



VEXCEL
IMAGING

ULTRACAM

Calibration Report

Camera:	UltraCam Eagle
Serial:	UC-E-1-60715585-f100
Laboratory Calibration Date:	Feb-25-2021
Camera Revision:	Rev12.00
Date of Report:	Mar-08-2021
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
Serial:	UC-E-1-60715585-f100

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

PPA Information:	X: -0.104 mm
	Y: 0.000 mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	68.016mm 104.052mm	13080pixel 20010pixel
Image Extent		(-34.008, -52.026)mm	(34.008, 52.026)mm
Pixel Size		5.200μm*5.200μm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	-0.104mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

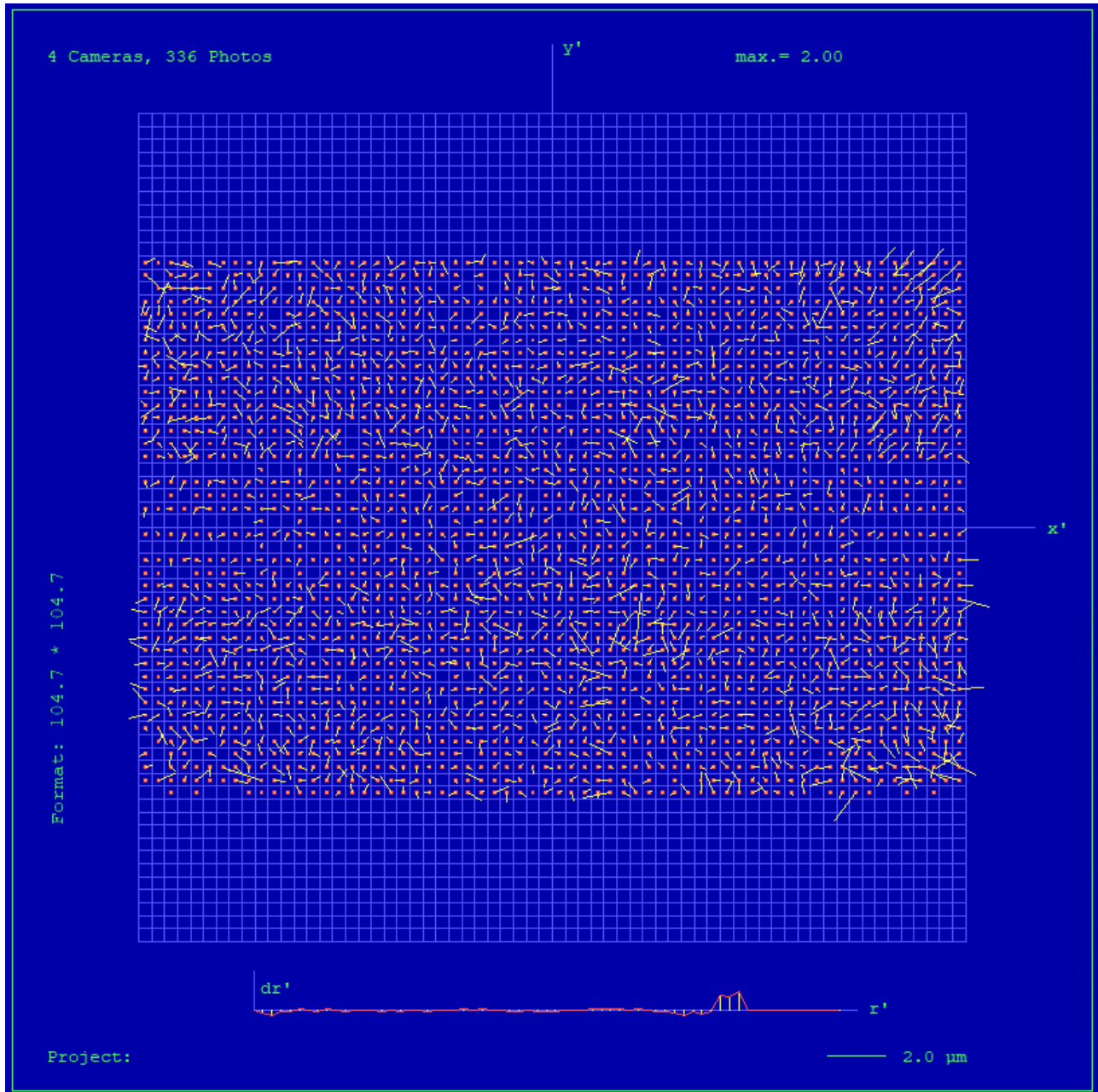
Multispectral Camera

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

Image Format	long track cross track	68.016mm 104.052mm	4360pixel 6670pixel
Image Extent		(-34.008, -52.026)mm	(34.008, 52.026)mm
Pixel Size		15.600μm*15.600μm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	-0.104mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		



