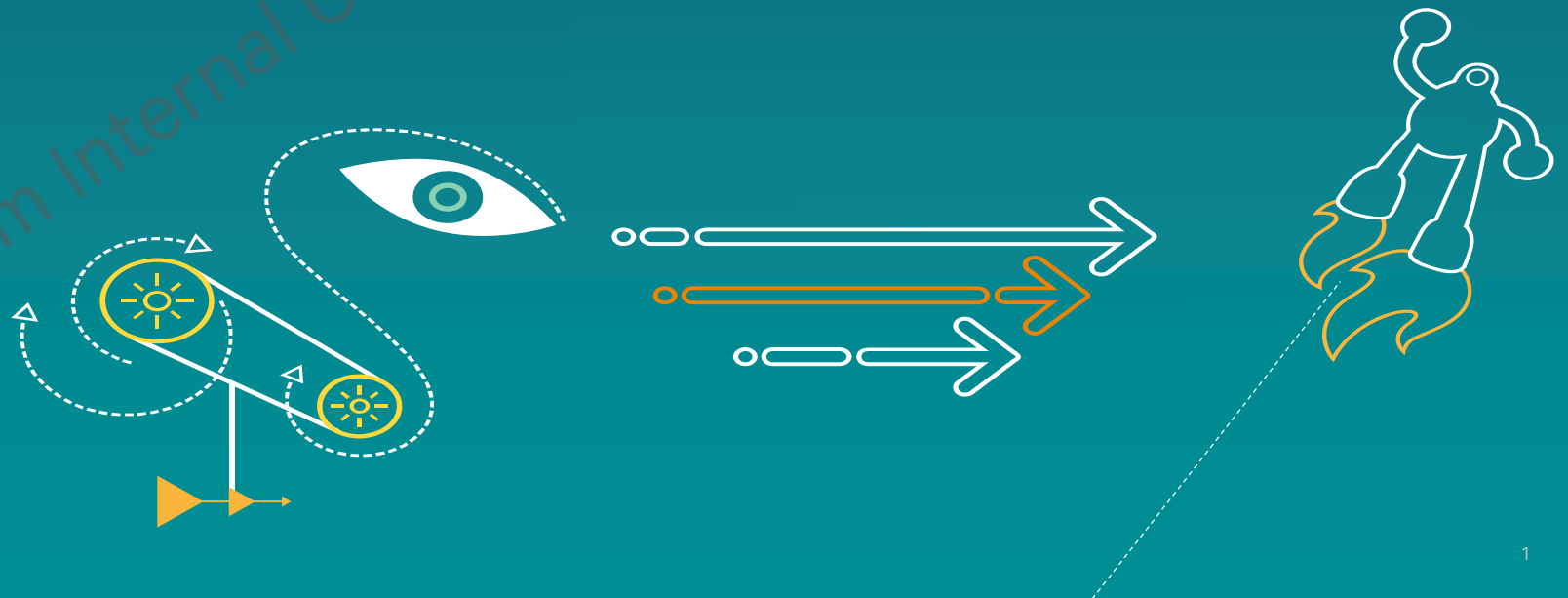
Mar 24th, 2015

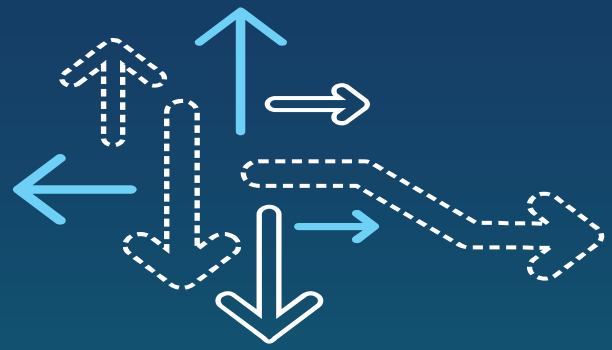
Dual camera – Overview, Applications, HW Requirements and Calibration

Version 1.21



Revision history

Revision	Date	Who	Note
Ver. 1.0	01/30/2015	rlay	Initial draft
Ver. 1.1	03/22/2015	rlay	Updated per below 1. Updated tolerances 2. Additional charts, tables for requirements and experiences 3. Complete reformatting from Version 1.0
Ver. 1.2	03/23/2015	Rlay	1. Changed references to “various aperture” to “variable aperture” 2. Modified slides 9, 10, 19 to more accurately capture support 3. Modified slide 11 to remove “at expense” statement, not relevant 4. Changed MPO descriptive section, more concise and accurate 5. Slide 15, slight change in descriptions 6. Slide 16, added AF calibration 7. Slide 20, removed reference to FOV 8. Slide 21, revised diagrams to better capture alignment of cases 9. HW Section starting slide 27: completely revised to better capture limitations 10. Wording changes throughout that help clarify meaning and intent
Ver. 1.21	03./24/2015	Rlay	1. Corrected slide 32, lower MSM numbering to 8956



QC Dual Camera – overview

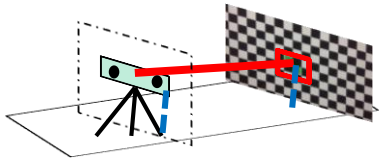
QC Dual Camera – High-Level Overview

Super fast and precise DDM
- Rendering below 1 second
- 8994 based example, 13M+2M

Multi HW sourcing
- QC's Calibration
- PVL Support

World Best Image Quality Foundation
- Top DxO Mark Scores
- http://www.dxomark.com/Mobiles

Qualcomm Dual camera



Faster, easier, calibration
- QC's own
- 2 frame capture
- Full IHV support – SW, Process, Validation

Rich dual camera feature set
- Comprehensive depth features by Qualcomm
- ISV support through API and MPO to application layer

First Things First: Why Qualcomm for Dual Camera Calibration and Libraries?

SW compatibility, HW multi-sourcing, and PVL alignment

- Qualcomm provides a robust calibration which enables any qualified HW vendor to provide components to the customer that seamlessly aligns with the Qualcomm dual camera SW framework and features
- QC's market proven PVL strategy will support dual camera HW sourcing while minimizing SW development support resources
- Supporting multiple vendor calibration and dual camera libraries is not practical for SW integration and performance optimization

Super fast and precise DDM

- Below 1 second, regardless resolution size
- DDM can be supported with a 2M aux camera. Save cost, power, space! No need to use BIG resolution for this purpose.

Rich dual feature set

- Instant AutoFocus and DDM based user-experiences are all supported by Qualcomm's dual camera solution.
- This builds upon our foundation of low-light enhancing, super-resolution, HDR features supported by the main camera.

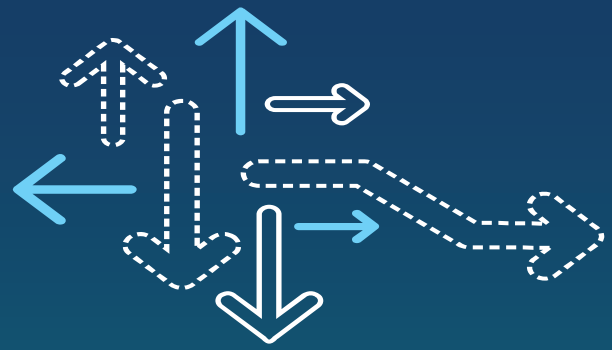
World best image quality foundation – In addition to the dual camera features, IQ is still most important!

