

Camera Calibration Certificate

No: DMC II 140 - 008



For

Midwest Aerial Photography

7535 West Broad Street

Galloway, OH 43119

U.S.A.

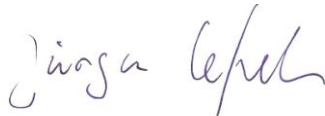
Camera: DMC II 140
Manufacturer: Intergraph Z/I Deutschland GmbH, D-73431 Aalen, Germany
Reference: PAN
Serial Number: 00119664 (PAN Head)
Date of Calibration: 15. September 2010
Date of Report: 21. October 2010
Number of Pages:

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: September 2010

Date of Certification: October 2010



Dipl. Ing. Jürgen Hefe, Senior Software
Developer

Dipl. Ing. Christian Müller, Technical Consultant

Camera Serial Numbers and Burn-In flight

Camera Head	Serial Number	Calib. Date
PAN (reference)	00119664	15.09.2010
MS1 (NIR)	00118796	23.03.2010
MS2 (Blue)	00118826	17.03.2010
MS3 (Red)	00118793	24.03.2010
MS4 (Green)	00118835	24.03.2010

Burn-In flight performed: 12. October 2010

Test block configuration

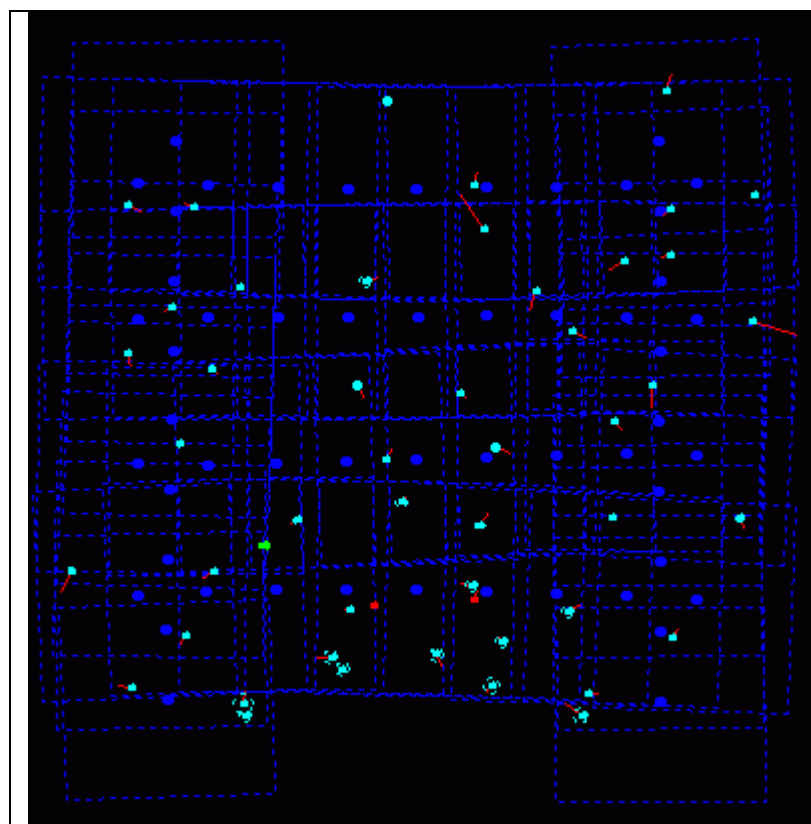



Photo Scale	1:6944.4
Flying Height [m]	640 AGL
Flying Altitude [m]	990 AMSL
Run-Spacing [m]	423.4
Base-Length [m]	224.0
Number of Exposures	54
Side-lap [%]	30
End-lap [%]	60
Terrain Height [m]	450
Number of strips	6
Photos in one strip	2 x 9 N-S 4 x 9 W-E
Photos Used	54
Control Points Used	9
Check Points Used	31
GSD [cm]	5

Aerial triangulation statistic results:

Parameter	X/Omega	Y/Phi	Z/Kappa	Key Statistics	
RMS Control	0.012	0.014	0.015	Sigma:	1.9 um
RMS Check	0.025	0.023	0.029	RMS Image (x, y):	1.4, 1.4 um
RMS Limits	0.001	0.001	0.001	Number of iterations:	2
Max Ground Residual	0.020	0.029	0.033	Degrees of Freedom:	5904
Residual Limits	0.001	0.001	0.001	Gross Image Blunders:	0
Mean Std Dev Object	0.014	0.014	0.038	Gross Control Blunders:	0
RMS Photo Position	0.032	0.029	0.031	Image Blunders:	0
RMS Photo Attitude	0.002	0.002	0.004	Solution Status:	
Mean Std Dev Photo Position	0.025	0.025	0.017	Solution outside of RMS tolerance.	
Mean Std Dev Photo Attitude	0.002	0.002	0.001	Solution outside of residual tolerance.	
Current Count				Cameras used: (1).	
Control Points Used:	9		Camera Id	Lens Di...	Grids
Check Points Used:	31		RMK_Dx	Off	Off
Photos Used:	54				
Photos Not Used:	0				
Image Points Used:	5073		Project Settings		
			Linear:	Meters	Refraction: Off
			Angular:	Degrees	Curvature: Off
			Deutsche Hauptdreiecksnetz - Gauss-Kruger (3-degree) (m)		

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 0.6 GSD in z.

Aerial Triangulation performed by


Dipl. Ing. C. Müller

21.10.2010
Date

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	00119664	
Number of rows/columns [pixels]	12096 x 11200	
Pixel Size [μm]	7.200 x 7.200	
Image Size [mm]	87.091 x 80.640	
Focal Length [mm]	91.9985 mm	+ /- 0.002 mm
Principal Point [mm]	X= -0.0064 mm, Y= -0.0102 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).

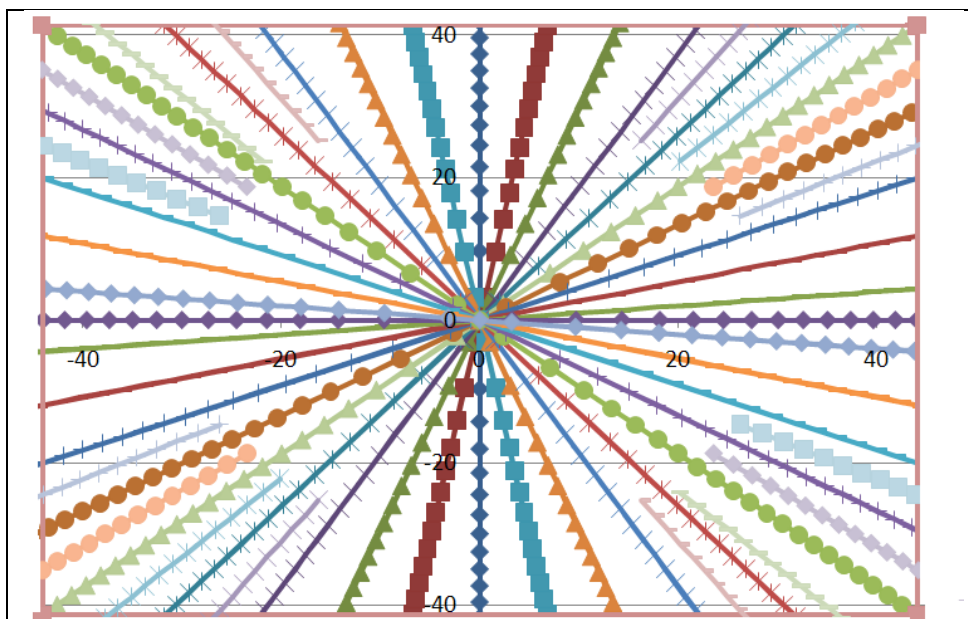


Figure 1: Light Target Pattern by Collimator

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.