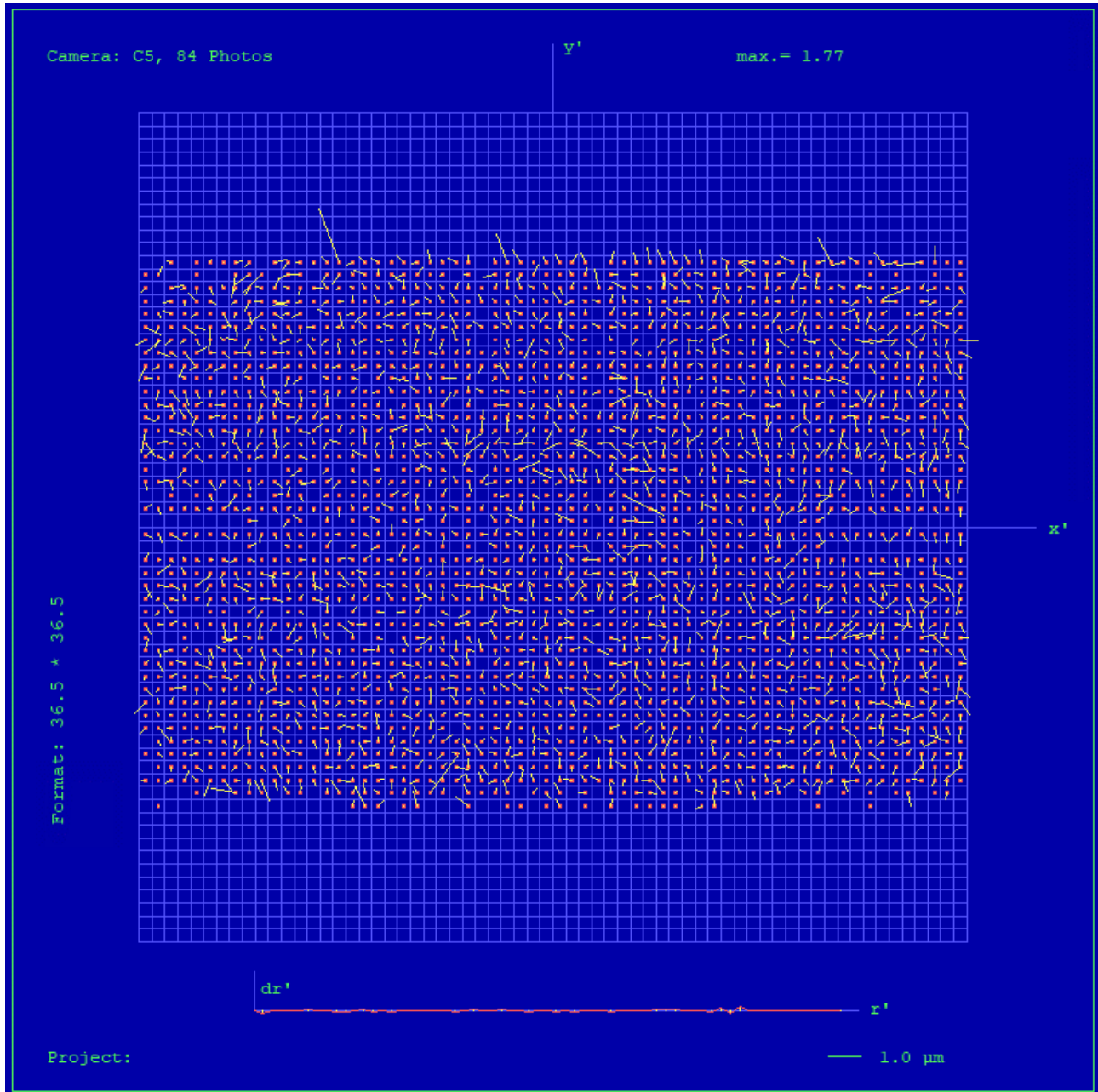
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): 0.67 μm



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): 0.57 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

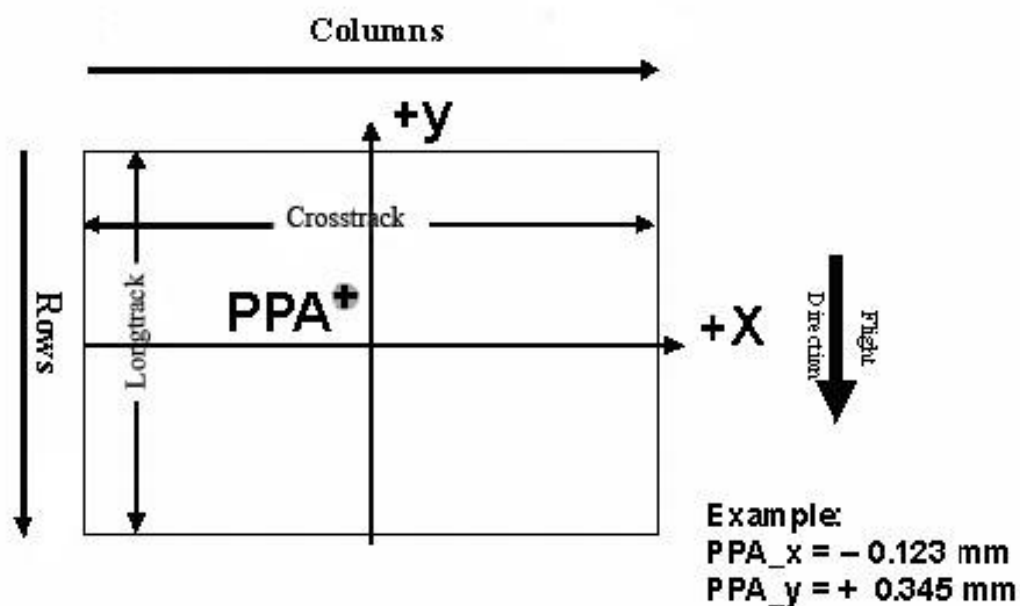
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.

