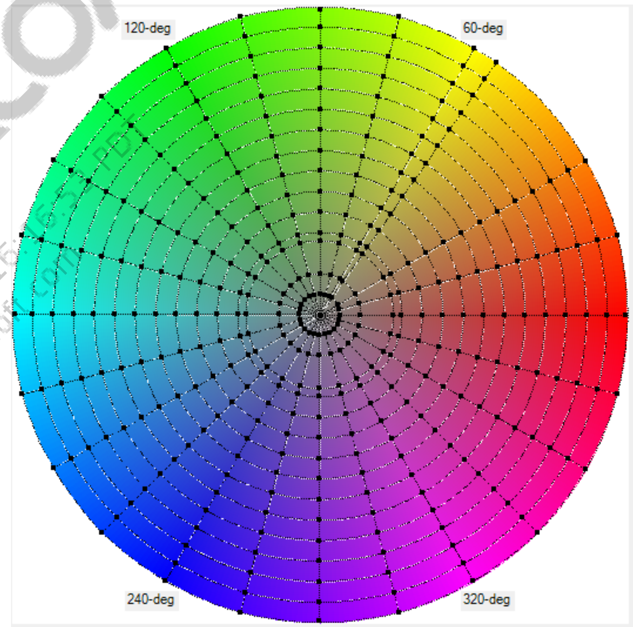
How to tune

- Users can edit lut_1d_h[25], lut_1d_s[16] in tool GUI (see the below left image)
- The updated 1D LUTs are reflected on the sampling points of color wheel



Index	Hue (degree)
0	0
1	15
2	30
3	55
4	60
5	75
6	90
7	105
8	120
9	135
10	150
11	165
12	180
13	195
14	210
15	225
16	240
17	255
18	270
19	285
20	300
21	315
22	330
23	345

Index	Saturation
0	0.000
1	0.067
2	0.133
3	0.240
4	0.267
5	0.333
6	0.400
7	0.467
8	0.533
9	0.600
10	0.667
11	0.733
12	0.800
13	0.867
14	0.933
15	1.000



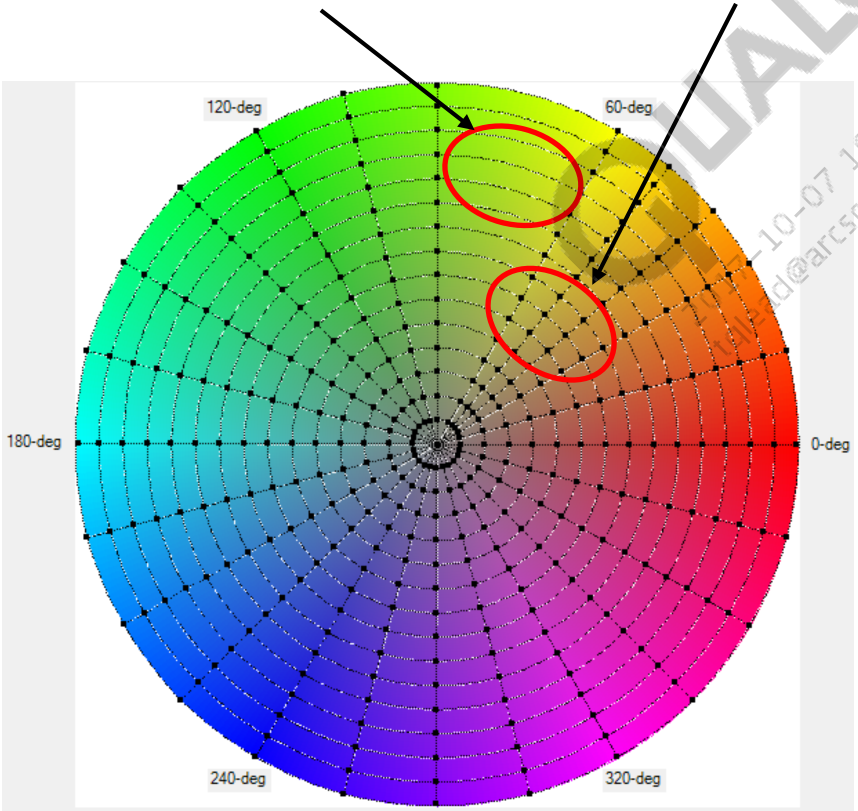
Note: Users can assign more sampling points for colors that need adjustment, like these 1D knee points don't have to be evenly spaced. 1D LUTs should be set before tuning 2D LUTs. Once tuned, 1D LUTs should not be changed when tuning 2D LUTs.

Step 1. Set 1D Knee Points (cont.)

- Below are examples of non-uniformly sampled 1D knee points
- Users can assign more knee points at colors that need adjustment

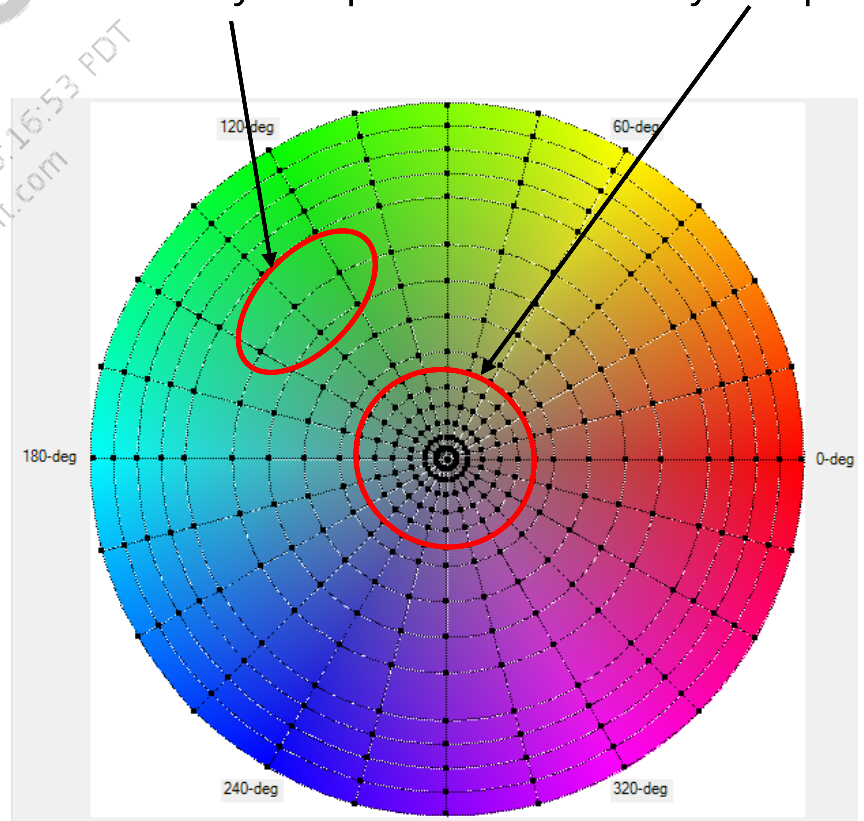
Non-uniform 1D hue LUT

Coarsely sampled　Densely sampled



Non-uniform 1D saturation LUT

Coarsely sampled　Densely sampled



Step 2. Set 2D Hue and Saturation LUTs

Set 2D LUTs in lut_2d_h[24][16], lut_2d_s[24][16] – core parameters (that is, multiple regions, often tune)

Related parameters

- lut_2d_h[24][16], lut_2d_s[24][16] represent deltaHue deltaSaturation at knee points, that is, how much hue/saturation to adjust
- Default value: All 0 entries for both LUTs

How to tune

- For each of the colors that need adjustment, users need to evaluate the difference of original color and target color, and set 2D LUTs accordingly
- There are two methods to set 2D LUTs. Users should choose from one of them. More details on the following slides

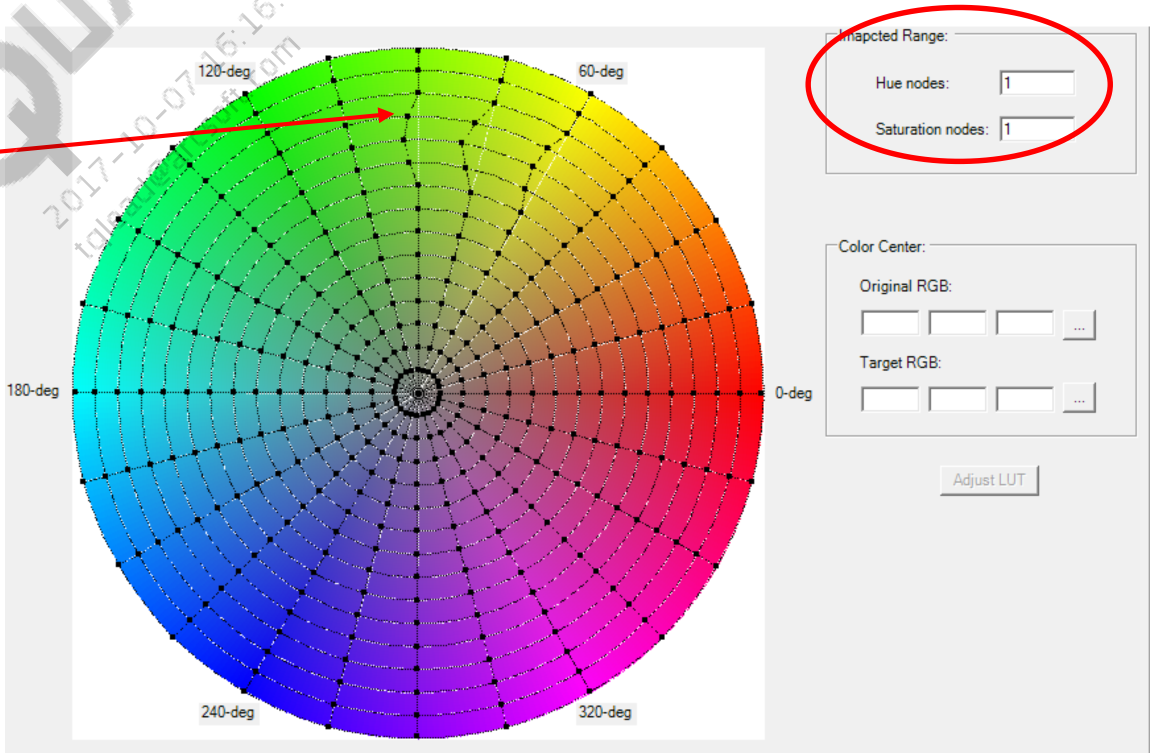
Note: To preserve gray area , hue and saturation should not change when saturation=0, i.e. first column in lut_2d_h[24][16], lut_2d_s[24][16] should be all 0

Step 3. Method A: Dragging Points to Set 2D LUTs

Steps for Method A

- At the color wheel of the tool GUI, users can drag grid points to the desired color
- Hue/saturation 2D LUTs will be updated accordingly
- Users can set “impacted range”, to control how many neighbor nodes are impacted with the adjustment. Larger adjustment requires larger “impacted range”, so that the changes are smooth

White grid lines denote original colors.
Black grid lines denote target colors.



Step 3. Method A: Dragging Points to Set 2D LUTs (cont.)

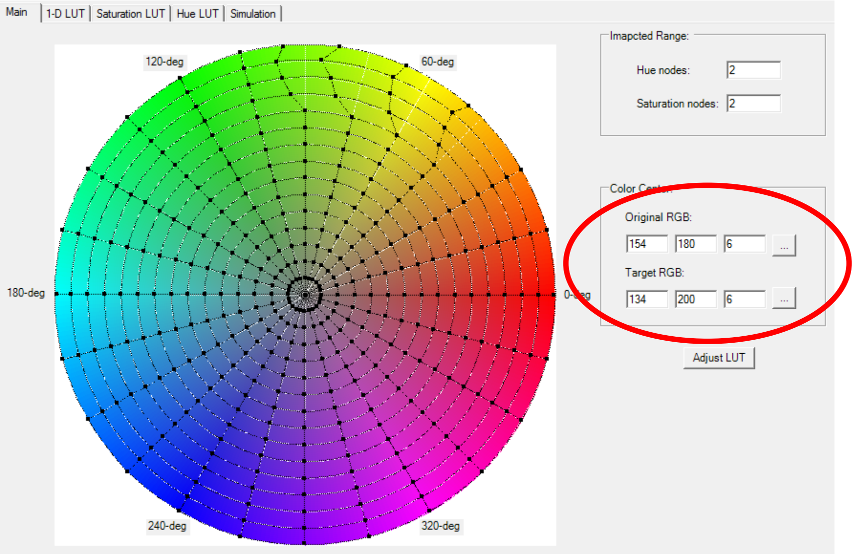
- Below is the target hue LUT generated from the color wheel from the previous slide. Target hue at angle 60, 75, 90 degree are updated
- By default, tool shows target hue/saturation in 2D LUTs. The Chromatix parameters lut_2d_h[24][16], lut_2d_s[24][16] should be delta hue/saturation

Hue	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
60	60	60	60	60	60	60	60	60	60	60	62	63	62	60	60	60
75	75	75	75	75	75	75	75	75	75	75	78	80	78	75	75	75
90	90	90	90	90	90	90	90	90	90	90	92	93	92	90	90	90
105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105
120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195
210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225
240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285
300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
345	345	345	345	345	345	345	345	345	345	345	345	345	345	345	345	345

Step 3. Method B: Use Original/Target RGB to Set 2D LUTs

Steps for Method B

- Users can input original and target RGB in text box. Alternatively, users can pick colors from sample images to get RGB values.
- Click “Adjust LUT” button, the grid points are adjusted, and hue/saturation 2D LUTs will be updated accordingly
- Users can set “impacted range”, to control how many neighbor nodes are impacted with the adjustment. Larger adjustment requires larger “impacted range”, so that the changes are smooth



Step 3. Method B: Use Original/Target RGB to Set 2D LUTs (cont.)

- Below is the target hue LUT generated from the color wheel from previous slide
  Target hue at angle 45, 60, 75, 90 degree are updated
- By default, tool shows target hue/saturation in 2D LUTs. The Chromatix parameters lut_2d_h[24][16], lut_2d_s[24][16] should be delta hue/saturation

Hue	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
45	45	45	45	45	45	45	45	45	45	45	45	45	48	50	51	49
60	60	60	60	60	60	60	60	60	60	60	60	60	65	67	68	66
75	75	75	75	75	75	75	75	75	75	75	75	75	81	83	86	82
90	90	90	90	90	90	90	90	90	90	90	90	90	94	96	97	95
105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105
120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195
210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225
240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285
300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
345	345	345	345	345	345	345	345	345	345	345	345	345	345	345	345	345

Method B: Examples

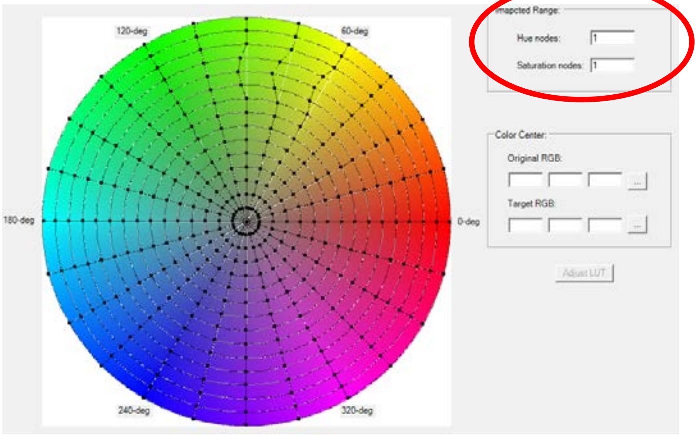
Effects of the 2D LUTs from previous slide. The grass is greener with the adjustment.

Original Color

After 2D LUT Enhancement

Step 3.1 Check 2D LUTs

- 2D LUT module is used for color enhancement. It is NOT intended for a dramatic color change
- In general, we recommend delta hue in lut_2d_h[24][16] to be in the range of ±30 degree, and delta saturation in lut_2d_s[24][16] to be in the range of ±0.20
- Users should make sure the target nodes in the color wheel are smooth
  - Users can set “impacted range”, to control how many neighbor nodes are impacted with the adjustment. Larger adjustment requires larger “impacted range”, so that the changes are smooth
- For fine tuning, users can directly modify 2D LUT data in the tool, and the nodes in the color wheel will update accordingly



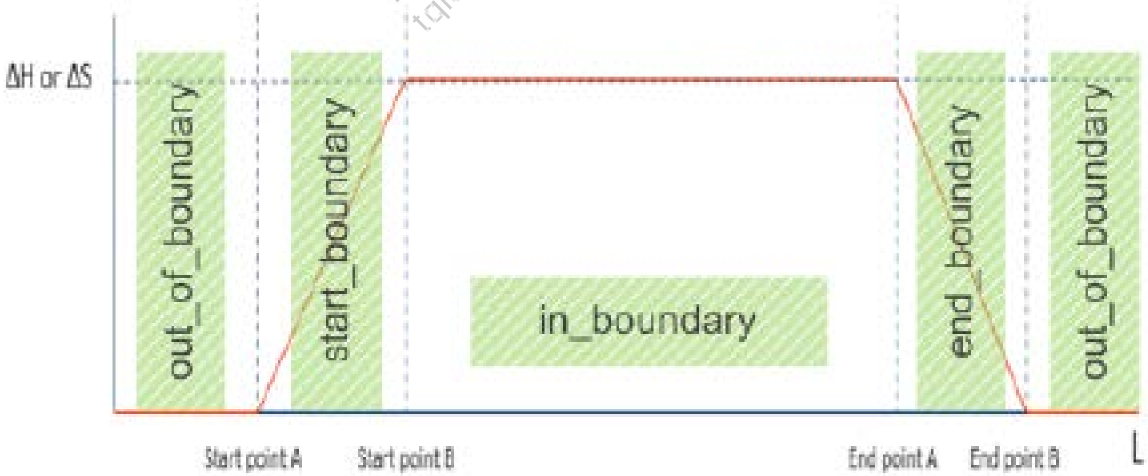
Examples of 2D LUT Color Enhancement

Blue sky is enhanced with +10 degree of hue, and +15% saturation

Step 4. Set L Boundary Points

If needed, set L boundary points (l_boundary_start_a, l_boundary_start_b, l_boundary_end_a, l_boundary_end_b), so that the color adjustment is only for the defined brightness range

- If in boundary, use deltaH/S from previous step (that is, from 2D LUT)
- If out of boundary, deltaH/S = 0
- If in transition area, interpolate
- All parameters are in the range [0.0, 1.0], that is percentage of Lightness range
- By default, l_boundary_start_a = l_boundary_start_b = 0, l_boundary_end_a = l_boundary_end_b = 1.0, that is, all lightness values use the full hue/saturation adjustment as defined in 2d LUTs



Set L Boundary Points – Example

- Setting 1: Adjust only the blue color for higher L values. Blue sky is enhanced, and the ground color is kept the same
- Setting 2: Adjust blue color for all L values (that is using default L boundary points). Blue sky is enhanced, and ground color is changed

Original Color

Setting 1

Setting 2

Step 5. Set Y_blend_factor

Set Y_blend_factor based on the preference of luma preservation vs color enhancement

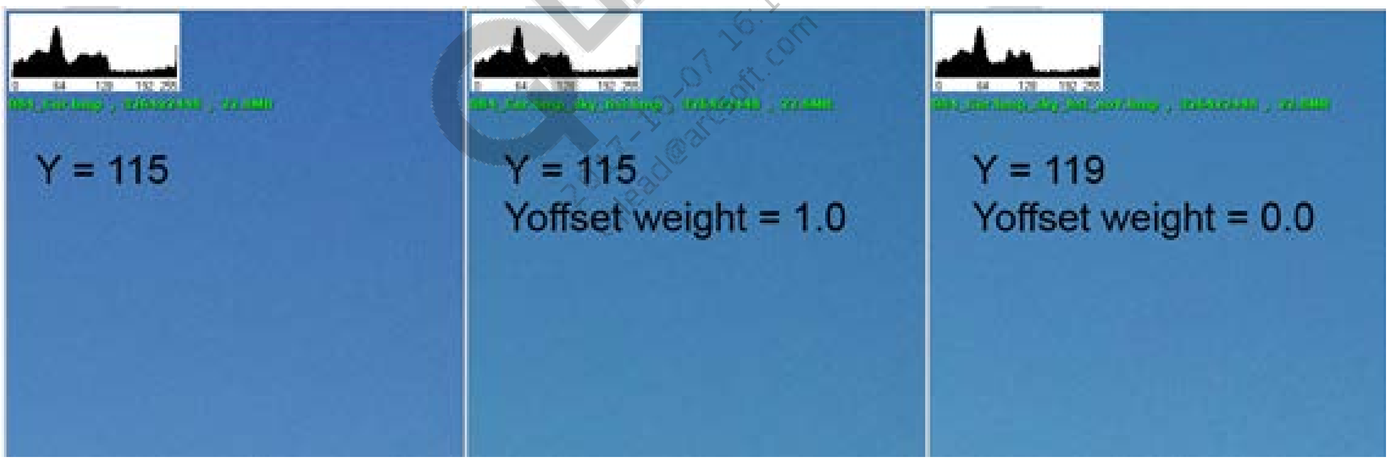
- In some cases, users may prefer to keep the luma value when enhancing color. Users can tune Y_blend_factor to achieve the desired results
- Y_blend_factor range [0, 1.0], default value 0
- When Y_blend_factor = 0, color is best expressed. This is recommended
- When Y_blend_factor = 1, Y value is best preserved

Step 5. Set Y_blend_factor – Example

Set Y_blend_factor based on the preference of luma preservation vs color enhancement

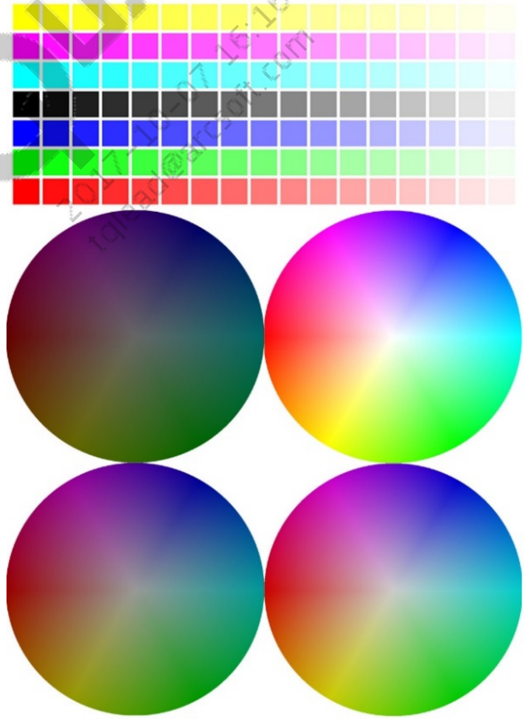
- Setting 1: Y_blend_factor = 1.0. Y value is kept the same at 115
- Setting 2: Y_blend_factor = 0. Y value is changed from 115 to 119

Original Color | Setting 1 | Setting 2



How to Evaluate 2D LUT Tuning

- 2D LUT module is often used to match the colors of a reference phone
  - Typical colors that need enhancement are: blue sky, green grass, skin colors
  - Users can use outdoor portrait images to evaluate those colors
- In addition to matching color preferences, users need to check:
  - Chroma noise is not enhanced with 2D LUT tuning, especially for low light
  - Use synthetic images like below to rule out side effects due to color tuning



Reserved Parameters

Chromatix Parameters	Type/ Range in Header	Default	Tuning Level	Tuning Notes
lut_1d_h[25]	float, [0, 360]	0,15,30,…,345,360, evenly spaced	Rarely tune	-- Must have lut_1d_h[0] = 0, lut_1d_h[24] = 360 -- LUT are always programmed in ascending order, and no two entries can be equal.
lut_1d_s[16]	float, [0, 1.0]	0.0625,0.125,…,0.9375,1.0	Rarely tune	-- Must have Lut_1d_s[15] = 1.0 -- LUT are always programmed in ascending order, and no two entries can be equal.
k_b_integer, k_r_integer	float, [0, 0.5]	k_b= 0.114, k_r= 0.299	Never tune	-- These parameters define RGB to Y conversion -- Users should not tune these
h_shift	uint, [0, 5]	1	Rarely tune	-- Default value means delta hue range is ±30 degree. -- Do not tune manually. This value is set dynamically by Chromatix tool. See next slide for details
s_shift	uint, [0, 3]	0	Rarely tune	-- Default value means delta saturation range is ±0.25 -- Do not tune manually. This value is set dynamically by Chromatix tool. See next slide for details

Reserved Parameters (cont.)

