Camera Calibration Certificate
No: DMC II 250 – 030

For

Aero Photo Europe Investigation

Aerodrome de Moulins
Montbeugny
Yzeure Cedex 03401

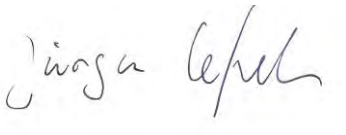
France

Camera:	DMC II 250
Manufacturer:	Z/I Imaging GmbH, D-73431 Aalen, Germany
Reference:	PAN
Serial Number:	00120554 (PAN Head)
Date of Calibration:	22. July 2011
Date of Report:	09. October 2012
Number of Pages:	

Calibration performed at: Carl Zeiss Jena, Carl-Zeiss-Promenade 10, 07745 Jena, Germany.

This camera system is certified by Z/I Imaging and is fully functional within its specifications and tolerances.

Date of Calibration: July 2011



Jürgen Hefele, Senior Software Developer

Date of Certification: October 2012

Dipl.Ing. Christian Müller, Technical Consultant

Camera Serial Numbers and Burn-In flight

Camera Head	Serial Number	Calib. Date
PAN (reference)	00120554	22.07.2011
MS1 (NIR)	00121916	22.08.2012
MS2 (Blue)	00122326	19.09.2012
MS3 (Red)	00121921	04.10.2012
MS4 (Green)	00122323	20.09.2012

Burn-In flight performed: 08. October 2012

Test block configuration

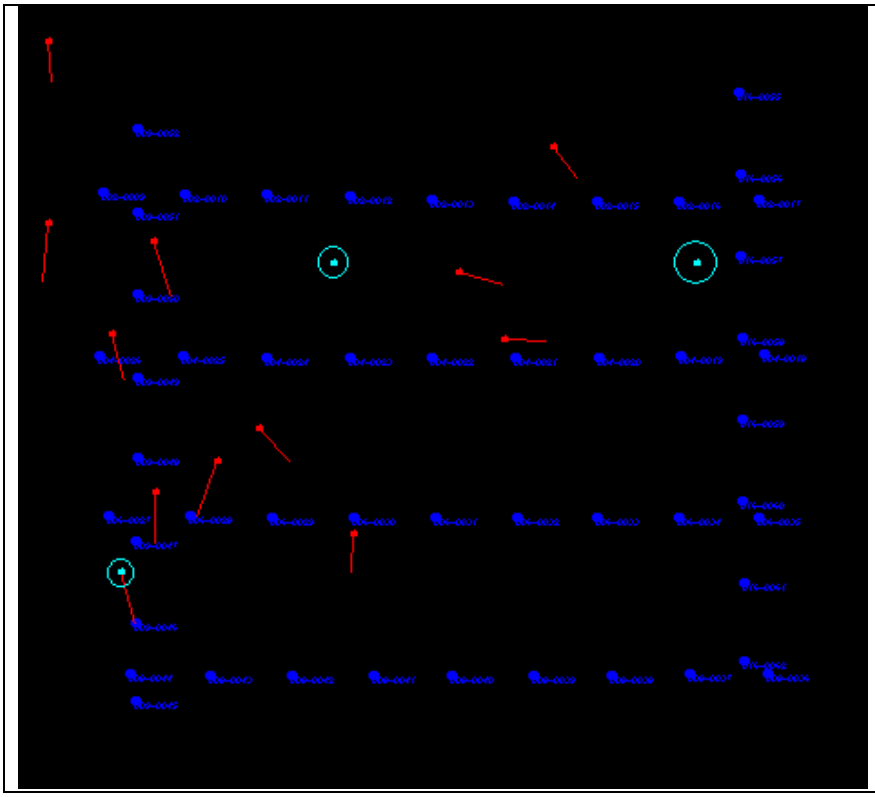
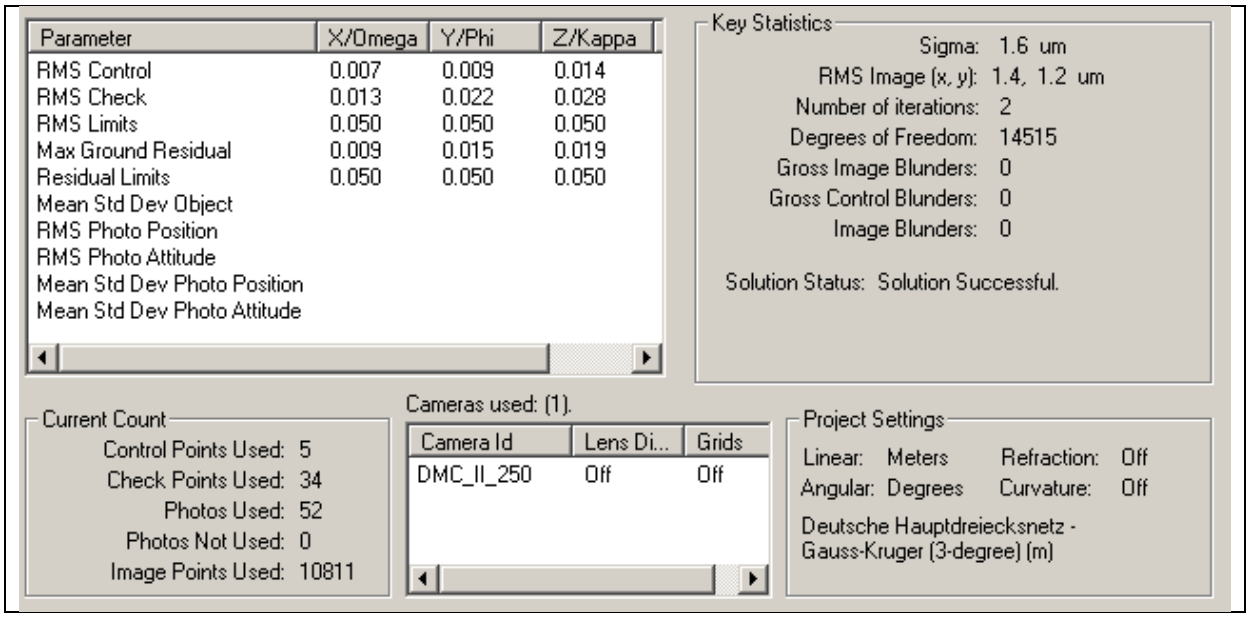


Photo Scale	1:8928.6
Flying Height [m]	1000 AGL
Flying Altitude [m]	1450 AMSL
Run-Spacing [m]	419.2
Base-Length [m]	210.2
Number of Exposures	52
Side-lap [%]	50
End-lap [%]	70
Terrain Height [m]	450
Number of strips	6
Photos in one strip	2 x 8 N-S 4 x 9 W-E
Photos Used	52
Control Points Used	5
Check Points Used	34
GSD [cm]	5

Aerial triangulation statistic results:



Parameter	X/Omega	Y/Phi	Z/Kappa
RMS Control	0.007	0.009	0.014
RMS Check	0.013	0.022	0.028
RMS Limits	0.050	0.050	0.050
Max Ground Residual	0.009	0.015	0.019
Residual Limits	0.050	0.050	0.050
Mean Std Dev Object			
RMS Photo Position			
RMS Photo Attitude			
Mean Std Dev Photo Position			
Mean Std Dev Photo Attitude			

The results of the aerial triangulation were generated with ImageStation Automatic Triangulation (ISAT), Version 6.2, from Intergraph Z/I Imaging. The maximum RMS in check points is ≤ 0.5 GSD in x,y and ≤ 0.7 GSD in z.

Aerial Triangulation performed by Dipl. Ing. C. Müller — Date: 09.10.2012

Geometric Calibration

The output image geometry is based on the Pan Camera head (reference head = master camera). All other camera heads are registered and aligned to this head. Aerial triangulation checks overall system performance based on.

Output image

Reference Camera	PAN	
Serial Number	00120554	
Number of rows/columns [pixels]	16768 x 14016	
Pixel Size [μm]	5.600 x 5.600	
Image Size [mm]	93.9008 x 78.4896	
Focal Length [mm]	112.0099 mm	+ /- 0.002 mm
Principal Point [mm]	X= -0.0020 mm Y= -0.0100 mm	+ /- 0.002 mm

The geometric calibration takes place at Carl Zeiss Jena on a certified test stand. More than 800 “light targets”, projected on 28 lines that are distributed diagonally on the focal plane, are automatically measured by finding their centers light with a precision of less than 1/10 of a pixel. The light targets are projected from the “infinity” by using a collimator (Figure 1).

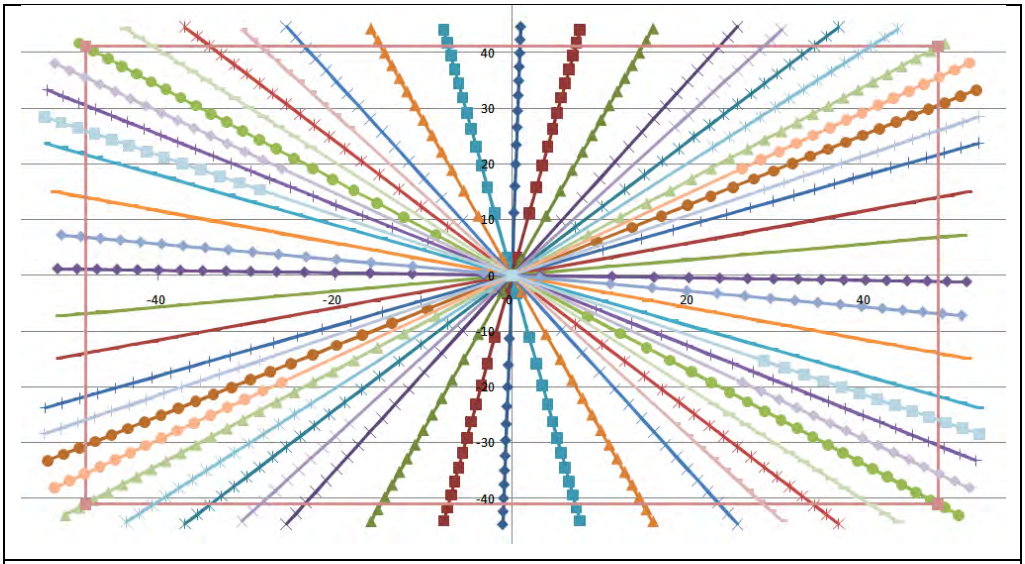


Figure 1: Light Target Pattern by Collimator

Geometric Calibration

Image Residuals

Figure 2 shows the image residuals, split in radial and tangential directions after the calibration adjustment. The maximum residuals are less than or equal to 1.5 microns and the RMSE values are below 0.5 microns.

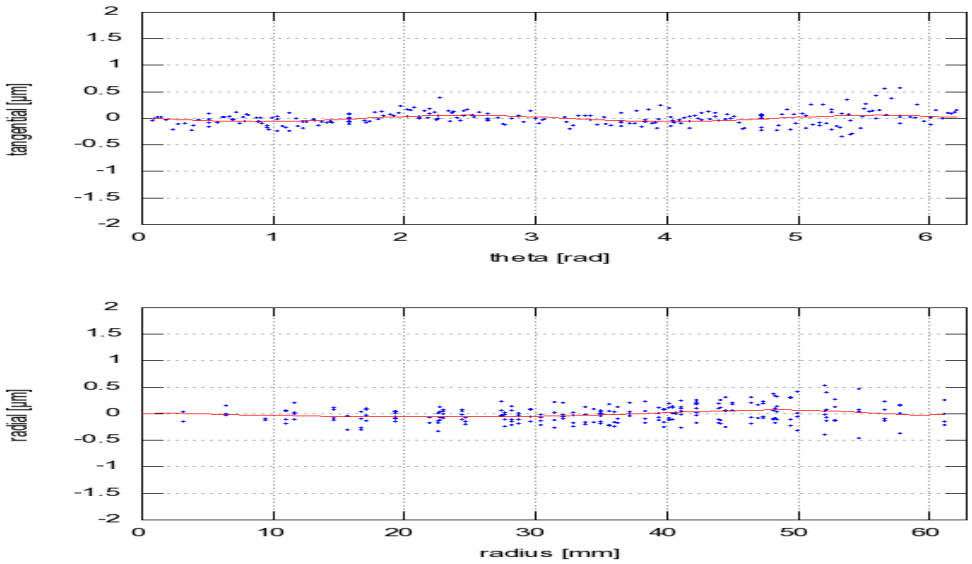


Figure 2: Tangential/Radial Distortion Residuals

Figure 3 shows the 2-D plot of the image residuals in mm.

