



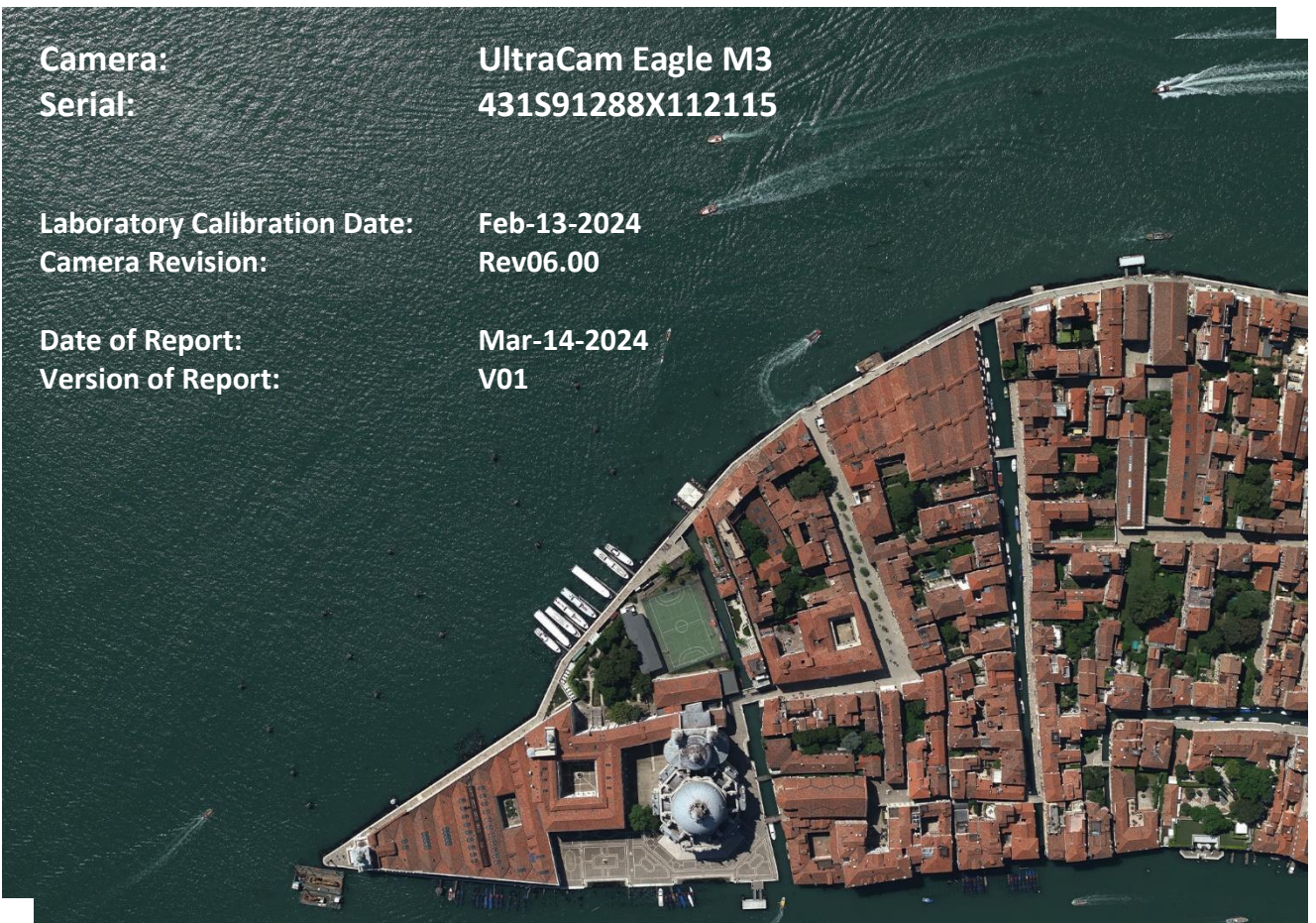
ULTRACAM

Calibration Report

Camera: UltraCam Eagle M3
Serial: 431S91288X112115

Laboratory Calibration Date: Feb-13-2024
Camera Revision: Rev06.00

Date of Report: Mar-14-2024
Version of Report: V01



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Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH



ULTRACAM

Geometric Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115

Panchromatic Camera: ck = 79.800 mm
Multispectral Camera: ck = 79.800 mm

PPA Information: X: 0.000mm
Y: 0.000mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	68.016mm 105.840mm	17004pixel 26460pixel
Image Extent		(-34.008, -52.920)mm	(34.008, 52.920)mm
Pixel Size		4.000µm*4.000µm	
Focal Length	ck	79.800mm	± 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		

