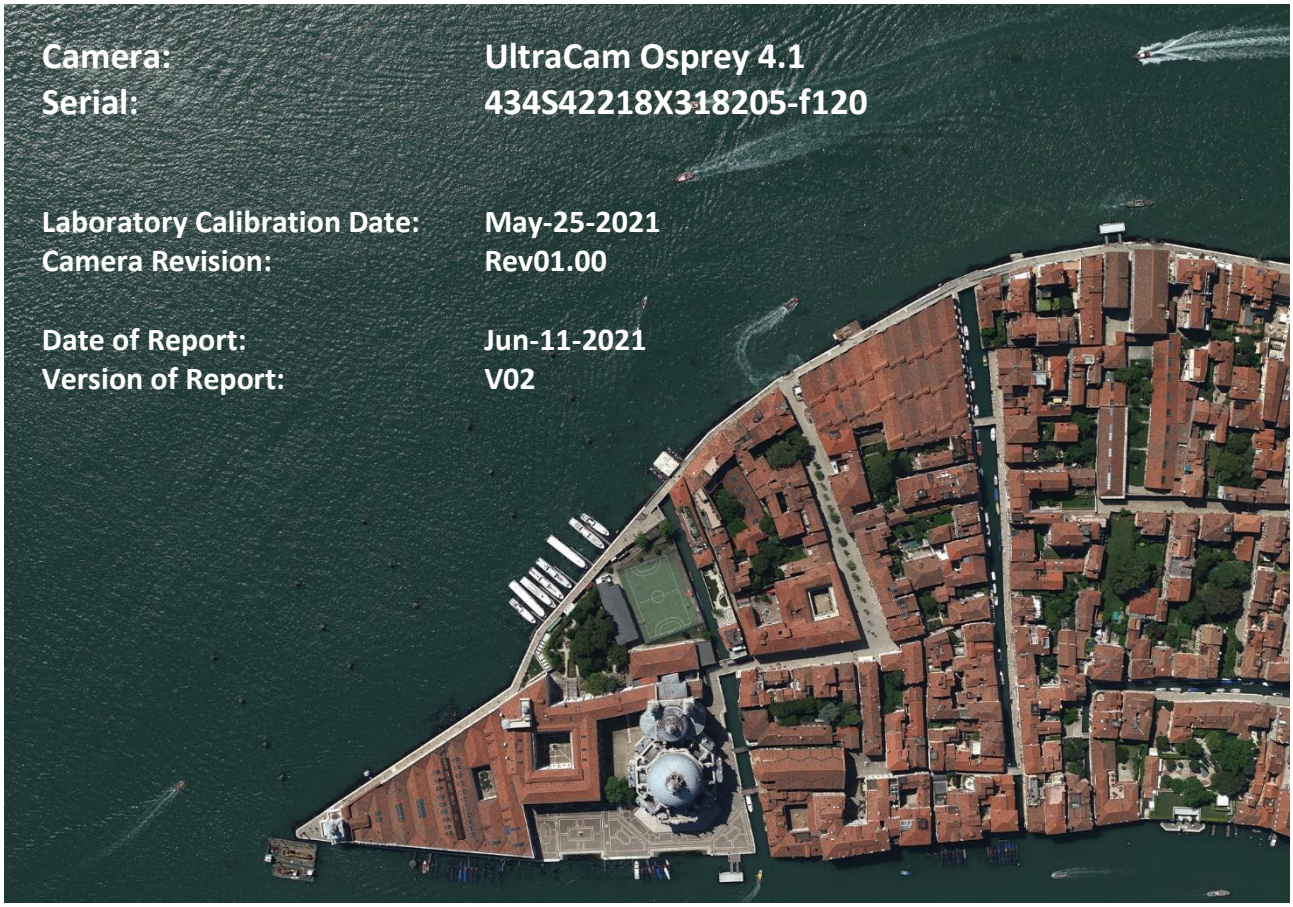
VEXCEL
IMAGING

ULTRACAM

Calibration Report



Camera:	**UltraCam Osprey 4.1**
Serial:	**434S42218X318205-f120**
Laboratory Calibration Date:	**May-25-2021**
Camera Revision:	**Rev01.00**
Date of Report:	**Jun-11-2021**
Version of Report:	**V02**

Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH

ULTRACAM

Geometric Calibration

Camera:	**UltraCam Osprey 4.1**
Serial:	**434S42218X318205-f120**
Panchromatic Camera:	**ck = 79.600 mm**
Multispectral Camera:	**ck = 49.750 mm**
Oblique Camera:	**ck = see table below**
PPA Information Nadir:	**X: 0.000 mm** **Y: 0.000 mm**
PPA Information Oblique:	**see table below**

Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	52.700mm 77.245mm	14016pixel 20544pixel
Image Extent		(-26.350, -38.623)mm	(26.350, 38.623)mm
Pixel Size		3.760µm*3.760µm	
Focal Length	ck	79.600mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

Medium Format Multispectral Output Image (Upscaled to panchromatic image format)

Image Format	long track cross track	52.700mm 77.245mm	8760pixel 12840pixel
Image Extent		(-26.350, -38.623)mm	(26.350, 38.623)mm
Pixel Size		6.016µm*6.016µm	
Focal Length	ck	49.750mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Oblique Camera

Oblique Output Image

Image Format	long track cross track		39.706mm 53.181mm	10560pixel 14144pixel
Image Extent			(-19.853, -26.591)mm	(19.853, 26.591)mm
Pixel Size			3.760µm*3.760µm	
Focal Length	C4 (Backward)	ck	123.380mm	± 0.002mm
	C5 (Right)	ck	123.380mm	± 0.002mm
	C6 (Left)	ck	123.380mm	± 0.002mm
	C7 (Forward)	ck	123.380mm	± 0.002mm
Principal Point (Level 2)	C4 (Backward)	X_ppa	0.000mm	± 0.002mm
		Y_ppa	0.000mm	± 0.002mm
	C5 (Right)	X_ppa	-6.680mm	± 0.002mm
		Y_ppa	0.000mm	± 0.002mm
	C6 (Left)	X_ppa	6.680mm	± 0.002mm
		Y_ppa	0.000mm	± 0.002mm
	C7 (Forward)	X_ppa	0.000mm	± 0.002mm
		Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm			

Enhanced Resolution output:

NADIR Images:

