

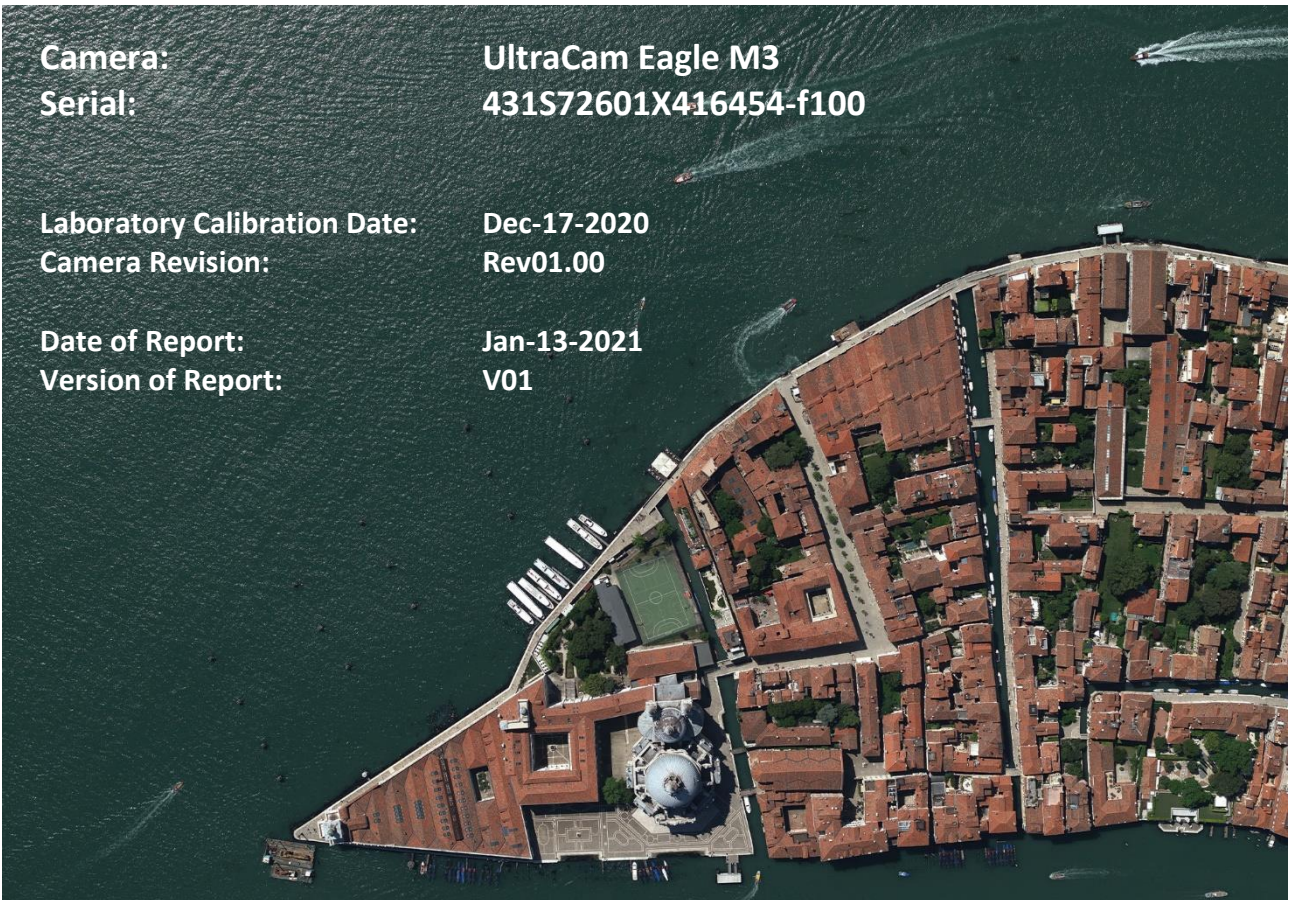


VEXCEL
IMAGING

ULTRACAM

Calibration Report

Camera:	UltraCam Eagle M3
Serial:	431S72601X416454-f100
Laboratory Calibration Date:	Dec-17-2020
Camera Revision:	Rev01.00
Date of Report:	Jan-13-2021
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:	431S72601X416454-f100

Panchromatic Camera:	ck = 100.500 mm
Multispectral Camera:	ck = 100.500 mm

PPA Information:	X: -0.160 mm
	Y: 0.000 mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track	68.016mm	17004pixel
	cross track	105.840mm	26460pixel
Image Extent		(-34.008, -52.920)mm	(34.008, 52.920)mm
Pixel Size		4.000μm*4.000μm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	-0.160mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