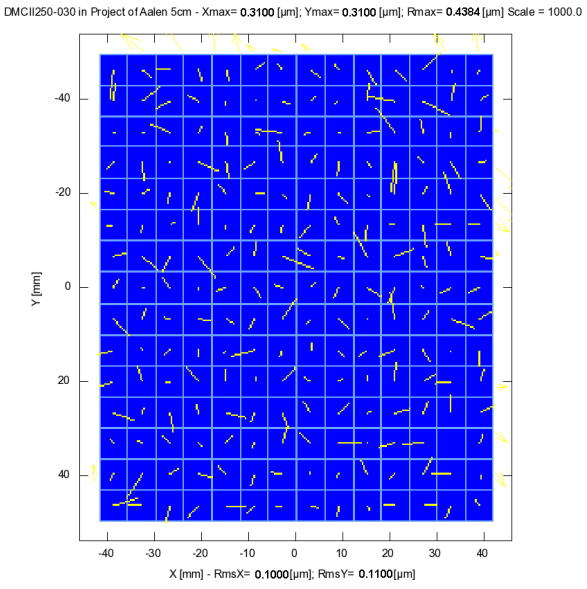


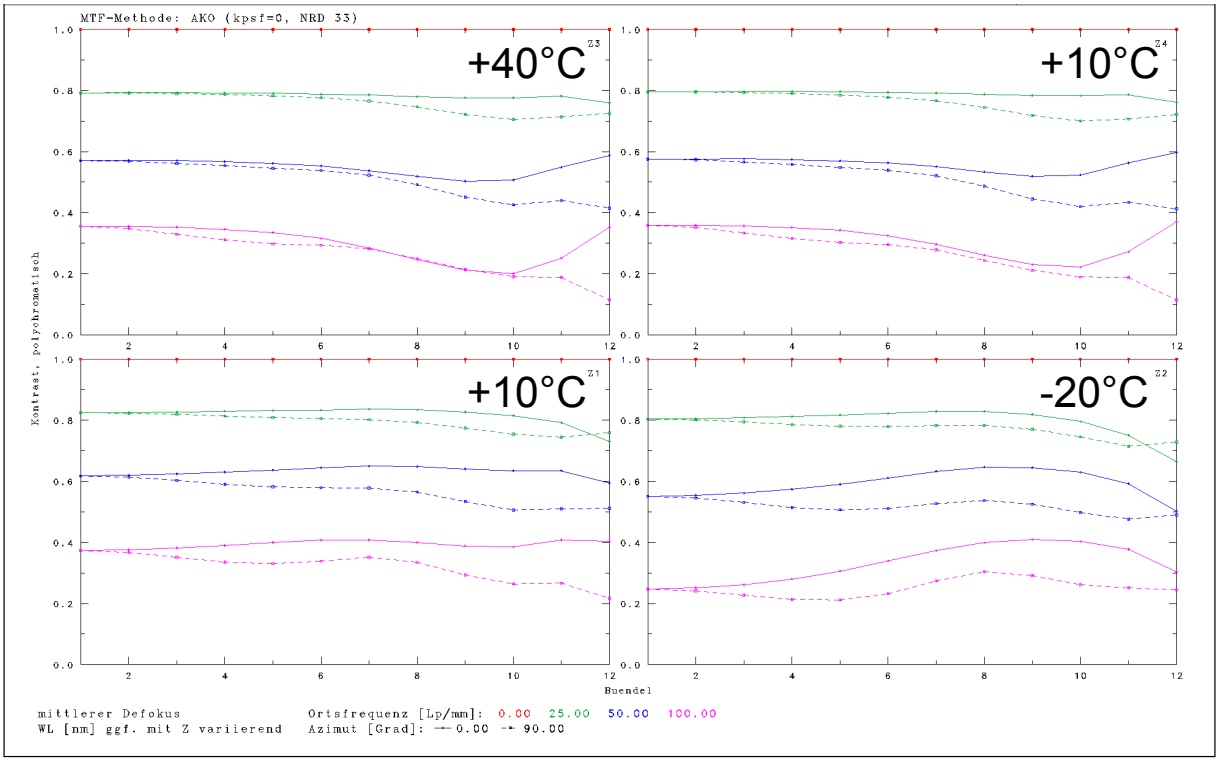
Figure 3: 2-D Image Residuals.

RMS < 0.11 um (maximum 0.44 microns)

Optical System

Modulation Transfer Function, MTF of PAN Camera (Reference)

DMC II PAN – MTF Polychromatic F/5.6 ; 112 mm – Temperature Stability

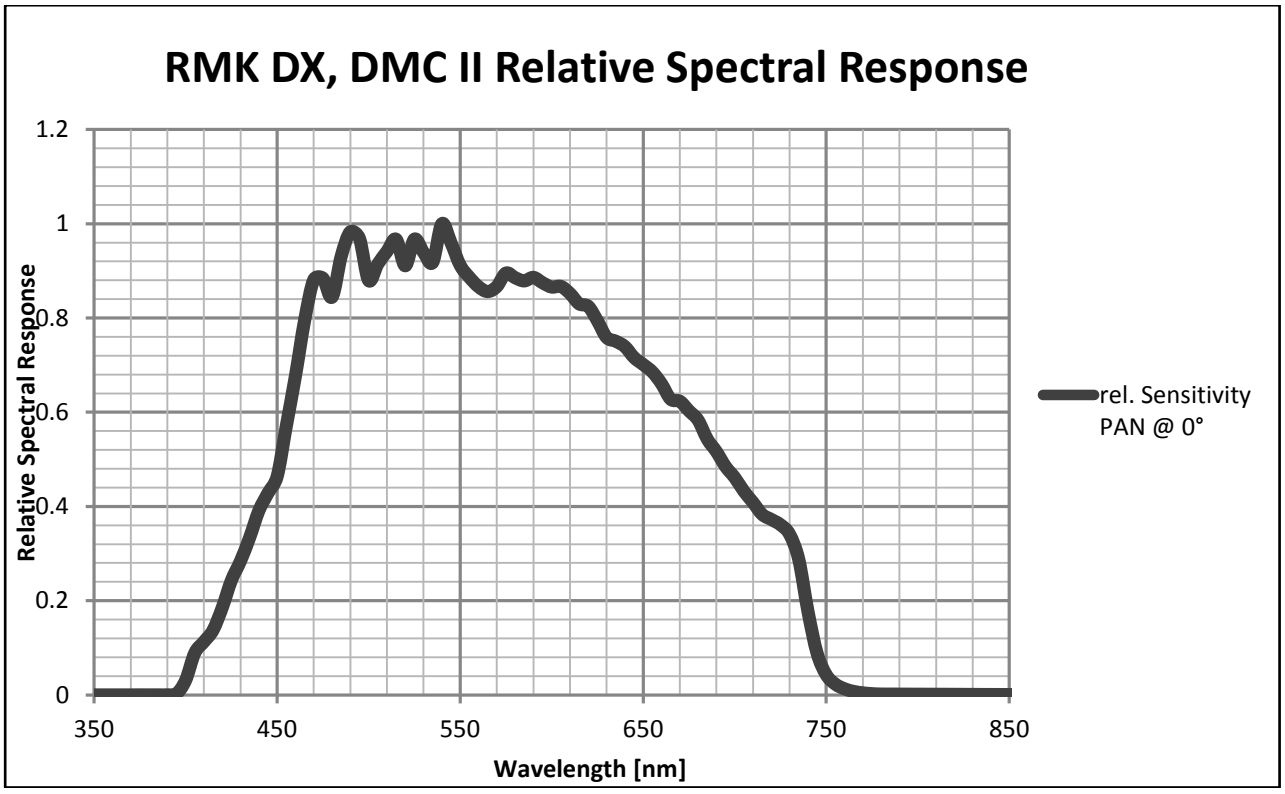


The MTF measurement is camera type specific and shows variation of the MTF within the specified temperature range.

This is a camera type specific measurement.

Radiometric Calibration

Sensitivity of PAN camera (Reference)



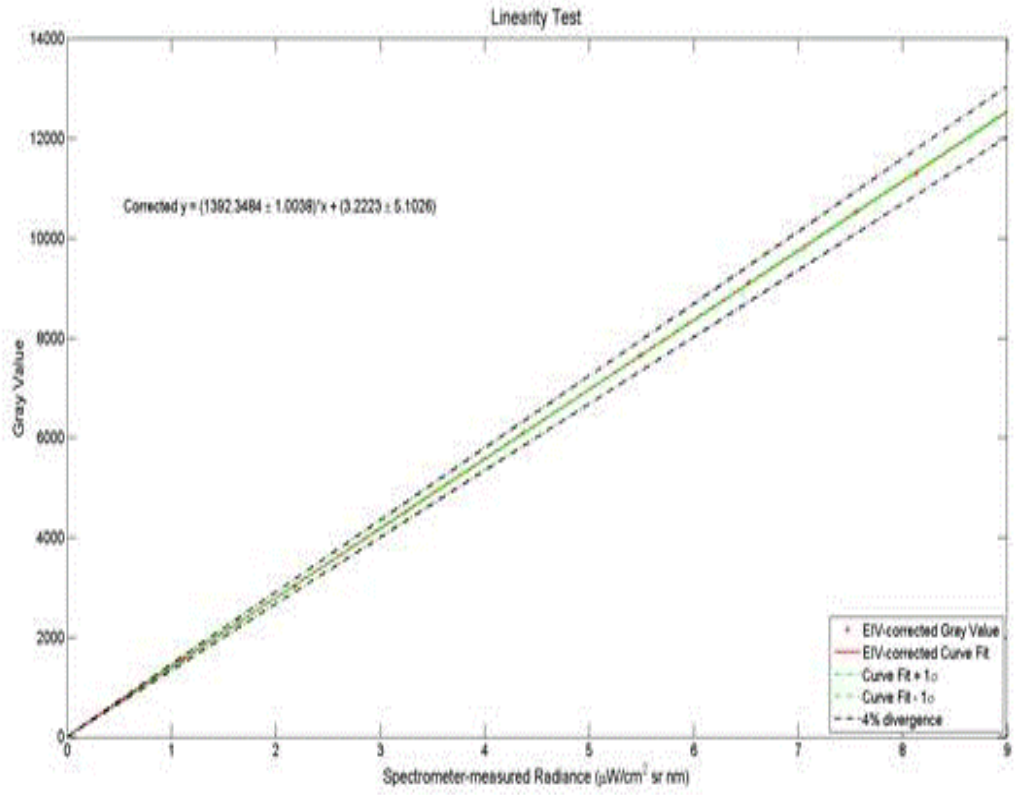
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 250 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera type specific calibration.

This is a camera type specific measurement.