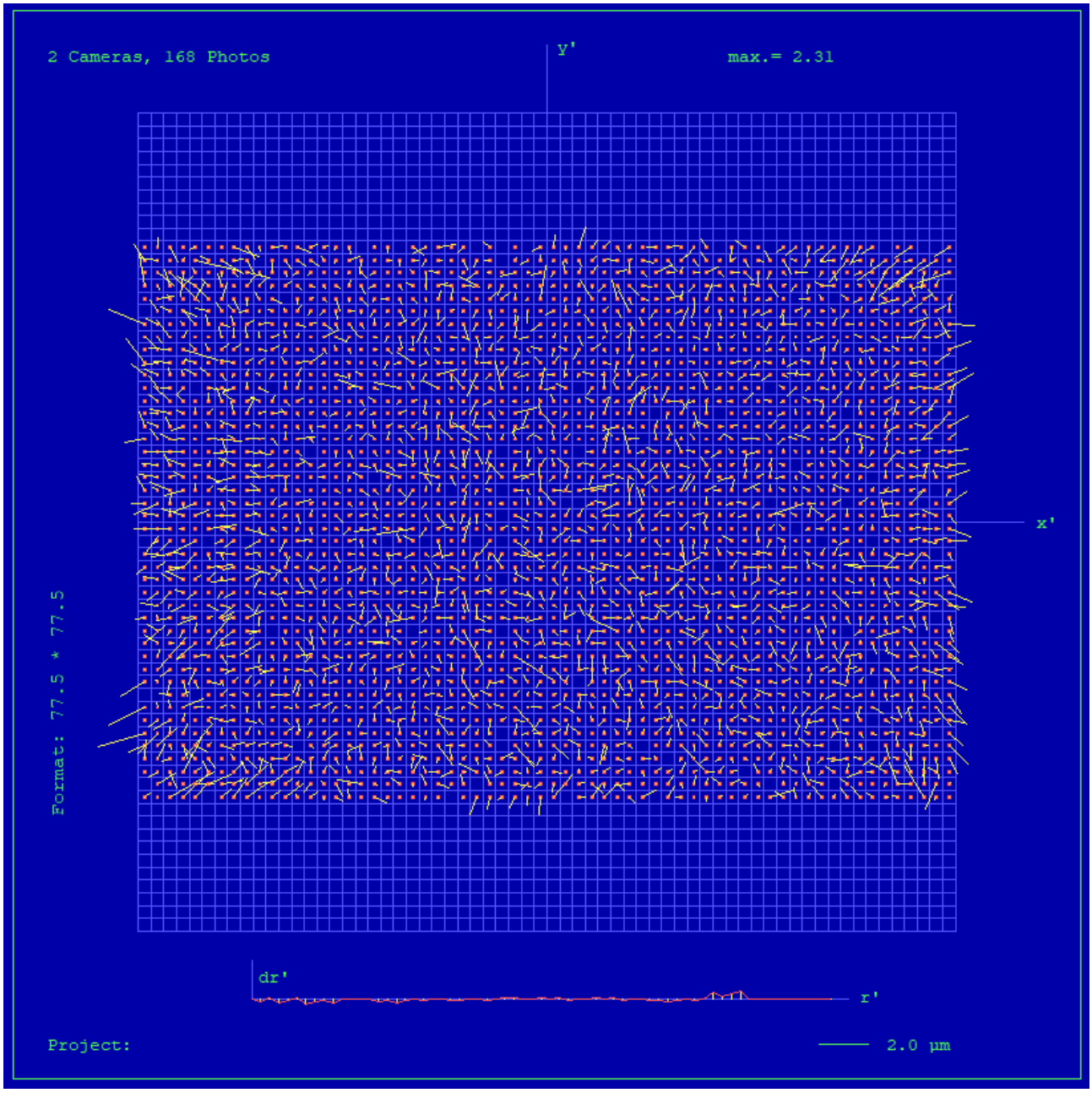
Image Format	long track cross track	52.700mm 77.245mm	21024pixel 30816pixel
Image Extent		(-26.350, -38.623)mm	(26.350, 38.623)mm
Pixel Size		2.506666667µm*2.506666667µm	

Oblique Images:

Image Format	long track cross track	39.706mm 53.181mm	12210pixel 16354pixel
Image Extent		(-19.853, -26.591)mm	(19.853, 26.591)mm
Pixel Size		3.251891892µm*3.251891892µm	

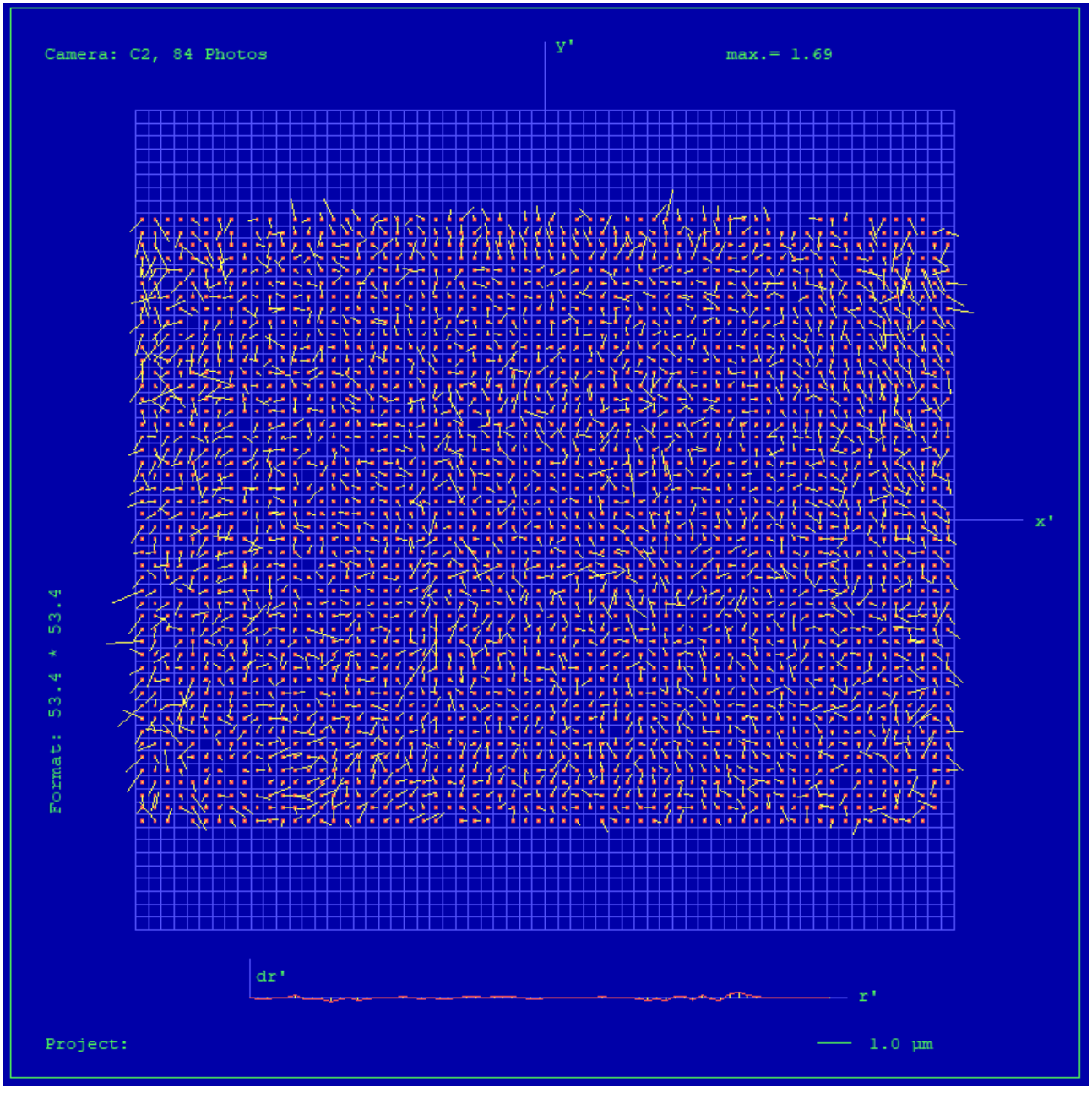
Other specifications, like Lens Distortion, Focal Length and Principal Point remain valid like stated on pages 4 and 5, therefore these values are not stated separately on this page.

Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.73 µm**

RGB Cone (Cone 2), Residual Error Diagram



Residual Error (RMS): **0.60 µm**

Explanations

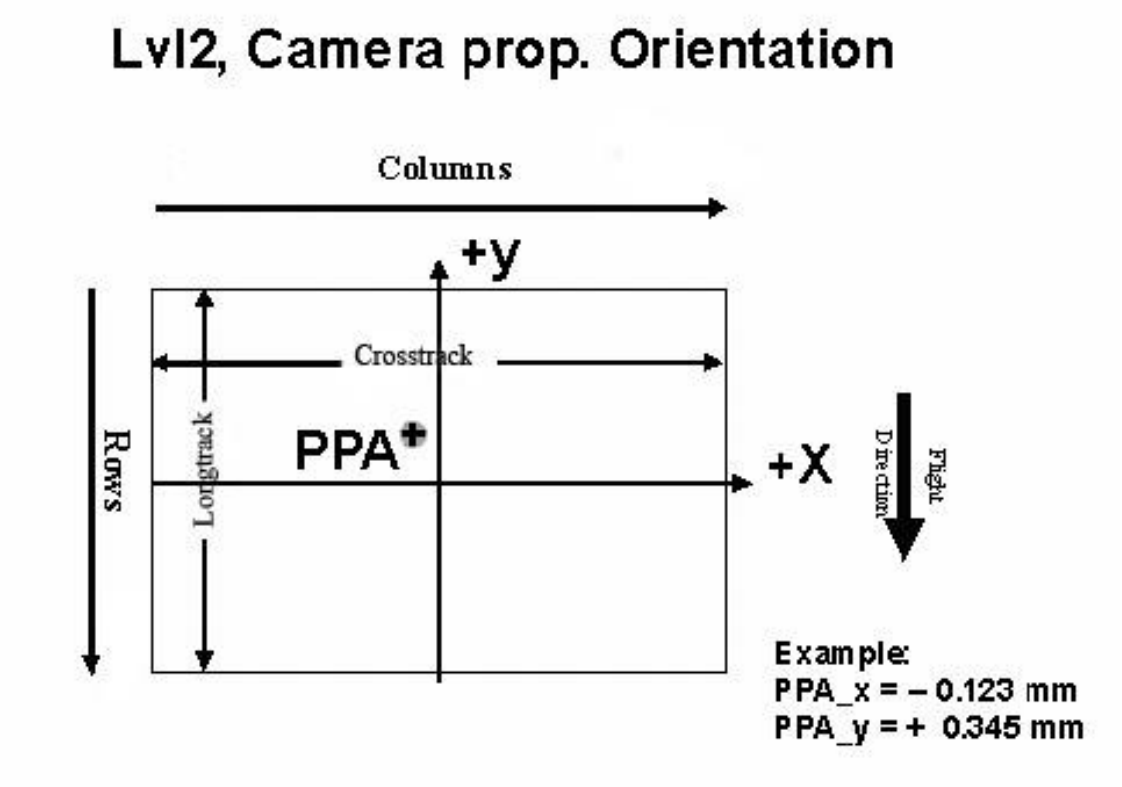
Calibration Method:

The geometric calibration is based on a set of 84 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera :	>16000
Number of point measurements for the multispectral camera :	>60000
Number of point measurements for the oblique camera :	>9000