- h_shift: adjust delta hue range in lut_2d_h
  - When h_shift=0, delta hue range is ±15 degree
  - When h_shift=1, delta hue range is ± 30 degree
  - When h_shift=2, delta hue range is ± 60 degree
  - When h_shift=3, delta hue range is ± 120 degree
  - When h_shift=4, delta hue range is ± 240 degree
  - When h_shift=5, delta hue range is ± 360 degree
- s_shift: adjust delta saturation range in lut_2d_s
  - When s_shift=0, delta saturation range is ± 0.25
  - When s_shift=1, delta saturation range is ± 0.5
  - When s_shift=2, delta saturation range is ± 1.0
- Chromatix tool will get max(abs(lut_2d_h)) and max(abs(lut_2d_s)), and set h_shift and s_shift accordingly
  - Should calculate max value of all data regions, since h_shift s_shift are global parameters controlling all regions

Core Parameters

Chromatix Parameters	Type/ Range in Header	Default	Tuning Level	Tuning Notes
lut_2d_h[24][16]	float, [-360, 360]	0	Often tune	To preserve gray area , hue and saturation should not change when saturation=0, i.e. first column in lut_2d_h[24][16], lut_2d_s[24][16] should be all 0 .
lut_2d_s[24][16]	float, [-1.0, 1.0]	0	Often tune	To preserve gray area , hue and saturation should not change when saturation=0, i.e. first column in lut_2d_h[24][16], lut_2d_s[24][16] should be all 0
l_boundary_start_a, l_boundary_start_b, l_boundary_end_a, l_boundary_end_b	float, [0, 1.0]	start_a = start_b = 0, end_a = end_b = 1.0	Rarely tune	Can adjust hue and saturation based on L (lightness) value
y_blend_factor_integer	float, [0, 1.0]	0	Rarely tune	Can limit the Y (luma) value changes due to enhancement

How to Coordinate with Other Modules

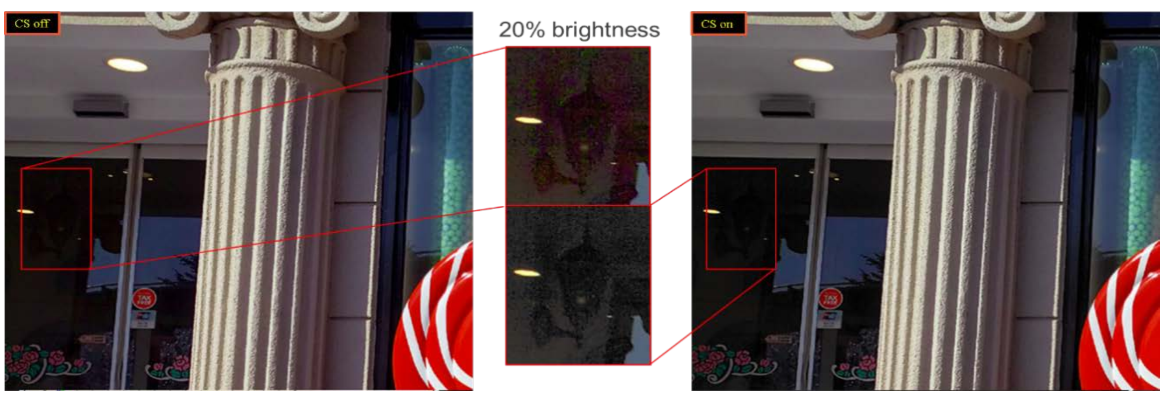
- Prior to color tuning
  - AEC (luma target) to be close to a target phone
  - AWB to be reasonably good
  - Recommend disabling chroma suppression
- Tune gamma and CCM
- Tune 2D LUT
- With 2D LUT, the following modules may not be needed for color tuning
  - Color conversion (CV): Use default
  - Memory color enhancement (MCE): Disable
  - Skin color enhancement (SCE): Disable

Chroma Suppression (CS)

Chroma Suppression – Background

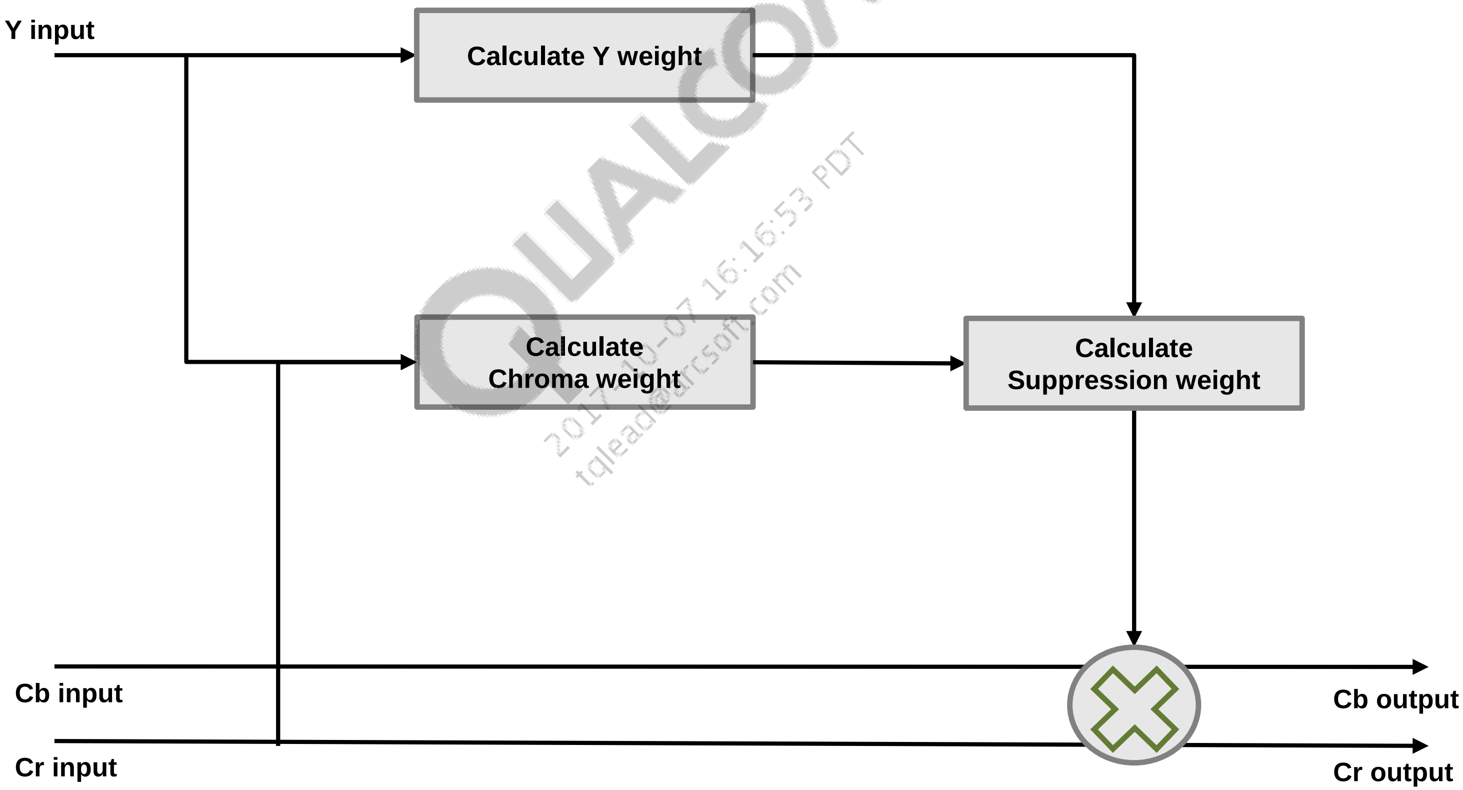
- Chroma suppression
  - To suppress Chroma for certain Luma range
    - Color tint in highlight is removed using CS

    - Color artifacts in lowlight are suppressed.



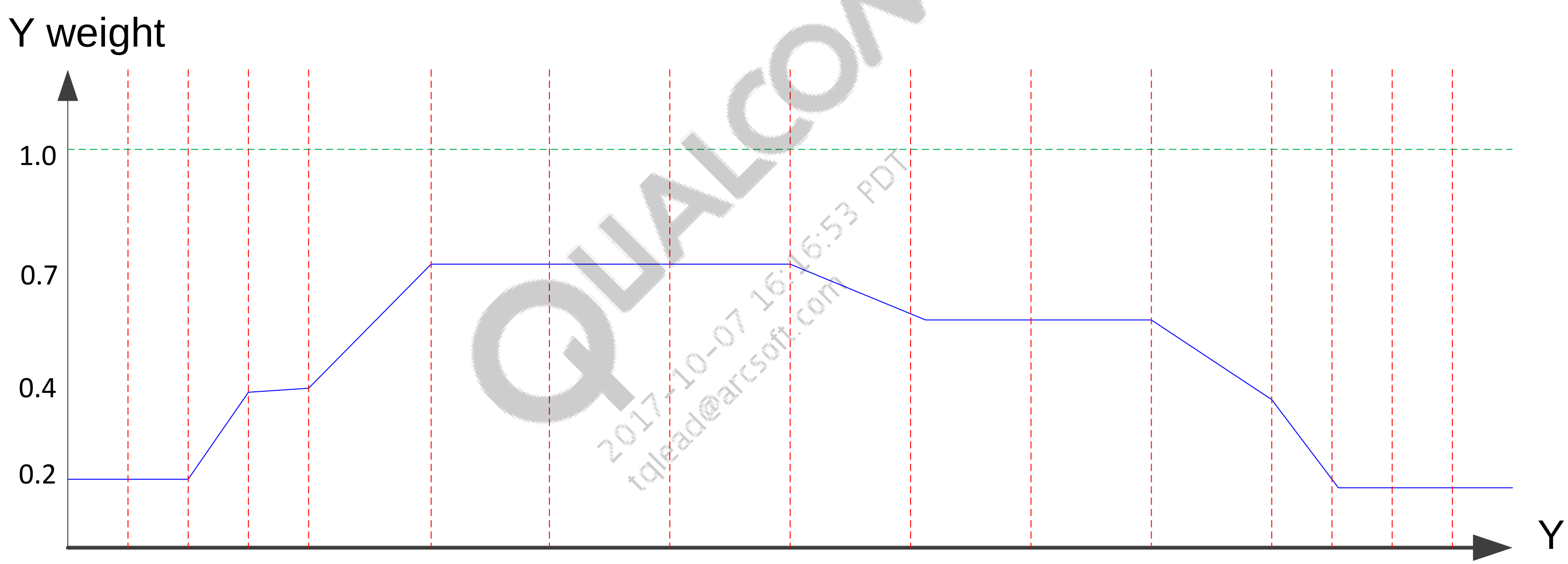
Overview

- Block diagram



Overview (cont.)

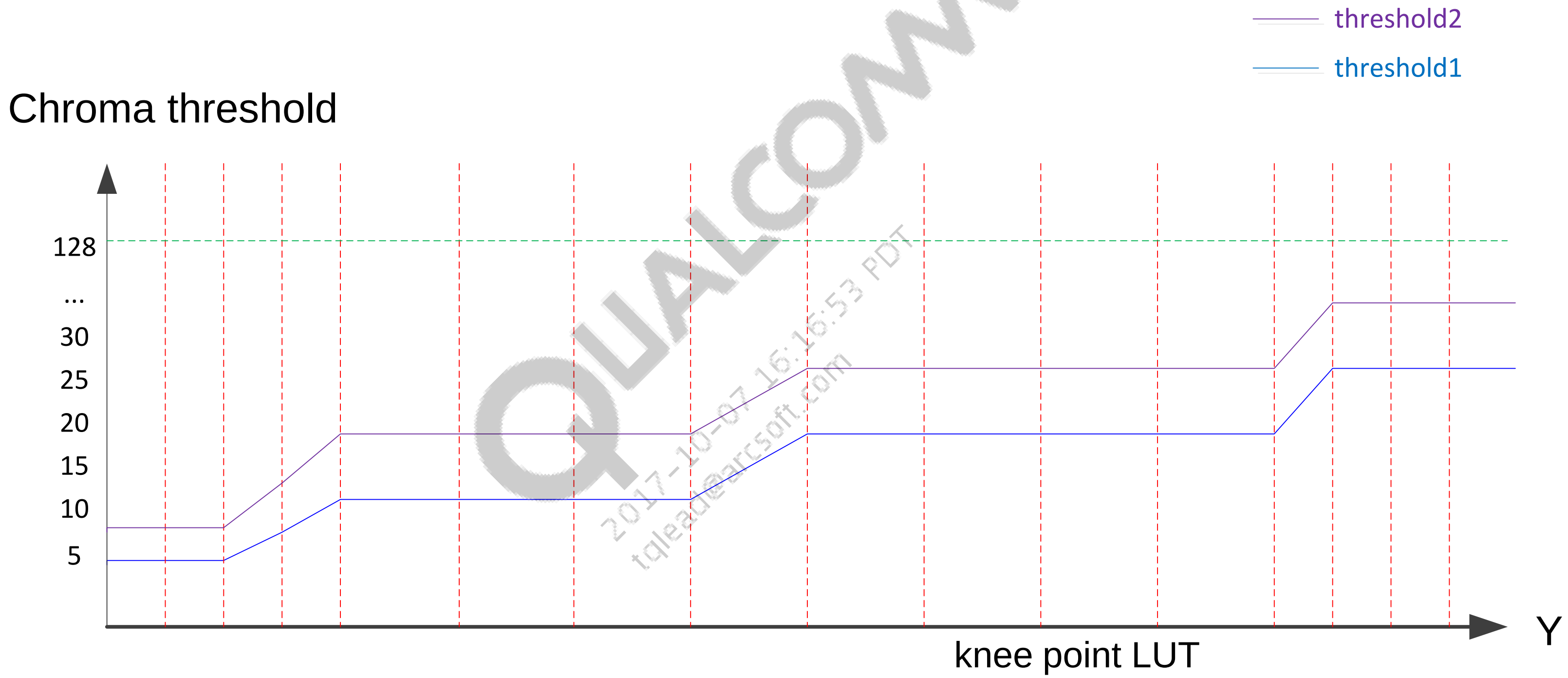
- Calculate Y weight



  - Knee point LUT [16]
    - 1D 16 flexible LUT to control not uniformly spaced Y
  - Y weight LUT [16]

Overview (cont.)

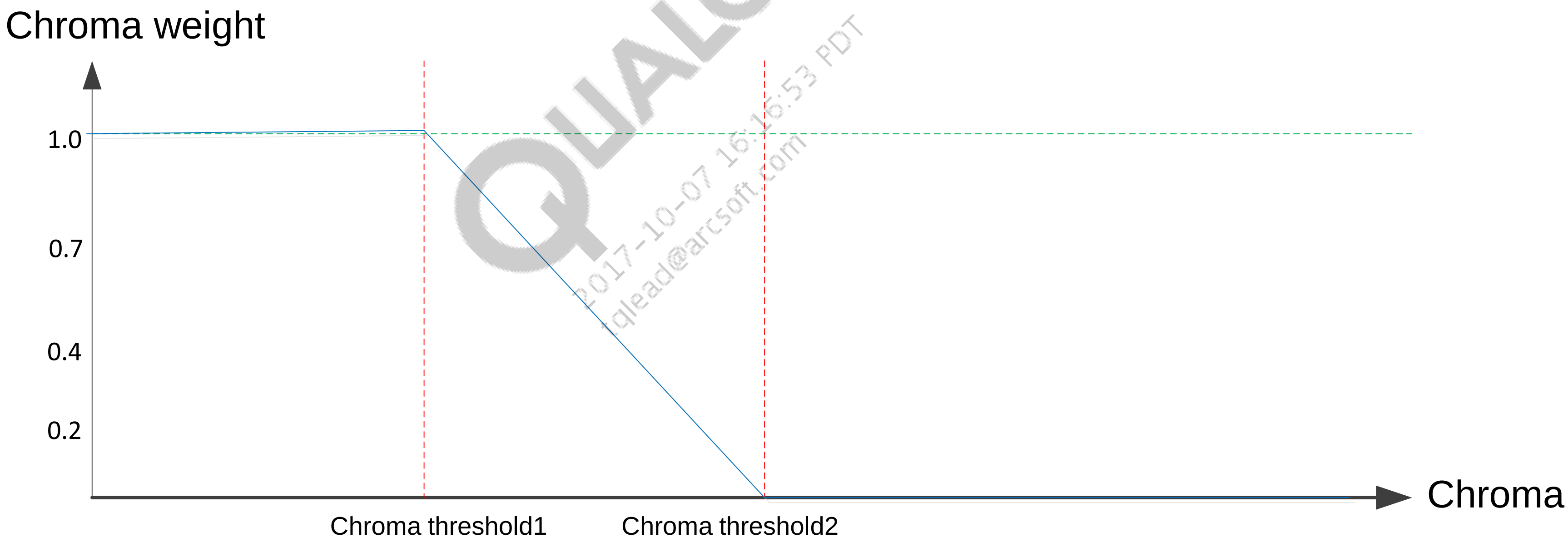
- Calculate chroma weight



  - Chroma threshold1 LUT [16]
  - Chroma threshold2 LUT [16]

Overview (cont.)

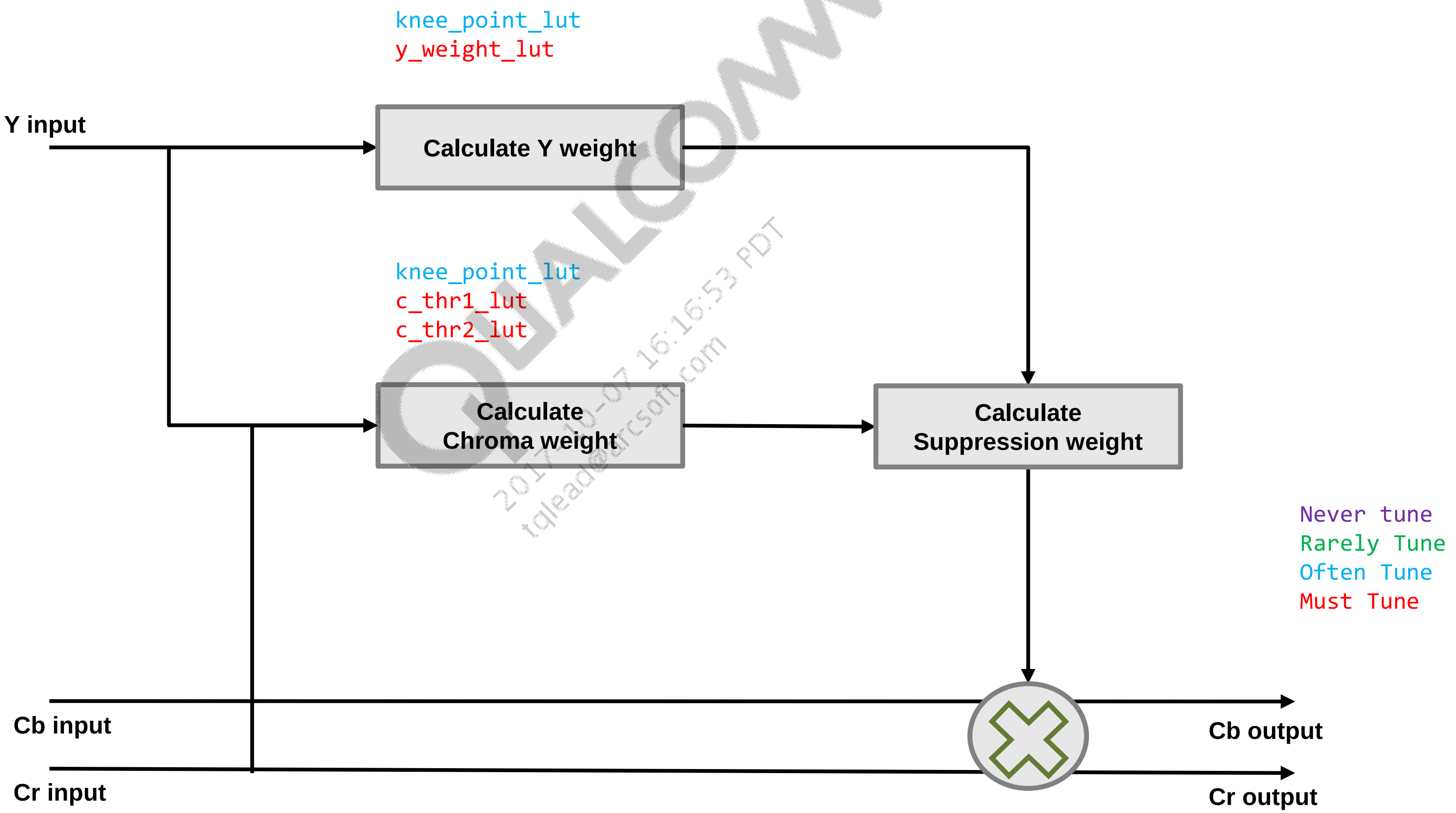
- Calculate chroma weight



Tuning Procedure

1. Set every parameter as default
2. Tune “Must tune” and “Often tune” parameters
   1. Set knee_point_lut to do flexible chroma suppression based on intensity.
   2. Set c_thr1_lut/c_thr2_lut to decide suppression amount based on chroma.
   3. Set y_weight_lut to suppress less based on intensity.

Effects of Parameters

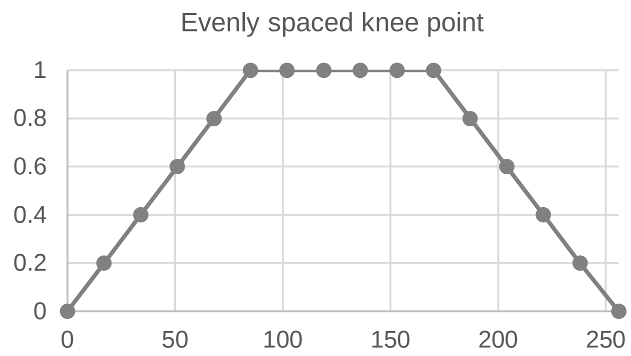


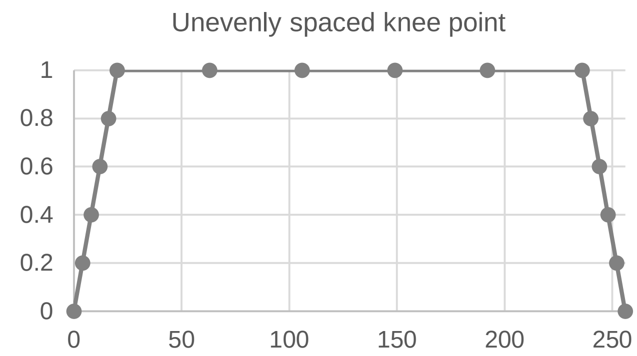
Step 1: Knee Point LUT

- knee_point_lut
  - Define the luma knee points users want to control.

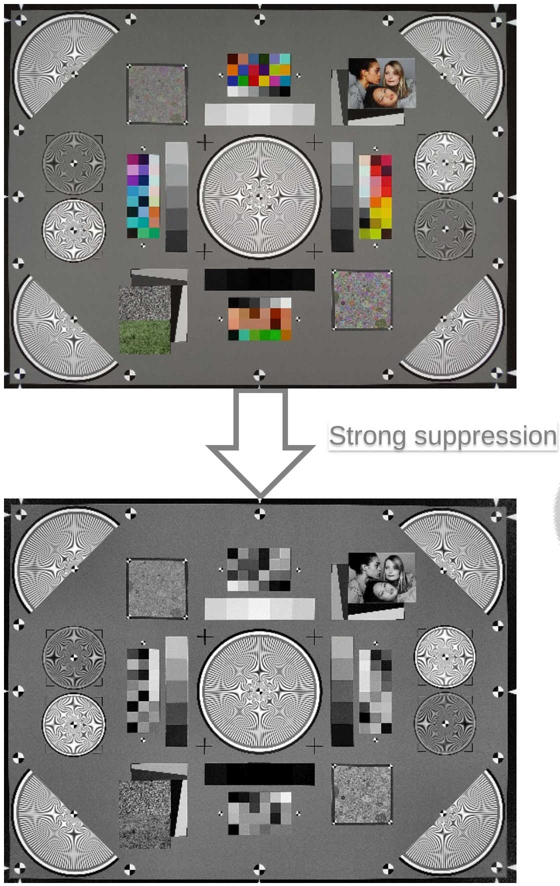
Length	Default	Min	Max	Effect
16	Evenly spaced	0	256	Define 16 knee points for both Y and Chroma weight

  - It applies to all 3 LUTs index. (y_weight_lut/ c_thr1_lut/ c_thr2_lut)
  - Default (last index 256 is hidden)
    - Evenly spaced
      - 0 17 34 51 68 85 102 119 136 153 170 187 204 221 238 256
    - Unevenly spaced
      - Recommend to use finer knee points for dark and highlight area to have flexible control.
      - 0 4 8 12 16 20 63 106 149 192 236 240 244 248 252 256





Step 1.1: c_thr1_lut/c_thr2_lut



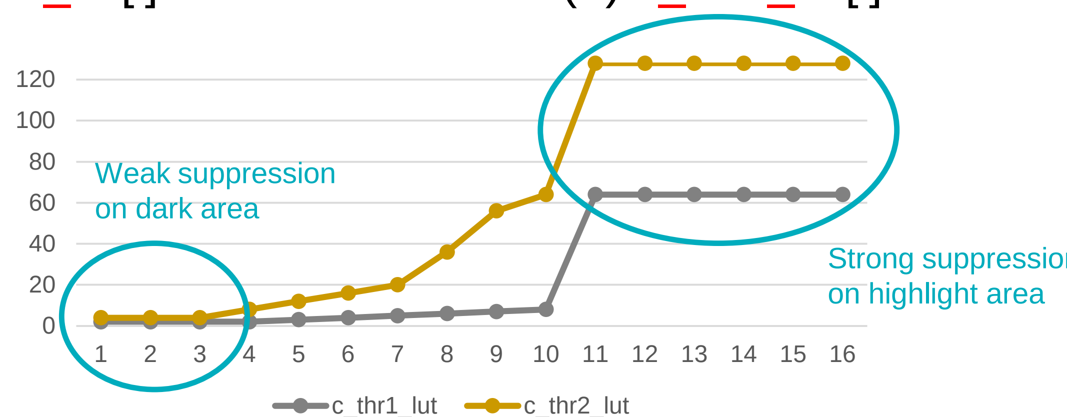
- c_thr1_lut [knee_point]
  - Define chroma threshold1. Chroma value smaller than this threshold will be suppressed with y_weight.