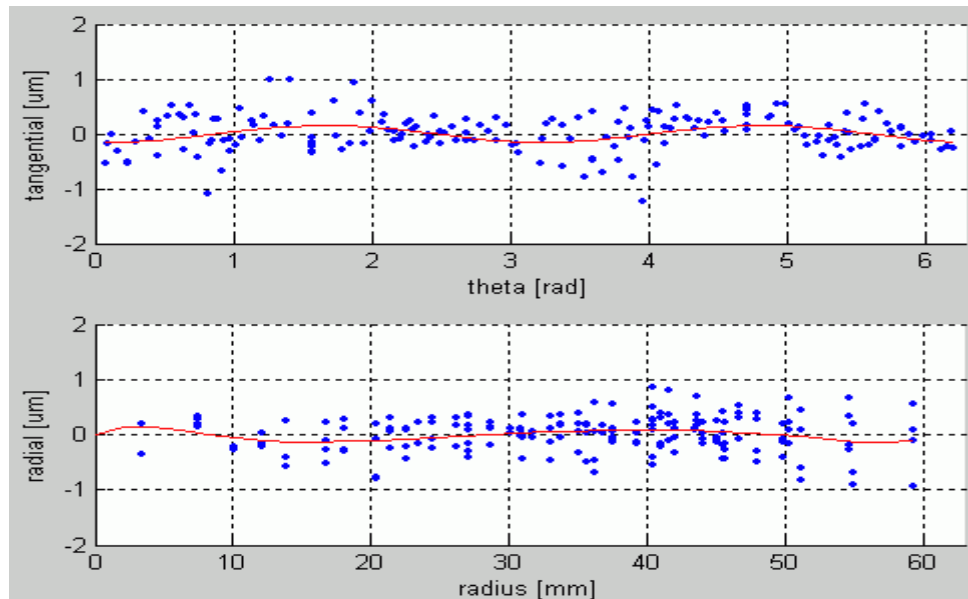


Figure 2: Tangential/Radial Distortion Residuals

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

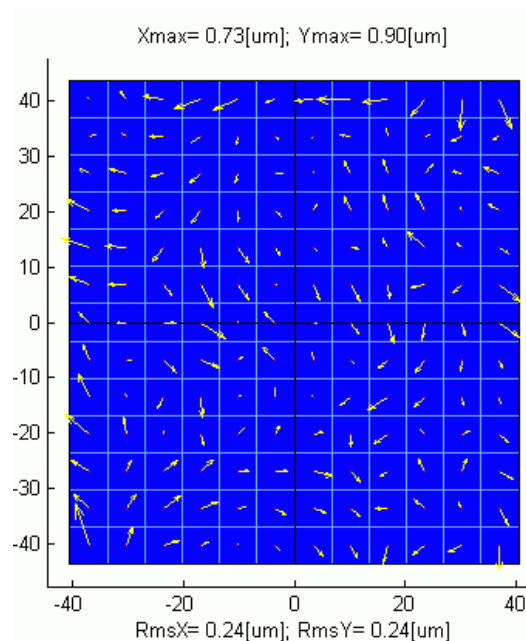


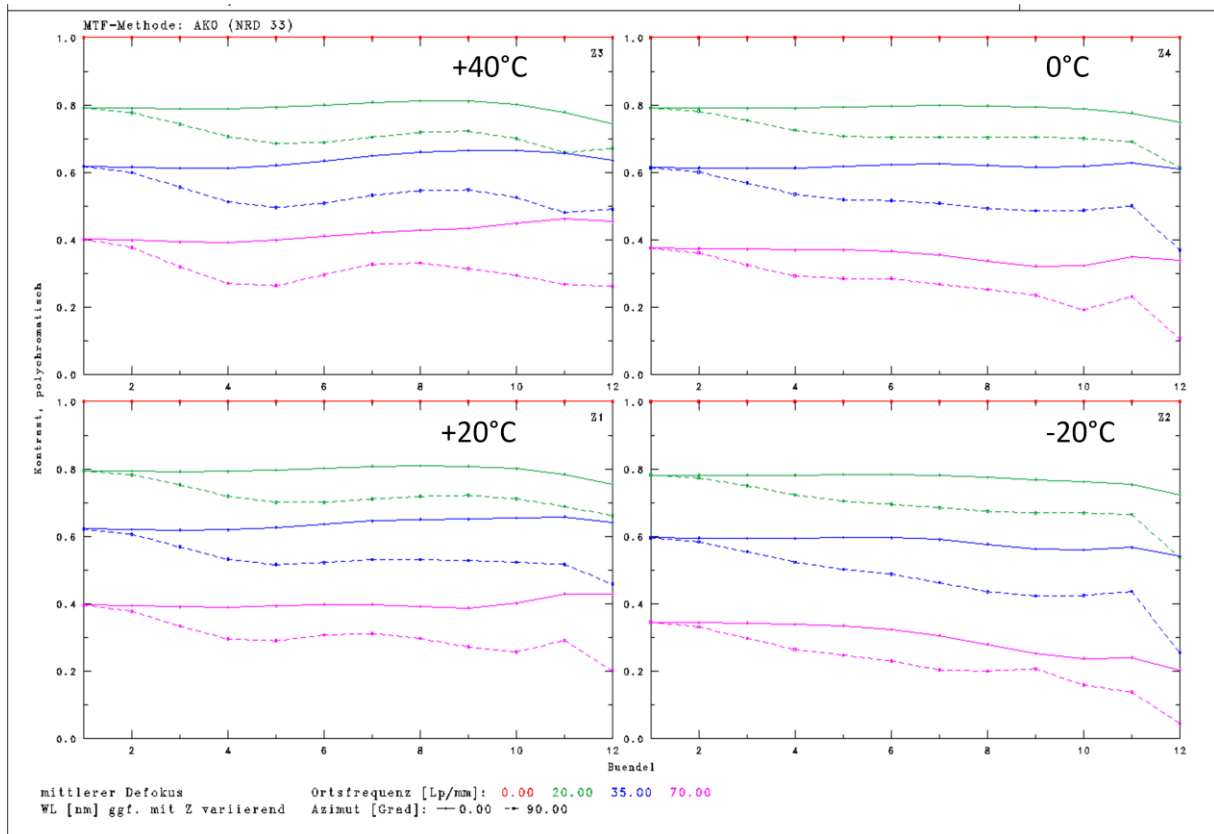
Figure 3: 2-D Image Residuals.

RMS<0.3um (maximum 0.9 microns)

Optical System

Modulation Transfer Function, MTF of PAN Camera (Reference)

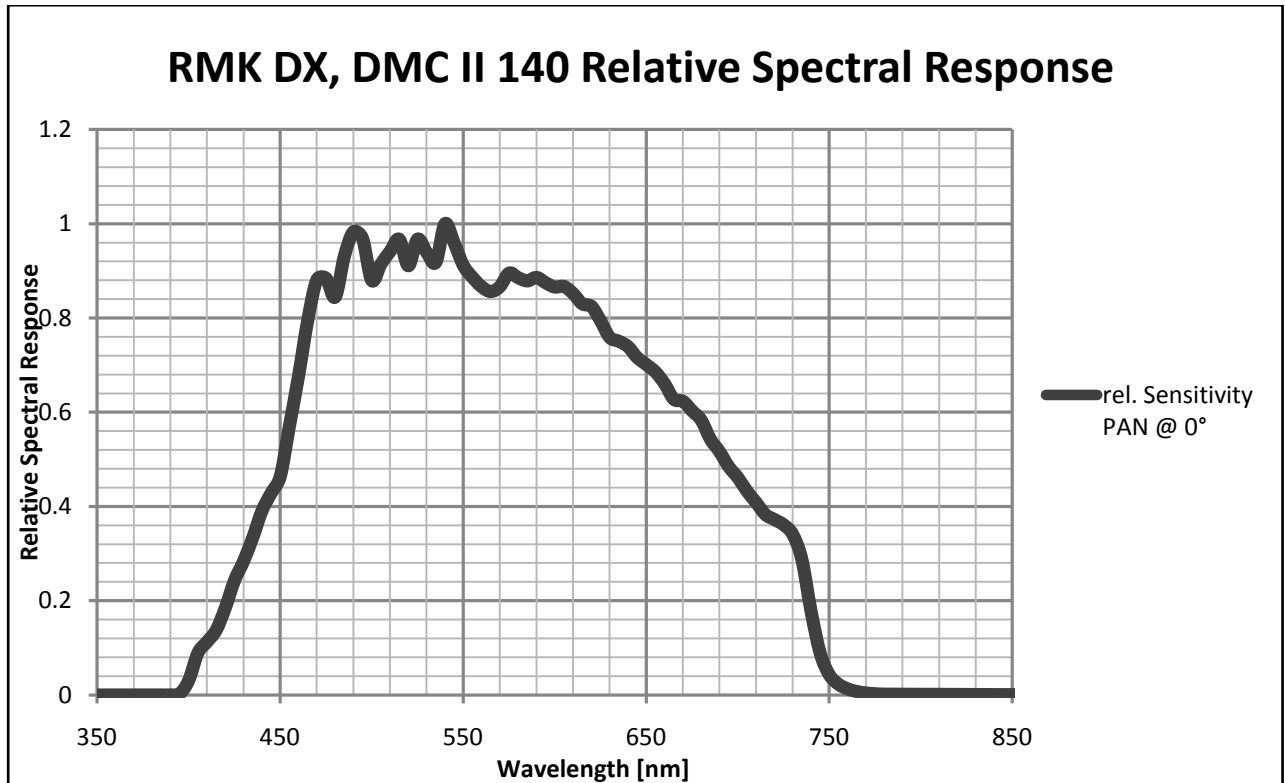
RMK DX / DMC II PAN – MTF Polychromatic F/5.6 ; 92 mm – Temperature Stability



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

Radiometric Calibration

Sensitivity of PAN camera (Reference)



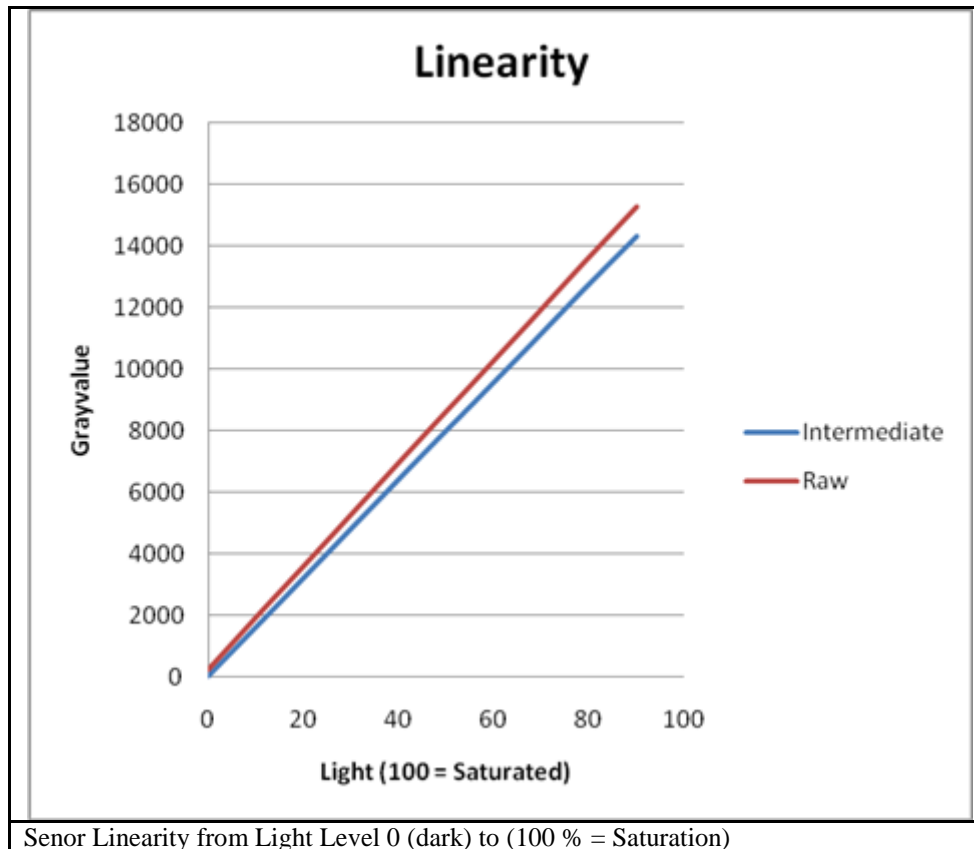
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 140 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera 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:

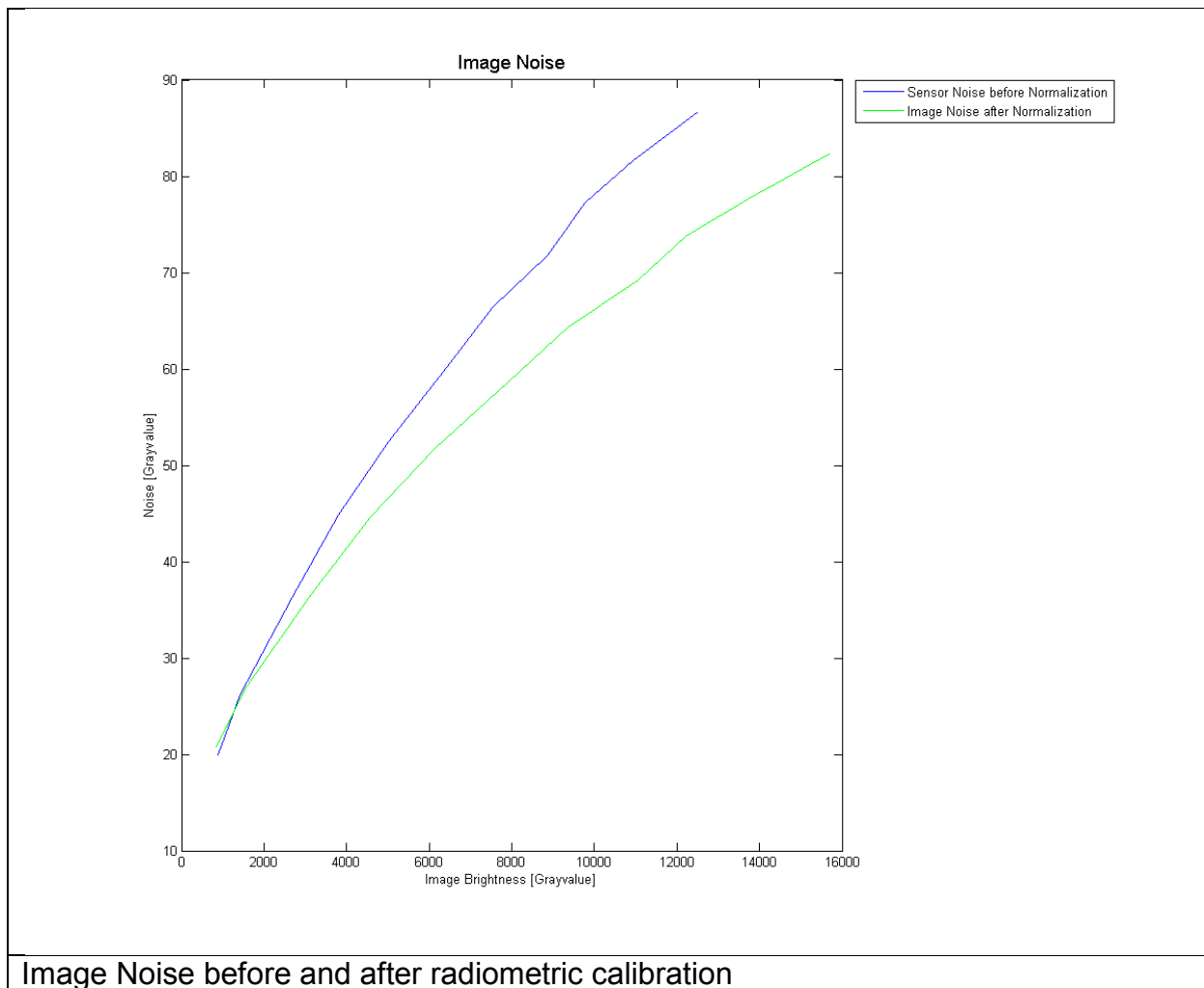


The deviation from the linearity is below 1%.