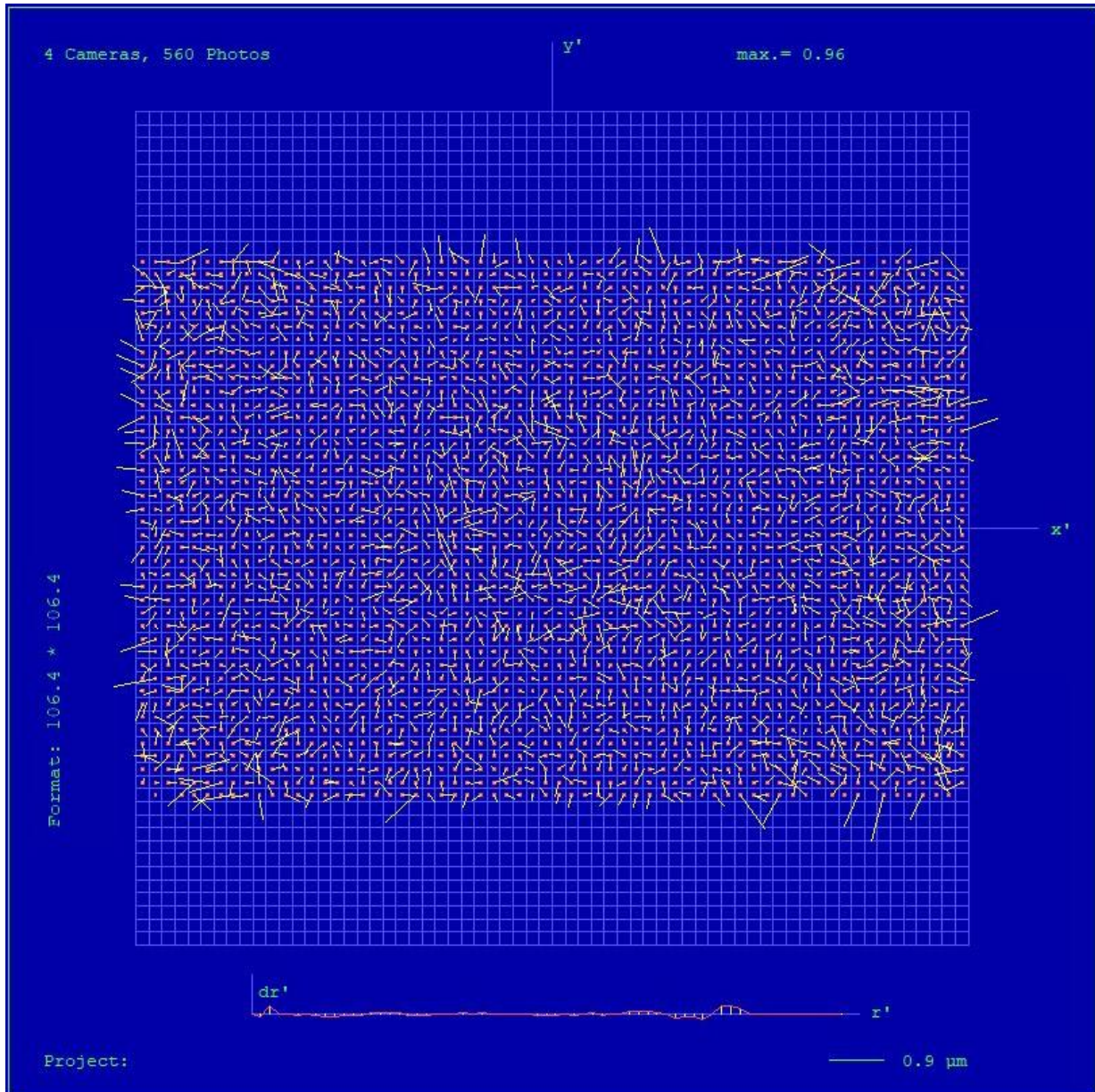
Multispectral Camera

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

Image Format	long track	68.016mm	5668pixel
	cross track	105.840mm	8820pixel
Image Extent		(-34.008, -52.920)mm	(34.008, 52.920)mm
Pixel Size		12.000μm*12.000μm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	-0.160mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		



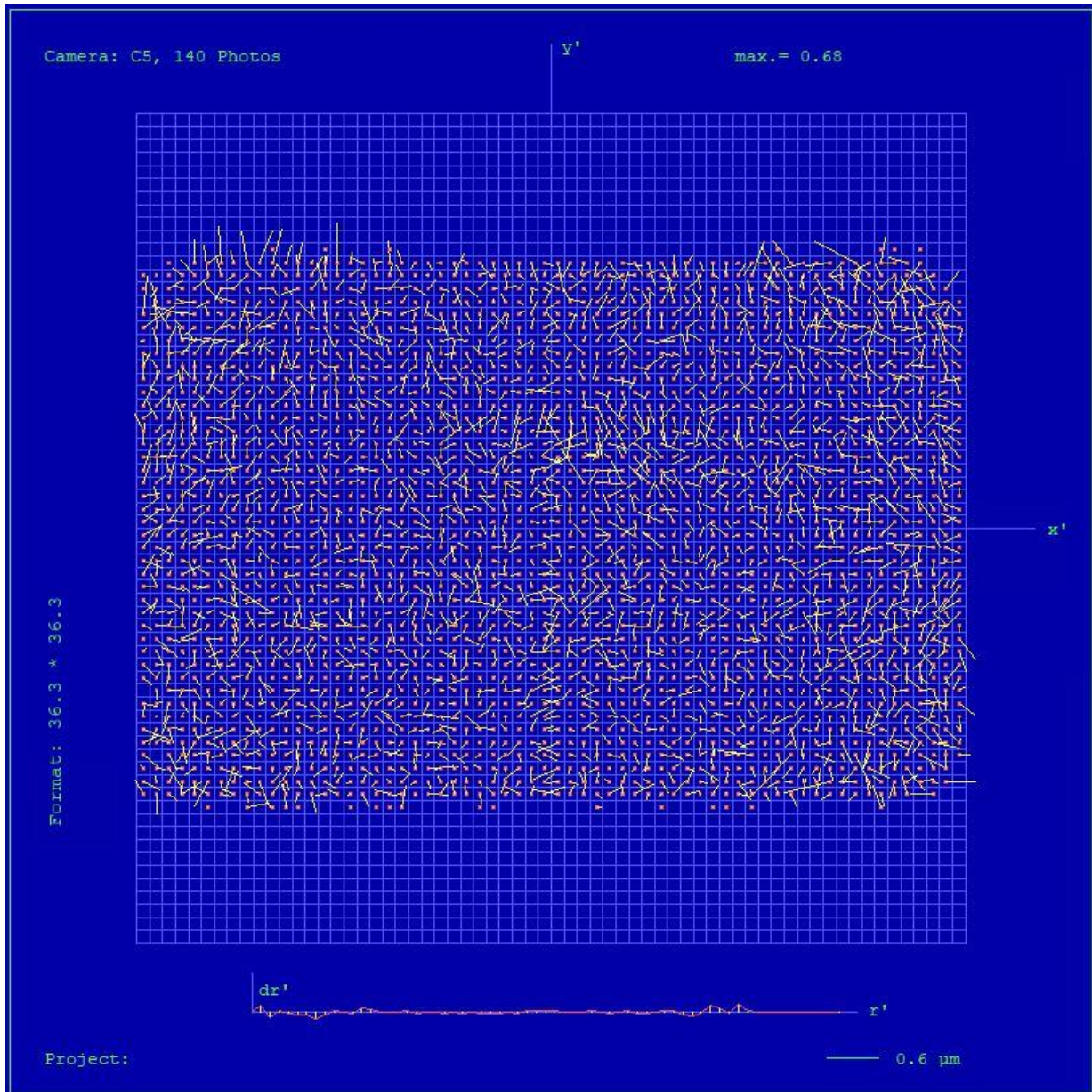
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): 0.55 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