Radiometric Calibration

Sensor Linearity (Reference)

The sensor linearity is measured in the Lab with calibrated spectrometer. This is a camera type specific calibration.
Below figure shows the linearity of the raw sensor and after flat fielding:



Senor Linearity

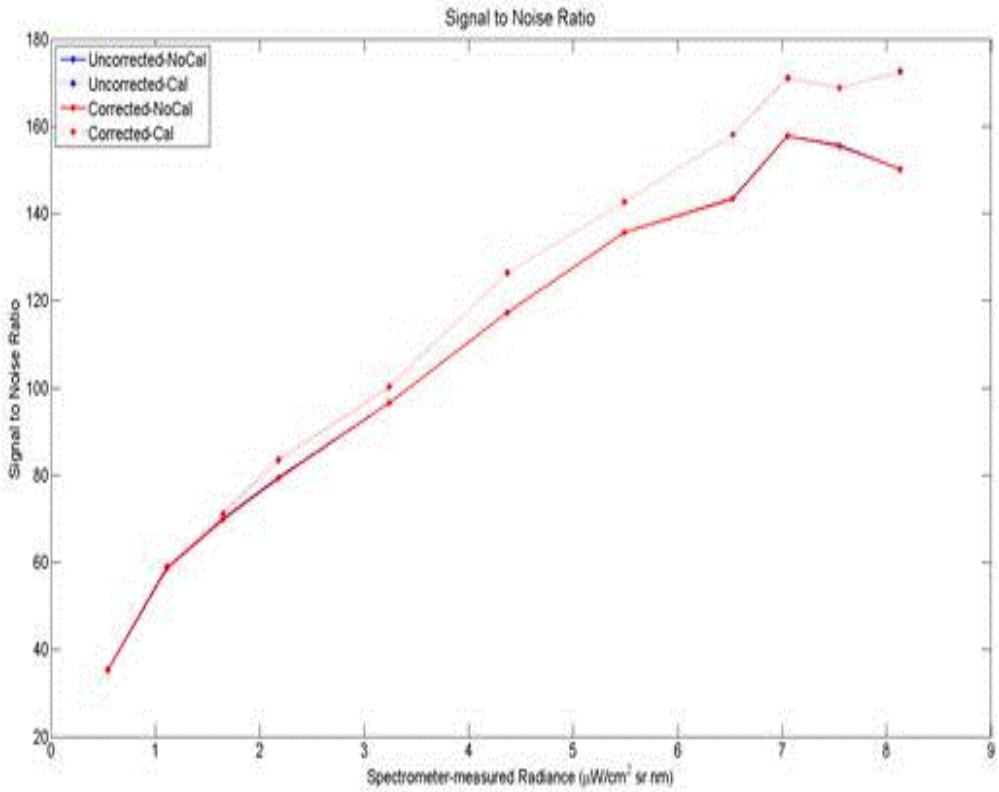
The deviation from the linearity is below 1%.

This is a camera type specific measurement.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 16 with exposure time of 16msec.



Sensor Signal to Noise Ratio

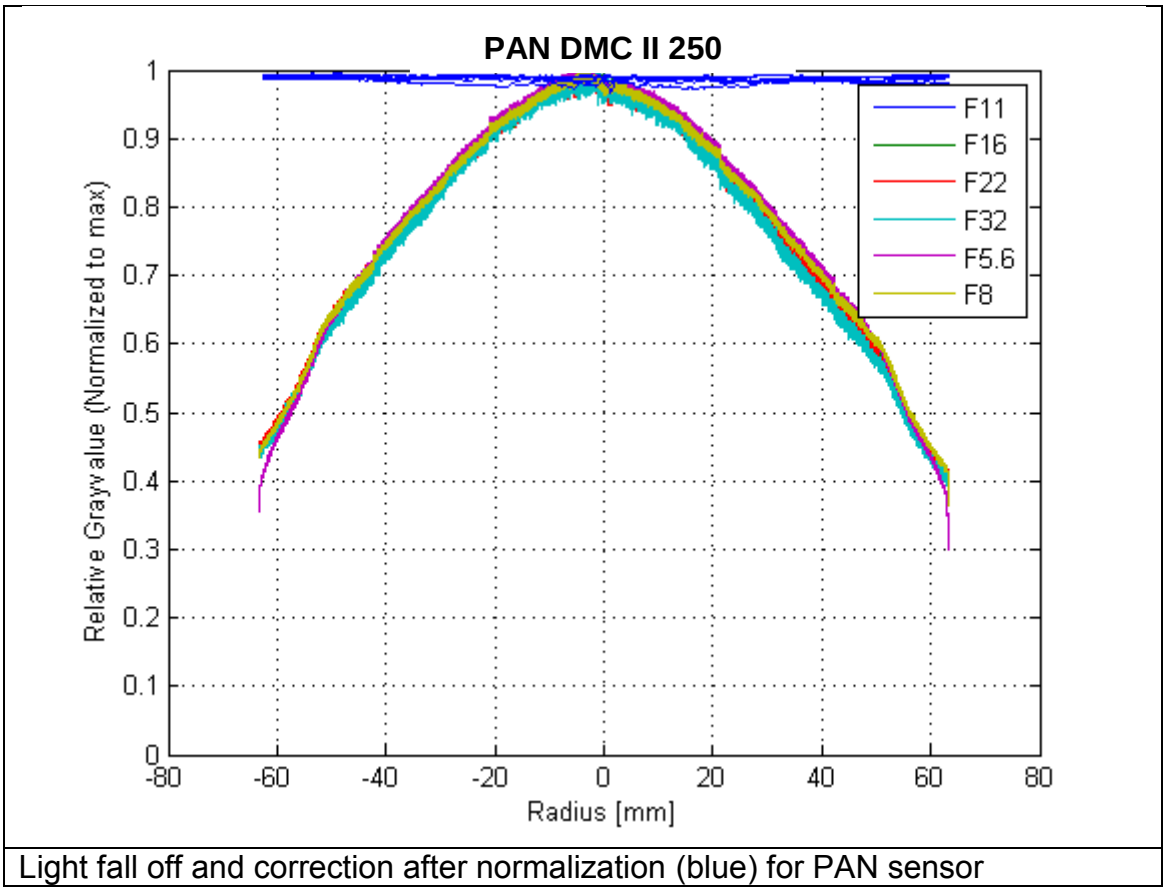
This is from a camera type specific calibration.

Radiometric Calibration

Aperture Correction (Reference)

Camera PAN (00120554)

The light fall off to the border due the influence of the optics depends on the aperture used. Therefore this calibration approach delivers individual calibration images for each aperture (Full F-Stop). In general the light fall off is a function of the image height (radial distance from center). The figure below shows the profile from the upper left corner to the lower right corner of the calibration images. Compensation of the light fall off can be measured after normalization and is within ± 2.5% of the dynamic range.



Light fall off and correction after normalization (blue) for PAN sensor

This is from a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Camera PAN (00120554)

Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix “Defect Pixel Recognition”.

Revision of calibration:	65537	
CCDRevision:	1	
Date Number:		1348652987
Date:		120926
Number of defect pixels:	128	
Number of defect clusters:	0	
Number of defect columns:	0	

Nr	Row	Column
0	10805	6
1	10806	6
2	10807	6
3	10805	7
4	10806	7
5	7499	16
6	7499	17
7	7501	17
8	7500	18
9	7501	18
10	13220	441
11	8091	1240
12	8092	1240
13	8091	1241
14	8092	1241
15	6022	2336
16	12716	2881
17	12717	2881
18	12713	2882
19	12714	2882
20	14089	3515
21	14087	3516
22	14088	3516
23	14089	3516
24	14088	3517
25	14087	3518
26	14083	3519
27	14085	3519
28	14081	3520
29	14084	3520
30	14078	3521
31	14080	3521
32	14081	3521
33	14082	3521
34	14079	3522
35	14080	3522
36	2606	3715
37	2607	3715
38	2606	3716
39	2607	3716
40	2608	3716
41	2606	3717
42	2607	3717
43	11166	4282
44	11164	4283

45	11165	4283
46	11166	4283
47	3116	4315
48	5195	6294
49	5195	6295
50	1074	6874
51	1398	7555
52	11786	8223
53	4005	8609
54	4006	8609
55	4005	8610
56	4006	8610
57	6044	9176
58	6045	9176
59	6044	9177
60	6045	9177
61	1377	11438
62	1377	11439
63	1376	11441
64	14503	12613
65	13164	13436
66	5844	13574
67	5845	13574
68	5844	13575
69	5845	13575
70	5846	13575
71	5844	13576
72	5845	13576
73	5846	13576
74	5847	13576
75	5844	13577
76	5845	13577
77	5846	13577
78	5847	13577
79	5845	13578
80	5846	13578
81	5847	13578
82	283	13663
83	14524	14056
84	14525	14056
85	14524	14057
86	14525	14057
87	14524	14058
88	14525	14058
89	14526	14058
90	14527	14058
91	14524	14059
92	14525	14059
93	14526	14059
94	14527	14059
95	14528	14059
96	14525	14060
97	14526	14060
98	14527	14060
99	2644	14387
100	2645	14387
101	2643	14388
102	2644	14388
103	2645	14388
104	142	14444
105	141	14445
106	142	14445
107	143	14445
108	141	14446
109	142	14446
110	143	14446
111	3078	15482
112	3079	15482
113	3078	15483
114	3079	15483
115	5168	15695
116	5169	15695
117	13015	16499
118	13014	16500
119	13015	16500
120	2732	16622
121	2731	16623

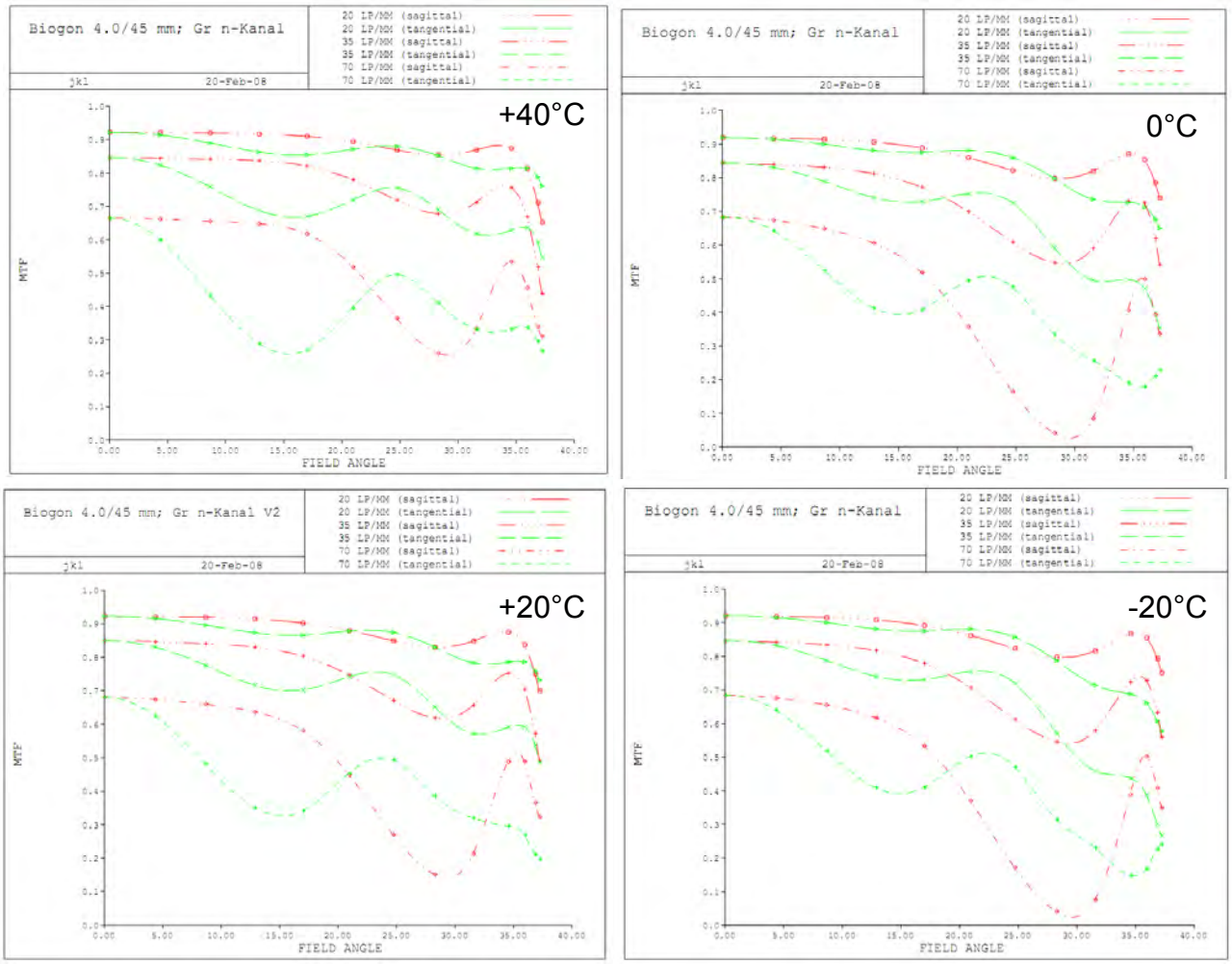
122	2729	16624
123	2730	16624
124	2728	16625
125	2727	16626
126	3137	17051
127	305	17214

