

Camera Calibration Certificate
No: DMC III 27550



For

Peregrine Aerial Surveys, Inc.

#201 1255 Townline Road
Abbotsford, B.C. V2T 6E1

Canada

This calibration certificate complies with DIN 18740-4

Camera: DMC III
Manufacturer: Leica Geosystems Technologies, D-73430 Aalen, Germany
Reference: PAN
Serial Number: 00126502 (PAN Head)
Date of Calibration: 06. July 2018
Date of Report: 06. July 2018
Number of Pages: 48

This camera system is certified by Leica Geosystems Technologies and is fully functional within its specifications and tolerances.

Date of Calibration: July 2018

Date of Certification: July 2018



Dipl.Ing. Christian Mueller, Product Manager

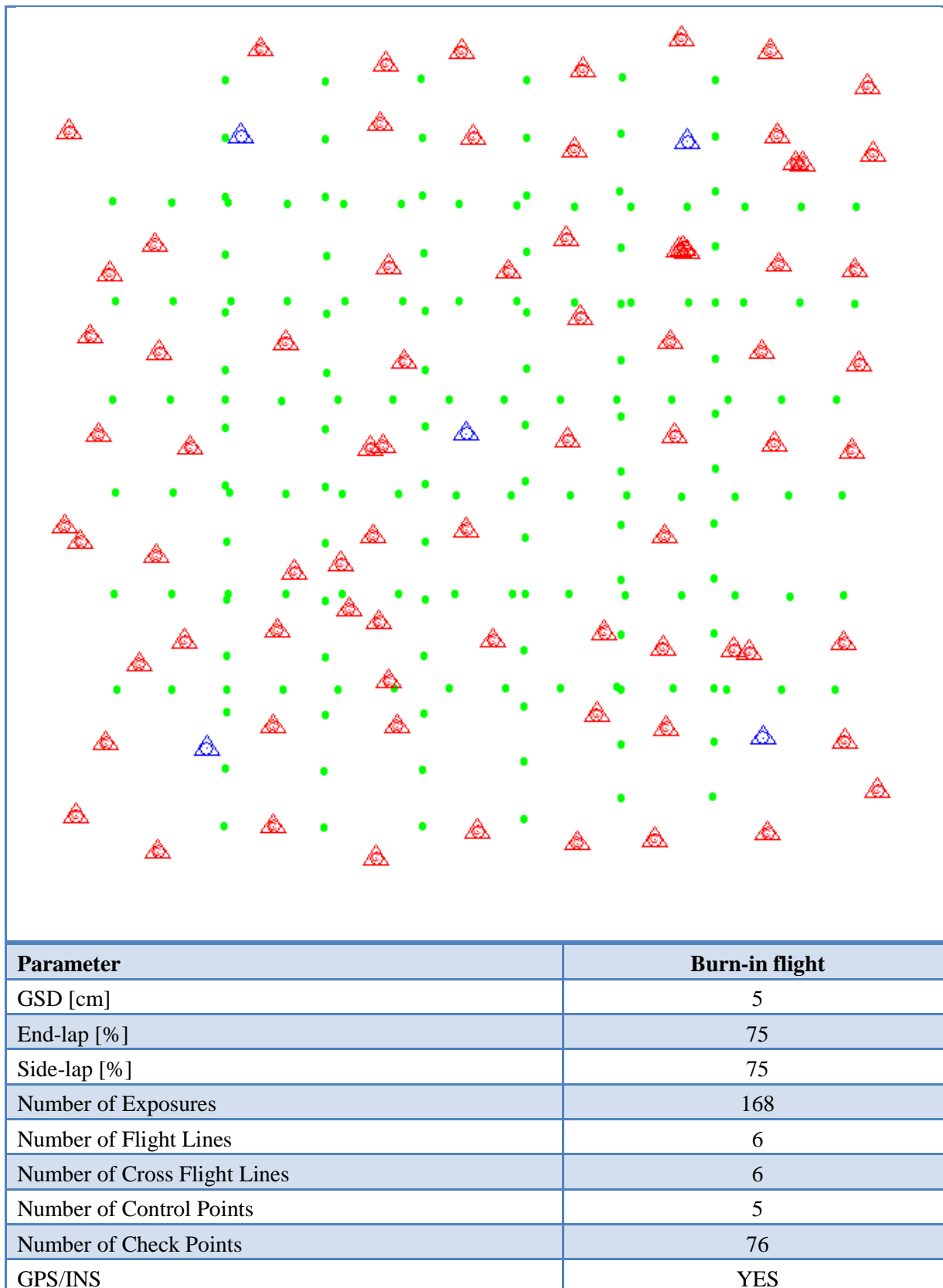
Dipl.Ing. Gerald Kapoun, Technical Consultant

Camera Serial Numbers and Calibration flight

Camera Head	Serial Number	Calib. Date
PAN (reference)	00126502	06.07.2018
MS1 (NIR)	00128786	06.07.2018
MS2 (Blue)	00128804	06.07.2018
MS3 (Red)	00127981	06.07.2018
MS4 (Green)	00128807	06.07.2018

Calibration flight performed: 02. July 2018

Flight parameters of 5cm Calibration Flight



Application

Parameter	Burn-in flight
Weighting for manual measured image points	1.0
Weighting for automatic measured image points	1.0
Weighting for Control Points	2.8 / 2.8 / 1.6
Weighting for GPS	1.6 / 1.6 / 1.6
Weighting for INS	0.2 / 0.2 / 0.1
Modeling of GPS systematic residuals	NO
Bore Sight Alignment (YES/NO)	NO
Camera Self Calibration (YES/NO)	NO