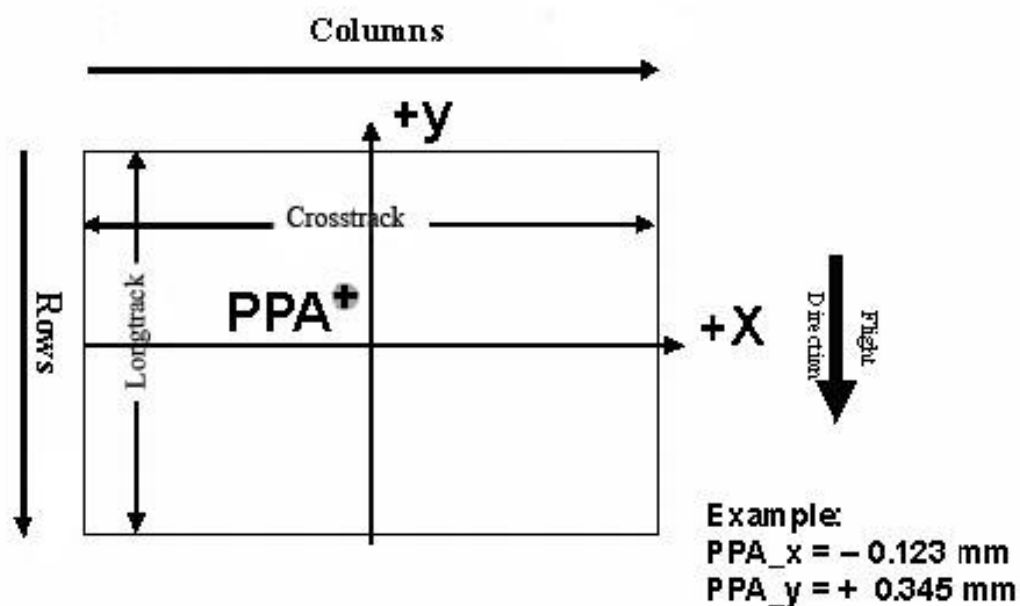
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.

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

Level 2 Image Coordinate System:

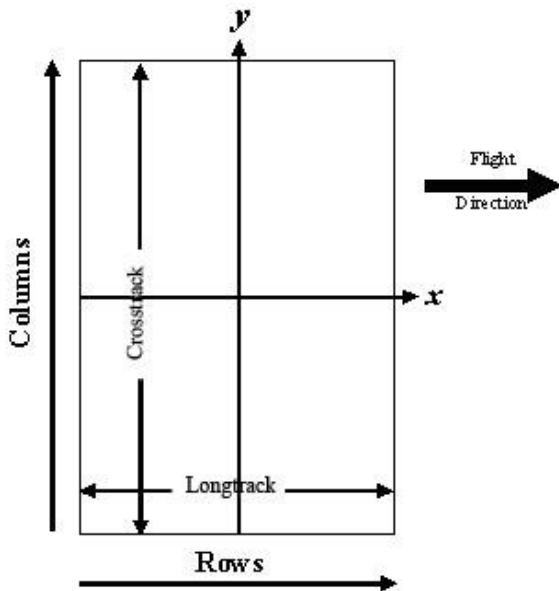
Lvl2, Camera prop. Orientation



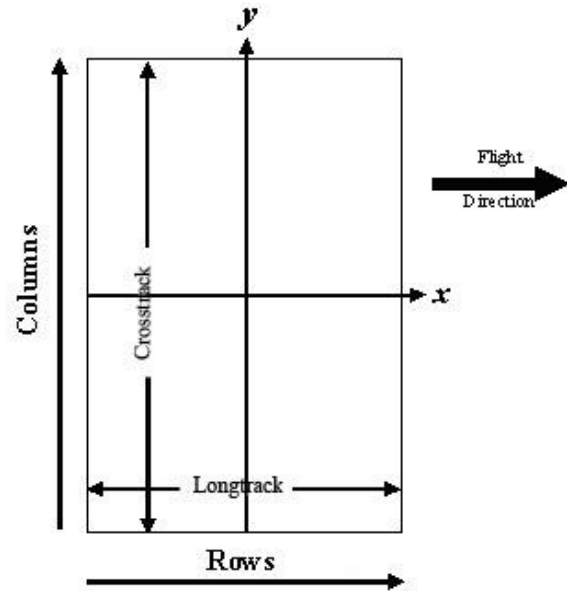
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



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



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

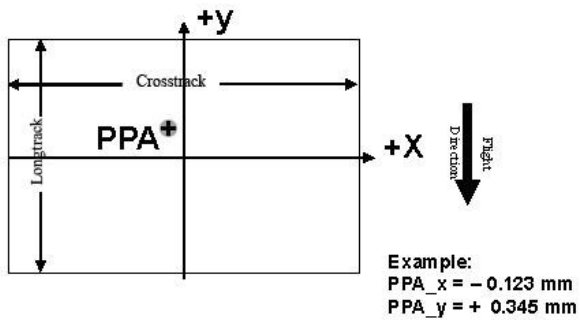
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified 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	-	-0.160	0.000
Level 3	0	-0.160	0.000
Level 3	90	0.000	0.160
Level 3	180	0.160	0.000
Level 3	270	0.000	-0.160

