VEXCEL IMAGING

ULTRACAM

Calibration Report

Bahia, Brasil 2013

Photo on page 1 courtesy of Hiparc Geotecnologia, Brasil

www.hiparc.com

UltraCam Lp, GSD25 cm, RGB

ULTRACAM

Geometric Calibration

Camera:	**UltraCam Falcon Prime**
Serial:	**UC-Fp-1-20519084-f100**
Panchromatic Camera:	**ck = 100.500 mm**
Multispectral Camera:	**ck = 100.500 mm**
PPA Information:	**X: 0.000**
	Y: 0.000
Calibration Date:	**Mar-10-2017**
Date of Report:	**Mar-14-2017**
Camera Revision:	**Rev03.00**
Version of Report:	**V01**

Panchromatic Camera

Large Format Panchromatic Output Image

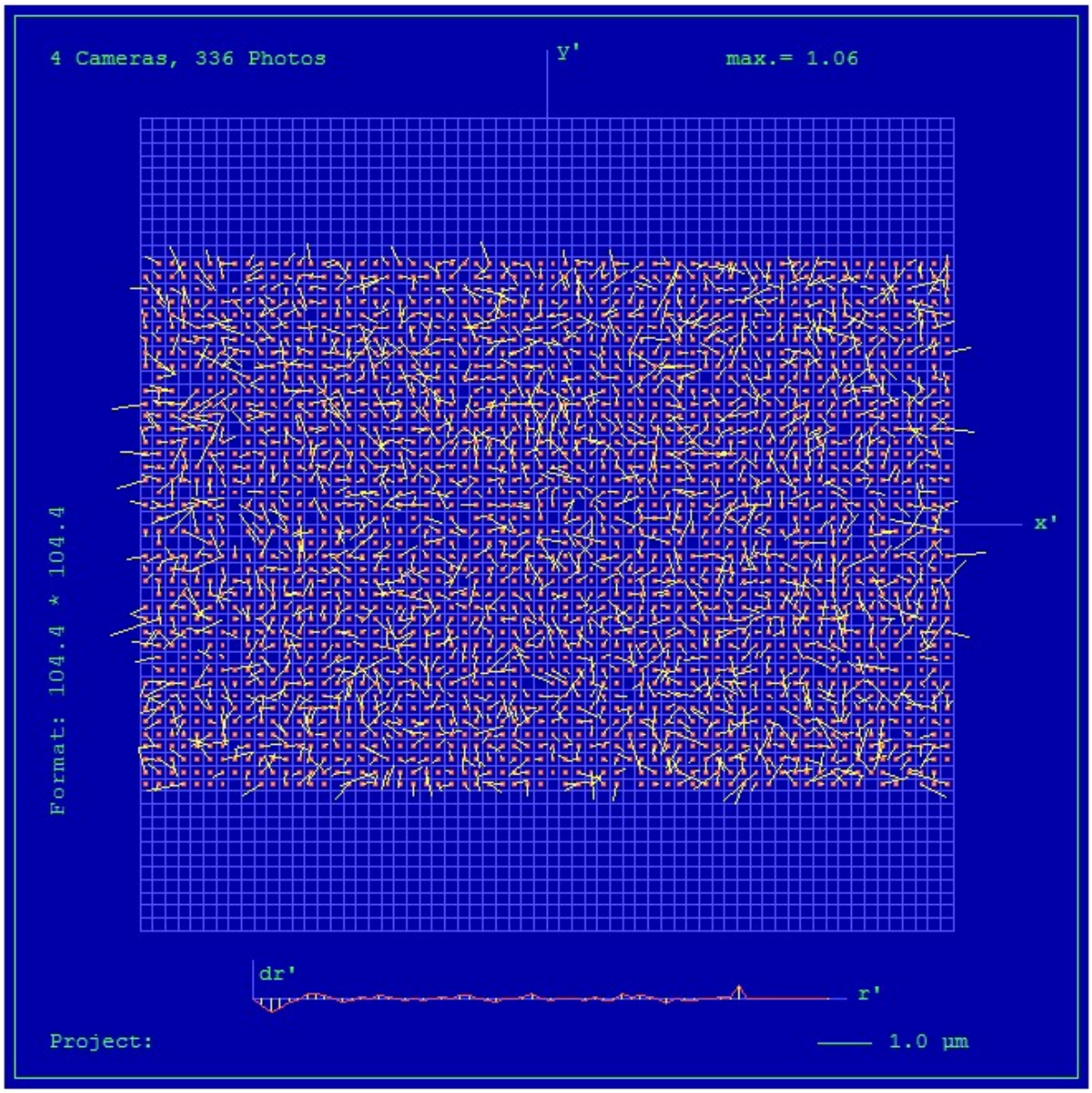
Image Format	long track cross track	67.860mm 103.860mm	11310pixel 17310pixel
Image Extent		(-33.930, -51.930)mm	(33.930, 51.930)mm
Pixel Size		6.000µm*6.000µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