Length	Default	Min	Max	Higher value	Lower value
16	All 0	0	128	Stronger suppression	Weaker suppression

- c_thr2_lut[knee_point]
  - Define chroma threshold2. Chroma value bigger than this threshold will not be suppressed.

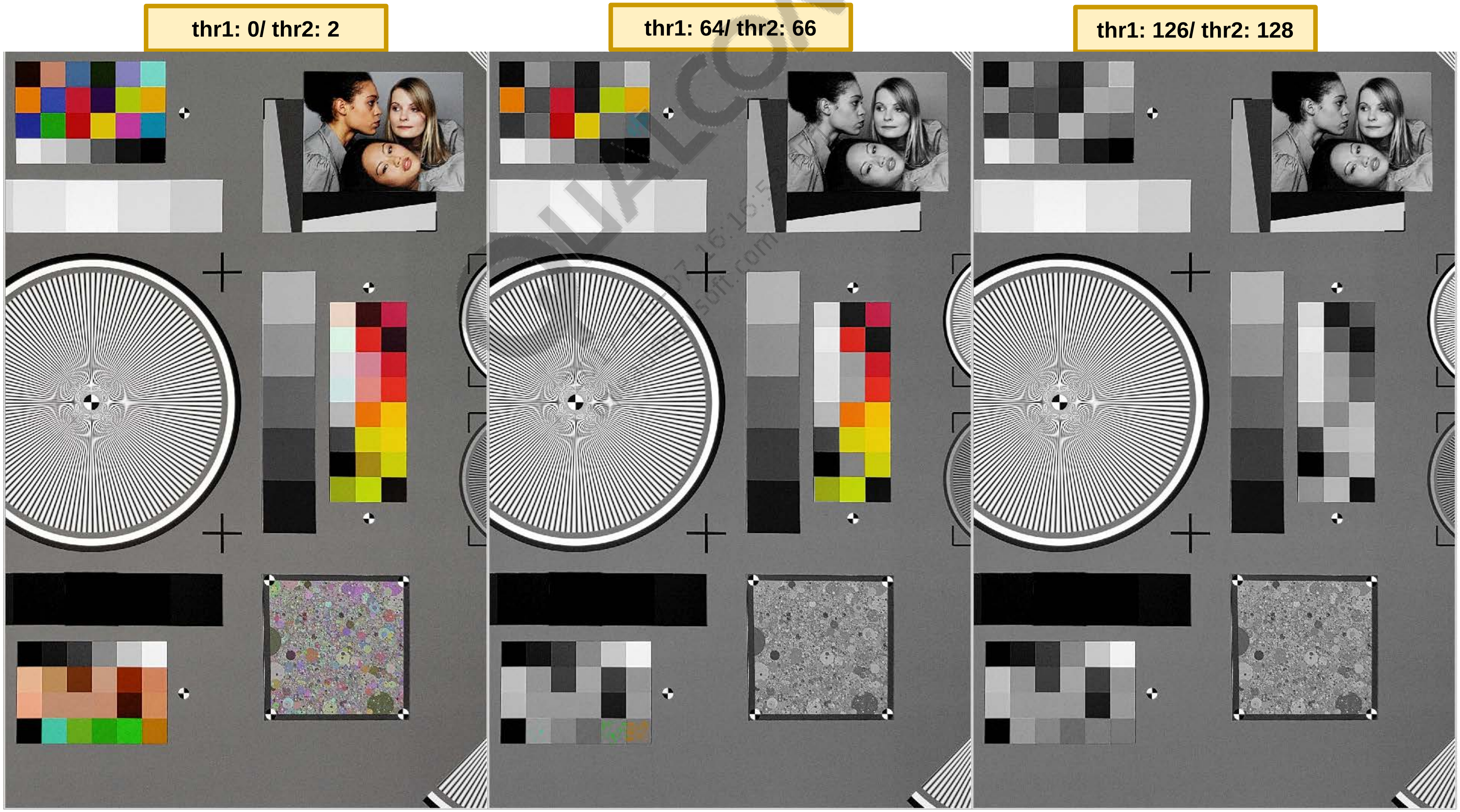
Length	Default	Min	Max	Higher value	Lower value
16	All 2	0	128	Stronger suppression	Weaker suppression

- c_thr1_lut[i] must be less than (<) c_thr2_lut[i]



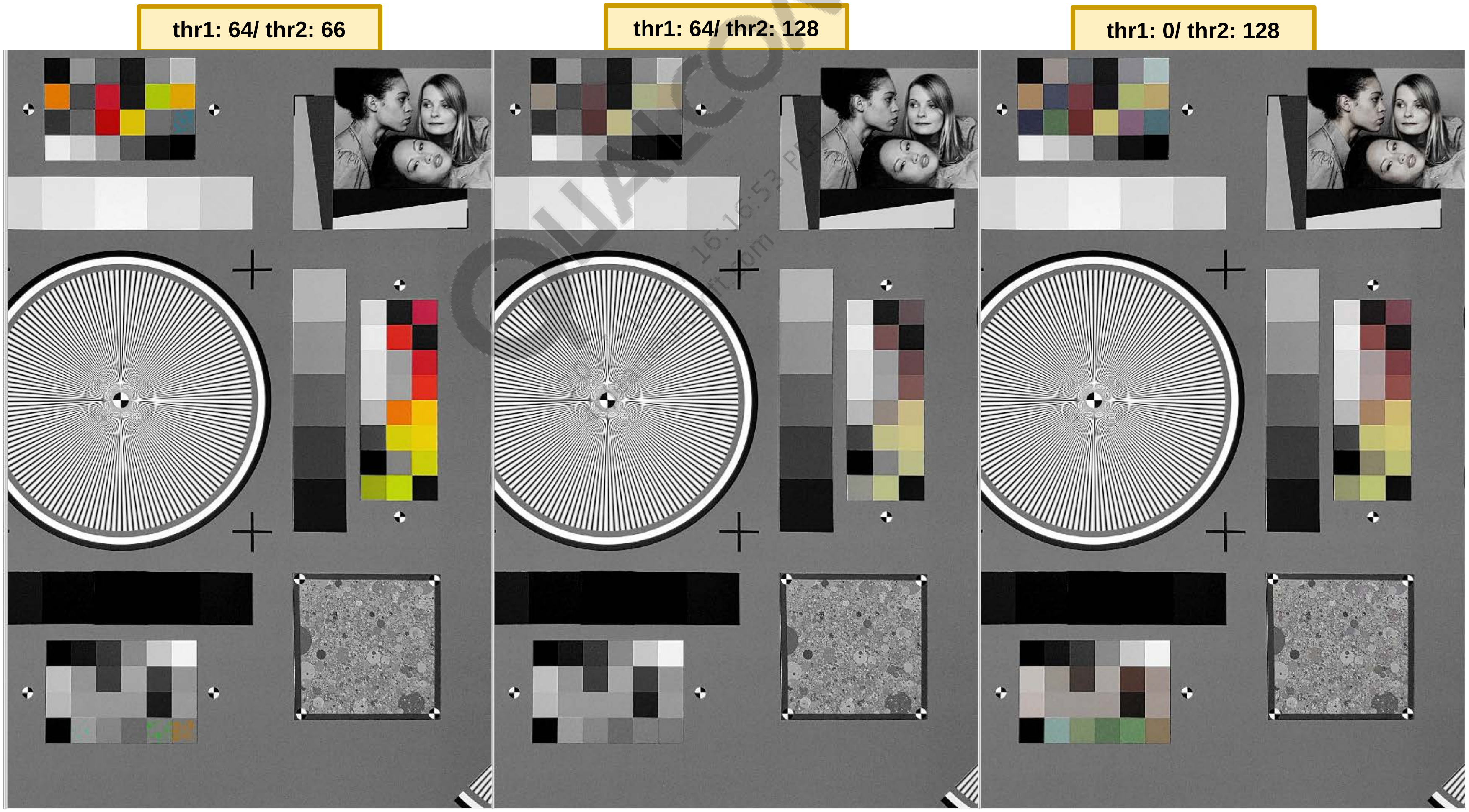
Step 1.1: c_thr1_lut/c_thr2_lut (cont.)

- c_thr1_lut/c_thr2_lut
  - When thr1 increases, chroma is suppressed.

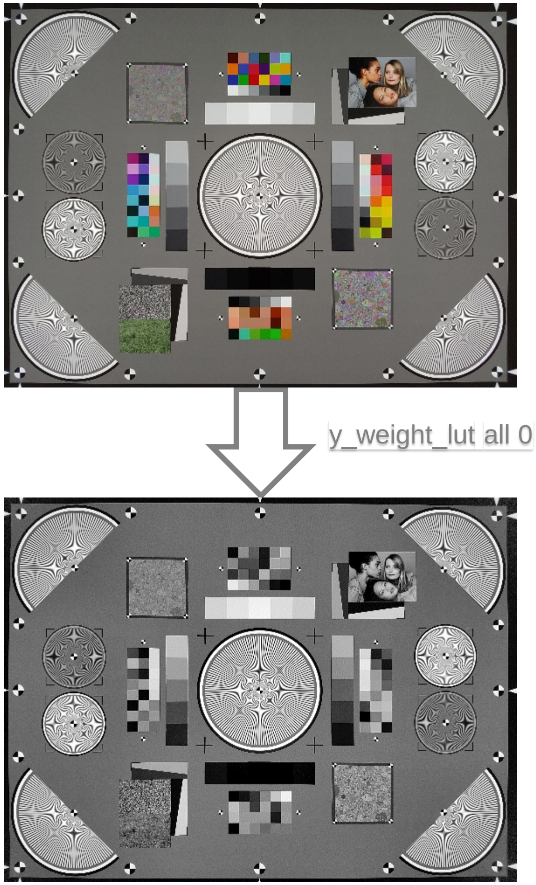


Step 1.1: c_thr1_lut/c_thr2_lut (cont.)

- c_thr1_lut/c_thr2_lut
  - When diff(c_thr2_lut–c_thr1_lut) is bigger, chroma is suppressed more smoothly



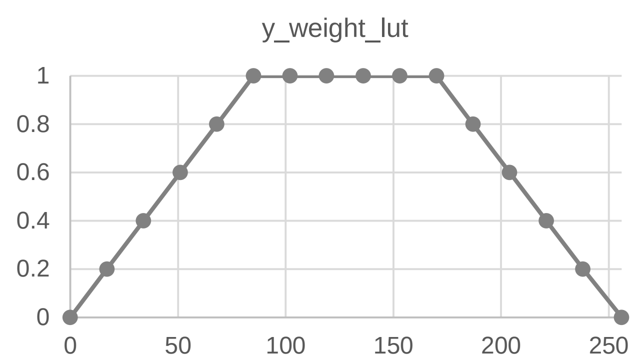
Step 2: y_weight_lut



- y_weight_lut[knee_points]
  - Define luma weight for chroma suppression at luma knee points

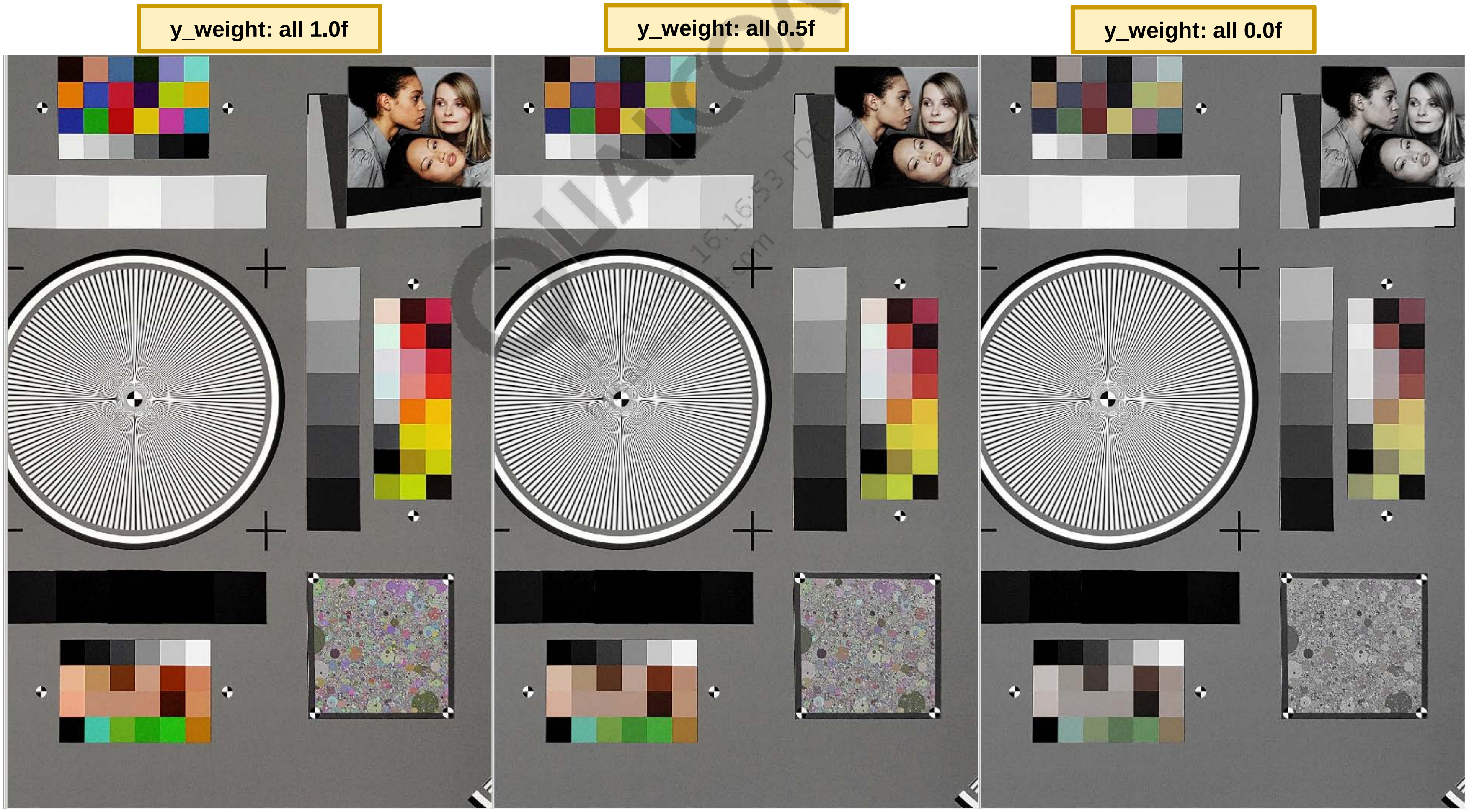
Length	Default	Min	Max	Higher value	Lower value
16	All 0	0.0f	1.0f	Weaker suppression	Stronger suppression

  - When y_weight_lut is “0.0f”, chroma suppression block is affected fully by c_thr1_lut&c_thr2_lut
  - When y_weight_lut is all “1.0f”, it is as same as disabling chroma suppression block
  - Recommend to apply strong suppression for dark/highlight area and try not to touch middle tone color



Step 2: y_weight_lut (cont.)

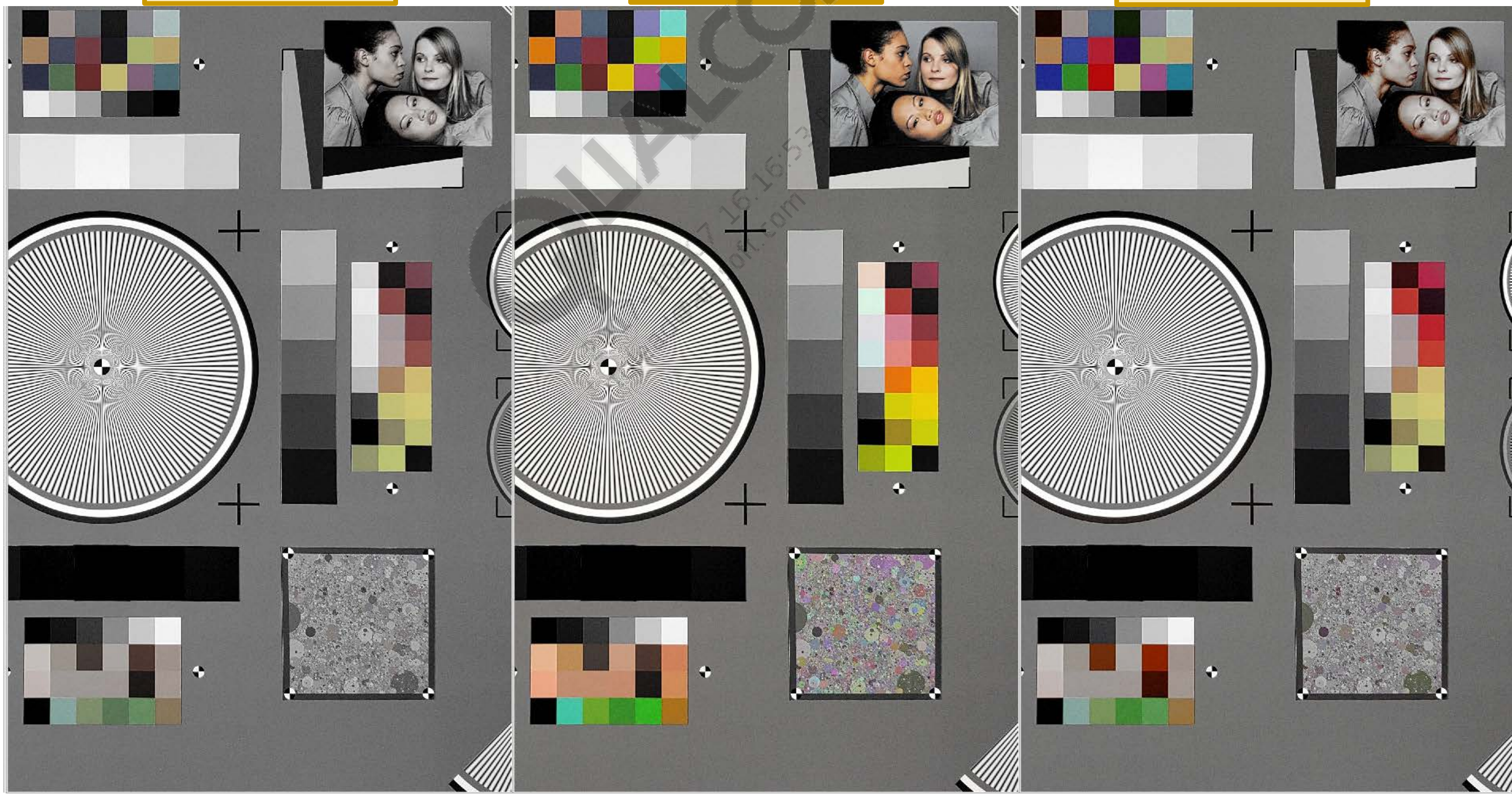
- y_weight_lut
  - Lower value can suppress more.



Step 2: y_weight_lut (cont.)

- y_weight_lut
  - Suppression strength can be controlled by intensity freely.

y_weight: all 0.0f | y_weight: 0.0f for dark area only | y_weight: 0.0f for highlight area only



How to Coordinate with Other Modules

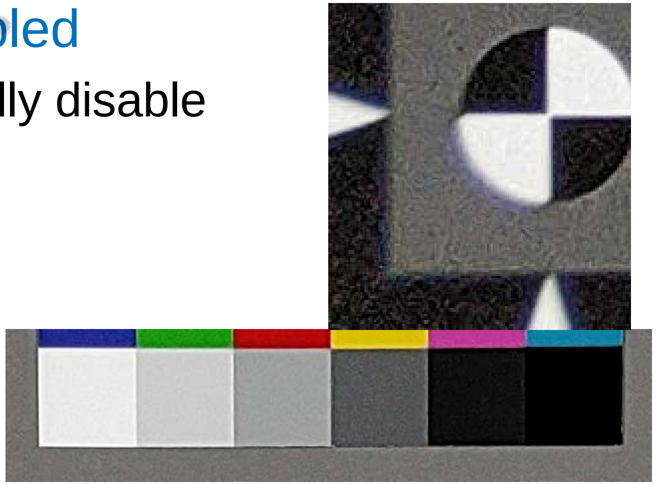
- Tune as a last module for color
- Disable CS with defaults when tuning color modules
- To suppress strong color for dark and highlight only, tuning with color NR
- To remove color tint, tune color NR firstly and try CS

Test Plan

- Enable/disable flags
  - chroma_suppression_enable;

- if disabled

- CS totally disable



- To bypass CS using parameters
  - **y_weight_lut = all 1**
  - The effect is same as CS disable
- How to confirm this module works normally
  - Take TE42 image
  - Check if color noise is not observed for dark/highlight area using this block
  - Check if color tint is observed on bright/ dark area
  - Check if discontinuity color data is observed by this block
  - Check if original colors are not suppressed by this block

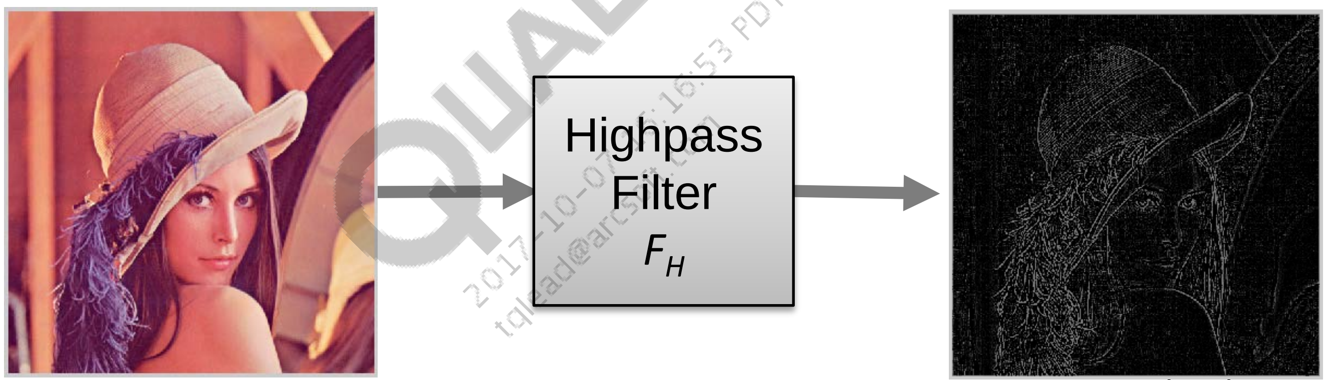
- Test images
  - TE42 chart
  - Outdoor with saturated/ near saturated lightness and backlight dark scenes
    - Light sources, the bright sky, white walls, whiteboards,
    - colorful objects, shade, dark backlight with building.

Adaptive Spatial Filter (ASF)

Adaptive Spatial Filter (ASF) – Introduction

Problem statement

- Edge enhancement is a common practice in image processing that increases the local contrast at boundaries, therefore making the image appear sharper. The ASF module is located in PPS of IPE
- Sharpening = Original image + highpass filtered image



Original (X) Output ($F_H X$)

High-emphasis filter enhances the details and edges.

Original (X) Highpass Filtered ($F_H X$) High-Emphasis ($F_{HE} X$)

Adaptive Spatial Filter (ASF) – Introduction (cont.)