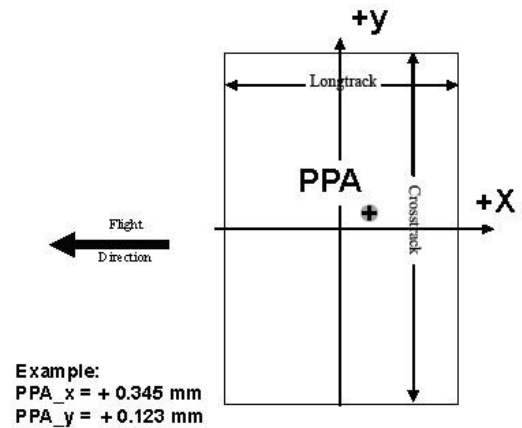


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

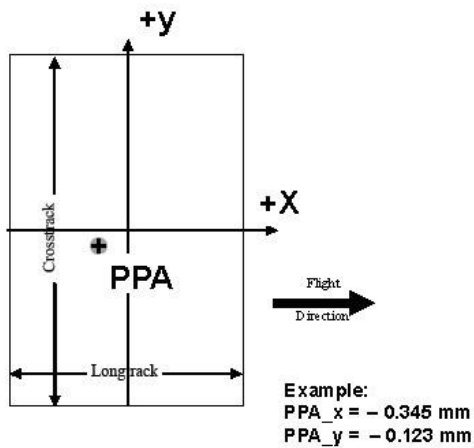
Lvl3, Rotation 0 deg clockwise



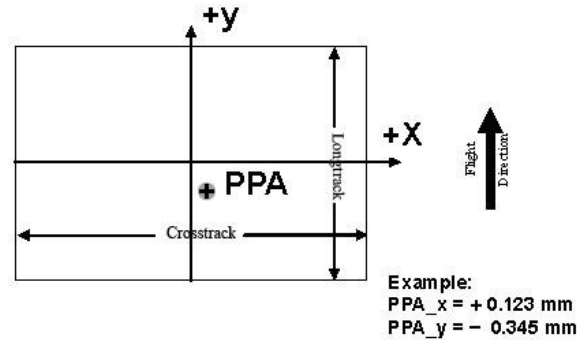
Lvl3, Rotation 90 deg clockwise



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.

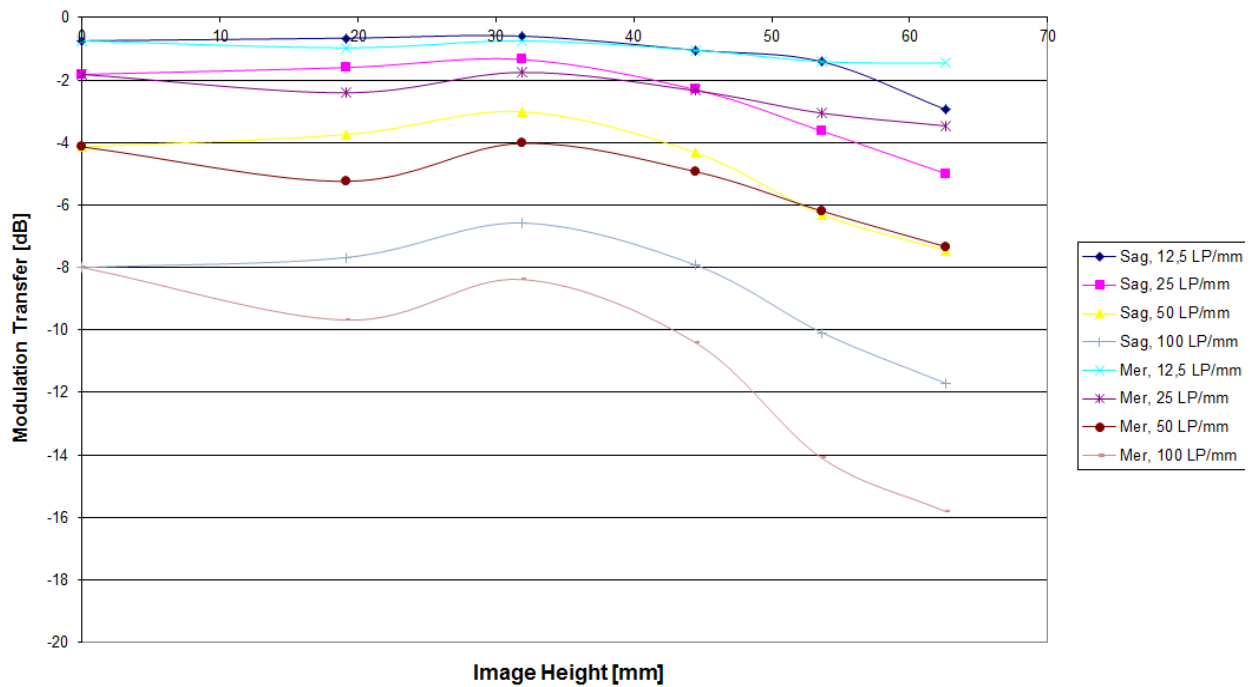
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

Lens types

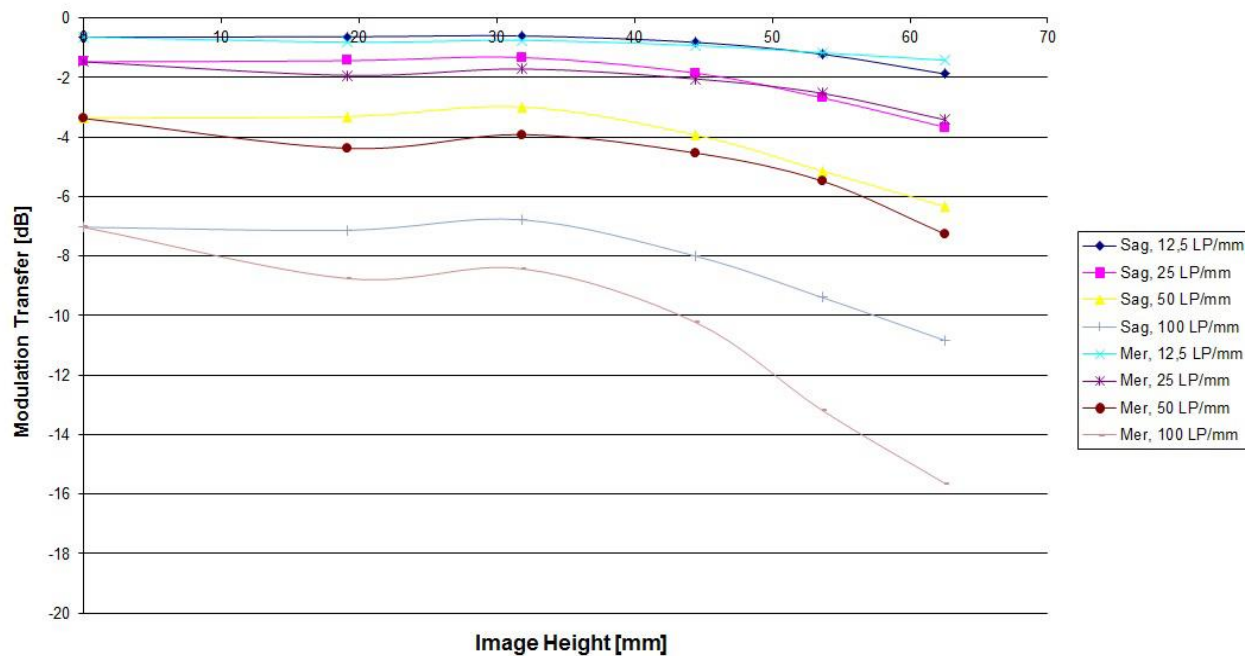
Cone	Lens
C0 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C1 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C2 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C3 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C4 (RED)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany
C5 (GREEN)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany
C6 (BLUE)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany
C7 (NIR)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany