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.

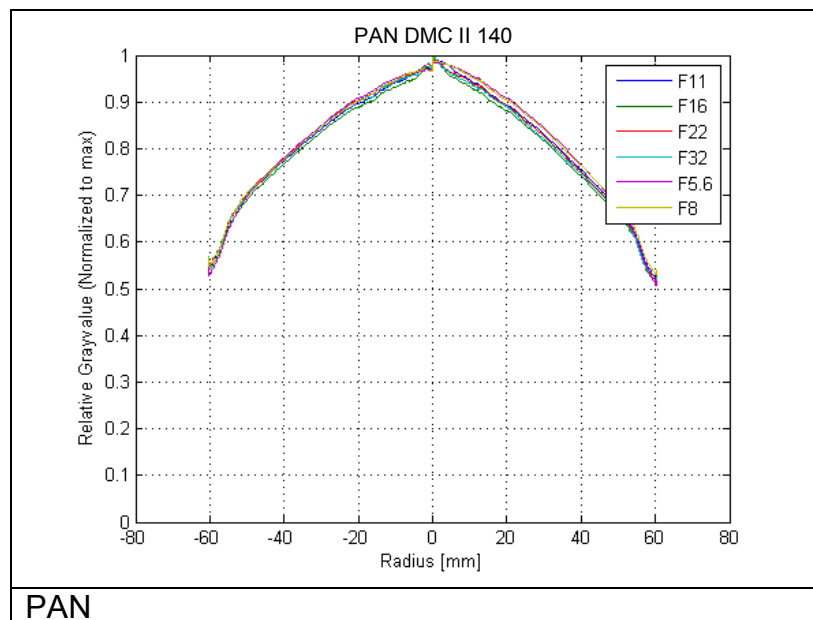


Radiometric Calibration

Aperture Correction (Reference)

Camera PAN (00119664)

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.



This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel (Reference)

Camera PAN (00119664)

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:	2	
CCDRevision:	1	
Date Number:		1284547382
Date:		100915

Number of defect pixels:	20
Number of defect clusters:	0
Number of defect columns:	0

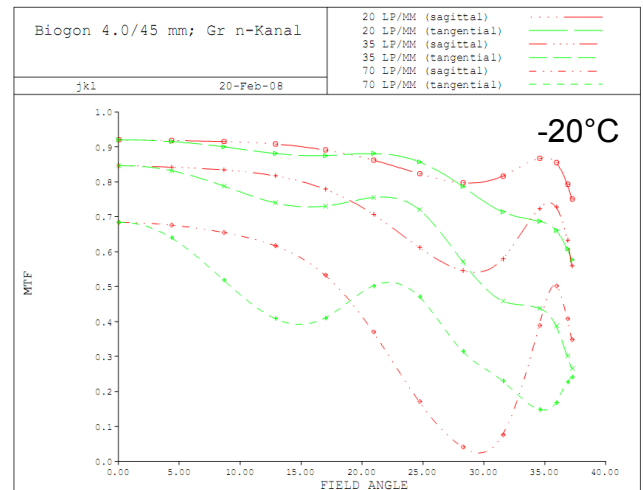
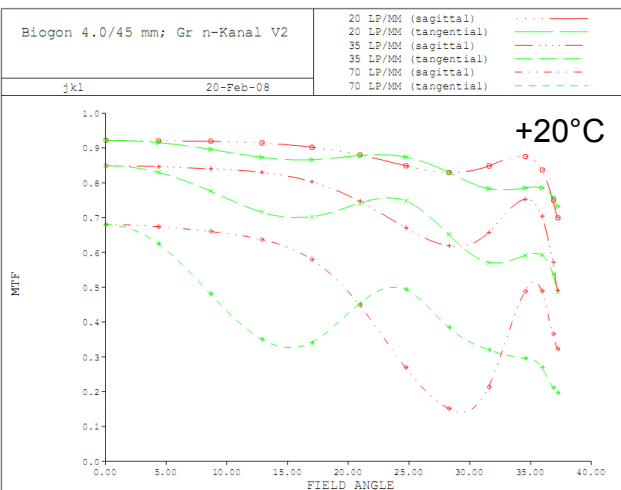
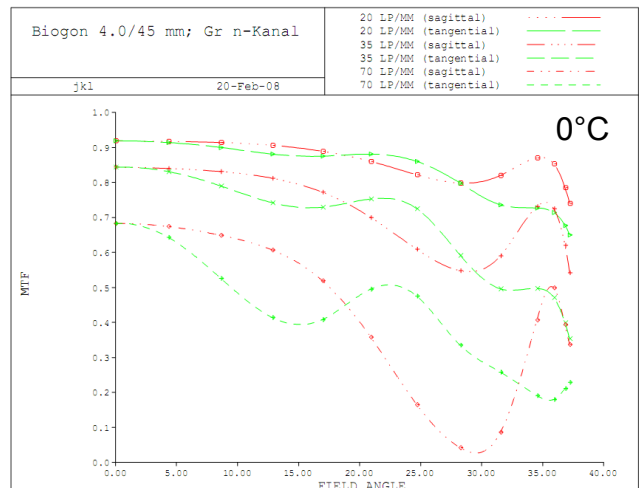
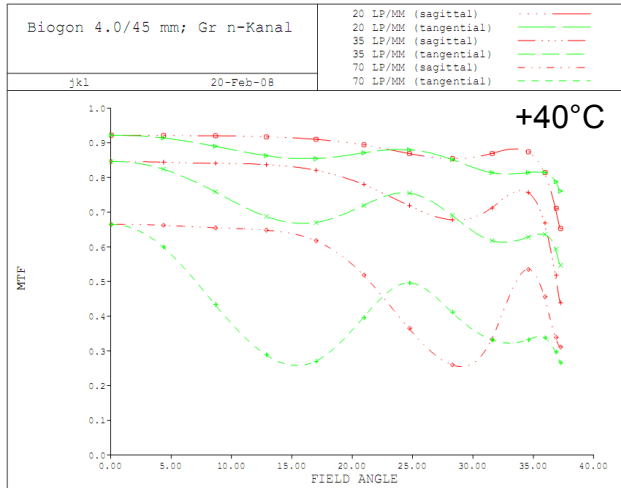
Nr	Row	Column
0	6076	382
1	6075	383
2	8786	527
3	4339	994
4	7663	1994
5	236	2399
6	8197	2828
7	8197	2829
8	8196	2830
9	7309	8002
10	7310	8002
11	7309	8003
12	7310	8003
13	7310	8004
14	7324	8014
15	454	8059
16	454	8060
17	5478	9555
18	1107	10865
19	1108	10865

Defect	Column	RowStart	ColumnStart	RowEnd	ColumnEnd
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Optical System

Modulation Transfer Function, MTF of Green camera

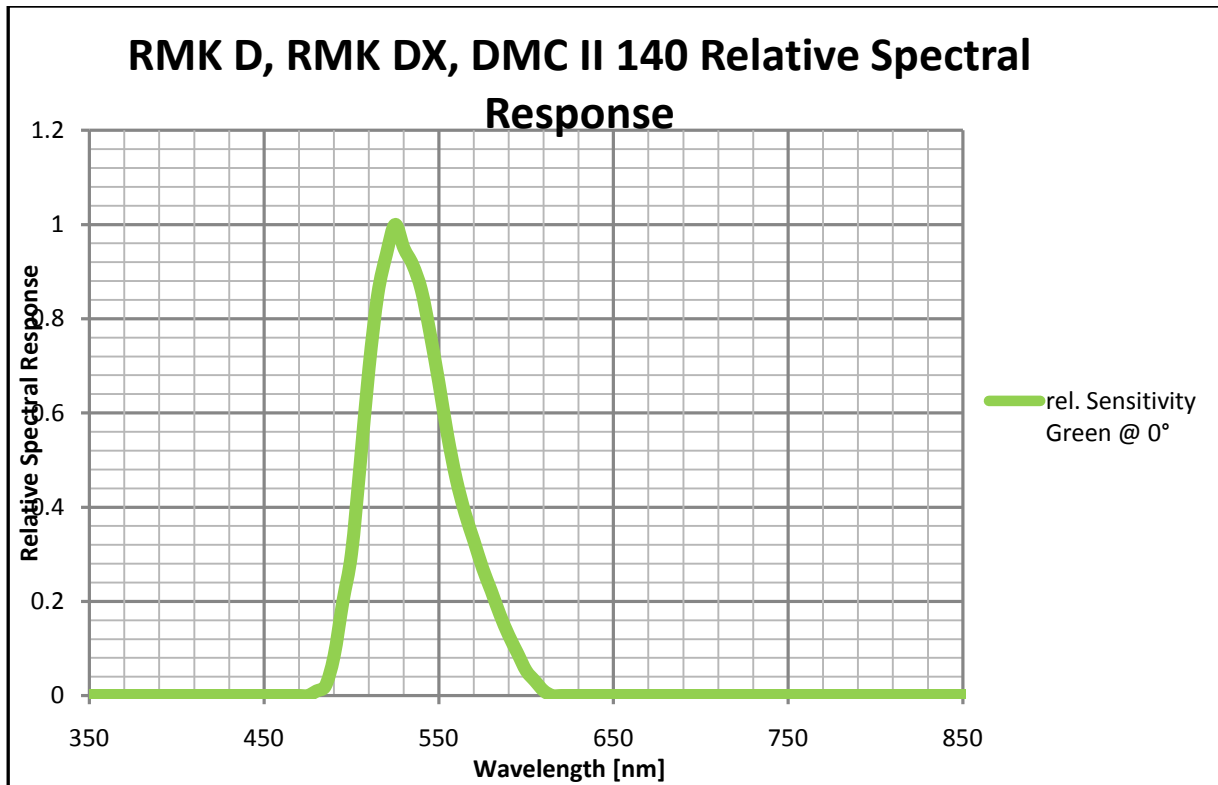
RMK D / RMK DX / DMC II MS Green – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Green camera

Spectral response curve of the single camera head.