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

Level 2 Image Coordinate System:

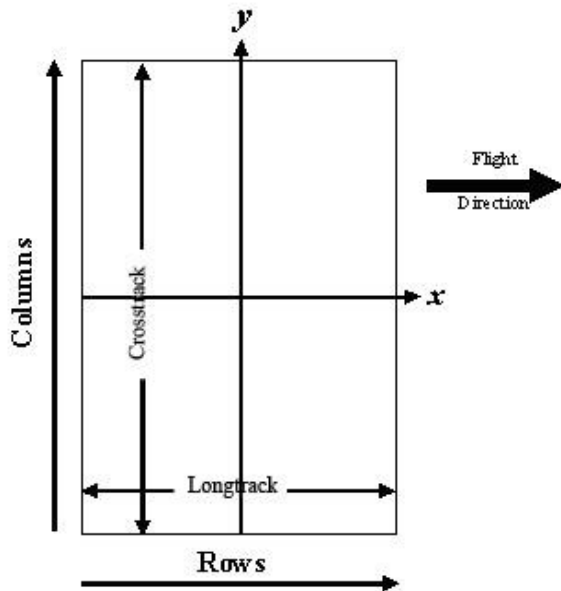
Lvl2, Camera prop. Orientation



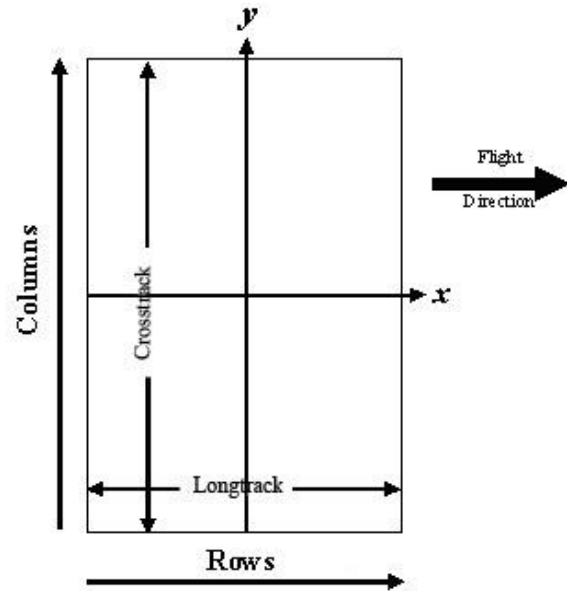
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



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



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

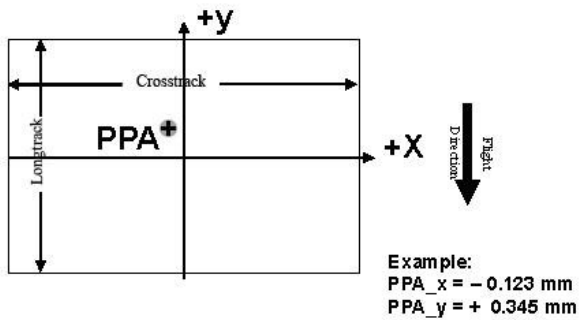
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified 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	-	-0.104	0.000
Level 3	0	-0.104	0.000
Level 3	90	0.000	0.104
Level 3	180	0.104	0.000
Level 3	270	0.000	-0.104

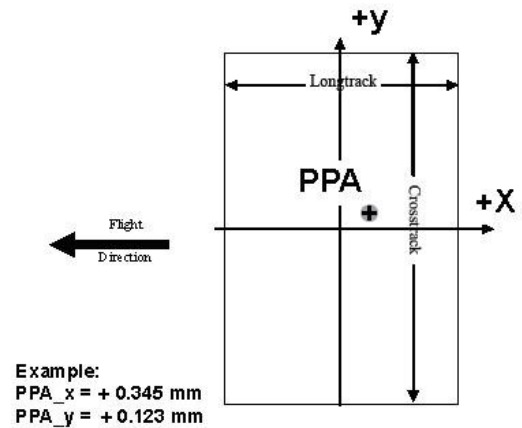


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

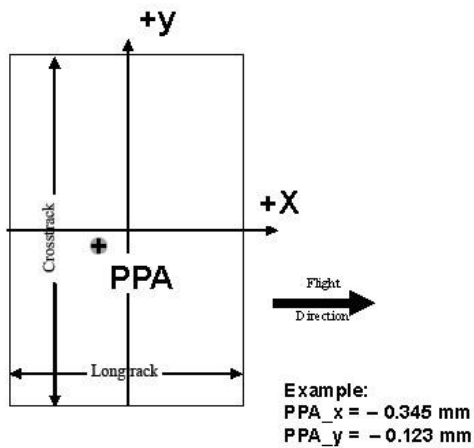
Lvl3, Rotation 0 deg clockwise



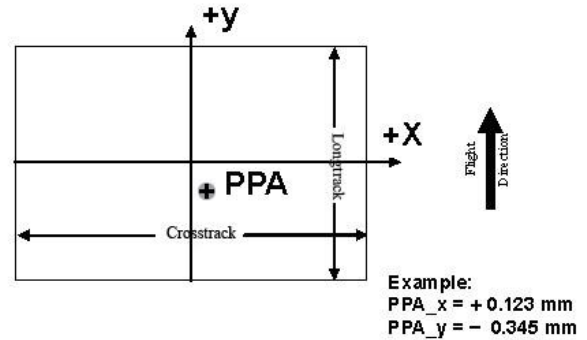
Lvl3, Rotation 90 deg clockwise



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.