Modulation versus Image Height - Aperture f/ 5.6

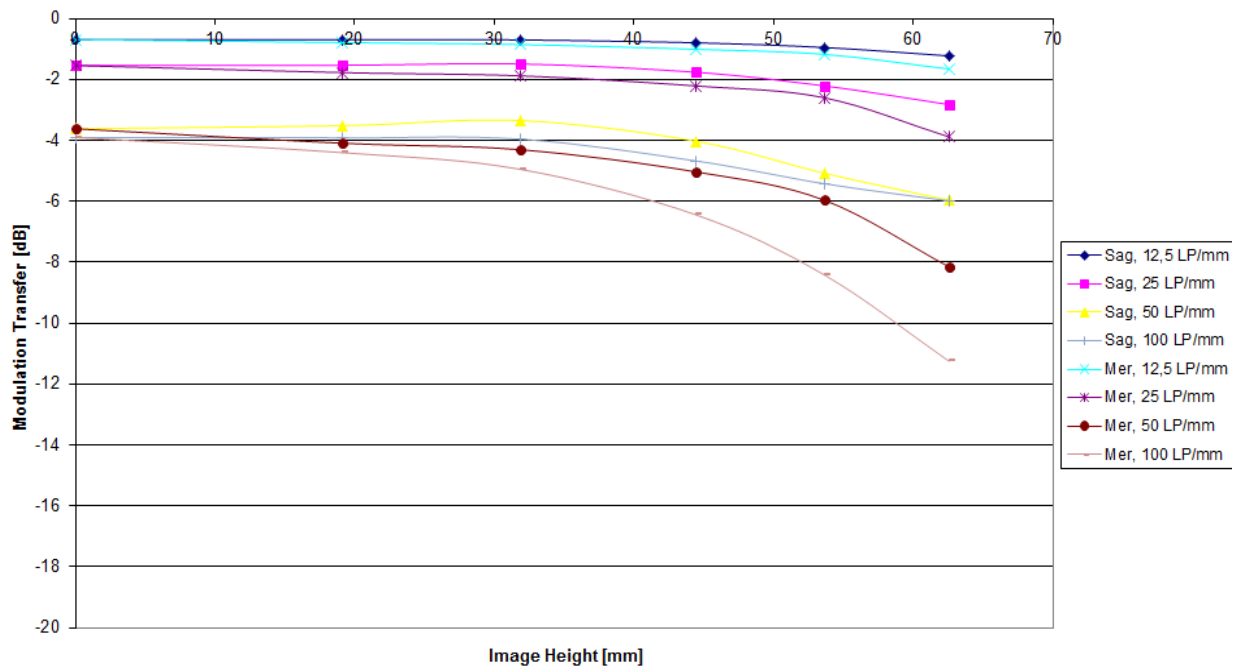


Modulation versus Image Height - Aperture f/ 6.7

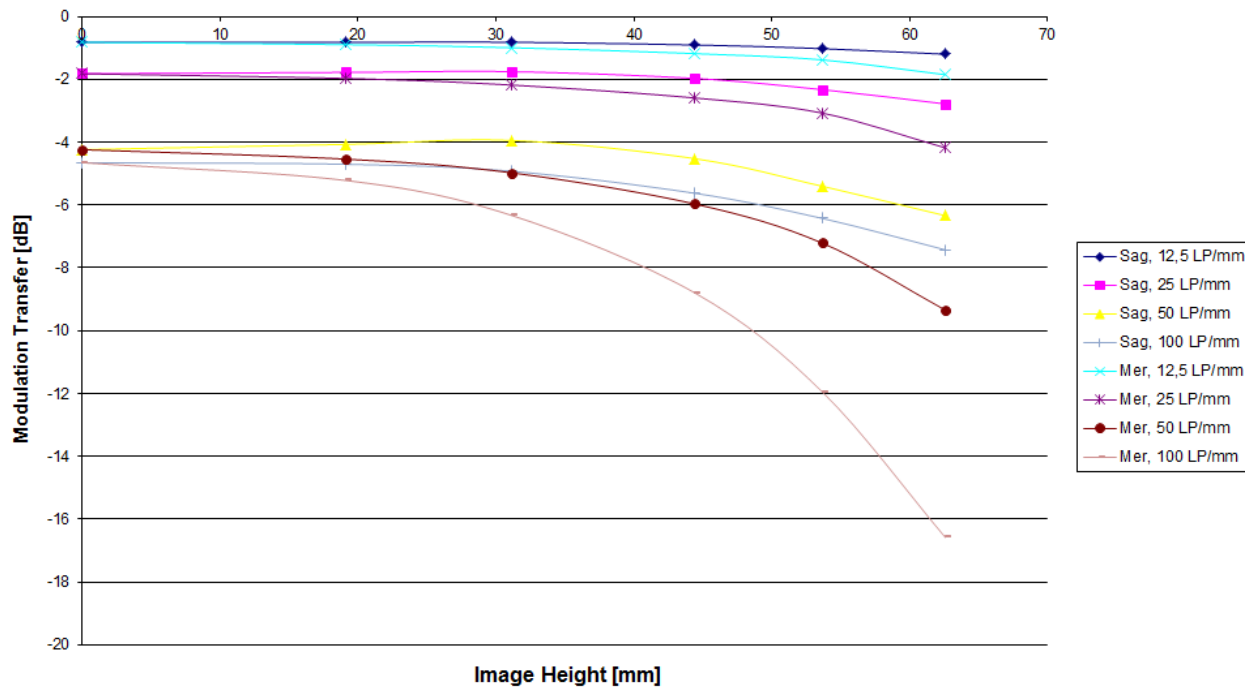




Modulation versus Image Height - Aperture f / 8