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

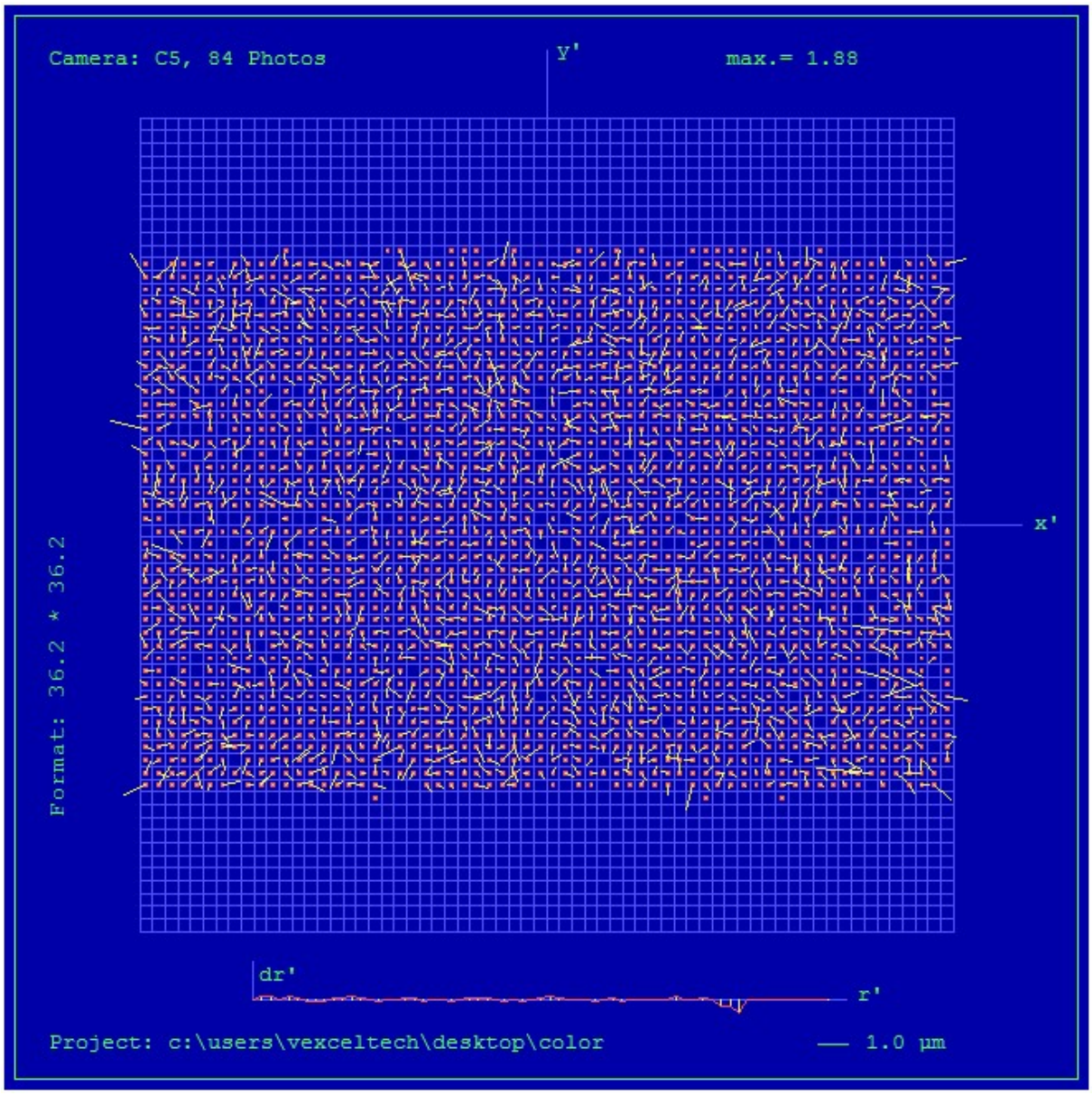
Image Format	long track cross track	67.860mm 103.860mm	3770pixel 5770pixel
Image Extent		(-33.930, -51.930)mm	(33.930, 51.930)mm
Pixel Size		18.000µm*18.000µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.49 µm**

Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.50 µm**

Explanations

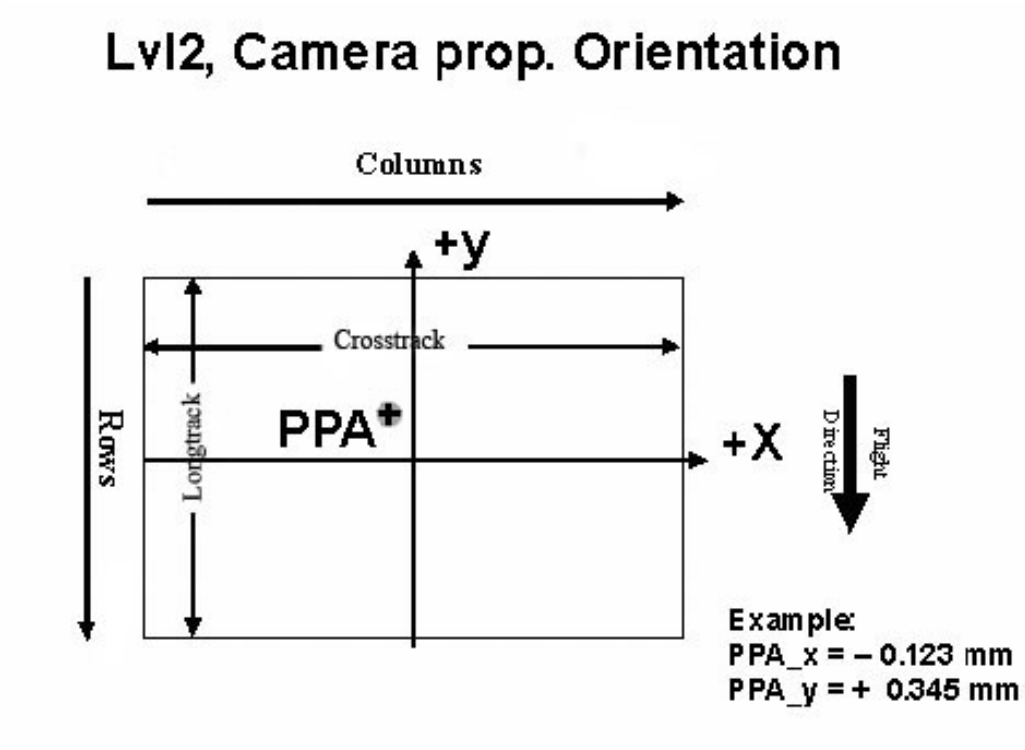
Calibration Method:

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

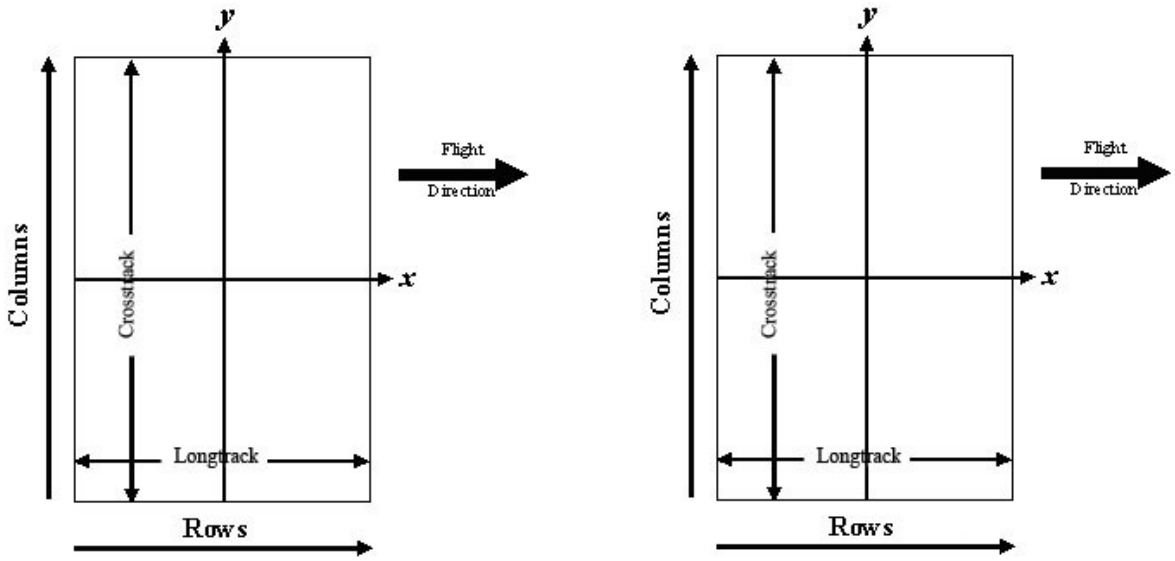
Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:



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

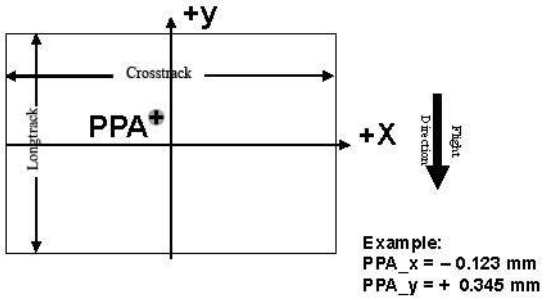
Position of Principal Point in Level 3 Image

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

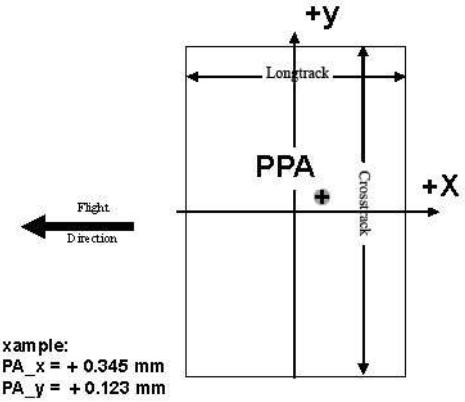
The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

Lvl3, Rotation 0 deg clockwise



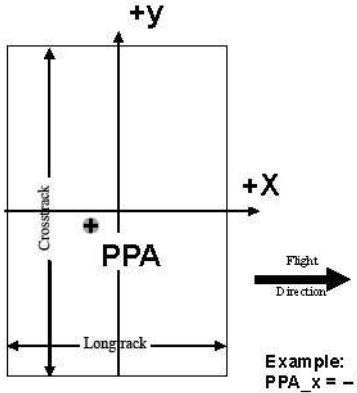
Example:
PPA_x = – 0.123 mm
PPA_y = + 0.345 mm

Lvl3, Rotation 90 deg clockwise



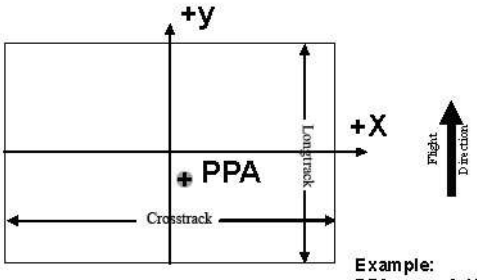
Example:
PPA_x = + 0.345 mm
PPA_y = + 0.123 mm