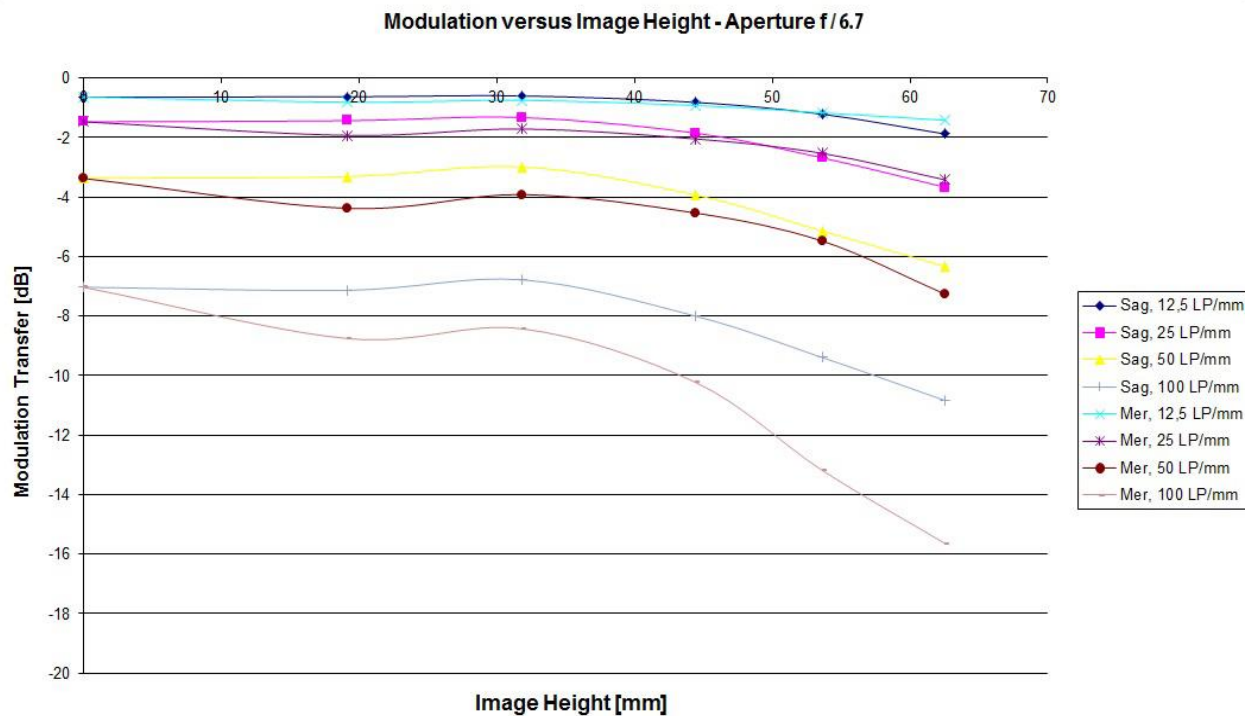
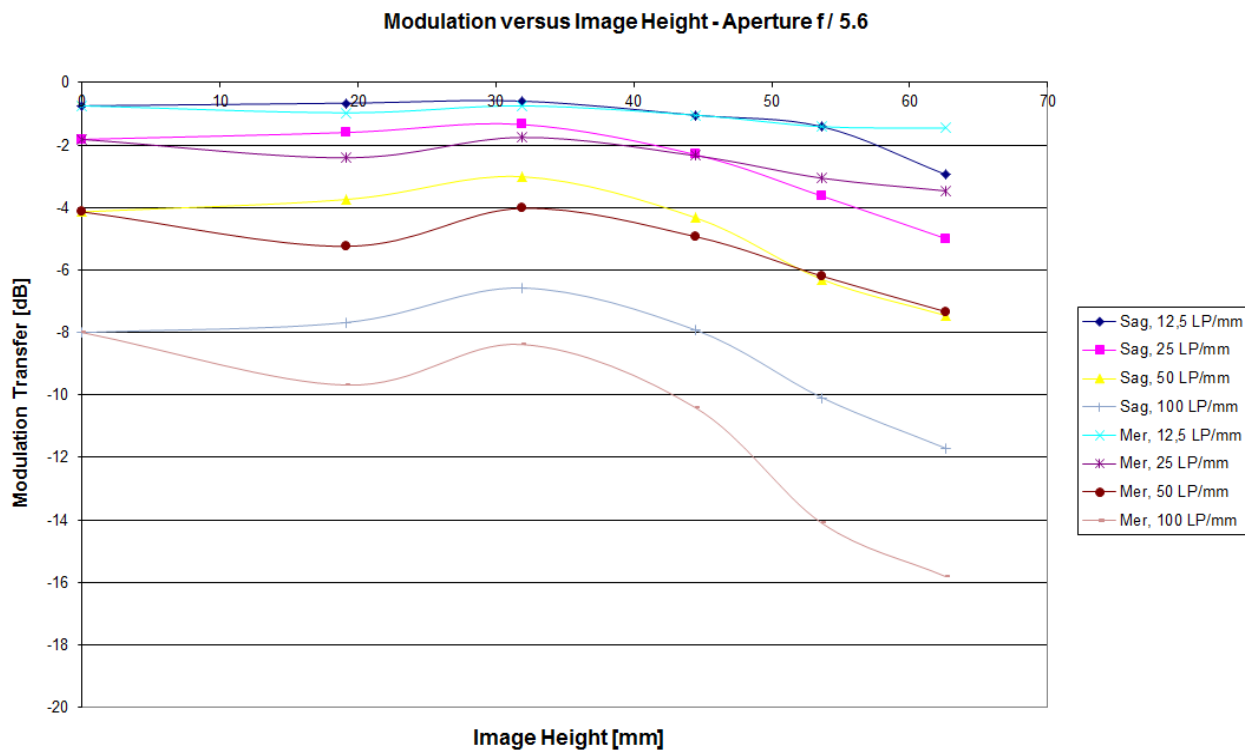
Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

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.