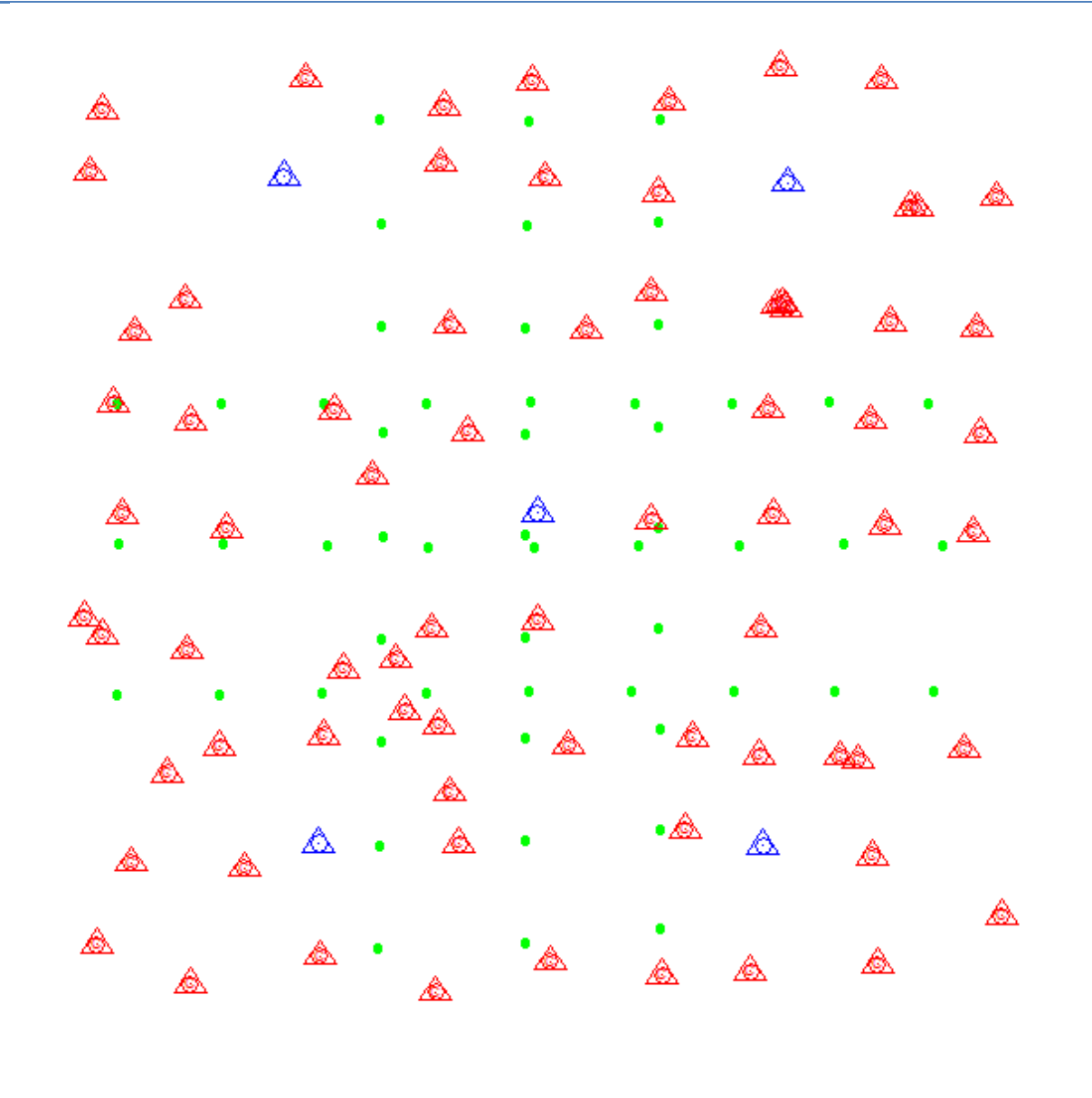
Statistics – Bundleblockadjustment

Parameter	Burn-in flight
Sigma0 [μm]	1.512
Mean Std Dev Photo Position [cm]	1.4 / 1.4 / 0.5
Mean Std Dev Photo Attitude [mdeg]	0.6 / 0.8 / 0.3
Mean Std Dev Control Points [cm]	0.6 / 0.6 / 1.3
Mean Std Dev Check Points [cm]	0.9 / 0.8 / 2.2
RMS Photo Position [cm]	1.1 / 1.1 / 1.1
RMS Photo Attitude [mdeg]	1.4 / 1.4 / 1.4

Statistics – Results

Parameter	Burn-in flight
RMS of Control Points – horizontal [cm]	1.5 / 1.1
Max Ground Residual of Control Points – horizontal [cm]	2.6 / 1.6
RMS of Control Points – vertical [cm]	0.6
Max Ground Residual of Control Points – vertical [cm]	1.1
RMS of Check Points – horizontal [cm]	1.7 / 1.9
Max Ground Residual of Check Points – horizontal [cm]	4.2 / 5.3
RMS of Check Points – vertical [cm]	2.6
Max Ground Residual of Check Points – vertical [cm]	5.9

Flight parameters of independent 8cm Reference Block

	
Parameter	Burn-in flight
GSD [cm]	8
End-lap [%]	70
Side-lap [%]	60
Number of Exposures	54
Number of Flight Lines	3
Number of Cross Flight Lines	3
Number of Control Points	5
Number of Check Points	72
GPS/INS	YES

Application

Parameter	Burn-in flight
Weighting for manual measured image points	1.0
Weighting for automatic measured image points	1.0
Weighting for Control Points	6.9 / 6.9 / 3.9
Weighting for GPS	3.9 / 3.9 / 3.9
Weighting for INS	0.2 / 0.2 / 0.1
Modeling of GPS systematic residuals	NO
Bore Sight Alignment (YES/NO)	NO
Camera Self Calibration (YES/NO)	NO

Statistics – Bundleblockadjustment


Parameter	Burn-in flight
Sigma0 [μm]	1.491
Mean Std Dev Photo Position [cm]	2.5 / 2.5 / 1.9
Mean Std Dev Photo Attitude [mdeg]	0.7 / 0.7 / 0.4
Mean Std Dev Control Points [cm]	1.0 / 1.0 / 1.7
Mean Std Dev Check Points [cm]	1.5 / 1.5 / 3.8
RMS Photo Position [cm]	1.2 / 0.9 / 1.0
RMS Photo Attitude [mdeg]	0.5 / 0.6 / 0.5

Statistics – Results from independent Referenceblock

Parameter	Burn-in flight
RMS of Control Points – horizontal [cm]	1.8 / 1.5
Max Ground Residual of Control Points – horizontal [cm]	2.7 / 2.9
RMS of Control Points – vertical [cm]	1.1
Max Ground Residual of Control Points – vertical [cm]	1.6
RMS of Check Points – horizontal [cm]	2.3 / 2.5
Max Ground Residual of Check Points – horizontal [cm]	6.2 / 6.7
RMS of Check Points – vertical [cm]	3.7
Max Ground Residual of Check Points – vertical [cm]	7.2

The results of the aerial triangulation were generated with ImageStation Automatic Triangulation (ISAT), 2016, from Intergraph Inc.. 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. Gerald Kapoun