Lvl3, Rotation 270 deg clockwise



Example:
PPA_x = – 0.345 mm
PPA_y = – 0.123 mm

Lvl3, Rotation 180 deg clockwise



Example:
PPA_x = + 0.123 mm
PPA_y = – 0.345 mm

Lens Resolving Power

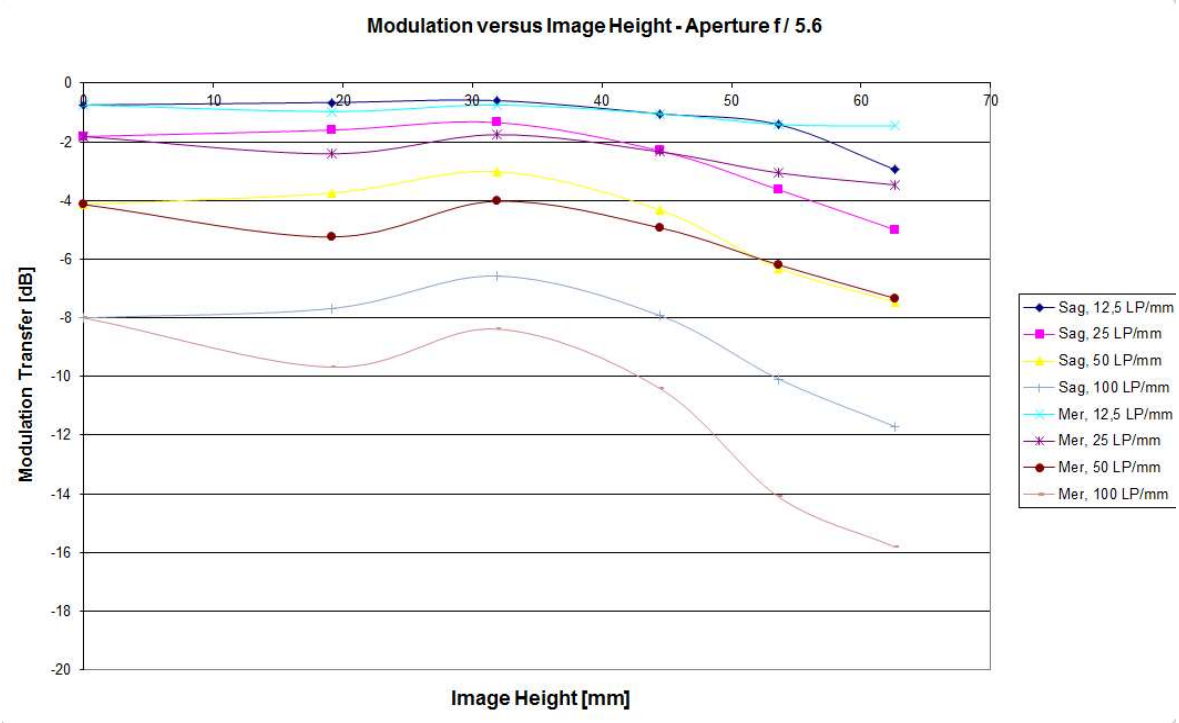
The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.
Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

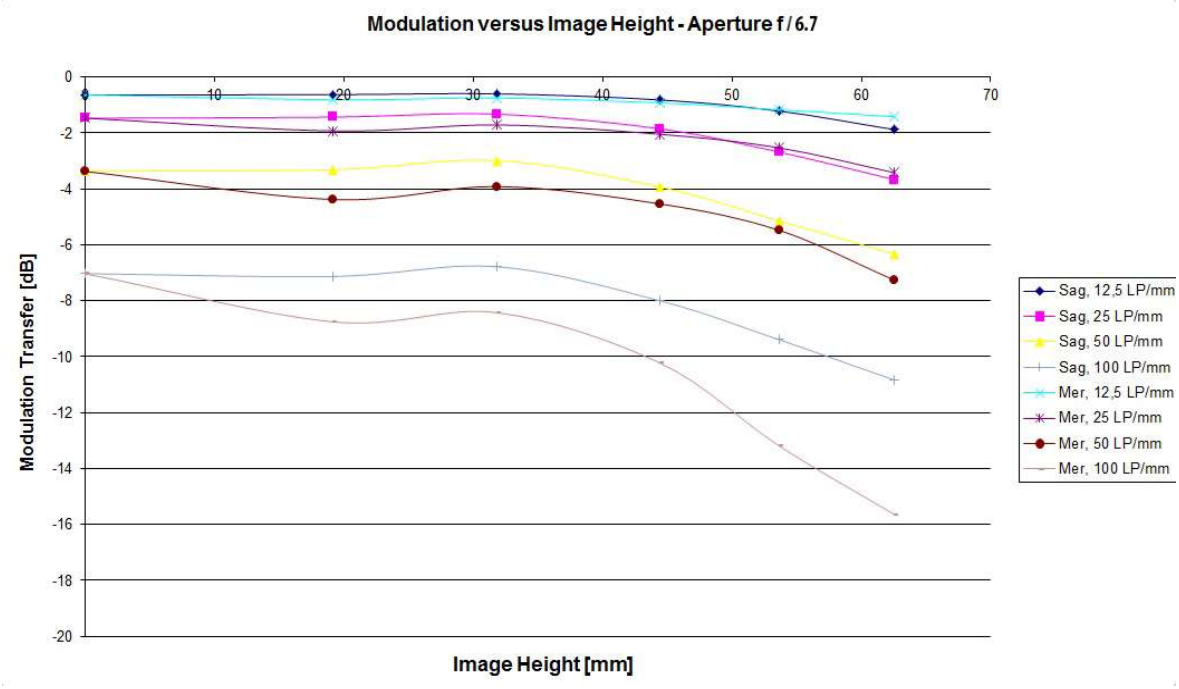
The curves are given for the meridonial (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

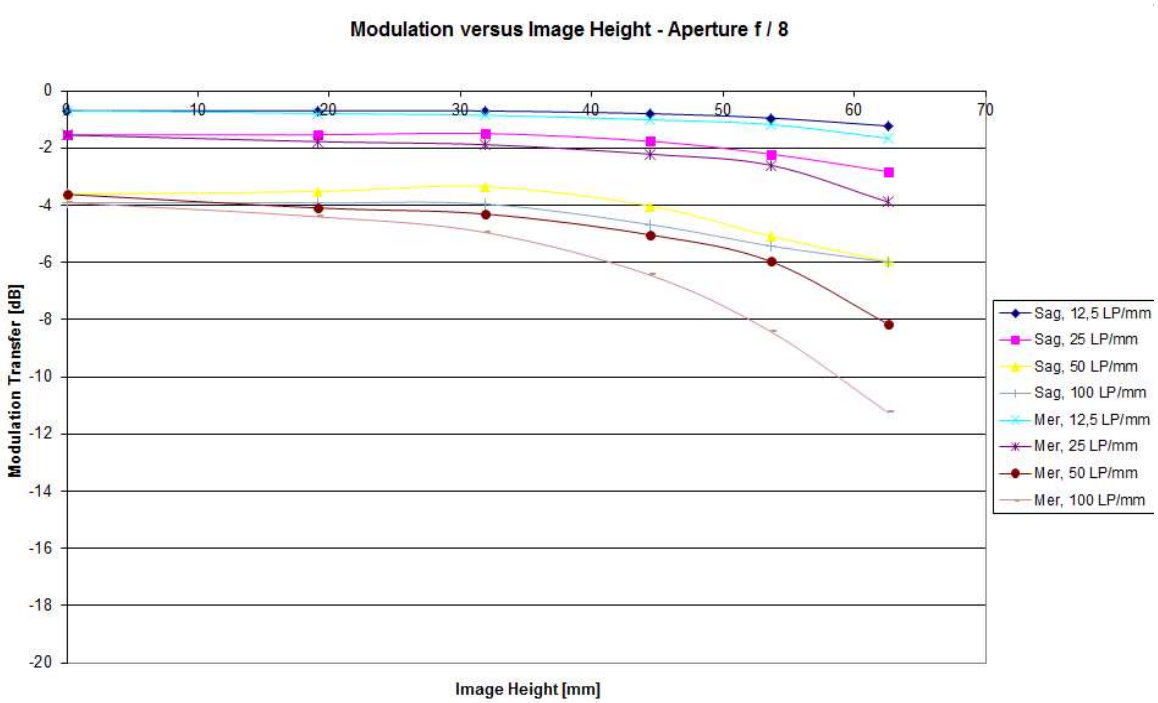
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