- Sharpening strength :

$$X + \alpha(F_H X) \rightarrow Y$$

big α

Original (X)

+ α

Sharpening Strength

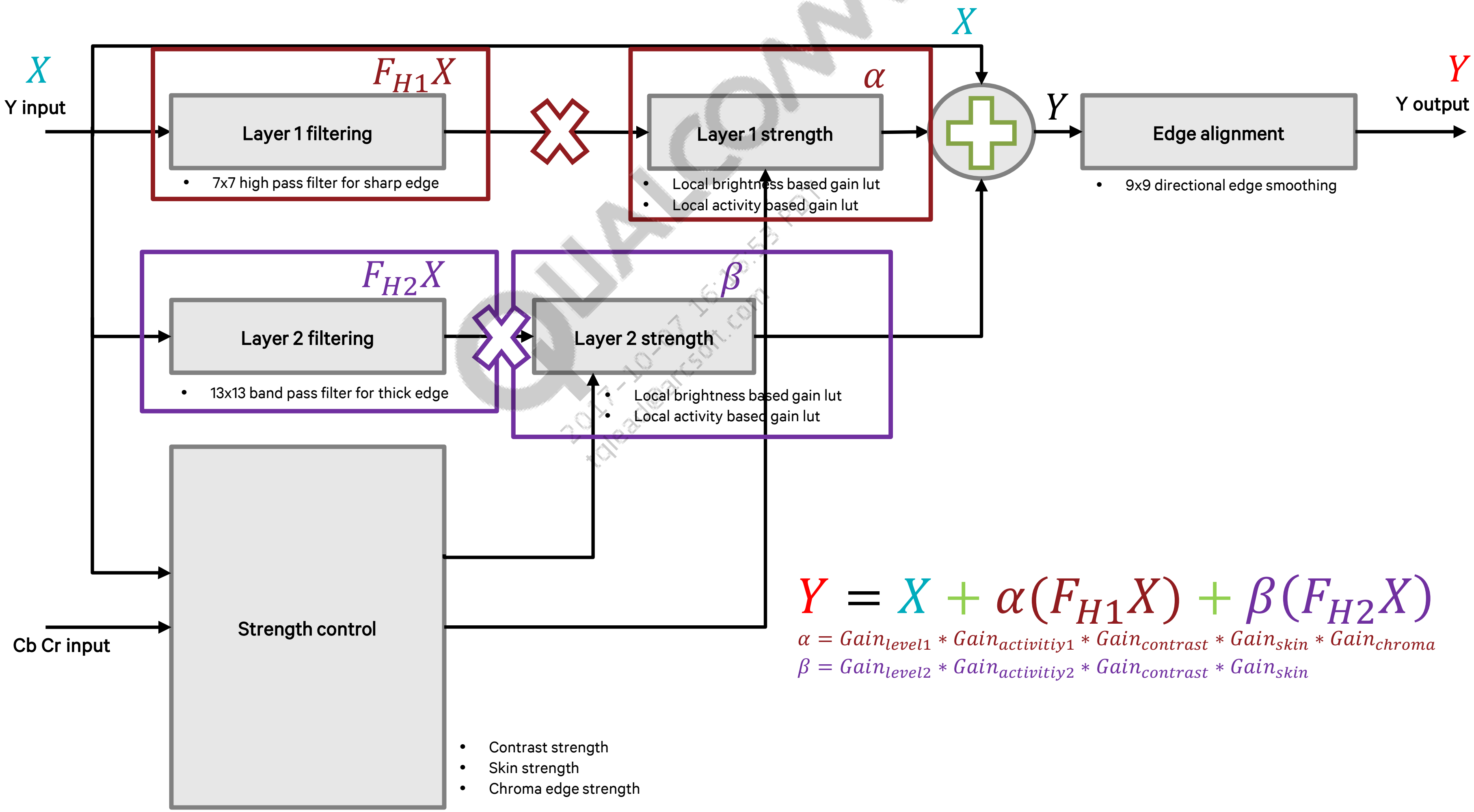
Highpass filtered ($F_H X$)

Output (Y)

small α

Overview

Block diagram



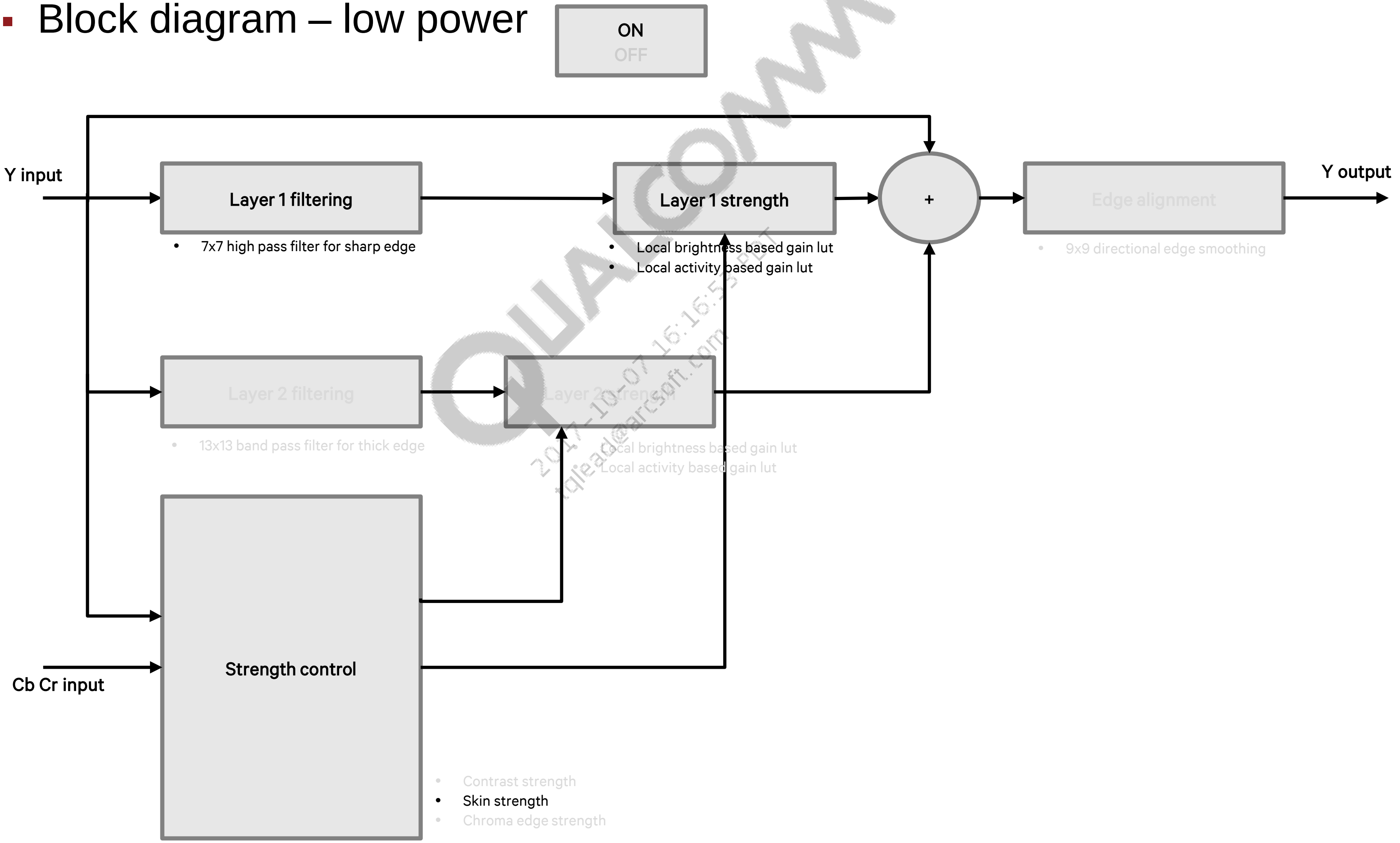
$$Y = X + \alpha(F_{H1}X) + \beta(F_{H2}X)$$

$$\alpha = Gain_{level1} * Gain_{activitiy1} * Gain_{contrast} * Gain_{skin} * Gain_{chroma}$$

$$\beta = Gain_{level2} * Gain_{activitiy2} * Gain_{contrast} * Gain_{skin}$$

Overview (cont.)

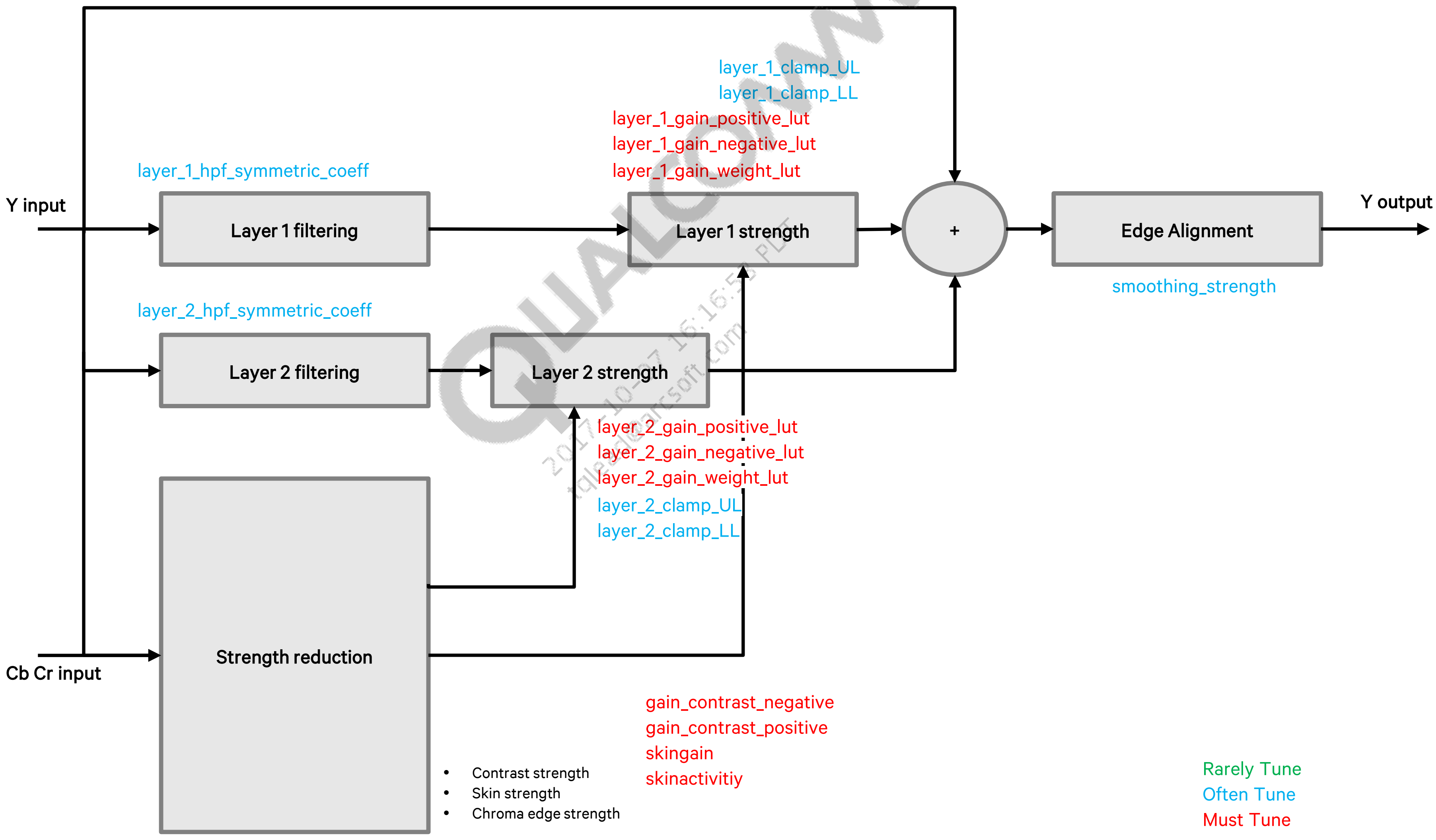
- Block diagram – low power



Tuning Procedure

1. Set every parameter as default
   - For radial and skin tuning, follow the instruction of each calibration.
2. Tune “Must tune” and “Often tune” parameters
   a) Set layer 1 symmetric kernel based on light condition
   b) Tune layer 1 gain strength based on level/activity to enhance steep edges and textures
   c) Set layer 2 kernel as default
   d) Tuning layer 2 gain strength based on level/activity to enhance thick edges and more local edge enhancement
   e) If you see halo, tune gain_contrast to reduce gain strength around edge
   f) If you see dirty skin, tune skin_gain to reduce sharpening on skin
   g) Tune smoothing strength to make edge smoothly
   h) Tune clamp if you still have halo after gain_contrast tuning
3. Tune “Rarely tune” for fine tuning
   a) When corner is noisier or less detail, tune radial parameters to make sharpening weaker or stronger.
   b) When halo is observed around chroma edge, tune gain_chroma to remove halo around chroma when contrast is not high
   c) When texture is connected by edge alignment unnaturally, tuning thresholds in edge alignment not to detect texture as edge

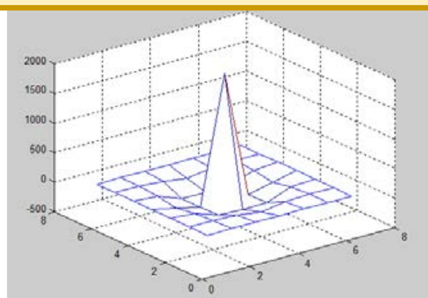
Effects of Parameters: Must Tune and Often Tune



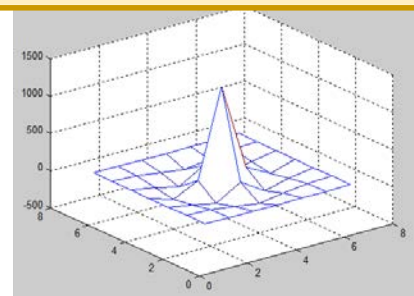
Step 2.1: Symmetric Kernel

- layer_1_hpf_symmetric_coeff
  - 1st layer 7x7 sharpening coefficients
  - Length: 10; Q10
  - Default
    - Thin Kernel (for outdoor)
      - 0, 0, 0, -1, -2, -25, -86, -173, -180, 1968
    - Mid Kernel (for indoor)
      - 0, 0, -3, -5, -10, -57, -106, -132, 65, 1232
    - Thick Kernel (for low light)
      - 0, -2, -9, -15, -22, -67, -89, -46, 144, 736

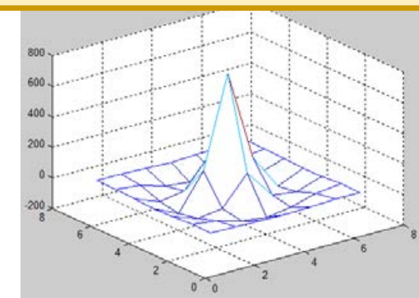
Thin kernel



Mid kernel



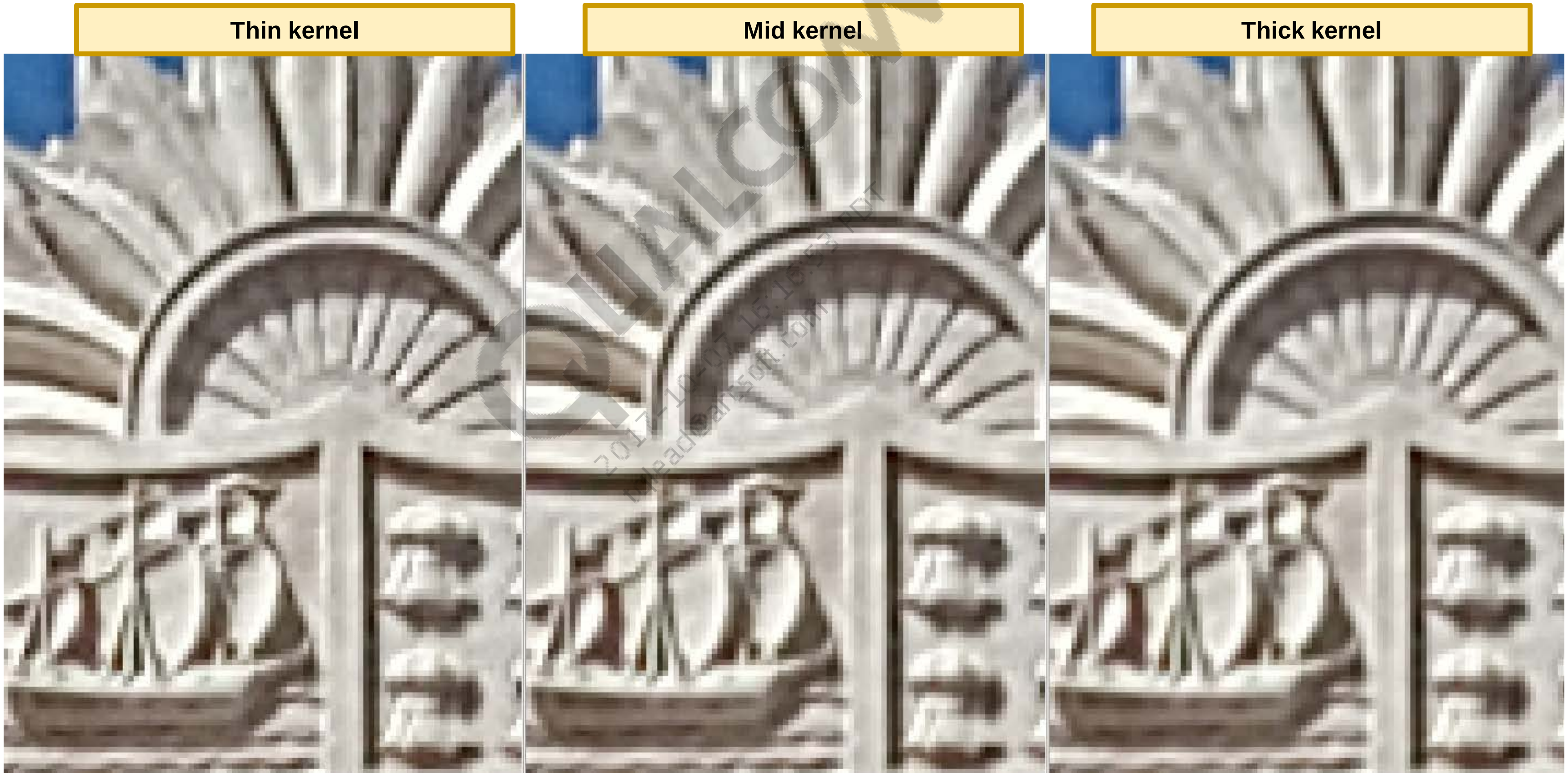
Thick kernel



  - The sum of kernel should be “0”
  - Not recommended to change kernel manually

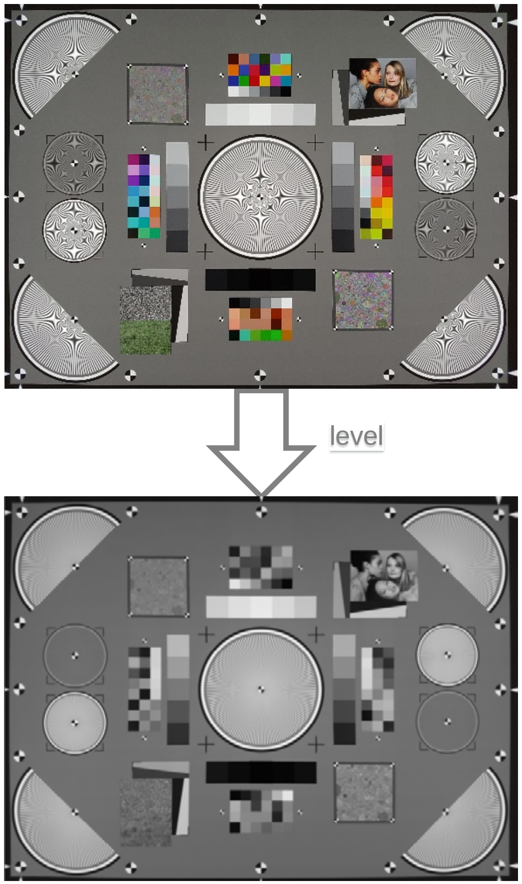
Step 2.1: Symmetric Kernel (cont.)

- layer_1_hpf_symmetric_coeff



- Thin kernel helps to show small details like tree and make the image sharp
- Thick kernel helps to show edges smoothly and less zaggy

Step 2.2: gain_positive/negative_lut



level = Y intensity value/4

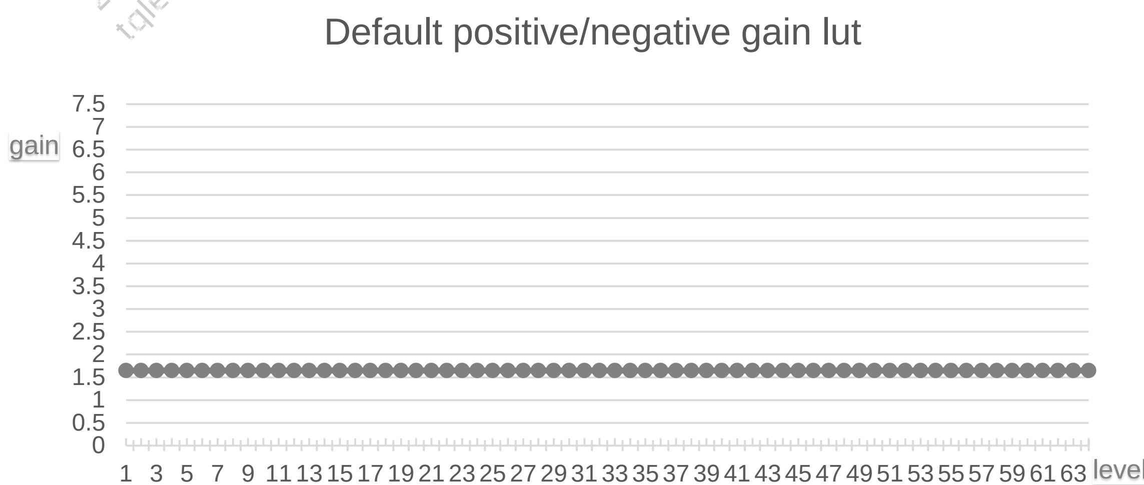
- layer_1_gain_positive_lut[level]
  - Level-based sharpening gain LUT for positive halo

Length	Default	Min	Max	Higher value	Lower value
64	All 1.65f	0.0f	7.9f	Stronger sharpening	Weaker sharpening

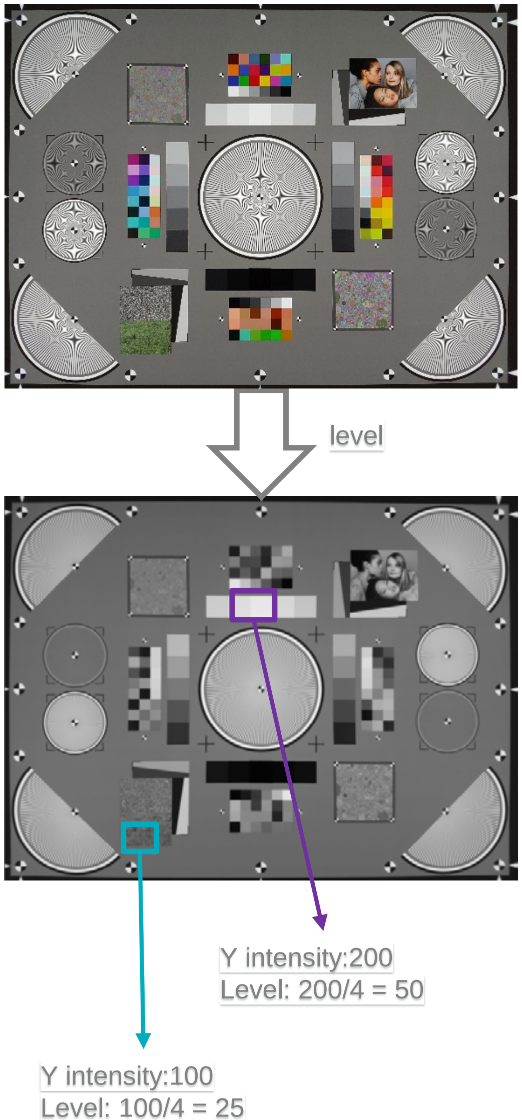
- layer_1_gain_negative_lut[level]
  - Level-based sharpening gain LUT for negative halo

Length	Default	Min	Max	Higher value	Lower value
64	All 1.65f	0.0f	7.9f	Stronger sharpening	Weaker sharpening

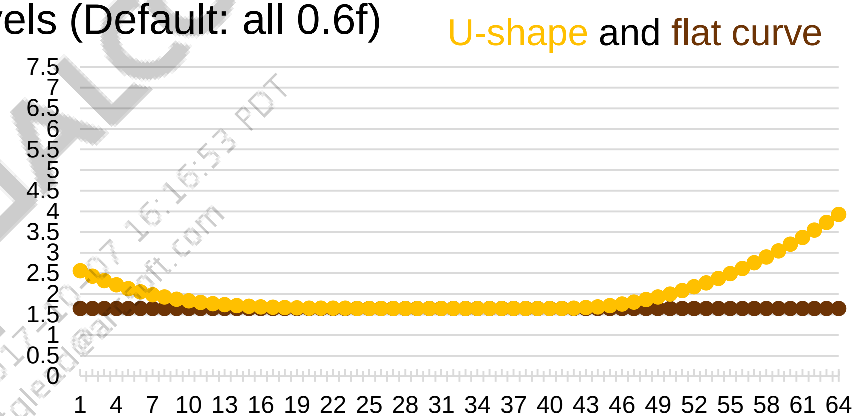
- Level is from layer_1_lpf_coeff



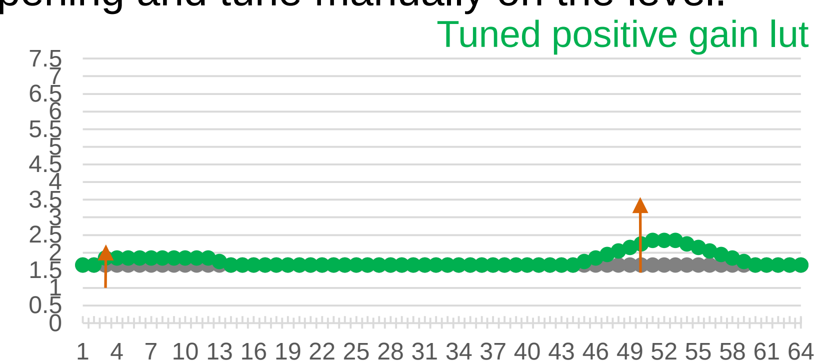
Step 2.2: gain_positive/negative_lut (cont.)