Defect Column RowStart ColumnStart RowEnd ColumnEnd

Optical System

Modulation Transfer Function, MTF of Green camera

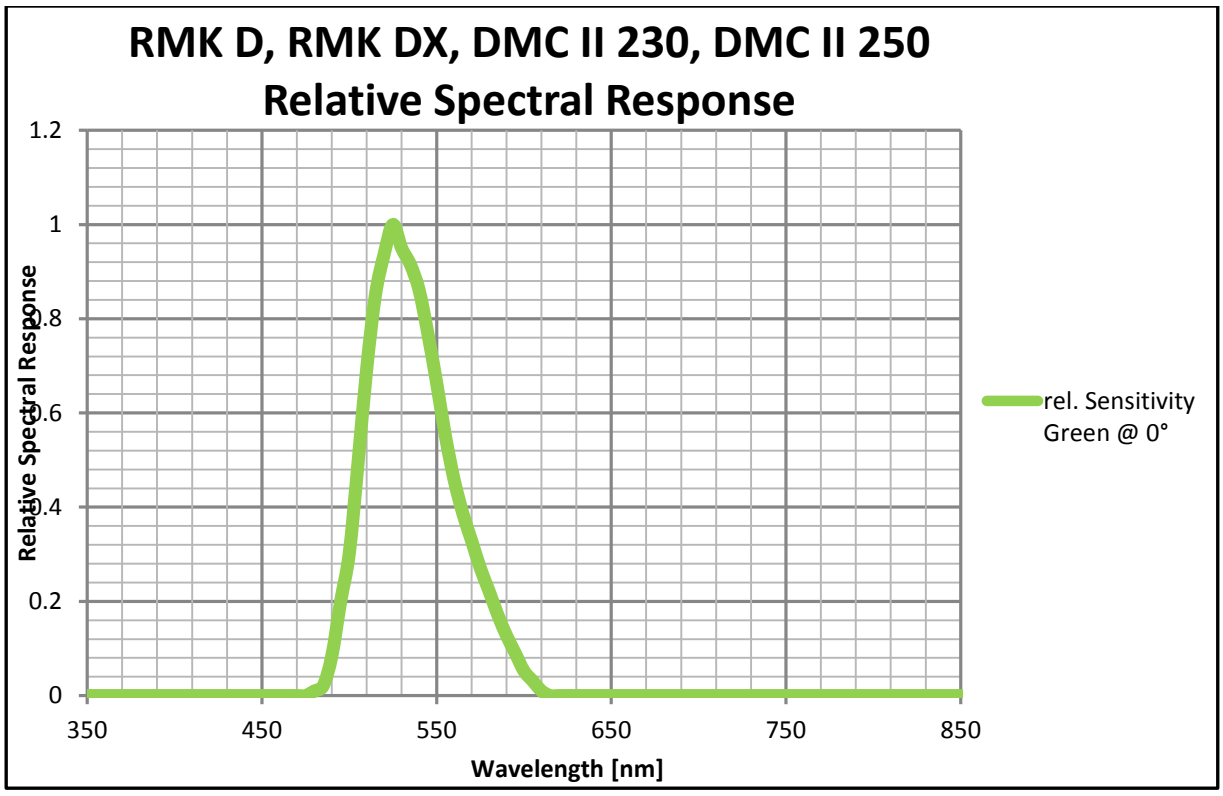
RMK D / RMK DX / DMC II MS Green – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Green camera

Spectral response curve of the single camera head.

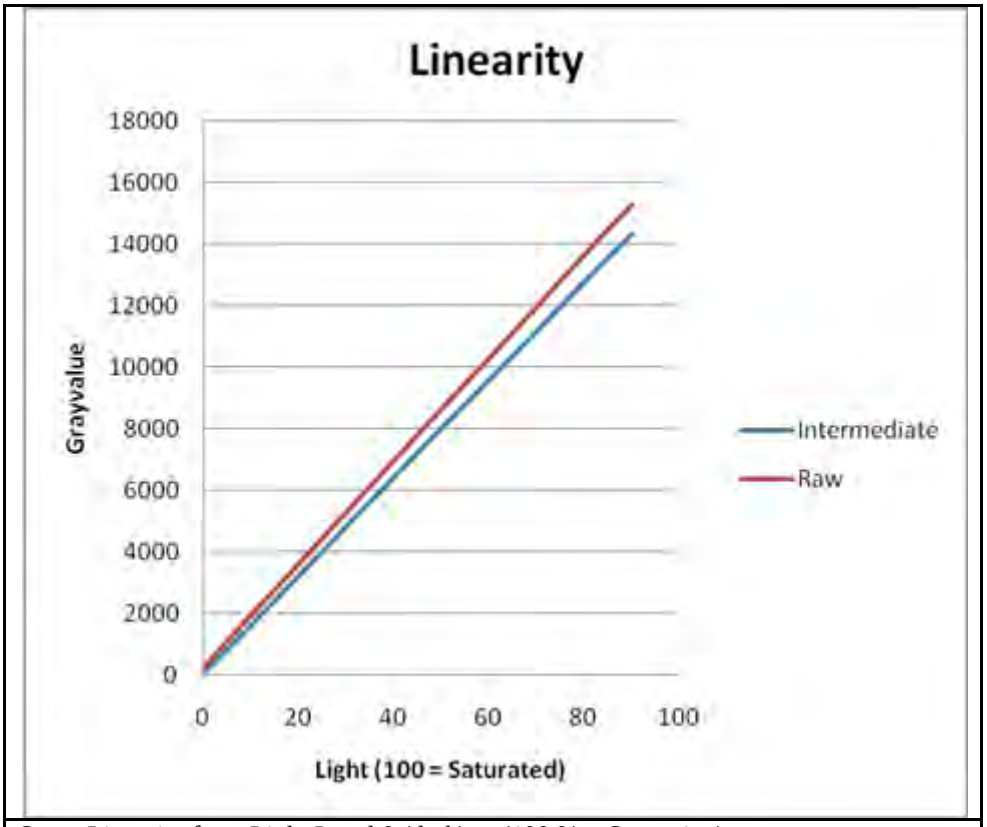


The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 250 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera type specific calibration.

Radiometric Calibration

Sensor Linearity (Reference)

The sensor linearity is measured in the Lab with calibrated spectrometer. This is a camera type specific calibration.
Below figure shows the linearity of the raw sensor and after flat fielding:



Senor Linearity from Light Level 0 (dark) to (100 % = Saturation)

The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 8 with exposure time of 22msec. Sensor noise after calibration shall be less or equal 0.5% of radiometric resolution. At 14bit radiometric resolution 0.5% (of 16384) is equal to 82 gray values. This is a camera type specific calibration.

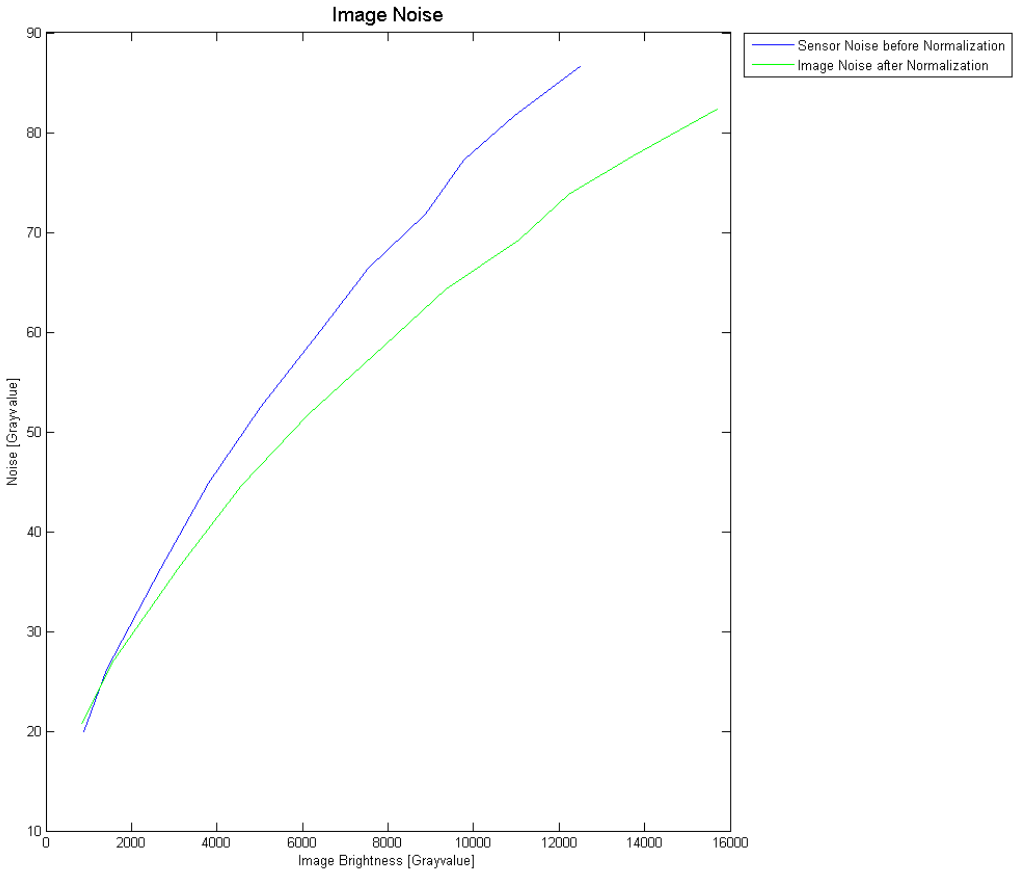


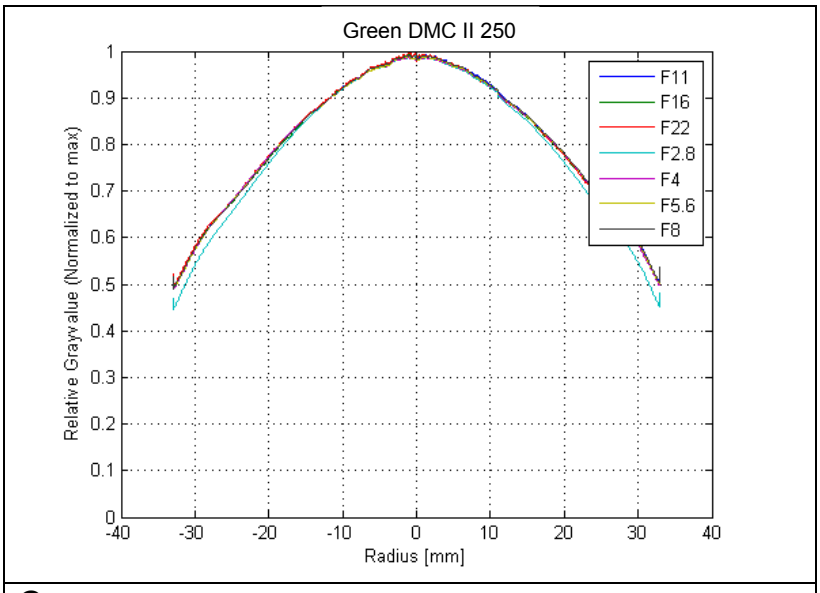
Image Noise before and after radiometric calibration

Radiometric Calibration

Aperture Correction

Green (00122323)

The light fall off to the border due the influence of the optics depends on the aperture used. Therefore this calibration approach delivers individual calibration images for each aperture (Full F-Stop). In general the light fall off is a function of the image height (radial distance from center). The figure below shows the profile from the upper left corner to the lower right corner of the calibration images.



Green

This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Green (00122323)

Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix “Defect Pixel Recognition”.

