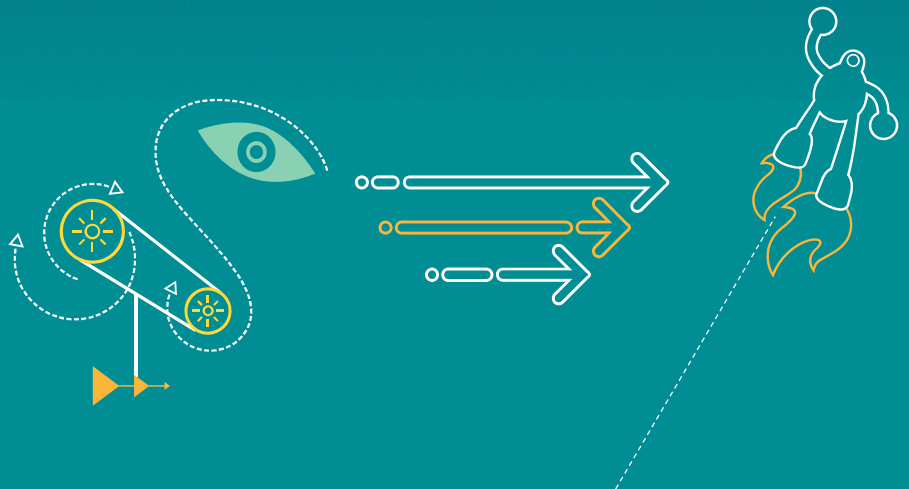
Camera ISP Overview for APQ8084/MSM8992/MSM8994/ MSM8996

Qualcomm Technologies, Inc.



80-NM328-68 D

Confidential and Proprietary – Qualcomm Technologies, Inc.

NO PUBLIC DISCLOSURE PERMITTED: Please report postings of this document on public servers or websites to: DocCtrlAgent@qualcomm.com.

Not to be used, copied, reproduced, or modified in whole or in part, nor its contents revealed in any manner to others without the express written permission of Qualcomm Technologies, Inc.

Chromatix is a product of Qualcomm Technologies, Inc. Other Qualcomm products referenced herein are products of Qualcomm Technologies, Inc. or its subsidiaries.>

Qualcomm is a trademark of Qualcomm Incorporated, registered in the United States and other countries. Chromatix is a trademark of Qualcomm Incorporated, registered in the United States and other countries. All Qualcomm Incorporated trademarks are used with permission. Other product and brand names may be trademarks or registered trademarks of their respective owners.

This technical data may be subject to U.S. and international export, re-export, or transfer (“export”) laws. Diversion contrary to U.S. and international law is strictly prohibited.

Qualcomm Technologies, Inc.
5775 Morehouse Drive
San Diego, CA 92121
U.S.A.

Revision History

Revision	Date	Description
A	August 2014	Initial release
B	November 2014	Added MSM8992 information
C	February 2015	Added MSM8996 information
D	July 2015	Updated slide 5

Contents

Camera System Comparison

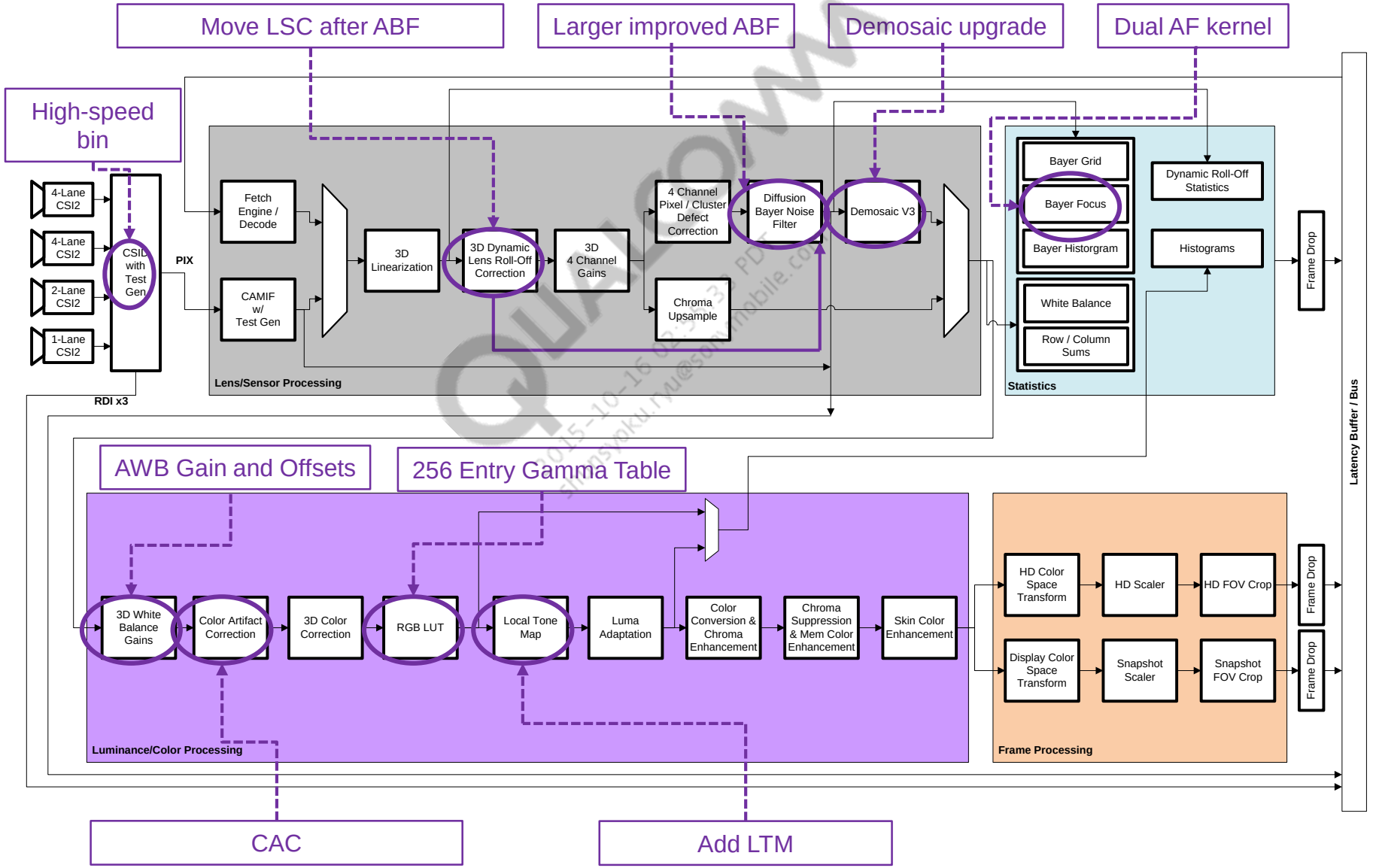
	MSM8974AB	APQ8084	MSM8992	MSM8994	MSM8996
Maximum real-time sensor input resolution	▪ ISP1 – 21 MP ▪ ISP2 – 13 MP	▪ ISP1 – 21 MP ▪ ISP2 – 13 MP	▪ ISP1 – 21 MP ▪ ISP2 – 8 MP	▪ ISP1 – 28 MP ▪ ISP2 – 13 MP	▪ ISP1 – 21 MP (16:9) ▪ ISP2 – 13 MP
Maximum output sizes (constraint on width)	▪ ISP1 enc – 5376 ▪ ISP1 view – 2560+10% ISP2 enc – 4288 ▪ ISP2 view – 2560+10%	▪ ISP1 enc – 5376 ▪ ISP1 view – 2560+10% ISP2 enc – 4288 ▪ ISP2 view – 2560+10%	▪ ISP1 enc – 6240 ▪ ISP1 view – 2560+10% ISP2 enc – 4288 ▪ ISP2 view – 2560+10%	▪ ISP1 enc – 6240 ▪ ISP1 view – 4608+10% ISP2 enc – 4288 ▪ ISP2 view – 2560+10%	▪ ISP1 enc – 6240 ▪ ISP1 view – 4608+10% ISP2 enc – 4288 ▪ ISP2 view – 2560+10%
VFE and CPP MHz Nominal/Turbo mode	▪ VFE – 320/465 ▪ CPP – 266/400	▪ VFE – 465/600 ▪ CPP – 370/600	▪ VFE – 465/600 ▪ CPP – 465/620	▪ VFE – 465/600 ▪ CPP – 465/620	465/600
MIPI CSI2 ports DPHY	4/4/4 or 4/4/2/1	4/4/4 or 4/4/2/1	4/4/4 or 4/4/2/1	4/4/4 or 4/4/2/1	4/4/4 or 4/4/2/1
JPEG hardware	▪ 2x encoder ▪ 1x decoder	▪ 2x encoder ▪ 1x decoder	▪ 1x encoder	▪ 2x encoder ▪ 1x decoder ▪ 1xDMA	▪ 1x encoder, ▪ 1x decoder
VFE feature highlights		LSC upgrade, ABF3, Demosaic, Dual AF, CAC, LTM, Gamma	LSC upgrade, ABF3, Demosaic, Dual AF, CAC, LTM, Gamma, **Green Imbalance, Pedestal, Stats Upgrades**	LSC upgrade, ABF3, Demosaic, **FIR+IIR Dual AF**, **CAC2+SNR**, **LTM**, Gamma, Green Imbalance, Pedestal, **Stats Upgrades**	LSC upgrade, ABF3, **BPC**, **Demosaic**, **FIR+IIR Dual AF**, **CAC2+SNR**, **LTM**, Gamma, Green Imbalance, Pedestal, **Stats Upgrades**
CPP feature highlights		New Adaptive Spatial Filter (ASF)	**3D Denoise**, new ASF	3D Denoise,new ASF	3D Denoise, **Low Light Chroma Denoise**, new ASF
Face Detection				Hardware	Hardware

ISP Block-By-Block Comparison

ISP blocks	MSM8974	APQ8084	MSM8992	MSM8994	MSM8996
BLC, Linearization, LSC, CCM, Gamma	√	√	√	√	√
Color Enhancement blocks (ACE, SCE, MCE, CS)	√	√	√	√	√
Wavelet Noise Reduction (WNR)	√	√	√	√	Improved (sixth layer)
Defect Pixel Correction	√	√	√	√	Improved
Demosaic	Demosaic 3	Demosaic 4	Demosaic 4	Demosaic 4	Demosaic 4 Improved G-interpolation
Auto Focus (AF) Stat	Single kernel (2x5)	**Dual kernel (2x11)**	**Dual kernel (2x11)**	**Dual kernel (2x11)**	**Dual kernel (FIR/IIR)**
Adaptive Bayer Filter (ABF)	ABF2	**ABF3**	**ABF3**	**ABF3**	**ABF3**
Radial Noise Reduction (RNR)					√
ASF	ASF2.0	ASF2.2	ASF2.2	ASF2.2	ASF2.2
Local Tone Mapping (LTM)		√	√	√	√
Chromatic Aberration Correction (CAC)		**CAC1**	**CAC1**	**CAC1**	**CAC2**
Green Imbalance Correction (GIC)				√	√
Temporal (or 3D) Noise Reduction (TNR)		**3DNR in VDP**	**TNR in CPP**	**TNR in CPP**	**TNR in CPP**
Skin Noise Reduction (SNR)					√

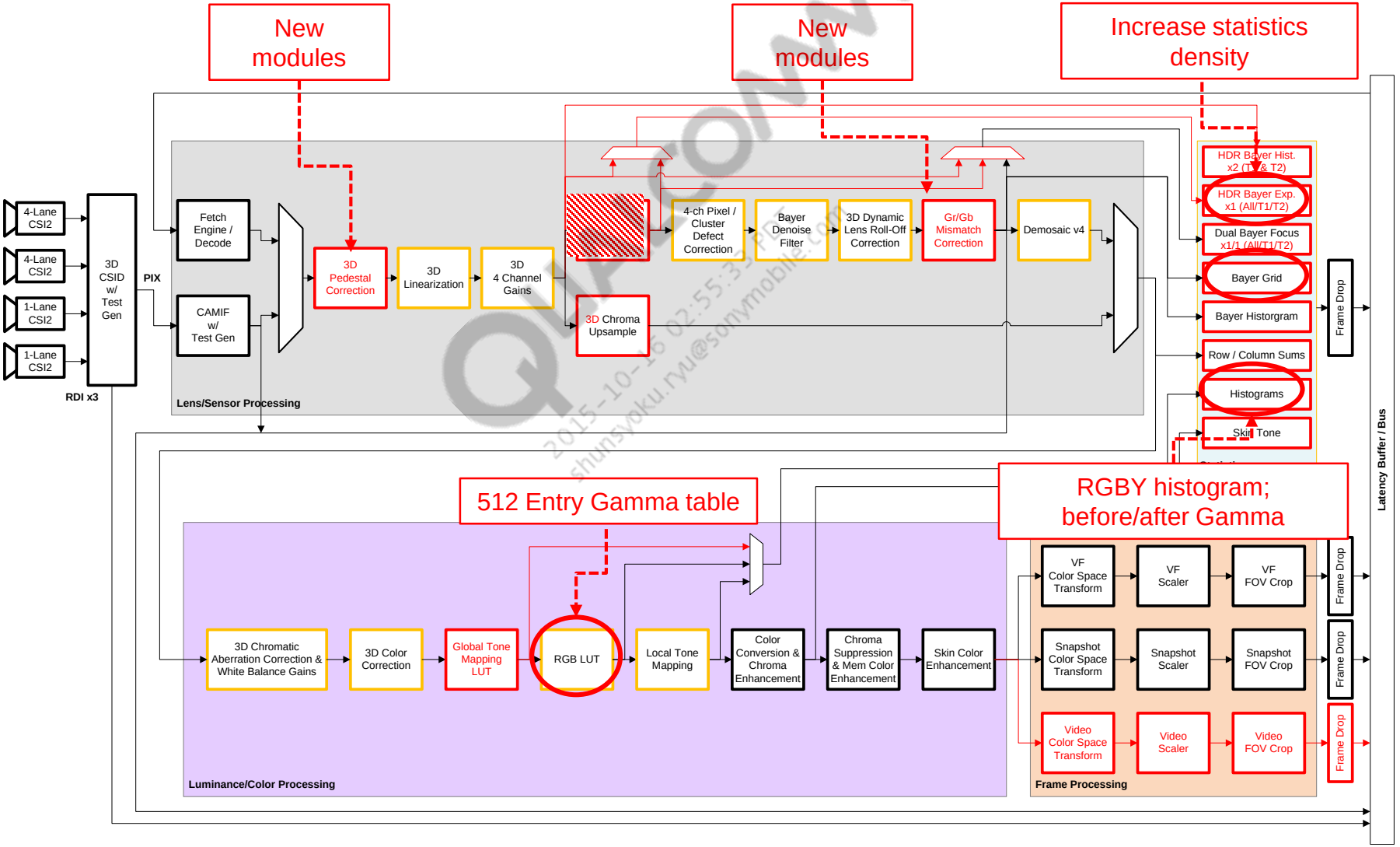
Camera Updates – VFE Overview

MSM8974 baseline | APQ8084/ MSM8992



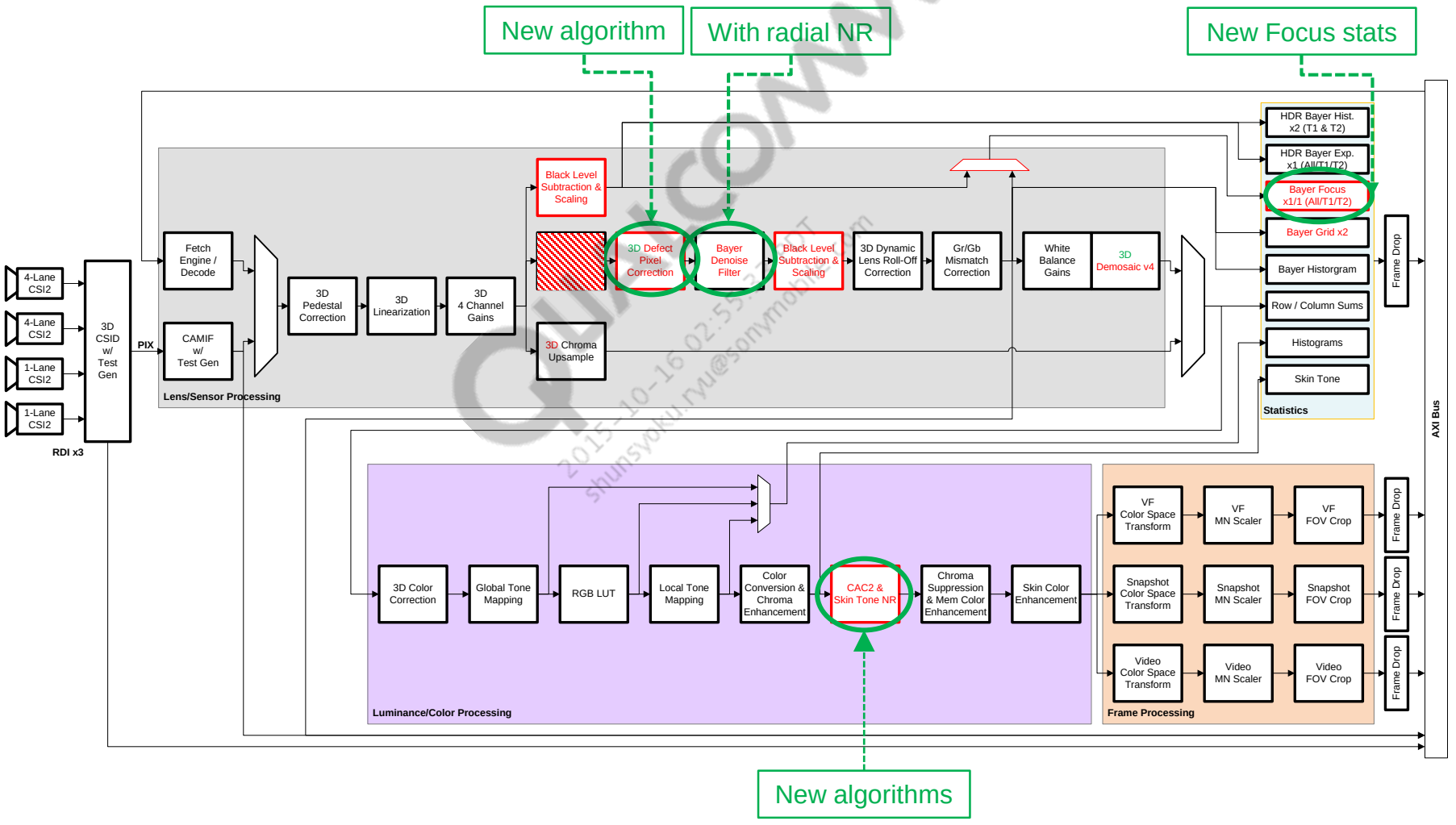
Camera Updates – VFE Overview (cont.)