- General setting for gain_positive/negative lut
  - Bright/ Normal light: U-shape curve, stronger enhancement for highlight & shadow
  - Low light: flat curve, same enhancement for all intensity levels (Default: all 0.6f)



- Manual curve tuning
  - Get level data of the part want to enhance or release sharpening and tune manually on the level.



Step 2.2: gain_positive/negative_lut (cont.)

- layer_1_gain_positive_lut/layer_1_gain_negative_lut
  - Sharpness on edge getting stronger by setting gain_lut higher

Flat : 1.00f	Flat : 1.65f	Flat : 3.0f

  - Details getting stronger by setting gain_lut higher but it increases noise as well

Flat : 1.00f	Flat : 1.65f	Flat : 3.0f

Step 2.2: gain_positive/negative_lut (cont.)

- layer_1_gain_positive_lut/layer_1_gain_negative_lut
  - U shape can generate stronger sharpening in highlight

Flat : 1.00f

Flat : 1.65f

U shape based on 1.65f

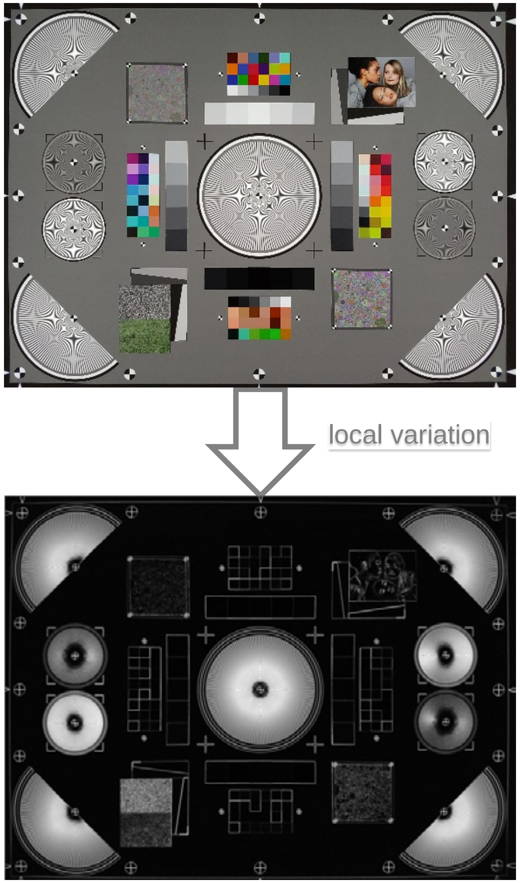
  - Manual shape also can make stronger sharpening as same as U shape curve

Flat : 1.65f

U shape based on 1.65f

Manual shape based on 1.65f

Step 2.2: gain_weight_lut



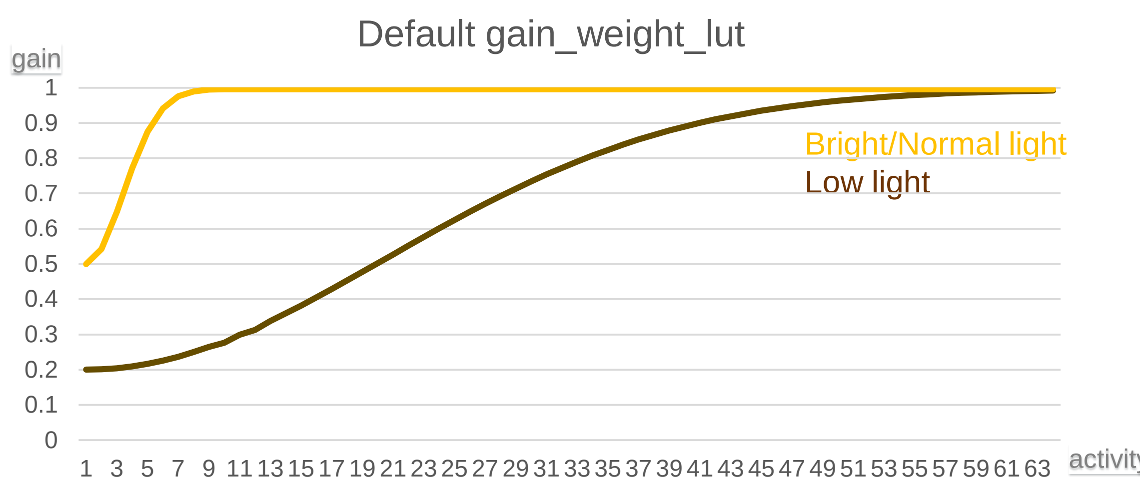
local variation(Q8)=
how active the pixel is
using band pass filter

activity = local variation/4

- layer_1_gain_weight_lut[activity]
  - Normalized activity-based sharpening gain LUT

Length	Default	Min	Max	Higher value	Lower value
64	From 0.5 to 1.0	0.0f	0.996f	Stronger sharpening	Weaker sharpening

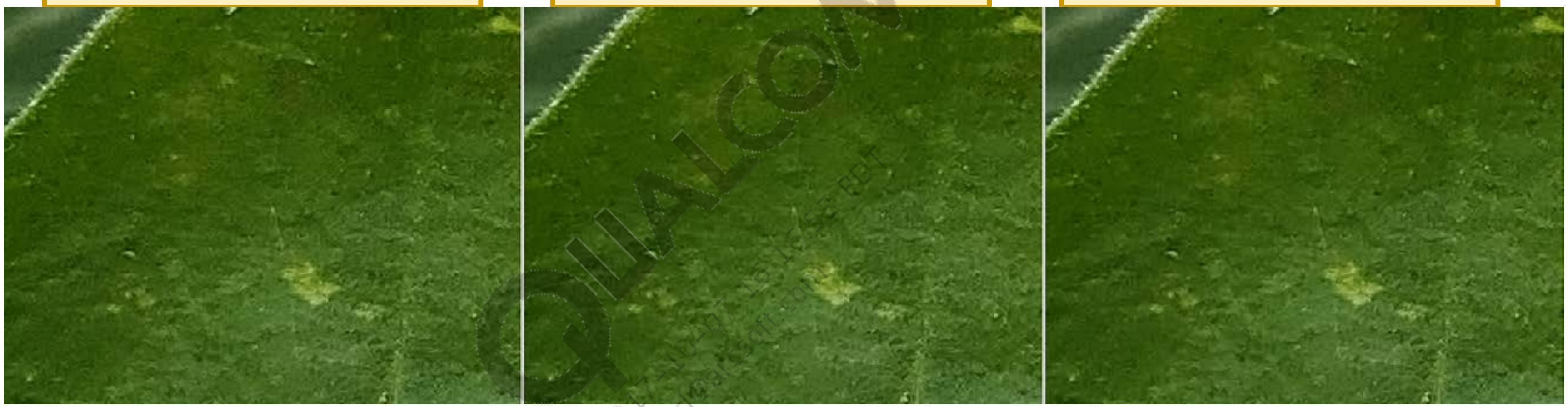
  - Activity : normalized 5x5 BPF & LPF of input
    - BPF using layer_1_activity_band_pass_coeff
    - Scaled using layer_1_norm_scale & layer_1_L2_norm_en
    - Clamped using layer_1_activity_clamp_threshold
    - Normalization using layer_1_activity_normalization_lut



Step 2.2: gain_weight_lut (cont.)

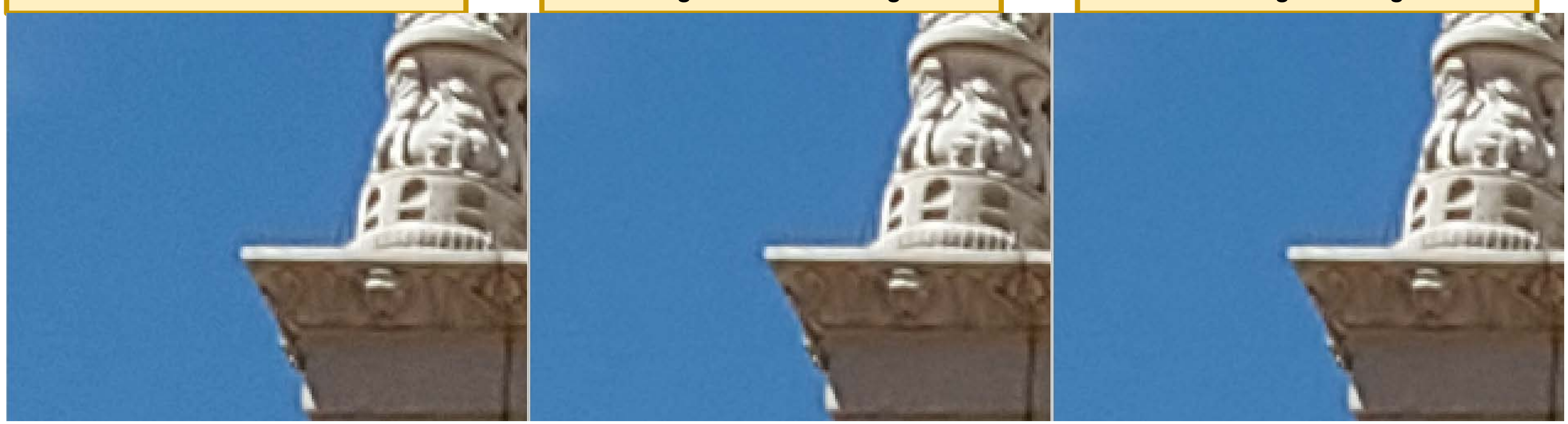
- layer_1_gain_weight_lut

Flat : 1.00f	Bright/Normal setting	Lowlight setting



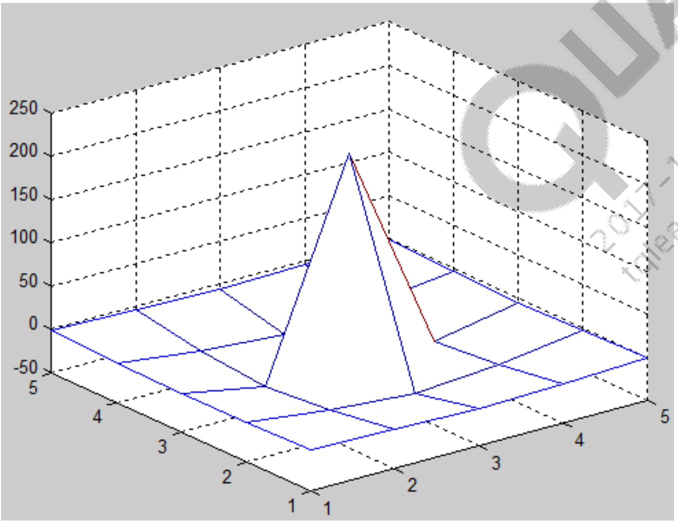
  - Details can be more observed when it is all 1.0 but noise on flat also comes together.

Flat : 1.00f	Bright/Normal setting	Lowlight setting



Step 2.3: Layer 2 Kernel

- layer_2_hpf_symmetric_coeff
  - 2st layer sharpening coefficients
  - Effect: 5x5 kernel on x2 downscaled image and x2 up-sampled
  - Length: 6; Q10
  - Default
    - -1, -4, -6, -16, -24, 220



  - The sum of kernel should be “0”
  - Not recommended to change kernel manually

Step 2.4: Layer 2 Luts

- layer_2_gain_positive_lut[level]
  - Level-based sharpening gain LUT for positive halo

Length	Default	Min	Max	Higher value	Lower value
64	All 0.55f	0.0f	7.9f	Stronger sharpening	Weaker sharpening

  - Weaker gain to avoid thick halo
- layer_2_gain_negative_lut[level]
  - Level-based sharpening gain LUT for negative halo

Length	Default	Min	Max	Higher value	Lower value
64	All 0.55f	0.0f	7.9f	Stronger sharpening	Weaker sharpening

  - Weaker gain to avoid thick halo
- layer_2_gain_weight_lut[activity]
  - Normalized activity-based sharpening gain LUT

Length	Default	Min	Max	Higher value	Lower value
64	From 0.5 to 1.0	0.0f	0.996f	Stronger sharpening	Weaker sharpening

  - Can make lut as same as layer 1

Step 2.4: Layer 2 Examples

- **Layer 1 and layer 2** parameters are the same. But the effect is different.

ASF input

Layer 1 output

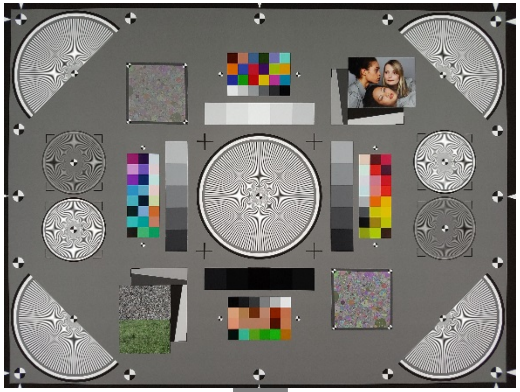
Both Layer 1 and Layer 2 output

Layer 1 only

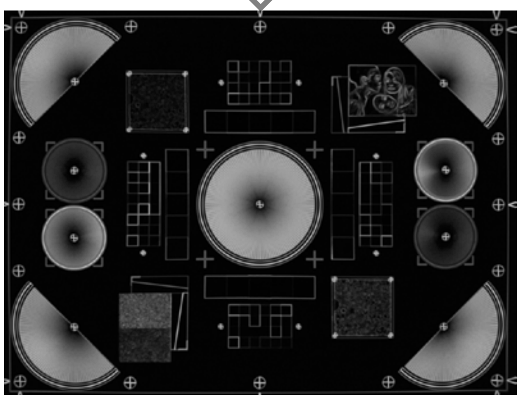
Layer 2 only

Layer 1 + Layer 2

Step 2.5: gain_contrast_positive/negative



Y min max diff

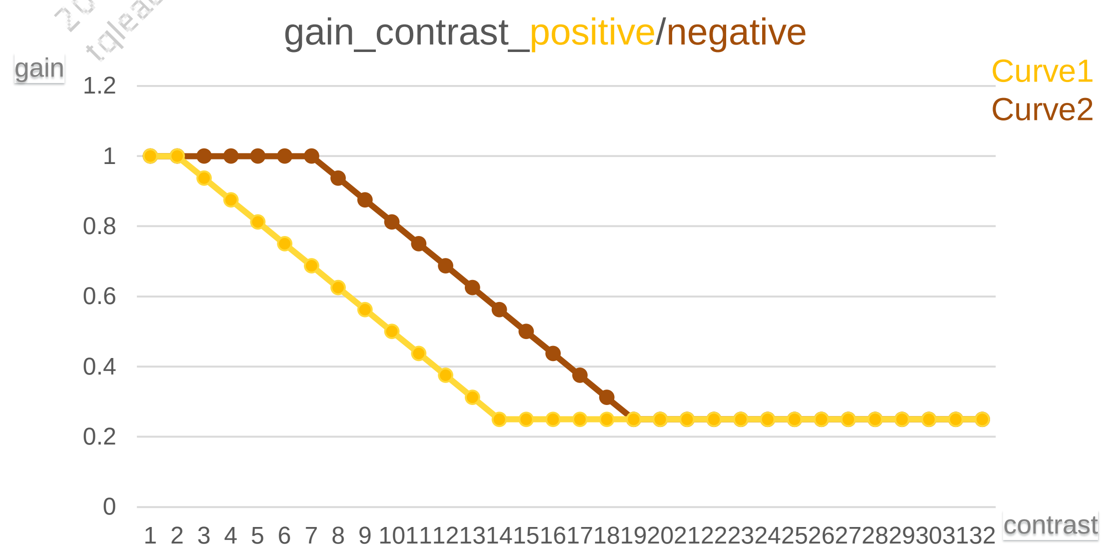


Y min max diff (Q8)
contrast = Y min max diff/4

- gain_contrast_positive/negative [contrast]
  - Contrast-based sharpening gain LUT

Length	Default	Min	Max	Higher value	Lower value
32	From 1.0 to 0.25	0.004f	1.00f	Stronger sharpening	Weaker sharpening

  - Strength control based on contrast
    - Define which area could have halo.
    - Reduce strength on high contrast area.
    - Usually positive halo looks worse than negative halo



Step 2.5: gain_contrast_positive/negative (cont.)

- gain_contrast_positive/negative
  - Curve 1 for gain_contrast_positive
  - Curve 2 for gain_contrast_negative

All 1.0 (contrast control off) | Curve 2 | Curve 1

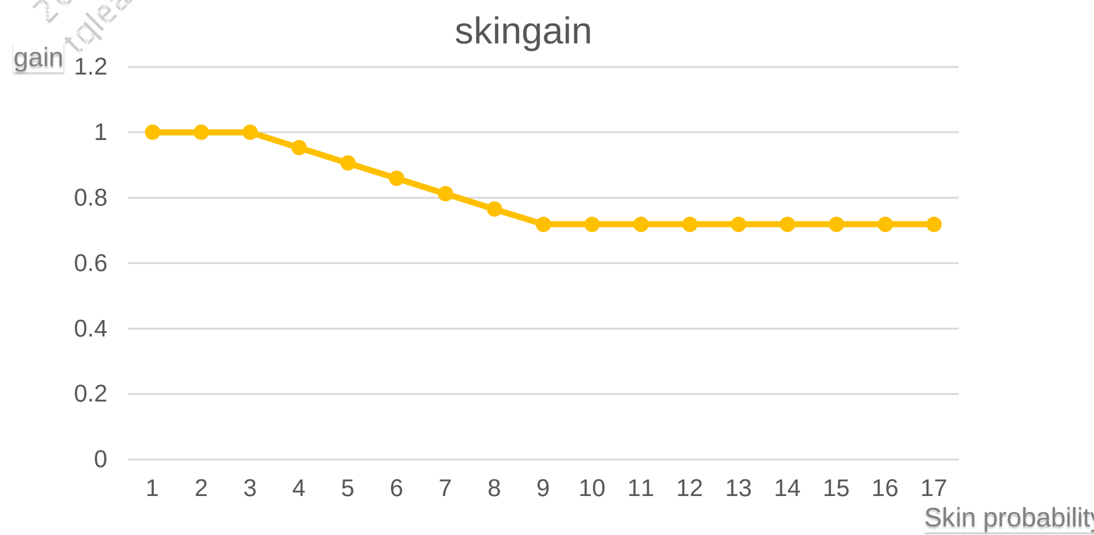
- Try to keep negative edge and reduce only positive by 2 shape of curve on each

Step 2.6: Skingain

- skingain
  - Skin color-based sharpening gain LUT

Length	Default	Min	Max	Higher value	Lower value
17	From 1.0 to 0.76	0.004f	1.00f	Stronger sharpening	Weaker sharpening

  - Strength control based on skin color
    - Define skin color and face.
    - Reduce **gain strength** on face.
    - Face can be smoothed by FD information.
      - Set by face_boundary & face_transition

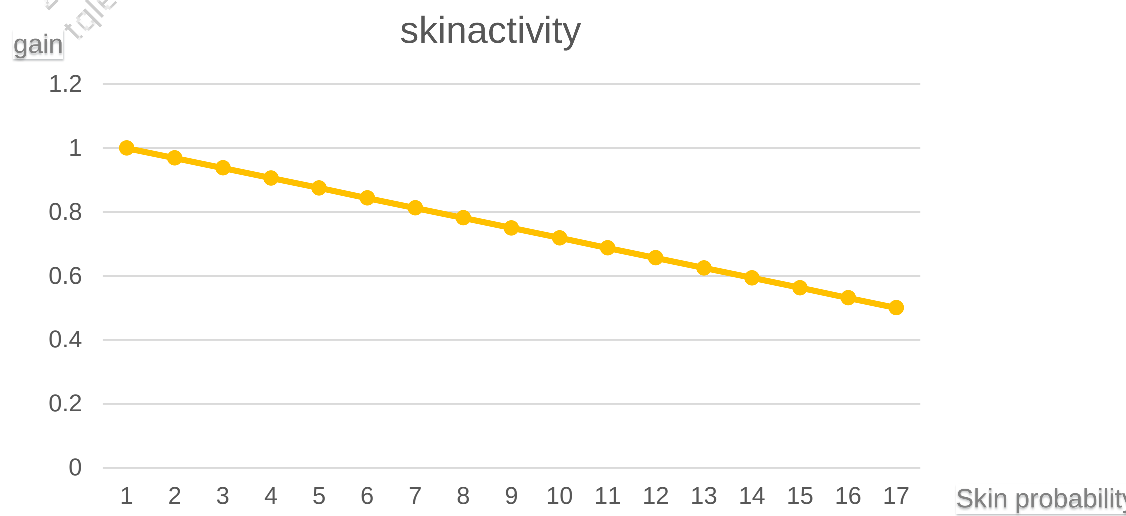


Step 2.7: Skinactivity

- skinactivity
  - Skin color-based sharpening gain activity LUT

Length	Default	Min	Max	Higher value	Lower value
17	From 1.0 to 0.5	0.004f	1.00f	Stronger sharpening	Weaker sharpening

  - Activity strength control based on skin color
    - Define skin color and face.
    - Reduce **activity data** on face.
    - Face can be smoothed by FD information.
      - Set by face_boundary and face_transition



Step 2.8: Skingain and Skinactivity

- skingain & skinactivity
  - Smooth face and keep details on other skin color using FD information.

All 1.0 (skin color control off)	Skin color control on	Skin color control + FD data on

Step 2.9: smoothing_strength

Edge

Texture

Flat

- smoothing_strength
  - Blending factor between original pixel and edge smoothed pixel

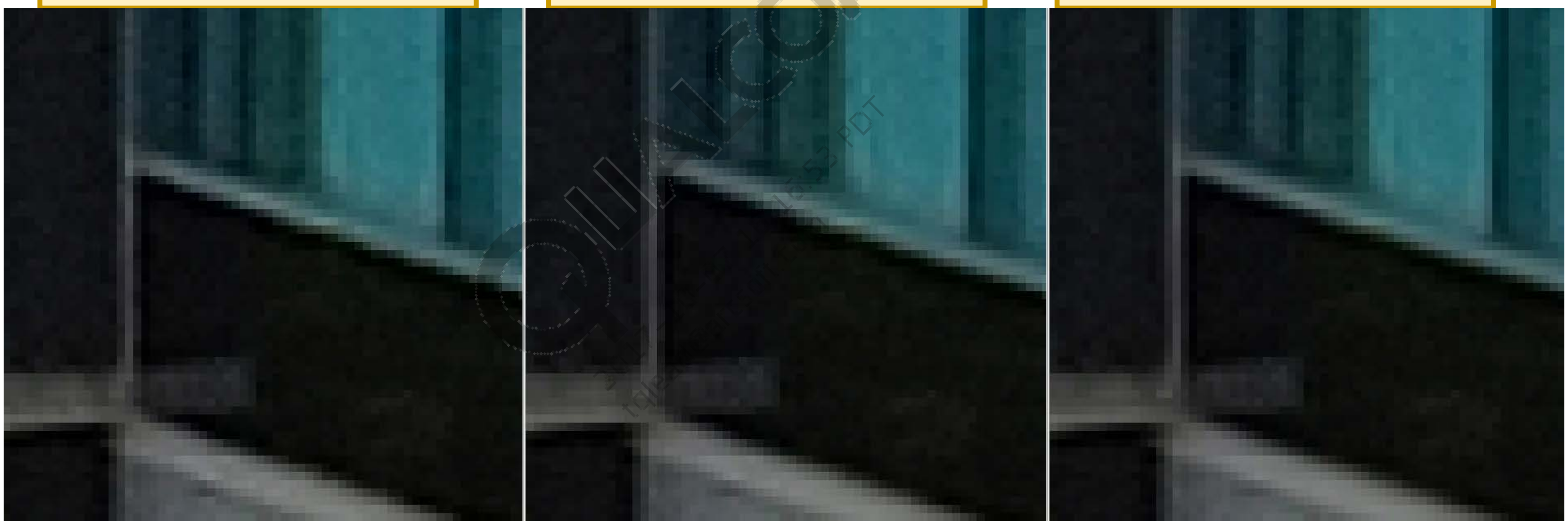
Length	Default	Min	Max	Higher value	Lower value
1	0.5f	0.0f	0.999f	Stronger smoothing	Weaker smoothing

  - Edge will be smoothed by direction.
    - If edge is not detected well by other parameters, this parameter doesn't work.
    - In the left edge map, each color of edge define the each direction of edge.

Step 2.9: smoothing_strength (cont.)

- smoothing_strength
  - Coarse edges are aligned without reducing texture.

Edge alignment off	Edge alignment on strength 1.0	Edge alignment on strength 0.6



  - Details don’t get hurt by edge alignment.