Revision of calibration:	65537	
CCDRevision:	1	
Date Number:		1348649834
Date:		120926
Number of defect pixels:	0	
Number of defect clusters:	0	
Number of defect columns:	0	

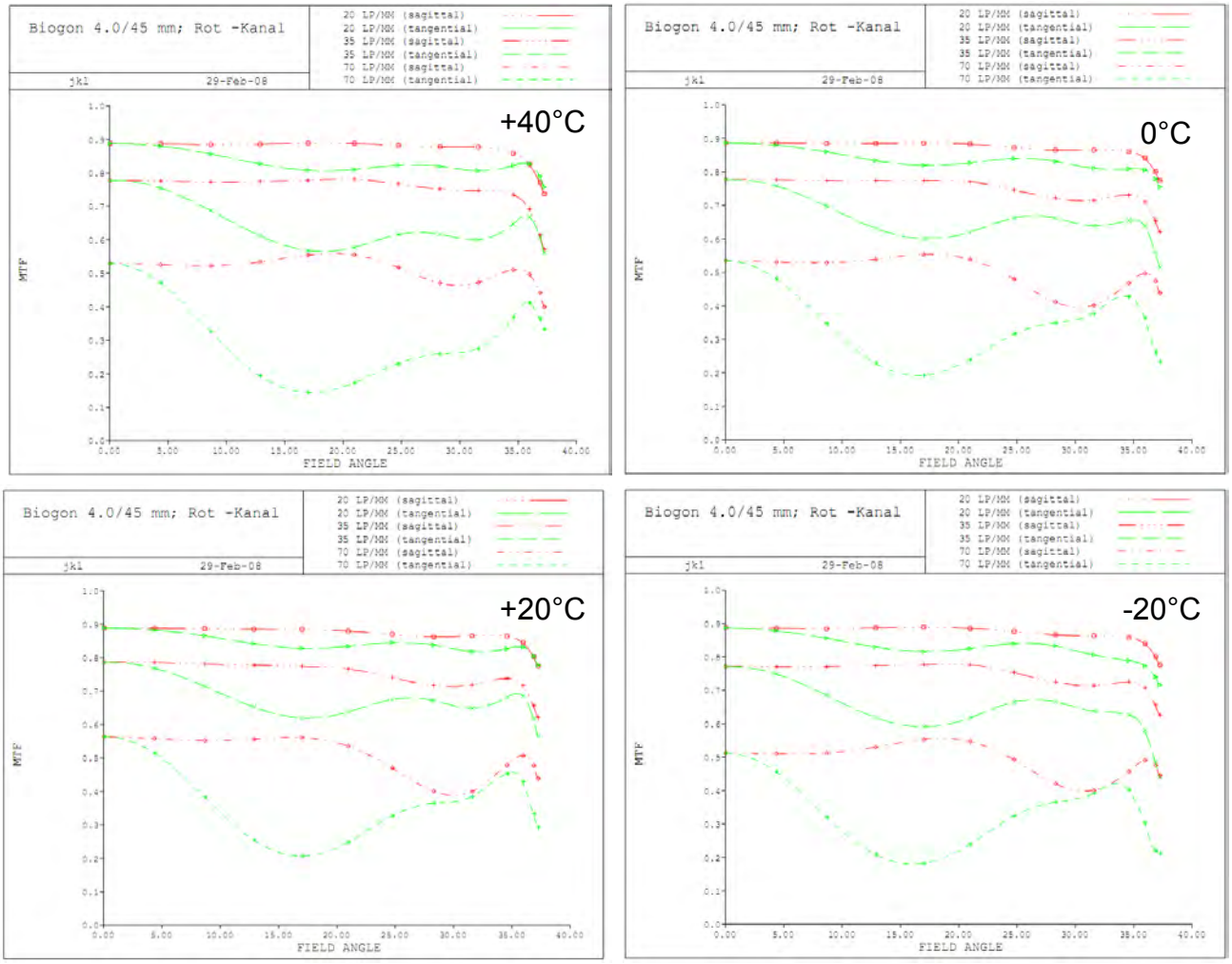
Nr Row Column

Defect Column RowStart ColumnStart RowEnd ColumnEnd

Optical System

Modulation Transfer Function, MTF of Red camera

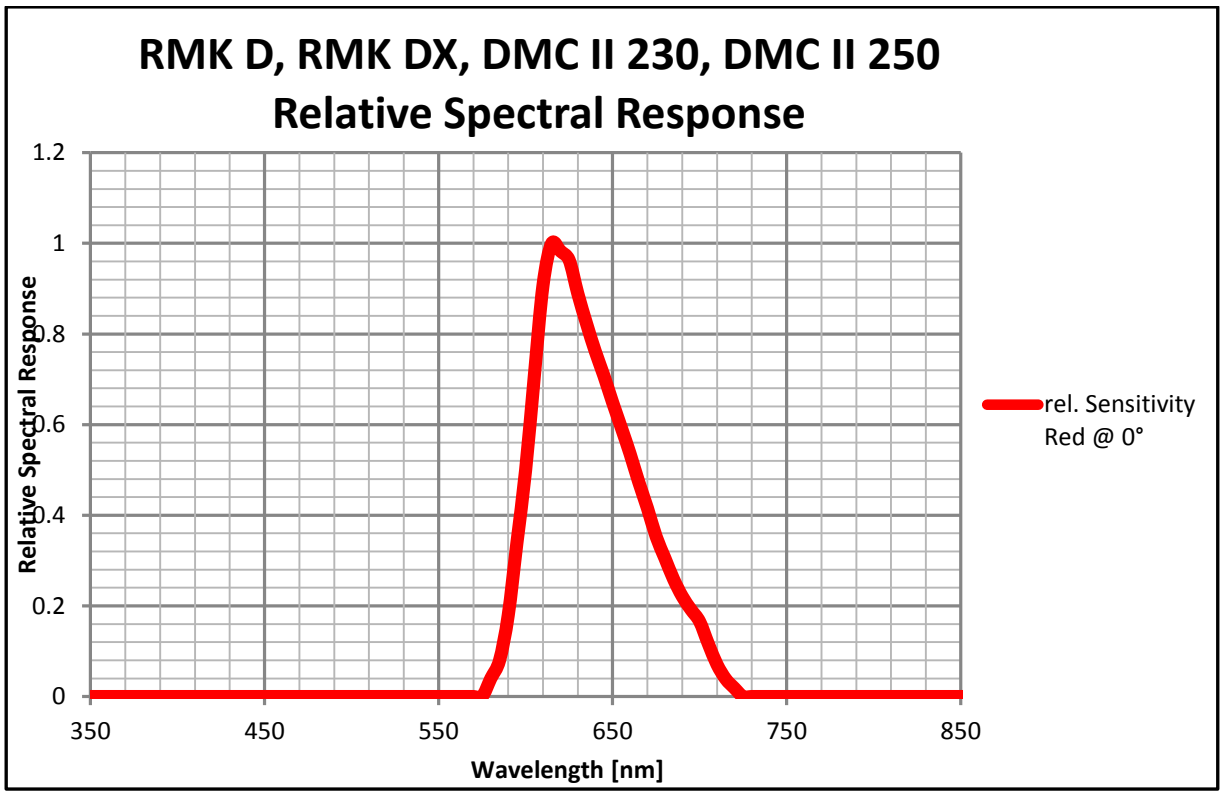
RMK D / RMK DX / DMC II MS Red – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Red camera

Spectral Response Curves of the single camera head.

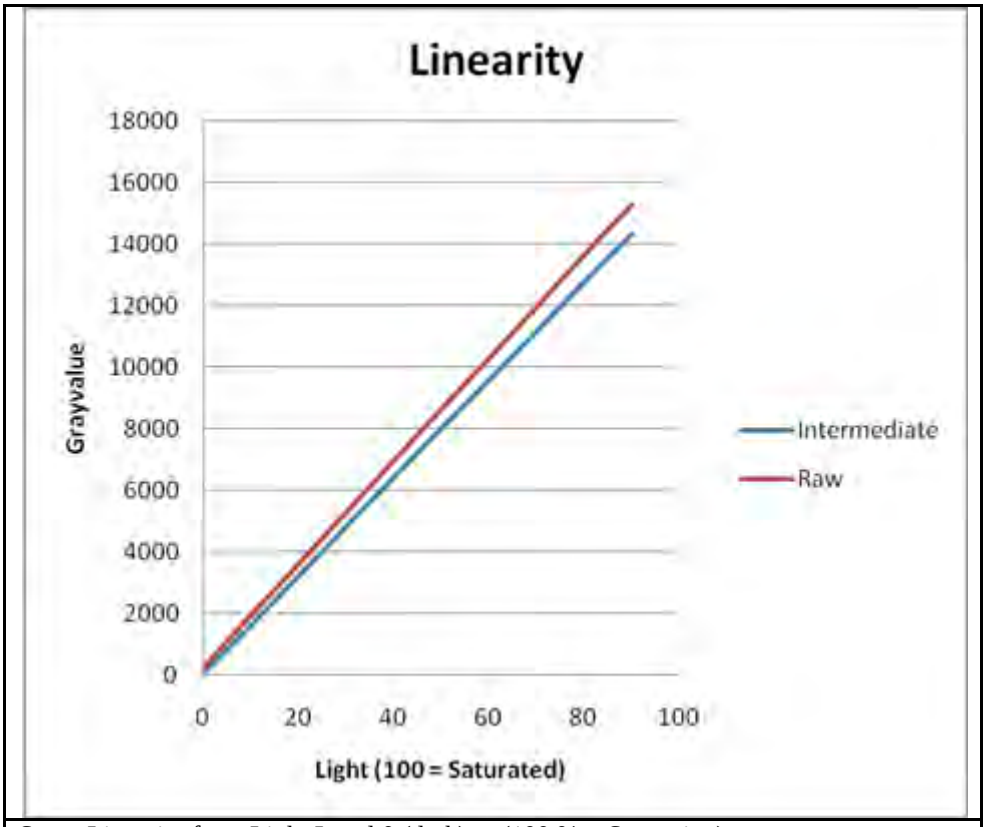


The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 250 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera type specific calibration.

Radiometric Calibration

Sensor Linearity (Reference)

The sensor linearity is measured in the Lab with calibrated spectrometer. This is a camera type specific calibration.
Below figure shows the linearity of the raw sensor and after flat fielding:



Senor Linearity from Light Level 0 (dark) to (100 % = Saturation)

The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 8 with exposure time of 22msec. Sensor noise after calibration shall be less or equal 0.5% of radiometric resolution. At 14bit radiometric resolution 0.5% (of 16384) is equal to 82 gray values. This is a camera type specific calibration.