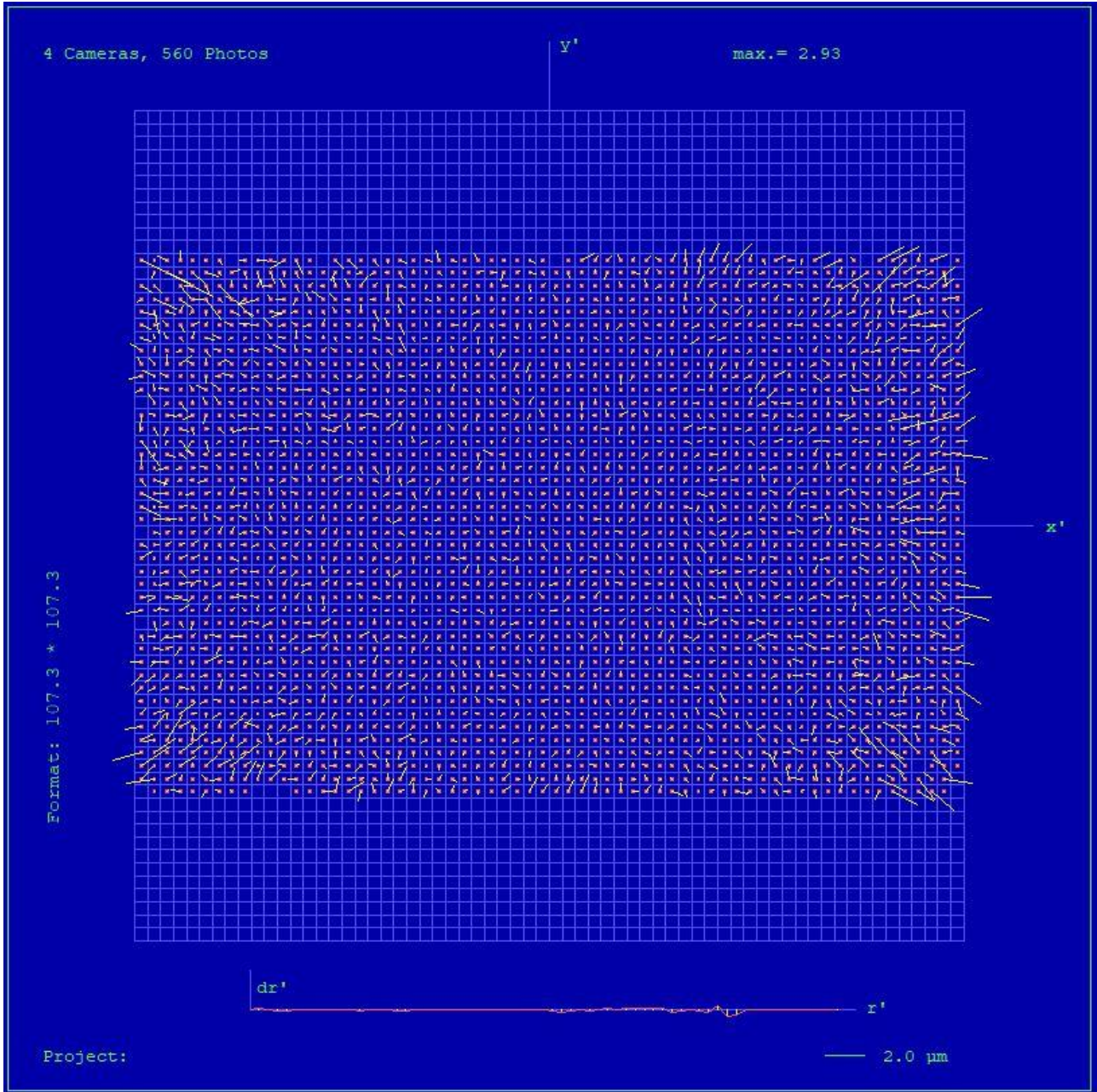
Multispectral Camera

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

Image Format	long track cross track	68.016mm 105.840mm	5668pixel 8820pixel
Image Extent		(-34.008, -52.920)mm	(34.008, 52.920)mm
Pixel Size		12.000µm*12.000µm	
Focal Length	ck	79.800mm	± 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		



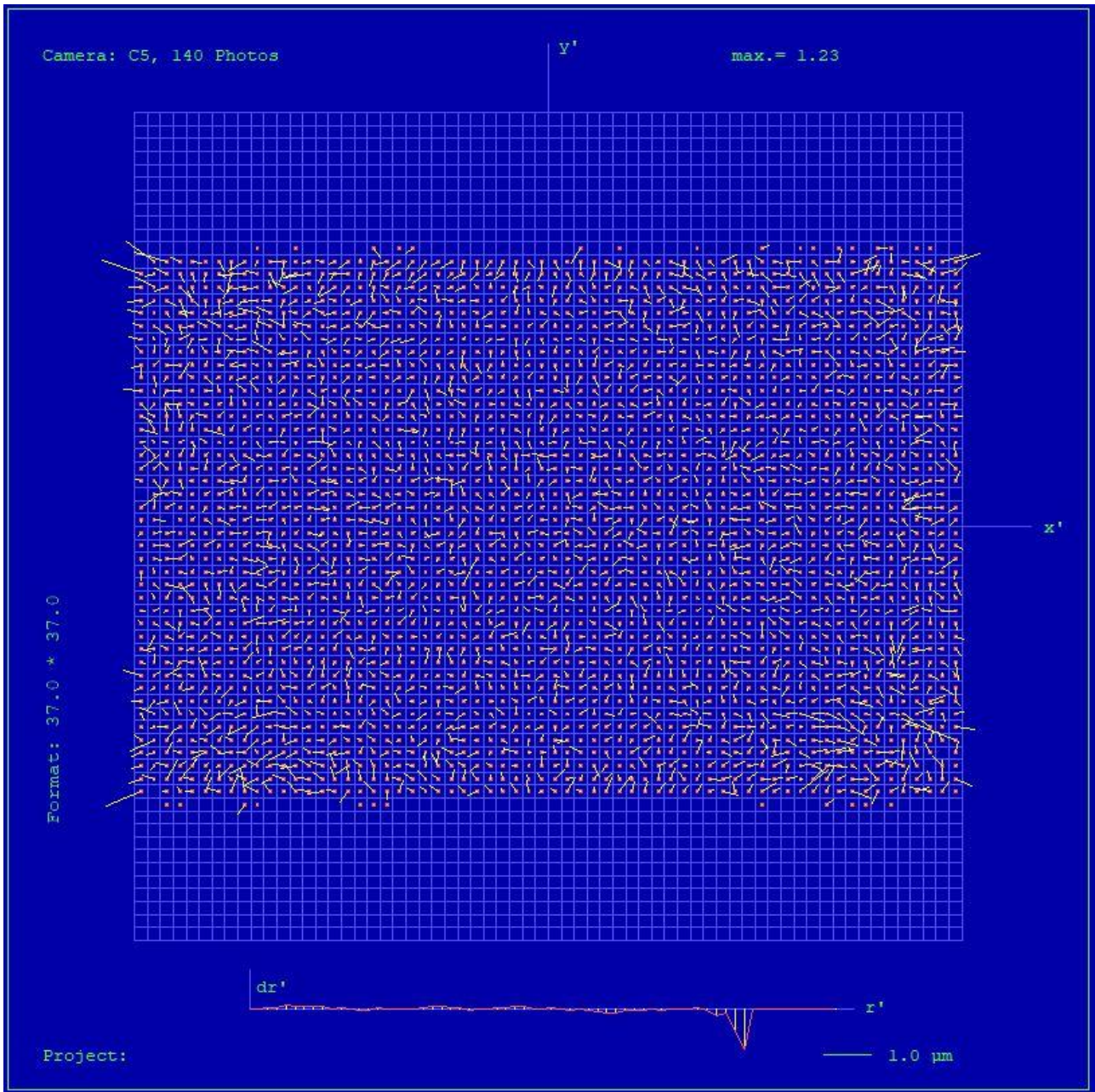
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.67 μm**



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.46 μm**



Explanations

Calibration Method:

The geometric calibration is based on a set of 140 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : >16000