MSM8974 baseline
MSM8994



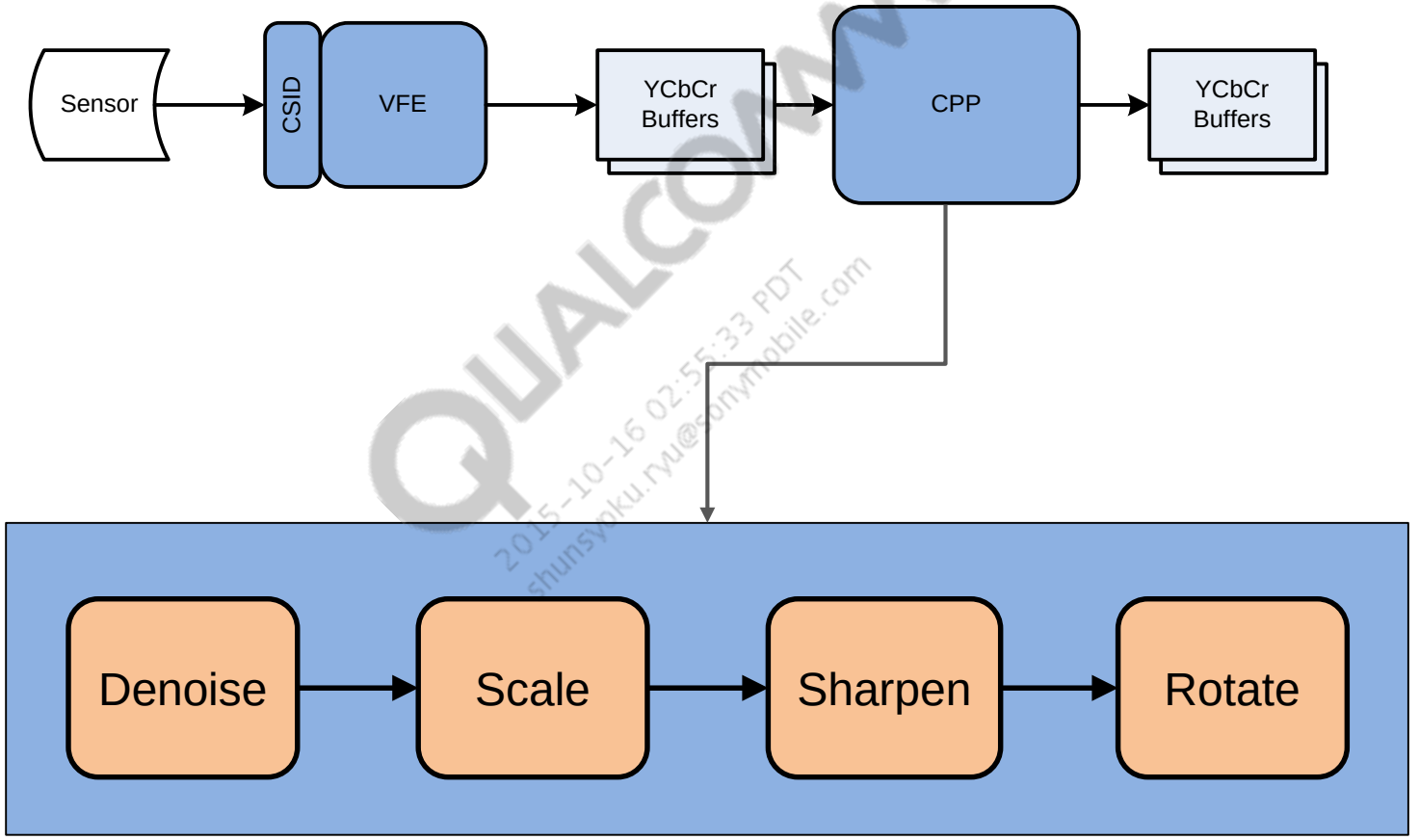
Camera Updates – VFE Overview (cont.)

MSM8974 baseline



Camera Updates – MSM8974 CPP

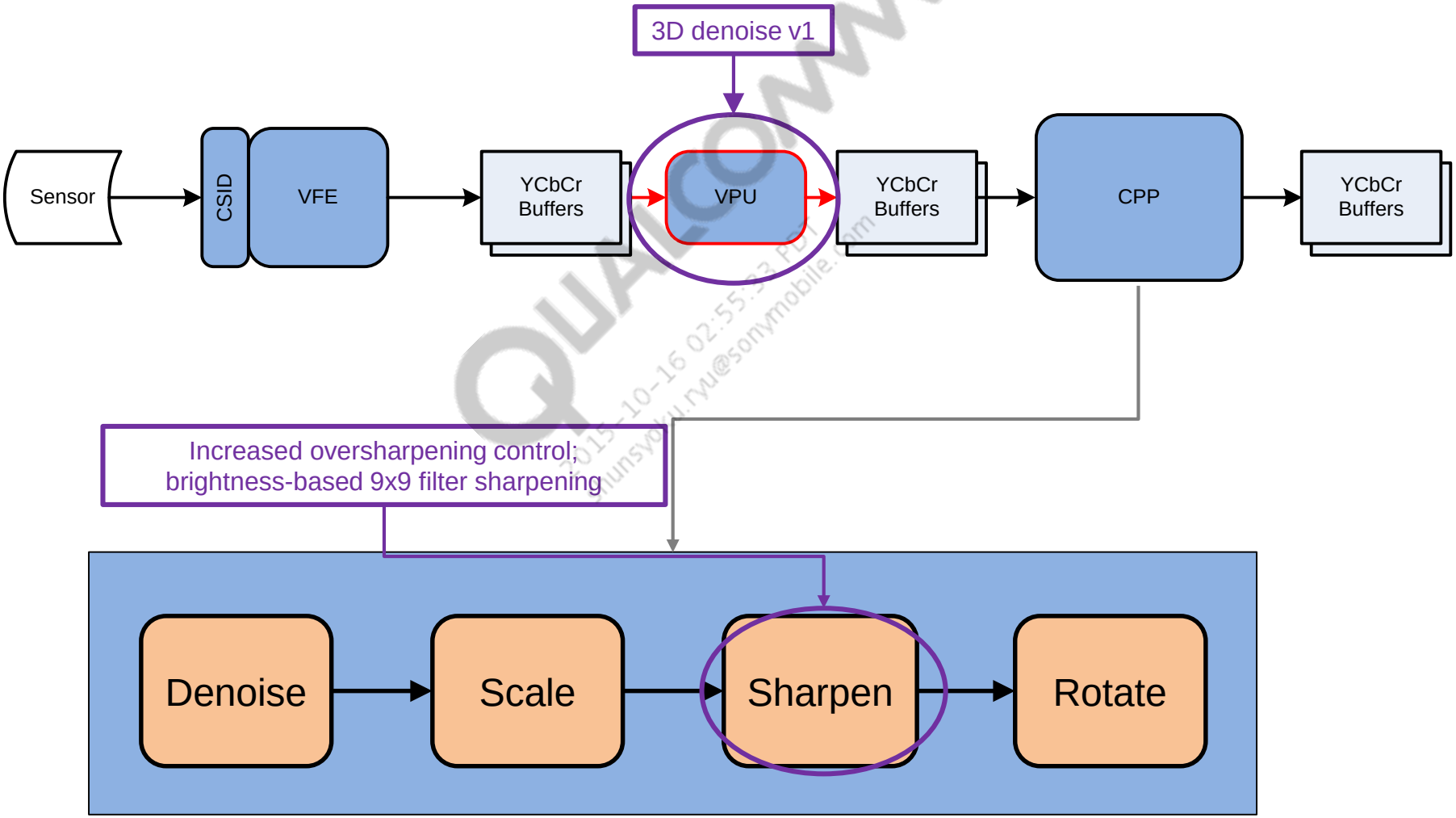
MSM8974 baseline | MSM8996



CPP core – 2D denoising, scaling, sharpening, rotation

Camera Updates – APQ8084 CPP/VPU

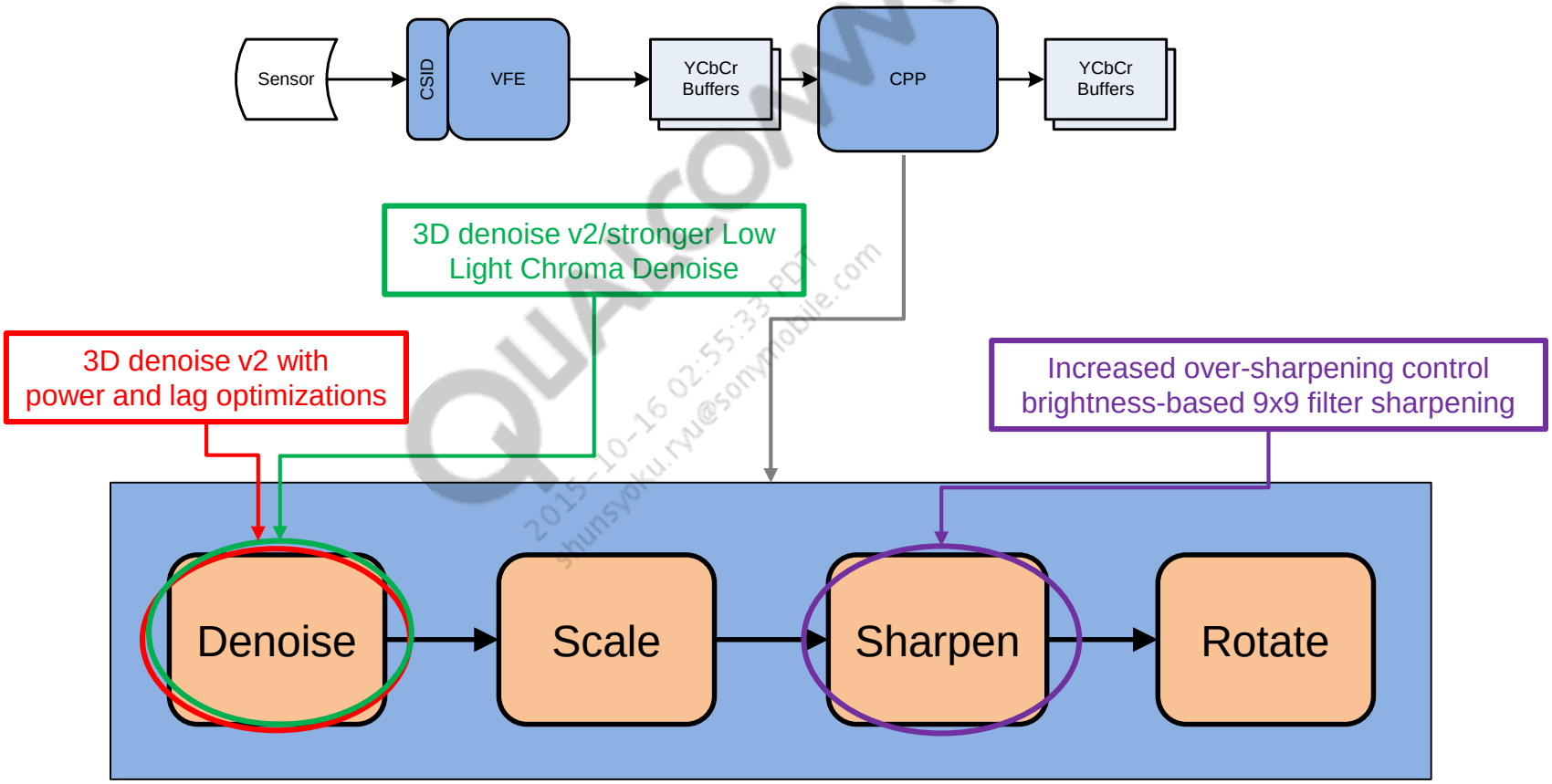
MSM8974 baseline | APQ8084



CPP core – 2D denoising, scaling, sharpening, rotation

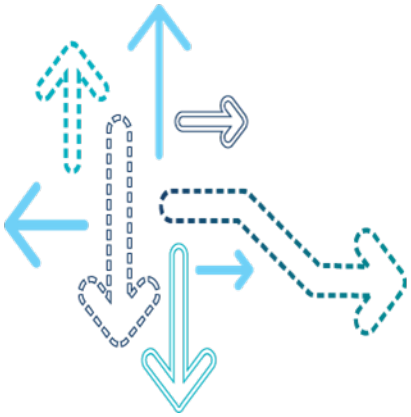
Camera Updates – MSM8992/MSM8994/ MSM8996 CPP

MSM8974 baseline	MSM8992/ MSM8994
MSM8996	APQ8084



CPP core – 2D/3D denoising, scaling, sharpening, rotation

Defective Pixel and Cluster Correction

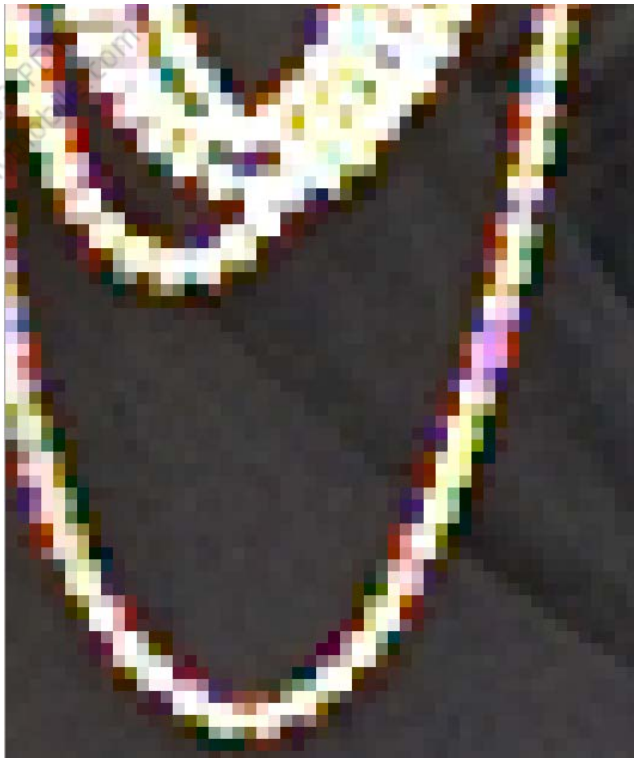


Problem – Defective Pixel and Cluster Correction

MSM8996

Problem	Defective pixel and cluster correction block corrects real defective pixel. However, unexpected color artifact can be caused by correcting normal pixels due to false positive defective pixel and cluster detection.