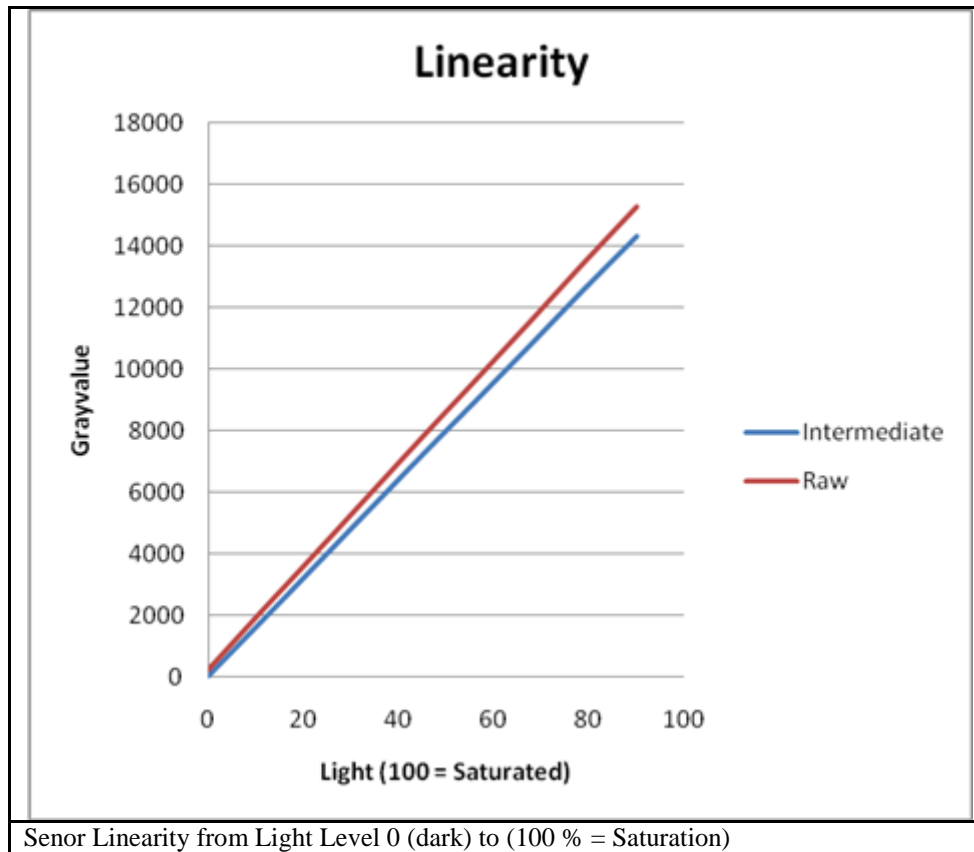
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 140 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera 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:

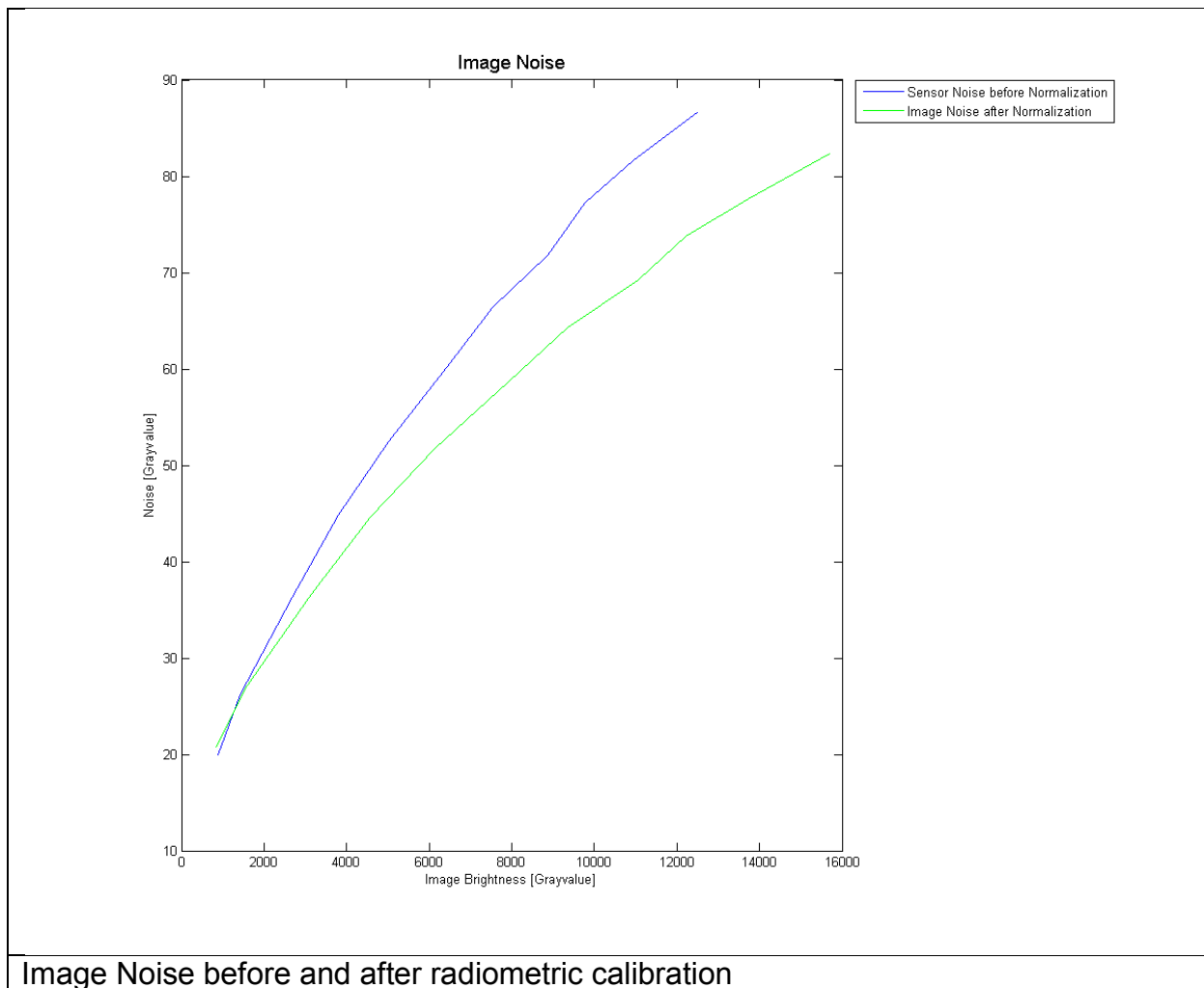


The deviation from the linearity is below 1%.

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.

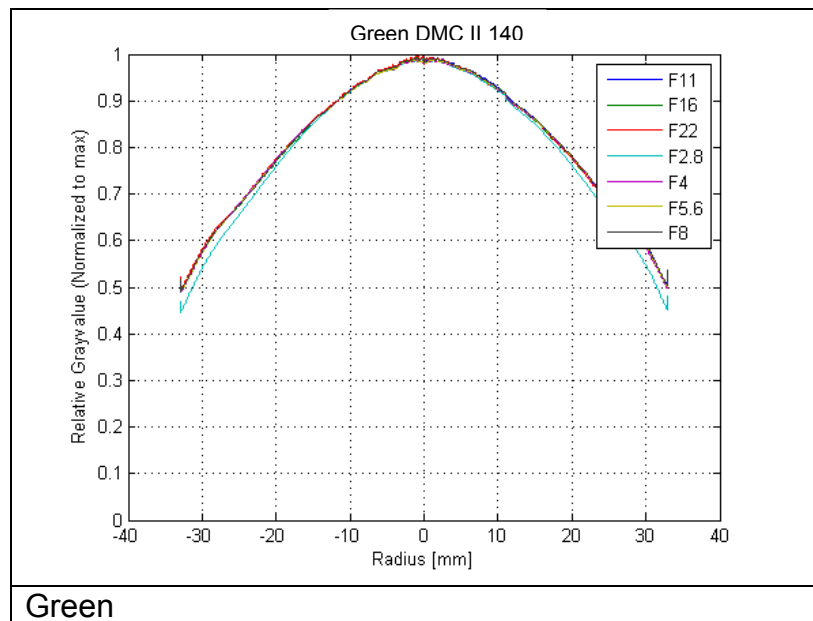


Radiometric Calibration

Aperture Correction

Green (00118835)

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.



This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Green (00118835)

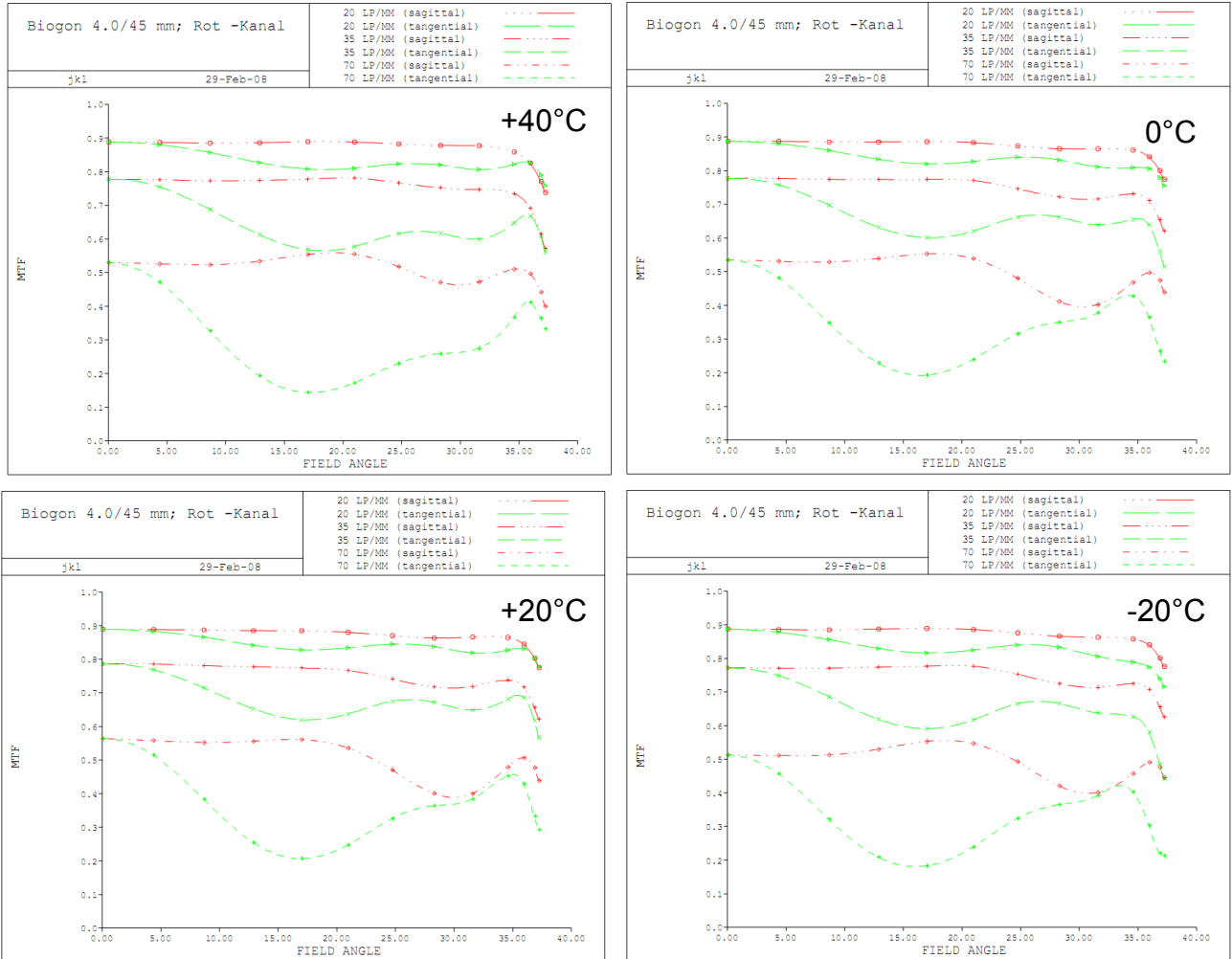
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix "Defect Pixel Recognition".