- The Qualcomm ISP has been proven world-wide in all market segments: Mobile, IoE, Automotive, etc.
- World best image quality is the foundation of all QC dual camera solutions – http://www.dxomark.com/Mobiles

Qualcomm fielded the world's first stereo camera solution and encompasses many years of experience.

QC Dual Camera – The Overview

Feature	Qualcomm Support
Scalable calibration	yes
Scalable HW sourcing	yes
End to End SW framework	yes
Feature set	rich, by both main/aux and main only
SDM Latency	Real time, 30fps
DDM latency	short, below 1 sec, regardless primary resolution size
ISP foundation	world's best image quality



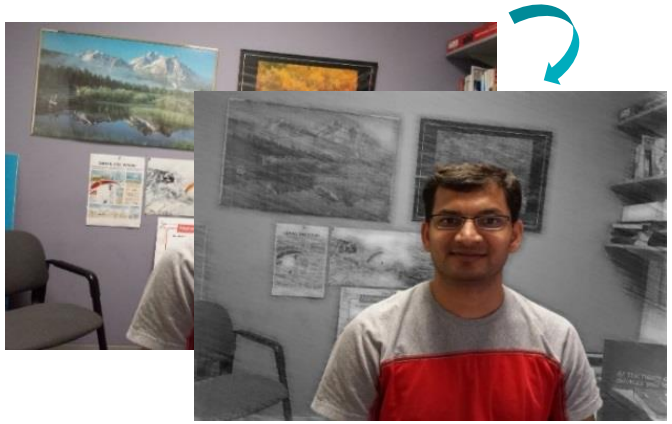
QC Dual Camera – deliverables

Qualcomm Supported or Enabled Dual Camera Features

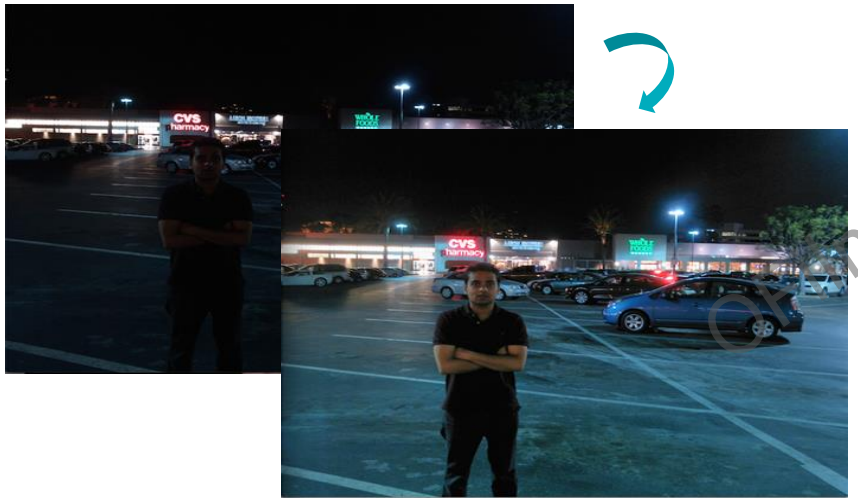
Instant AF and Range measurement

Re-Focus

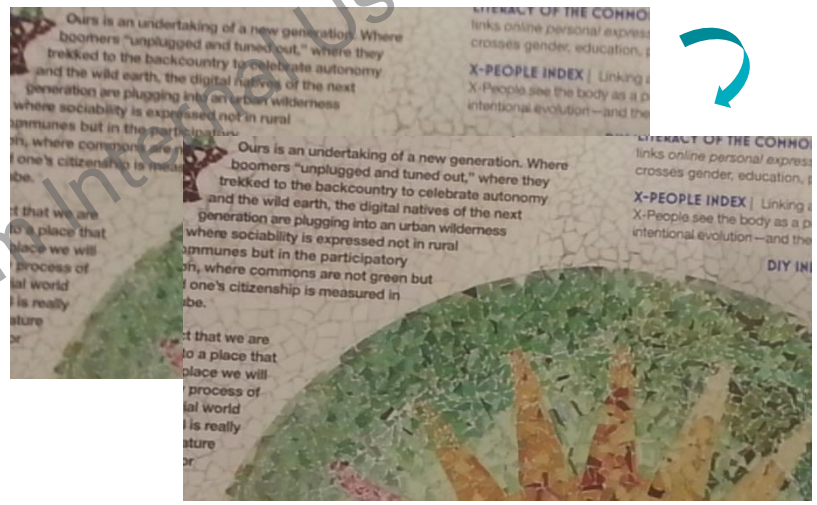
Bokeh with variable Aperture



Segmentation with background editing/replacement



Low Light Enhancement



Super-resolution

High Dynamic Range

Qualcomm Supported or Enabled Dual Camera Features

	Dual camera		Note
	Using main and aux	Main only	
Depth Map Enabled Features			
Instant AF	🟢	N/A	
Range estimation	🟢	N/A	
Re-focus	🟢	🟡	🟡 by UbiFocus, multi-capture using different lens-positions
Bokeh/variable aperture	🟢	🟡	🟡 by TruePortrait, human portrait only
Segmentation, background editing	🟢	🟡	🟡 by TruePortrait, human portrait only
Multi-Frame Fusion Applications			
Low-light enhancement	🟠	🟢	🟢 by StillMore, multi-capture
Super-resolution	🟠	🟢	🟢 by OptiZoom, multi-capture
HDR	🟠	🟢	🟢 by GB HDR, multi-capture with different exposure
		🟡	🟡 by StillMore (in case of low-light, multi-capture)

🟢 **Optimum Experience** 🟡 **competitive experience** 🟠 **Framework support for 3rd party apps**

One Size Doesn’t Fit All !

- Different dual camera configurations have different feature support capabilities, and cost
- Asymmetric (full Res + Low Res Aux) provides rich features at low eBOM adder
- Symmetric (full Res + full Res Aux) provides same depth features as asymmetric, possible fusion features at higher eBom adder
- Wide + Tele give the experience of zoom. Can support depth in the overlapping FOV regions

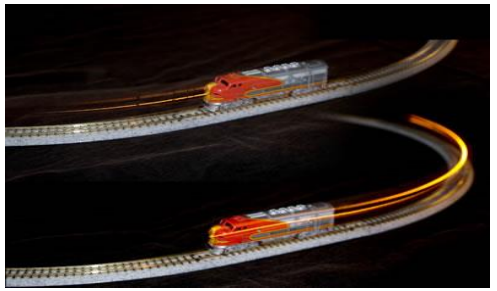
	Asymmetric	Symmetric	Wide + Tele (two different FOV)
Instant / Fast AF	🟢	🟢	🟡
Dense Depth Map	🟢	🟢	🟡
Re-focus, Variable Aperture, Segmentation, etc	🟢	🟢	🟡
SNR/Resolution Enhancement (Low-light)	🔴	🟠	🔴
HDR	🔴	🟠	🔴
Optical Zoom	🔴	🔴	🟢