Without BPC

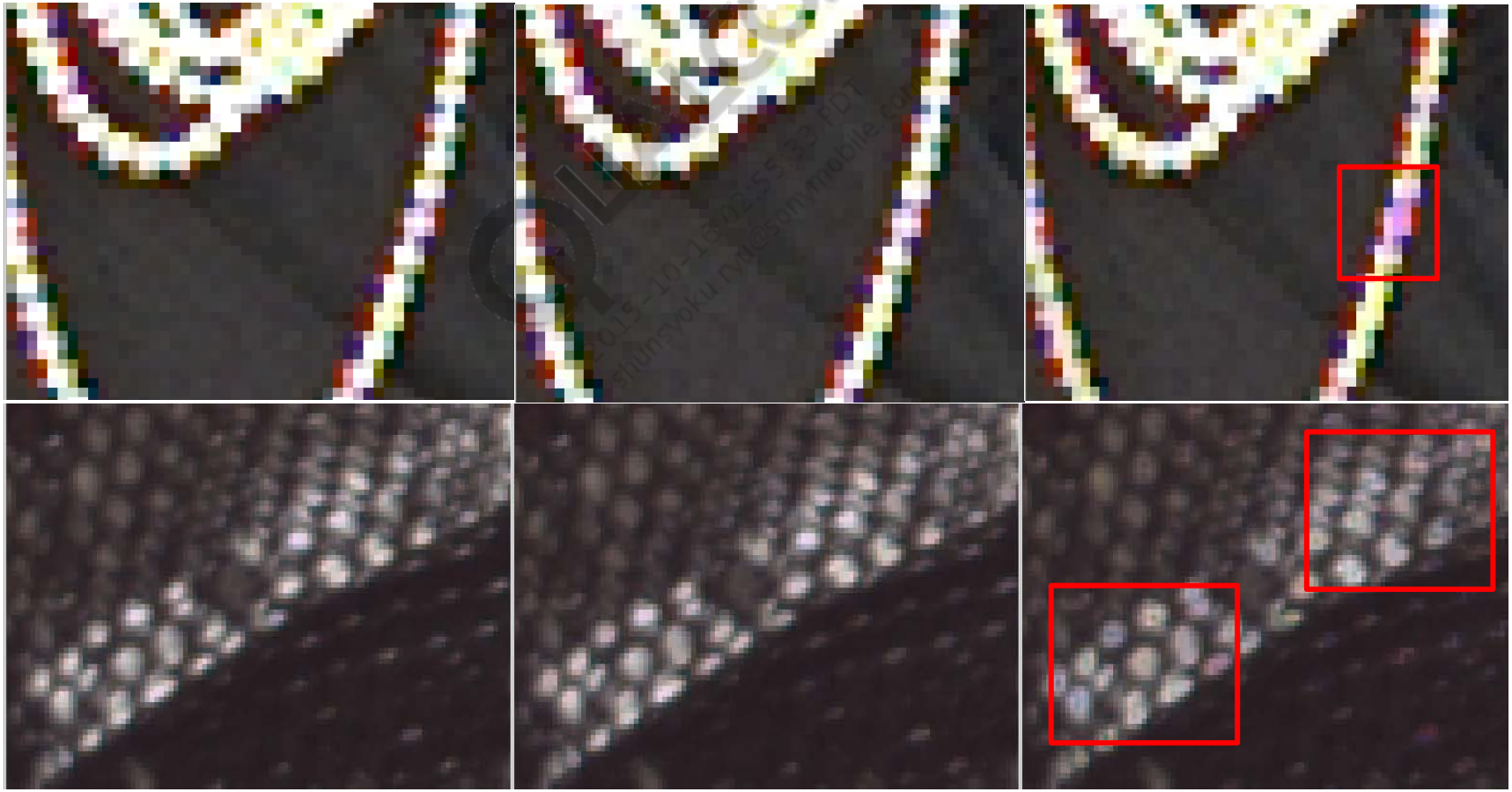


With BPC+False positive detection

Solution – Defective Pixel and Cluster Correction

MSM8996

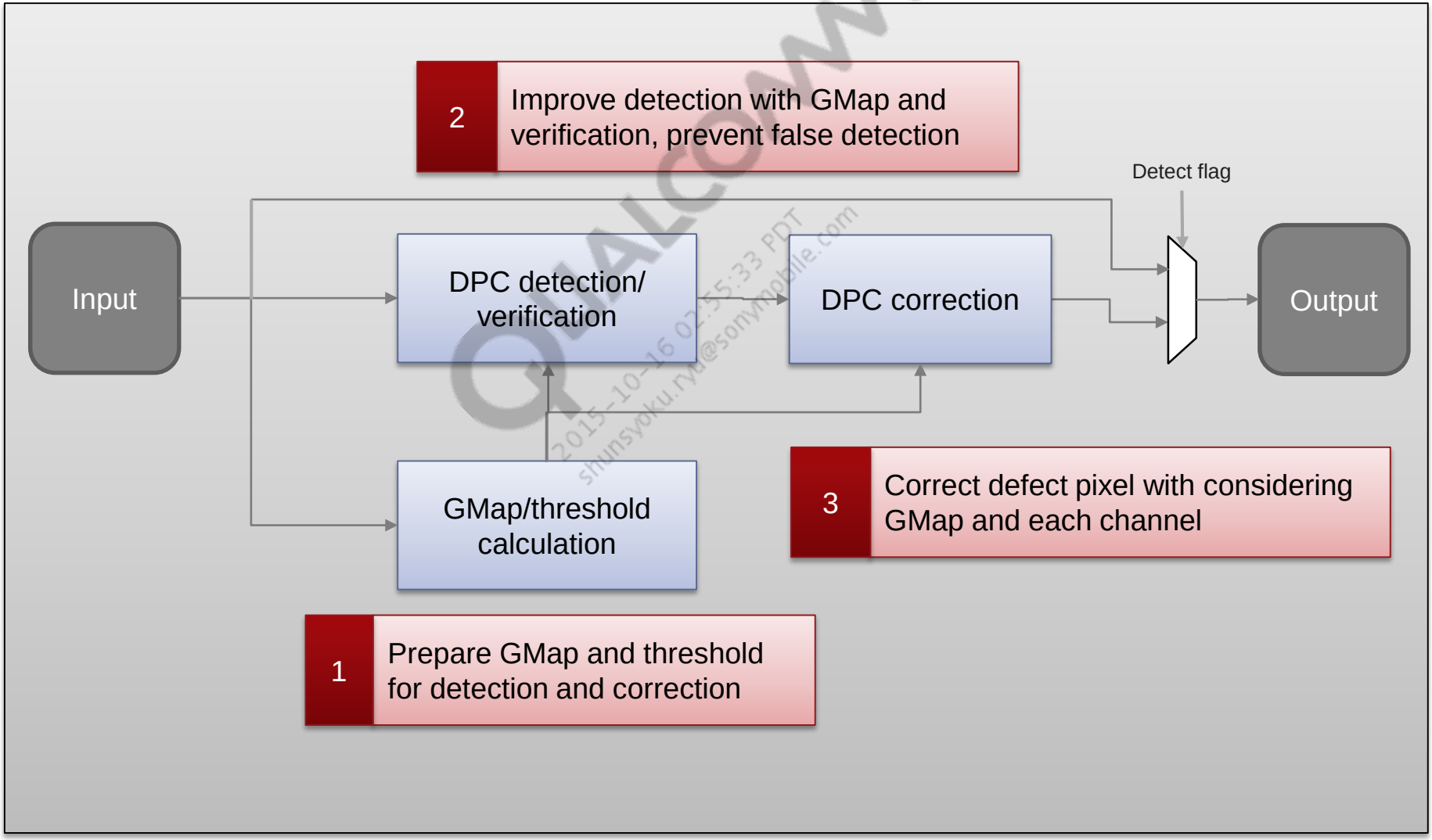
Solution	Improve defective pixel and cluster detection algorithm; prevent color artifacts that can be caused by false positive detection



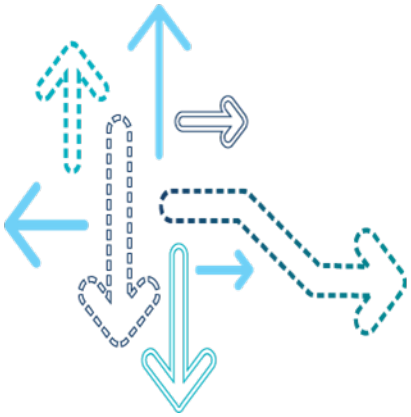
Without BPC | MSM8996 | MSM8084/MSM8994/MSM8992

Block Diagram – Defective Pixel and Cluster Correction

MSM8996



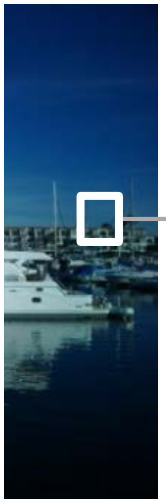
Adaptive Bayer Filter, Ver 3 (ABF3)



Problem – ABF3

APQ8084/ MSM8992 | MSM8994 | MSM8996

Problem	Images captured by mobile camera sensor have a lot of noise that could be amplified by certain processing steps, making it more difficult to reduce in later phases of the imaging pipeline.



Without ABF3

With ABF3

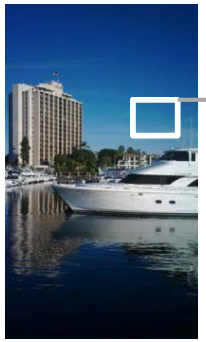
Solution – ABF3

APQ8084/ MSM8992 | MSM8994 | MSM8996

Solution	ABF3 minimizes noise in an early stage (Bayer domain) of the camera pipeline, improves performance in other modules, and reduces moderate green imbalance artifacts.

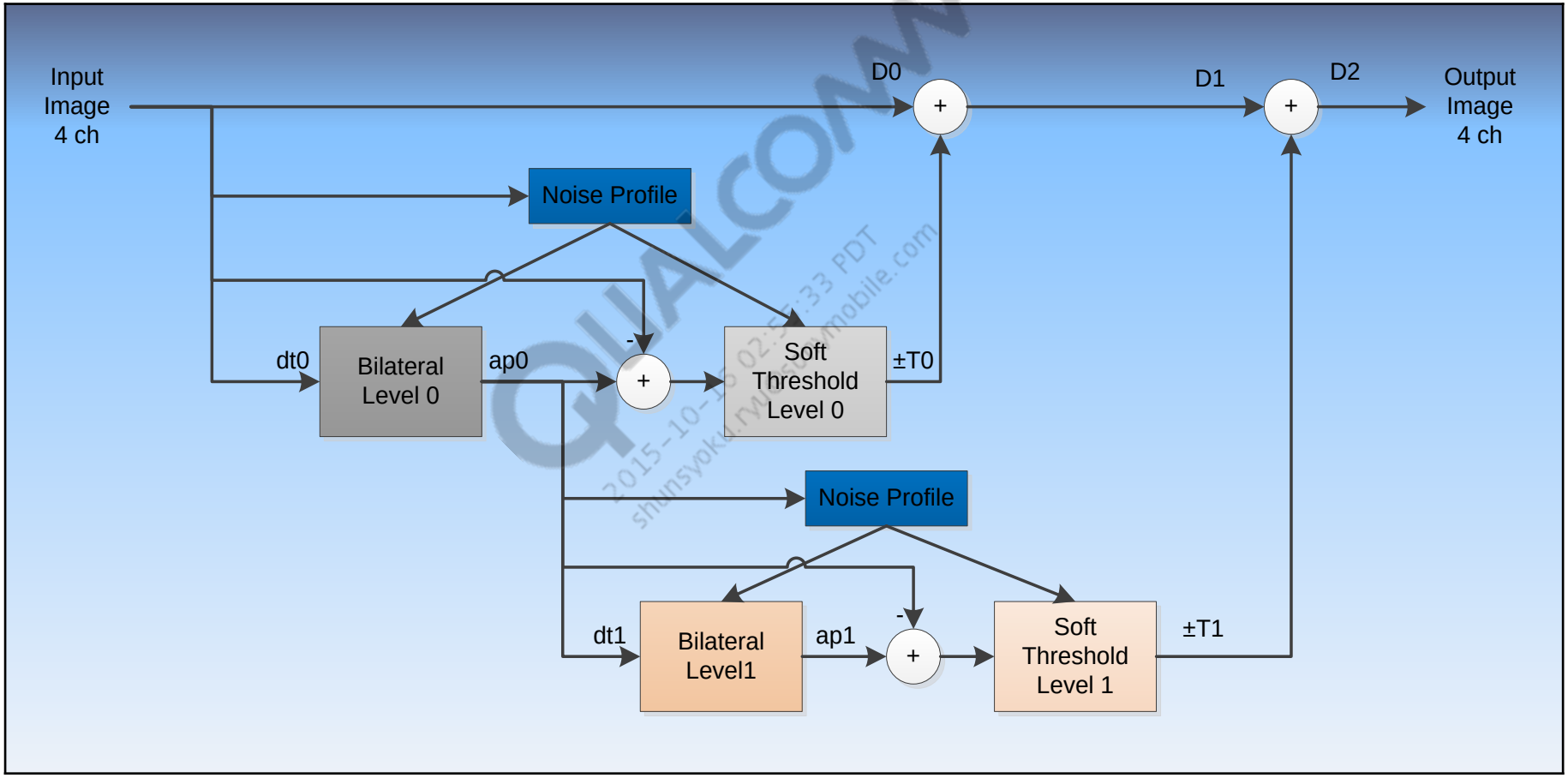
Without ABF3

With ABF3

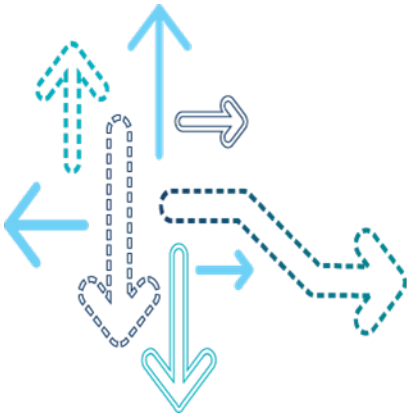


Block Diagram – ABF3

APQ8084/ MSM8992 | MSM8994 | MSM8996



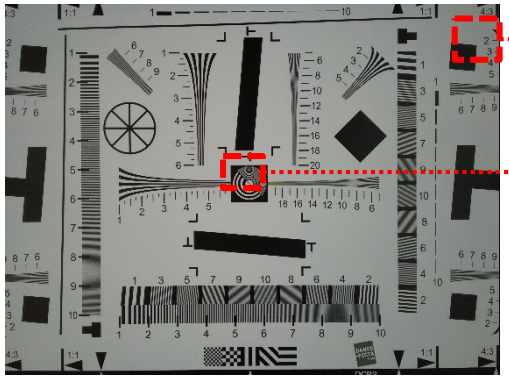
RNR

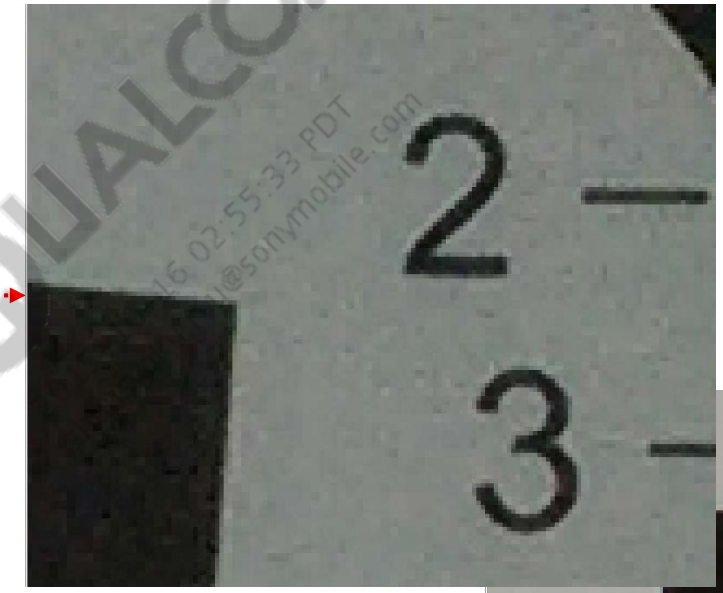


Problem – RNR

MSM8996

Problem	Noise, due to rolloff correction and other gain-related changes, is not uniformly distributed across the image. The corners of an image often suffer from increased noise.