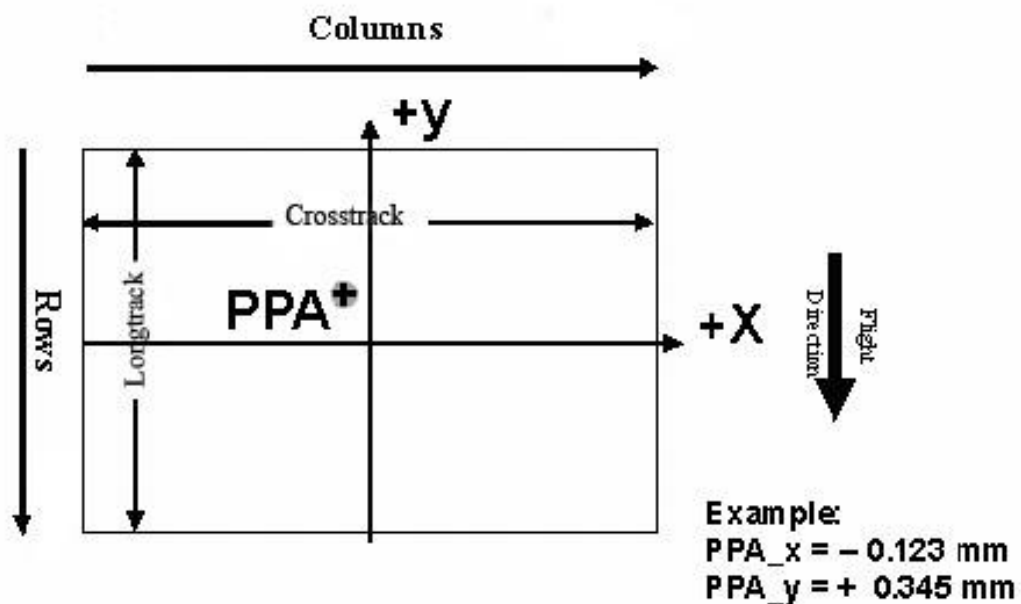
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.

Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:

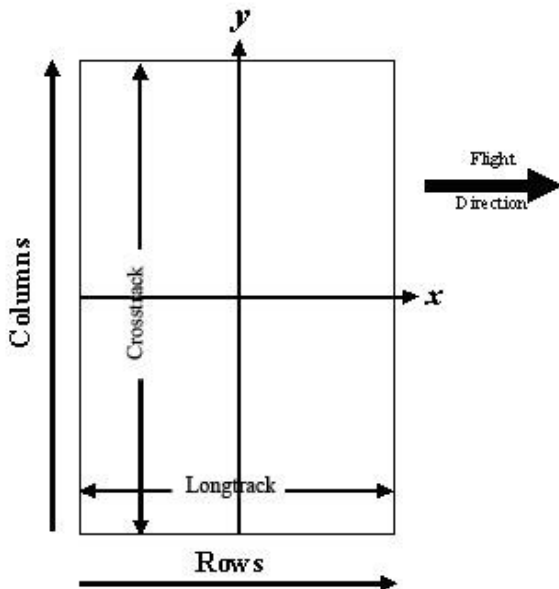
Lvl2, Camera prop. Orientation



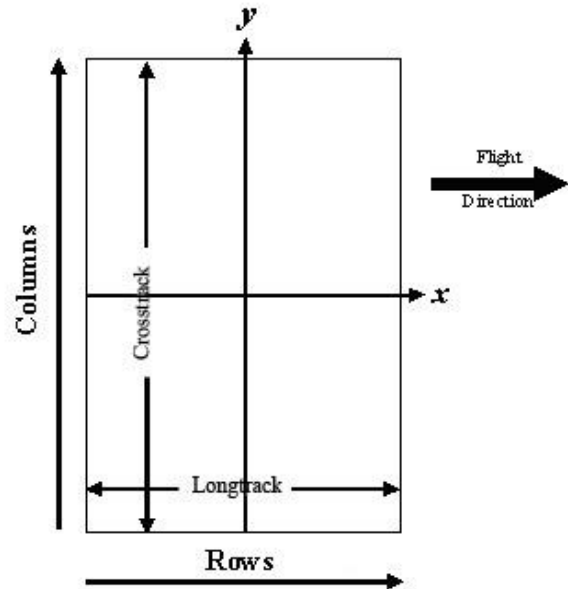
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



Level 3 Image Coordinate System:
(after rotation of 270° CW)



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

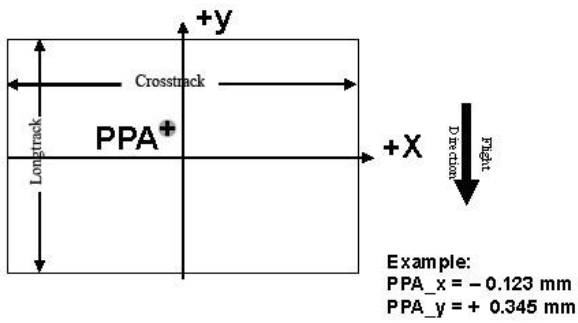
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 4 for high- and low resolution images.

Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	0.000	0.000
Level 3	0	0.000	0.000
Level 3	90	0.000	0.000
Level 3	180	0.000	0.000
Level 3	270	0.000	0.000

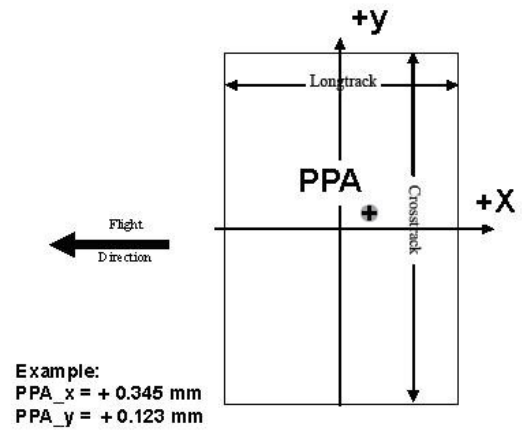


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

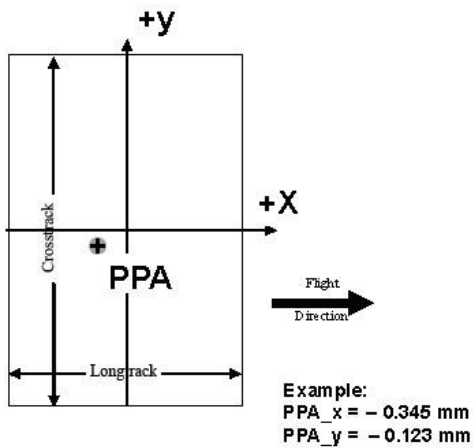
Lvl3, Rotation 0 deg clockwise



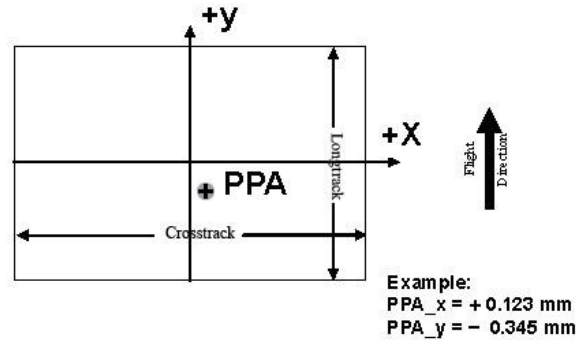
Lvl3, Rotation 90 deg clockwise



Lvl3, Rotation 270 deg clockwise



Lvl3, Rotation 180 deg clockwise





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 meridional (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