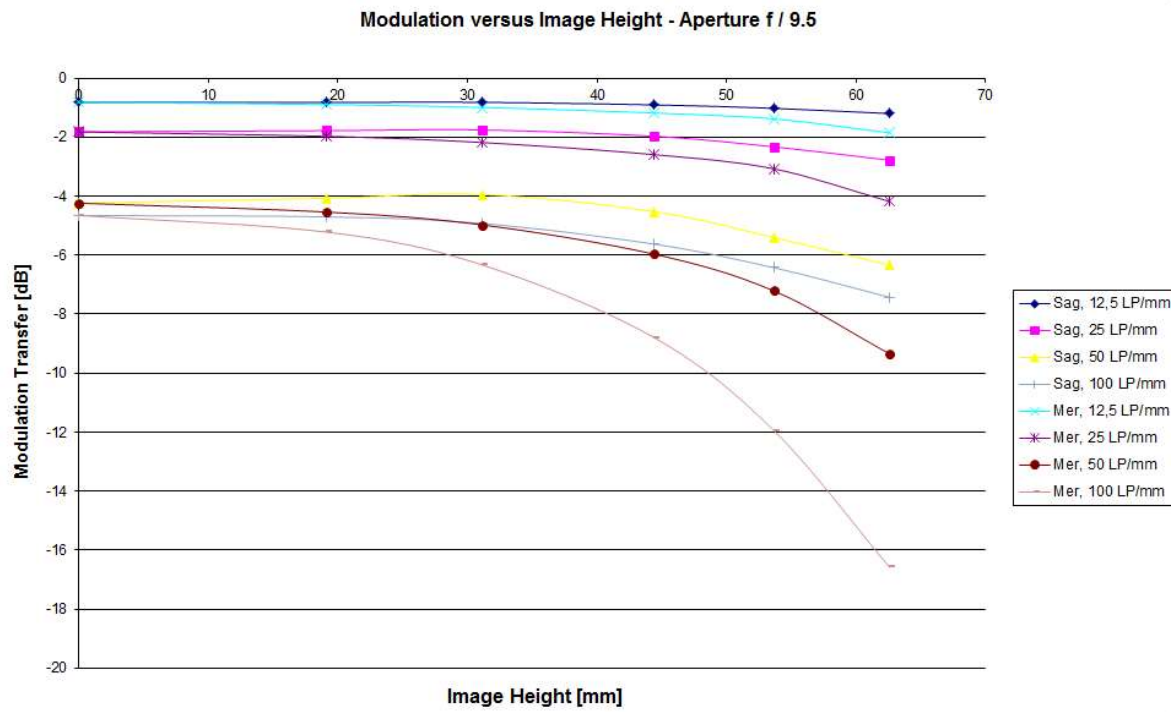
Lens types

Cone	Lens
C0	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C1	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C2	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C3	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C4 (RED)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C5 (GREEN)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C6 (BLUE)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C7 (NIR)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany

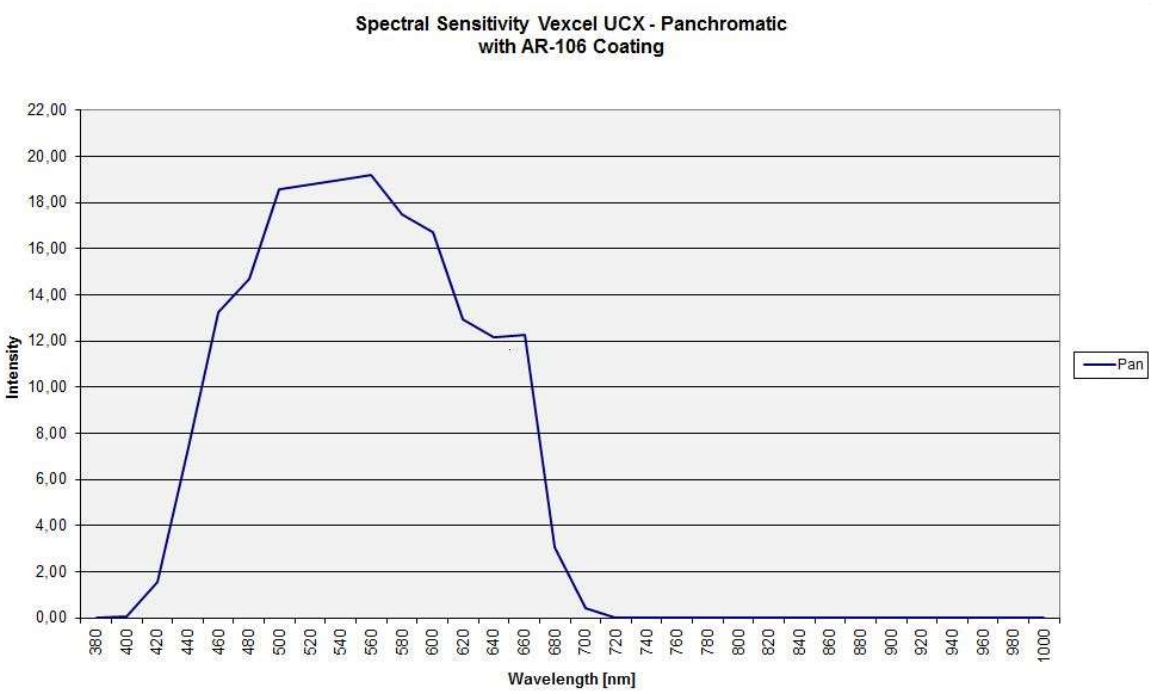

Modulation versus Image Height - Aperture f / 5.6
Modulation Transfer [dB]
Image Height [mm]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm

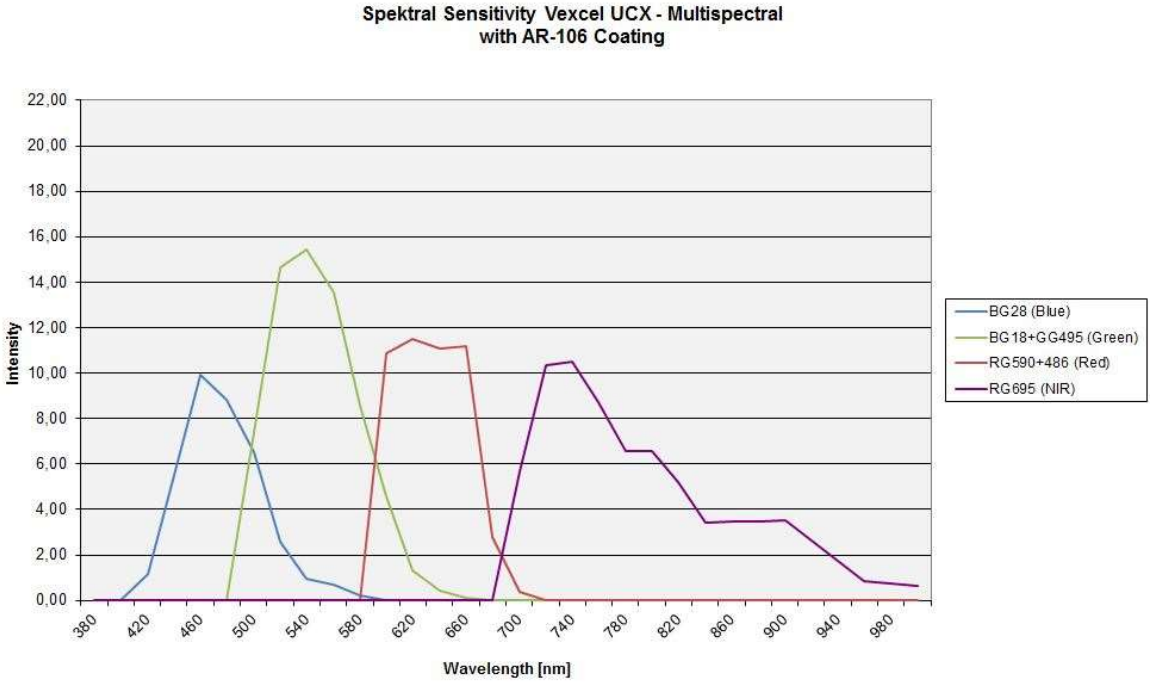

Modulation versus Image Height - Aperture f / 6.7
Modulation Transfer [dB]
Image Height [mm]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm


Modulation versus Image Height - Aperture f / 8
Modulation Transfer [dB]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Image Height [mm]
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm


Modulation versus Image Height - Aperture f / 9.5
Modulation Transfer [dB]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Image Height [mm]
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm

Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: **UltraCam Falcon Prime**
Serial: **UC-Fp-1-20519084 -f100**

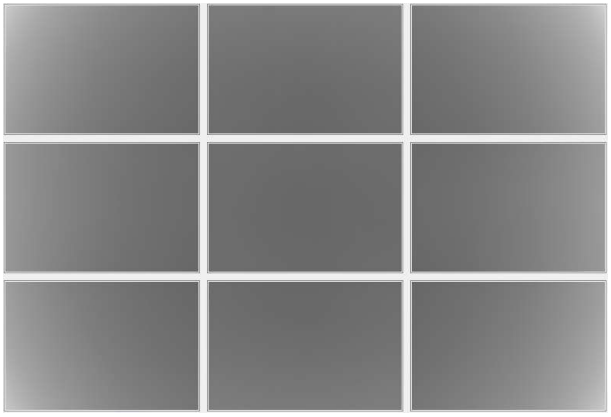
	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.6	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

Calibration Date: **Mar-10-2017**
Date of Report: **Mar-14-2017**
Camera Revision: **Rev03.00**
Version of Report: **V01**

Calibration of Vignetting for working Aperture F6.7

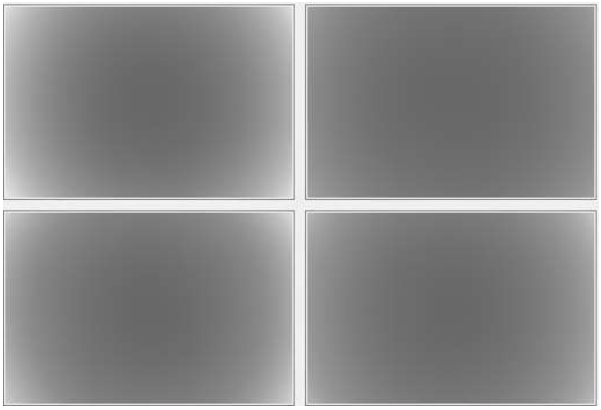
	PAN	R, G, NIR	B
Aperture	F6.7	F5.6	F4.8