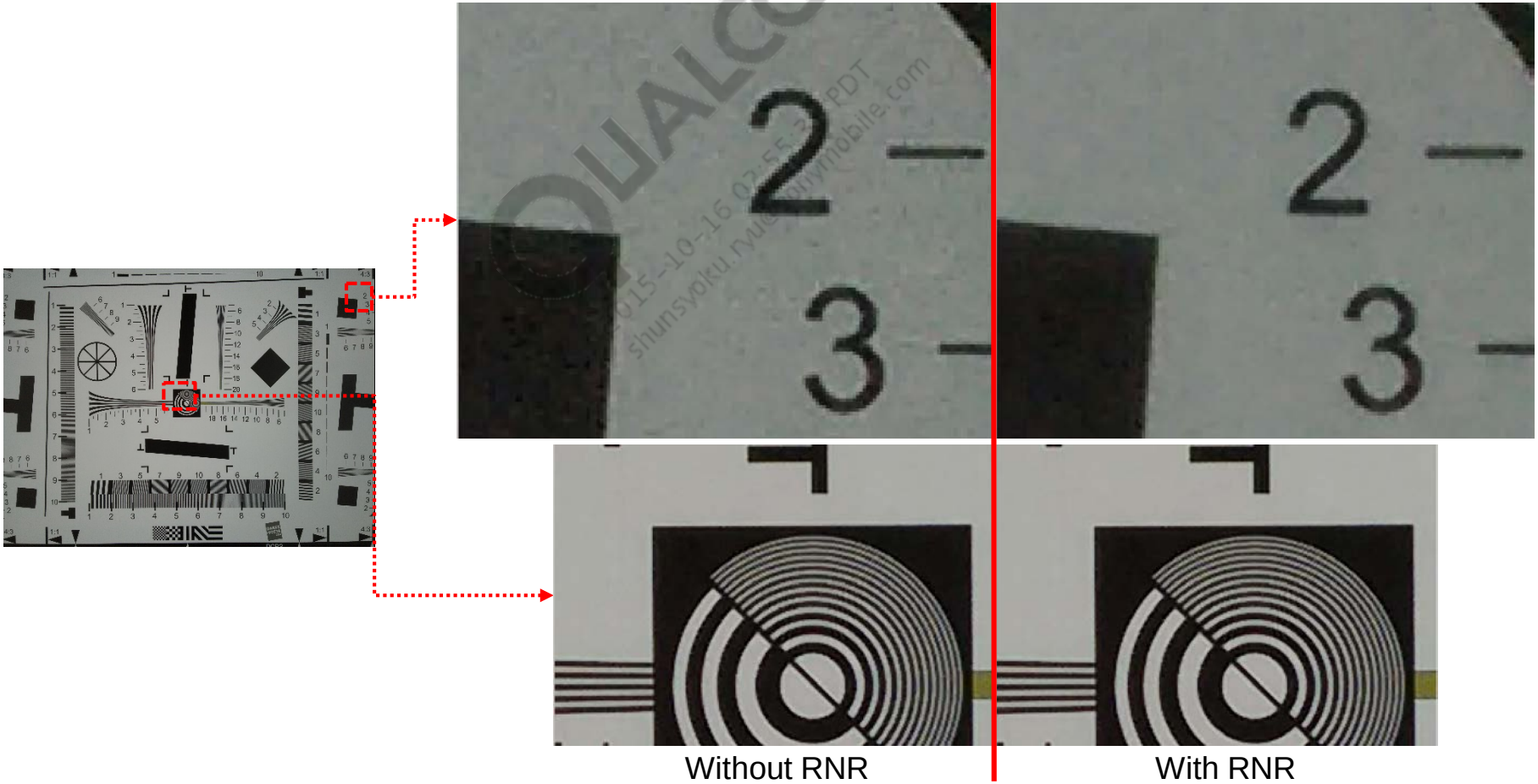
Corner

Center

Solution – RNR

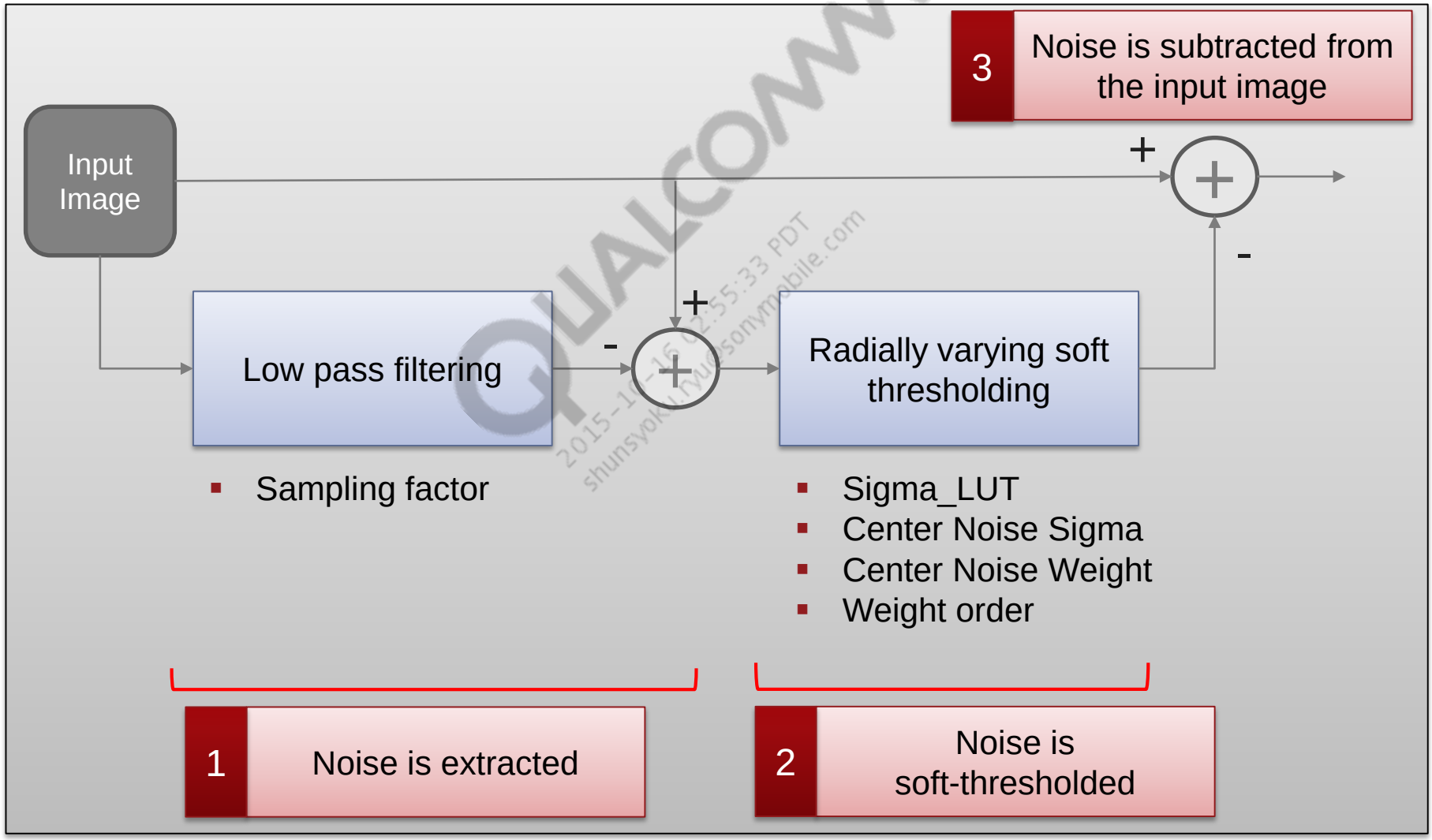
MSM8996

Solution	The purpose of RNR is to reduce nonuniformly distributed noise by applying different denoise strength radially based on the pixel position in the image. WNR is the main denoise block, while RNR is used to correct spatial nonuniformity noise issues.

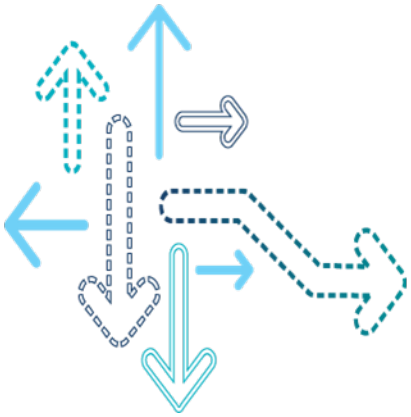


Block Diagram – RNR

MSM8996



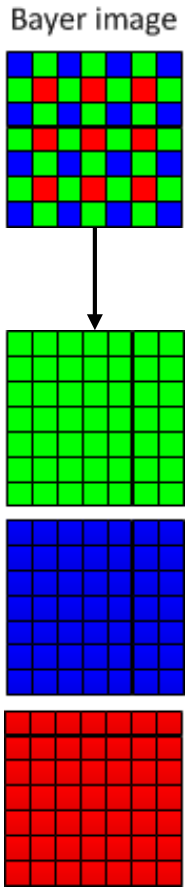
Demosaic



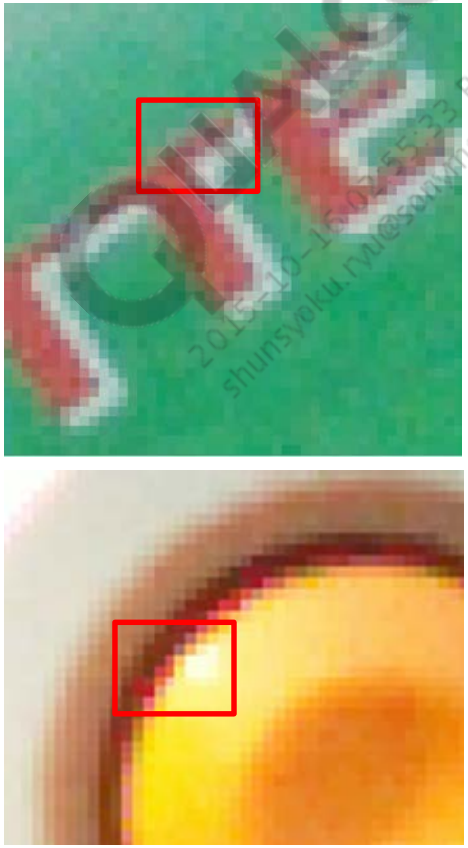
Problem – Demosaic

APQ8084/ MSM8992 | MSM8994 | MSM8996

Problem	Demosaic v3 (MSM8974) recovers high-resolution details, but suffers from jagged and zipper artifacts on diagonal color and high-contrast edges.



Demosaic



Jaggy artifacts

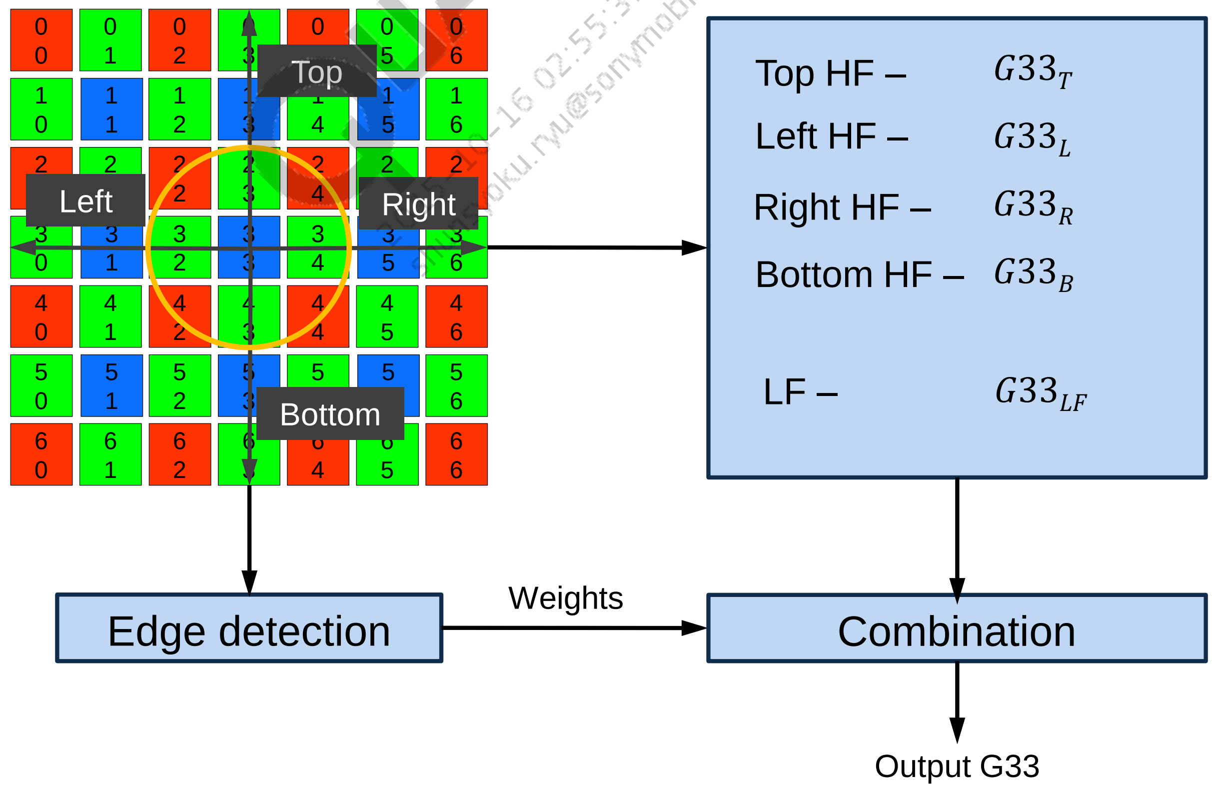
Zipper artifacts

Solution – Demosaic

APQ8084/ MSM8992 | MSM8994 | MSM8996

Solution	Instead of using 2-directional interpolation, Demosaic v4 (APQ8084/MSM8992/ MSM8994) uses 4-directional High-Frequency (HF) interpolation combined with Low-Frequency (LF) interpolation to obtain separate estimates of color differences in four different directions. This removes jagged and zipper artifacts while preserving high resolution.

Take G33 interpolation for example



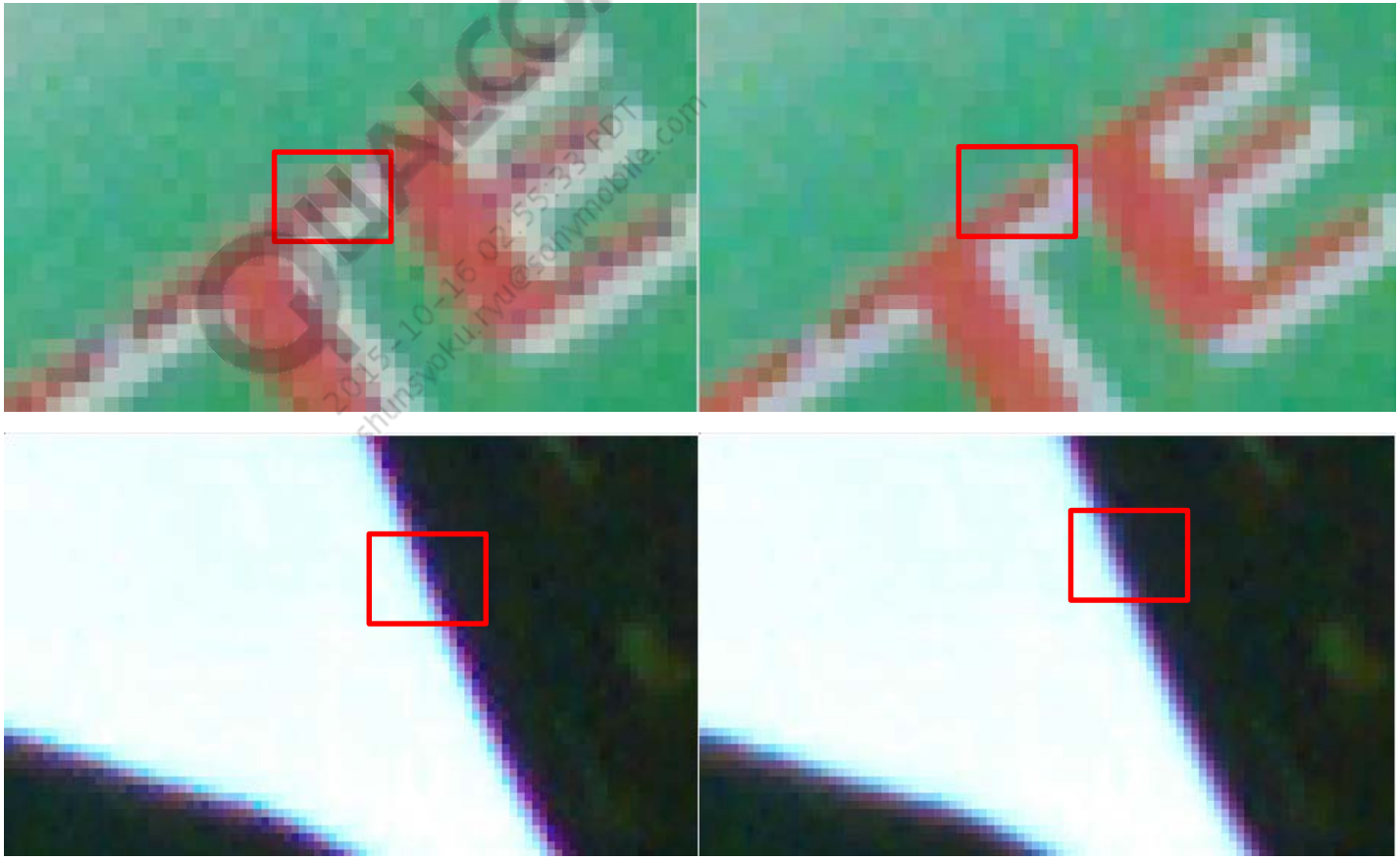
Sample Image – Demosaic

APQ8084/ MSM8992 | MSM8994 | MSM8996

Demosaic	Demosaic v4 removes jagged/zipper artifacts and improves edge continuity along diagonal color and high contrast edges.

Jagged edges

Zipper artifacts

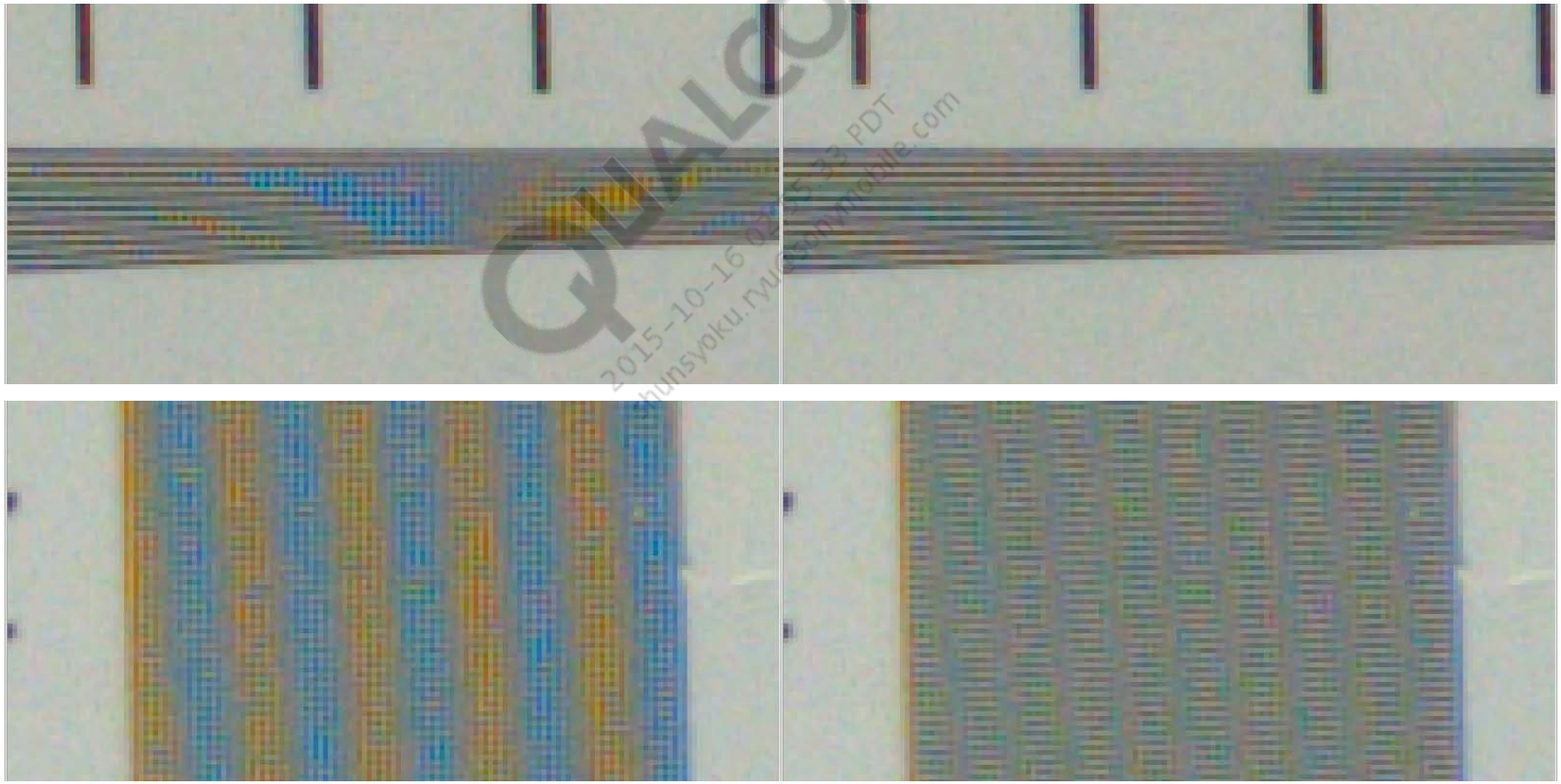


Demosaic v3 | Demosaic v4

Sample Image – Demosaic (cont.)