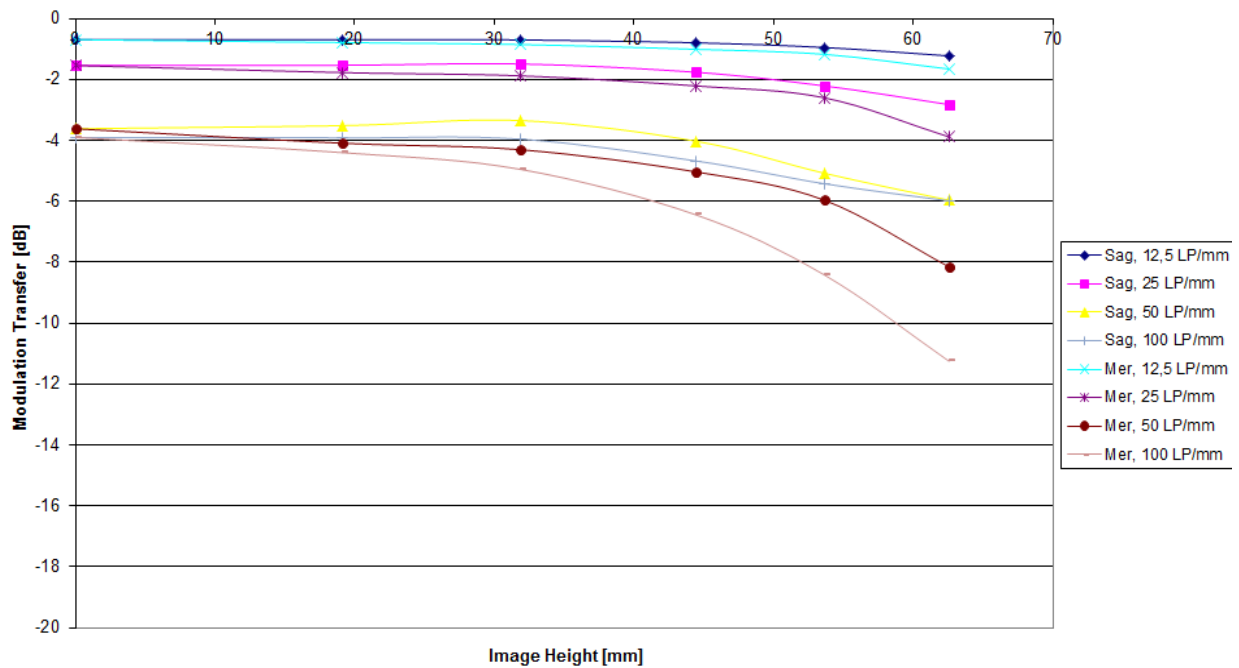
Lens types

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

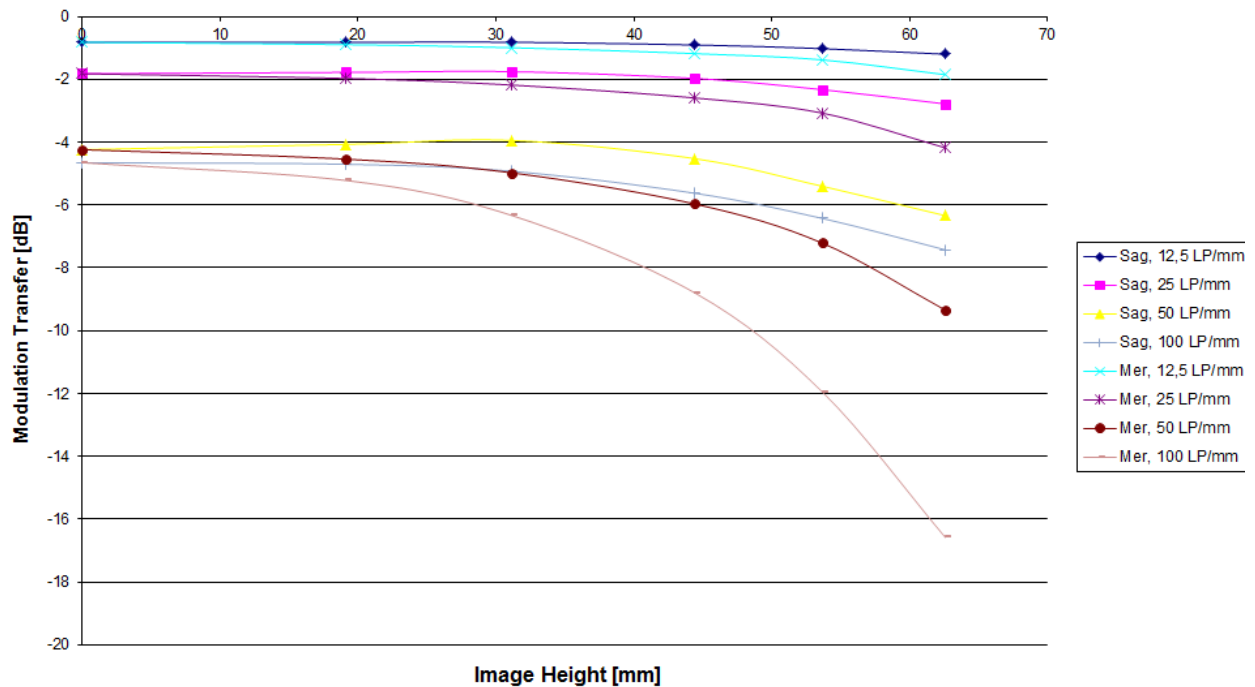