🟢 Great Experience 🟡 Partial Support 🟠 Framework Support 🔴 No support

Qualcomm Dual Camera – SW Framework, Key Notes

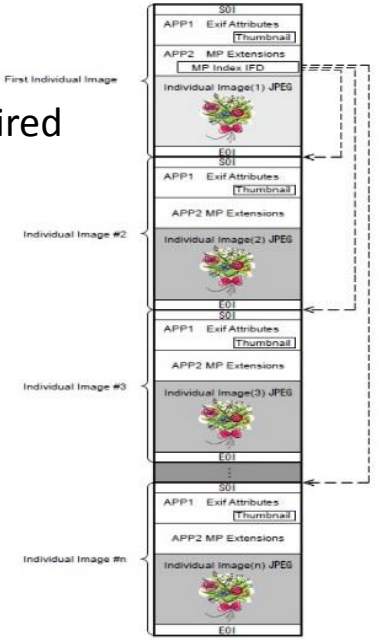
Dual Camera Synchronization and Control (AE, AWB, and Timing)

- For Bayer + YUV configuration, exposure matching to be supported
- For Bayer + Bayer configuration, both exposure and white balance matching by scale factor to be supported
- Independent application control of each camera enabled
- HW sync, sensors need to be hard wired to insure frame synchronization.
  - Lack of frame sync will produce depth map errors when camera, or objects in FOV are moving



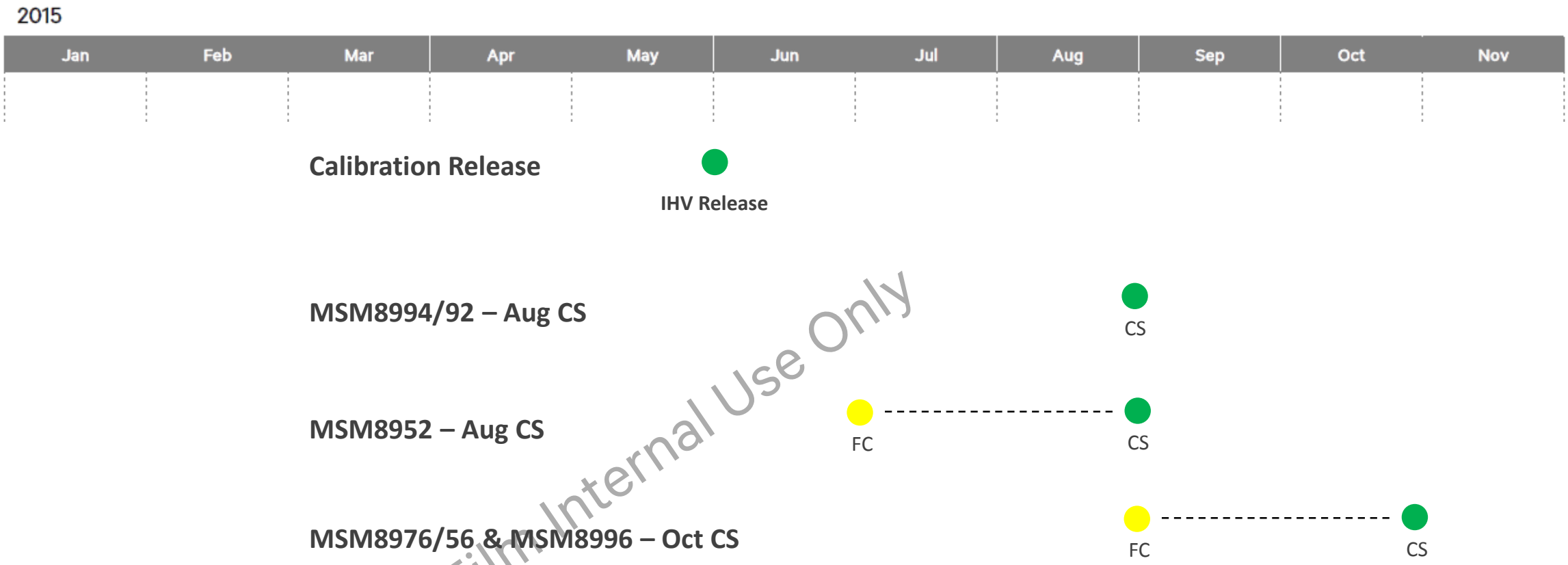
MPO wrapper support

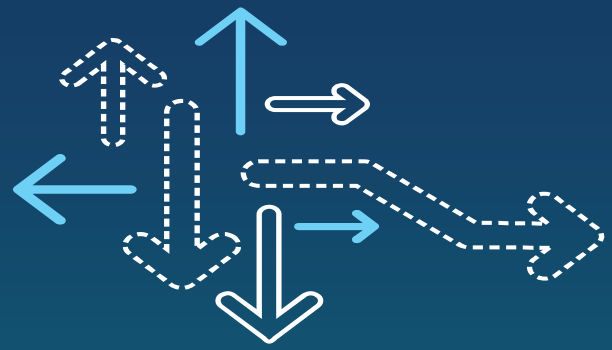
- To enable post process of dual-camera snapshots and 3rd party applications, Qualcomm will provide all the required elements in a single file using the JPEG multi-picture format (MPO)
  - Encapsulates the right image, left image, and calibration data
- Both images are encoded in JPEG format
- The format is backward compatible with most JPEG decoders



Calibration Release plan vs. SW Products

- Calibration release schedule provides adequate buffer in supporting customer schedule requirements

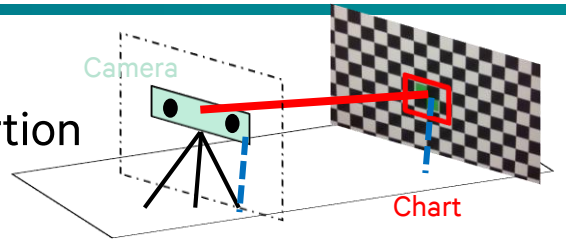




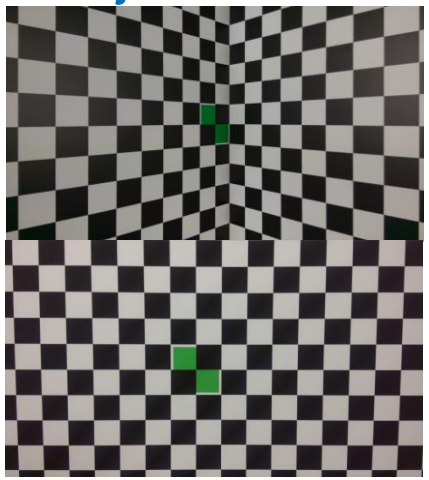
QC Dual camera – Calibration

QTI Static calibration

- End-to-end stereo calibration process and tools
- Correction for both geometric lens distortion and projective distortion
- Superior performance compared to OpenCV
  - Depth accuracy , Scale homogeneity, Residual vertical disparity
  - Only two calibration scenes required
  - Only single (aux) image rectification required
    - Preserves main image quality
    - Processing time reduced by 90% relative to OpenCV
- QTI offers a proven design currently in use by OEMs and Vendors
- Evaluation of single combination chart underway
  - Combination chart will still require 2 captures
  - DUT or chart will require repositioning between the 2 captures