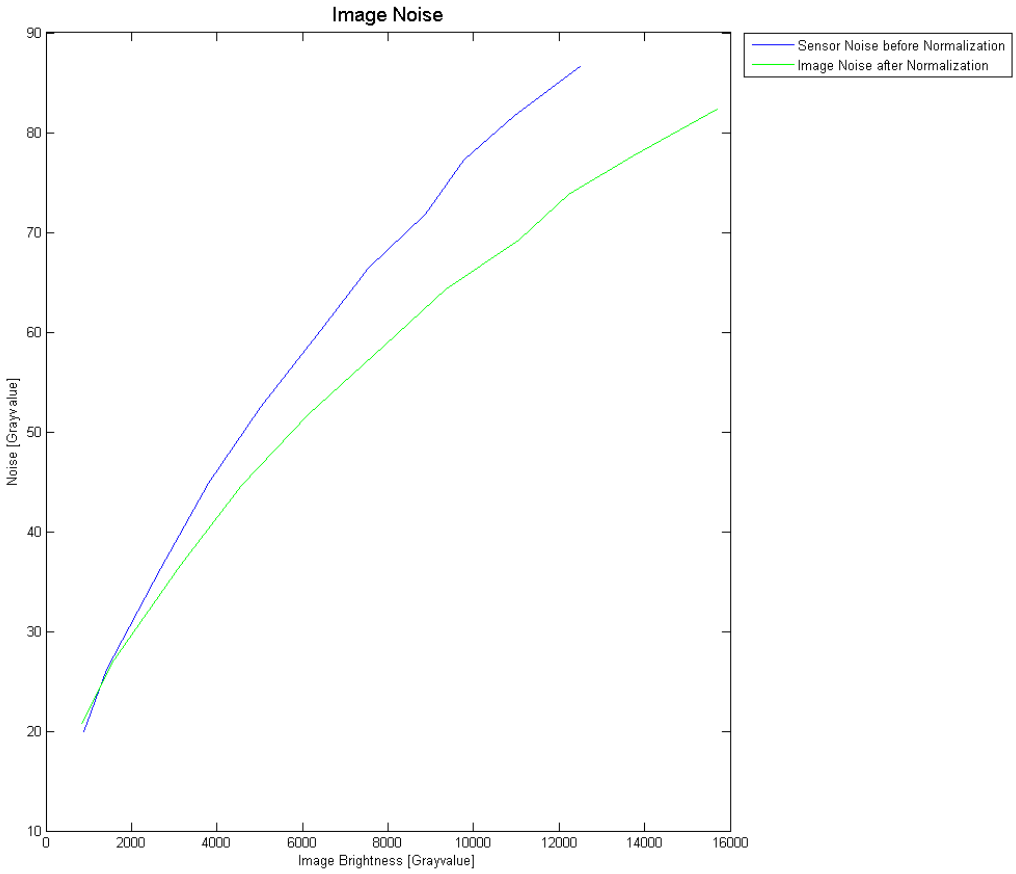


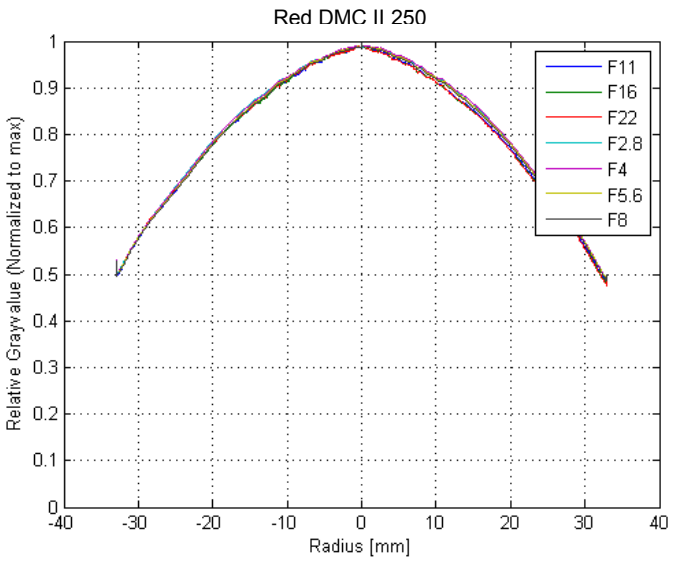
Image Noise before and after radiometric calibration

Radiometric Calibration

Aperture Correction

Red (00121921)

The light fall off to the border due the influence of the optics depends on the used aperture. Therefore this calibration approach has for each aperture (Full F-Stop) its own calibration image. In general the light fall off is a function of the image radius. In this calibration approach instead of function the real measured values in the image is used. The figure below shows the profile from the upper left corner to the lower right corner of each of this calibration images to give a feeling on the amount of correction.



Red

This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Red (00121921)

Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix “Defect Pixel Recognition”.

Revision of calibration:	65537	
CCDRevision:	1	
Date Number:		1349692713
Date:		121008

Number of defect pixels:	2
Number of defect clusters:	0
Number of defect columns:	0

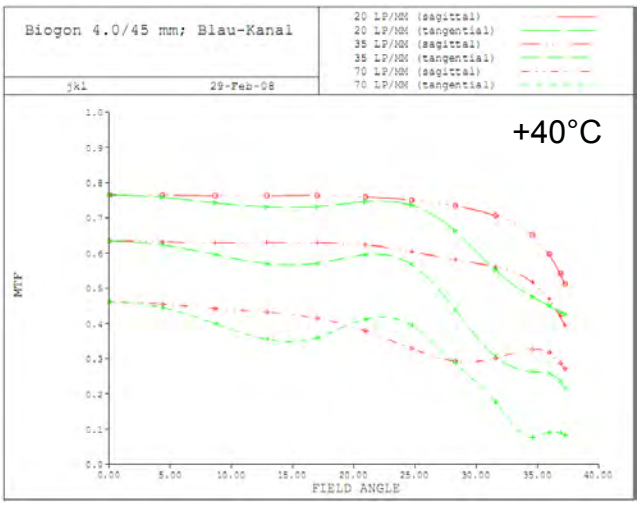
Nr	Row	Column
0	6182	2002
1	1667	2035

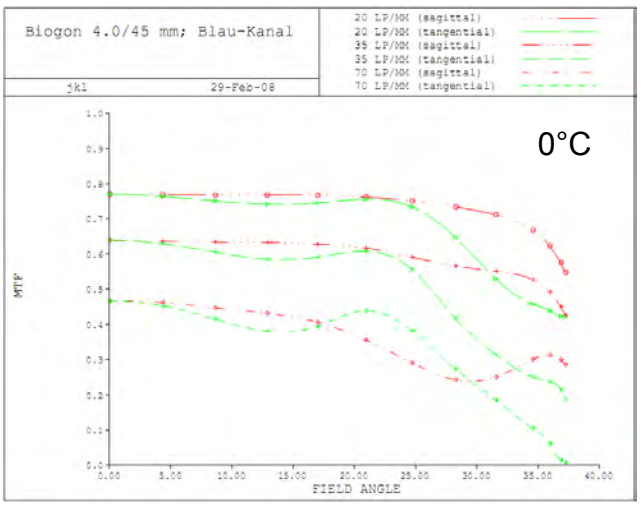
Defect Column RowStart ColumnStart RowEnd ColumnEnd

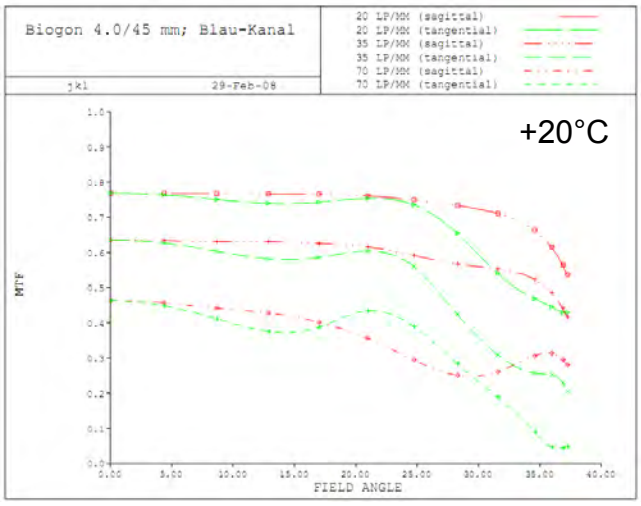
Optical System

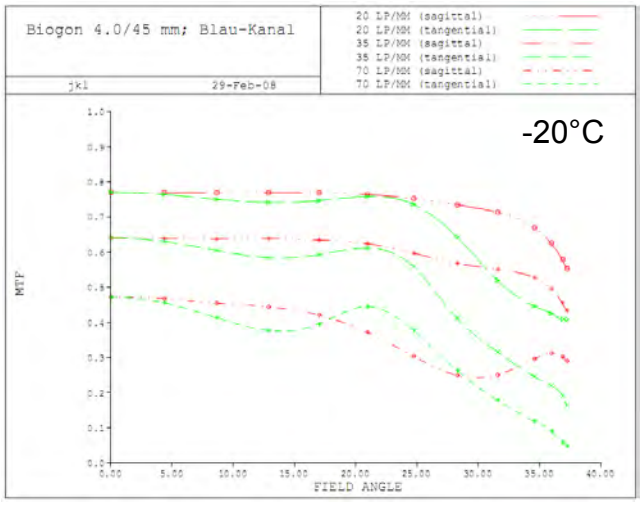
Modulation Transfer Function, MTF of Blue camera

RMK D / RMK DX / DMC II MS Blue – MTF F/4.0 ; 45 mm– Temperature Stability





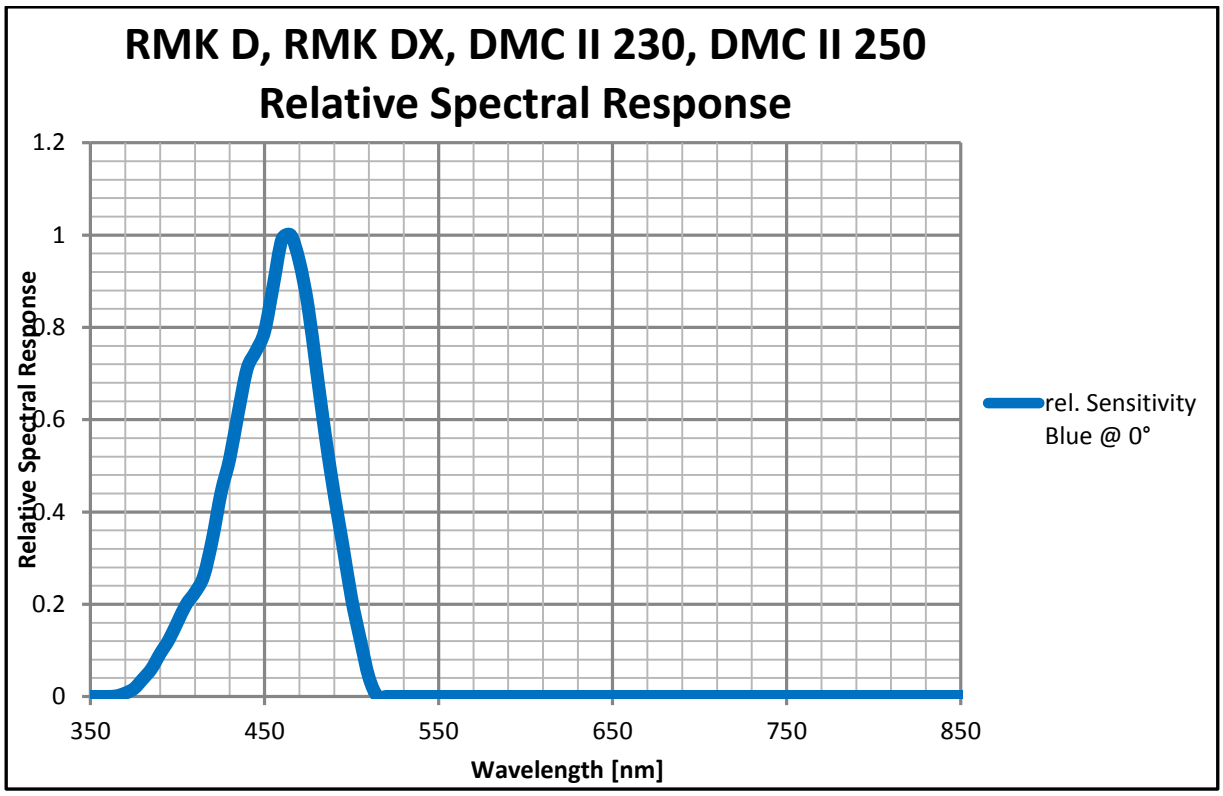




Radiometric Calibration

Sensitivity of Blue camera

Spectral Response Curves of the single camera head.

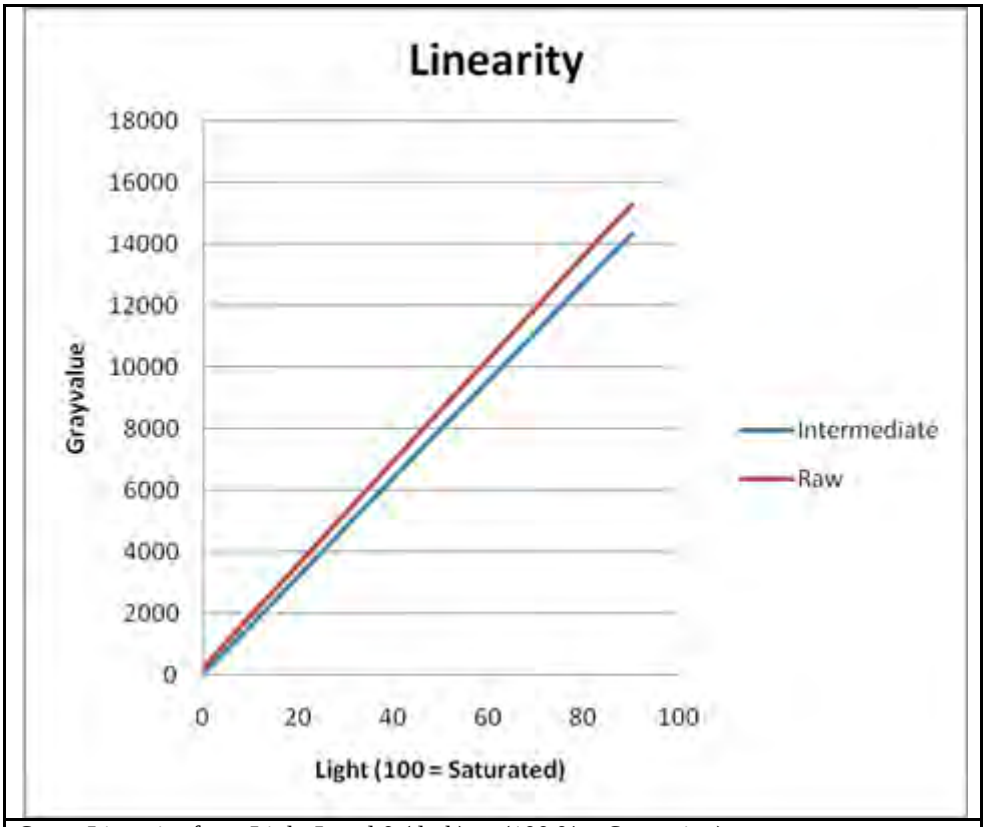


The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 250 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera type specific calibration.