MSM8996

Demosaic	MSM8996 chipset has improved green channel interpolation on top of Demosaic v4.

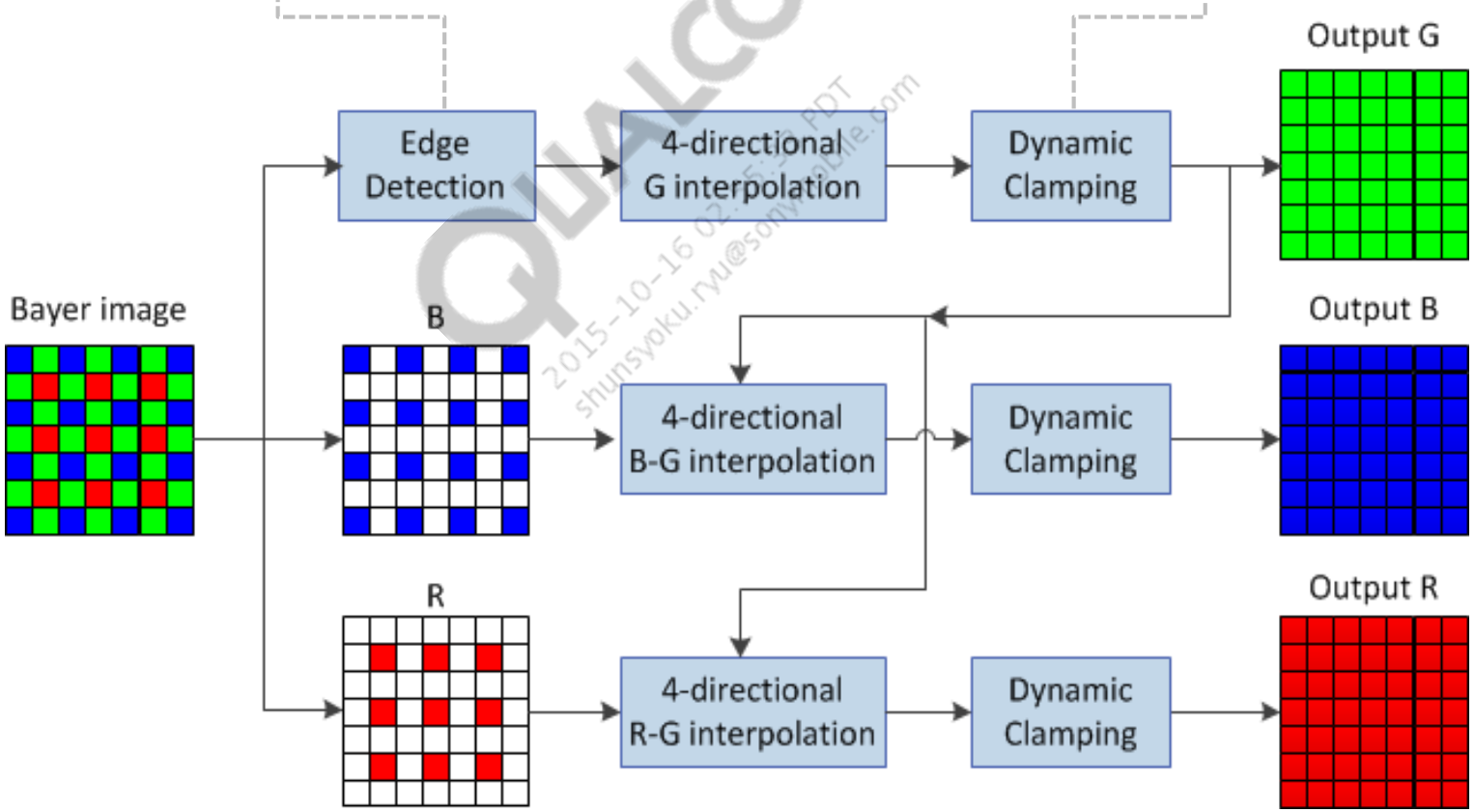


APQ8084/MSM8992/MSM8994 MSM8996

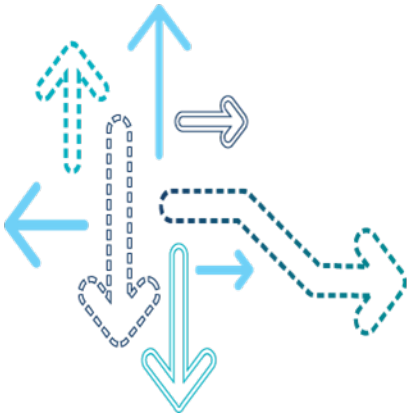
Block Diagram – Demosaic

APQ8084/ MSM8992 | MSM8994 | MSM8996

Edge Detection	Detects the edge direction by the variations along horizontal and vertical directions
Dynamic Clamping	Clamps the pixel value to the data range of its neighborhood to avoid possible zipper artifacts



ASF



Problem – ASF

MSM8992/ MSM8994 | APQ8084
MSM8996

Problem	Images look blurry and lack enough contrast/details after WNR.

After WNR

With ASF

Solution – ASF

MSM8992/ MSM8994 | APQ8084 | MSM8996

Solution	Comparison between MSM8974 and MSM8994/MSM8992/APQ8084 – The key benefit of MSM8994/MSM8992/APQ8084 ASF over MSM8974 ASF is that MSM8994/MSM8992/ APQ8084ASF can apply accurate enhancement based on local intensity with more angular resolution for sharpening.

MSM8974

MSM8994/MSM8992/APQ8084

Sample Image – ASF

MSM8992/ MSM8994 | APQ8084 | MSM8996

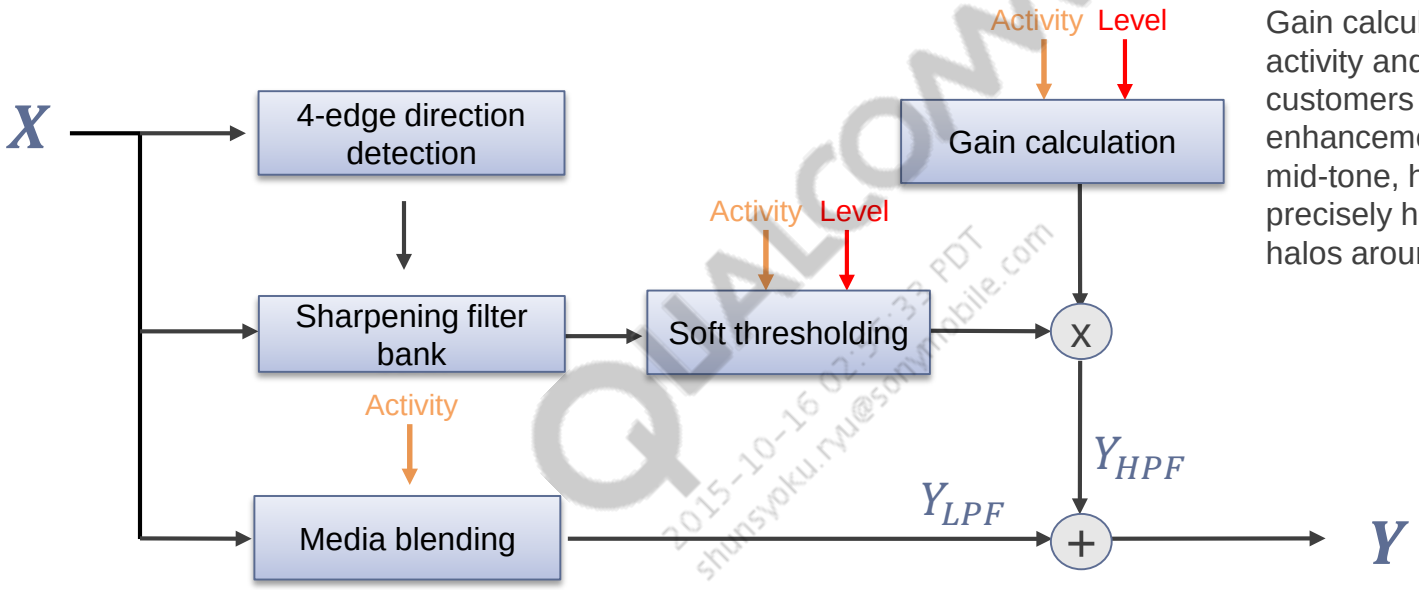
ASF	Comparison between directional and symmetric sharpening

4-directional and symmetric sharpening

Symmetric sharpening

Block Diagram – ASF

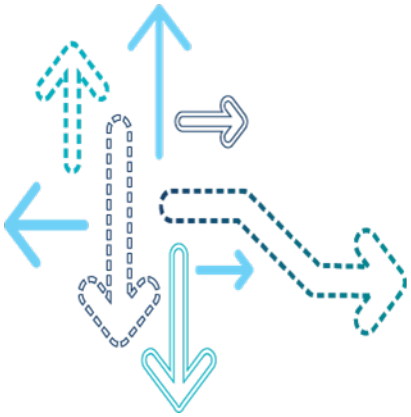
MSM8992/ MSM8994 | APQ8084 | MSM8996



Gain calculation is based on both activity and level. This enables customers to apply accurate enhancement for shadows, mid-tone, highlights, and to precisely handle sensor noise and halos around strong edges.

Activity – Measure of local patch variance/business
Level – Approximation of local brightness level

New AF Statistic

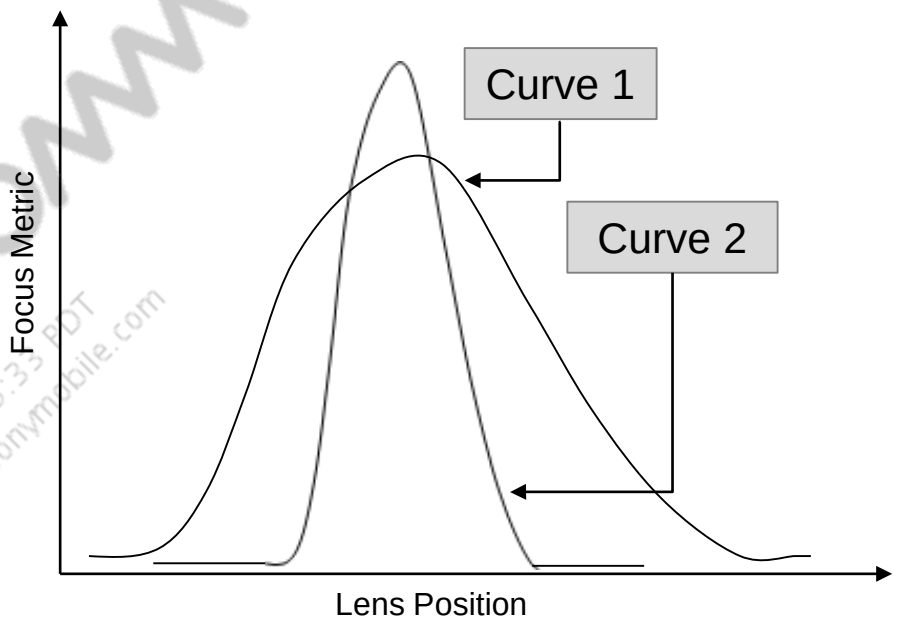


New AF Statistic – APQ8084/MSM8994/MSM8992

MSM8994

APQ8084/ MSM8992

- Dual kernels and larger kernels will improve AF performance
  - Dual kernel
    - Kernel1 provides metrics based on larger regions of the image; this provides a smooth and robust measure for driving the direction of the actuator.
    - Kernel2 provides metrics based on fine detail; this gives good accuracy for achieving the peak focus position.
    - Together the two kernels allow for a fast and accurate focus search.
  - Larger kernels
    - Larger AF kernels allow for better frequency response in handling large resolution sensors.

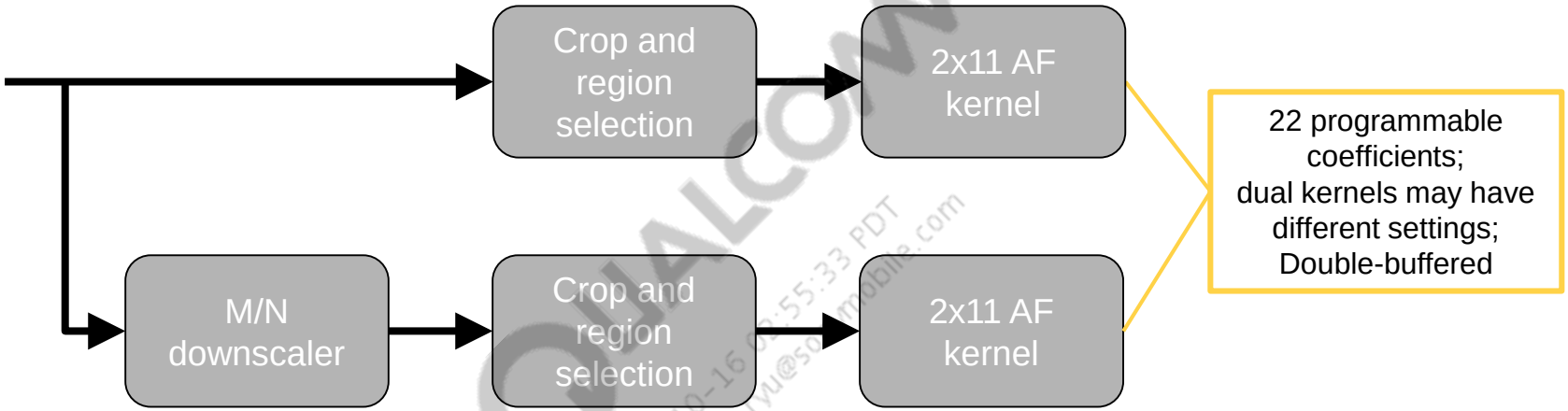


Bayer Focus Update – APQ8084/MSM8994/MSM8992

MSM8994

APQ8084/ MSM8992

- Architecture – Add one set of Bayer focus filter with a downscaler.