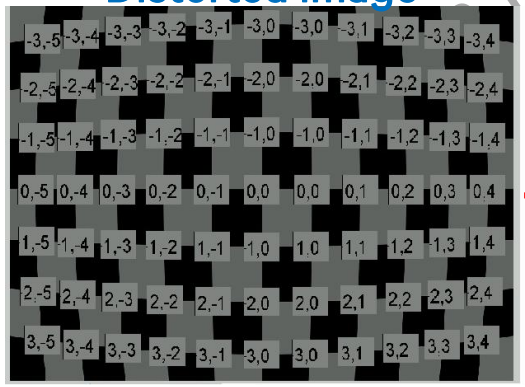


Projective chart

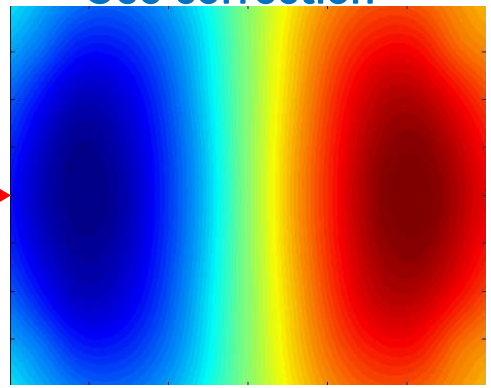


Geometric chart

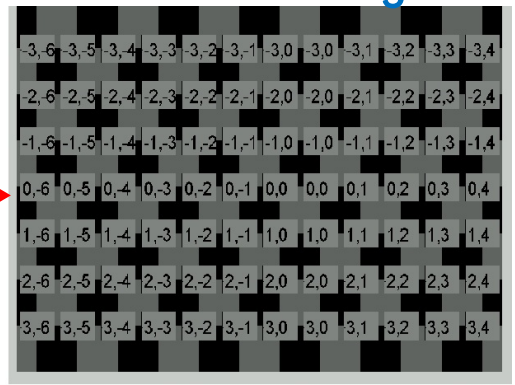
Distorted image



Geo correction



Corrected image



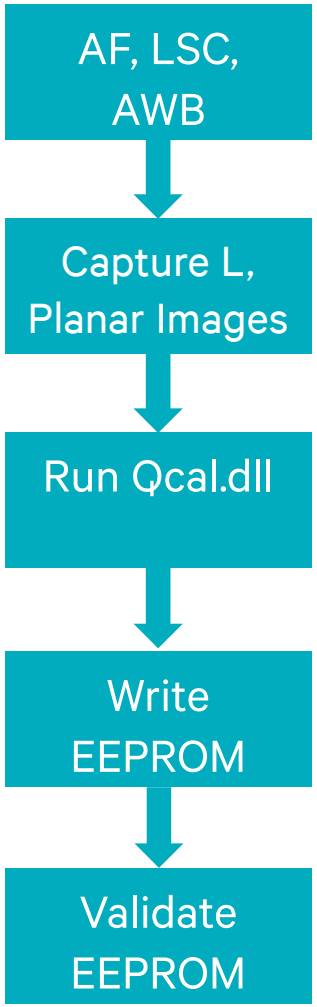
QTI Static calibration

- Non-planar L-chart
  - Comprised of two perpendicular checkerboards
  - The L-chart is used to compute the projective calibration component

- Planar checker board chart
  - Used for geometric distortion correction calibration

- What is provided by Qualcomm?
  - 80-Nxxxx Qualcomm Stereo Calibration Procedure
  - 80-Nxxxx-1_A_Qualcomm_Dual_Camera_Guideline
  - The calibration chart designs used to create the test scenes
  - The calibration dll SW
  - Calibration processes and requirements
  - Calibration set-up validation process
  - EEPROM Map

QTI Static calibration – Process Flow



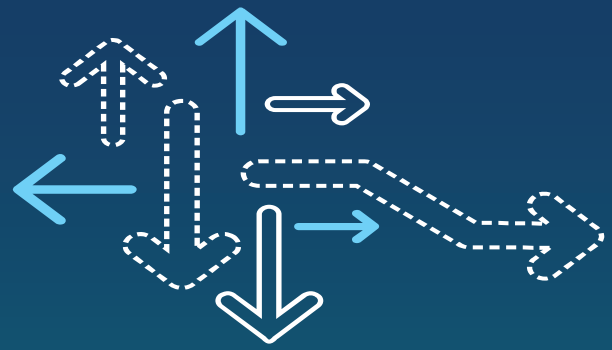
Perform AF, LSC and AWB calibration consistent with customer requirements

Using IHV frame grabber, capture the specified planar and projective charts

Attachment, 80-Nxxxx Qualcomm Stereo Calibration Procedure

EEPROM map provided in 80-Nxxxx-1_A_Qualcomm_Dual_Camera_Guidelines

Per section 4, 80-Nxxxx Qualcomm Stereo Calibration Procedure

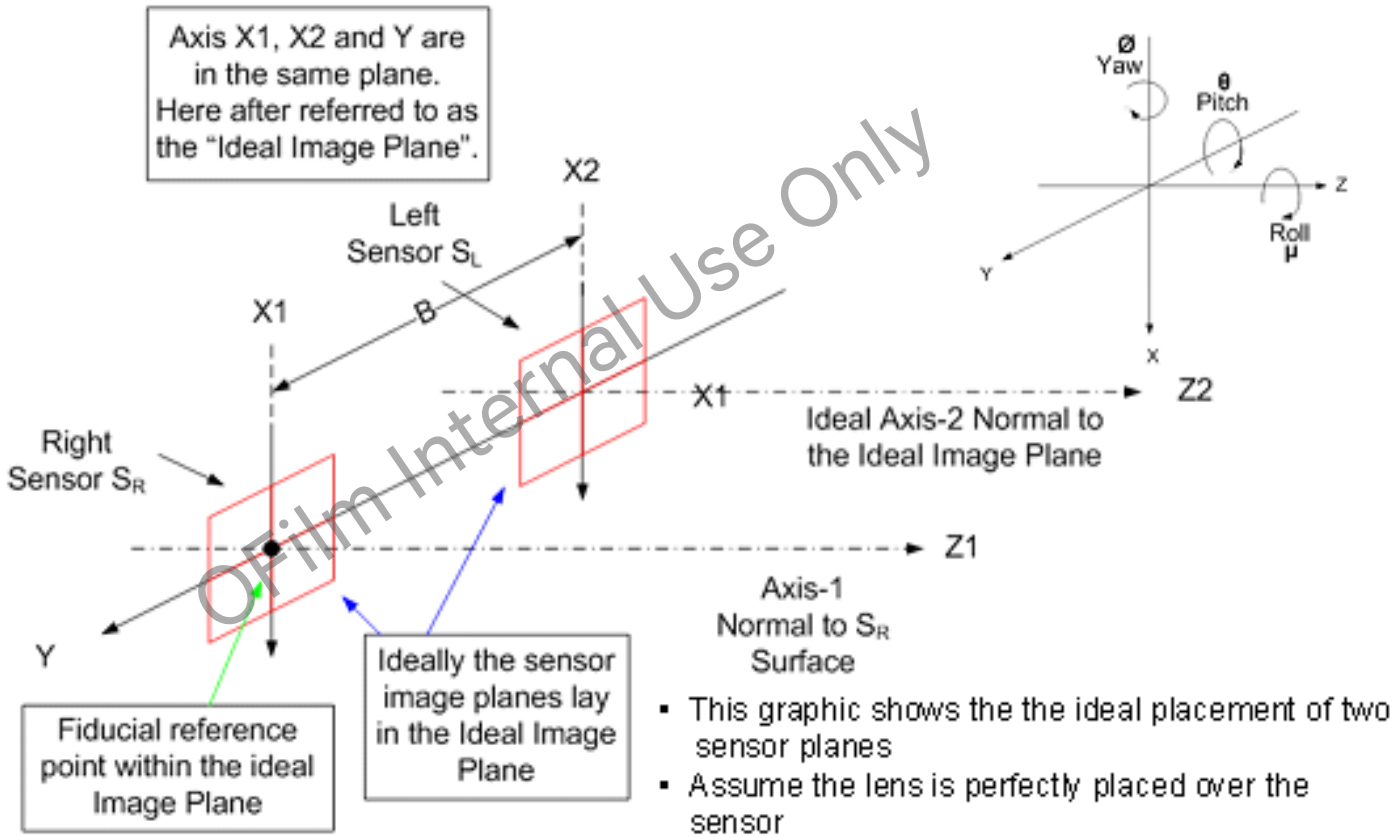


QC Dual camera – HW Component

Dual camera HW – Pre and Post Calibration Tolerances

- Pre-Calibration (Static) Tolerances
  - Static rotational tolerances for pitch, yaw, and tilt are 0.5° max.
  - The static translational tolerance for shift of baseline B, and |X1-X2|, |Y1-Y2| is 0.3mm