Step 3.1: Clamp

- layer_1_clamp_UL/ layer_2_clamp_UL
  - Manual fixed positive clamping level sharpening

Length	Default	Min	Max	Higher value	Lower value
1	255	0	255	Stronger sharpening	Weaker sharpening

- layer_1_clamp_LL/ layer_2_clamp_LL
  - Manual fixed negative clamping level sharpening

Length	Default	Min	Max	Higher value	Lower value
1	-255	-255	0	Weaker sharpening	Stronger sharpening

- Halo control parameters are preferred to be used first instead of clamp
- Users can tighten clamps as needed at the final step of ASF tuning. Tighter clamps (i.e. smaller absolute value) can reduce halo, producing more natural images, especially for normal/low light conditions.

Step 3.1: Clamp (cont.)

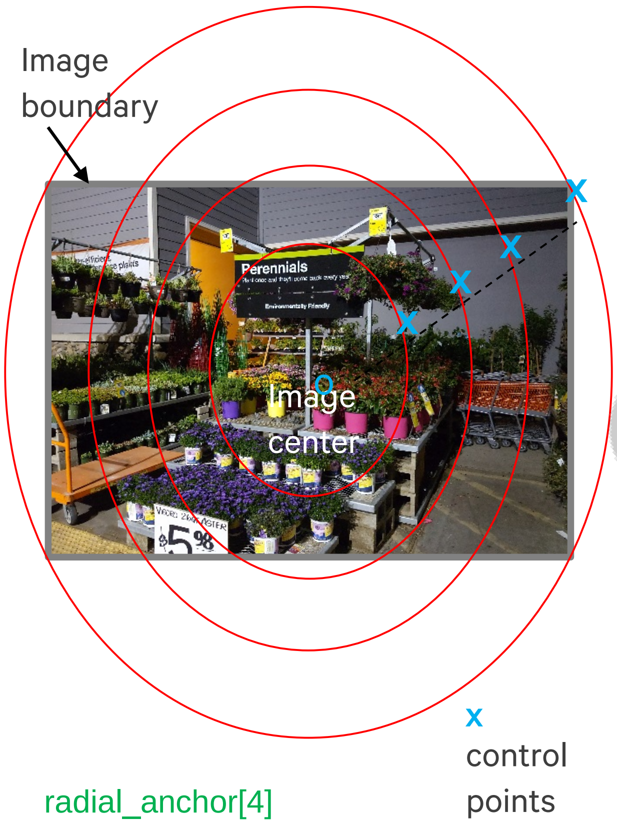
- layer_1_clamp_UL

255	16	8

- layer_1_clamp_LL

255	16	8

Step 3.2: Radial



radial_anchor[4]
= {r1, r2, r3, r4}
= {0.2500, 0.5, 0.75, 1.00}
// percentage of the image

r4 is always at the corner which is 1

- radial_activity_adj
  - Correction factor for activity based on radial distance

Length	Default	Min	Max	Higher value	Lower value
4	From 1.0 to 0.6	0.0f	7.96f	Stronger sharpening	Weaker sharpening

  - Apply to activity
  - {1.0, 1.0, 0.8, 0.6}
- radial_gain_adj
  - Correction factor for gain based on radial distance

Length	Default	Min	Max	Higher value	Lower value
4	From 1.0 to 1.0	0.0f	7.96f	Stronger sharpening	Weaker sharpening

  - Apply to gain
  - {1.0, 1.0, 1.0, 1.0}
- Both parameters can be increased to enhance edge at corner

Step 3.2: Radial (cont.)

- Center details are the same and corner noises are removed

Corner: all 1.0

Corner: both activity/ gain

Center: all 1.0

Center: both activity/ gain

radial_activity_adj
{1.0, 0.8, 0.6, 0.2}
radial_gain_adj
{1.0, 0.8, 0.6, 0.2}

Note: Refer radial calibration document for detail

Step 3.2: Radial (cont.)

radial_activity_adj
{1.0, 1.0, 1.0, 1.0}
radial_gain_adj
{1.0, 0.8, 0.6, 0.2}

Corner: gain adjust only

radial_activity_adj
{1.0, 0.8, 0.6, 0.2}
radial_gain_adj
{1.0, 1.0, 1.0, 1.0}

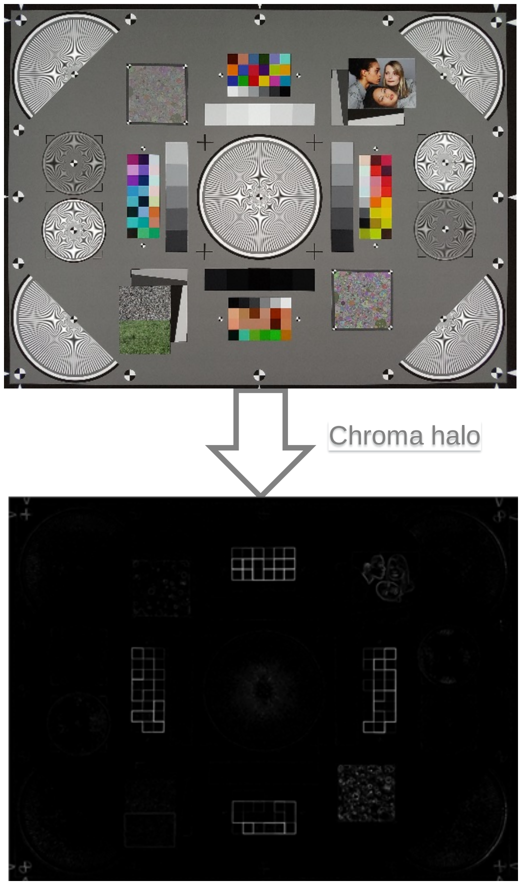
Corner: activity adjust only

radial_activity_adj
{1.0, 0.8, 0.6, 0.2}
radial_gain_adj
{1.0, 0.8, 0.6, 0.2}

Corner: both activity/ gain adjust

- To preserve details at image corner, using of activity adjustment for radial processing is recommended

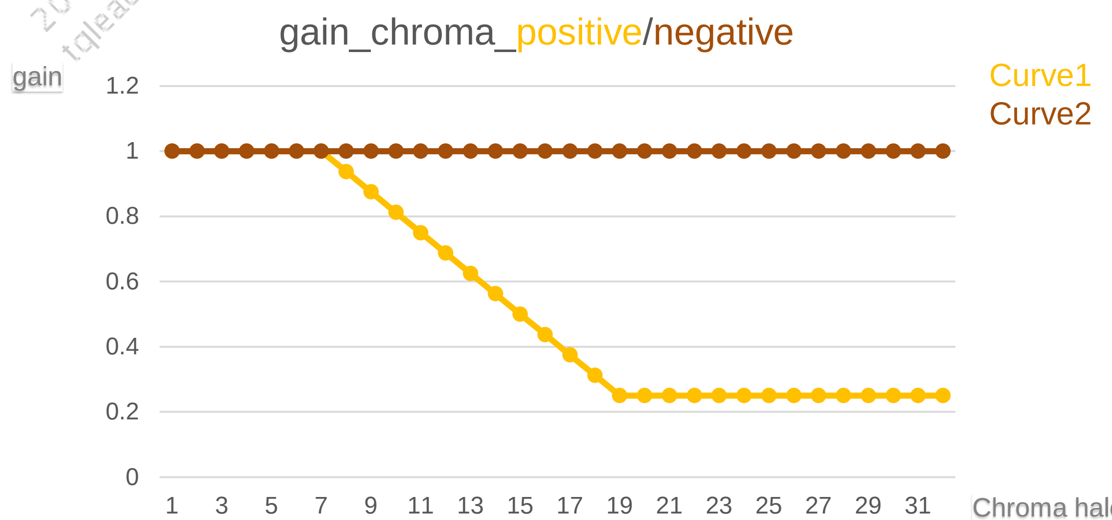
Step 3.3: gain_chroma_positive/negative



- gain_chroma_positive/negative[chroma_halo]
  - Contrast-based sharpening gain LUT

Length	Default	Min	Max	Higher value	Lower value
32	From 1.0 to 0.25	0.004f	1.00f	Stronger sharpening	Weaker sharpening

  - Strength control based on chroma edge
    - Define which area could have halo around chroma.
    - Reduce strength around chroma edge when there is no contrast. (usually chroma to chroma)
    - Mainly used for positive halo control around chroma



Step 3.3: gain_chroma_positive/negative (cont.)

- gain_chroma_positive/negative
  - Curve 1 for gain_chroma_positive/Curve 2 for gain_chroma_negative
  - Negative halo helps to keep contrast.

All 1.0 (chroma halo control off)

Curve 1 for both posi/nega

Curve 1 for posi/ Curve 2 for nega

Step 3.4: Edge Alignment Threshold

Edge direction

Edge

Texture

Flat

- flat_threshold
  - Apply edge smoothing only when max of each edge value is larger or equal to flat_threshold

Length	Default	Min	Max	Higher value	Lower value
1	8	0	255	Less edge detection - Less smoothing	More edge detection - More smoothing

  - If you increase this threshold, edge will not be detected and edge smoothing will not work on flat

Step 3.4: Edge Alignment Threshold (cont.)

similarity_threshold (corner_threshold)
2 -> 10

Edge

Texture

Flat

More texture observed than edge

- similarity_threshold (corner_threshold)
  - Edge smoothing value is applied only when max >= min * similarity_threshold (corner_threshold)

Length	Default	Min	Max	Higher value	Lower value
1	2	0	63.999f	Less edge detection - Less smoothing	More edge detection - More smoothing

  - Gray color is edge similarity with other direction so it doesn't get smoothed. Considered as texture.
- texture_threshold (max_smoothing_clamp)
  - Edge smoothing value change is clamped by texture_threshold (max_smoothing_clamp)

Length	Default	Min	Max	Higher value	Lower value
1	8	0	255	Stronger smoothing	Weaker smoothing

  - Clamping of edge smoothing

How to Coordinate with Other Modules

- Tune as a last module
- Enable ASF with defaults when tuning NR modules
  - To check artifacts and noise patterns more obvious
- To check if how much noise level is amplified by ASF
  - Maybe disable ASF during NR tuning
  - The starting level of activity LUT determines the high-frequency noise amplification level in ASF. This value needs to be considered together with NR modules.
- To remove zigzag pattern amplified by ASF
  - Tune GIC and ABF blocks to remove it in bayer firstly
- To enhance edge more strong with max ASF gain
  - Reduce NR strength near edge
- To enhance corner details
  - Reduce radial noise reduction in NR blocks firstly
- To make flat area noise pattern more natural
  - Use Grain block instead of increasing ASF gain on flat area

Test Plan

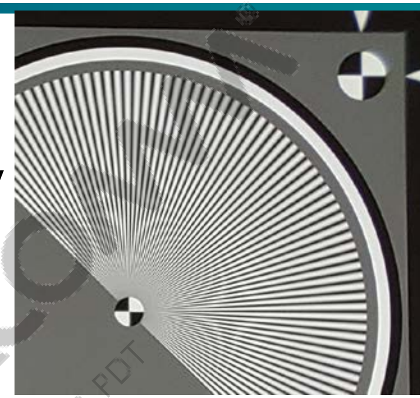
- Enable/Disable flags — If disabled
  - layer_1_enable; — 1st layer totally disable
  - layer_2_enable; — 2nd layer totally disable
  - radial_enable; — do not apply gain for radial location
  - contrast_enable; — do not apply gain for contrast
  - chroma_gradient_enable; — do not apply gain for chroma gradient
  - skin_enable; — do not apply gain for skin
  - face_enable; — do not use face detection data for skin
  - edge_alignment_enable; — do not smooth edge

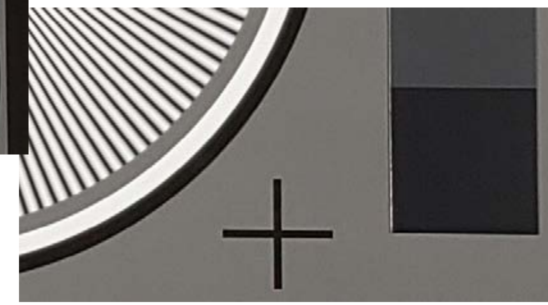
- To bypass ASF using parameters
  - layer_1_clamp_UL/ layer_2_clamp_UL = 0
  - layer_1_clamp_LL/ layer_2_clamp_LL = 0
  - layer_1_sp = 0
  - smoothing_strength = 0
  - The effect is same as ASF disable

Test Plan (cont.)

- How to confirm this module works normally
  1. Take TE42 image
  2. Check if flat area has no dots or artifact by this block
  3. Check if details are good enough to see
  4. Check if the edge is strong enough
  5. Check if corner looks not noisy or less sharpened
  6. Check if halo is not observed
  7. Check if skin looks smooth

- Test images
  - Resolution chart
  - All light conditions (outdoor/ indoor/ lowlight/ very lowlight from 1500lux to 4lux)
    - This module is sensitive to noise. All light condition should be carefully tuned.
  - High frequency components
    - trees, bushes, skies, roads, and rocks to check for artifacts





Upscaler

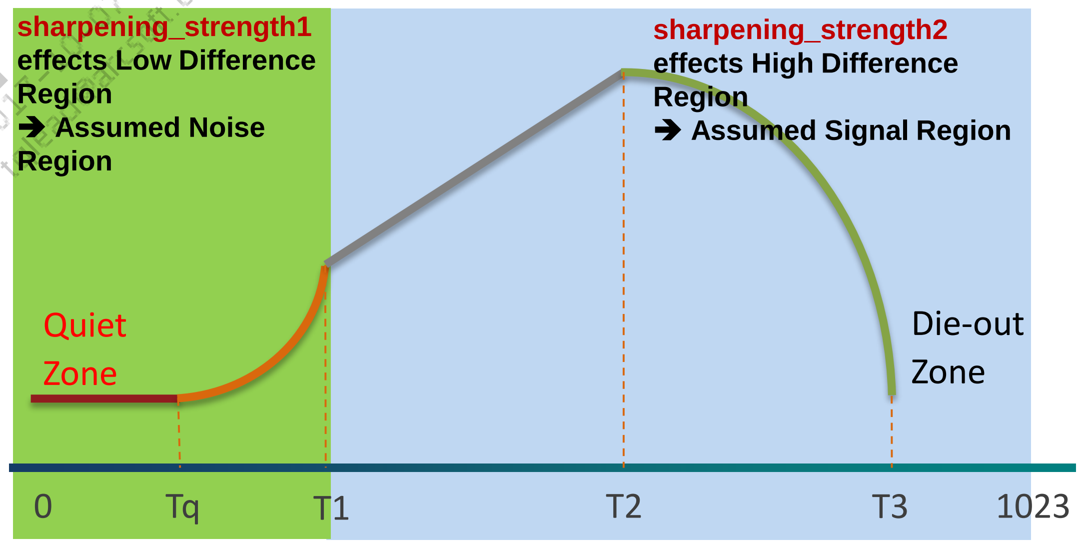
Background

- Detail enhancer in upscaler
  - Detail enhancer, based on direction detection
    - Sharpening = Original + details in original image extracted by unsharp mask

$$Y = X + \alpha \boxed{(F_H X)}$$

Tq → tquiet
T1 → decurvet1
T2 → decurvet2
T3 → curverange

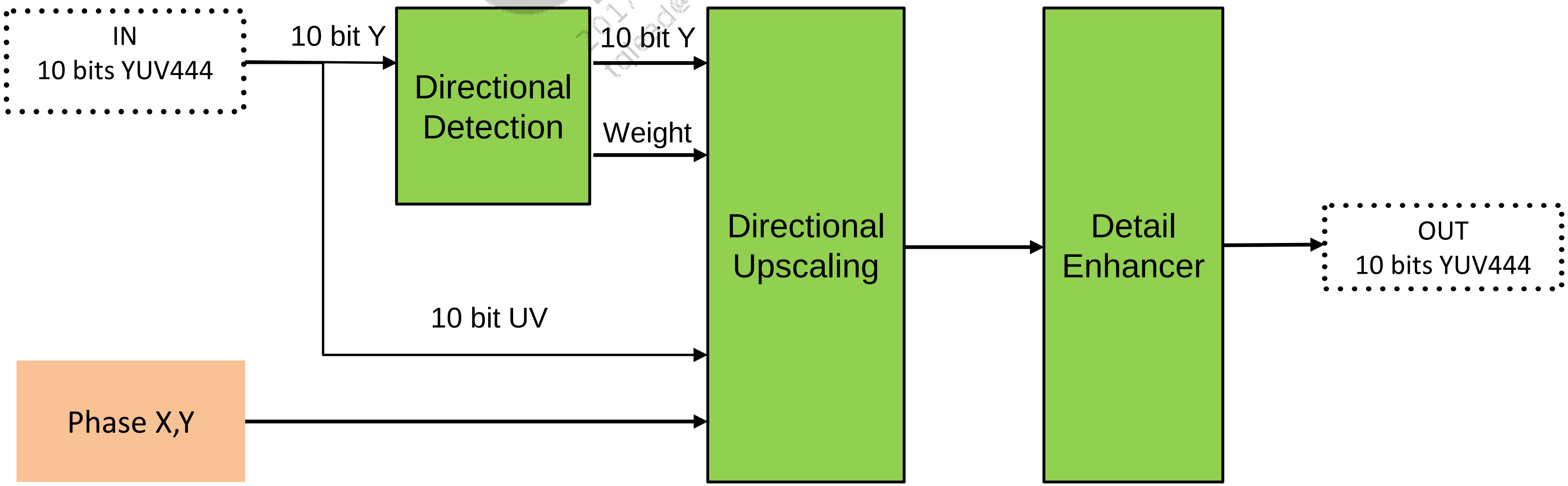
Sharpening strength
sharpening_strength1,
sharpening_strength2



The parameterized mapping curve

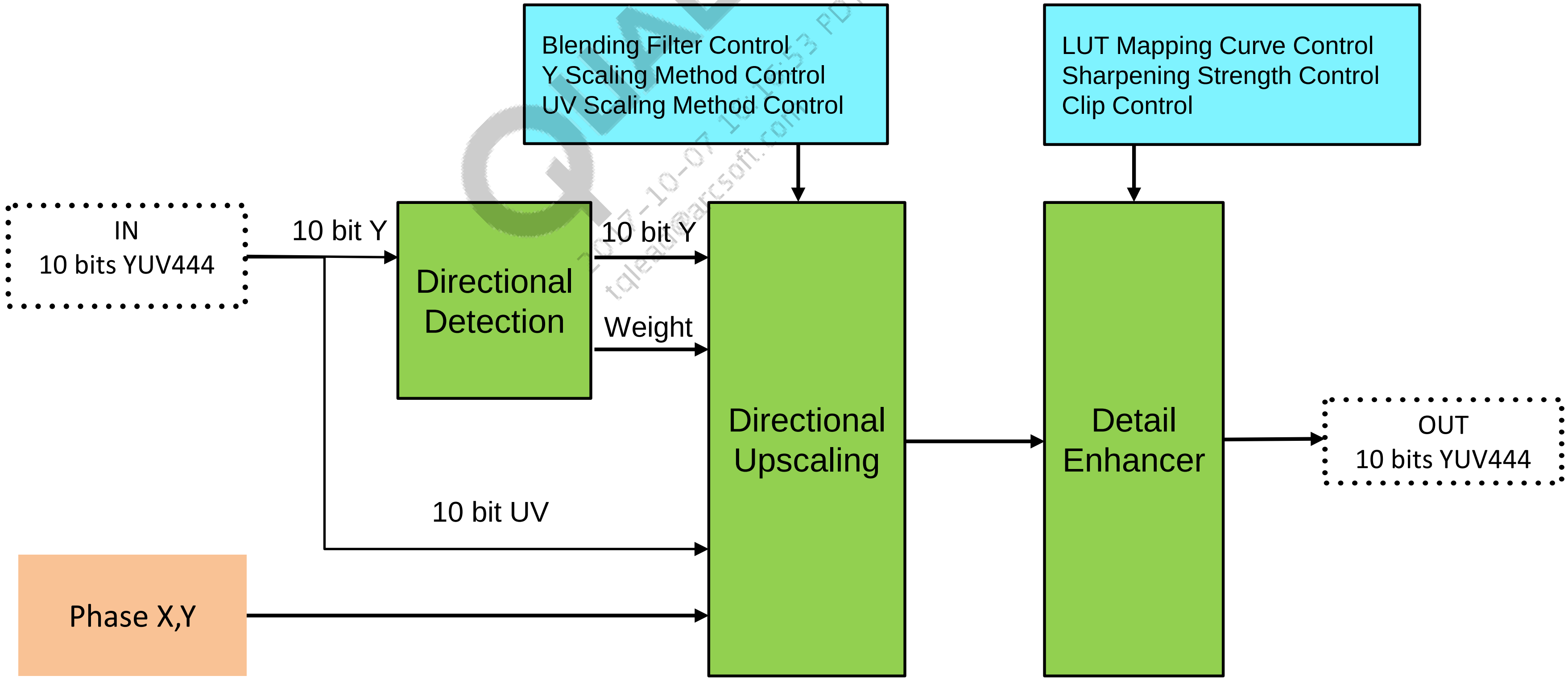
Overview of Algorithm

- Upscaler 2.0 in PPS
  - Performing filtering/scaling/sharpening
  - Using directional filtering to improve quality
  - Sharpening/Smoothing image in detail enhancer
- Supported scaling range is 1×-20× upscaling
- 10bit YUV444 input and 10 bit YUV444 output



Overview of Algorithm (cont.)