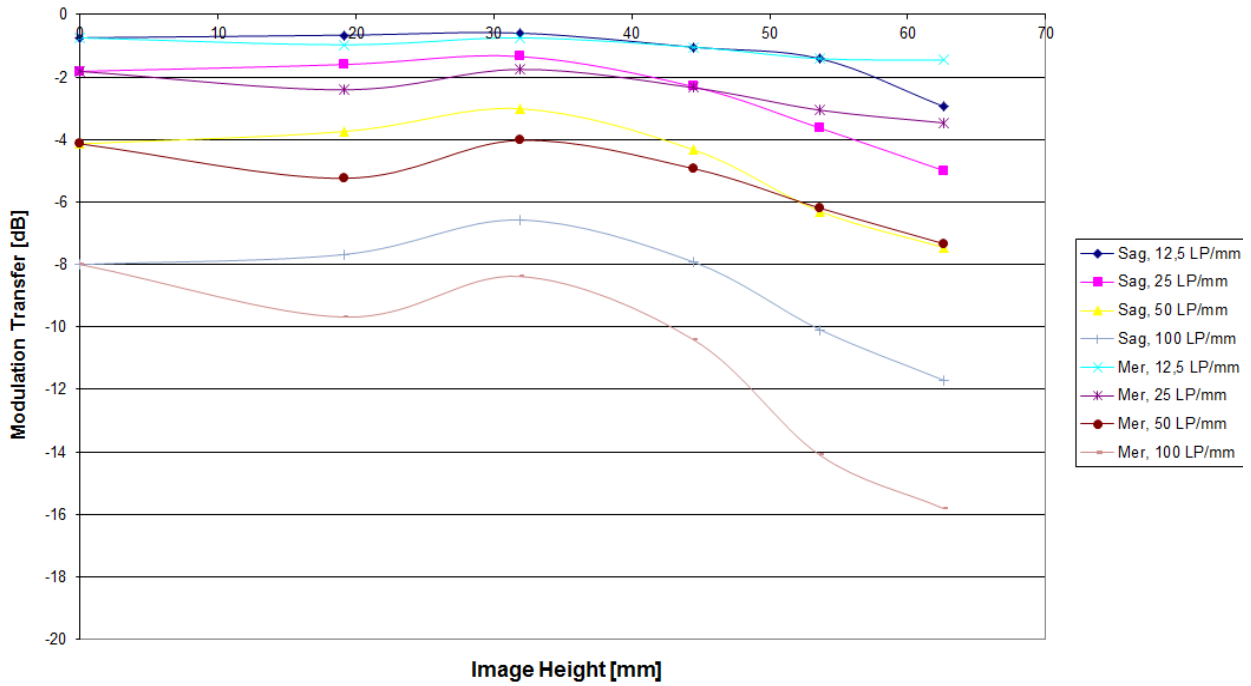
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

Lens types

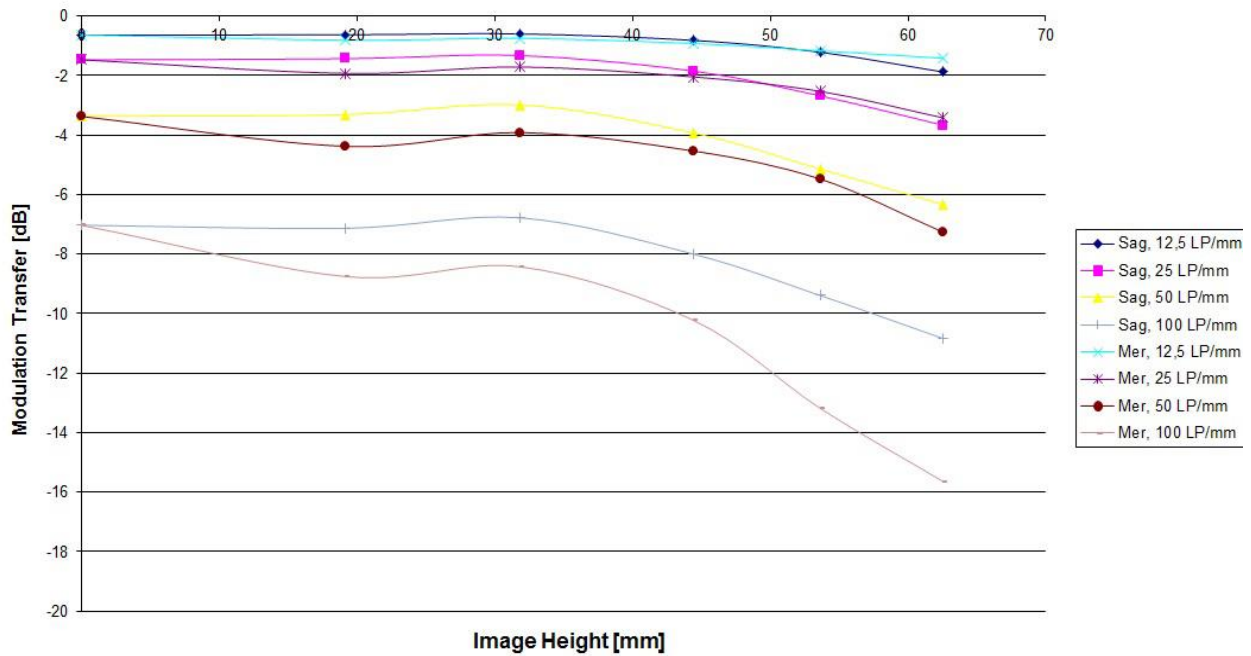
Cone	Lens
C0 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C1 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C2 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C3 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C4 (RED)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany
C5 (GREEN)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany
C6 (BLUE)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany
C7 (NIR)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany



Modulation versus Image Height - Aperture f/ 5.6

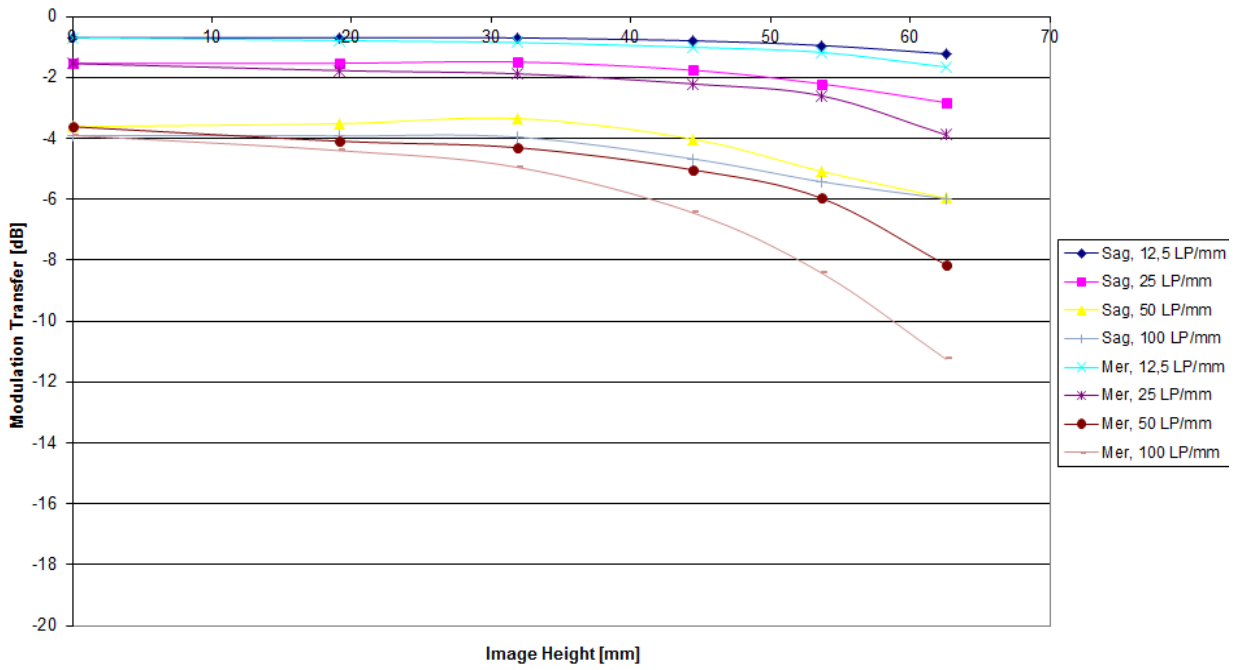


Modulation versus Image Height - Aperture f/ 6.7

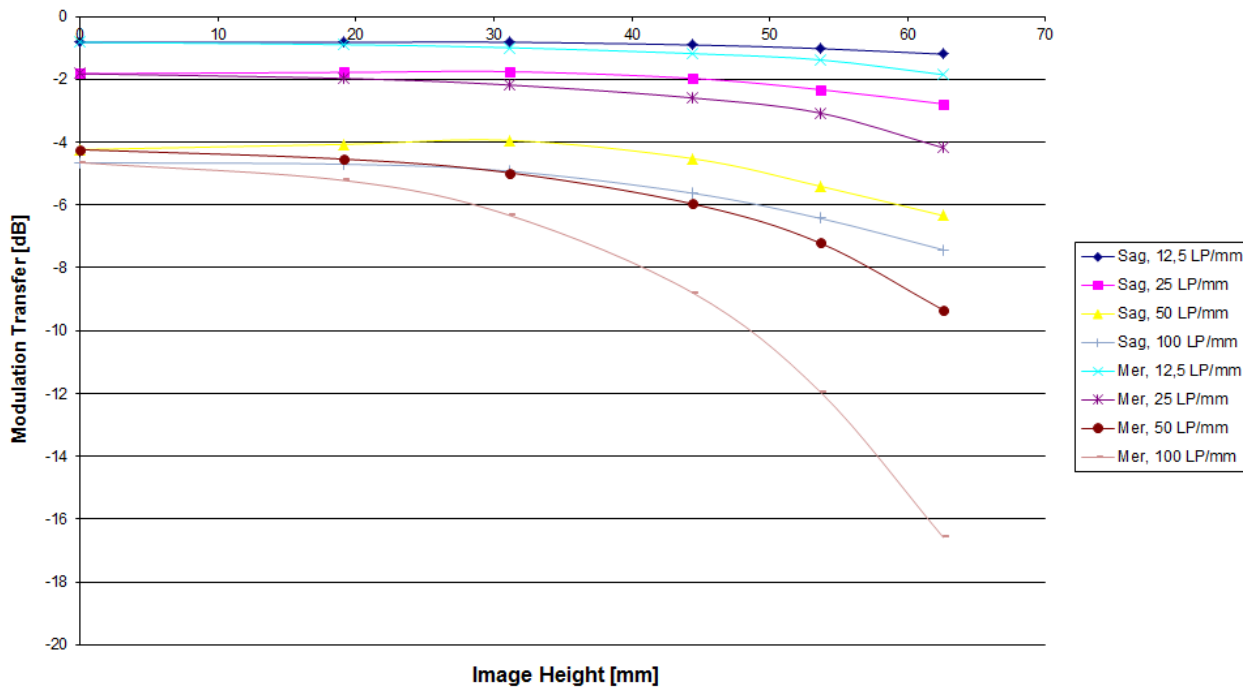




Modulation versus Image Height - Aperture f / 8

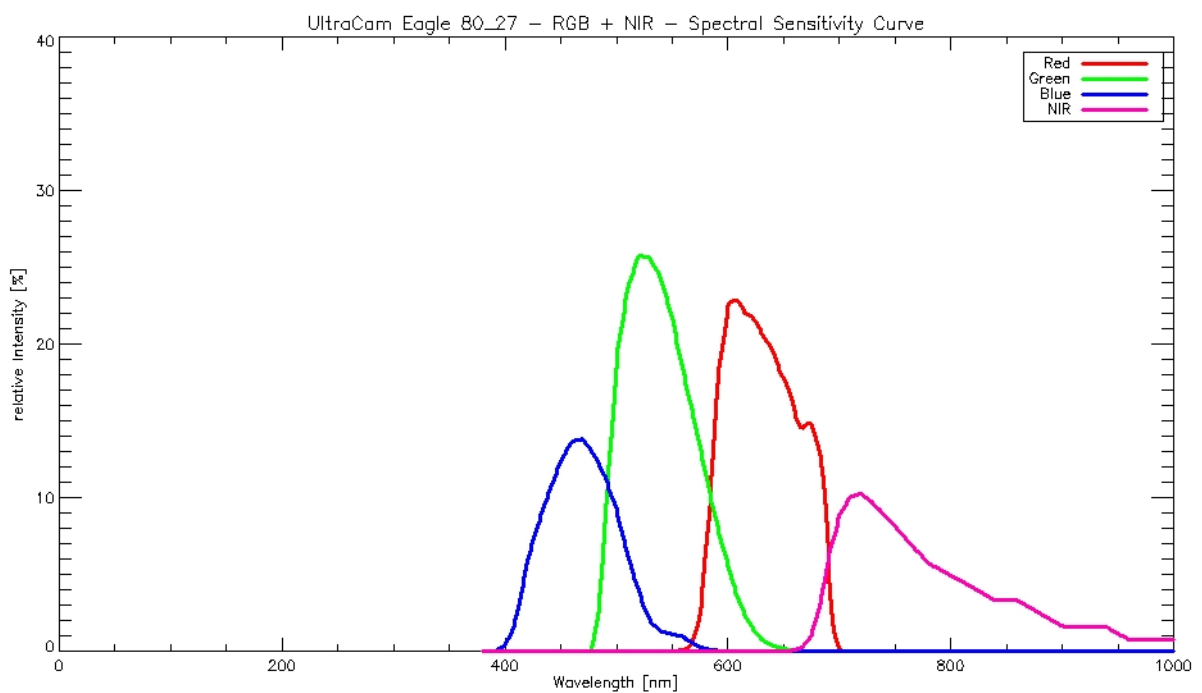
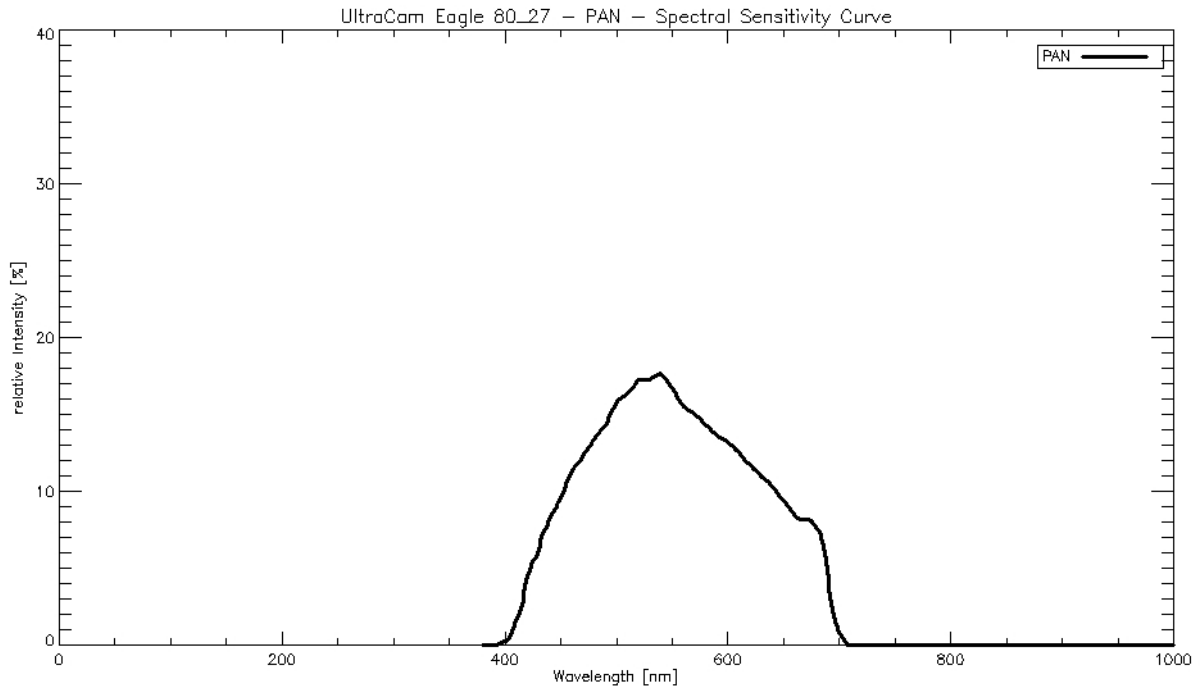


Modulation versus Image Height - Aperture f / 9.5





Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115

	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.4	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