06.07.2018
Date

Geometric Calibration

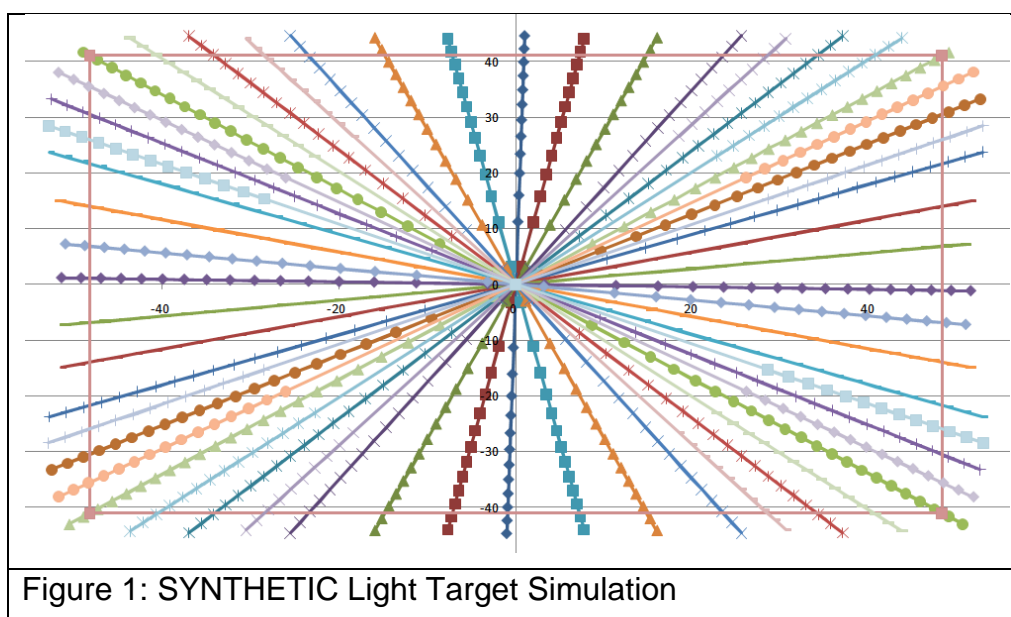
The output image geometry is based on the Pan Camera head (reference head = master camera). All other camera heads are registered and aligned to this head. Aerial triangulation checks overall system performance based on.

Output image

Reference Camera	PAN	
Serial Number	00126502	
Number of rows/columns [pixels]	25728 x 14592	
Pixel Size [μm]	3.900 x 3.900	
Image Size [mm]	100.3392 x 56.9088	
Focal Length [mm]	92.0000 mm	+ /- 0.001 mm
Principal Point [mm]	X= 0.0000 mm, Y= 0.0000 mm	+ /- 0.001 mm

The “SYNTHETIC” geometric calibration is based on a simulated mathematical lens distortion calculation based on the detailed optical design data of the lens.

It is equivalent to the DMC II collimator calibration procedure, projecting 800 “light targets” on 28 lines that are distributed diagonally on the focal plane.



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 1.0 microns and the RMSE values are below 0.5 microns.

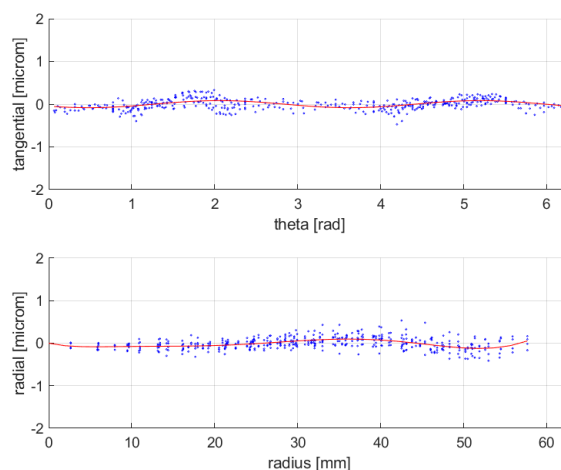


Figure 2: Tangential/Radial Distortion Residuals

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

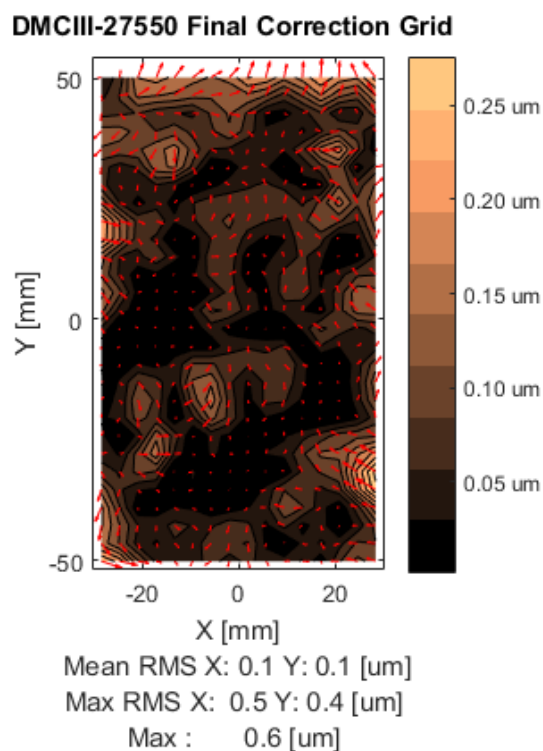


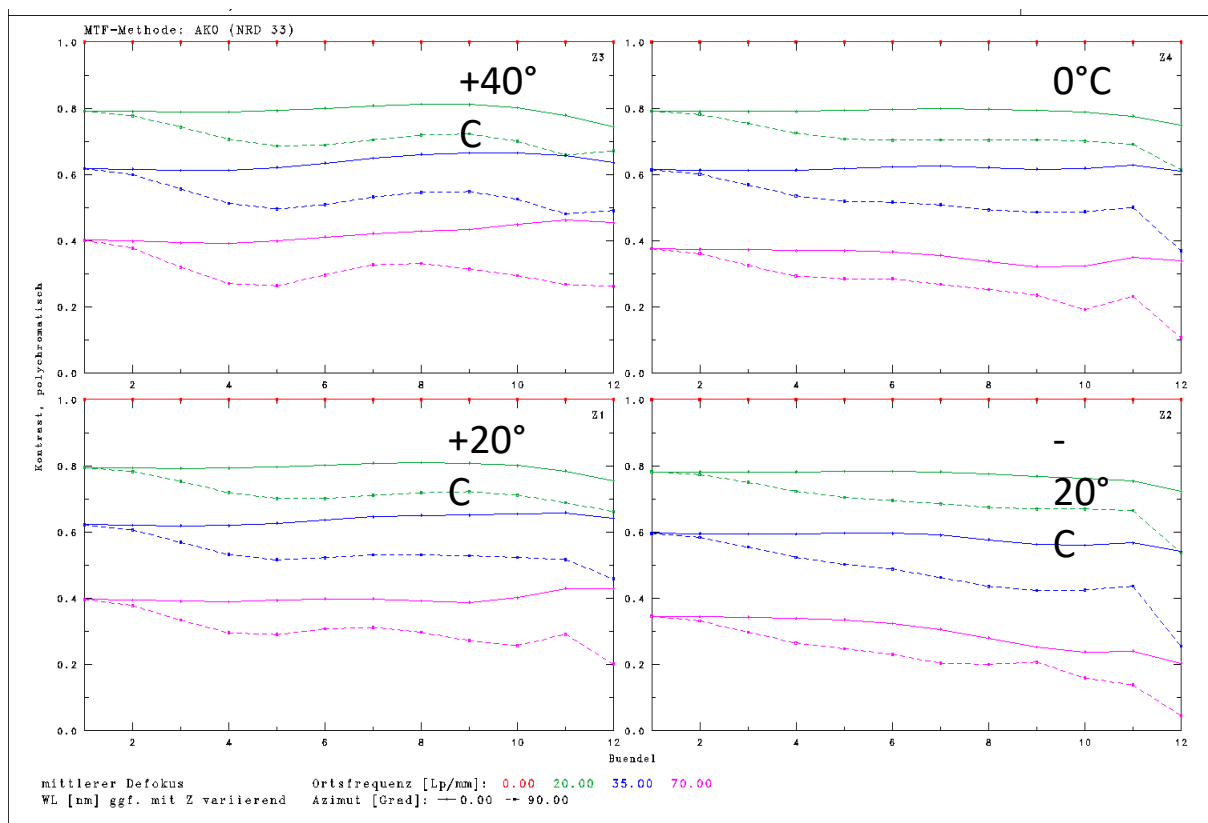
Figure 3: 2-D Image Residuals.