- Post-Calibration (Dynamic) Tolerances
  - Dynamic rotational tolerance for pitch, yaw, and tilt is 0.2° max.
  - The dynamic translational tolerance for shift for baseline B, and |X1-X2|, |Y1-Y2| is 0.1mm



Dual camera HW – spacing

All spacings will WORK, but need to consider the performance implications

- Accuracy of AutoFocus
- Quality of dense depth map
- Overlap of FOV
- Impact on mechanical tolerances

	Wide (2cm – 3cm)	1cm	Close (below 1cm)
Instant AF	🟢	🟡	🟡
Dense Depth Map & DDM based use-cases	🟢	🟡	🟠
Image Fusion	🟠	🟠	🟢

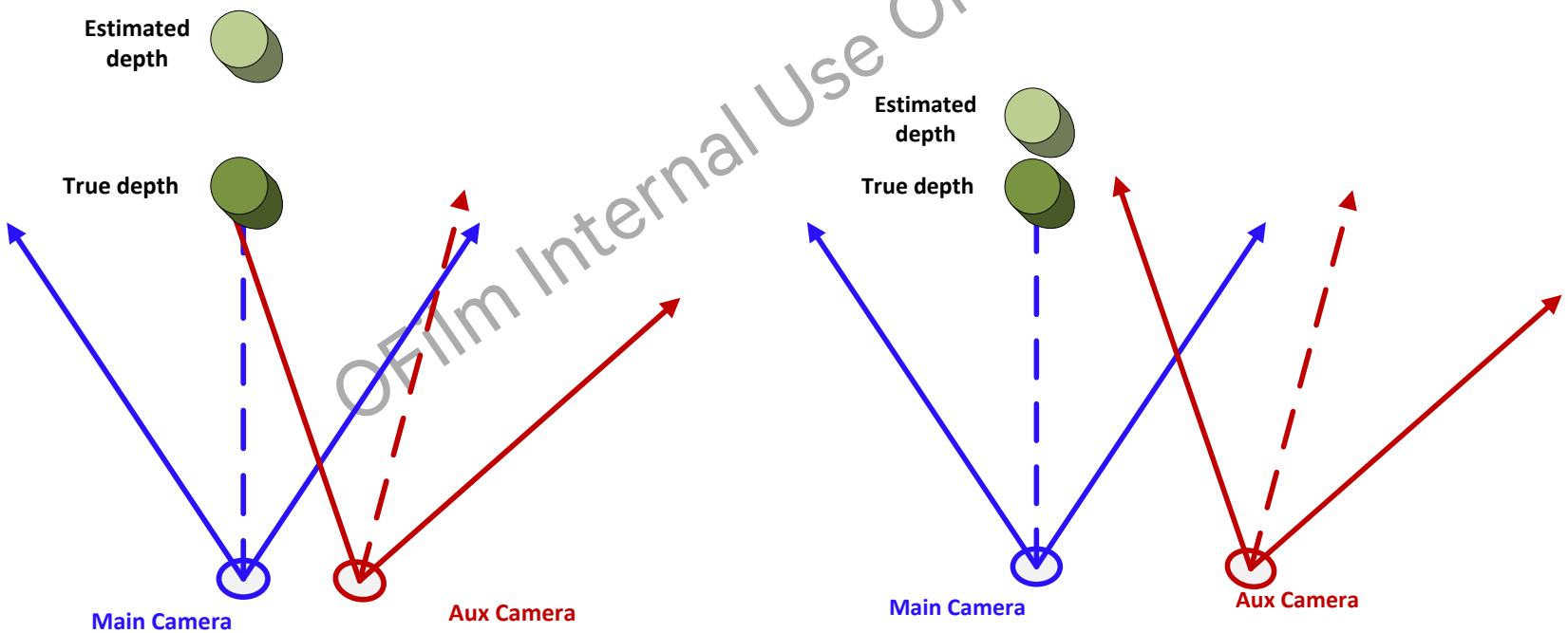
🟢 Optimal Performance 🟡 Acceptable Performance 🟠 Compromised Performance

Camera Spacing vs. Feature Performance

- iAF can operate acceptably with as little as 1cm spacing
- Dense depth map is optimized with wider spacing, 2cm – 3cm
- Fusion will be optimized with minimum spacing between modules
- Mechanical tolerances are diluted with wider spacing. Half the spacing means tolerances are halved as well.

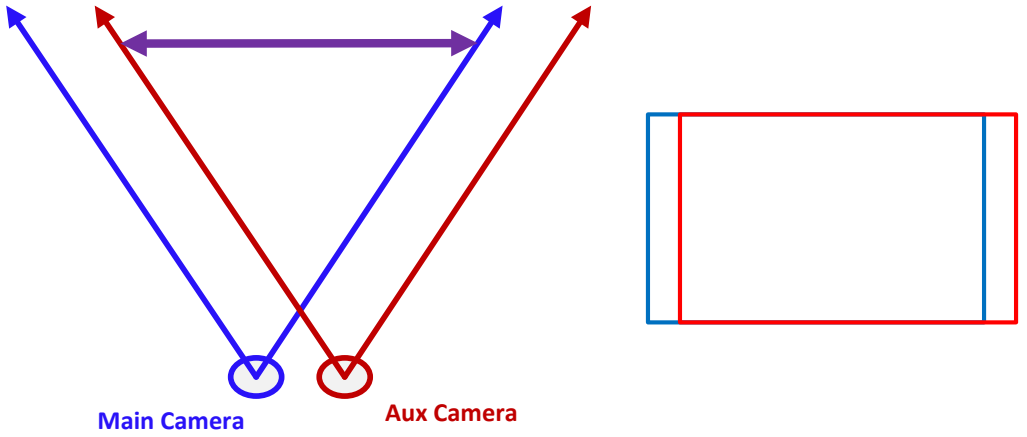
Baseline selection

- Determines key point matching range
- Application dependent
  - IAF can live with 1cm baseline (we need accuracy comparable to DoF)
  - Instant Depth map requires larger baseline 2cm+ since the goal is much better depth accuracy
- Wider baseline dilutes the effects of residual calibration errors!!!
- Wider baseline eases the mechanical tolerances for a given depth accuracy requirement