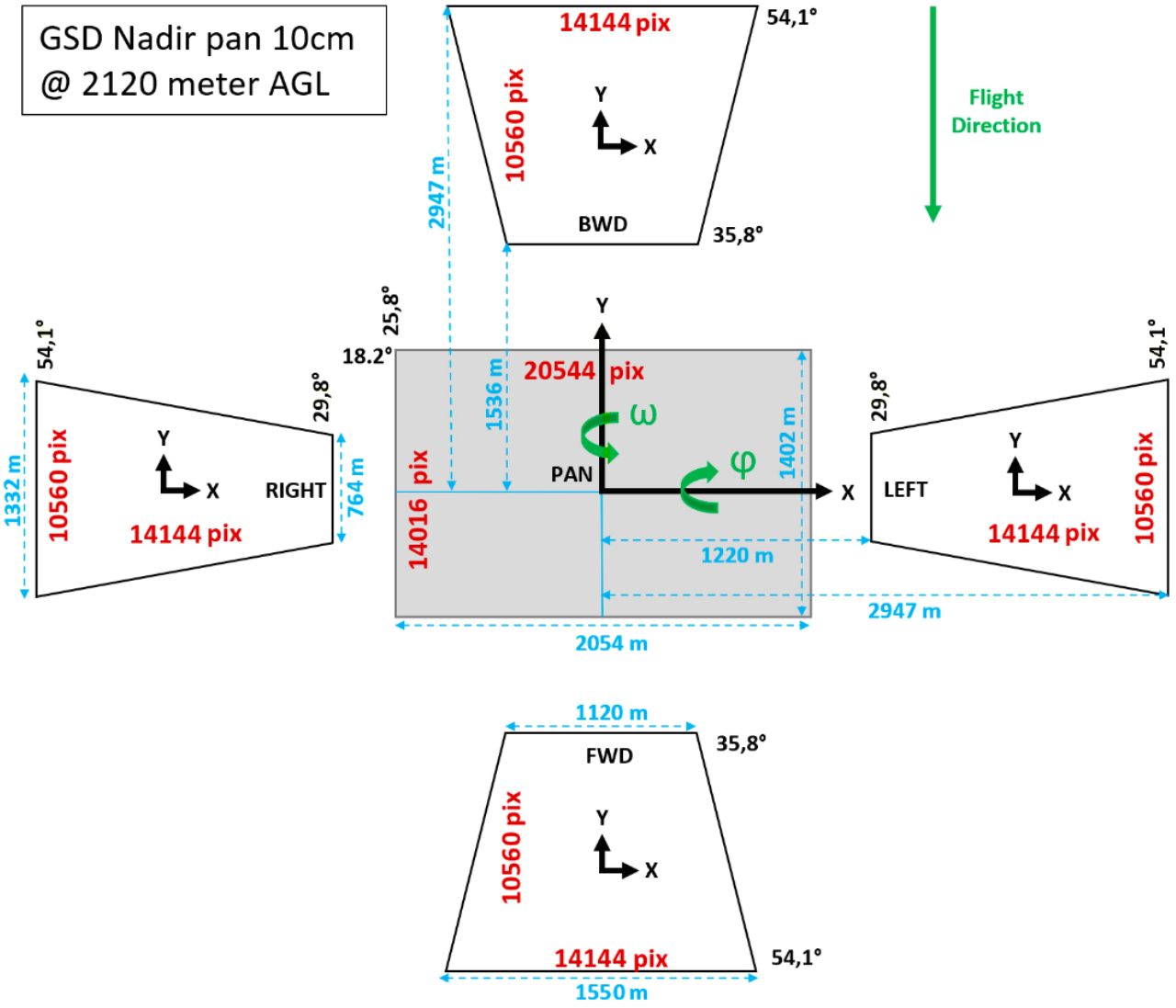
Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:



The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4/5 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).

Image Orientation Oblique Camera:



Eccentricity

Following Eccentricities are applicable for the oblique cones:

Camera	X [mm]	Y [mm]	Z [mm]	Phi [degree]	Omega [degree]	Kappa [degree]
PAN camera (C0 &C1)	0.000	0.000	0.000	0.000	0.000	0.000
RGB/I camera (C2 and C3)	0.000	0.000	0.000	0.000	0.000	0.000
C4 (Backward)	-106.811	-21.626	-8.174	0.062	-44.985	0.012
C5 (Right)	-115.289	-86.119	145.279	-44.988	0.063	0.028
C6 (Left)	-35.268	-86.178	5.750	44.986	0.003	0.028
C7 (Forward)	-106.804	-100.200	-130.076	0.013	45.025	0.020

Lens Resolving Power

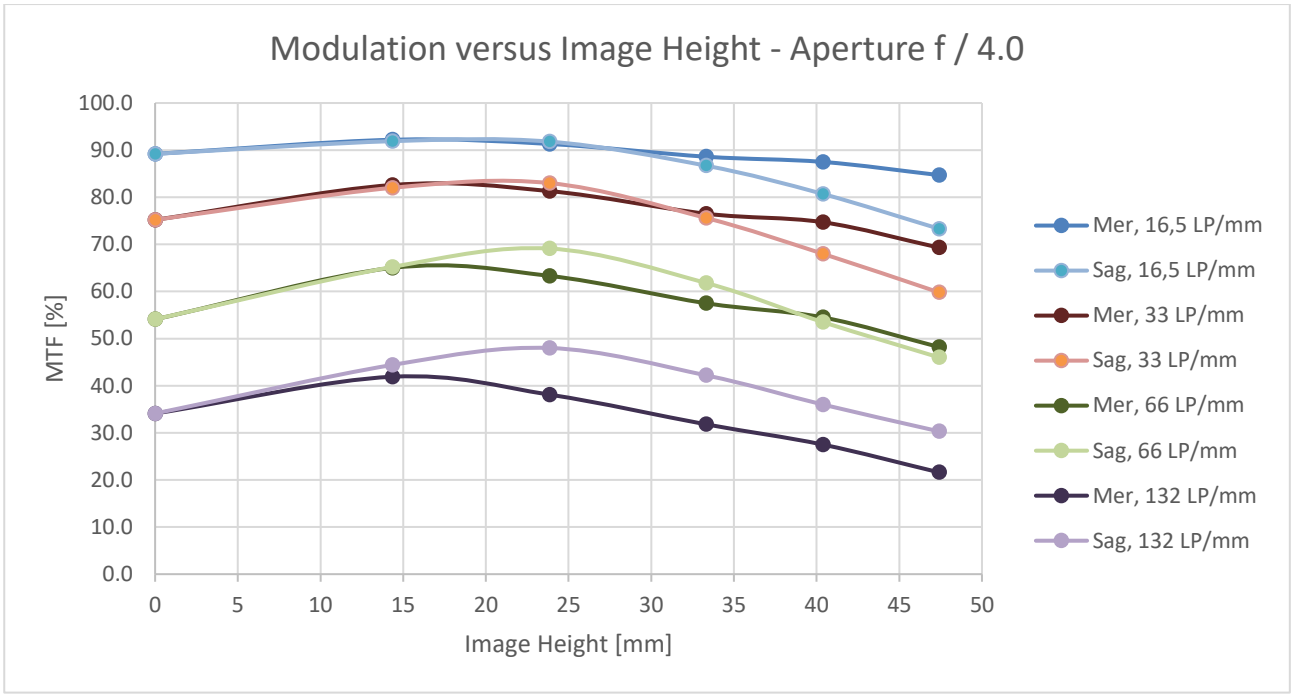
The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.
Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