Mean RMS ≤ 0.1 um (maximum 0.5 microns)

Optical System

Modulation Transfer Function, MTF of PAN Camera (Reference)

DMC III PAN – MTF Polychromatic F/5.6 ; 92 mm – Temperature Stability

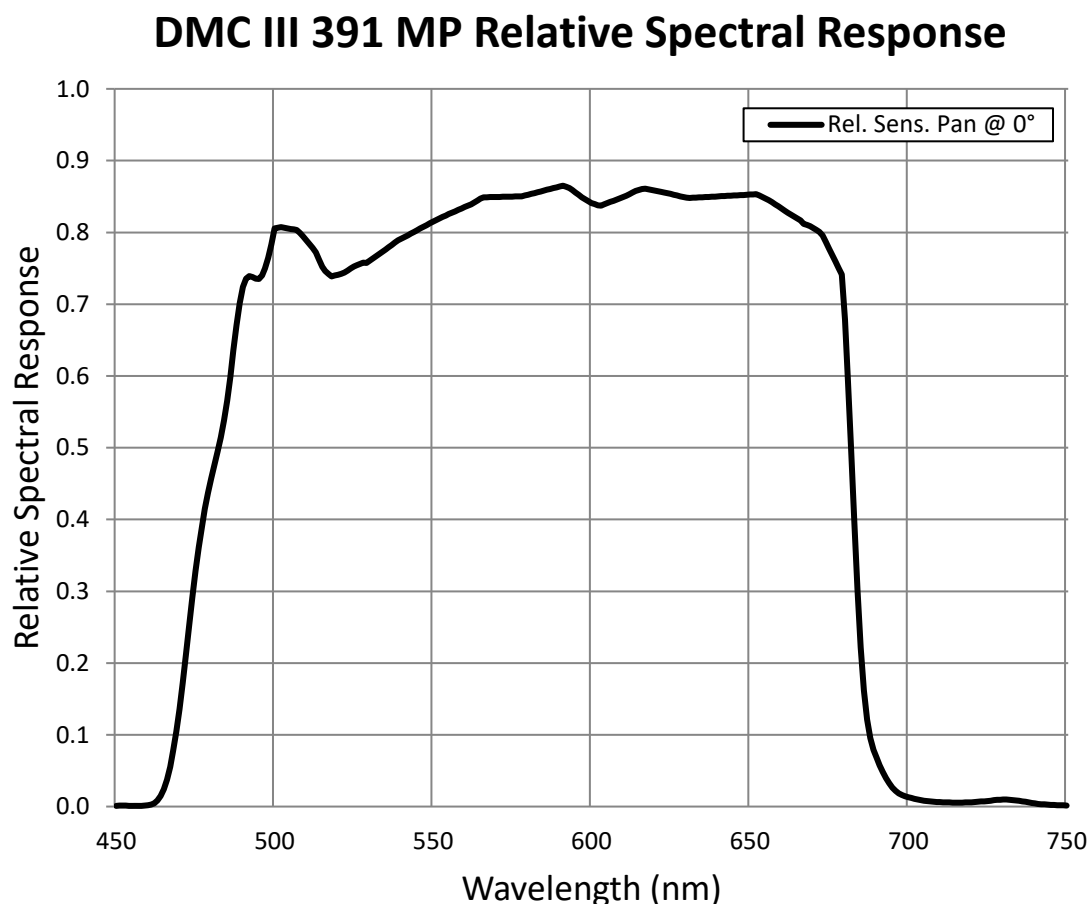


The MTF measurement is camera type specific and shows variation of the MTF within the specified temperature range.

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 III is calibrated with a NIST traceable spectroradiometer and an integrating sphere. This allows computing pixel radiance values from pixels digital numbers and is a camera type specific calibration.

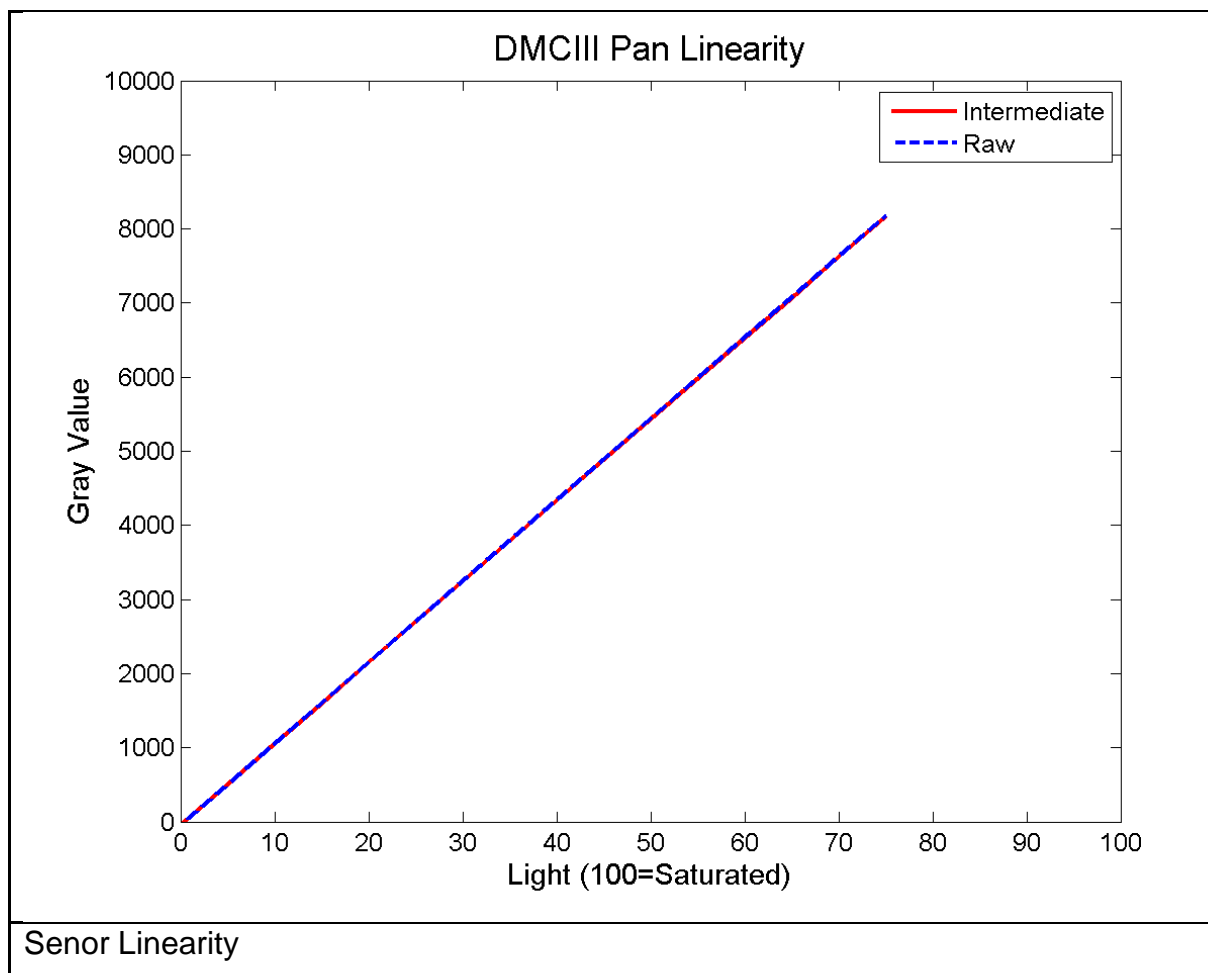
This is a camera type specific measurement.