Modulation versus Image Height - Aperture f / 8

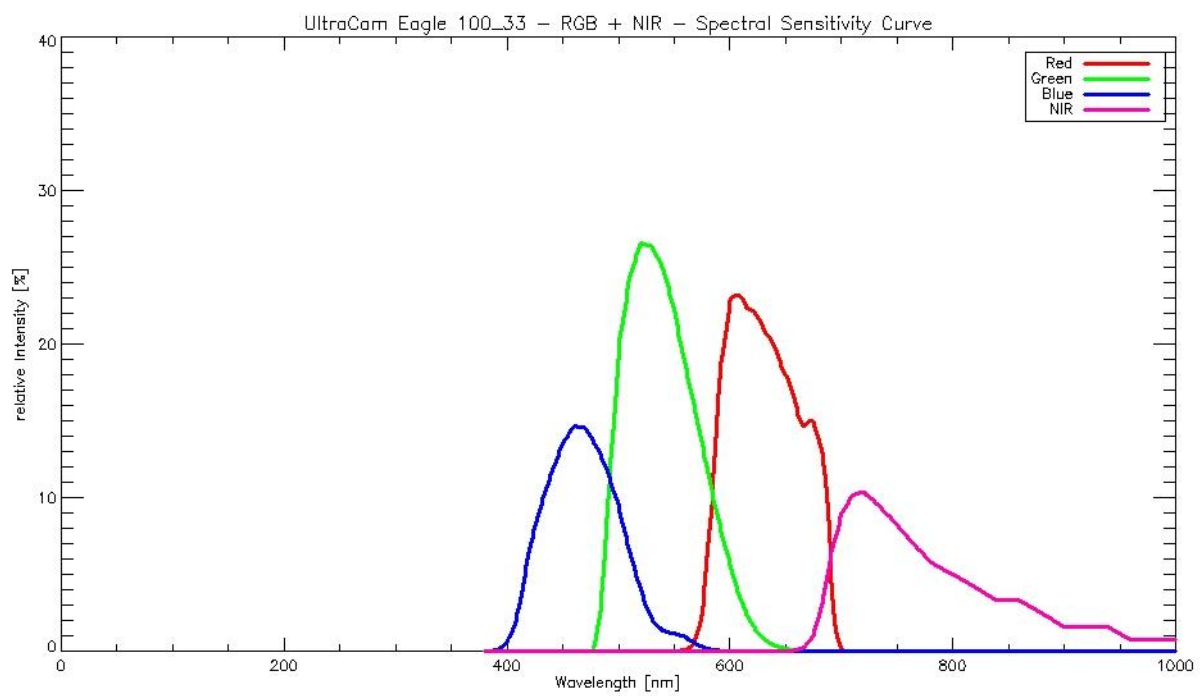
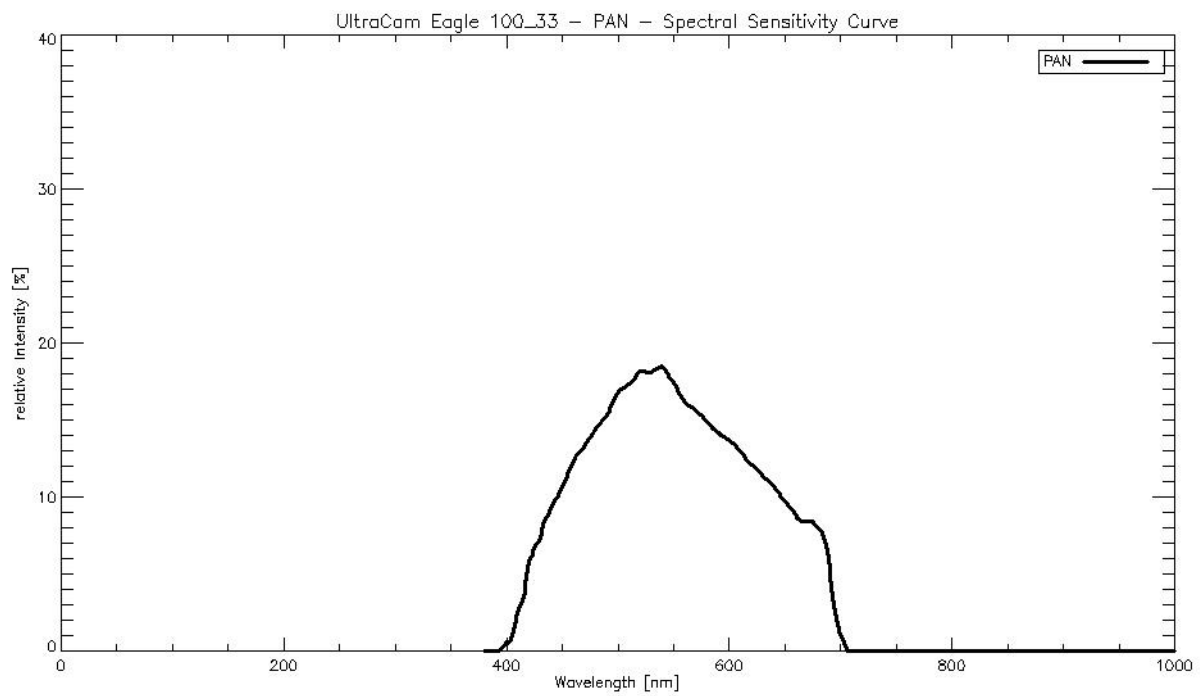