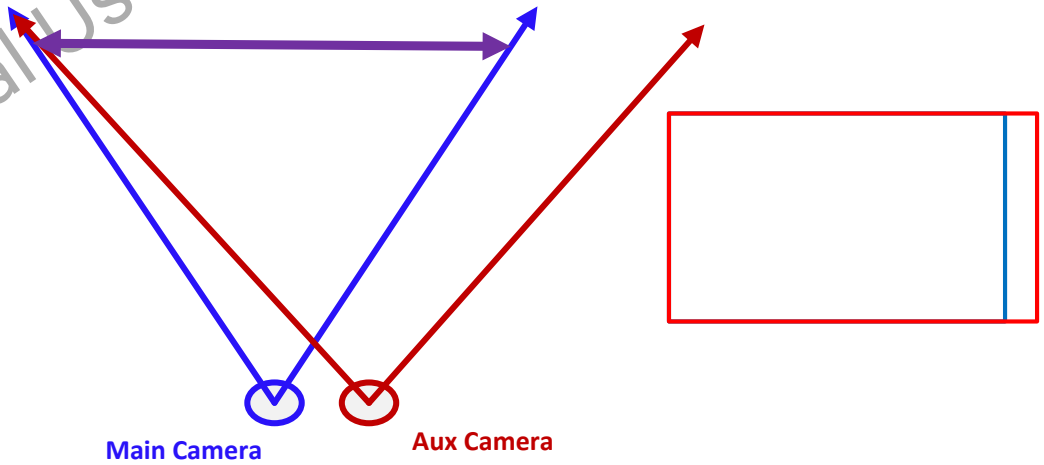


FOV overlap , baseline, auxiliary sensor FOV

- For identical FOV sensors - greater baseline -> smaller FOV overlap



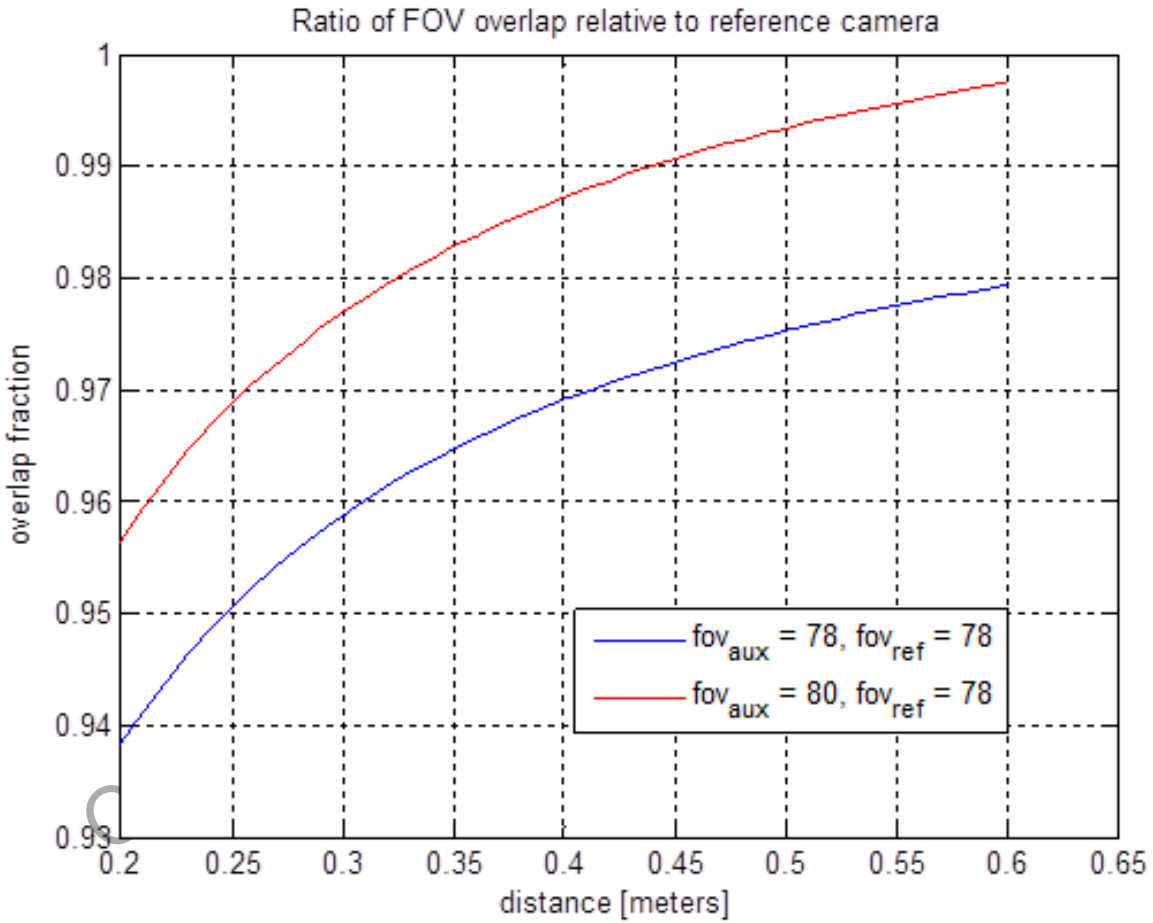
- If 100% FOV overlap is critical, use Aux. sensor with larger FOV



These examples assume perfect alignment. Larger aux FOV also insures overlap with misalignment.

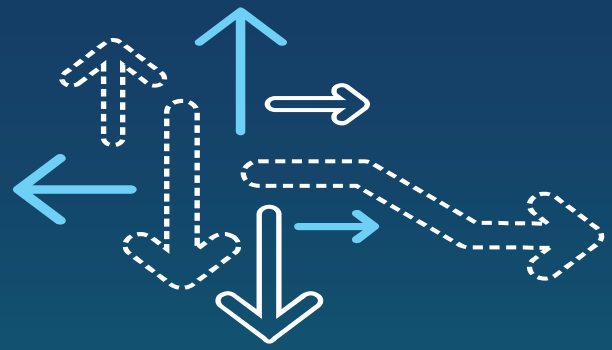
Example Dual Camera FOV Overlap– Asymmetric and Symmetric Spacing and Lens FOV

- Dual camera FOV overlap vs FOV: 2cm Baseline



Aux Camera Resolution selection

- Two depth quantifiers
  - Absolute depth error – error between true and estimated depth
  - Depth granularity – ability to differentiate between objects at similar depths
- Auxiliary sensor resolution “somewhat” determines depth accuracy
  - There is always residual calibration error that causes depth error
  - Increasing resolution beyond that does not improve depth accuracy
  - Corollary : For IAF purposes , no higher than VGA resolution is needed
- Auxiliary sensor resolution determines depth granularity
  - Dense depth map used for segmentation purposes requires distinction between objects at similar depths (not the absolute depth)
- Auxiliary sensor resolution limits and benefits
  - Dense depth map is generated using a subsample of the aux camera
  - ¼ resolution in vertical and horizontal planes is all that is required for DDM
  - Dense depth map is satisfactory with a 21Mpix + 2Mpixel. Additional aux resolution does not improve depth map experience, and adds much cost, power, size