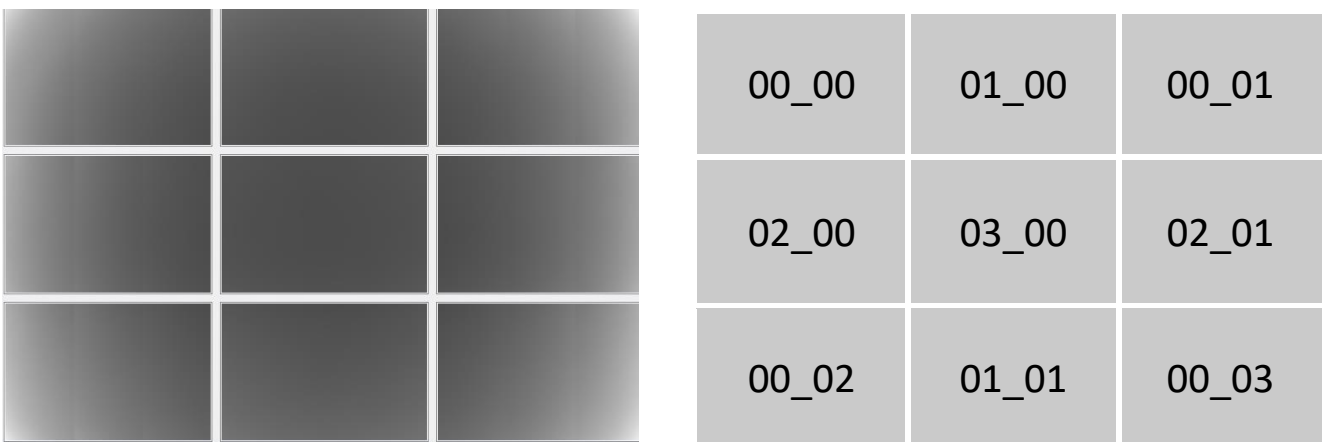
Dead Pixel Report: see Appendix I



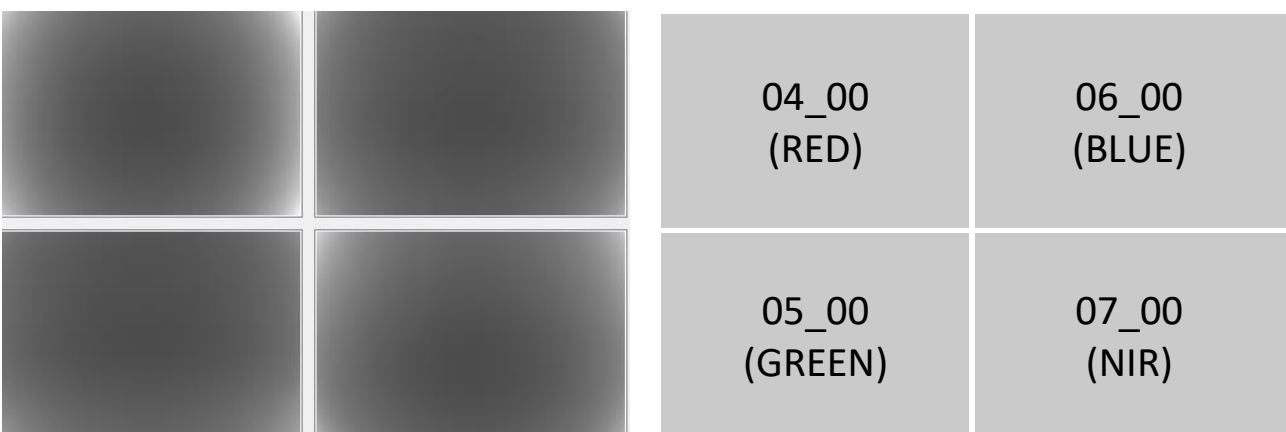
Calibration of Vignetting for working Aperture F6.7

	PAN	R, G, NIR	B
Aperture	F6.7	F5.4	F4.8

Graphical Overview of Pan Sensors:



Graphical Overview of Multispectral Sensors:





Explanations

Calibration Method:

The radiometric calibration is based on a series of 50 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 CCD 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.