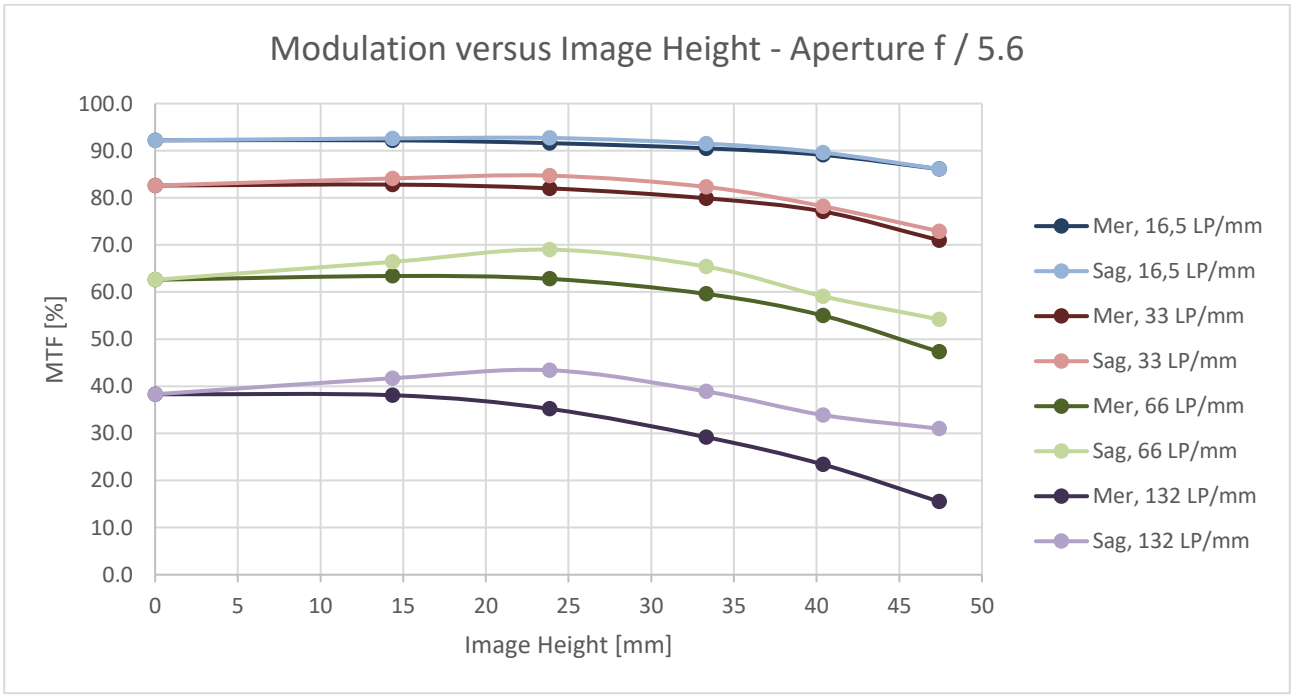
The curves are given for the meridonial (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

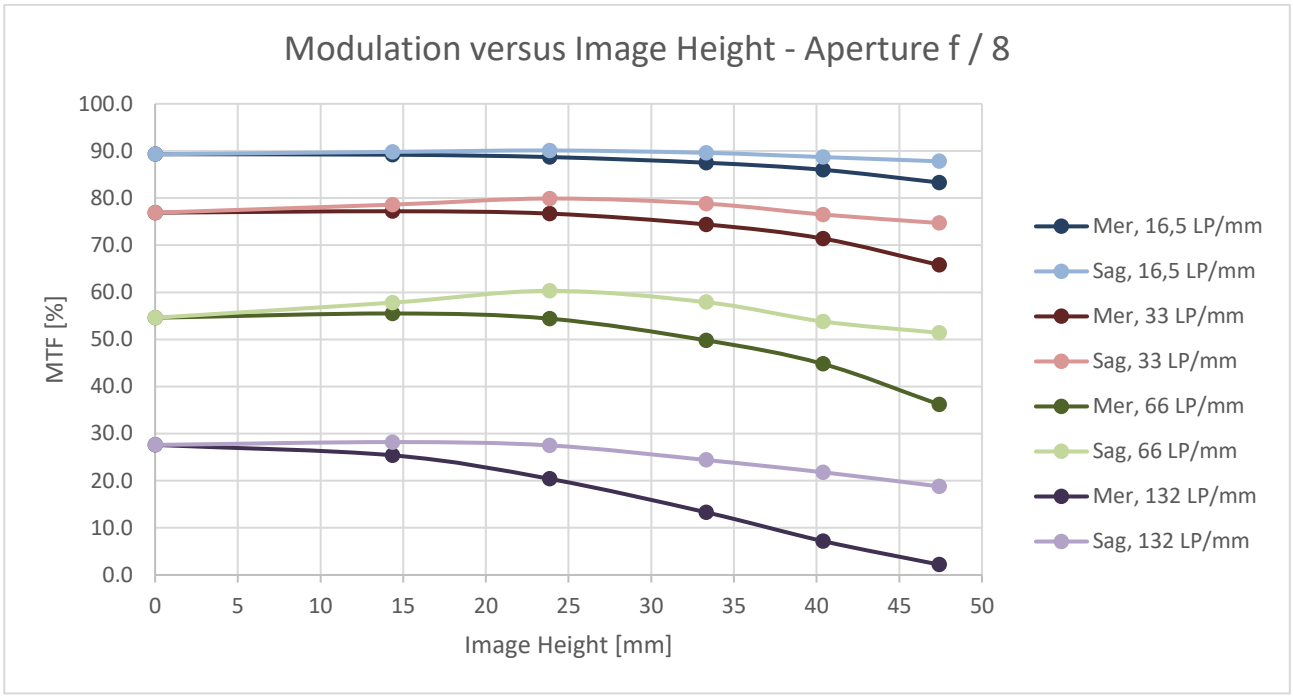
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