Dual camera HW – Sensor Selections

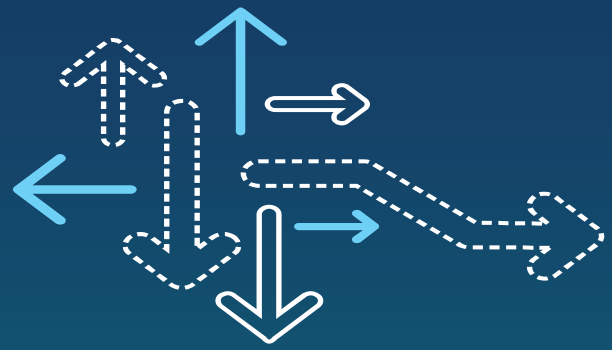
Asymmetric Dual camera HW configuration vs. MSM

Primary Resolution	Primary Sensor	Aux Resolution	Aux Sensor	Support
21Mpixel, Bayer	**IMX230**	**2MP, YUV**	**OV2685**	8992, 8994, 8996 8956, 8976
16Mpixel, Bayer*	**2P8**	**2MP, YUV**	**OV2685**	8992, 8994, 8996 8952, 8956, 8976
13Mpixel, Bayer	**OV13850**	**2MP, YUV**	**OV2685**	8992, 8994, 8996 8952, 8956, 8976

*Proposed

Symmetric Dual camera HW configuration vs. MSM

Resolution	Sensor	Support
13Mpixel	**OV13850**	8992, 8994, 8996 8956, 8976
13Mpixel	**3M2**	8992, 8994, 8996 8956, 8976
8Mpixel	**OV8865** **OV8858**	8992, 8994, 8996 8952, 8956, 8976



Dual camera HW – System Considerations

Dual Camera – MSM Architectural considerations

- This section discusses sensor resolution, sensor selection, and MIPI interfaces
- You need to take into account
  - MSM MIPI interface capability
  - MSM ISP architecture
  - Sensor resolution
  - Sensor MIPI interface speeds
- The MIPI interface examples are conceptual, and you need to review the MIPI combo phy design of your specific MSM to get the proper lane configurations. Clocks are not shown in these conceptual diagrams, and the combo PHY remaps MIPI lanes to enable additional clocks when mapping the 4-lane interface to a 2/1 lane configuration.

Asymmetric Dual Camera – MSM8952 Architectural considerations

There are caveats when selecting aux sensors and self-view sensors in light of a 13+2 asymmetric camera architecture

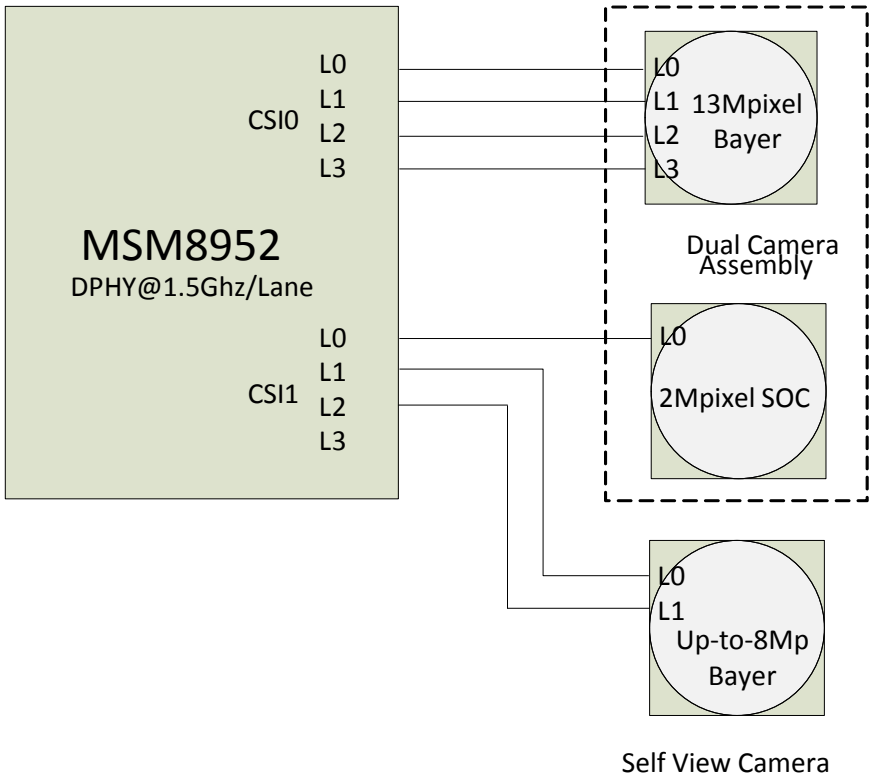
Self View sensor selection has to be considered relative to interface and ISP limitations:

2 x 8Mpixel ISP
2 x 4-Lane CSI-1
CSI1 is a combo PHY: 4-Lane OR 2+1-Lane

2 Lanes will support up-to-8MPixel Self-View Sensor
- 8Mpixel self-view with 2 lanes@30fps limited to 2 sensors in the industry
  - OV8858, OV8865
- 8Mpixel sensors that require 4-lanes will necessitate a MIPI mux

Aux camera is restricted to SOC sensors that support 1-MIPI lane operation
- 2Mpixel SOC is run 2x2 bin for an 800x600@30fps
- Sensors that require 2 lanes for this mode of operation will impose limitations on the self-view, or require a mux

PiP/ViV Limitations
- PiP/ViV can be run with Primary 13Mpixel configured as 8Mpixel + self-view 8Mpixel

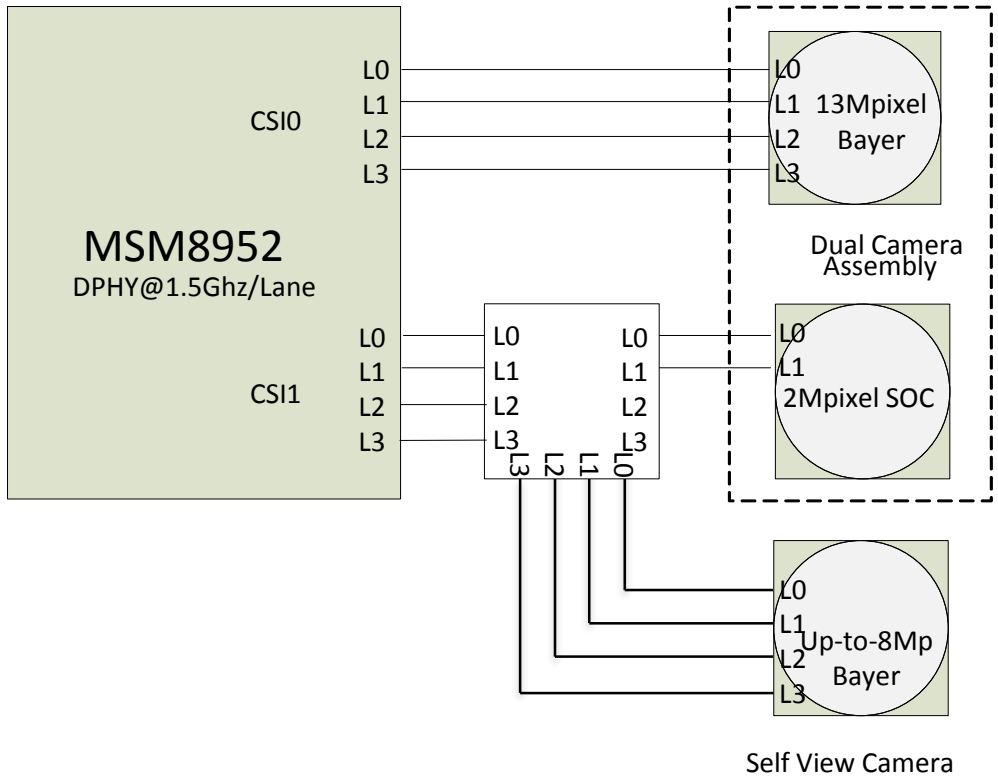


Asymmetric Dual Camera – MSM8952 Architectural considerations

A MIPI mux will be required when using an aux sensor that requires more than 1 lane
Or
When using a self-view sensor that requires more than 2 lanes