Certain pixels that are named Qmax pixels due to the fact that they can only store and transfer charge up to a certain maximum amount are detected in an additional calibration step. These pixels are treated differently during post processing, since their behavior can affect not only single pixel values but whole columns.



ULTRACAM

Shutter Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115

Panchromatic Camera: 4 * Prontor Magnetic 0 HS
Prontor-Werk Alfred Gauthier GmbH, Germany

Multispectral 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 F5.6 [ms]	SRT F6.7 [ms]	SRT F8 [ms]	SRT F9.5 [ms]	SRT F11 [ms]	SRT F13 [ms]	SRT F16 [ms]	SRT F22 [ms]	Measurement Tolerance [ms]
C0 (Pan)	12 09 99 26	6.65	6.86	7.19	7.42	7.59	7.77	7.96	8.26	+/- 0.2
C1 (Pan)	12 09 99 31	7.22	7.42	7.77	8.02	8.14	8.30	8.46	8.65	+/- 0.2
C2 (Pan)	12 09 99 30	6.58	6.84	7.11	7.38	7.52	7.69	7.88	8.21	+/- 0.2
C3 (Pan)	12 09 99 25	6.52	6.76	7.05	7.25	7.40	7.57	7.62	7.93	+/- 0.2
C4 (Red)	12 09 99 36	7.80	7.81	7.98	8.10	8.20	8.27	8.37	8.57	+/- 0.2
C5 (Green)	12 09 99 38	7.57	7.67	7.85	7.96	8.05	8.11	8.20	8.36	+/- 0.2
C6 (Blue)	12 09 99 37	8.04	8.06	8.06	8.04	8.18	8.27	8.47	8.74	+/- 0.2
C7 (NIR)	12 09 99 34	8.15	8.27	8.36	8.46	8.56	8.61	8.74	8.87	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115

Panchromatic Camera: 9 * FTF9060-M Area CCD Sensor by DALSA
Multispectral Camera: 4 * FTF9060-M Area CCD Sensor by DALSA



Calibration of Negative Substrate Voltage (VNS):

For optimum performance of the DALSA CCD sensors, the negative substrate voltage is adjusted to a value specified by DALSA.

This voltage value is measured to achieve the best anti-blooming performance possible for each particular sensor.

Currently used VNS and VOG values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	VNS Voltage [V]	VOG Voltage [V]
00_00	FTF9060-M	18 7966/003	22.40	6.33
00_01	FTF9060-M	18 7966/034	22.80	6.78
00_02	FTF9060-M	18 4458/052	22.00	6.68
00_03	FTF9060-M	18 4458/056	22.40	5.98
01_00	FTF9060-M	18 4458/041	22.20	6.25
01_01	FTF9060-M	18 4458/051	22.80	6.59
02_00	FTF9060-M	18 7966/069	22.40	6.32
02_01	FTF9060-M	18 4458/044	22.20	6.35
03_00	FTF9060-M	18 7966/050	22.40	6.35
04_00 (red)	FTF9060-M	18 4458/037	22.00	6.32
05_00 (green)	FTF9060-M	18 4458/060	22.40	6.14
06_00 (blue)	FTF9060-M	18 4458/047	22.00	6.11
07_00 (NIR)	FTF9060-M	18 7966/059	22.40	6.37



Calibration of Intensity Threshold for Exposure Control:

Each CCD 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 CCD and electronics.

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

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]	
			Tap 1	Tap2
00_00	FTF9060-M	18 7966/003	13510	12480
00_01	FTF9060-M	18 7966/034	13360	12590
00_02	FTF9060-M	18 4458/052	13620	12770
00_03	FTF9060-M	18 4458/056	13520	13160
01_00	FTF9060-M	18 4458/041	13540	12520
01_01	FTF9060-M	18 4458/051	12910	12080
02_00	FTF9060-M	18 7966/069	13830	12940
02_01	FTF9060-M	18 4458/044	13490	12680
03_00	FTF9060-M	18 7966/050	13960	13110
04_00 (red)	FTF9060-M	18 4458/037	13590	12770
05_00 (green)	FTF9060-M	18 4458/060	13530	12620
06_00 (blue)	FTF9060-M	18 4458/047	13500	12580
07_00 (NIR)	FTF9060-M	18 7966/059	13580	12630



ULTRACAM

Summary

Camera:	UltraCam Eagle M3
Serial:	431S91288X112115
Laboratory Calibration Date:	Feb-13-2024
Camera Revision:	Rev06.00
Date of Report:	Mar-14-2024
Version of Report:	V01

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:

Sensor number	Anomaly type	X-Coordinate	Y-Coordinate
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C00-00

PIXEL: 3489/ 82	PIXEL: 5169/1691	PIXEL: 5060/2687	
PIXEL: 46/3199	PIXEL: 5564/3393	PIXEL: 5557/3398	PIXEL: 6134/3470
PIXEL: 3904/4241	PIXEL: 5843/4953	PIXEL: 5843/4954	PIXEL: 8192/5332
PIXEL: 224/ 487	PIXEL: 390/ 490	PIXEL: 468/ 937	PIXEL: 789/1298
PIXEL: 1469/1419	PIXEL: 379/1432	PIXEL: 3125/1693	PIXEL: 1724/1932
PIXEL: 3489/3631	PIXEL: 2985/4549	PIXEL: 6848/2741	

C00-01

PIXEL: 937/ 327	PIXEL: 6508/ 672	PIXEL: 6555/ 986	
PIXEL: 943/1463	PIXEL: 4285/2349	PIXEL: 6181/2868	PIXEL: 7781/3556
PIXEL: 3498/4232	PIXEL: 7597/4244	PIXEL: 5823/4595	PIXEL: 5328/4598
PIXEL: 4256/4619	PIXEL: 7354/4751	PIXEL: 7369/4769	PIXEL: 7116/5171
PIXEL: 4072/5417	PIXEL: 2622/5599	PIXEL: 6749/5639	PIXEL: 5623/5870
PIXEL: 8445/ 242	PIXEL: 8167/ 574	PIXEL: 8917/1430	PIXEL: 3072/4198
PIXEL: 3072/4199	PIXEL: 7865/4563	PIXEL: 7639/4598	PIXEL: 7640/4598
PIXEL: 8935/4941	PIXEL: 6682/5158	PIXEL: 1599/5221	PIXEL: 963/5227
PIXEL: 4217/5254	PIXEL: 4217/5255	PIXEL: 935/5358	PIXEL: 1003/5645
PIXEL: 52/5886	PIXEL: 9022/5890		