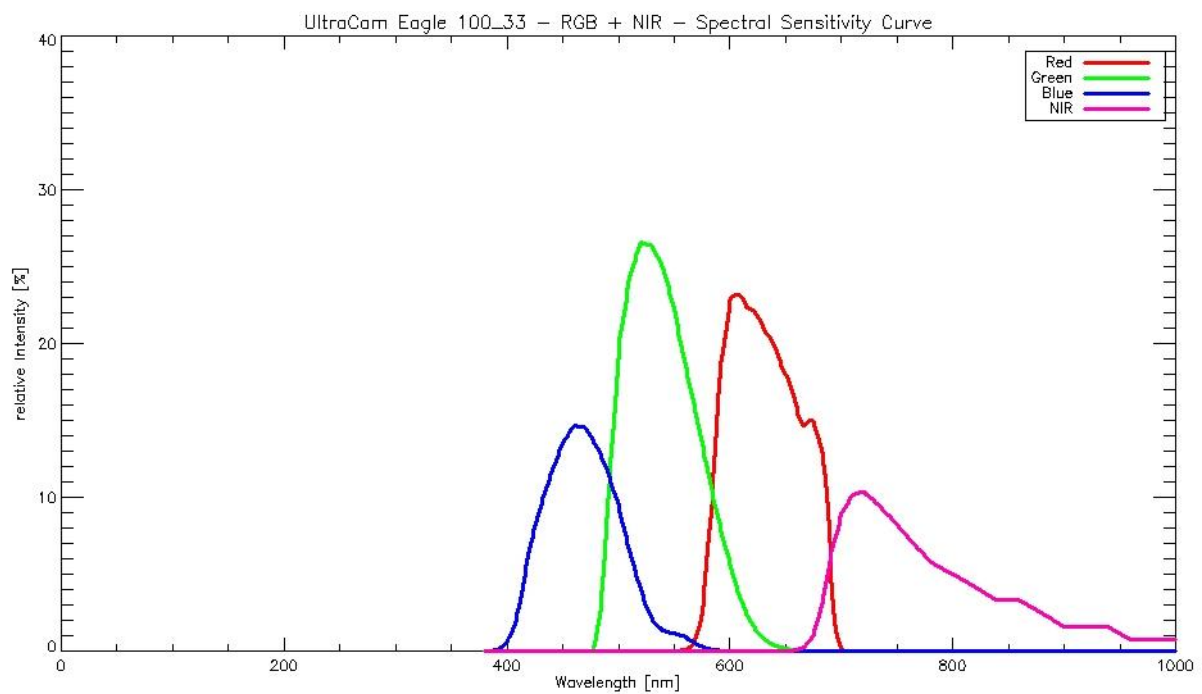
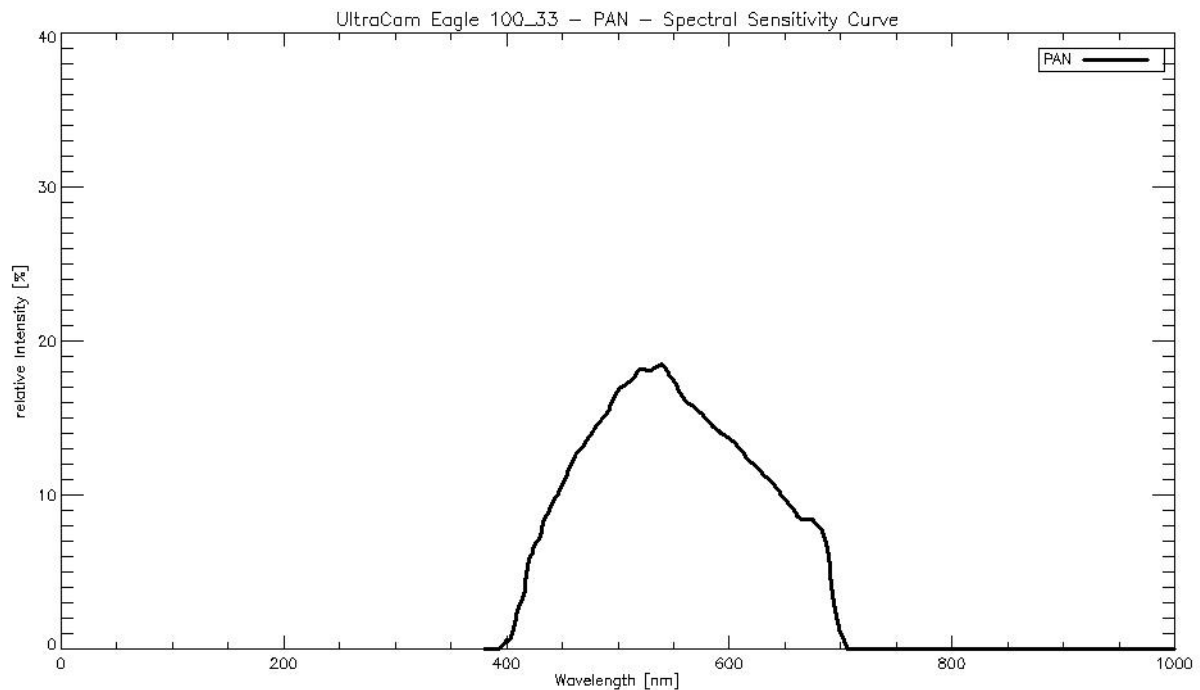


Modulation versus Image Height - Aperture f / 9.5





Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: UltraCam Eagle M3
Serial: 431S72601X416454-f100