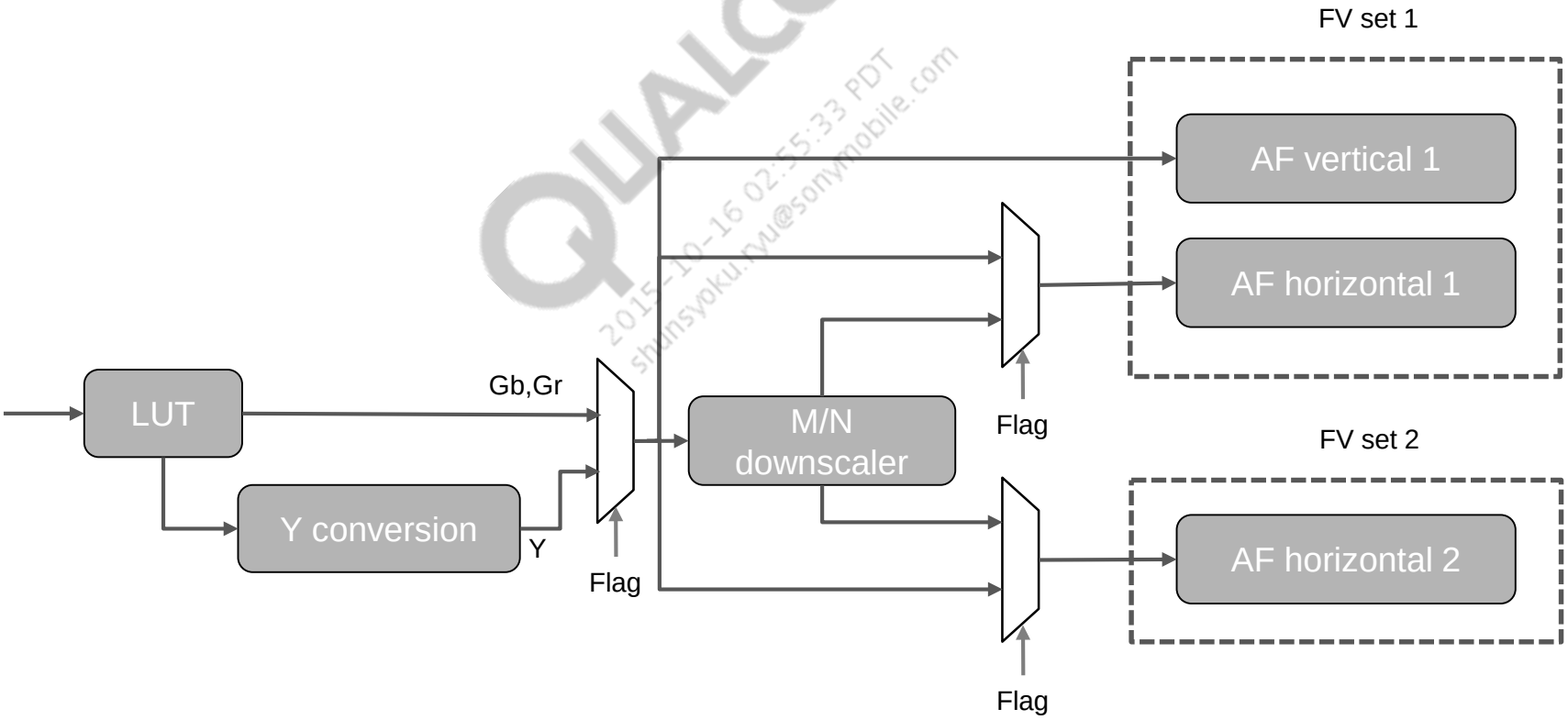


- Region of interest is divided into a grid with up to 18x14 regions
- Calculation of sharpness metric for R, B, Gr, Gb channels in each region

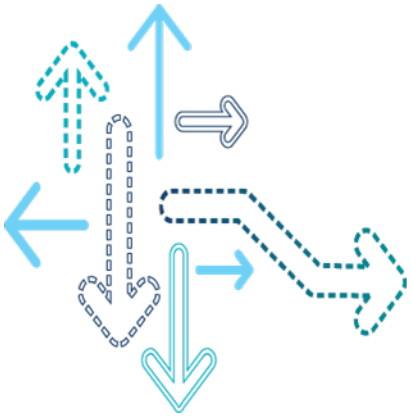
New AF Statistic – MSM8996

MSM8996

- FIR and IIR filters in horizontal and vertical focus engines
  - FV_H – 13-tap FIR+Fourth order IIR; FV_V – 5-tap FIR+Second order IIR
- Dual scales of horizontal focus engines



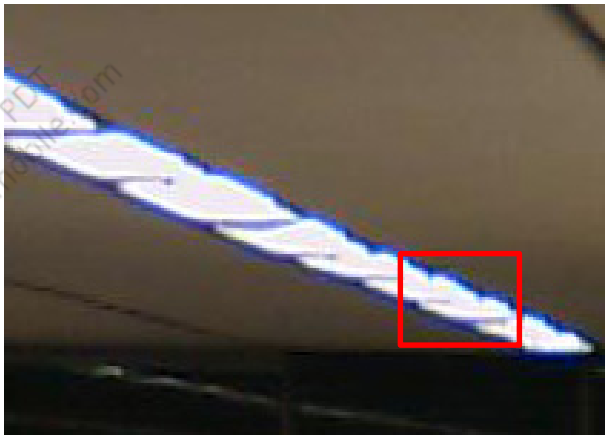
CAC Ver 1 and Ver 2



Problem – CAC Ver 1

APQ8084/ MSM8992 | MSM8994

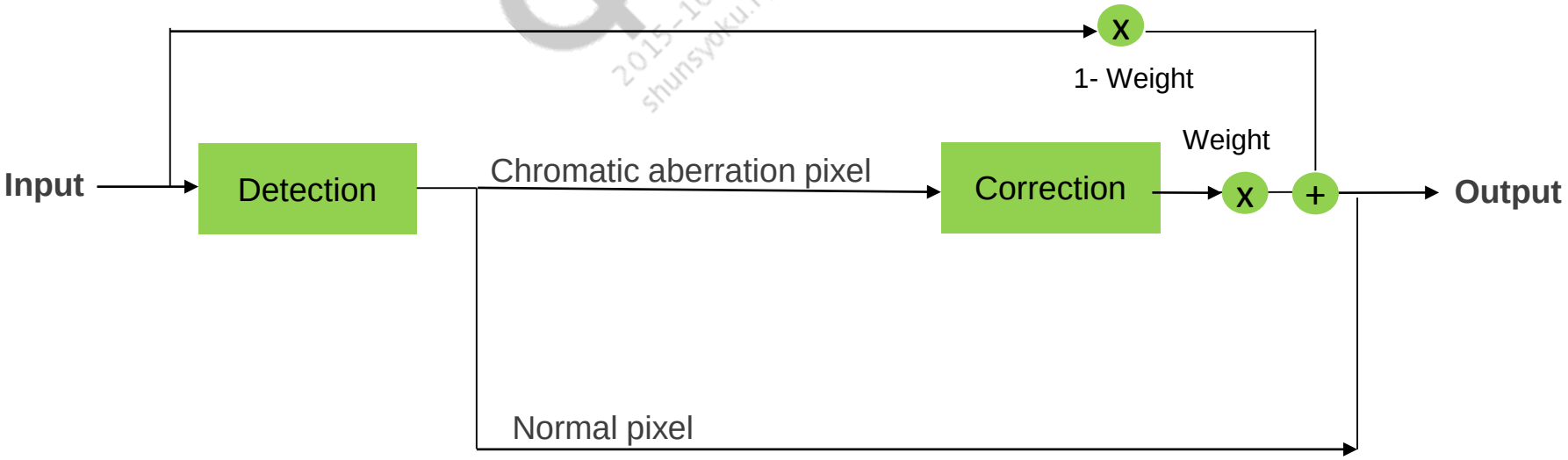
Problem	Chromatic aberration produces undesirable colors that may appear at light and dark boundaries in an image, which negatively impacts the image quality.



Solution – CAC Ver 1

APQ8084/ MSM8992 | MSM8994

Solution	Detection – Pixels must meet the following conditions: ▪ An Edge Pixel ▪ Beside a saturated region ▪ Neighbor's luminance monotonically changing ▪ Inside a color range ▪ Not among color range from its neighbors Correction – Use weighted average between: ▪ (*Max* of its neighbors) *and* (original chromatic value), or ▪ (*Min* of its neighbors) *and* (original chromatic value)

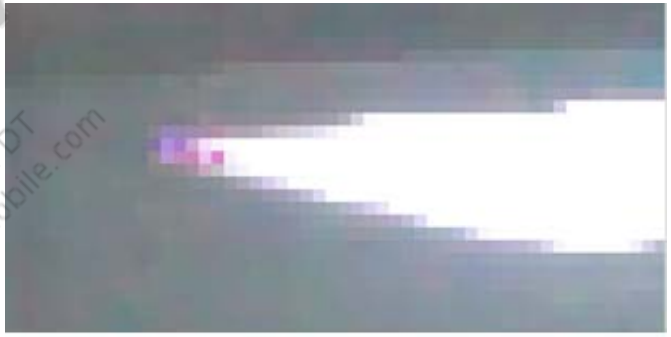


Sample Image – CAC Ver 1

APQ8084/ MSM8992 | MSM8994

CAC	Can remove chromatic aberration successfully

CAC off



CAC on

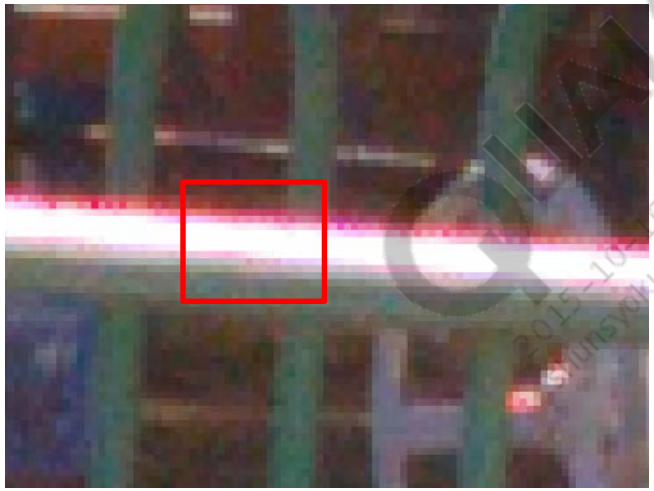
CAC off

CAC on

Problem – CAC Ver 2

MSM8996

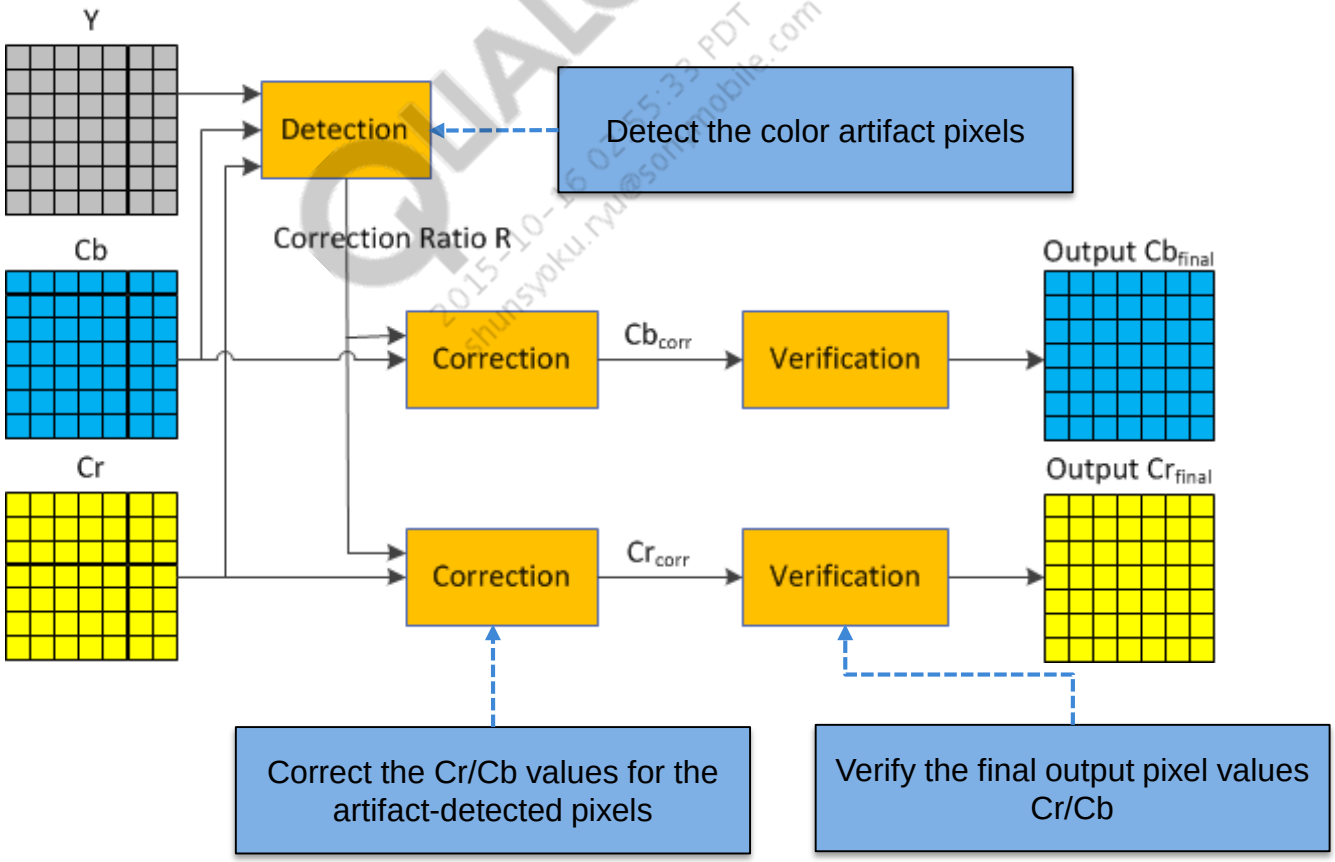
Problem	Chromatic aberration produces undesirable colors that may appear at light and dark boundaries or spot in an image, which negatively impacts the image quality.



Solution – CAC Ver 2

MSM8996

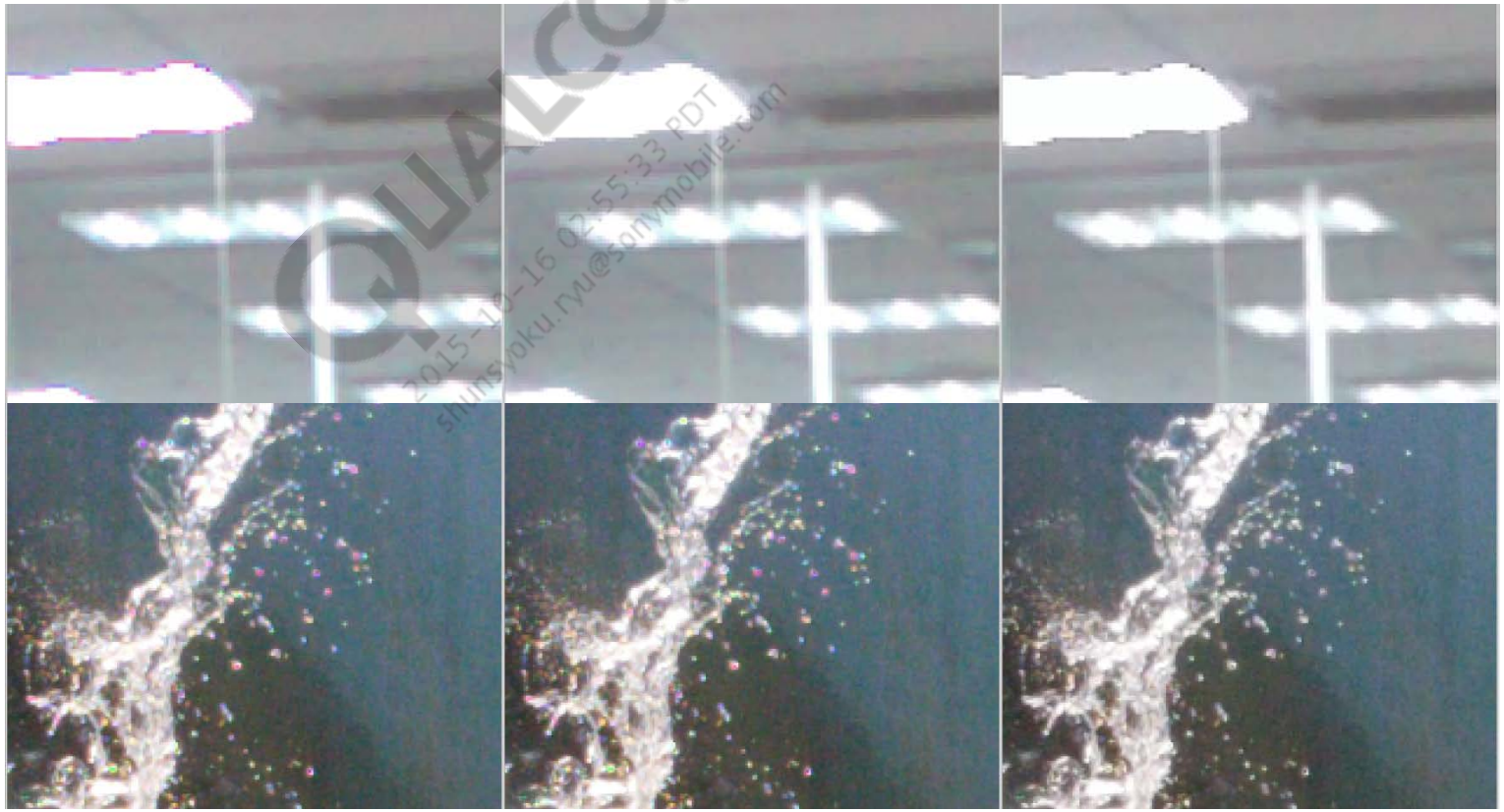
Solution	Detection – Pixels must meet the following conditions: ▪ Color spot or within Y saturation threshold ▪ Inside a color saturation range Correction: ▪ Using 5x3 median filter with direction ▪ Correcting CbCr and clamping range



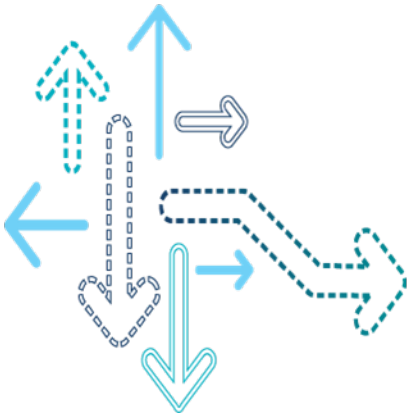
Sample Image – CAC Ver 2

MSM8996

CAC	Can remove false color on edge and color spot successfully



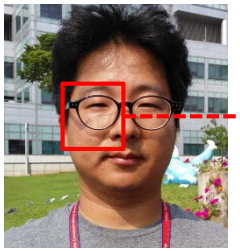
SNR



Problem – SNR

MSM8996

Problem	Natural scenes usually require strong sharpening for better visual quality. However, sharpening block generates unpleasing artifacts for skin-tone regions when applying strong enhancement.