This architecture removes the restrictions on the self-view resolution

The PiP/ViV restrictions remain limited to the 8Mpixel + 8Mpixel imposed by the ISP capability of the MSM8952



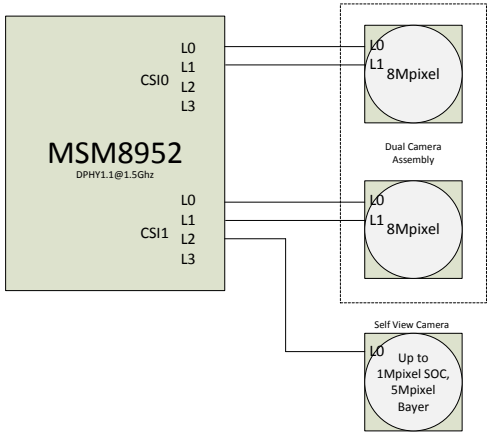
Symmetric Dual Camera – MSM8952 Architectural considerations

2 x 8Mpixel ISP
2 x 4-Lane CSI-1

Sensor selection relative to interface limitations:

2 Lane 8MPixel Sensor + SOC self-view

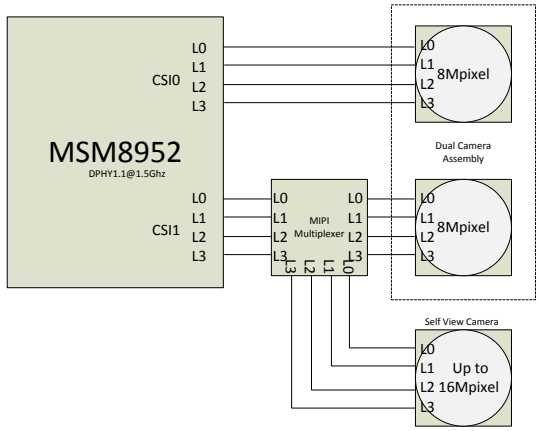
+ Allows for PiP/ViV with dual camera and SOC self-view
- Limited to 2 sensors in the industry that support 30fps over 2 lanes
  OV8858, OV8865
- Self-view camera limited to 2Mpixel raw, 1Mpixel SOC
  MIPI lane restricted
-PiP/ViV w/dual limited to 1Mpixel SOC



4 Lane 8MPixel Sensor or Bayer self-view: Must use a multiplexer

+ No sensor selection restrictions
+ No self-view resolution restriction, up to ISP capability

- Allows for PiP, but not with dual camera
- Cost/area for MIPI mux



Asymmetric Dual Camera – MSM8956 Architectural considerations

21Mpixel primary camera shown, but can also be lower resolutions

Self-view sensor selection has to be considered relative to interface and ISP limitations:

2 Lane supports up-to-8MPixel Self-View Sensor

8Mpixel self-view with 2 lanes limited to 2 sensors in the industry that support 30fps over 2 lanes

Self-view aux camera limited to 2Mpixel SOC

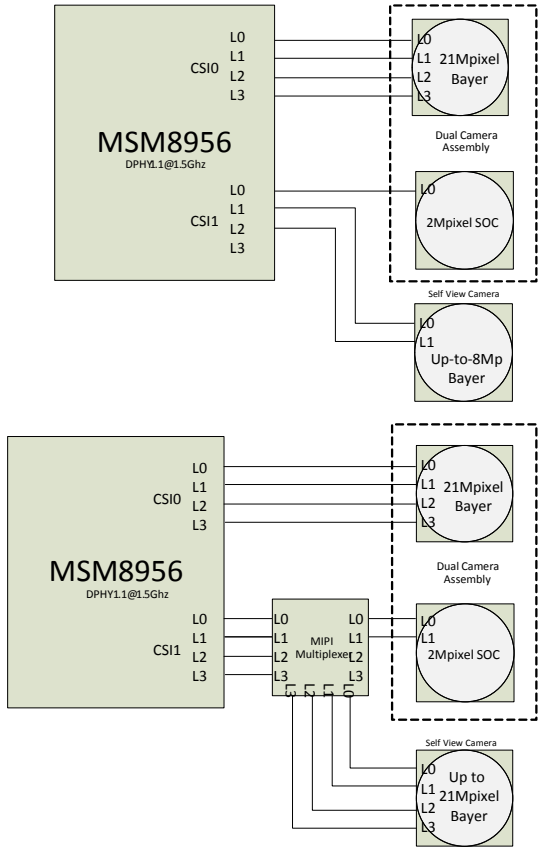
1-MIPI lane restricted

PiP/ViV 8Mpixel + 8Mpixel w/dual with raw self-view camera

MIPI Mux Enables Higher Lane Counts/Resolution for Self-View Sensor and Aux Sensor

+ No sensor selection restrictions
+ No self-view resolution restriction, up to ISP capability (w/o PiP/ViV)

- Allows for PiP/ViV, but not with dual camera
- Cost/area for MIPI mux



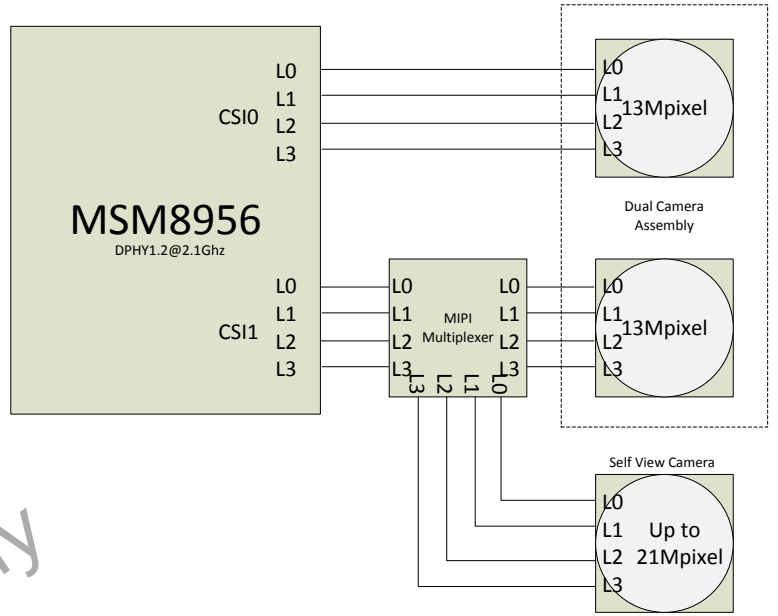
Symmetric Dual Camera – MSM8956 Architectural considerations

2 x 13Mpixel ISP
2 x 4-Lane CSI @ 2.1Ghz

A MIPI Mux will be required for any symmetric dual camera solution on the MSM8956 using 4 lane sensors

+ Allows for PiP/ViV with primary camera
+ No limitations on self-view, up to ISP limit

- Cost/area of CSI mux



Thank you

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