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:



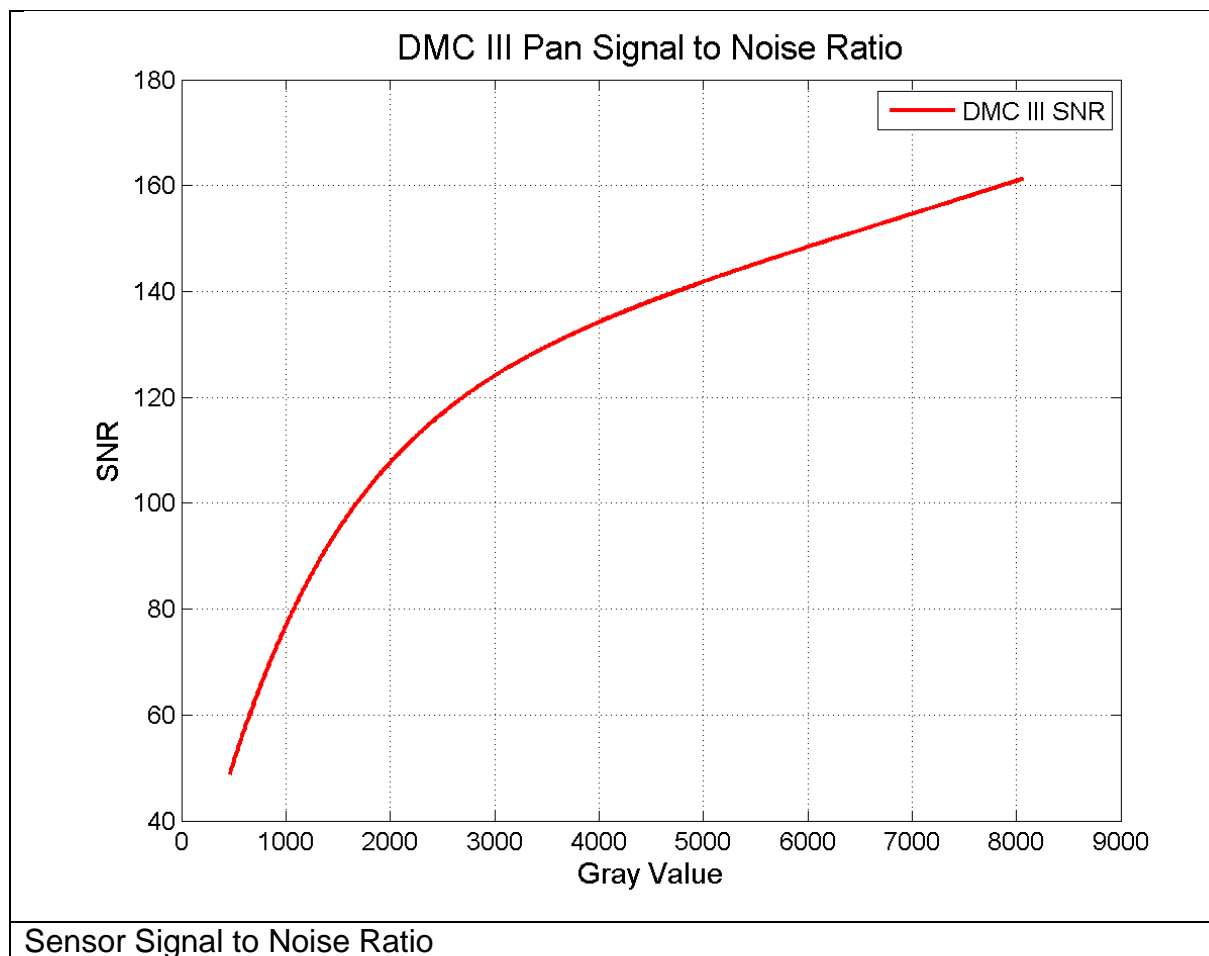
The deviation from the linearity is below 1%.

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.