Modulation versus Image Height - Aperture f / 9.5





Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: UltraCam Eagle
Serial: UC-E-1-60715585-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



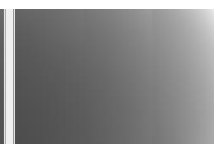

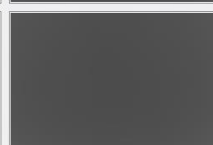
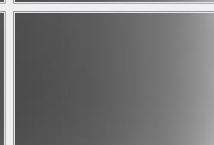



Dead Pixel Report: see Appendix I







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
Serial: UC-E-1-60715585-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 27 38 31	6.41	6.63	6.94	7.18	7.36	7.51	7.65	7.92	+/- 0.2
C1 (Pan)	12 27 38 40	6.87	7.13	7.41	7.70	7.86	8.06	8.21	8.44	+/- 0.2
C2 (Pan)	12 27 38 29	6.85	7.09	7.40	7.66	7.89	7.98	8.11	8.27	+/- 0.2
C3 (Pan)	12 27 38 42	6.30	6.54	6.83	7.10	7.27	7.42	7.50	7.76	+/- 0.2
C4 (Red)	12 24 50 18	7.01	7.15	7.30	7.41	7.46	7.55	7.64	7.83	+/- 0.2
C5 (Green)	12 24 50 20	7.36	7.49	7.64	7.83	7.94	7.98	8.00	8.25	+/- 0.2
C6 (Blue)	12 23 11 73	7.01	7.01	7.01	7.12	7.32	7.45	7.53	7.69	+/- 0.2
C7 (NIR)	12 23 11 77	7.17	7.24	7.37	7.59	7.72	7.72	7.69	7.69	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera:	UltraCam Eagle
Serial:	UC-E-1-60715585-f100

Panchromatic Camera:	9 * FTF7046-M Area CCD Sensor by DALSA
Multispectral Camera:	4 * FTF7046-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]
00_00	FTF7046-M	15 7349/050	24.40
00_01	FTF7046-M	16 0872/086	24.00
00_02	FTF7046-M	16 0872/116	24.00
00_03	FTF7046-M	16 0872/069	23.80
01_00	FTF7046-M	16 0872/088	24.00
01_01	FTF7046-M	16 2469/031	24.40
02_00	FTF7046-M	16 0872/128	24.00
02_01	FTF7046-M	16 0872/073	23.80
03_00	FTF7046-M	16 0872/117	24.00
04_00 (red)	FTF7046-M	16 2469/064	24.40
05_00 (green)	FTF7046-M	16 0872/111	24.00
06_00 (blue)	FTF7046-M	16 0872/097	24.00
07_00 (NIR)	FTF7046-M	16 2469/010	24.60



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]
00_00	FTF7046-M	15 7349/050	13320
00_01	FTF7046-M	16 0872/086	13120
00_02	FTF7046-M	16 0872/116	12600
00_03	FTF7046-M	16 0872/069	13350
01_00	FTF7046-M	16 0872/088	13170
01_01	FTF7046-M	16 2469/031	13200
02_00	FTF7046-M	16 0872/128	12410
02_01	FTF7046-M	16 0872/073	12760
03_00	FTF7046-M	16 0872/117	12440
04_00 (red)	FTF7046-M	16 2469/064	12860
05_00 (green)	FTF7046-M	16 0872/111	12770
06_00 (blue)	FTF7046-M	16 0872/097	12630
07_00 (NIR)	FTF7046-M	16 2469/010	13980



ULTRACAM

Summary

Camera:	UltraCam Eagle
Serial:	UC-E-1-60715585-f100
Laboratory Calibration Date:	Feb-25-2021
Camera Revision:	Rev12.00
Date of Report:	Mar-08-2021
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: 570/3587

PIXEL: 3729/3499

PIXEL: 1951/4131

PIXEL: 2845/ 780

PIXEL: 2845/ 781

PIXEL: 5079/2940

PIXEL: 5473/2048

PIXEL: 5474/2046

PIXEL: 5474/2048

PIXEL: 5866/2851

PIXEL: 6681/ 647

C00-01

PIXEL: 158/ 188

PIXEL: 5223/1585

PIXEL: 6077/4560

PIXEL: 6197/1875

PIXEL: 811/ 669

PIXEL: 1034/4065

PIXEL: 2354/2433

PIXEL: 2354/2434

PIXEL: 3937/ 464

PIXEL: 4630/2092

PIXEL: 5096/3774

PIXEL: 5275/ 645

PIXEL: 5503/4162

PIXEL: 5657/2106

PIXEL: 5657/2107

PIXEL: 5993/1950

PIXEL: 6797/4625

C00-02

PIXEL: 2627/3205

PIXEL: 3586/1110

PIXEL: 6155/4271

PIXEL: 5899/4618

PIXEL: 5899/4619

PIXEL: 5900/4618

PIXEL: 5900/4619



C00-03

PIXEL: 361/1718
PIXEL: 1328/1053
PIXEL: 1854/4032
PIXEL: 2060/2907
PIXEL: 5500/2213
PIXEL: 6621/1683
PIXEL: 6934/3784
PIXEL: 6934/3785
PIXEL: 787/1873
PIXEL: 787/1874
PIXEL: 2992/ 133
PIXEL: 5336/ 236
PIXEL: 6477/1964