Revision of calibration:	2				
CCDRevision:	1				
Date Number:		1274346044			
Date:		100520			
Number of defect pixels:	5				
Number of defect clusters:	0				
Number of defect columns:	1				
Nr	Row	Column			
0	4876	507			
1	2012	2046			
2	4930	2730			
3	5783	5563			
4	5782	5564			
Defect Column	RowStart	ColumnStart	RowEnd	ColumnEnd	
0	2874	97	6845	98	

Optical System

Modulation Transfer Function, MTF of Red camera

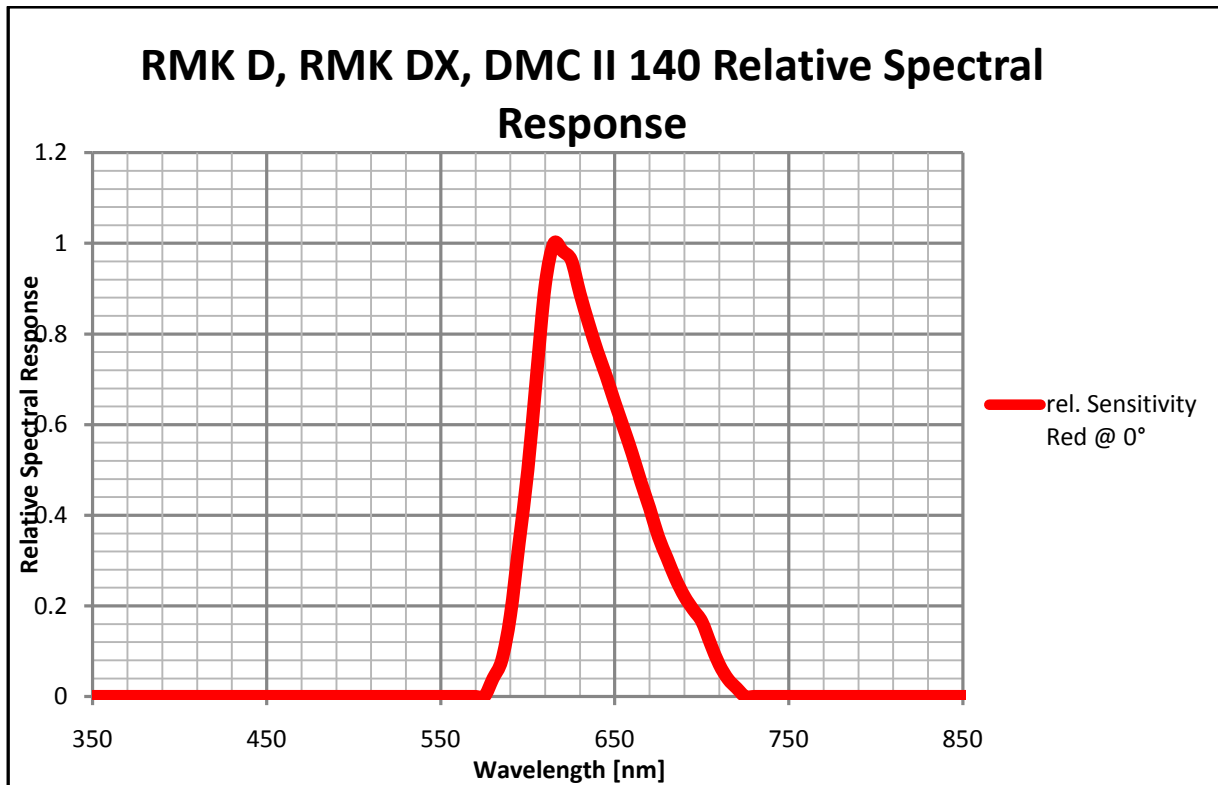
RMK D / RMK DX / DMC II MS Red – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Red camera

Spectral Response Curves of the single camera head.



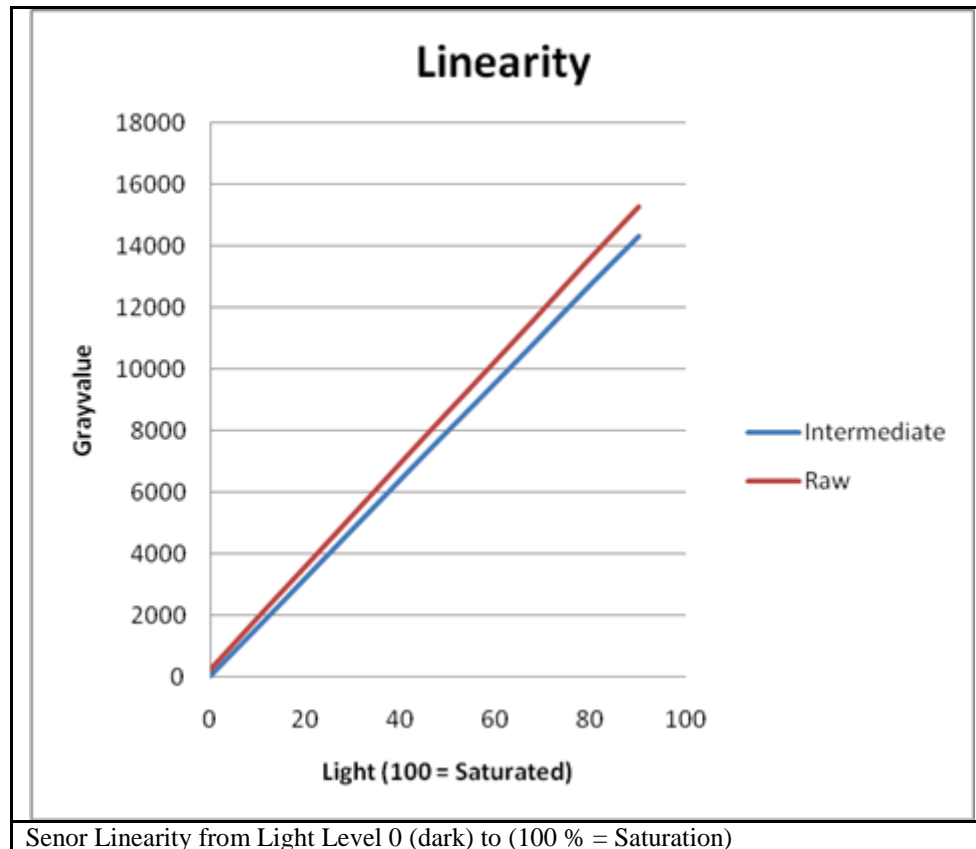
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 140 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera 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:



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.

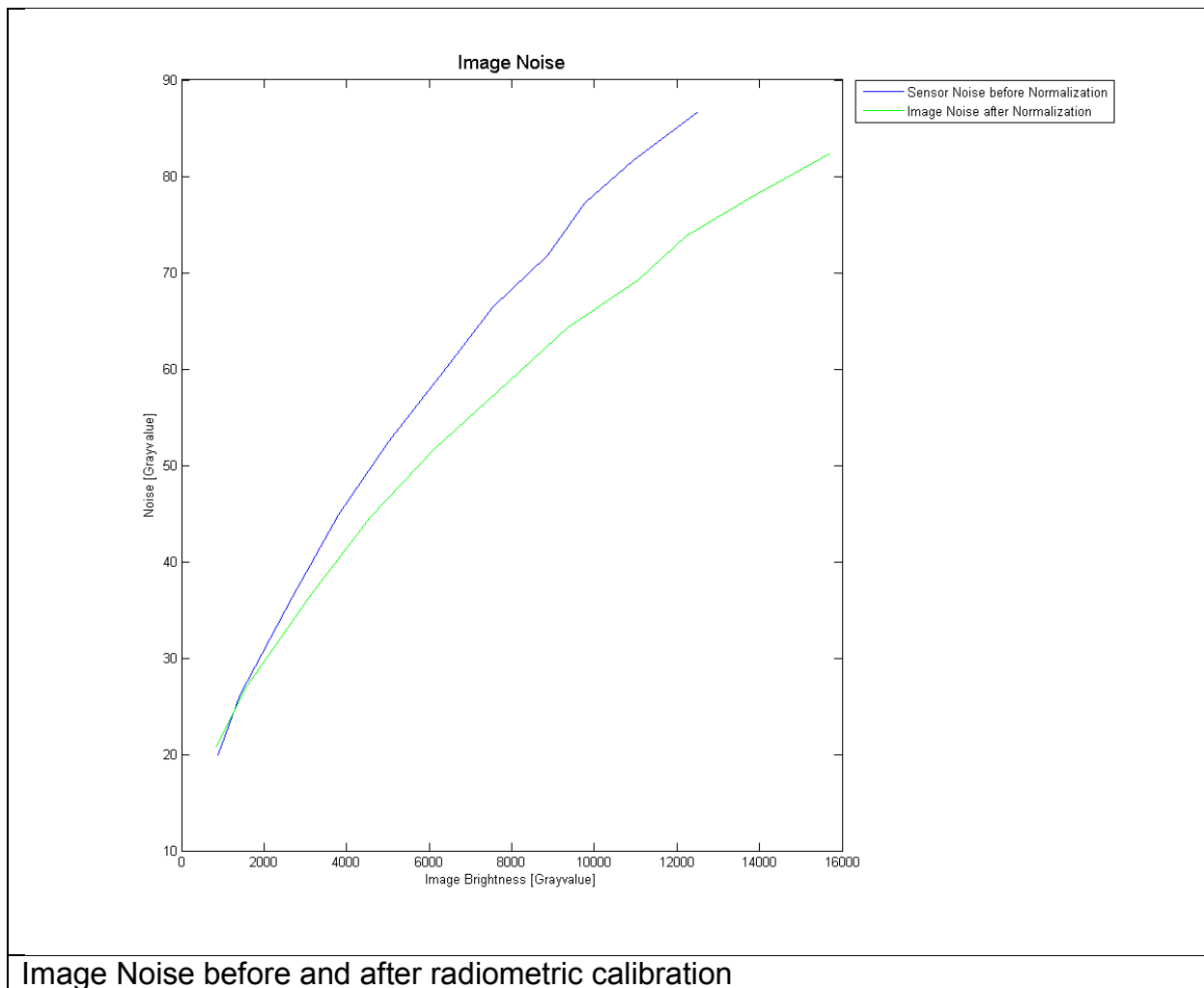


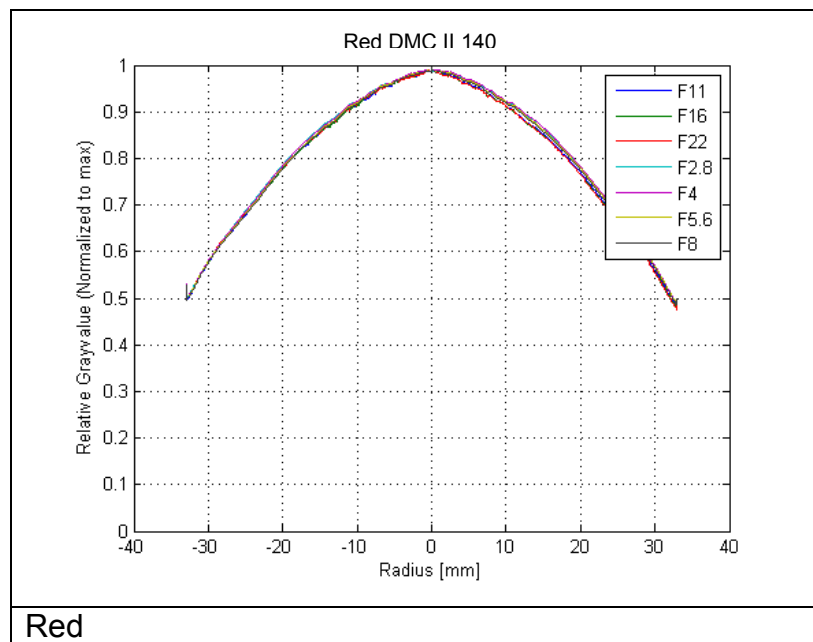
Image Noise before and after radiometric calibration

Radiometric Calibration

Aperture Correction

Red (00118793)

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.