C00-02

PIXEL: 2551/ 461	PIXEL: 4350/ 880	PIXEL: 121/1716	PIXEL: 8638/3492
PIXEL: 1471/4496	PIXEL: 3059/4514	PIXEL: 8467/ 808	PIXEL: 212/1595
PIXEL: 509/1914	PIXEL: 1153/2929	PIXEL: 5110/4223	PIXEL: 4530/5282
PIXEL: 95/5408	PIXEL: 8805/5533	PIXEL: 2425/5610	PIXEL: 8722/5786
PIXEL: 9024/5925			

C00-03

PIXEL: 2942/ 58			
PIXEL: 3733/ 444	PIXEL: 7879/1776	PIXEL: 2085/2473	PIXEL: 5566/2719
PIXEL: 8167/3196	PIXEL: 7862/3433	PIXEL: 1569/4051	PIXEL: 7313/4253
PIXEL: 2352/4445	PIXEL: 6428/4499	PIXEL: 8176/4760	PIXEL: 3166/4924
PIXEL: 7695/5169	PIXEL: 8853/ 989	PIXEL: 2581/1746	PIXEL: 1413/1915
PIXEL: 7894/2342	PIXEL: 2655/2505	PIXEL: 3906/5979	PIXEL: 3906/5980



C01-00

PIXEL: 3901/ 197	PIXEL: 320/ 621		
PIXEL: 6611/1030	PIXEL: 74/1632	PIXEL: 5775/2224	PIXEL: 1371/2744
PIXEL: 3487/4466	PIXEL: 7380/5766	PIXEL: 7026/5782	PIXEL: 2798/6014
PIXEL: 505/1320	PIXEL: 4546/1653	PIXEL: 188/3328	PIXEL: 4886/3928
PIXEL: 8360/5117	PIXEL: 7668/5373	COLUMN: 3253/1401	

C01-01

PIXEL: 5860/1878	PIXEL: 3511/2310	PIXEL: 4665/2537	
PIXEL: 4666/2537	PIXEL: 4662/2538	PIXEL: 1503/2595	PIXEL: 8035/2696
PIXEL: 7193/2860	PIXEL: 1137/2887	PIXEL: 6322/3744	PIXEL: 4437/3958
PIXEL: 4786/5006	PIXEL: 1313/5389	PIXEL: 7818/5643	PIXEL: 1554/5990
PIXEL: 9022/ 93	PIXEL: 459/5075	PIXEL: 2712/5215	PIXEL: 1064/5672
PIXEL: 8870/5679			

C02-00

PIXEL: 1777/ 527			
PIXEL: 4517/1628	PIXEL: 1800/1829	PIXEL: 4169/1918	PIXEL: 3574/2329
PIXEL: 5477/2897	PIXEL: 5100/4265	PIXEL: 1668/4605	PIXEL: 961/4810
PIXEL: 1969/4854	PIXEL: 4145/5578	PIXEL: 3862/5899	PIXEL: 6357/5986
PIXEL: 407/2395	PIXEL: 365/4108		

C02-01

PIXEL: 4498/ 641	PIXEL: 4585/1101	PIXEL: 5808/1232	PIXEL: 4334/1554
PIXEL: 8779/1782	PIXEL: 6806/2058	PIXEL: 4299/3050	PIXEL: 3693/3797
PIXEL: 1183/4437	PIXEL: 7513/4551	PIXEL: 65/5297	PIXEL: 3824/5649
PIXEL: 2395/5897	PIXEL: 8728/ 355	PIXEL: 3855/1520	PIXEL: 8792/2441
PIXEL: 8593/4763			

C03-00

	PIXEL: 3957/ 39		
PIXEL: 2556/1280	PIXEL: 3180/1428	PIXEL: 600/1940	PIXEL: 3432/2787
PIXEL: 5838/3513	PIXEL: 8039/3763	PIXEL: 3353/3769	PIXEL: 3757/4283
PIXEL: 2964/5086	PIXEL: 3361/5340	PIXEL: 8747/5584	PIXEL: 6805/5744
PIXEL: 7413/5822	PIXEL: 7413/5823	PIXEL: 7415/5829	PIXEL: 562/5856
PIXEL: 3399/5878	PIXEL: 314/4831	PIXEL: 315/4831	



C04-00

PIXEL: 5786/ 19	PIXEL: 7418/ 648	PIXEL: 2161/2238	
PIXEL: 8229/3058	PIXEL: 3017/3133	PIXEL: 3276/4317	PIXEL: 5730/4323
PIXEL: 5730/4324	PIXEL: 3884/4976	PIXEL: 1938/5772	PIXEL: 203/ 40
PIXEL: 8905/ 812			

C05-00

PIXEL: 5089/3963			
PIXEL: 2337/4153	PIXEL: 609/ 342	PIXEL: 3195/ 629	PIXEL: 3884/ 792
PIXEL: 5624/1014	PIXEL: 803/2285	PIXEL: 4696/4247	

C06-00

PIXEL: 8959/4168	PIXEL: 4935/ 62	PIXEL: 6675/ 823	
PIXEL: 7909/1595	PIXEL: 4992/1669	PIXEL: 8456/3612	PIXEL: 5034/5716
PIXEL: 6836/5855	PIXEL: 4003/5999	PIXEL: 730/1047	PIXEL: 8661/1386
PIXEL: 579/2468	PIXEL: 7877/2486	PIXEL: 8958/4168	PIXEL: 1048/5160
PIXEL: 3157/5930	PIXEL: 3158/5930	PIXEL: 3157/5931	PIXEL: 1870/ 211

C07-00

PIXEL: 8942/1752	PIXEL: 8038/1890		
PIXEL: 6970/3234	PIXEL: 5983/4240	PIXEL: 376/4315	PIXEL: 2692/5839
PIXEL: 106/5976	PIXEL: 192/1365	PIXEL: 6115/1746	PIXEL: 6987/3635
PIXEL: 4956/5595	PIXEL: 4957/5595		

Notes

COLUMN anomaly: all pixels below the Qmax detector at location (X,Y) may be affected.
PIXEL anomaly: single detector at location (X,Y) is not functioning within normal range

The Level0 coordinates exclude the two leftmost pixels containing the line index: the corresponding pixel can therefore be located at column (X+2,Y).



Appendix II

Calibration and Modification Dates

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	Feb-13-2024	Feb-13-2024	
Radiometric Calibration	Feb-13-2024	Feb-13-2024	
Shutter Calibration	Feb-13-2024	Feb-13-2024	
Electronics and Sensor Calibration	Feb-13-2024	Feb-13-2024	

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