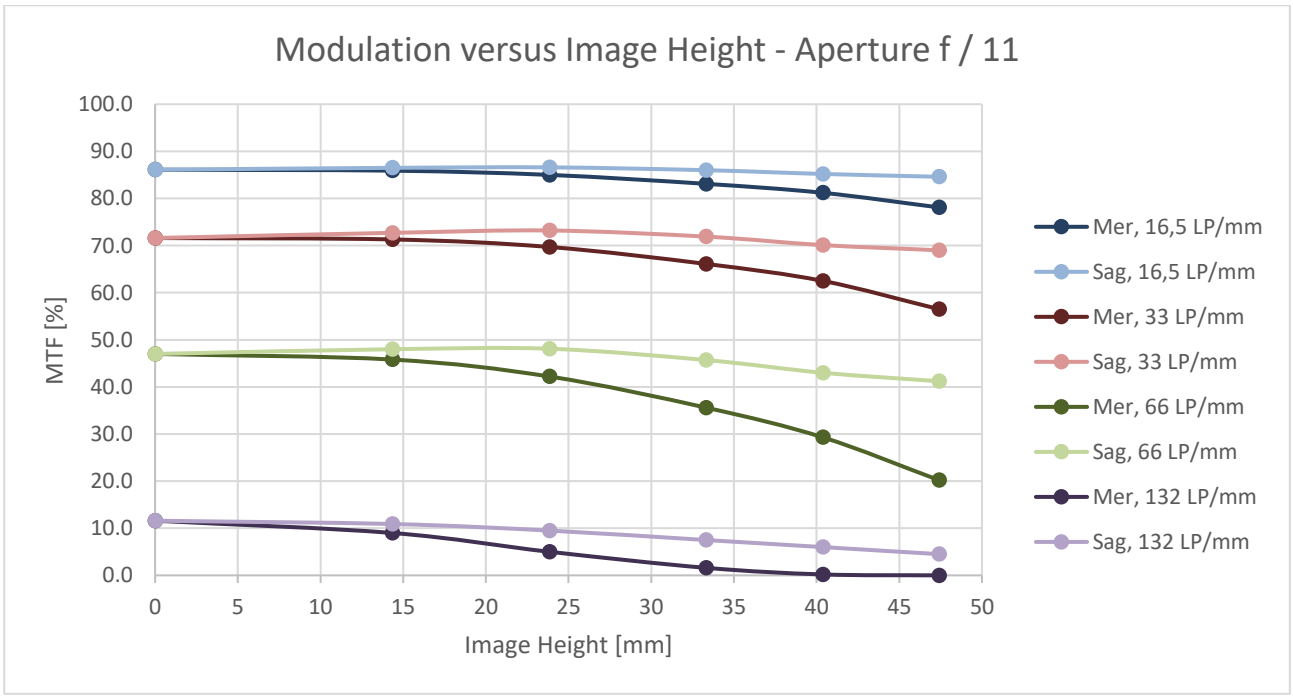
Lens types

Cone	Lens
C0 (PAN)	Qioptic Vexcel HR Digaron 1:4.3/80mm, Qioptic GmbH, Germany
C1 (PAN)	Qioptic Vexcel HR Digaron 1:4.3/80mm, Qioptic GmbH, Germany
C2 (RGB)	Qioptic Vexcel HR Digaron 1:4.2/50mm, Qioptic GmbH, Germany
C3 (NIR)	Qioptic Vexcel HR Digaron 1:4.2/50mm, Qioptic GmbH, Germany
C4 (Backward)	Qioptic Vexcel HR Digaron 1:4.2/120mm, Qioptic GmbH, Germany
C5 (Right)	Qioptic Vexcel HR Digaron 1:4.2/120mm, Qioptic GmbH, Germany
C6 (Left)	Qioptic Vexcel HR Digaron 1:4.2/120mm, Qioptic GmbH, Germany
C7 (Forward)	Qioptic Vexcel HR Digaron 1:4.2/120mm, Qioptic GmbH, Germany

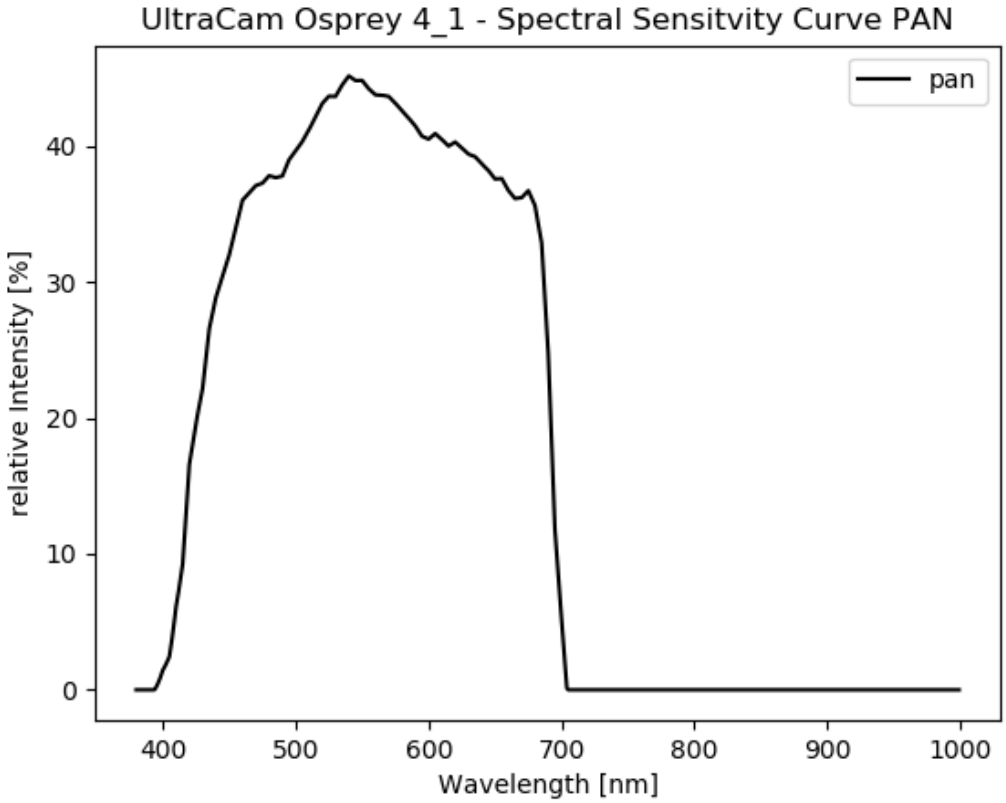

Modulation versus Image Height - Aperture f / 4.0
MTF [%]
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
5
10
15
20
25
30
35
40
45
50
Image Height [mm]
Mer, 16,5 LP/mm
Sag, 16,5 LP/mm
Mer, 33 LP/mm
Sag, 33 LP/mm
Mer, 66 LP/mm
Sag, 66 LP/mm
Mer, 132 LP/mm
Sag, 132 LP/mm