Solution – SNR

MSM8996

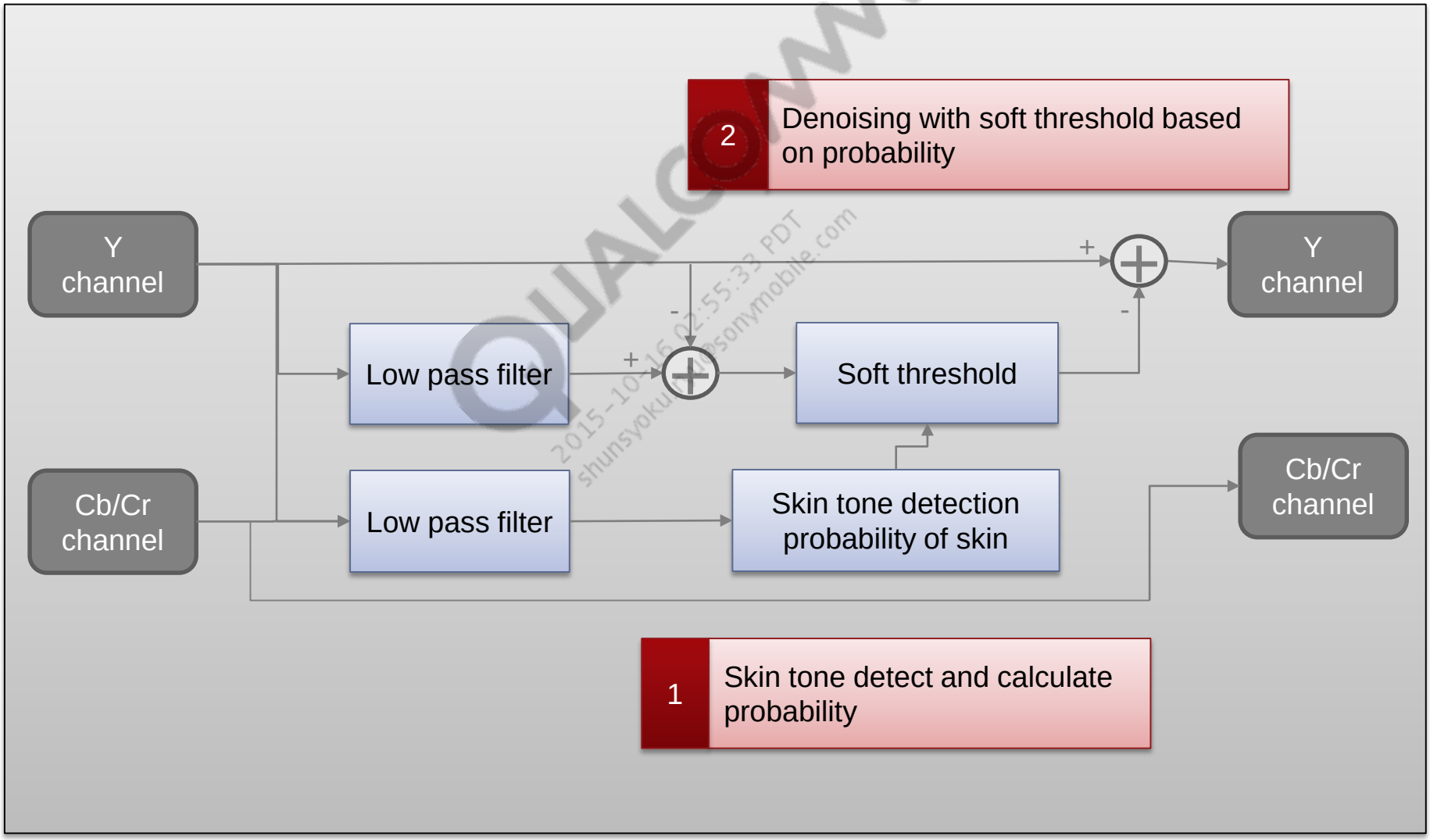
Solution	Applying denoise to Y channel of pixels that is detected as skin tone soft threshold based on probability of skin tone pixels

Without SNR

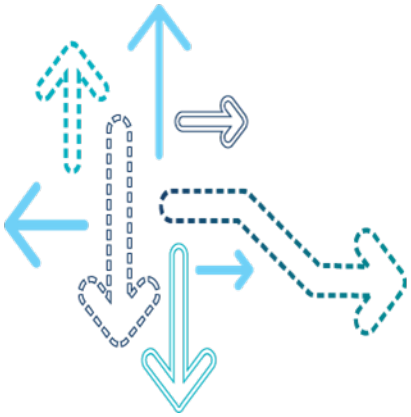
With SNR

Block Diagram – SNR

MSM8996



LTM



Problem – LTM

MSM8994
MSM8996
APQ8084/
MSM8992

Problem	Natural scenes typically have a wide dynamic range. Images captured by a camera system have a lot of information that is not easily visible or obvious on display devices. Two tone mapping approaches can be used to bring obscured details in dark or bright regions to a more visible data range. The following two approaches can be used: ▪ **Global Tone Mapping** – Adjusts all pixels based on their values ▪ **LTM** – Examines each pixel's neighborhood and decides whether the pixel needs lightening or not Although GTM can lighten area regions, it reduces contrast in normal and bright regions. As a result, the image may looks flattened.

Problem
Typical camera imaging pipe cannot handle this wide dynamic range very well

Very bright area

Very dark area
Difficult to discern the details in the dark area

Solution – LTM

MSM8994
MSM8996
APQ8084/
MSM8992

LTM	LTM is designed to illuminate dark areas while keeping other tone regions untouched. Also, highlight can be suppressed in order to avoid light saturation.

Original image

GTM

LTM

Normal light areas are also modified by GTM and result in either contrast loss or tone change.

With LTM, dark areas are lightened while other areas are not touched.

Sample Image – LTM

MSM8994
MSM8996
APQ8084/
MSM8992

Original

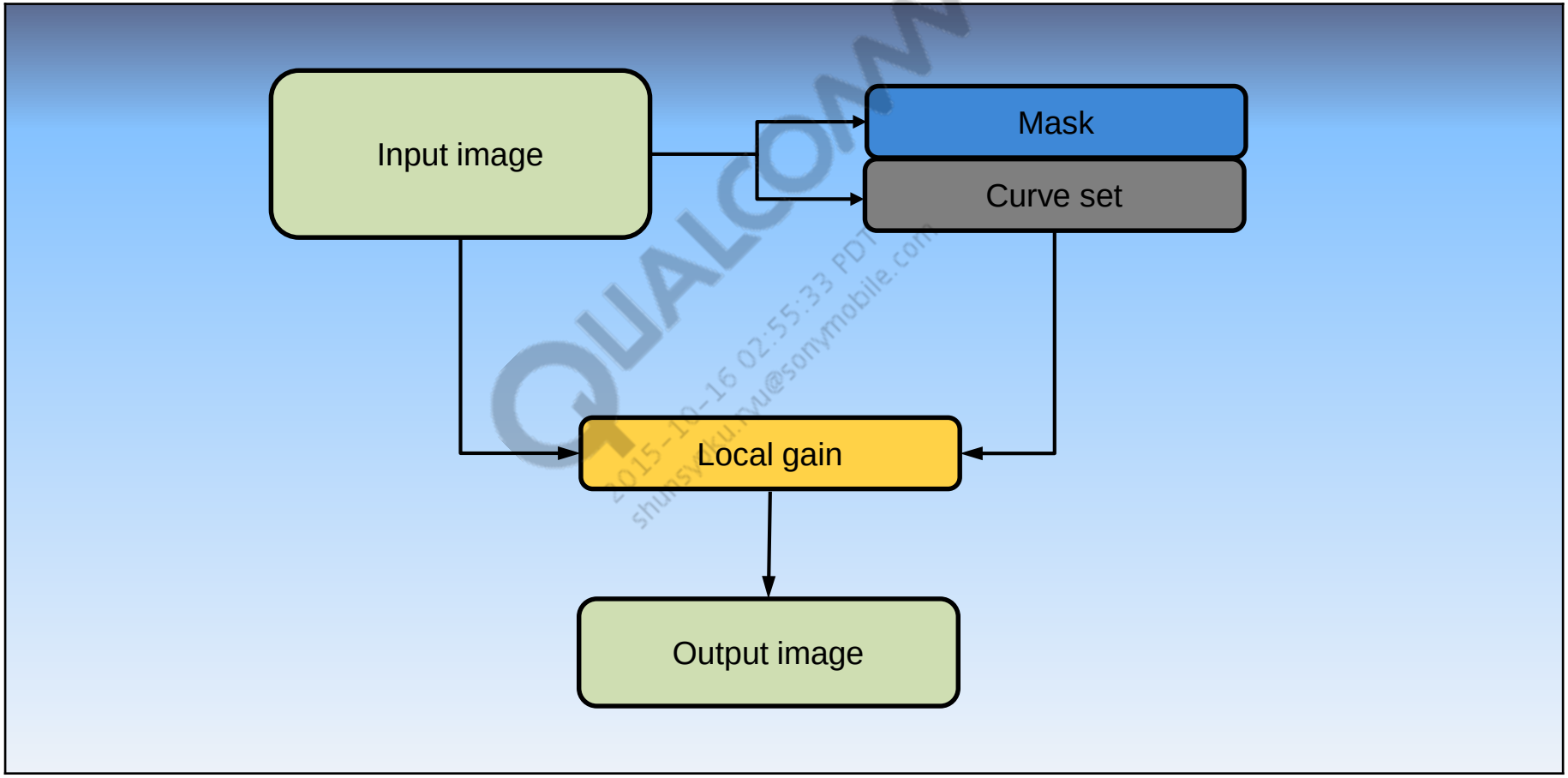
LTM

Highlight tone details are preserved

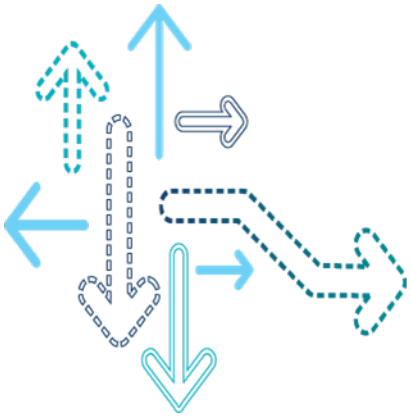
Dark details are more visible with LTM

Block Diagram – LTM

MSM8994
MSM8996
APQ8084/
MSM8992



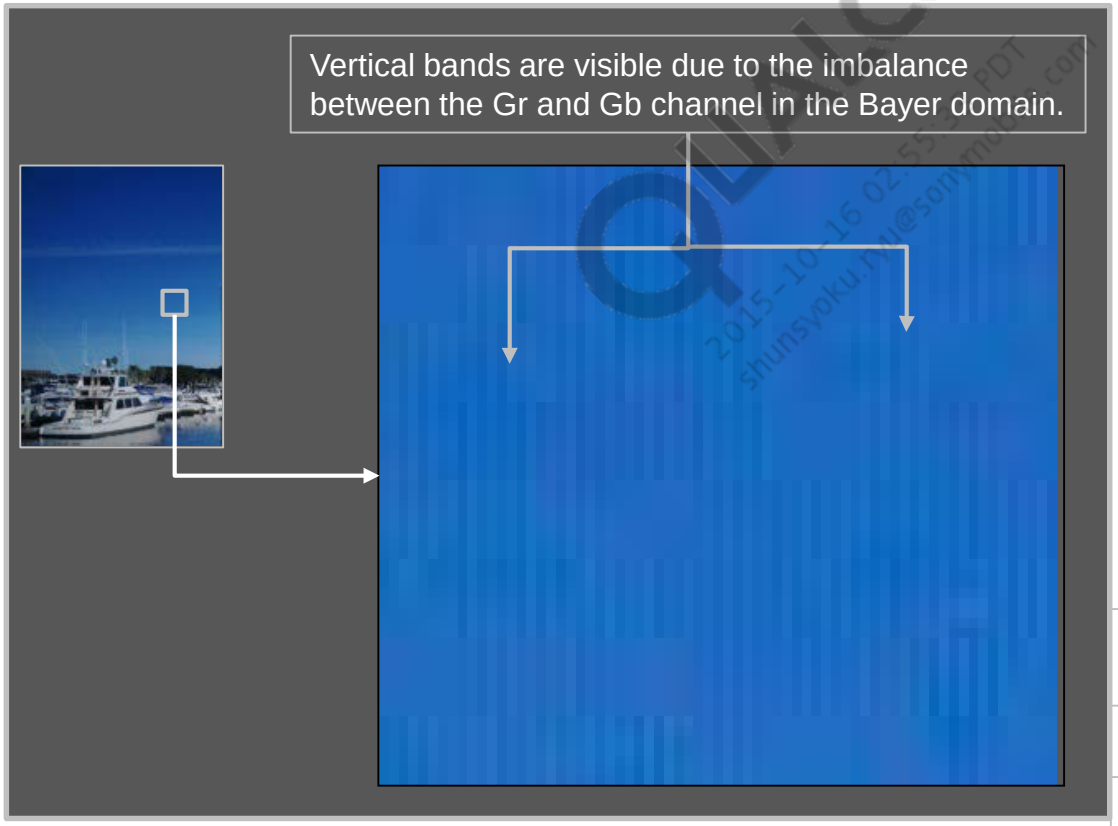
GIC



Problem – GIC

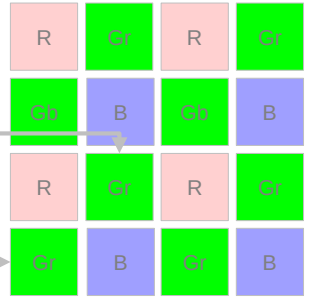
MSM8994
MSM8996

Problem	Some sensors have a significant imbalance between Gb and Gr channels. Those artifacts may not be fully corrected by the noise reduction block in the Bayer domain ABF in MSM8994.



Sensor without Gr/Gb imbalance

Same sensitivities of Gr/Gb channels



Sensor showing Gr/Gb imbalance

Different sensitivities of Gr/Gb channels

Gr/Gb imbalance artifact

Solution – GIC

MSM8994
MSM8996

Solution	GIC removes the banding artifacts caused by the different sensor sensitivities between Gr and Gb channels.

Bayer noise reduction – Off
Green Imbalance Correction – Off

Bayer noise reduction – On
Green Imbalance Correction – Off

Bayer noise reduction – On
Green Imbalance Correction – On

Sample Image – GIC

MSM8994
MSM8996

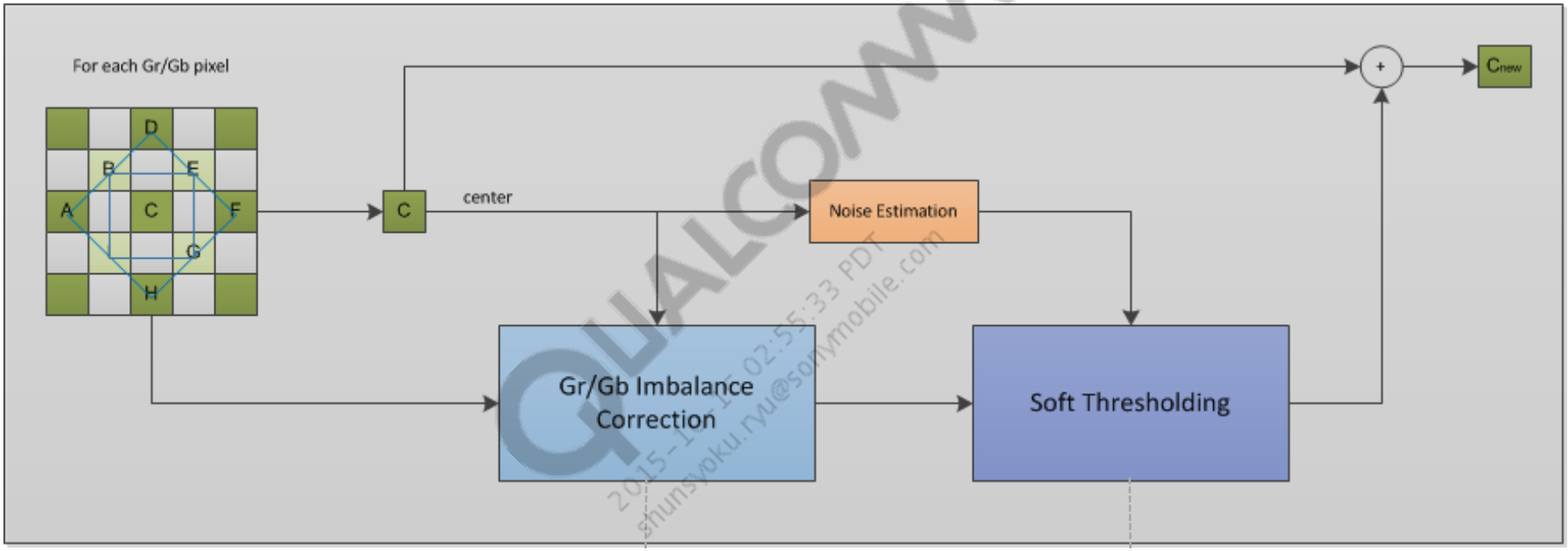
GIC	GIC is designed to remove strong green imbalance artifacts.