Used Apertures	PAN	R, G, NIR	B
	F5.6	F4.8	F4.8
	F6.7	F5.6	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	F5.6	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: 431S72601X416454-f100

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 57 52 47	6.55	6.79	7.05	7.30	7.49	7.62	7.72	8.07	+/- 0.2
C1 (Pan)	12 57 52 59	6.81	7.11	7.41	7.62	7.83	8.01	8.23	8.65	+/- 0.2
C2 (Pan)	12 57 52 46	6.51	6.77	7.01	7.27	7.44	7.59	7.72	8.12	+/- 0.2
C3 (Pan)	12 57 52 48	6.65	6.93	7.27	7.51	7.72	7.83	7.94	8.37	+/- 0.2
C4 (Red)	12 51 84 48	7.13	7.31	7.44	7.53	7.61	7.77	7.88	7.88	+/- 0.2
C5 (Green)	12 52 68 49	7.00	7.12	7.27	7.45	7.54	7.66	7.80	8.02	+/- 0.2
C6 (Blue)	12 52 68 58	7.29	7.29	7.30	7.41	7.65	7.73	7.85	8.11	+/- 0.2
C7 (NIR)	12 51 84 22	7.19	7.33	7.51	7.74	7.94	8.02	8.22	8.22	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Eagle M3
Serial: 431S72601X416454-f100

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	201289/099	21.60	6.55
00_01	FTF9060-M	205220/031	21.60	6.43
00_02	FTF9060-M	201289/101	21.60	6.27
00_03	FTF9060-M	201289/089	21.40	6.37
01_00	FTF9060-M	205220/001	21.80	7.01
01_01	FTF9060-M	201289/112	21.40	6.11
02_00	FTF9060-M	201289/095	21.80	6.42
02_01	FTF9060-M	201289/081	21.20	5.86
03_00	FTF9060-M	201289/094	21.60	6.12
04_00 (red)	FTF9060-M	209941/040	20.00	6.27
05_00 (green)	FTF9060-M	205220/003	21.60	6.52
06_00 (blue)	FTF9060-M	201289/109	22.20	6.13
07_00 (NIR)	FTF9060-M	201289/079	22.00	6.19



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	201289/099	13400	12730
00_01	FTF9060-M	205220/031	13630	12940
00_02	FTF9060-M	201289/101	13500	12300
00_03	FTF9060-M	201289/089	13490	13110
01_00	FTF9060-M	205220/001	13360	12520
01_01	FTF9060-M	201289/112	13110	12740
02_00	FTF9060-M	201289/095	13270	12590
02_01	FTF9060-M	201289/081	13690	12680
03_00	FTF9060-M	201289/094	13200	12650
04_00 (red)	FTF9060-M	209941/040	14470	13370
05_00 (green)	FTF9060-M	205220/003	14080	12740
06_00 (blue)	FTF9060-M	201289/109	13390	12690
07_00 (NIR)	FTF9060-M	201289/079	13280	12320



ULTRACAM

Summary

Camera:	UltraCam Eagle M3
Serial:	431S72601X416454-f100
Laboratory Calibration Date:	Dec-17-2020
Camera Revision:	Rev01.00
Date of Report:	Jan-13-2021
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

C00-00

PIXEL: 1609/3504
PIXEL: 1850/5854
PIXEL: 2491/3086
PIXEL: 3700/1545
PIXEL: 3769/3800
PIXEL: 4235/3945
PIXEL: 5140/1371
PIXEL: 5508/3229
PIXEL: 5530/4417
PIXEL: 5830/4191
PIXEL: 8982/ 225
PIXEL: 384/6004
PIXEL: 1877/4521
PIXEL: 3645/5095
PIXEL: 3645/5096
PIXEL: 3794/4986
PIXEL: 8787/ 423
PIXEL: 8848/ 173
PIXEL: 383/6004
PIXEL: 3644/5096
PIXEL: 3646/5096
PIXEL: 3645/5097
PIXEL: 3794/4987
PIXEL: 3795/4987
PIXEL: 3786/4977
PIXEL: 8788/ 423
PIXEL: 8848/ 172

C00-01

PIXEL: 2432/3874
PIXEL: 3476/3981
PIXEL: 5186/ 38
PIXEL: 5462/2879
PIXEL: 7673/2164
PIXEL: 8385/3987



C00-02

PIXEL: 159/ 744
PIXEL: 28/1245
PIXEL: 592/4068
PIXEL: 2844/4857
PIXEL: 3582/2295
PIXEL: 4663/ 963
PIXEL: 4823/2007
PIXEL: 6241/4503
PIXEL: 6610/4721
PIXEL: 7107/2709
PIXEL: 7575/ 120
PIXEL: 158/ 744
PIXEL: 159/ 743
PIXEL: 159/ 745
PIXEL: 433/ 101
PIXEL: 653/3606
PIXEL: 433/ 102

C00-03

PIXEL: 1000/2467
PIXEL: 1141/1735
PIXEL: 1616/3435
PIXEL: 3129/3598
PIXEL: 3723/5076
PIXEL: 4274/5101
PIXEL: 4618/3144
PIXEL: 4936/4756
PIXEL: 246/5687
PIXEL: 1500/2609
PIXEL: 4168/2027
PIXEL: 5509/2308
PIXEL: 7341/3420
PIXEL: 8052/1967
PIXEL: 8262/5698
PIXEL: 8495/ 157
PIXEL: 8495/ 158
PIXEL: 8496/ 157
PIXEL: 8263/5698

C01-00

PIXEL: 5020/4699
PIXEL: 8403/2379
PIXEL: 95/5716
PIXEL: 458/5365
PIXEL: 705/5344
PIXEL: 1085/1298
PIXEL: 1462/4162
PIXEL: 1817/3447
PIXEL: 2294/3432



PIXEL: 4344/4381
PIXEL: 8252/4016
PIXEL: 8252/4017
PIXEL: 8629/ 420
PIXEL: 8699/2371
PIXEL: 95/5715
PIXEL: 1817/3448
PIXEL: 2294/3433
PIXEL: 8251/4017
PIXEL: 8629/ 421
PIXEL: 2293/3432
PIXEL: 706/5344