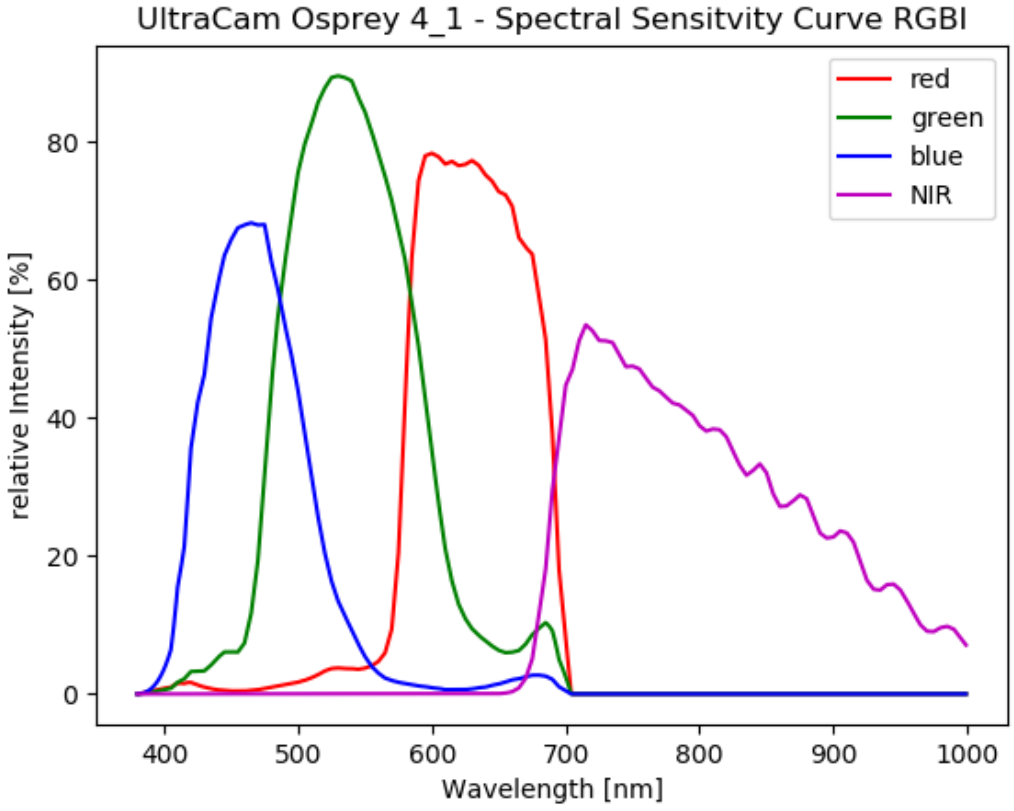

Modulation versus Image Height - Aperture f / 5.6
MTF [%]
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
5
10
15
20
25
30
35
40
45
50
Image Height [mm]
Mer, 16,5 LP/mm
Sag, 16,5 LP/mm
Mer, 33 LP/mm
Sag, 33 LP/mm
Mer, 66 LP/mm
Sag, 66 LP/mm
Mer, 132 LP/mm
Sag, 132 LP/mm


Modulation versus Image Height - Aperture f / 8
MTF [%]
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
5
10
15
20
25
30
35
40
45
50
Image Height [mm]
Mer, 16,5 LP/mm
Sag, 16,5 LP/mm
Mer, 33 LP/mm
Sag, 33 LP/mm
Mer, 66 LP/mm
Sag, 66 LP/mm
Mer, 132 LP/mm
Sag, 132 LP/mm


Modulation versus Image Height - Aperture f / 11
MTF [%]
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
5
10
15
20
25
30
35
40
45
50
Image Height [mm]
Mer, 16,5 LP/mm
Sag, 16,5 LP/mm
Mer, 33 LP/mm
Sag, 33 LP/mm
Mer, 66 LP/mm
Sag, 66 LP/mm
Mer, 132 LP/mm
Sag, 132 LP/mm

Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: **UltraCam Osprey 4.1**
Serial: **434S42218X318205-f120**

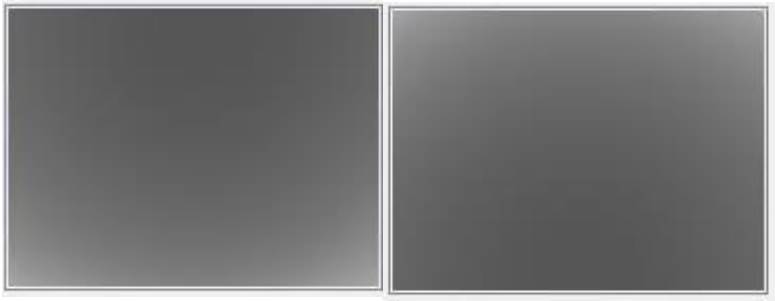
	PAN	RGB, NIR	Oblique
Used Apertures	4.8	F4.0	F4.0
	F5.6	F4.8	F4.8
	F6.7	F5.6	F5.6
	F8	F6.7	F6.7
	F9.5	F8	F8
	F11	F9.5	F9.5
	F13	F11	F11
	F19	F16	F16
	F27	F22	F22

Dead Pixel Report: see Appendix I

Calibration of Vignetting for working Aperture F4

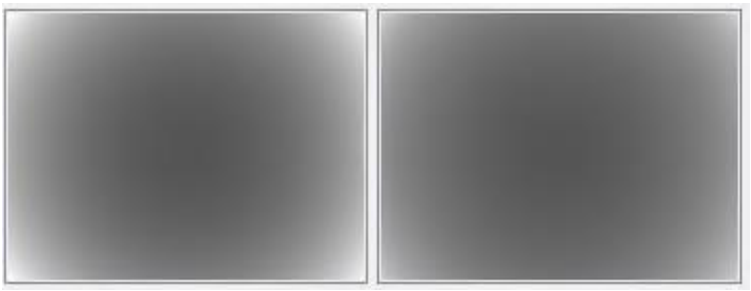
	PAN	RGB, NIR	Oblique
Aperture	F4.8	F4.0	F4.0

Graphical Overview of Pan Sensor Gain Values:



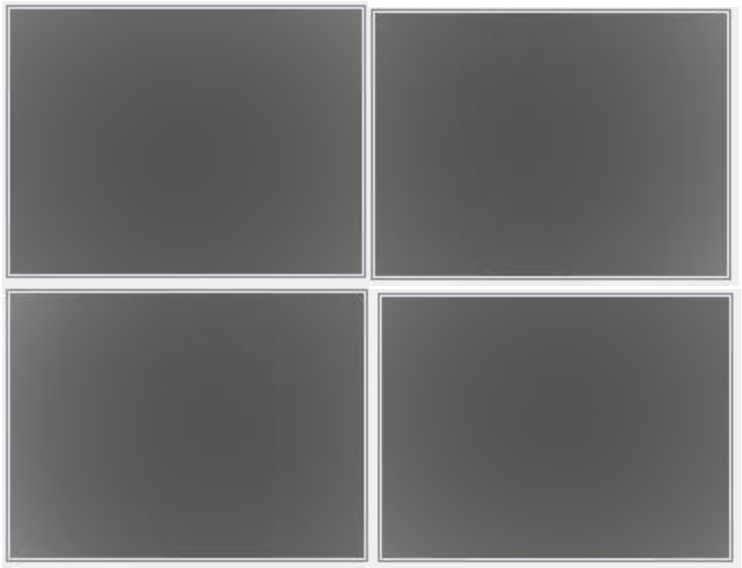
00_00 (PAN)	01_00 (PAN)

Graphical Overview of Multispectral Sensor Gain Values:



02_00 (RGB)	03_00 (NIR)

Graphical Overview of Oblique Sensor Gain Values:



04_00 (Backward)	05_00 (Right)
06_00 (Left)	07_00 (Forward)

Explanations

Calibration Method:

The radiometric calibration is based on a series of 60 flat field images for each aperture size and sensor. The flat field is illuminated by eight normal light lamps with known spectral illumination curves.