- 2D filtering controls: Blending filter, Y scaling method, UV scaling method
- Detail enhancer controls: LUT mapping curve, sharpening strength, clip



Tuning Procedure

1. Set every parameter as default
2. Enable desired features in enable section
3. Tuning important parameters:
   - Upscaling ratio adjustment: **out_width, out_height**
   - Choice of edge-directed blending filter method: **blend_filter**
   - Choice of YUV scaling method: **comp0_filter_method, comp1_2_filter_method**
   - Detail enhancer LUT mapping curve adjustment: **tquiet, decurvet1, decurvet2, curverange**
   - High and low frequency region adjustment: **decurvet1**
   - Sharpening Strength adjustment: **sharpening_strength1, sharpening_strength2**
   - Prevent overshoot : **de_clip_shift**

Step 1: Parameters for Enable Controls

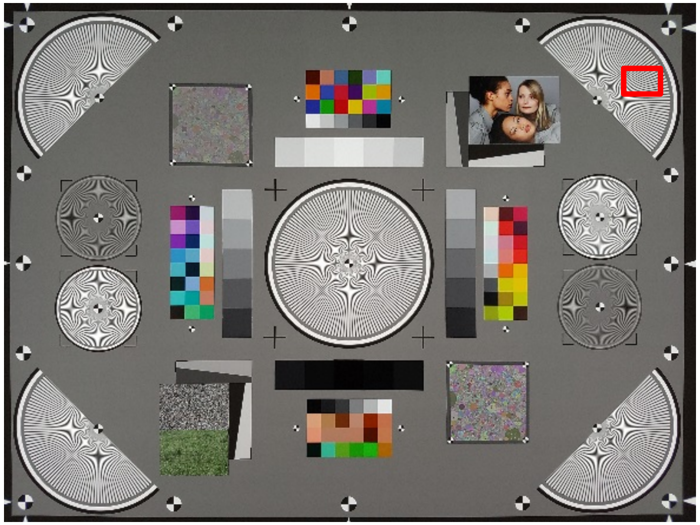
- Parameters in enable section:
  - **upscale_enable**: Upscaler enable
  - **enable**: Detail enhancer enable

Step 2: Upscaling Ratio Adjustment

- **out_width, out_height**
  - Decide upscaling ratio
  - Supported scaling range is 1×-20× upscaling
  - Length: 1
  - Default: Same as input size
  - Effect: Get upscaled image what it is setting

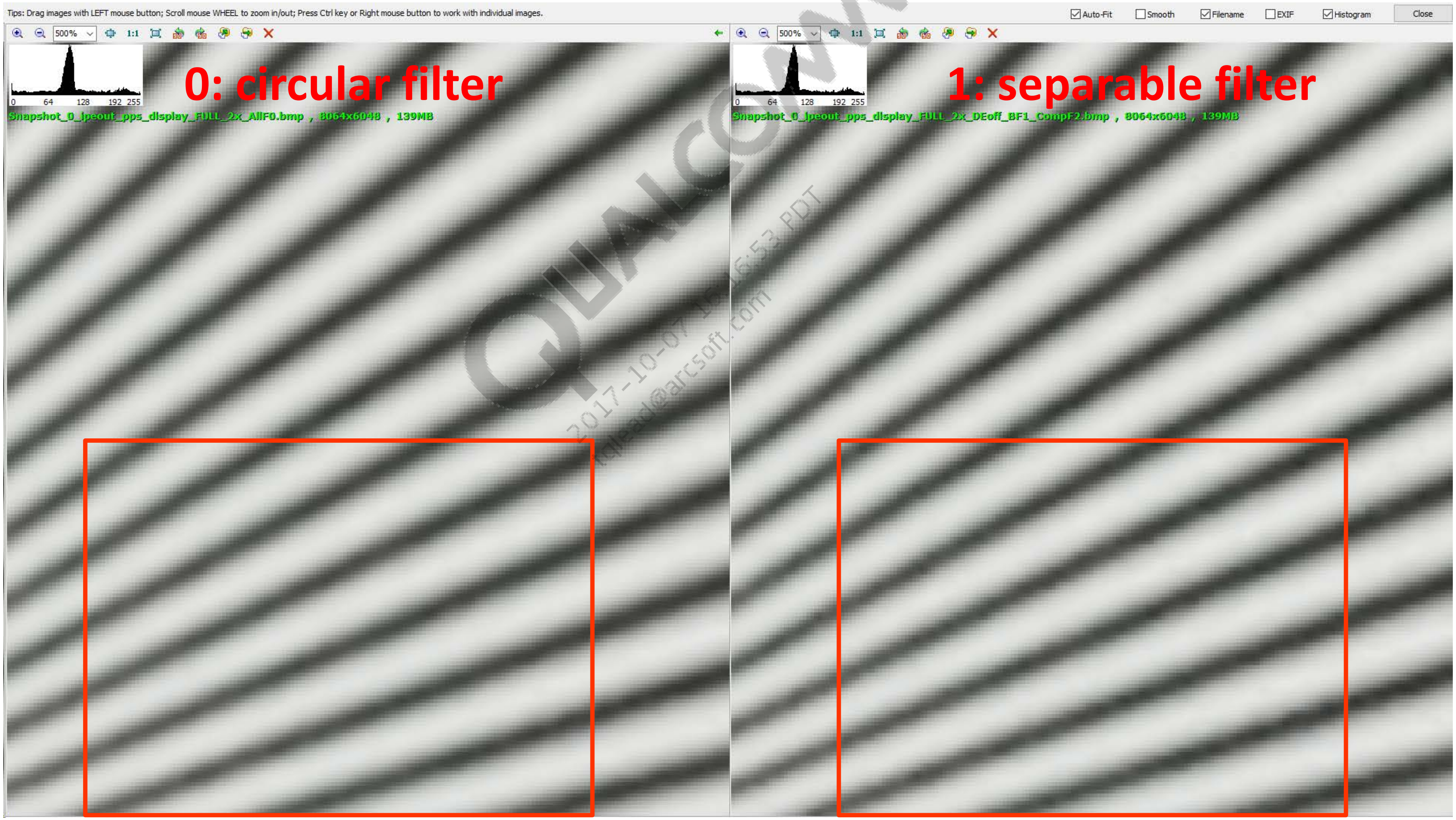
Step 2.1: Choice of Edge-directed Blending Filter Method

- **blend_filter**
  - Chooses the filter that is combined with directional filter to generate filter coefficients for edge-directed interpolation
  - Length: 1
  - Default: 0
  - Min: 0; Max: 1
  - Effect: ‘0’: Circular filter, more directional edge preserved
  - Effect: ‘1’: Separable filter, less directional edge preserved
  - Calibration: none
  - Suggestion: To preserve directional edge, set 0
  - Example: with ×2 scaling ratio, circular filter vs separable filter



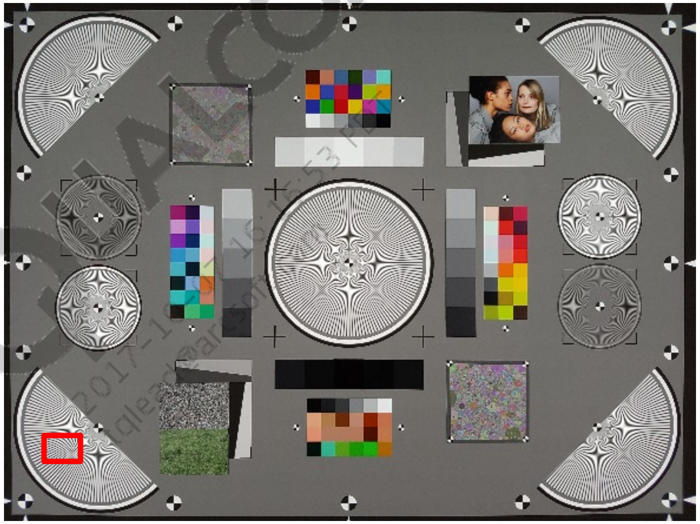
Step 2.1: Choice of Edge-directed Blending Filter Method (cont.)

- blend_filter



Step 2.3: Choice of YUV Scaling Method

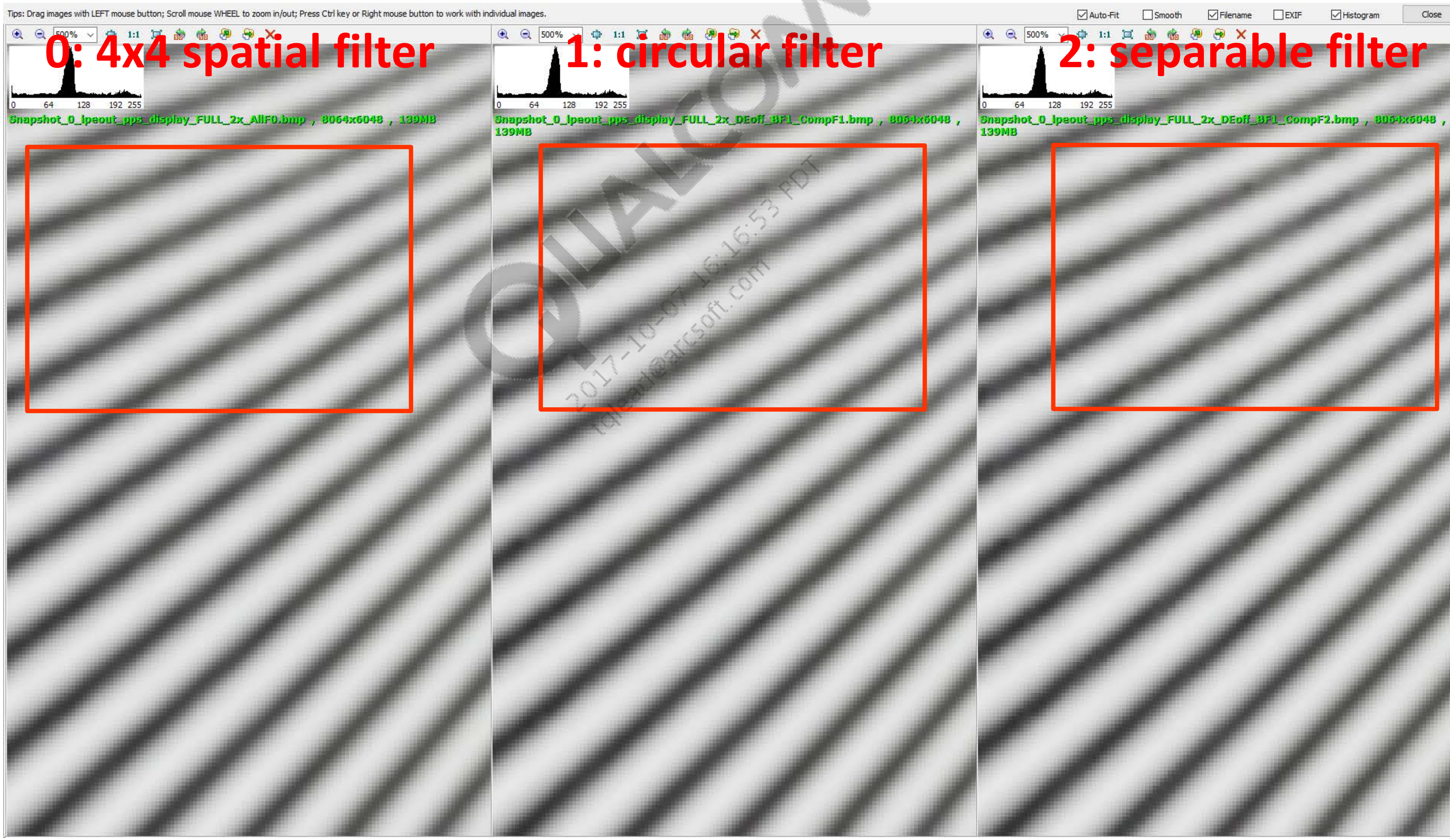
- **comp0_filter_method, comp1_2_filter_method**
  - specifies the scaling method that is applied to Y(**comp0_filter_method),** UV(**comp1_2_filter_method**)component of YUV format
  - Length: 1
  - Default: 0
  - Min: 0; Max: 2



  - Effect: ‘0’ : 2D 4x4 filter > more directional edge preserved
  - Effect: ‘1’ : 2D circular filter > less directional edge preserved than ‘0’
  - Effect: ‘2’ : 1D Separable filter > less directional edge preserved than ‘1’
  - Calibration: None
  - Suggestion: To preserve directional edge, set 0
  - Example: with ×2 scaling ratio, 4×4(directional) vs circular vs separable filter

Step 2.4: Choice of Edge-directed Blending Filter Method

- comp0_filter_method, comp1_2_filter_method



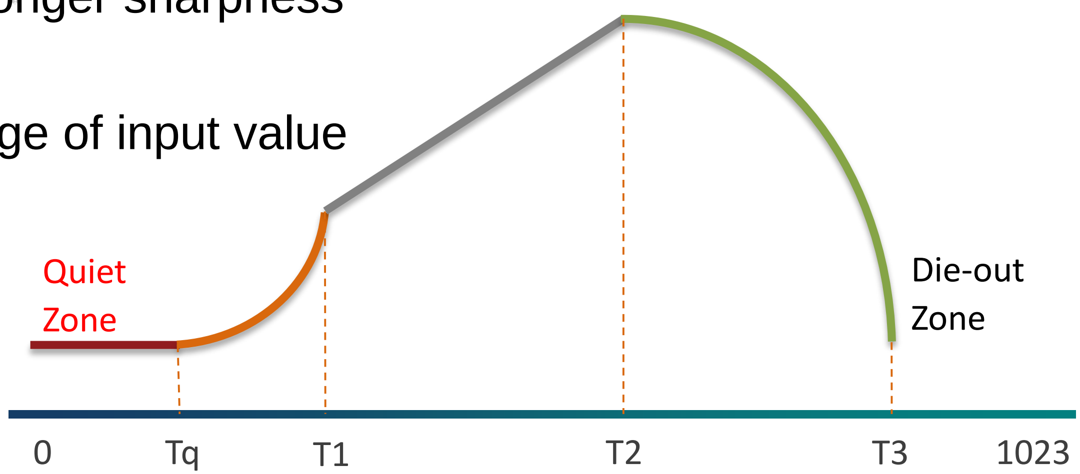
Step 2.5: Detail Enhancer LUT Mapping Curve Adjustment

- **tquiet, decurvet1, decurvet2, curverange**
  - Decide LUT curve for detail enhancer

name	length	Default	min	max
tquiet	1	20	0	255
decurvet1	1	70	tquiet	255
decurvet2	1	150	decurvet1	1023
curverange	1	400	decurvet2	1023

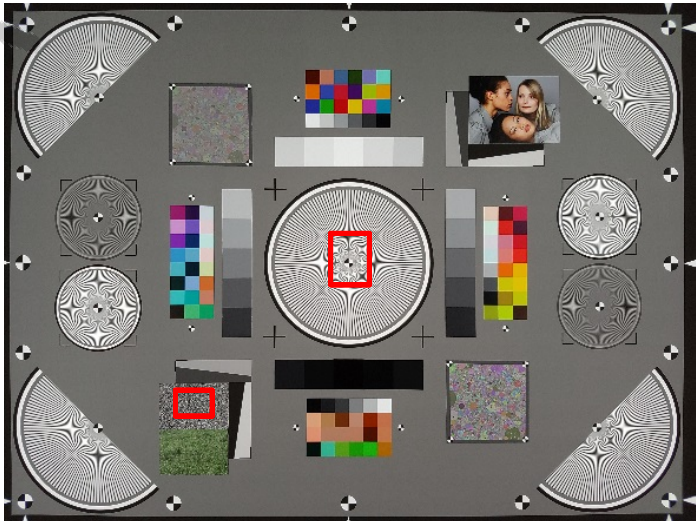
  - Effect: lower values make stronger sharpness
  - Calibration: None
  - Suggestion: Consider the range of input value

Tq → tquiet
T1 → decurvet1
T2 → decurvet2
T3 → curverange



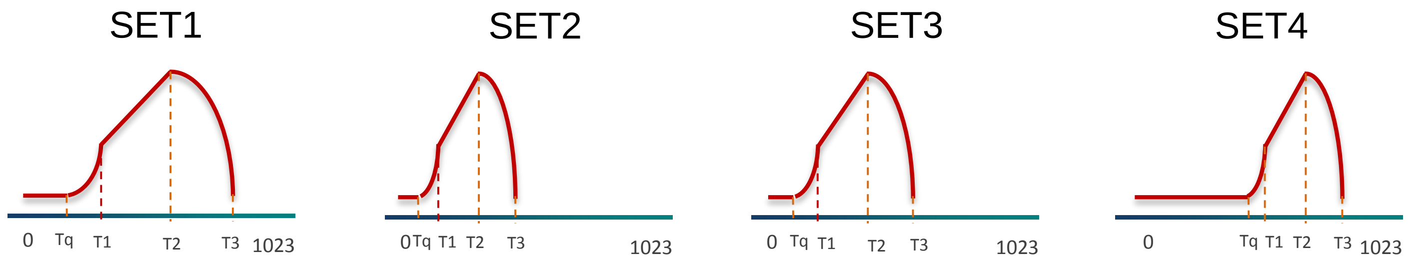
Step 2.5: Detail Enhancer LUT Mapping Curve adjustment (cont.)

- **tquiet, decurvet1, decurvet2, curverange**
  - Examples



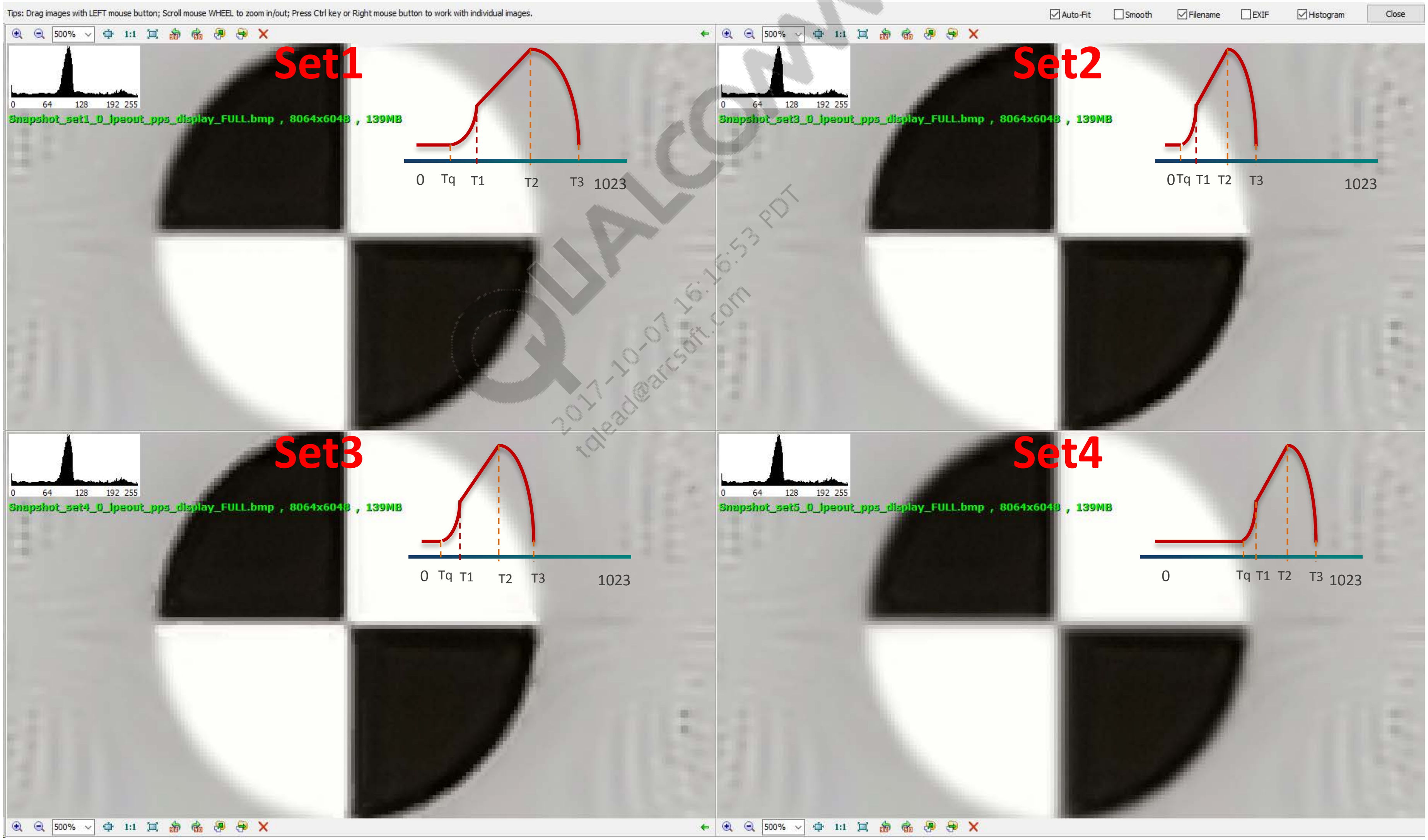
	SET1	SET2	SET3	SET4
Tquiet	10	10	10	400
Decurvet1	150	50	70	600
Decurvet2	550	250	450	850
curverange	950	450	700	950

  - Test images on x2 scaling ratio
  - Fix Sharpening Strength1,2 values on 60



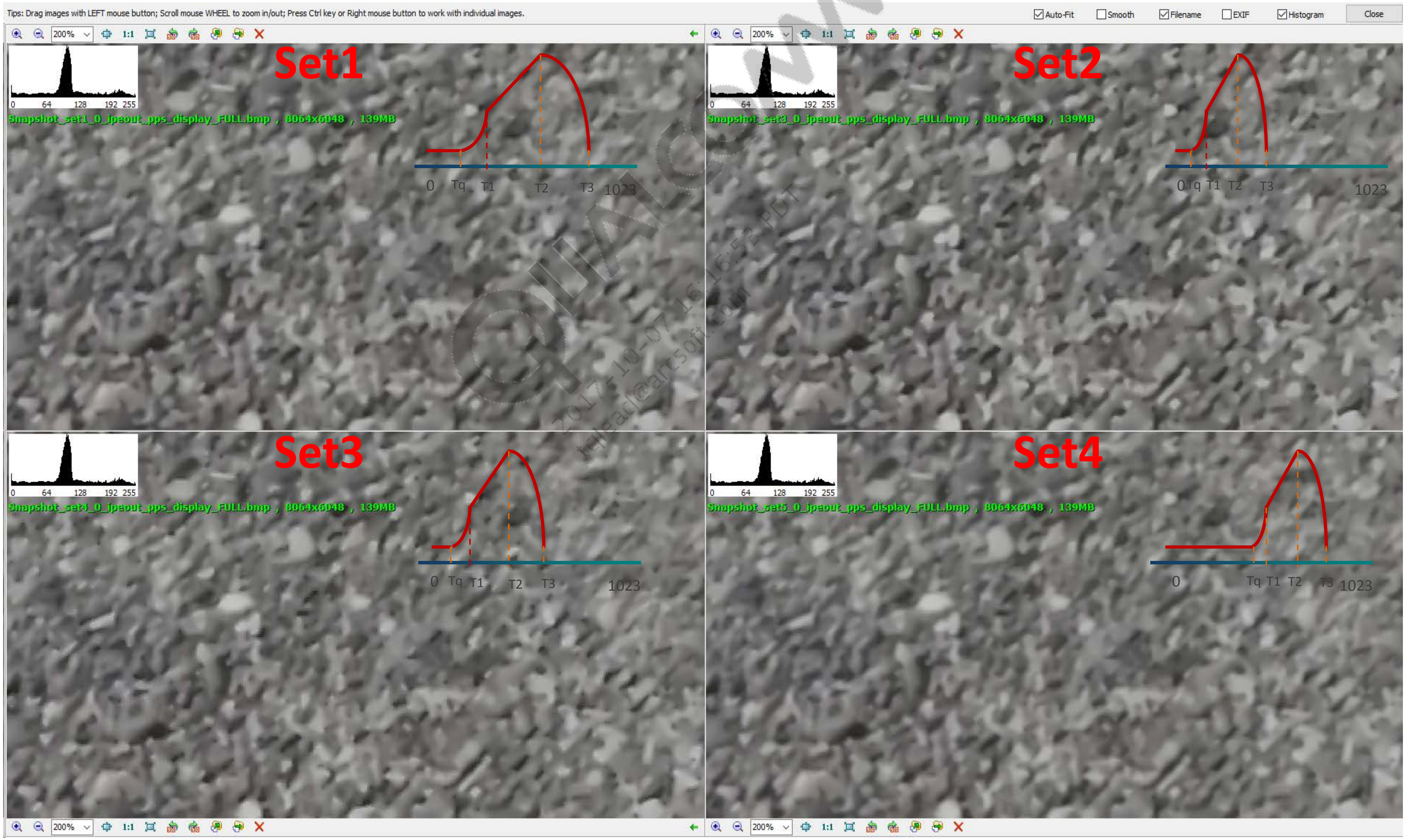
Step 3.4: Detail Enhancer LUT Mapping Curve Adjustment (cont.)

- tquiet, decurvet1, decurvet2, curverange



Step 2.5: Detail Enhancer LUT Mapping Curve Adjustment (cont.)