Graphical Overview of Pan Sensors:



00_00	01_00	00_01
02_00	03_00	02_01
00_02	01_01	00_03

Graphical Overview of Multispectral Sensors:



04_00 (RED)	06_00 (BLUE)
05_00 (GREEN)	07_00 (NIR)

Dead Pixel Report:

Sensor number		
Anomaly type	X-Coordinate	Y-Coordinate

C00-00

PIXEL: 811/3399
PIXEL: 1698/3165
PIXEL: 1951/ 794
PIXEL: 3611/1860
PIXEL: 3732/3098
PIXEL: 3930/1031
PIXEL: 4141/1440
PIXEL: 4769/3177
PIXEL: 5232/1354
PIXEL: 5937/2474

C00-01

PIXEL: 75/3509
PIXEL: 224/ 655
PIXEL: 344/3032
PIXEL: 394/3040
PIXEL: 691/ 626
PIXEL: 768/1924
PIXEL: 1393/3975
PIXEL: 1567/2498
PIXEL: 1789/3413
PIXEL: 1819/3938
PIXEL: 2466/2730
PIXEL: 3072/1665
PIXEL: 3084/ 149
PIXEL: 3278/3114
PIXEL: 3496/3504
PIXEL: 3597/2362
PIXEL: 3962/ 634
PIXEL: 4246/3305
PIXEL: 4699/1706
PIXEL: 4891/2287
PIXEL: 5127/1115
PIXEL: 5547/2251
PIXEL: 5598/ 424
PIXEL: 5922/2565
PIXEL: 5875/3858

C00-02

PIXEL: 270/ 964

PIXEL: 384/1450
PIXEL: 399/1475
PIXEL: 833/ 697
PIXEL: 1116/2159
PIXEL: 1228/3277
PIXEL: 1308/2064
PIXEL: 1596/ 473
PIXEL: 2371/3470
PIXEL: 2407/1271
PIXEL: 2803/2940
PIXEL: 3202/3782
PIXEL: 5412/1716
PIXEL: 5530/ 928
PIXEL: 1768/3945

C00-03

PIXEL: 120/ 630
PIXEL: 568/2579
PIXEL: 703/ 382
PIXEL: 1127/2579
PIXEL: 2441/ 663
PIXEL: 3345/ 232
PIXEL: 3787/ 288
PIXEL: 4403/ 637
PIXEL: 4617/1234
PIXEL: 5437/2885
PIXEL: 5808/1693
PIXEL: 254/3798
PIXEL: 440/ 288
PIXEL: 443/3956
PIXEL: 559/3745
PIXEL: 604/3700
PIXEL: 846/3639
PIXEL: 1309/3919
PIXEL: 4264/3703
PIXEL: 5460/1324
PIXEL: 4968/3874
PIXEL: 251/3960

C01-00

PIXEL: 266/1347
PIXEL: 410/ 281
PIXEL: 1062/ 104
PIXEL: 1117/1135
PIXEL: 1589/ 913
PIXEL: 2063/2144
PIXEL: 2533/1627
PIXEL: 2674/2684
PIXEL: 3000/3731
PIXEL: 3087/ 135

PIXEL: 3183/3399
PIXEL: 3812/1793
PIXEL: 4326/ 40
PIXEL: 4383/1238
PIXEL: 4404/2354
PIXEL: 4472/3555
PIXEL: 4693/1725
PIXEL: 5150/ 373
PIXEL: 5225/ 895
PIXEL: 5448/2546
PIXEL: 5525/1065
PIXEL: 5819/3855
PIXEL: 5861/3504
PIXEL: 345/3992
PIXEL: 182/3938

C01-01

PIXEL: 190/1155
PIXEL: 450/ 713
PIXEL: 590/1200
PIXEL: 677/3066
PIXEL: 3371/2195
PIXEL: 3708/ 447
PIXEL: 3993/ 834
PIXEL: 4234/ 954
PIXEL: 5363/ 663
PIXEL: 5439/3426

C02-00

PIXEL: 160/2713
PIXEL: 411/ 975
PIXEL: 707/3483
PIXEL: 972/2213
PIXEL: 1240/3899
PIXEL: 1755/1263
PIXEL: 1955/2416
PIXEL: 2306/3779
PIXEL: 2470/2235
PIXEL: 2587/3970
PIXEL: 4025/1291
PIXEL: 4075/2419
PIXEL: 4141/2810
PIXEL: 4155/3062
PIXEL: 4285/1877
PIXEL: 4512/1915
PIXEL: 4824/2277
PIXEL: 5089/3330
PIXEL: 5354/1830
PIXEL: 5489/ 271
PIXEL: 5509/1097

PIXEL: 5779/ 659
PIXEL: 5783/ 322
PIXEL: 5785/ 207
PIXEL: 5969/3651
PIXEL: 4002/ 369

C02-01

PIXEL: 95/ 369
PIXEL: 157/ 127
PIXEL: 189/1735
PIXEL: 191/3444
PIXEL: 1116/1760
PIXEL: 1317/3959
PIXEL: 1420/3336
PIXEL: 1718/2011
PIXEL: 1779/3739
PIXEL: 3151/1045
PIXEL: 3153/ 118
PIXEL: 5395/ 322
PIXEL: 5993/1180
PIXEL: 2294/1125
PIXEL: 3092/2944
PIXEL: 3652/ 410
PIXEL: 4872/2840

C03-00

PIXEL: 735/2116
PIXEL: 820/1257
PIXEL: 1665/2735
PIXEL: 2901/1146
PIXEL: 3138/ 552
PIXEL: 3471/3133
PIXEL: 3513/3168
PIXEL: 3588/ 533
PIXEL: 4606/1977
PIXEL: 4841/1588
PIXEL: 4850/2982
PIXEL: 5222/ 471
PIXEL: 5437/ 670
PIXEL: 5959/1688
PIXEL: 542/1798
PIXEL: 542/1799
PIXEL: 894/ 207
PIXEL: 895/ 207
PIXEL: 3166/1259