This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Red (00118793)

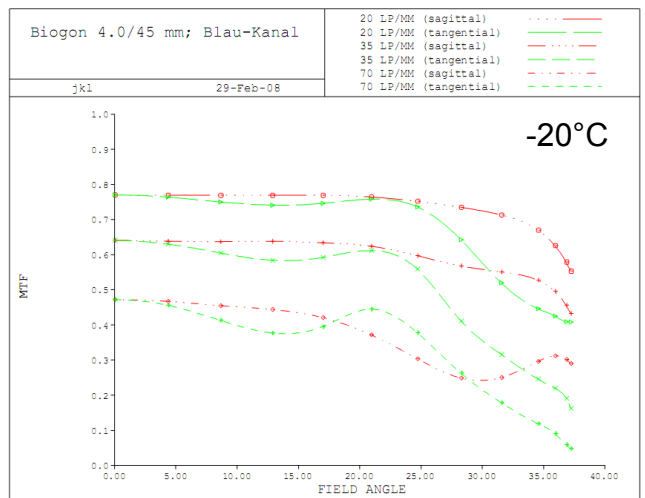
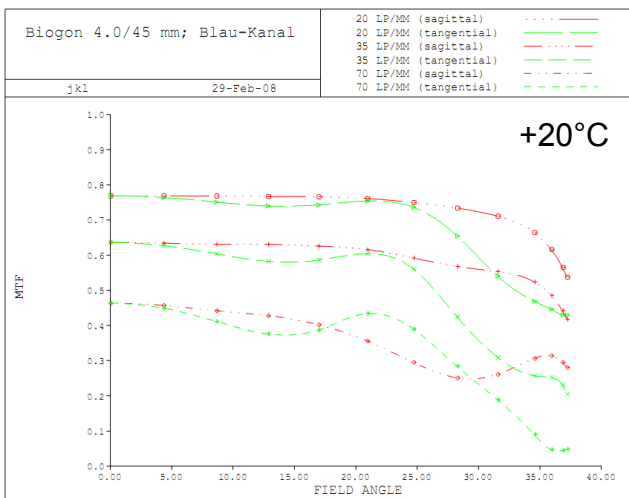
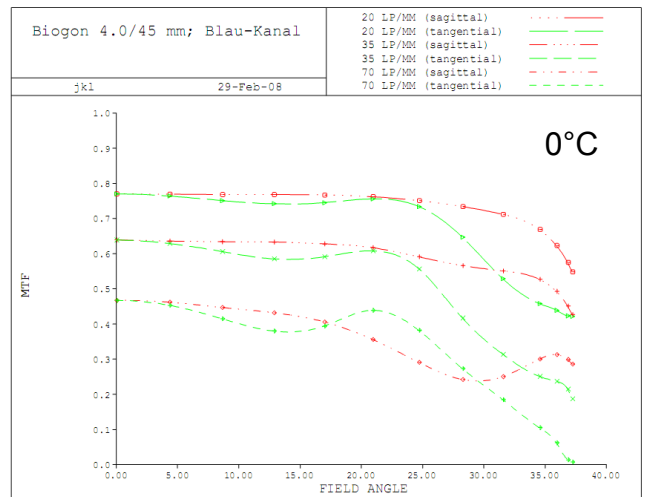
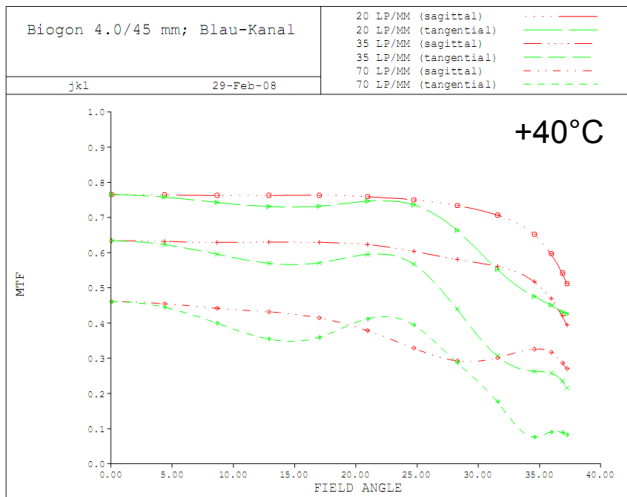
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix "Defect Pixel Recognition".

Revision of calibration:	2				
CCDRevision:	1				
Date Number:		1272034801			
Date:		100423			
Number of defect pixels:	4				
Number of defect clusters:	0				
Number of defect columns:	0				
Nr	Row	Column			
0	3692	464			
1	3691	465			
2	3693	465			
3	1510	2209			
Defect Column	RowStart	ColumnStart	RowEnd	ColumnEnd	

Optical System

Modulation Transfer Function, MTF of Blue camera

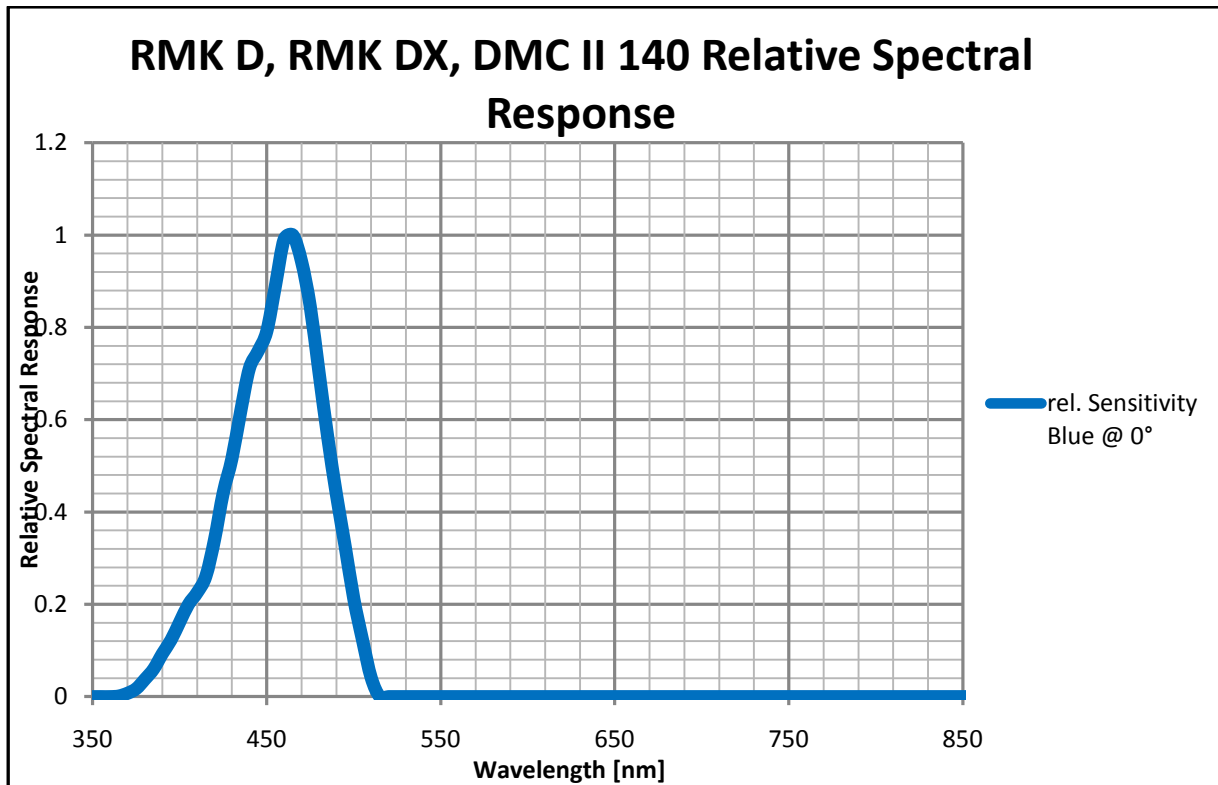
RMK D / RMK DX / DMC II MS Blue – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Blue camera

Spectral Response Curves of the single camera head.



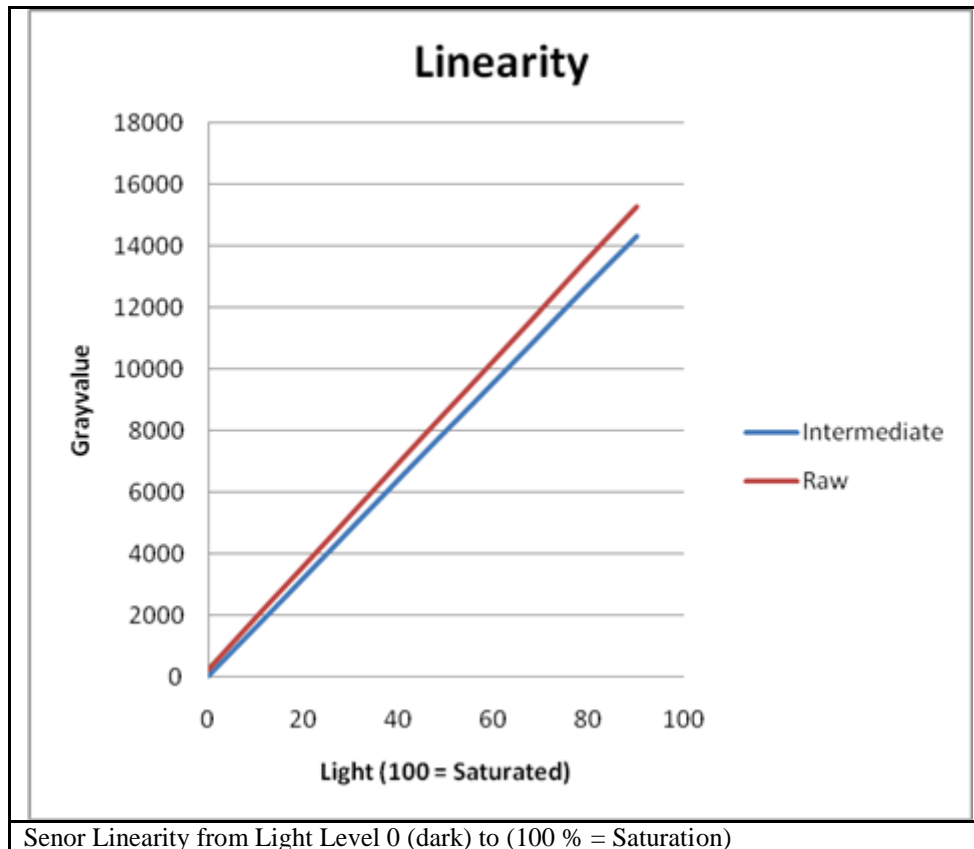
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 140 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera 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:

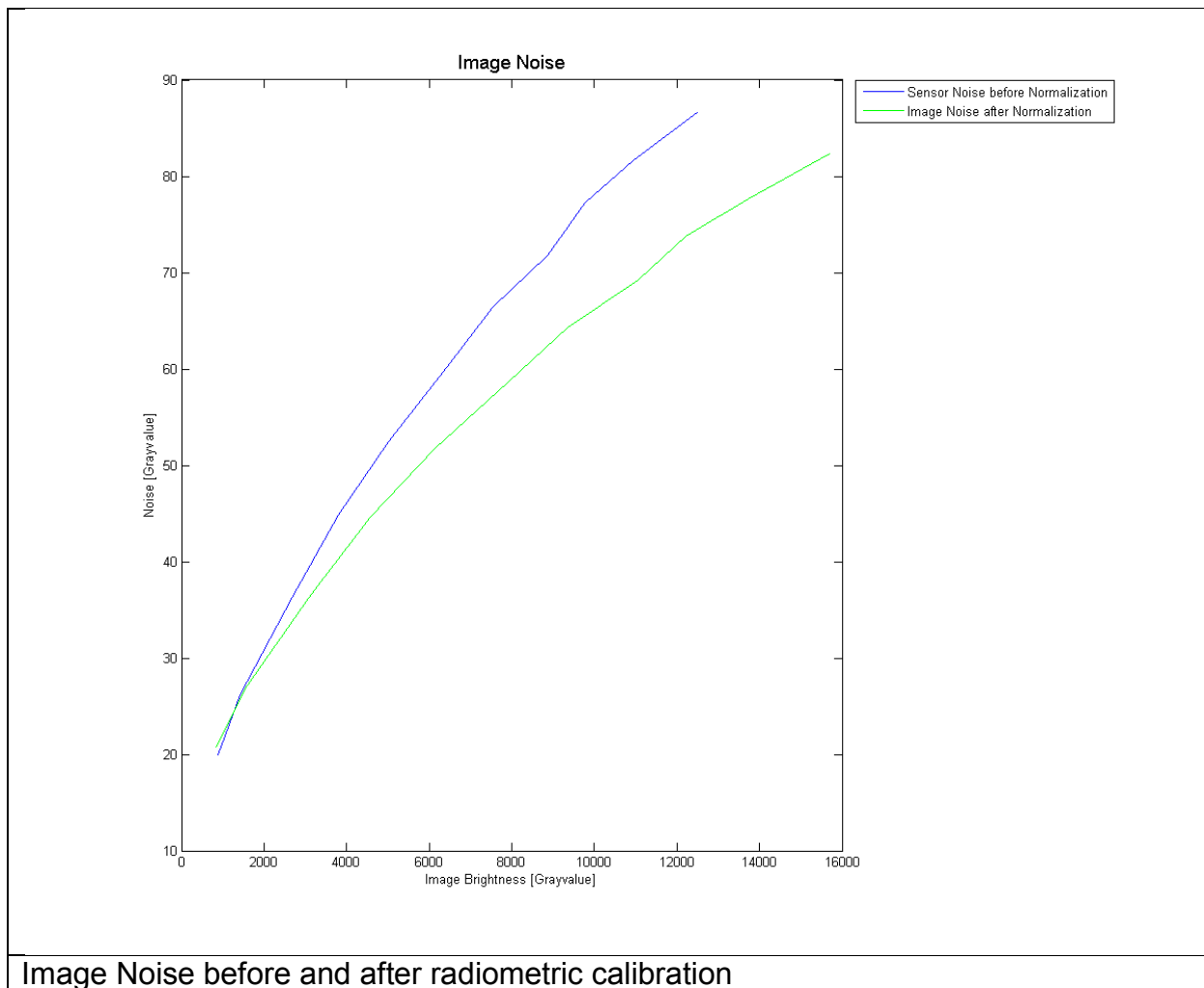


The deviation from the linearity is below 1%.

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.

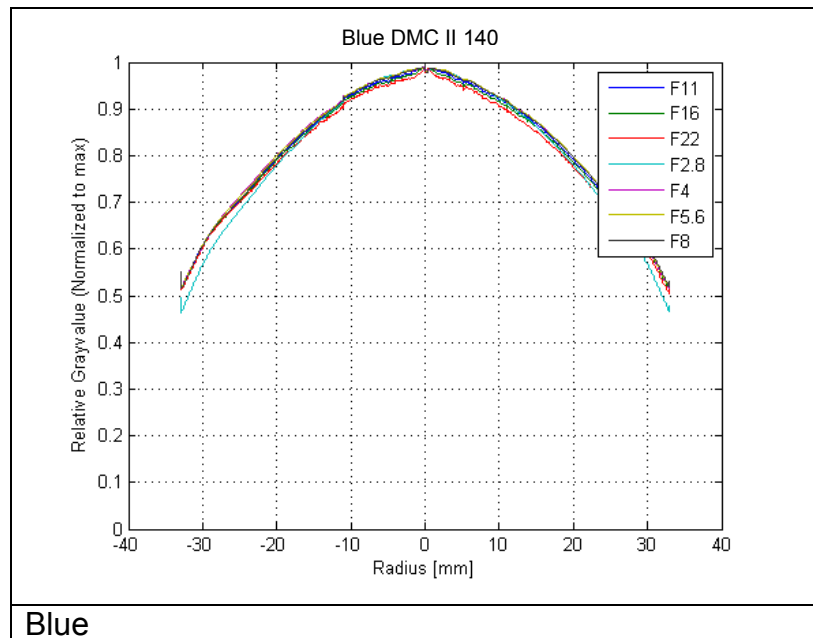


Radiometric Calibration

Aperture Correction

Blue (00118826)

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.



This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Blue (00118826)

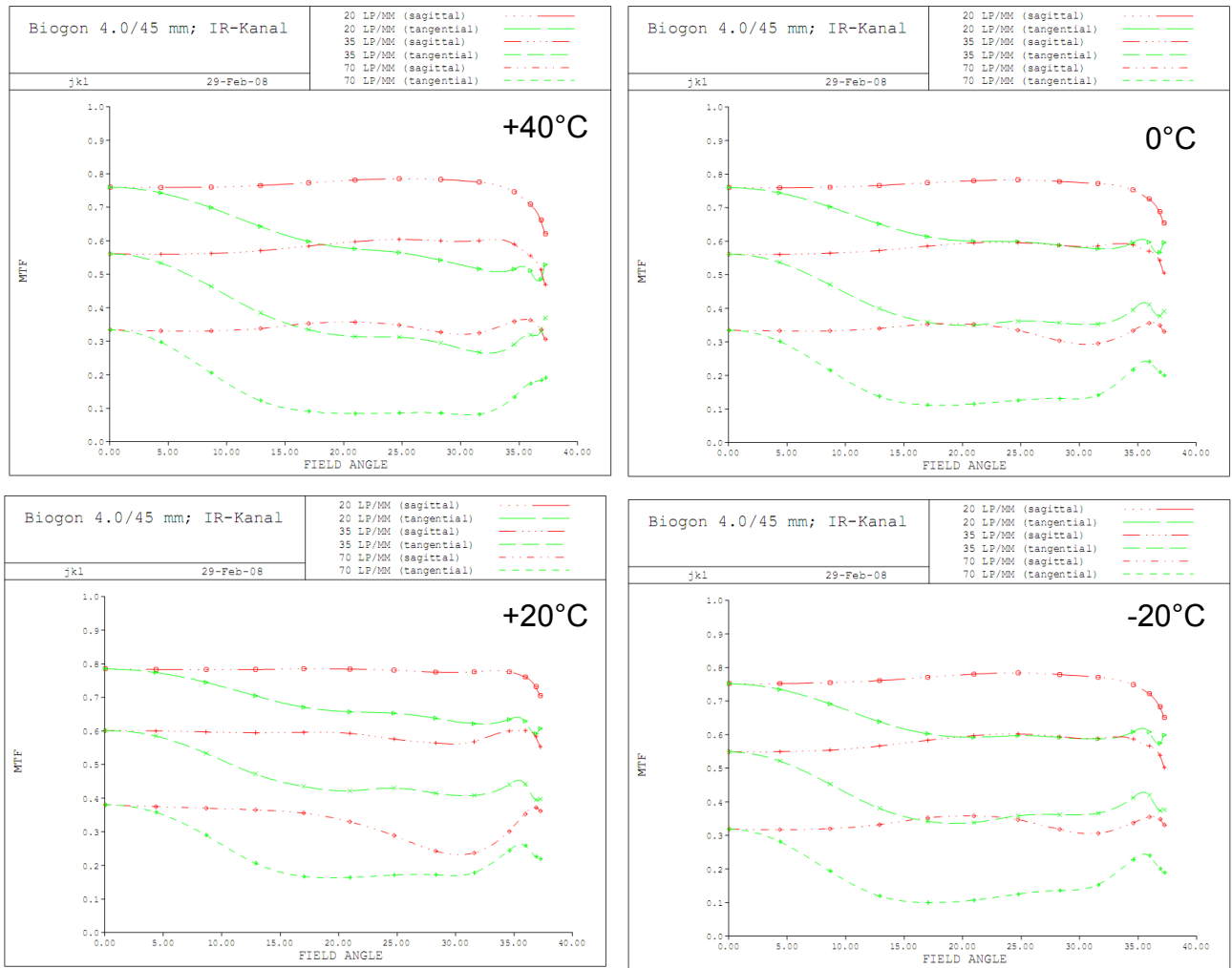
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images. The quantity and cumulative percentage and specification of defects is described in Appendix "Defect Pixel Recognition".