C01-00

PIXEL: 5375/3803
PIXEL: 6908/3893
PIXEL: 3665/ 707
PIXEL: 3665/ 708
PIXEL: 5064/ 30
PIXEL: 5064/ 31
PIXEL: 5065/ 30
PIXEL: 5066/ 30
PIXEL: 5066/ 31
PIXEL: 5067/ 29
PIXEL: 5067/ 31
PIXEL: 5068/ 27
PIXEL: 5068/ 28
PIXEL: 5068/ 29
PIXEL: 5069/ 27
PIXEL: 5069/ 28

C01-01

PIXEL: 129/2046
PIXEL: 316/ 290
PIXEL: 480/3702
PIXEL: 930/3704
PIXEL: 1921/ 288
PIXEL: 1997/3251
PIXEL: 2632/1934
PIXEL: 2649/ 794
PIXEL: 2753/1096
PIXEL: 3675/2427
PIXEL: 5553/1095
PIXEL: 6192/ 503
PIXEL: 6412/3169
PIXEL: 6471/1351
PIXEL: 6472/1844
PIXEL: 6704/ 850

C02-00

PIXEL: 477/3550
PIXEL: 480/2733
PIXEL: 554/2943



PIXEL: 984/1363
PIXEL: 1080/4145
PIXEL: 1107/4191
PIXEL: 1250/1182
PIXEL: 1262/2122
PIXEL: 1650/4573
PIXEL: 1866/1771
PIXEL: 2131/4115
PIXEL: 2429/2368
PIXEL: 2437/1632
PIXEL: 2486/1300
PIXEL: 2504/4154
PIXEL: 2531/3381
PIXEL: 2791/3097
PIXEL: 2917/1905
PIXEL: 3295/ 266
PIXEL: 3603/2499
PIXEL: 4097/ 435
PIXEL: 4224/ 317
PIXEL: 4933/4248
PIXEL: 5396/2237
PIXEL: 6178/2406
PIXEL: 6469/2237
PIXEL: 6503/2679
PIXEL: 6687/ 940
PIXEL: 6755/2943
PIXEL: 6773/3457
PIXEL: 6790/1098
PIXEL: 325/ 128
PIXEL: 898/ 97
PIXEL: 899/ 96
PIXEL: 899/ 97
PIXEL: 900/ 96
PIXEL: 2007/1259
PIXEL: 3866/1680
PIXEL: 4288/3891
PIXEL: 4606/3042
PIXEL: 4606/3043
PIXEL: 3585/2930

C02-01

PIXEL: 1189/ 212
PIXEL: 1608/3848
PIXEL: 4806/ 117
PIXEL: 6616/3957
PIXEL: 1058/3380
PIXEL: 1058/3381
PIXEL: 1059/3379
PIXEL: 1059/3380
PIXEL: 3537/1905
PIXEL: 3632/2333
PIXEL: 4339/ 909
PIXEL: 4340/ 909
PIXEL: 4340/ 910
PIXEL: 5718/4136



C03-00

PIXEL: 312/3257
PIXEL: 428/2627
PIXEL: 726/3604
PIXEL: 760/2402
PIXEL: 2761/3533
PIXEL: 3763/1304
PIXEL: 5050/4089
PIXEL: 128/2959
PIXEL: 131/2960
PIXEL: 4022/1594
PIXEL: 5148/3743
PIXEL: 5148/3744

C04-00

PIXEL: 1097/ 799
PIXEL: 1284/1435
PIXEL: 2661/ 651
PIXEL: 5062/4509
PIXEL: 5726/2462
PIXEL: 6568/1298
PIXEL: 1199/4208
PIXEL: 1199/4209
PIXEL: 3212/1583
PIXEL: 3212/1584
PIXEL: 3628/1509
PIXEL: 4878/1456
PIXEL: 6515/ 612
PIXEL: 6515/ 613
PIXEL: 6516/ 614
PIXEL: 6517/ 614

C05-00

PIXEL: 1498/1347
PIXEL: 5572/3831

C06-00

PIXEL: 586/2919
PIXEL: 1197/3668
PIXEL: 2466/3004
PIXEL: 3306/2396
PIXEL: 5700/4313
PIXEL: 6777/ 696
PIXEL: 2217/2566
PIXEL: 4962/4196
PIXEL: 5419/4604
PIXEL: 5838/2209
PIXEL: 6157/4412
PIXEL: 6515/1472
PIXEL: 6515/1473
PIXEL: 6777/1402
PIXEL: 6778/1402
PIXEL: 2217/2565
PIXEL: 5837/2209
PIXEL: 5837/2210
PIXEL: 6158/4412



PIXEL: 6159/4411
PIXEL: 6778/1403

C07-00
PIXEL: 1260/3021
PIXEL: 1845/3212
PIXEL: 2181/3068
PIXEL: 2576/ 542
PIXEL: 3149/ 289
PIXEL: 3777/1005
PIXEL: 3959/3222
PIXEL: 4010/2439
PIXEL: 4262/ 79
PIXEL: 4849/2492
PIXEL: 4864/2183
PIXEL: 5848/ 982
PIXEL: 6145/4073
PIXEL: 6334/4278

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	25.Feb.2021		
Radiometric Calibration	25.Feb.2021		
Shutter Calibration	25.Feb.2021		
Electronics and Sensor Calibration	25.Feb.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.