Radiometric Calibration

Sensor Linearity (Reference)

The sensor linearity is measured in the Lab with calibrated spectrometer. This is a camera type specific calibration.
Below figure shows the linearity of the raw sensor and after flat fielding:



Senor Linearity from Light Level 0 (dark) to (100 % = Saturation)

The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 8 with exposure time of 22msec. Sensor noise after calibration shall be less or equal 0.5% of radiometric resolution. At 14bit radiometric resolution 0.5% (of 16384) is equal to 82 gray values. This is a camera type specific calibration.

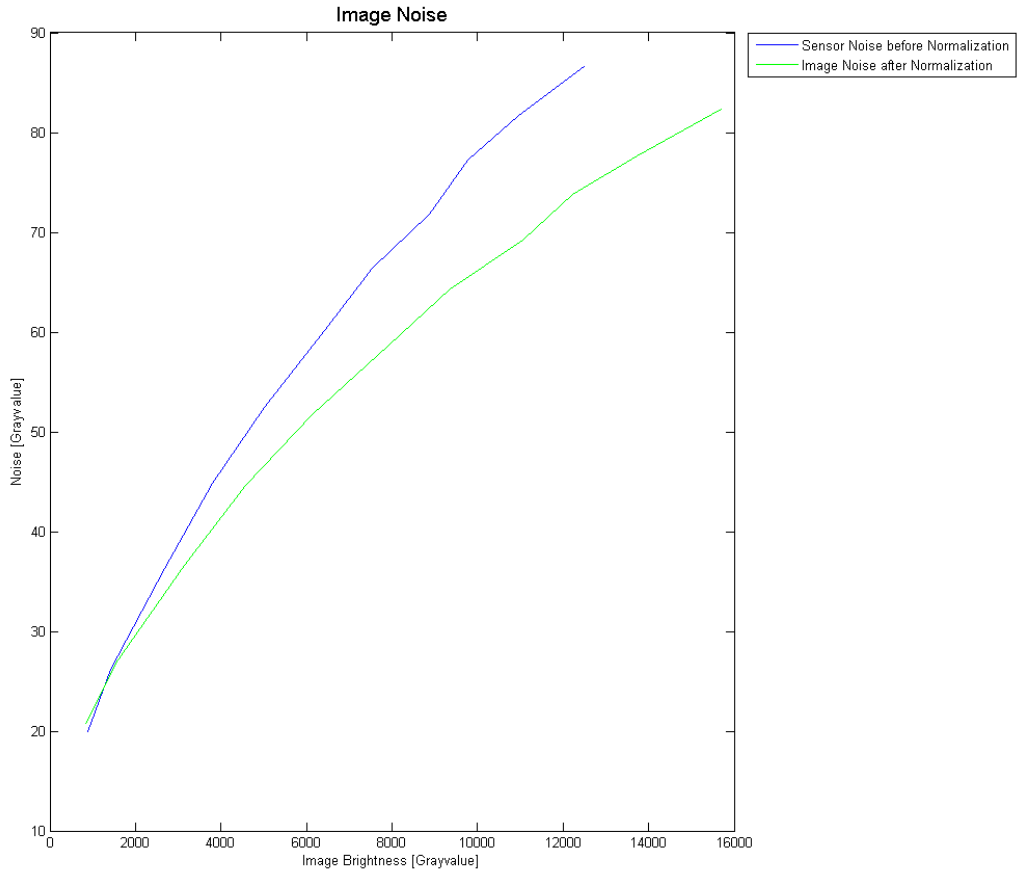


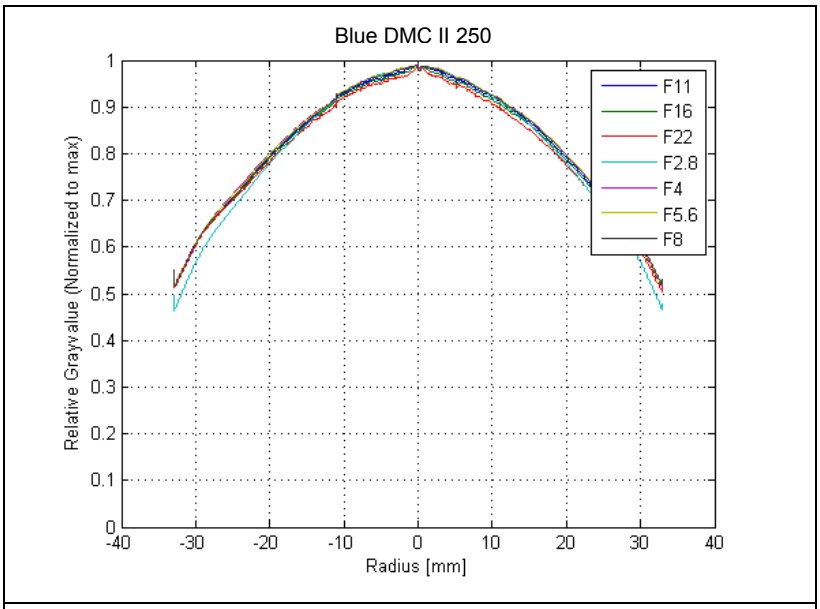
Image Noise before and after radiometric calibration

Radiometric Calibration

Aperture Correction

Blue (00122326)

The light fall off to the border due the influence of the optics depends on the used aperture. Therefore this calibration approach has for each aperture (Full F-Stop) its own calibration image. In general the light fall off is a function of the image radius. In this calibration approach instead of function the real measured values in the image is used. The figure below shows the profile from the upper left corner to the lower right corner of each of this calibration images to give a feeling on the amount of correction.



Blue

This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Blue (00122326)

Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix “Defect Pixel Recognition”.

Revision of calibration:	65537	
CCDRevision:	1	
Date Number:		1348650892
Date:		120926
Number of defect pixels:	4	
Number of defect clusters:	0	
Number of defect columns:	0	

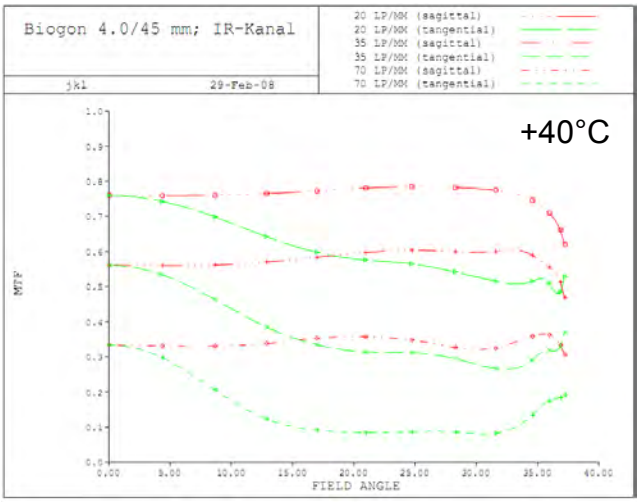
Nr	Row	Column
0	2119	91
1	5059	2710
2	5777	3388
3	315	6082

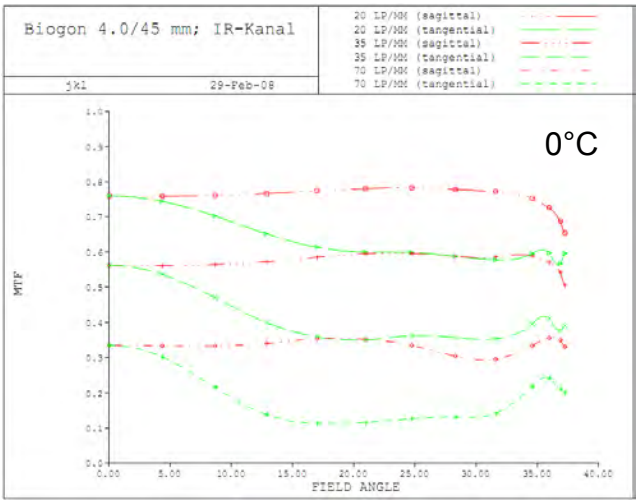
Defect Column RowStart ColumnStart RowEnd ColumnEnd

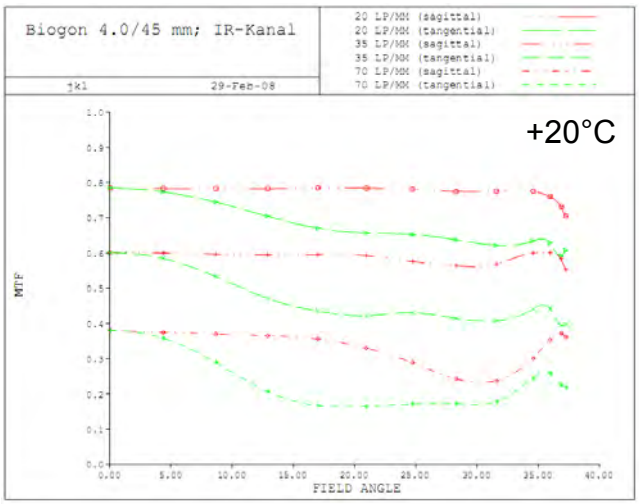
Optical System

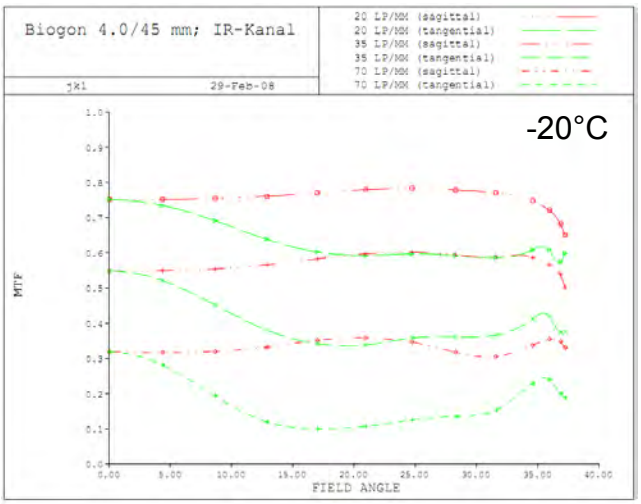
Modulation Transfer Function, MTF of IR camera