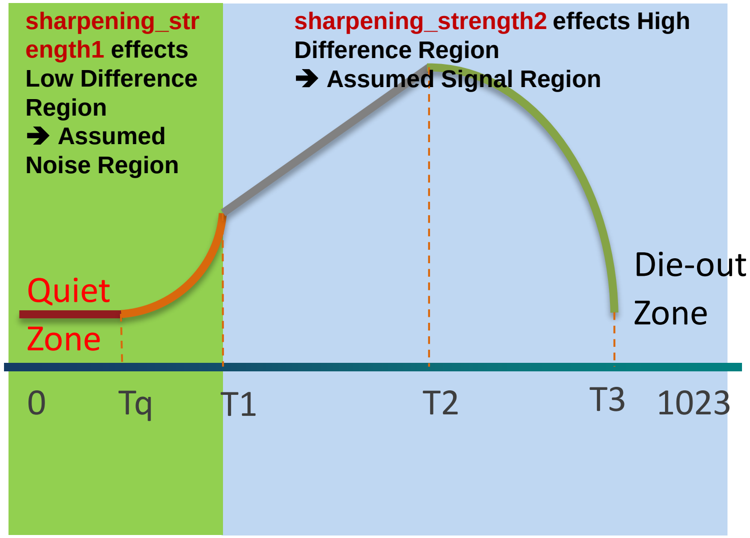
- tquiet, decurvet1, decurvet2, curverange



Step 2.6: High and Low frequency Region Adjustment

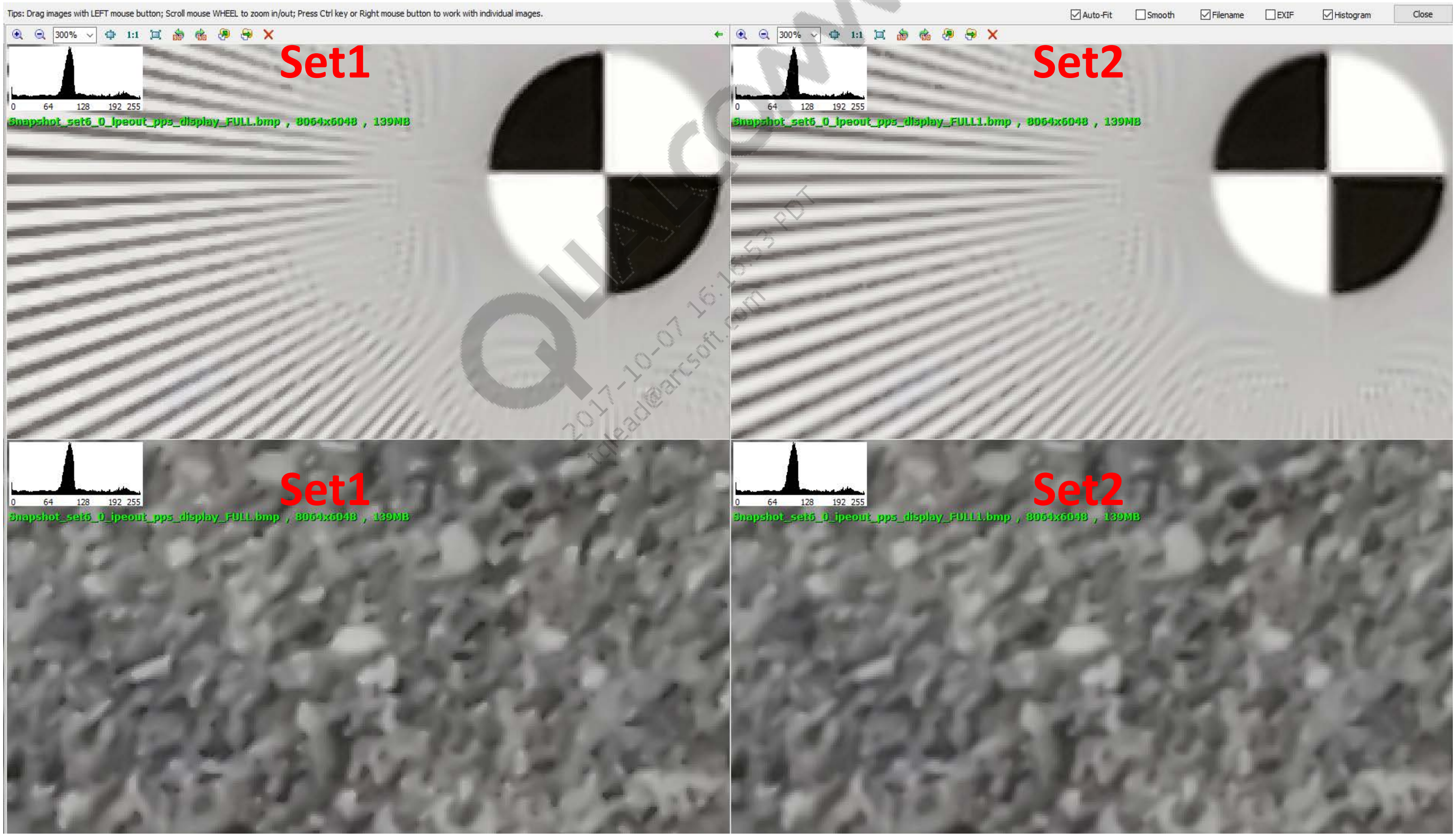
- **decurvet1**
  - Decide the image region between low and high frequency to control sharpness strength
  - ➔ In case of LUT pixel value is $\leq$ **decurvet1, Sharpening_Strength1 effect**
  - ➔ In case of LUT pixel value is $>$ **decurvet1, Sharpening_Strength2 effect**
  - Length: 1
  - Default: 70
  - Min: 0; Max: 255
  - Effect: the low and high difference regions are classified by **decurvet1**
  - Calibration: none
  - Suggestion: Consider low and high diff. region
  - Examples:

	SET1	SET2
Tquiet	10	10
Decurvet1	50	90
Decurvet2	150	150
curverange	400	400
Sharpening_Strength_1	1	1
Sharpening_Streingth_2	50	50



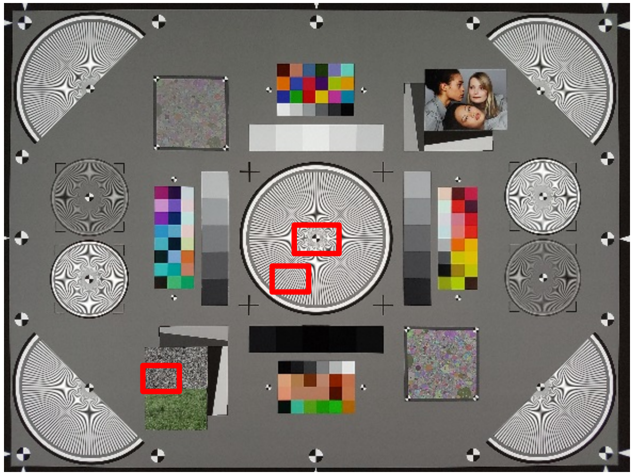
Step 2.7: Sharpening Strength Adjustment

- **decurvet1**



Step 2.8: High and Low Frequency Region Adjustment

- **Sharpening_Strength1, Sharpening_Strength2**
  - Adjust strength according to **decurvet1**
  - Length: 1
  - Default: SS1:40 SS2:40
  - Min: -32; Max: 160
  - Effect(+value): higher value stronger sharpening
  - Effect(-value): lower value stronger smoothing
  - Suggestion:



Sharpening_Strength1 > only effect in the image region of low difference.

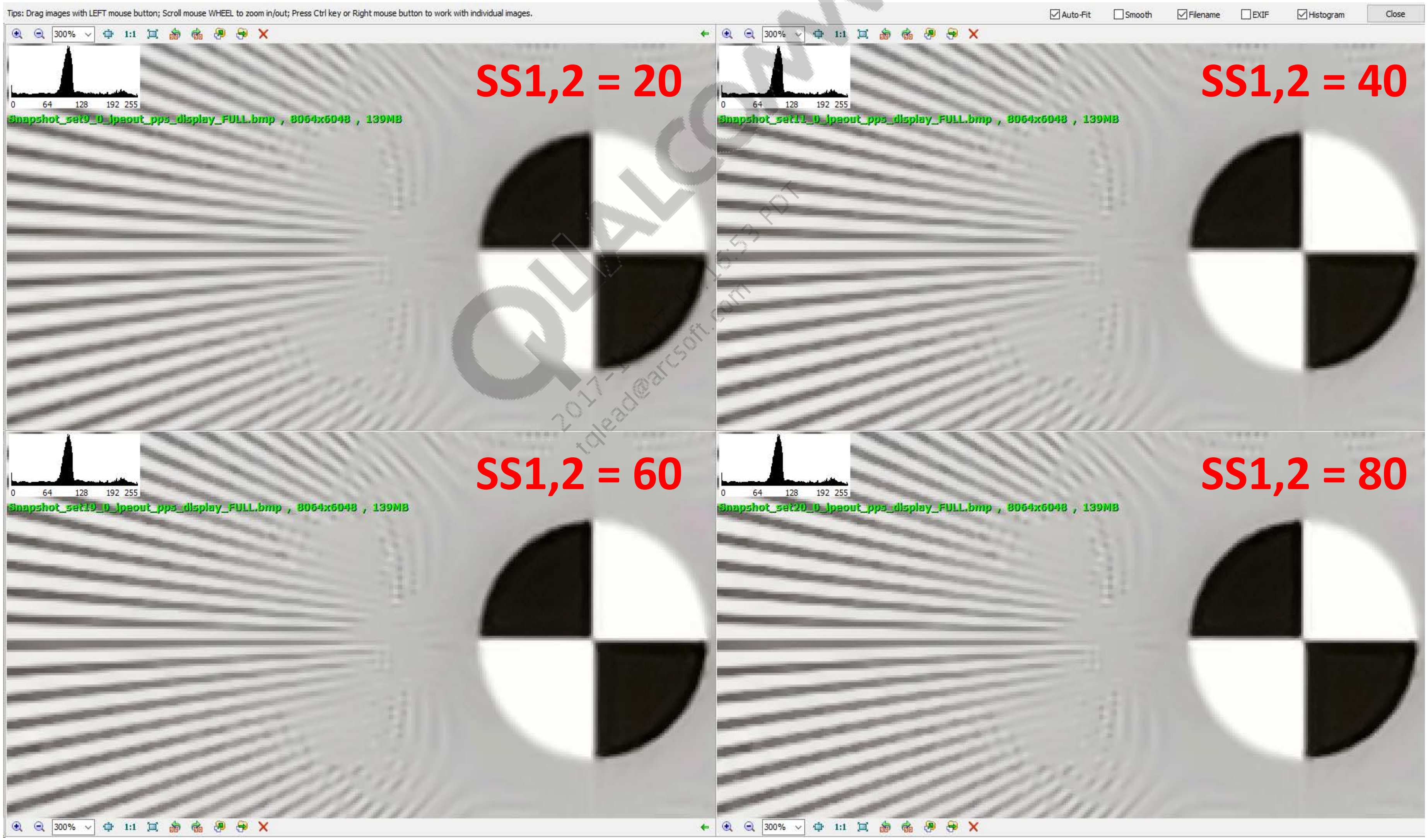
Sharpening_Strength2 > only effect in the image region of high difference.

  - Calibration: None
  - Examples:

	SET1
Tquiet	10
Decurvet1	70
Decurvet2	150
curverange	400
Sharpening_Strength_1	??
Sharpening_Streingth_2	??

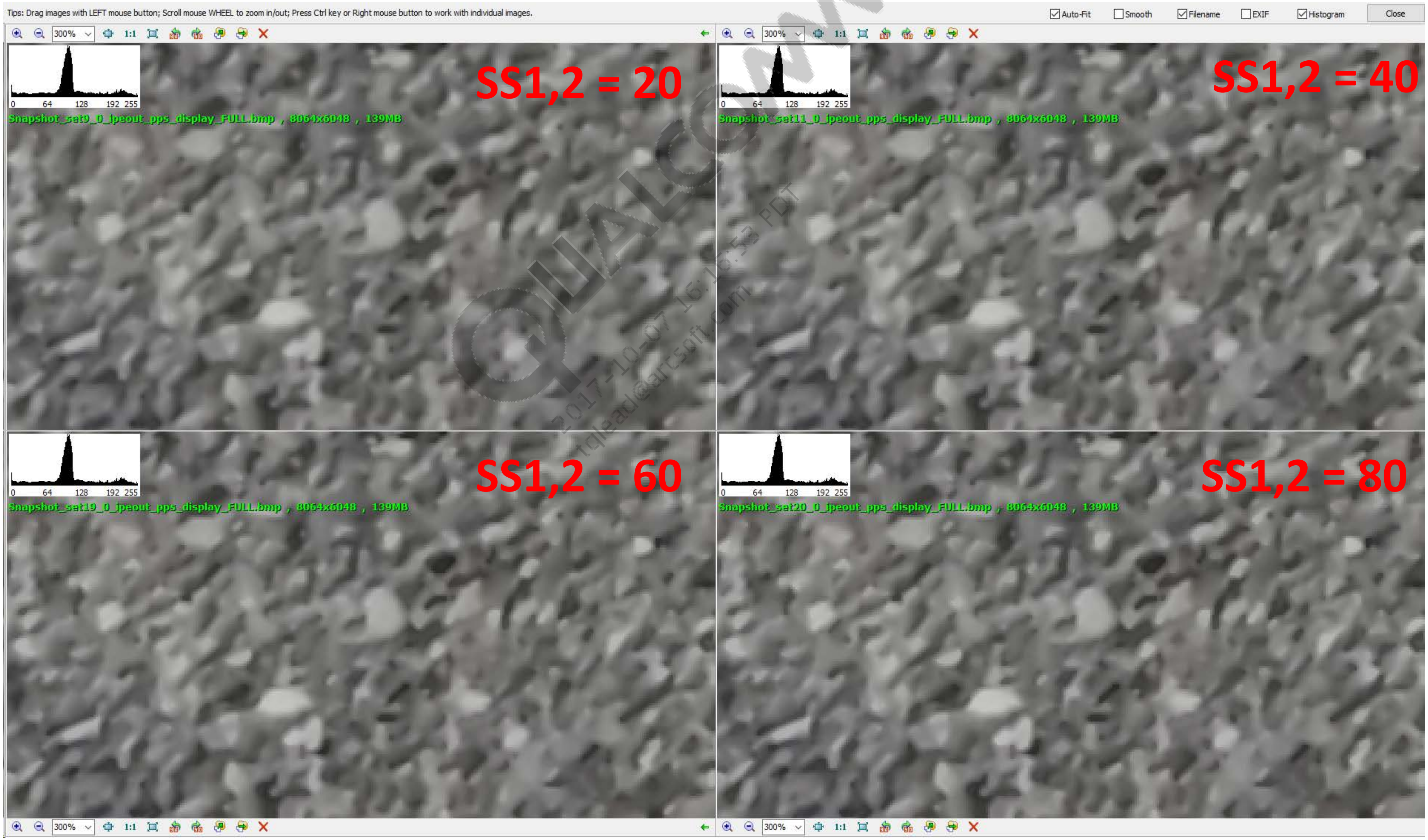
Step 2.9: Sharpening Strength Adjustment

- **Sharpening_Strength1, Sharpening_Strength2**



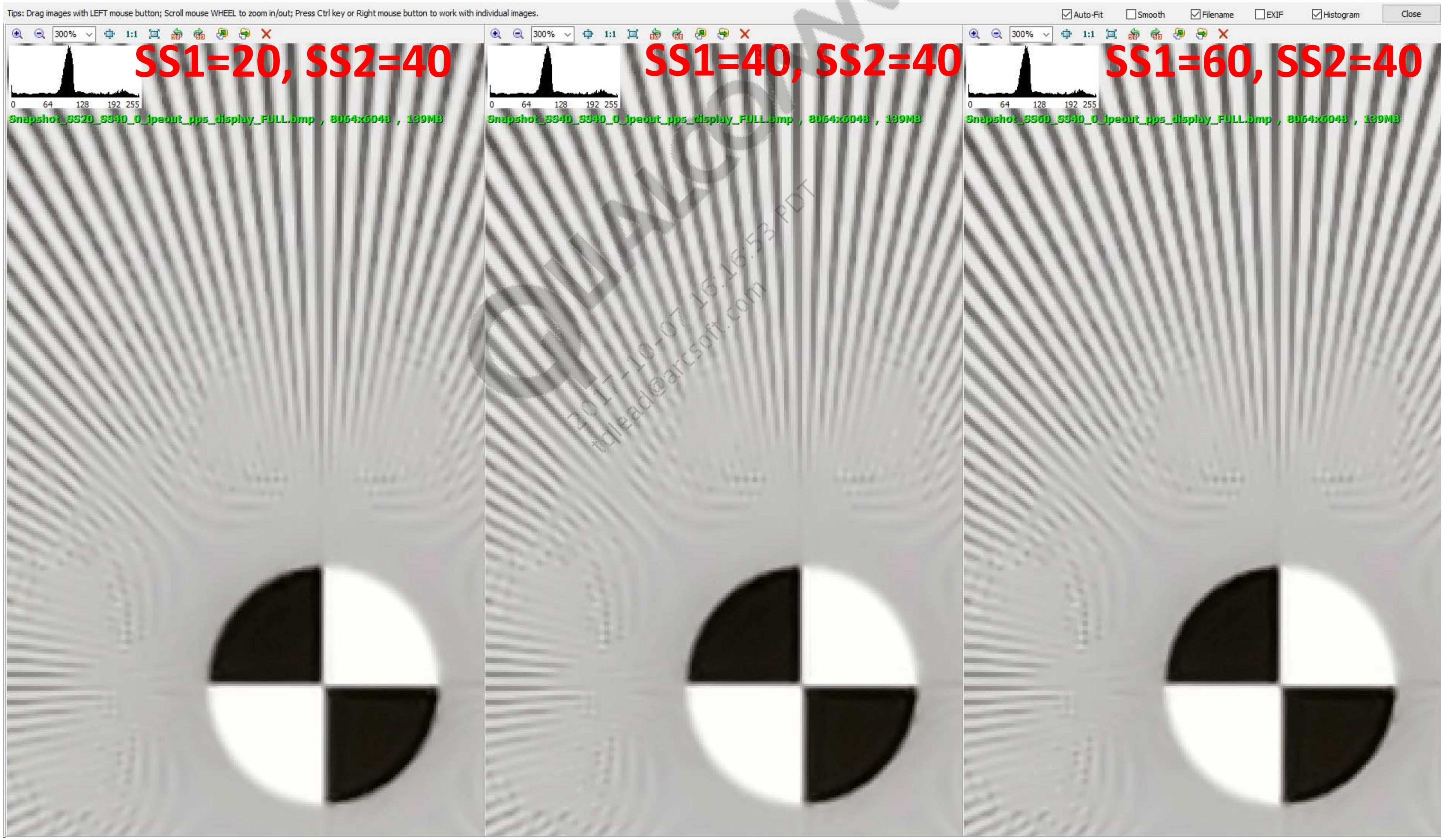
Step 2.9: Sharpening Strength Adjustment (cont.)

- **Sharpening_Strength1, Sharpening_Strength2**



Step 2.9: Sharpening Strength Adjustment (cont.)

- **Sharpening_Strength1, Sharpening_Strength2**

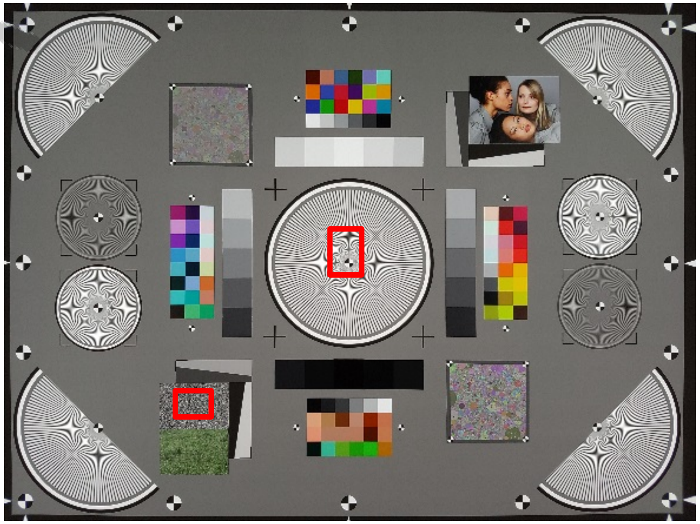


Step 2.9: Sharpening Strength Adjustment (cont.)

- **Sharpening_Strength1, Sharpening_Strength2**

Step 3: Prevent Overshoot

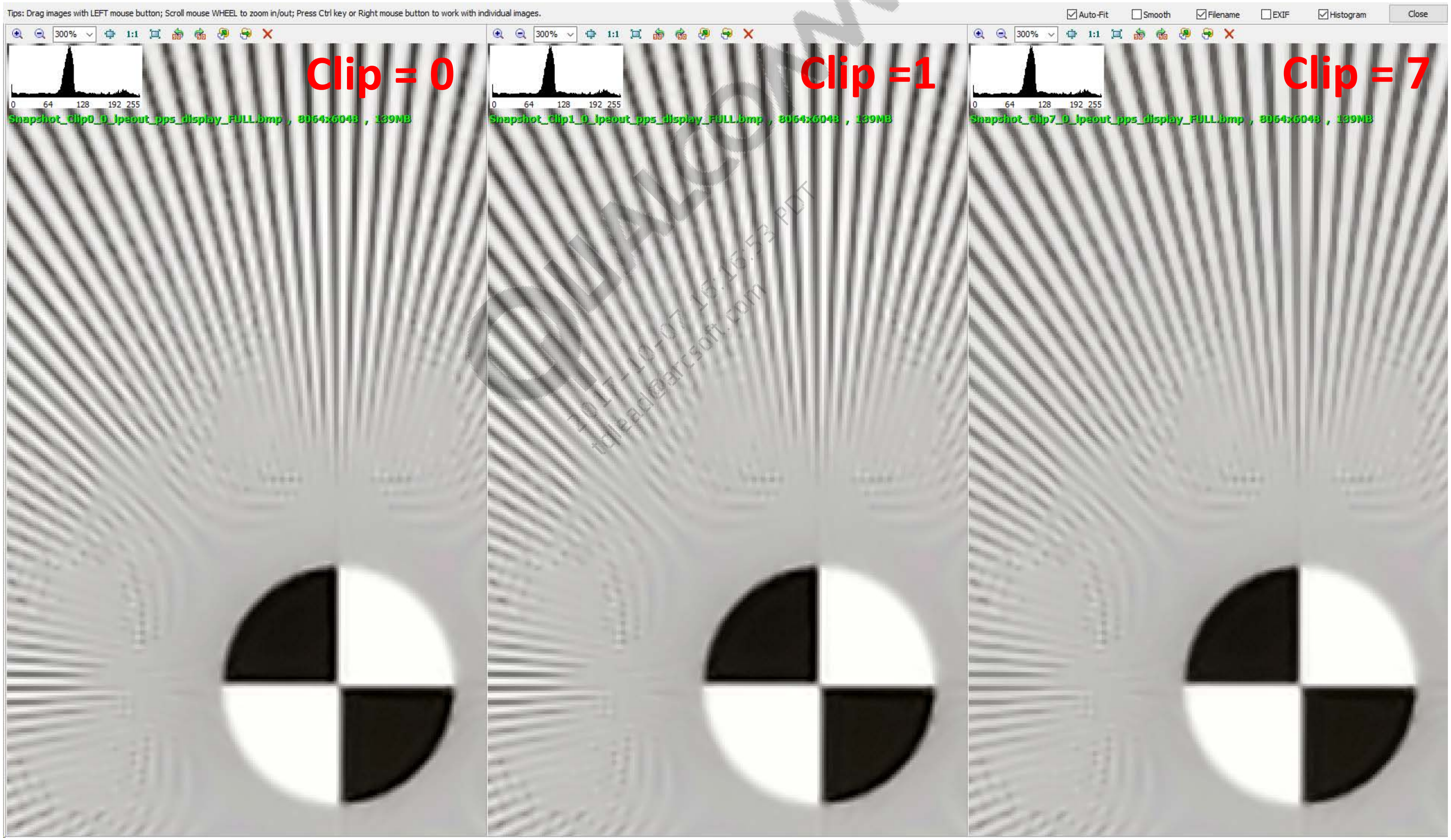
- **de_clip_shift**
  - Prevent overshoot problems
  - Length: 1
  - Default: 7
  - Min: 0; Max: 7
  - Effect: higher value more prevent overshoot
  - Suggestion: Consider the tradeoff Sharpness
  - Calibration: None
  - Examples:



	SET1
Tquiet	10
Decurvet1	70
Decurvet2	150
curverange	400
Sharpening_Strength_1	40
Sharpening_Streingth_2	40
de_clip_shift	0,1,7

Step 3: Prevent Overshoot (cont.)

- de_clip_shift



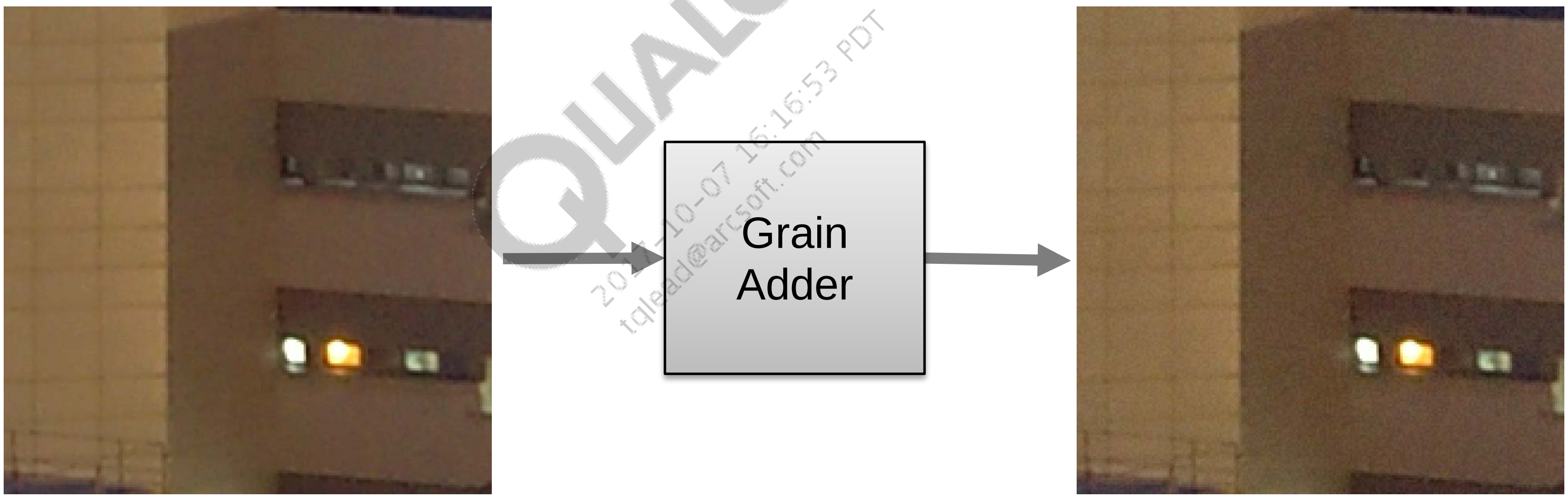
Step 3: Prevent Overshoot (cont.)

- de_clip_shift

Grain Adder (GRA)

Grain Adder – Background

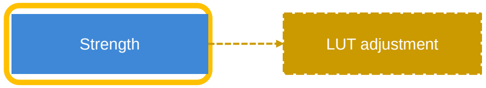
- Grain adder
  - Adds fine granularity to images
  - Can perform dithering



Tuning Flow Diagram

Legend: Basic Advanced

Tuning Steps – Strength Basic



- Strength
  - Controls the amount of grain added the image
    - Higher value = more grain
    - Lower value = less grain

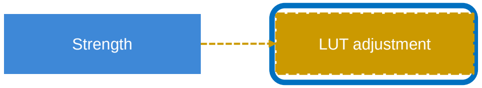
Grain Adder disabled

Strength low

Strength mid

Strength high

Tuning Steps – Strength Advanced



- y_weight_lut
  - 32 entries LUT
  - Change grain strength according to pixel luminance value
  - Higher value= more grain
- cb_weight_lut and cr_weight_lut
  - 32 entries each LUT
  - Change grain strength according to pixel chroma value
  - May be used for applying less grain for example for skin and sky colors
  - Higher value = more gain

How to Coordinate with Other Modules

- Module tuning
  - Should be tuned as the last module in the pipe
- Other module influence
  - Making a change in noise reduction modules (ANR, HNR, TF) may require different grain strength

Questions?

https://createpoint.qti.qualcomm.com