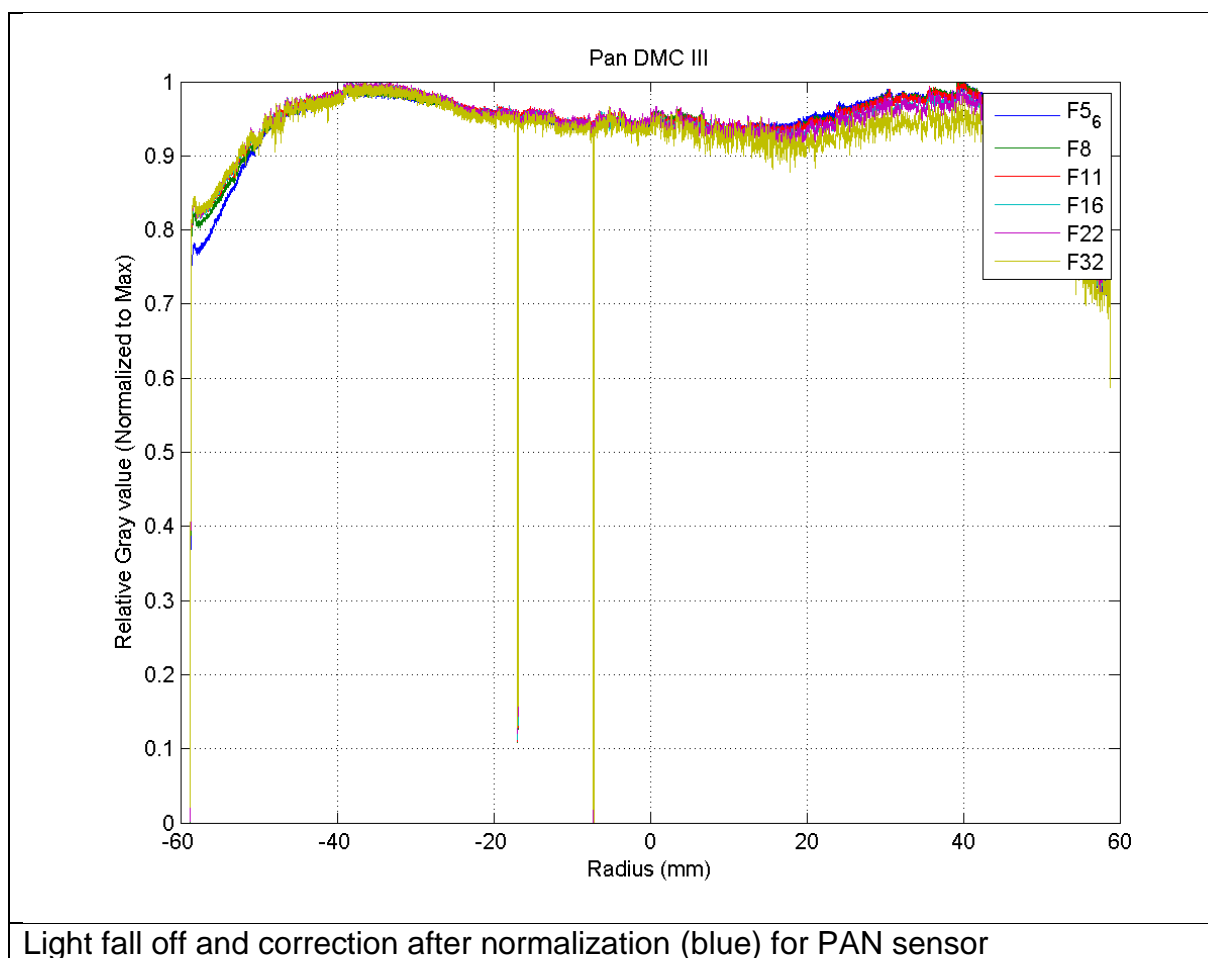
This is from a camera type specific calibration.

Radiometric Calibration

Aperture Correction (Reference)

Camera PAN (00126502)

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 $\pm 2.5\%$ of the dynamic range.



This is from a camera type specific calibration.

Radiometric Calibration

Defect Pixel

Camera PAN (00126502)

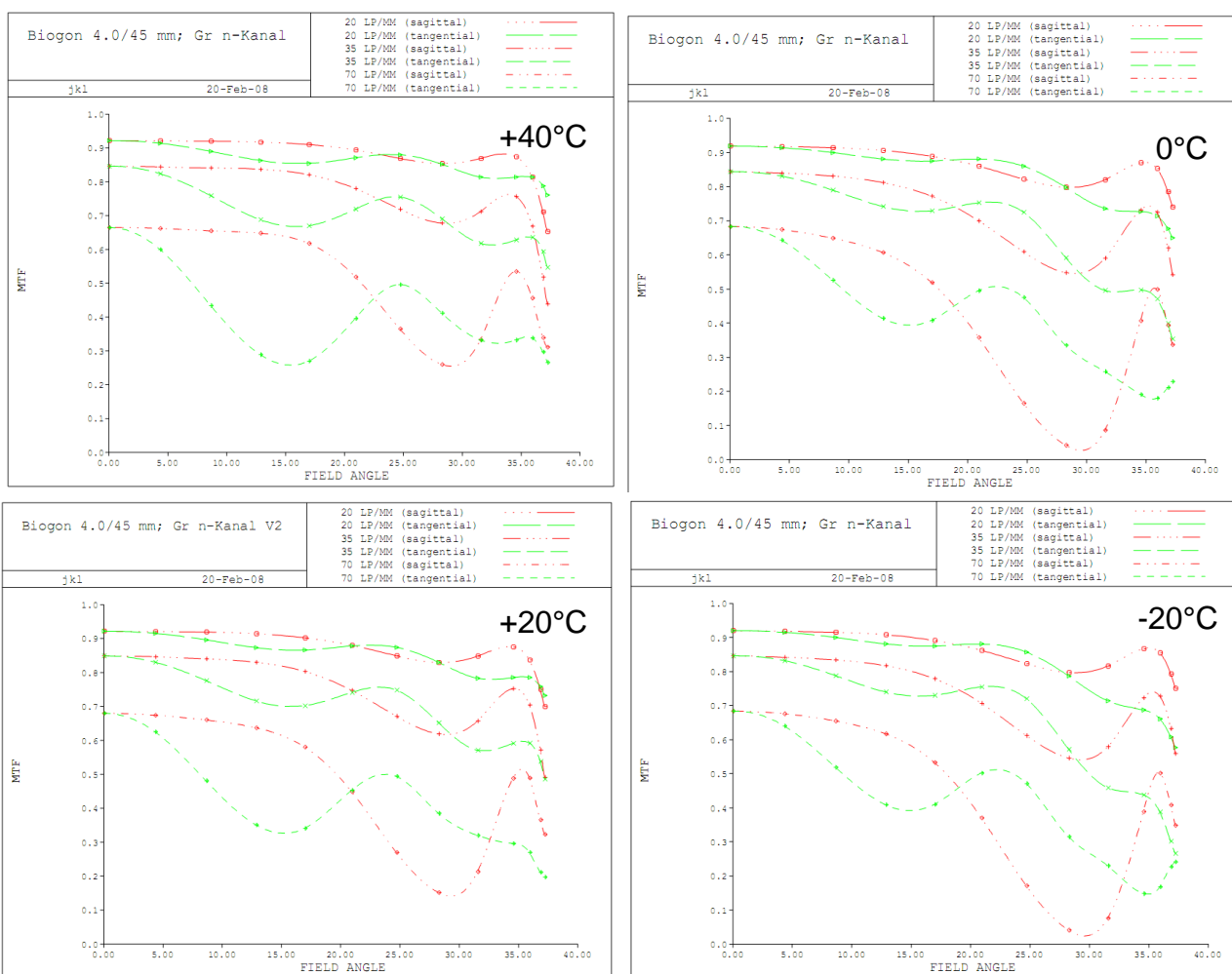
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images.

The quantity and cumulative percentage and specification of defects are described in Appendix “Defect Pixel Recognition” at page 46.