Without independent GIC

With independent GIC

Block Diagram – GIC

MSM8994
MSM8996



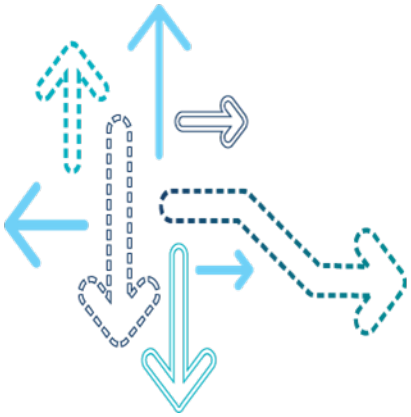
Gr/Gb Imbalance Correction

Taking the center value C and its Gr/Gb neighborhood pixel values, determine the amount of the imbalance correction. The amount of pixel value correction will be applied to the center pixel value to generate a new output Cnew.

Soft Thresholding

Refine the amount of the imbalance correction based on the noise estimation. The noise is characterized as a function of pixel level (brightness). In APQ8084/MSM8994, the noise estimation can be shared with ABF3.

WNR



Problem – WNR

Problem	Low frequency color noise in lowlight scene is noticeable on the image even though denoising is applied with the fourth layer WNR.

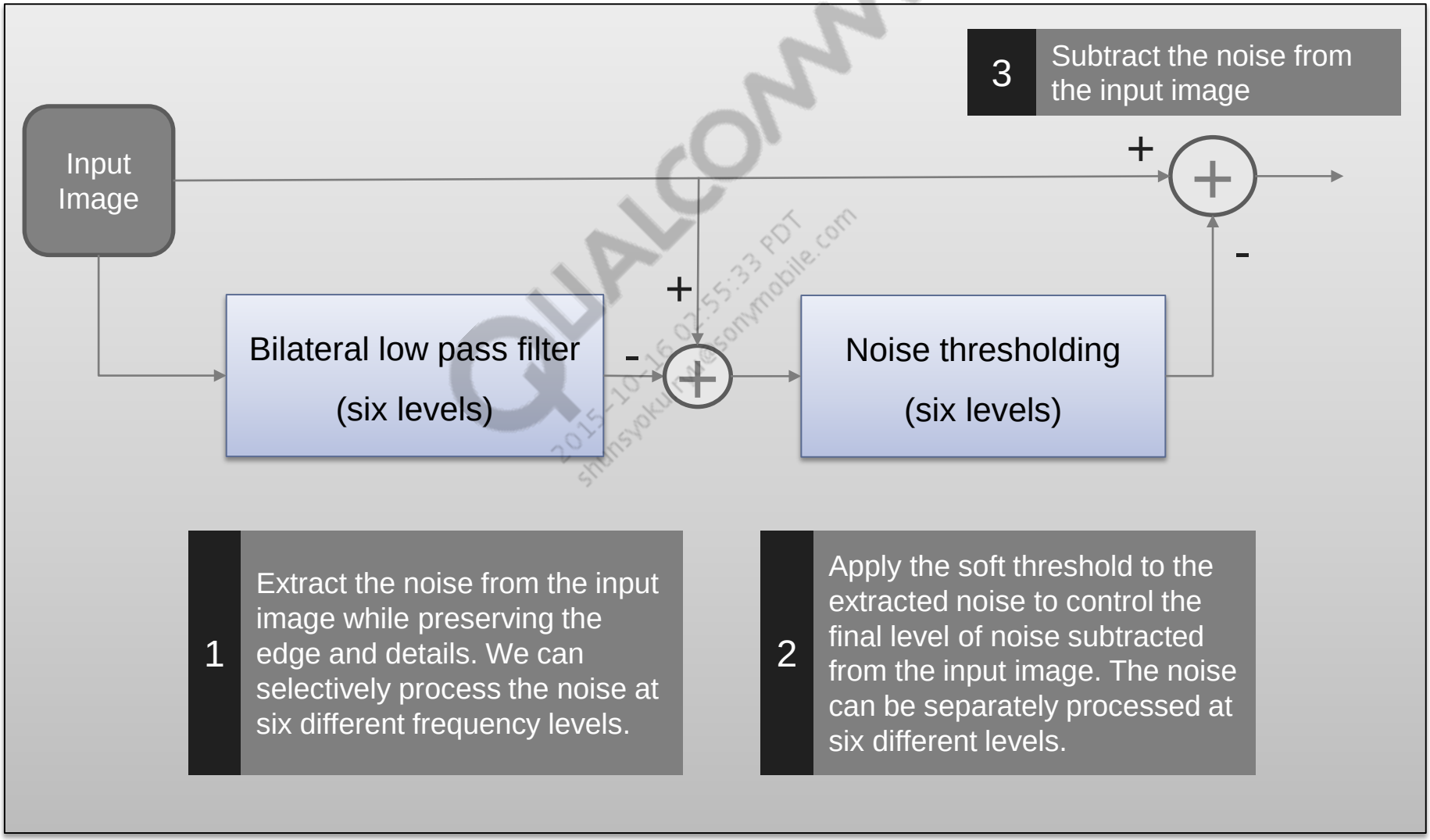
Solution – WNR

Solution	Adding fifth, sixth layer to WNR for reducing low frequency noise

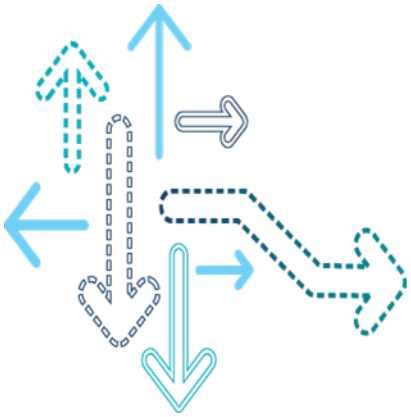
Fourth layer WNR
MSM8974/APQ8084/MSM8994/MSM8992

Sixth layer WNR
MSM8996

Block Diagram – WNR



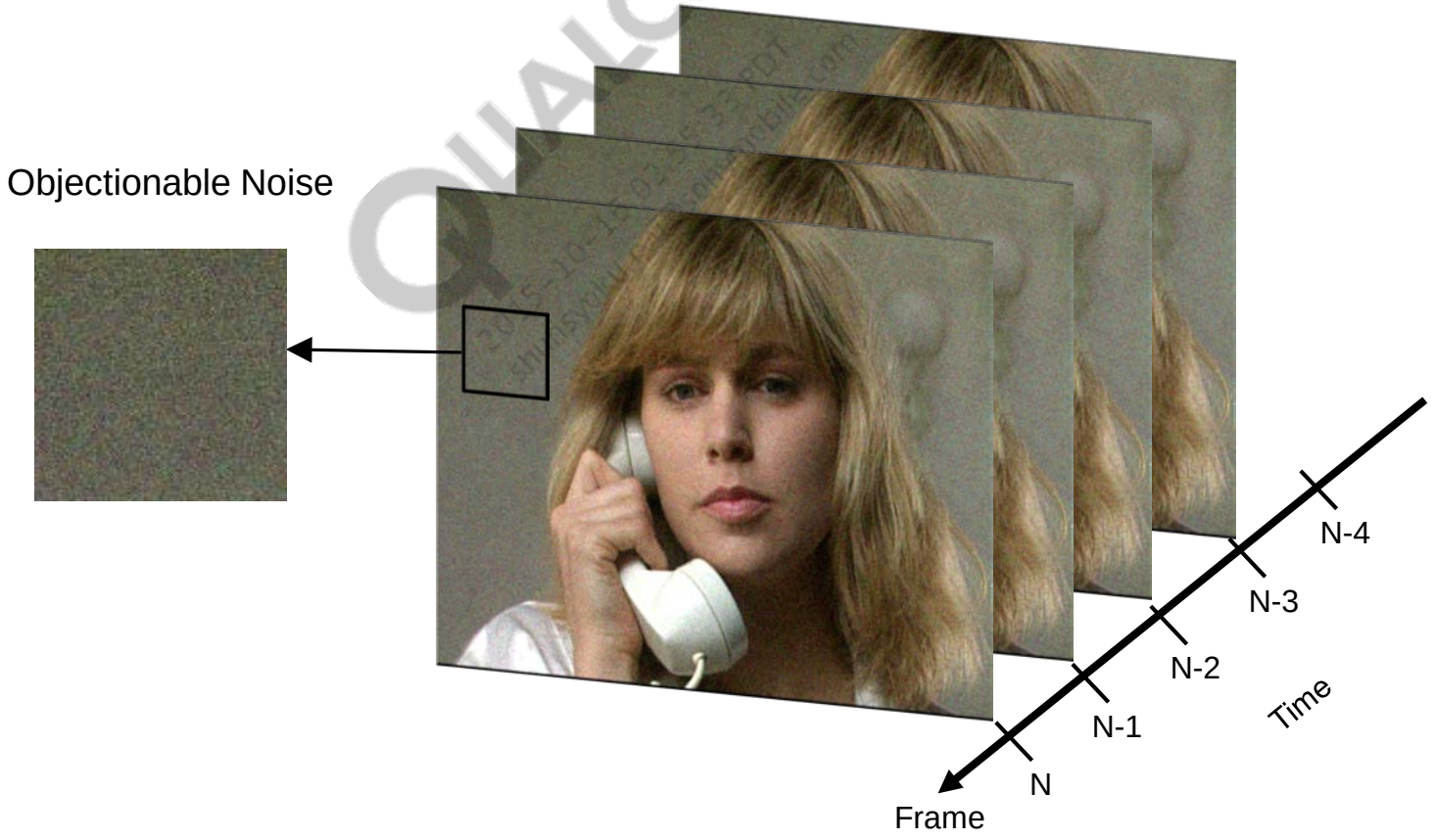
TNR



Problem – TNR

MSM8992/ MSM8994 | APQ8084
MSM8996

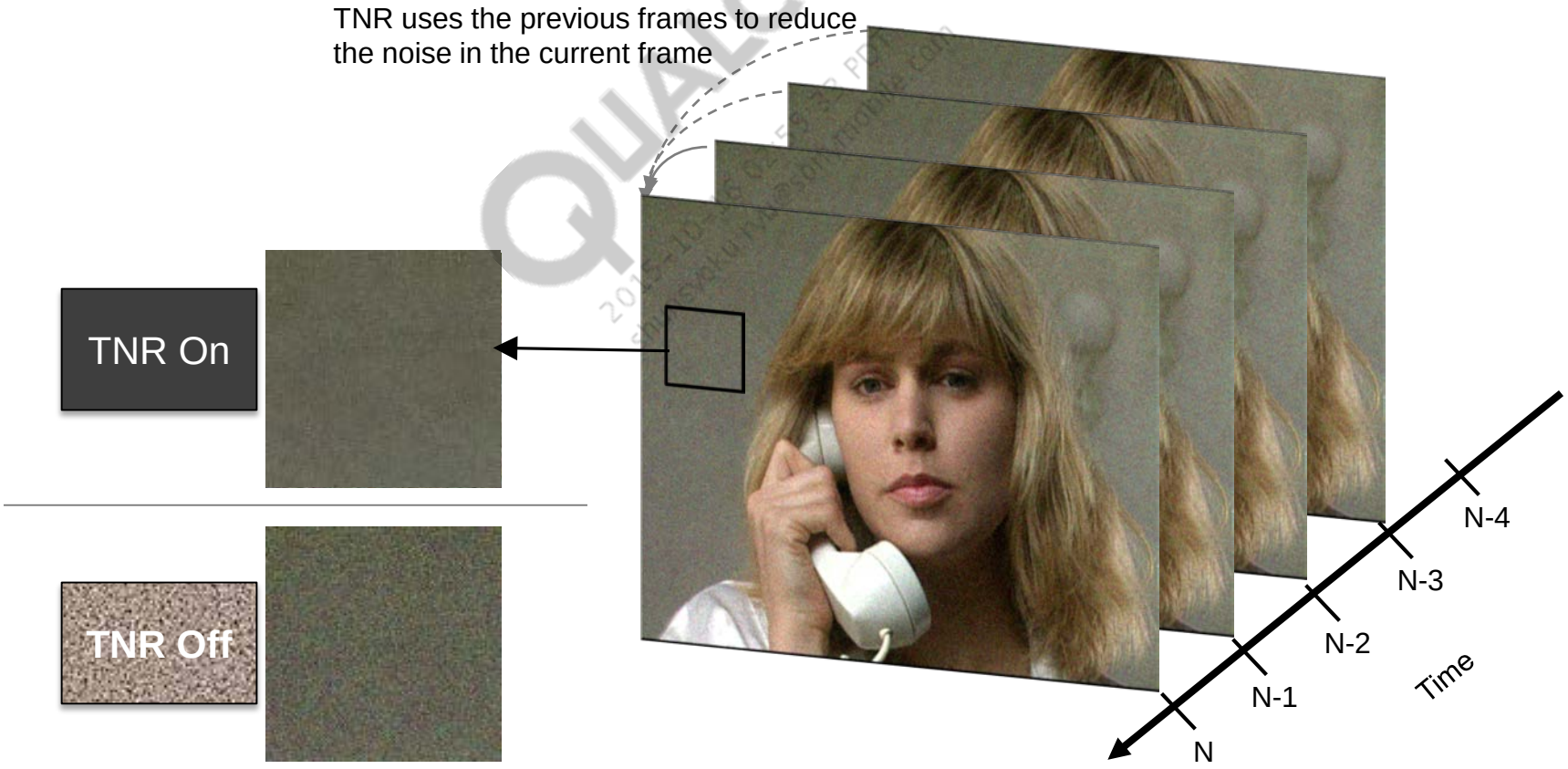
Problem	In the video (camera preview or video recorded from camera), noise is not efficiently reduced by using only the spatial noise reduction block, e.g., WNR in CPP.



Solution – TNR

MSM8992/ MSM8994 | APQ8084
MSM8996

Solution	TNR block efficiently reduces the temporal noise by appropriately processing the current and previous frames.



Sample Video – TNR

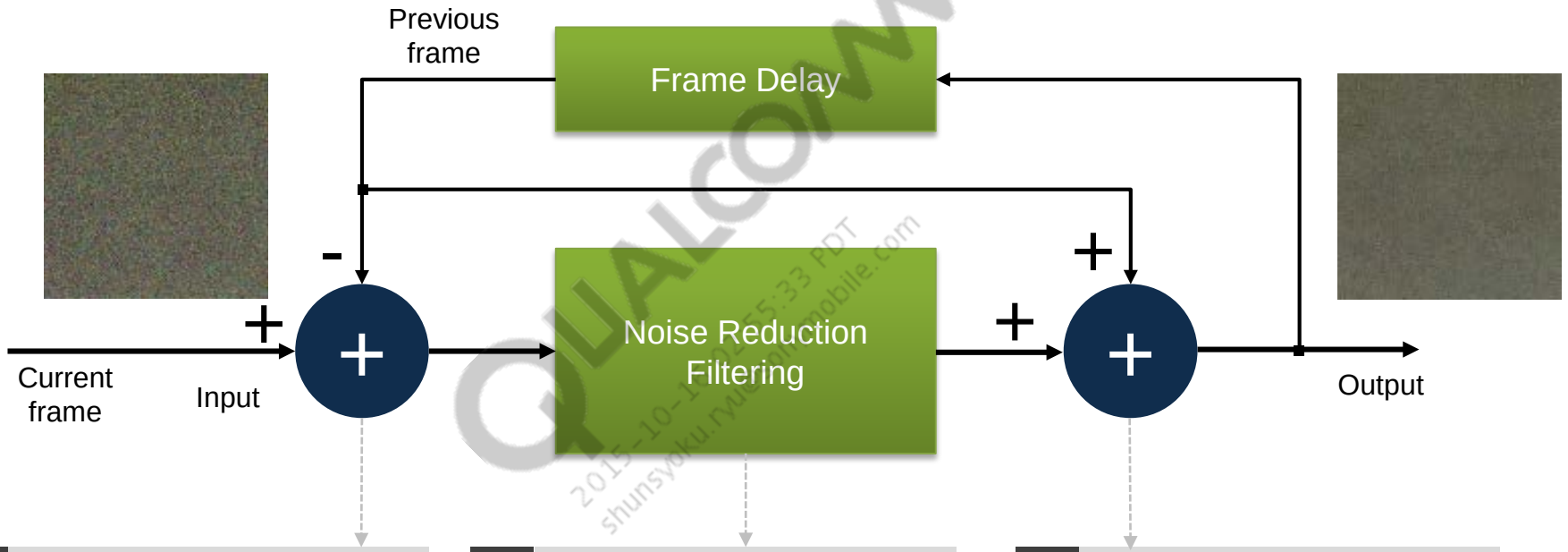
MSM8992/ MSM8994 | APQ8084
MSM8996

TNR Off

TNR On

Block Diagram – TNR

MSM8992/ MSM8994 | APQ8084
MSM8996



1	Generate the image between the current and previous frames.
2	Reduce the noise.
3	Add the previous frame image to the noise reduced image to generate the final output.

Acronyms

Acronyms	
Term	**Definition**
ABF3	Adaptive Bayer Filter, Ver 3
ABF	Adaptive Bayer Filter
ASF	Adaptive Spatial Filter
AF	Auto Focus
CAC	Chromatic Aberration Correction
GIC	Green Imbalance Correction
HF	High-Frequency
LTM	Local Tone Mapping
LF	Low-Frequency
RNR	Radial Noise Reduction
SNR	Skin Noise Reduction
TNR	Temporal Noise Reduction
WNR	Wavelet Noise Reduction

Questions?

https://createpoint.qti.qualcomm.com