RMK D / RMK DX / DMC II MS IR – MTF F/4.0 ; 45 mm– Temperature Stability





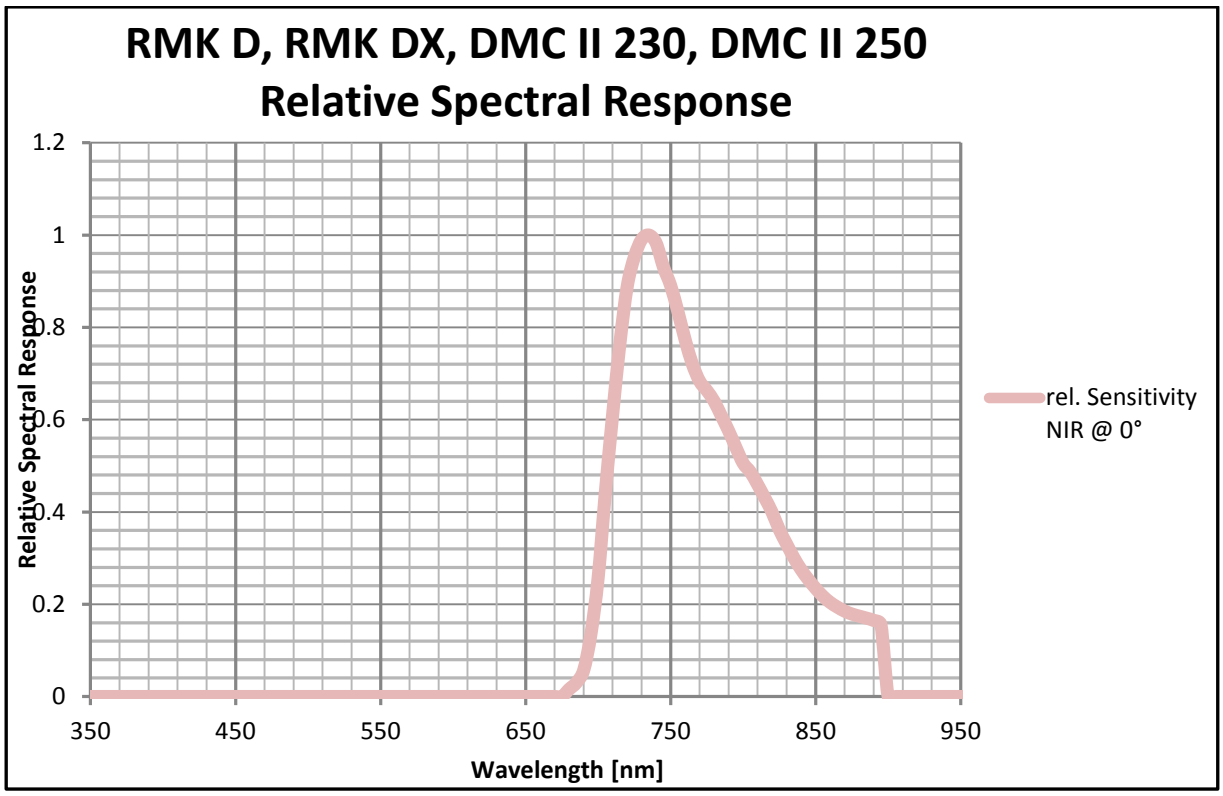




Radiometric Calibration

Sensitivity of NIR camera

Spectral Response Curves of the single camera head.

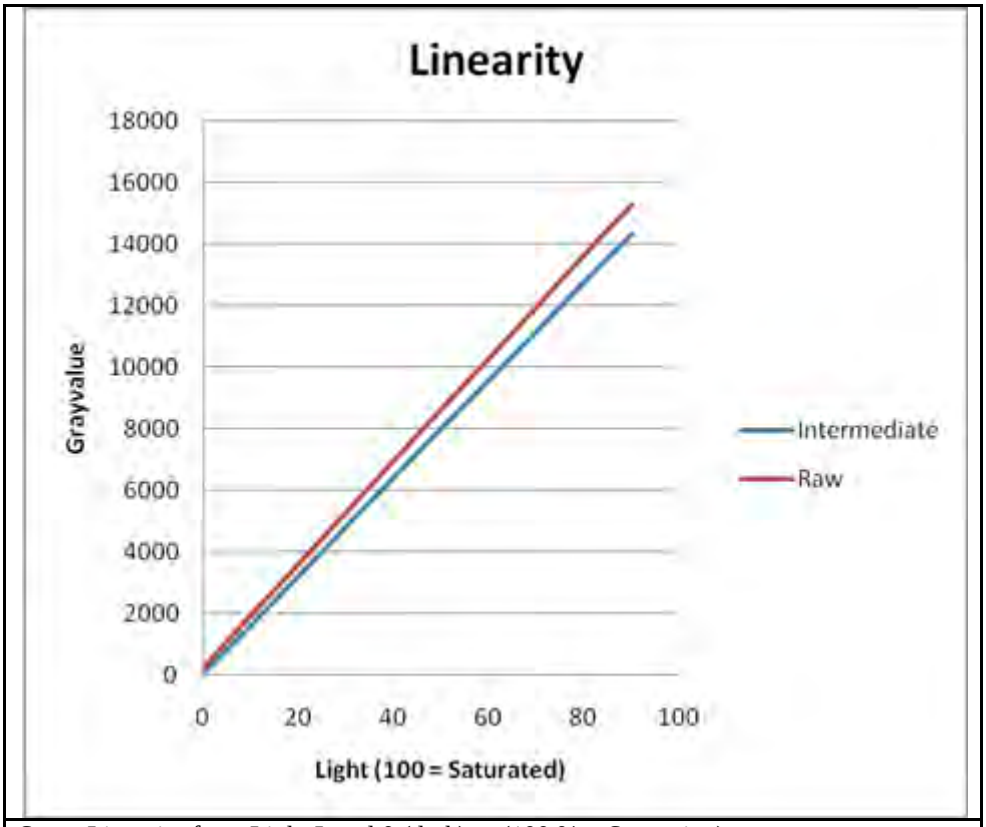


The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 250 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera type specific calibration.

Radiometric Calibration

Sensor Linearity (Reference)

The sensor linearity is measured in the Lab with calibrated spectrometer. This is a camera type specific calibration.
Below figure shows the linearity of the raw sensor and after flat fielding:



Senor Linearity from Light Level 0 (dark) to (100 % = Saturation)

The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 8 with exposure time of 22msec. Sensor noise after calibration shall be less or equal 0.5% of radiometric resolution. At 14bit radiometric resolution 0.5% (of 16384) is equal to 82 gray values. This is a camera type specific calibration.

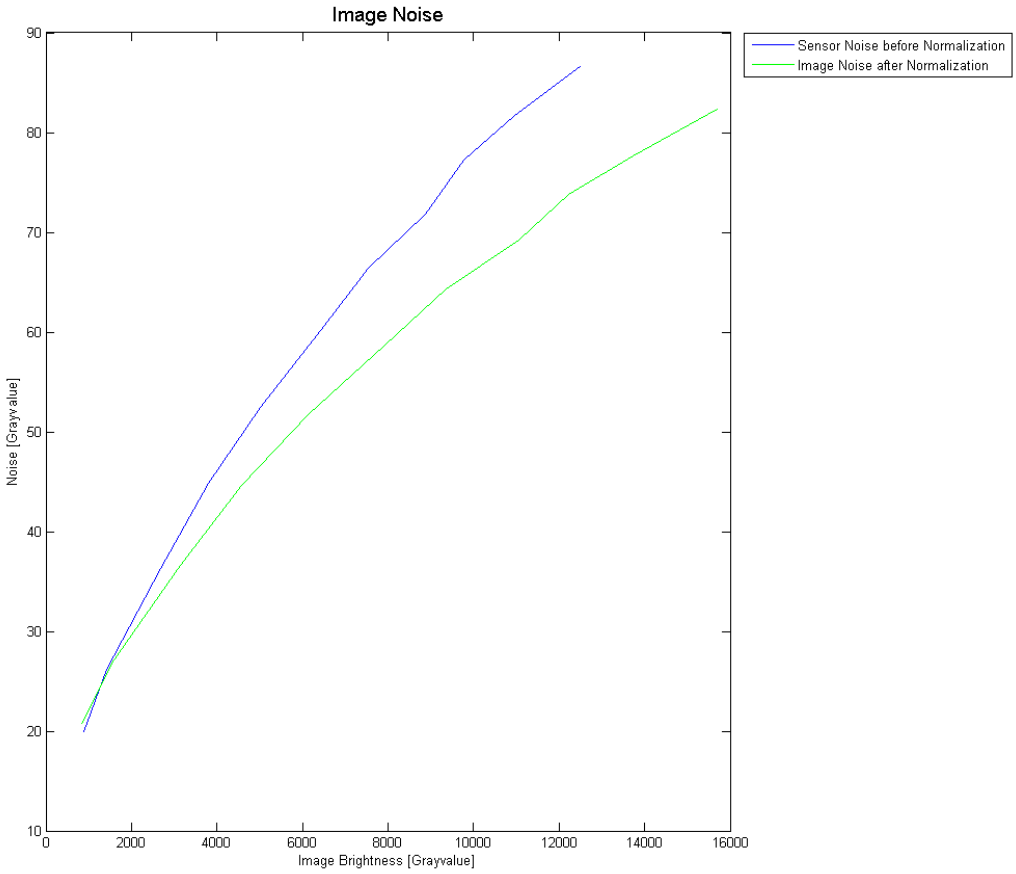


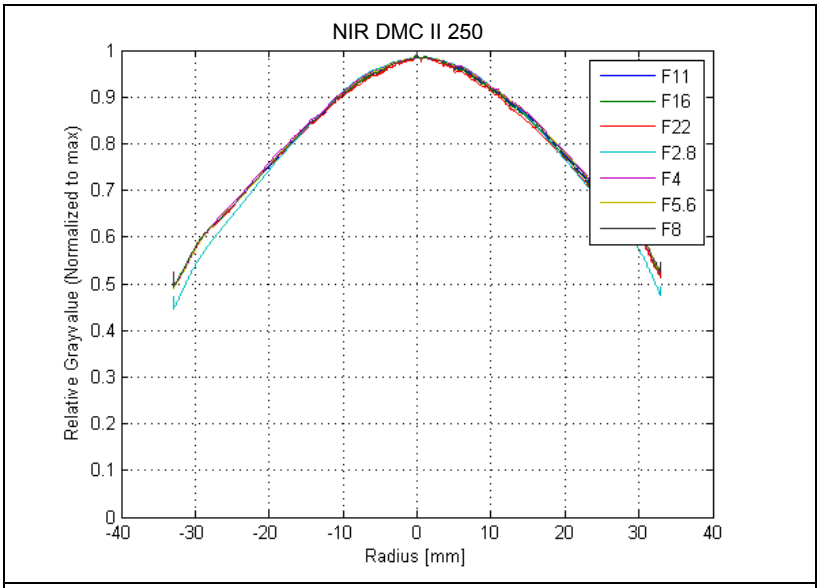
Image Noise before and after radiometric calibration

Radiometric Calibration

Aperture Correction

NIR (00121916)

The light fall off to the border due the influence of the optics depends on the used aperture. Therefore this calibration approach has for each aperture (Full F-Stop) its own calibration image. In general the light fall off is a function of the image radius. In this calibration approach instead of function the real measured values in the image is used. The figure below shows the profile from the upper left corner to the lower right corner of each of this calibration images to give a feeling on the amount of correction.



NIR

This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

NIR (00121916)

Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix “Defect Pixel Recognition”.

Revision of calibration:	65537	
CCDRevision:	1	
Date Number:		1348649299
Date:		120926
Number of defect pixels:	5	
Number of defect clusters:	0	
Number of defect columns:	0	

Nr	Row	Column
0	591	200
1	869	3727
2	6075	5868
3	6075	5869
4	6076	5869

Defect Column RowStart ColumnStart RowEnd ColumnEnd

Sensor Geometric Accuracy

Large area CCD imagers are composed (stitched) from several blocks. Stitching on wafer with semiconductor lithographic equipment results in geometric accuracy better than 0.1µm (Stoldt, H. (2010).
Therefore the geometric accuracy of individual pixels within a block can be assumed as better or equal the stitching accuracy.

Defect Pixel Recognition

The table below shows the maximal allowed physical defects on the CCD Sensor and its definitions.

	Description	CCD Spec
Pixel	Bright image	Pixel whose signal, at nominal light (illumination at 50% of the linear range), deviates more than ±30% from its neighboring pixels.
	Dark image	Pixel whose signal, in dark, deviates more than 6mV from its neighboring pixels (about 1% of nominal light).
	Max Count	PAN ≤ 3500 MS <500

	Description	CCD Spec
Column	Definition	A column which has more than 8 pixel defects in 1 1x 12 kernel Column defects must be horizontally separated by 5 columns for single line defects and 10 for double line defects
	Recognition (bright and dark)	Same as defect pixel recognition
	Max Single column	PAN ≤ 140 MS ≤ 20
	Max double Column	PAN ≤ 40 MS ≤ 6

The Post-Processing-Software is correcting following pixel and columns:

	PPS Correction
Pixel	Pixel whose gray value in a 16 x16 kernel differs from the median more than 30%

	PPS Correction
Column	Pixel whose gray value in a 16 x16 kernel differs from the median more than 5% and more than 15 defects in one column

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