C04-00

PIXEL: 1123/3756
PIXEL: 1126/3755
PIXEL: 2303/3882

PIXEL: 2355/3418
PIXEL: 2497/2984
PIXEL: 5972/1054
PIXEL: 853/ 33
PIXEL: 4856/1050
PIXEL: 4856/1051
PIXEL: 4857/1050
PIXEL: 4857/1051
PIXEL: 4858/1050
PIXEL: 5043/2852
PIXEL: 5044/2852
PIXEL: 5044/2853

C05-00

PIXEL: 218/ 742
PIXEL: 248/3728
PIXEL: 2002/3388
PIXEL: 2115/1373
PIXEL: 2259/2731
PIXEL: 2526/2575
PIXEL: 2713/2903
PIXEL: 3702/ 673
PIXEL: 4757/ 128
PIXEL: 5320/1148
PIXEL: 5669/2751

C06-00

PIXEL: 220/3080
PIXEL: 322/ 182
PIXEL: 569/ 69
PIXEL: 1046/ 892
PIXEL: 1450/3189
PIXEL: 1663/1032
PIXEL: 2017/3236
PIXEL: 2035/1681
PIXEL: 2228/3078
PIXEL: 3095/1266
PIXEL: 3615/2287
PIXEL: 3920/1791
PIXEL: 4030/ 884
PIXEL: 4346/3312
PIXEL: 5363/ 298
PIXEL: 5726/ 450
PIXEL: 5772/ 159
PIXEL: 4941/2523

C07-00

PIXEL: 866/ 155
PIXEL: 1688/1457
PIXEL: 3092/ 952

PIXEL: 3120/2311
PIXEL: 4819/ 754
PIXEL: 5012/2093
PIXEL: 2667/3749

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).

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 Falcon Prime**
Serial:	**UC-Fp-1-20519084-f100**
Panchromatic Camera:	**4 * Prontor Magnetic 0** **Prontor-Werk Alfred Gauthier GmbH, Germany**
Multispectral Camera:	**4 * Prontor Magnetic 0** **Prontor-Werk Alfred Gauthier GmbH, Germany**
Calibration Date:	**Mar-10-2017**
Calibration Date:	**Mar-14-2017**
Camera Revision:	**Rev03.00**
Version of Report:	**V01**

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.

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 13 49 35	10.16	10.68	11.20	11.74	11.83	12.13	12.29	13.00	+/- 0.2
C1 (Pan)	12 13 00 84	10.42	10.77	11.33	11.74	12.11	12.40	12.71	13.06	+/- 0.2
C2 (Pan)	12 13 00 79	10.70	11.12	11.77	12.15	12.49	12.68	12.87	13.29	+/- 0.2
C3 (Pan)	12 13 00 86	9.27	9.78	10.29	10.66	10.96	11.13	11.32	11.72	+/- 0.2
C4 (Red)	12 13 00 96	11.45	11.73	11.99	12.22	12.40	12.52	12.60	12.96	+/- 0.2
C5 (Green)	12 13 00 91	10.62	10.91	11.16	11.47	11.61	11.76	11.91	12.14	+/- 0.2
C6 (Blue)	12 13 00 94	10.21	10.21	10.55	10.85	11.10	11.35	11.51	11.78	+/- 0.2
C7 (NIR)	12 13 00 93	10.68	10.97	11.21	11.38	11.51	11.70	11.88	11.97	+/- 0.2

ULTRACAM

Electronics and Sensor Calibration

Camera:	**UltraCam Falcon Prime**
Serial:	**UC-Fp-1-20519084-f100**
Panchromatic Camera:	**9 * FTF6040-M Area CCD Sensor by DALSA**
Multispectral Camera:	**4 * FTF6040-M Area CCD Sensor by DALSA**
Calibration Date:	**Mar-10-2017**
Calibration Date:	**Mar-14-2017**
Camera Revision:	**Rev03.00**
Version of Report:	**V01**

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.

Cone_Sensor	Sensor Type	Sensor Serial Number	VNS Voltage [V]
00_00	FTF6040-M	14 3859/056	22.50
00_01	FTF6040-M	14 3859/053	22.80
00_02	FTF6040-M	14 3859/046	22.60
00_03	FTF6040-M	14 3859/051	22.60
01_00	FTF6040-M	14 3859/043	22.60
01_01	FTF6040-M	14 3859/042	22.60
02_00	FTF6040-M	14 3859/006	22.60
02_01	FTF6040-M	14 3859/014	22.50
03_00	FTF6040-M	14 4982/023	22.50
04_00 (red)	FTF6040-M	14 3859/058	22.50
05_00 (green)	FTF6040-M	14 892/058	22.30
06_00 (blue)	FTF6040-M	14 2892/061	22.30
07_00 (NIR)	FTF6040-M	14 2892/057	22.10

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.

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]
00_00	FTF6040-M	14 3859/056	14010
00_01	FTF6040-M	14 3859/053	13480
00_02	FTF6040-M	14 3859/046	13780
00_03	FTF6040-M	14 3859/051	13410
01_00	FTF6040-M	14 3859/043	13980
01_01	FTF6040-M	14 3859/042	13860
02_00	FTF6040-M	14 3859/006	13990
02_01	FTF6040-M	14 3859/014	13390
03_00	FTF6040-M	14 4982/023	13260
04_00 (red)	FTF6040-M	14 3859/058	14050
05_00 (green)	FTF6040-M	14 892/058	13630
06_00 (blue)	FTF6040-M	14 2892/061	13400
07_00 (NIR)	FTF6040-M	14 2892/057	13800

ULTRACAM

Summary

Camera:	**UltraCam Falcon Prime**
Serial:	**UC-Fp-1-20519084-f100**
Calibration Date:	**Mar-10-2017**
Calibration Date:	**Mar-14-2017**
Camera Revision:	**Rev03.00**
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.

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