Optical System

Modulation Transfer Function, MTF of Green camera

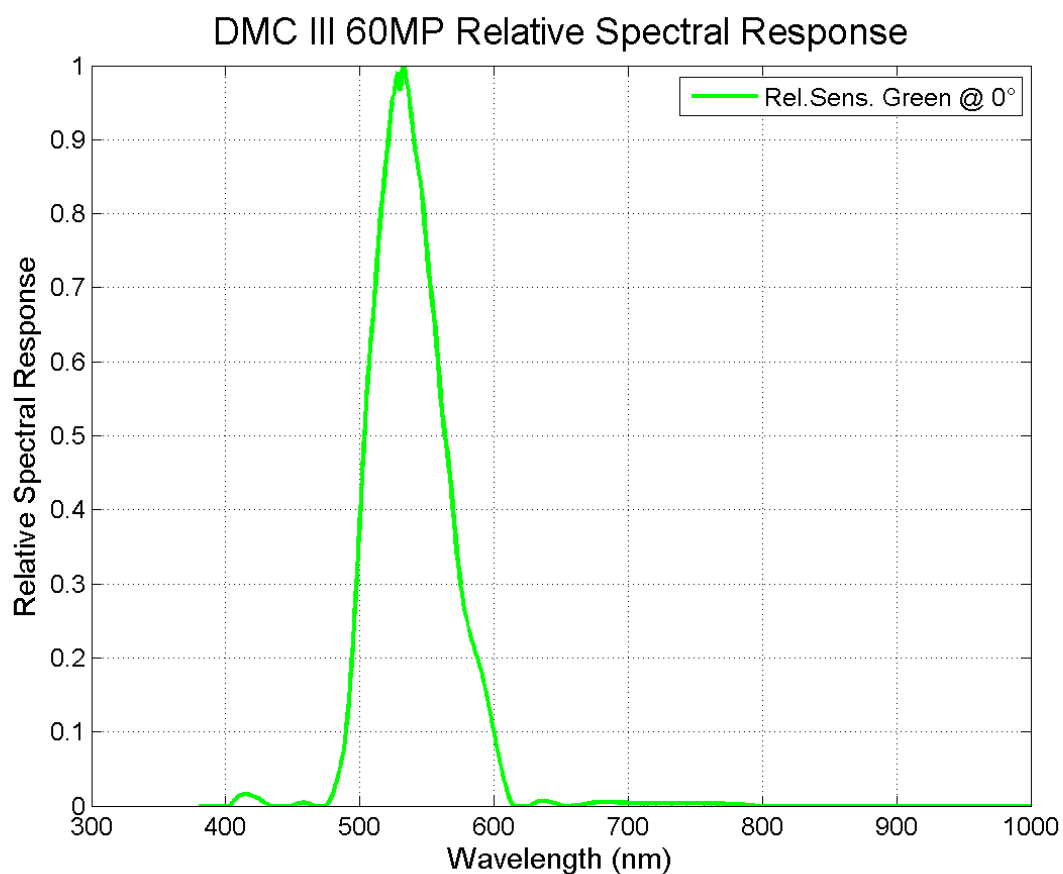
DMC III MS Green – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Green camera

Spectral response curve of the single camera head.

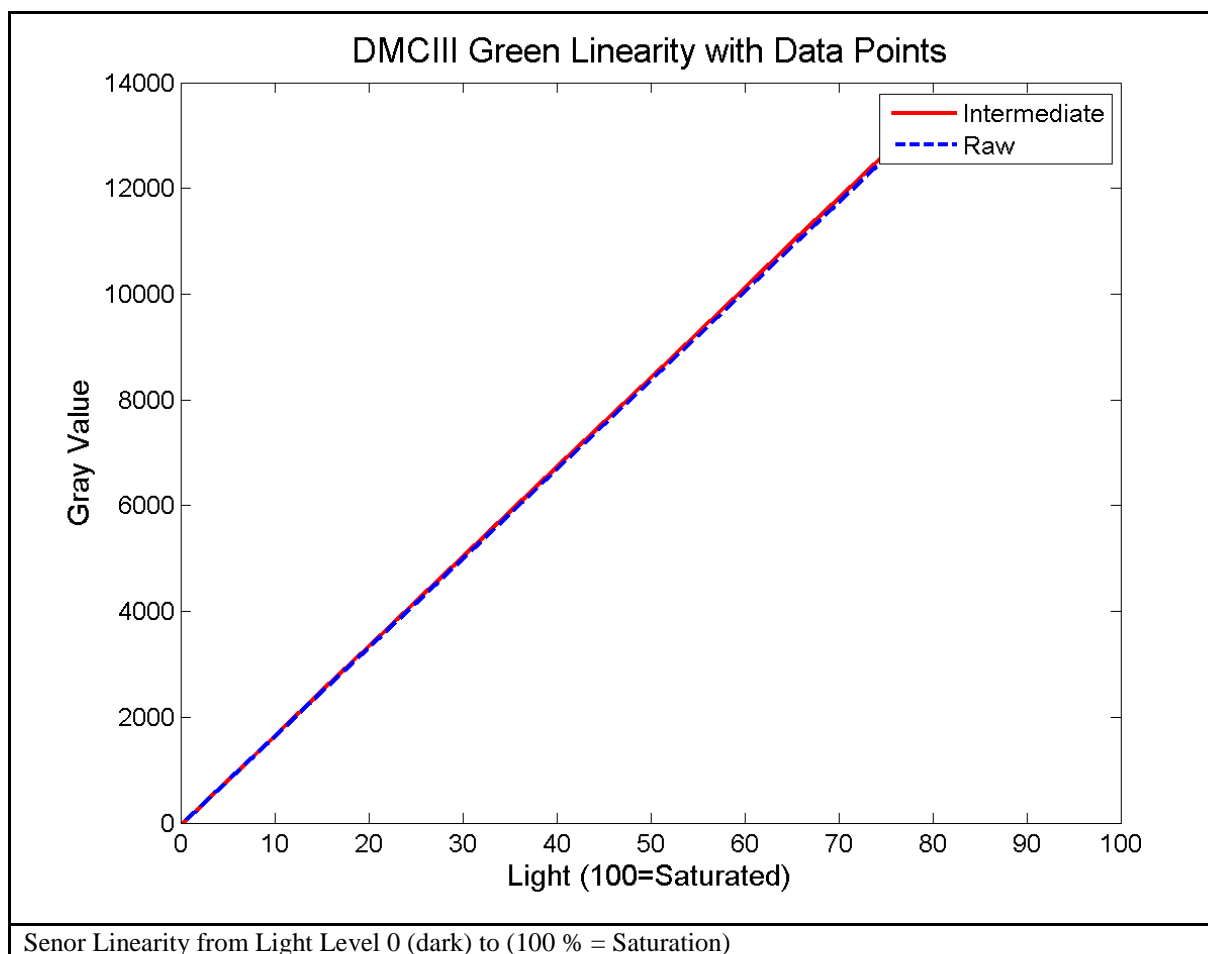


The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC III is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera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