C01-01

PIXEL: 736/4789
PIXEL: 2113/5501
PIXEL: 2420/6005
PIXEL: 2421/6004
PIXEL: 2421/6005
PIXEL: 2426/6001
PIXEL: 4744/1451
PIXEL: 5039/3511
PIXEL: 6987/4668
PIXEL: 7179/5721
PIXEL: 8257/3297
PIXEL: 780/3428
PIXEL: 780/3935
PIXEL: 781/3428
PIXEL: 1479/1074
PIXEL: 1602/ 756
PIXEL: 2138/2734
PIXEL: 3285/ 271
PIXEL: 4963/1052
PIXEL: 5012/1055
PIXEL: 5012/1056
PIXEL: 5023/1029
PIXEL: 5024/1029
PIXEL: 6190/2886
PIXEL: 7001/ 953
PIXEL: 7347/4857
PIXEL: 7878/4798
PIXEL: 7929/1662
PIXEL: 8334/3818
PIXEL: 8622/5865
PIXEL: 8761/ 813
PIXEL: 8762/ 812
PIXEL: 8762/ 813
PIXEL: 8776/2191
PIXEL: 8776/2192
PIXEL: 780/3429



PIXEL: 1604/ 746
PIXEL: 1603/ 746
PIXEL: 1601/ 747
PIXEL: 1592/ 751
PIXEL: 1593/ 751
PIXEL: 1596/ 748
PIXEL: 1602/ 755
PIXEL: 2139/2734
PIXEL: 4963/1051
PIXEL: 4964/1051
PIXEL: 5023/1028
PIXEL: 7928/1662
PIXEL: 7925/1684
PIXEL: 8335/3818
PIXEL: 8335/3819
PIXEL: 8333/3818

C02-00

PIXEL: 2245/2401
PIXEL: 4926/5305
PIXEL: 7216/3589
PIXEL: 572/ 568
PIXEL: 1884/5003
PIXEL: 1884/5004
PIXEL: 573/ 568
PIXEL: 554/ 547

C02-01

PIXEL: 4440/5156
PIXEL: 7735/2112
PIXEL: 8945/ 264
PIXEL: 7489/5431
PIXEL: 7490/5430
PIXEL: 7491/5428
PIXEL: 8055/5615
PIXEL: 8937/3089
PIXEL: 7489/5430
PIXEL: 7490/5428
PIXEL: 7506/5431
PIXEL: 7494/5430
PIXEL: 7489/5419
PIXEL: 7487/5424
PIXEL: 7496/5427
PIXEL: 7493/5427
PIXEL: 8054/5614
PIXEL: 8055/5614

C03-00

PIXEL: 5944/3740
PIXEL: 6783/3920



PIXEL: 8002/5272
PIXEL: 8002/5273
PIXEL: 8016/5300
PIXEL: 531/ 403
PIXEL: 5682/5357
PIXEL: 8865/ 207
PIXEL: 5682/5356
PIXEL: 8865/ 208
COLUMN: 1928/2737

C04-00

PIXEL: 166/2898
PIXEL: 174/4810
PIXEL: 174/4811
PIXEL: 160/5770
PIXEL: 185/5714
PIXEL: 185/5715
PIXEL: 250/4564
PIXEL: 1429/ 770
PIXEL: 4295/4825
PIXEL: 4587/2290
PIXEL: 8540/5608
PIXEL: 8540/5607
PIXEL: 8541/5607

C05-00

PIXEL: 1443/5195
PIXEL: 3031/5724
PIXEL: 3534/5700
PIXEL: 4358/4953
PIXEL: 8804/ 724
PIXEL: 42/2108
PIXEL: 62/2883
PIXEL: 219/5554
PIXEL: 219/5555
PIXEL: 500/5075
PIXEL: 522/5318
PIXEL: 701/5246
PIXEL: 791/ 702
PIXEL: 951/4773
PIXEL: 1185/5443
PIXEL: 1185/5444
PIXEL: 1439/ 140
PIXEL: 2586/4704
PIXEL: 7890/4111
PIXEL: 8468/ 730
PIXEL: 8552/ 935
PIXEL: 8900/ 345
PIXEL: 196/5552
PIXEL: 700/5246



PIXEL: 790/ 702
PIXEL: 951/4774
PIXEL: 2587/4704
PIXEL: 2587/4705

C06-00

PIXEL: 7355/3919
PIXEL: 7920/ 123
PIXEL: 8053/2238
PIXEL: 184/ 143
PIXEL: 427/5889
PIXEL: 467/5498
PIXEL: 497/ 229
PIXEL: 3064/2907
PIXEL: 3064/2908
PIXEL: 4856/1577
PIXEL: 6981/4135
PIXEL: 7520/4990
PIXEL: 8480/5895
PIXEL: 8481/5894
PIXEL: 8850/ 397
PIXEL: 212/ 150
PIXEL: 227/ 163
PIXEL: 466/5498
PIXEL: 467/5497
PIXEL: 496/ 229
PIXEL: 3065/2907
PIXEL: 4857/1577
PIXEL: 7519/4990
PIXEL: 7520/4991
PIXEL: 8850/ 398

C07-00

PIXEL: 8394/3172
PIXEL: 36/ 70
PIXEL: 147/2134
PIXEL: 147/2135
PIXEL: 148/2135
PIXEL: 600/ 690
PIXEL: 1989/3085
PIXEL: 1989/3086
PIXEL: 5773/3168
PIXEL: 5773/3169
PIXEL: 5774/3168
PIXEL: 5774/3169
PIXEL: 8927/4985
PIXEL: 8958/2468
PIXEL: 8974/3430
PIXEL: 9032/5994
PIXEL: 1990/3086



PIXEL: 5772/3169
PIXEL: 8959/2468
PIXEL: 8974/3429
PIXEL: 8975/3430
PIXEL: 9032/5995
PIXEL: 9031/5998
PIXEL: 8927/4984

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	17.Dec.2020		
Radiometric Calibration	17.Dec.2020		
Shutter Calibration	17.Dec.2020		
Electronics and Sensor Calibration	17.Dec.2020		

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.