These images are used to calculate the specific sensitivity of each pixel to compensate local as well as global variations in sensitivity. Sensitivity tables are calculated for each sensor and aperture setting, and applied during post processing from level 0 to level 1.

Outlier Pixels that do not have a linear behavior as described in the CMOS specifications are marked as defective during the calibration procedure. These pixels are not used or only partially used during post processing and the information is restored by interpolation between the neighborhood pixels surrounding the defective pixels.

ULTRACAM

Shutter Calibration

Camera:	**UltraCam Osprey 4.1**
Serial:	**434S42218X318205-f120**
Panchromatic Camera:	**2 * Prontor Magnetic 0 HS** **Prontor-Werk Alfred Gauthier GmbH, Germany**
Multispectral Camera:	**2 * Prontor Magnetic 0 HS** **Prontor-Werk Alfred Gauthier GmbH, Germany**
Oblique Camera:	**4 * Prontor Magnetic 0 HS** **Prontor-Werk Alfred Gauthier GmbH, Germany**

Calibration of Shutter Release Times:

The shutter release times measured during the calibration describe the time from the moment when the electrical current through the shutter is turned off by the electronics, until the shutter is mechanically closed.

This time is relevant for the exposure control and needs to be known before image recording can take place.

Currently used SRT values (operation values):

Cone Number	Lens Serial Number	SRT F4.0 [ms]	SRT F4.8 [ms]	SRT F5.6 [ms]	SRT F6.7 [ms]	SRT F8 [ms]	SRT F9.5 [ms]	SRT F11 [ms]	SRT F16 [ms]	SRT F22 [ms]	Measurement Tolerance [ms]
C0 (Pan)	12 59 59 87	5.93	6.17	6.58	6.86	7.01	7.23	7.39	7.64	7.66	+/- 0.2
C1 (Pan)	12 59 59 79	5.72	5.98	6.31	6.55	6.75	6.98	7.09	7.34	7.39	+/- 0.2
C2 (RGB)	12 59 19 91	6.24	6.43	6.79	7.03	7.26	7.43	7.54	7.77	7.82	+/- 0.2
C3 (NIR)	12 59 19 95	6.38	6.54	6.91	7.03	7.21	7.45	7.59	7.81	7.86	+/- 0.2
C4 (Backward)	12 59 30 87	5.47	5.74	6.29	6.65	6.97	7.25	7.40	7.71	7.87	+/- 0.2
C5 (Right)	12 59 56 37	5.72	5.99	6.54	6.95	7.22	7.54	7.68	8.00	8.18	+/- 0.2
C6 (Left)	12 59 30 85	5.24	5.54	6.05	6.40	6.72	6.96	7.12	7.37	7.57	+/- 0.2
C7 (Forward)	12 59 30 79	5.25	5.53	6.03	6.36	6.64	6.86	7.05	7.29	7.43	+/- 0.2

ULTRACAM

Electronics and Sensor Calibration

Camera:	**UltraCam Osprey 4.1**
Serial:	**434S42218X318205-f120**
Panchromatic Camera:	**2 * IMX411-ALR-M CMOS Sensor by SONY**
Multispectral Camera:	**1 * IMX411-AQR-C CMOS Sensor by SONY**
	1 * IMX411-ALR-M CMOS Sensor by SONY
Oblique Camera:	**4 * IMX411-AQR-C CMOS Sensor by SONY**

Calibration of Intensity Threshold for Exposure Control:

Each CMOS sensor and electronics module varies slightly in global sensitivity and intensity scale.

Therefore the maximum possible intensity of each sensor needs to be measured to evaluate the sensitivity behavior of the CMOS and electronics.

This value is used as a threshold for the exposure control dialogue shown in the in-flight user interface of the Camera.

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]
00_00 (PAN)	IMX411-ALR-M	00001cca95d101	16130
01_00 (PAN)	IMX411-ALR-M	00001cca5a5001	16130
02_00 (RGB)	IMX411-AQR-C	00001cca6bfe01	16130
03_00 (NIR)	IMX411-ALR-M	00001ccb72e101	16100
04_00 (Backward)	IMX411-AQR-C	00001cca7a0301	16130
05_00 (Right)	IMX411-AQR-C	00001cca88a101	16130
06_00 (Left)	IMX411-AQR-C	00001cca908101	16130
07_00 (Forward)	IMX411-AQR-C	00001cca89F301	16130

ULTRACAM

Summary

Camera:	**UltraCam Osprey 4.1**
Serial:	**434S-42218X318205-f120**
Laboratory Calibration Date:	**May-25-2021**
Camera Revision:	**Rev01.00**
Date of Report:	**Jun-11-2021**
Version of Report:	**V02**

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Radiometric Calibration
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH

Dipl. Ing. (FH) Helmut Jauk
Senior Project Engineer R&D
Vexcel Imaging GmbH

Appendix I

Dead Pixel Report:

Cone_Sensor	Dead Pixel Count
00_00 (PAN)	432
01_00 (PAN)	357
02_00 (RGB)	476
03_00 (NIR)	510
04_00 (Backward)	456
05_00 (Right)	546
06_00 (Left)	460
07_00 (Forward)	517

Appendix II

Calibration and Modification Dates

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	**25.May.2021**	**25.May.2021**	
Radiometric Calibration	**25.May.2021**	**25.May.2021**	
Shutter Calibration	**25.May.2021**	**25.May.2021**	
Electronics and Sensor Calibration	**25.May.2021**	**25.May.2021**	

Note: The above-mentioned Laboratory Calibration Dates represent the dates the camera was calibrated in one of our calibration labs for a full Laboratory Calibration. The Modification date represents a date on which the calibration has been modified due to a calibration enhancement or part exchange. It is an additional information and does not replace the Laboratory Calibration date in any way. With the Modification Reason, always the last modification to the calibration is highlighted.