Revision of calibration:	2				
CCDRevision:	1				
Date Number:		1272079416			
Date:		100424			
Number of defect pixels:	2				
Number of defect clusters:	0				
Number of defect columns:	0				
Nr	Row	Column			
0	71	3041			
1	1438	5001			
Defect Column	RowStart	ColumnStart	RowEnd	ColumnEnd	

Optical System

Modulation Transfer Function, MTF of IR camera

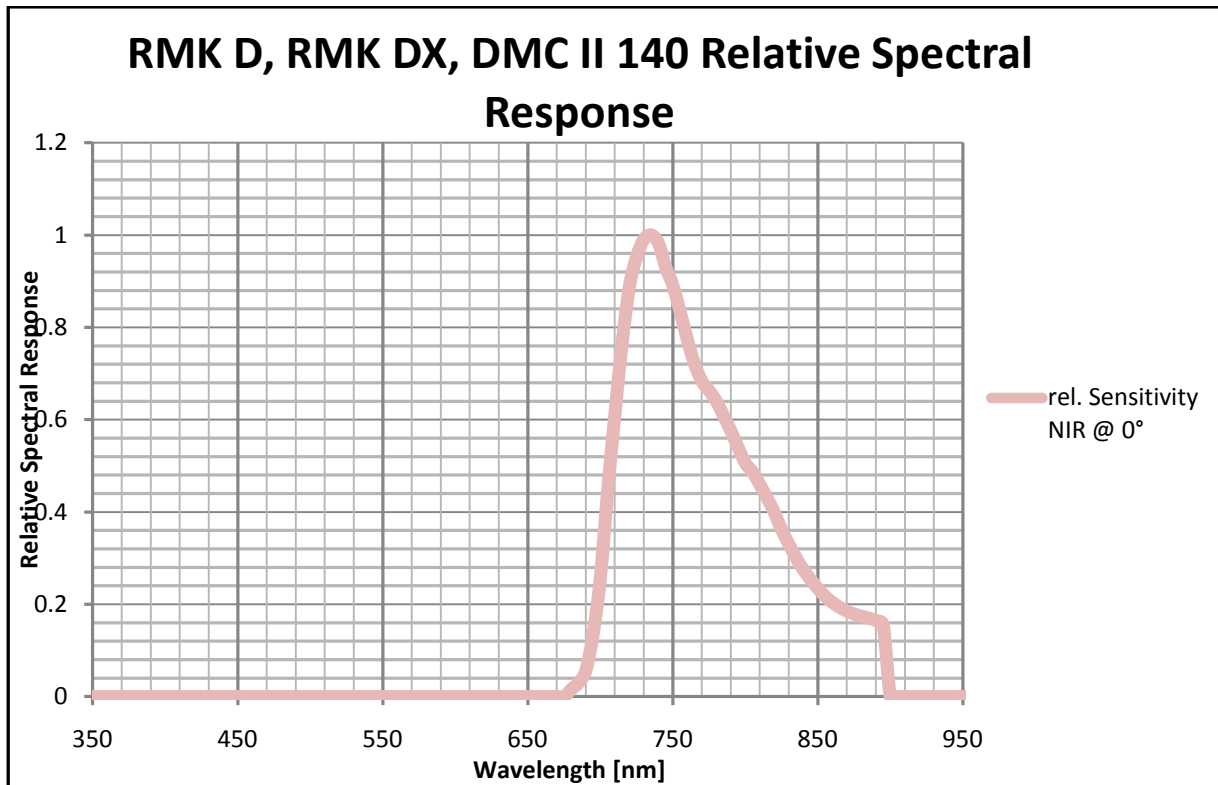
RMK D / RMK DX / DMC II MS IR – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of NIR camera

Spectral Response Curves of the single camera head.



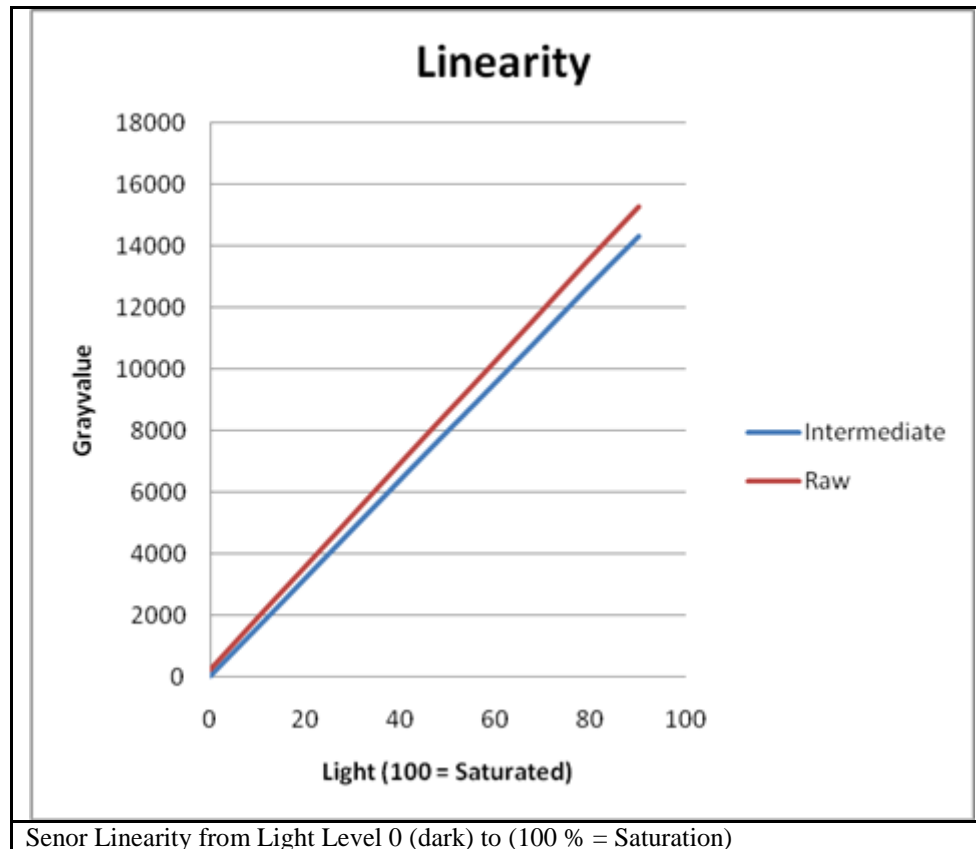
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC II 140 is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera 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:



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.

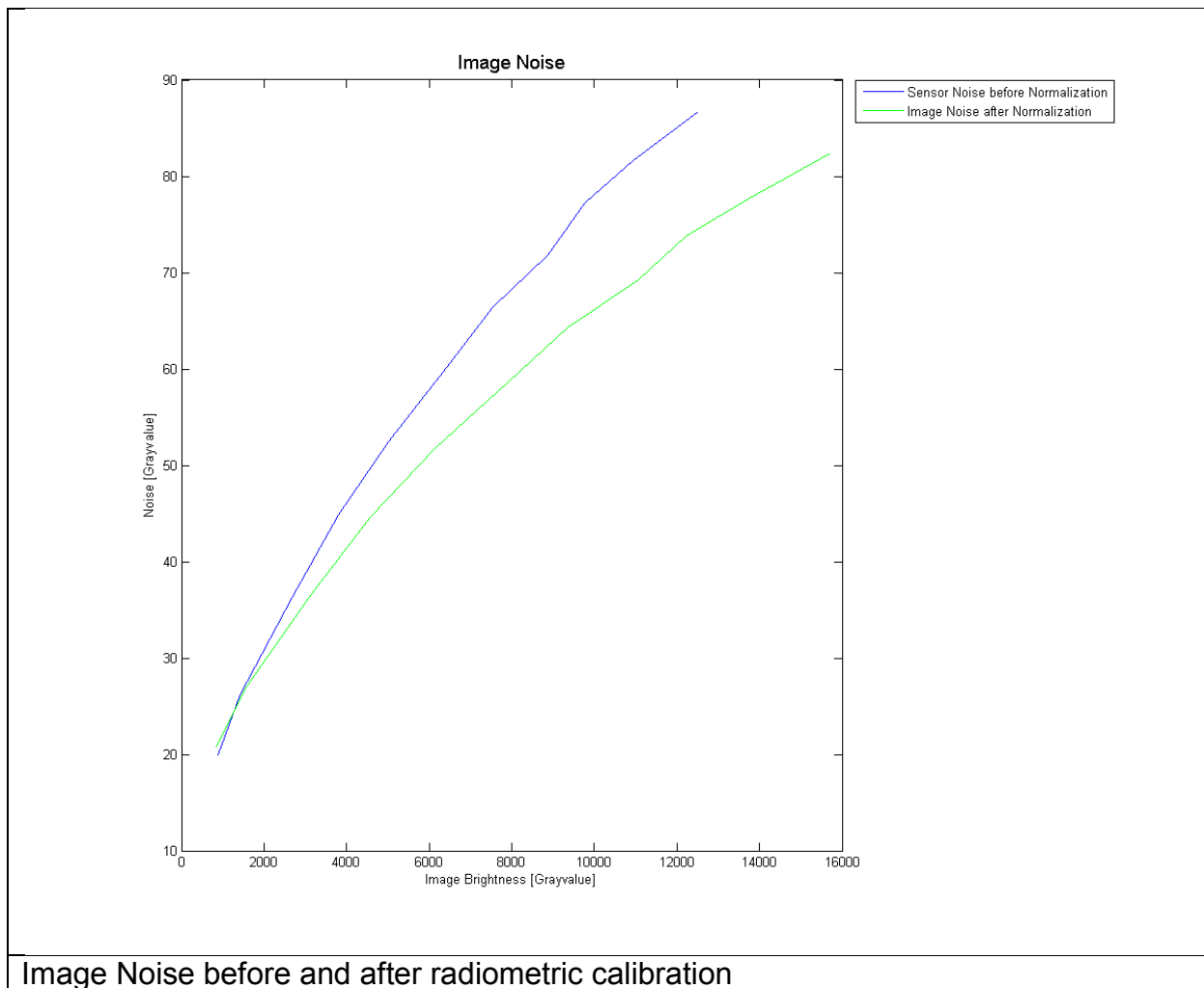


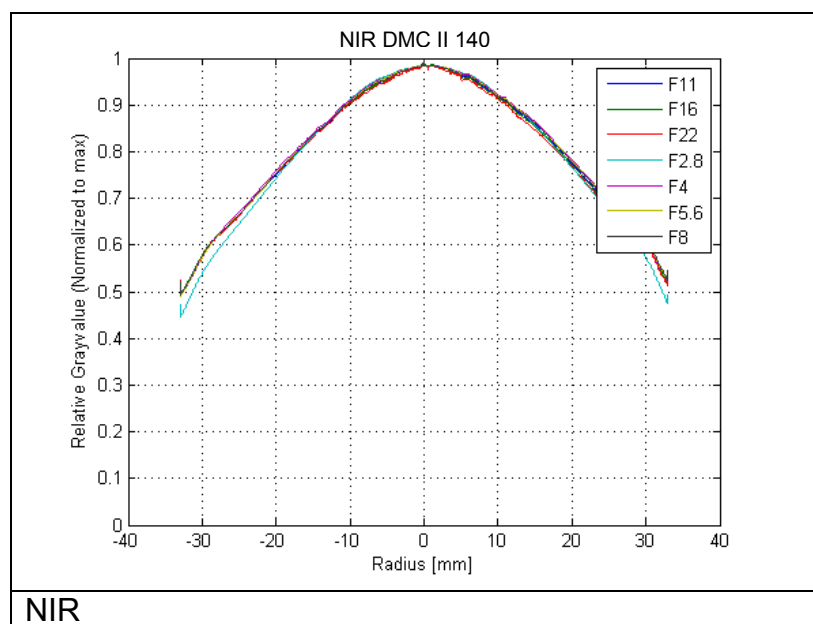
Image Noise before and after radiometric calibration

Radiometric Calibration

Aperture Correction

NIR (00118796)

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.



This is a camera type specific calibration.

Radiometric Calibration

Defect Pixel

NIR (00118796)

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:	2				
CCDRevision:	1				
Date Number:		1272057101			
Date:		100423			
Number of defect pixels:	5				
Number of defect clusters:	0				
Number of defect columns:	0				
Nr	Row	Column			
0	6066	2905			
1	6067	2907			
2	208	3021			
3	4538	3135			
4	4538	3136			
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 $0.1\mu\text{m}$ (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 $\pm 30\%$ 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 \leq 2000 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 \leq 80 MS \leq 20
	Max double Column	PAN \leq 20 MS \leq 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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