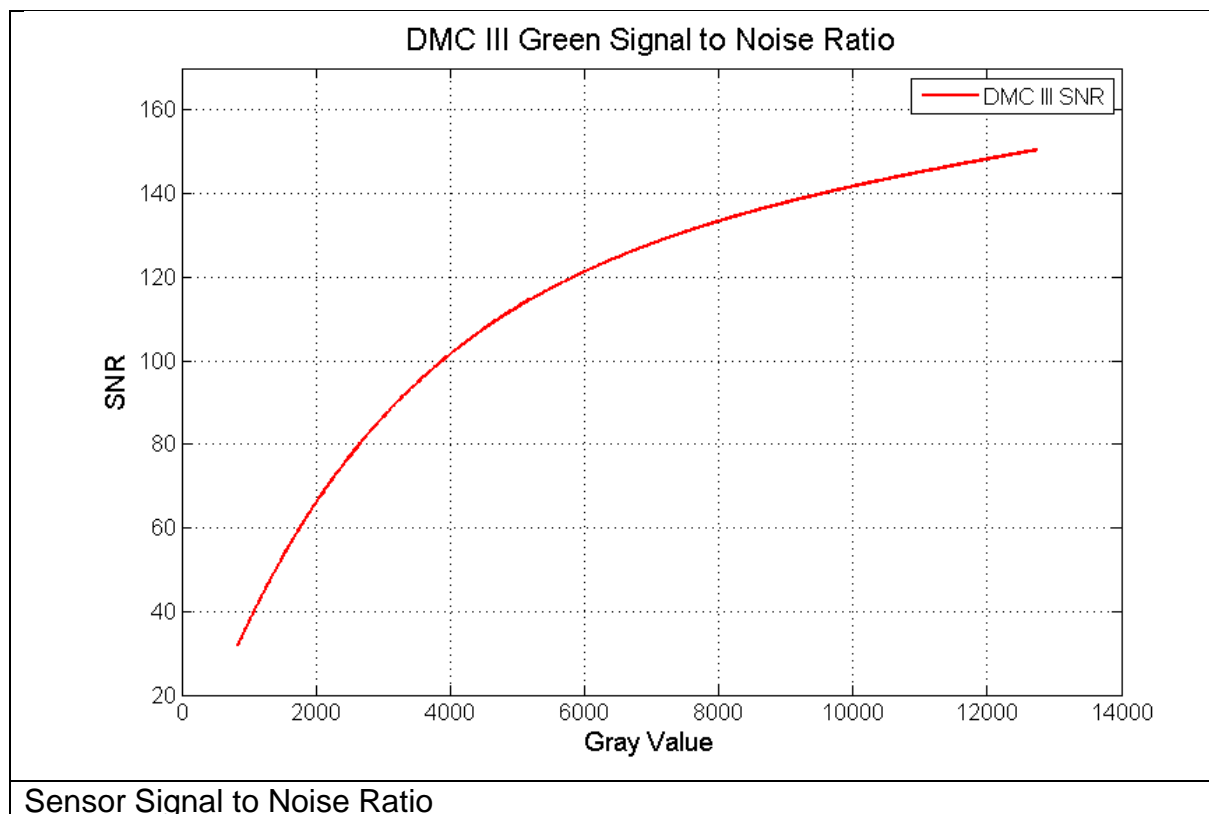


The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 5.6 with exposure time of 10msec.

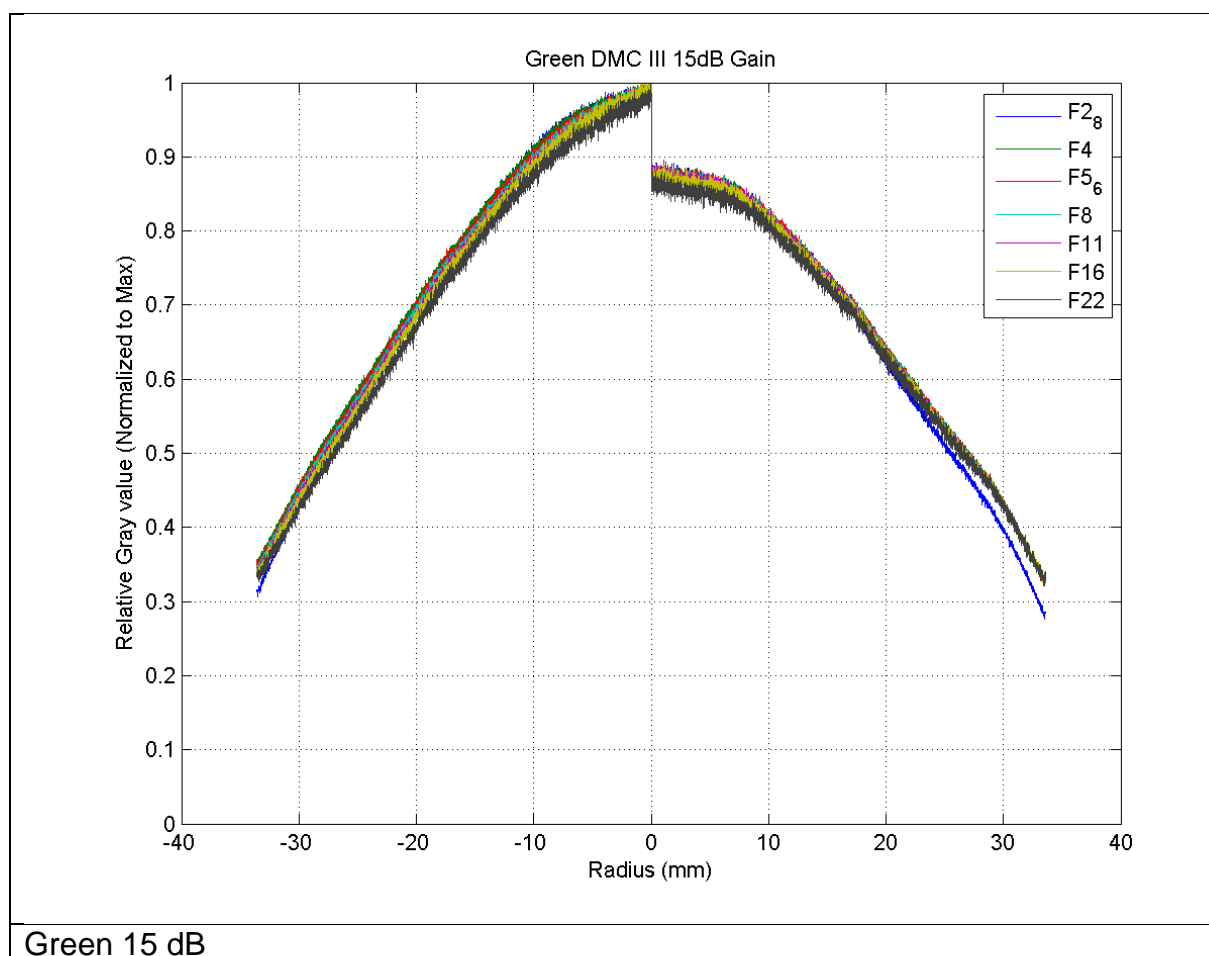


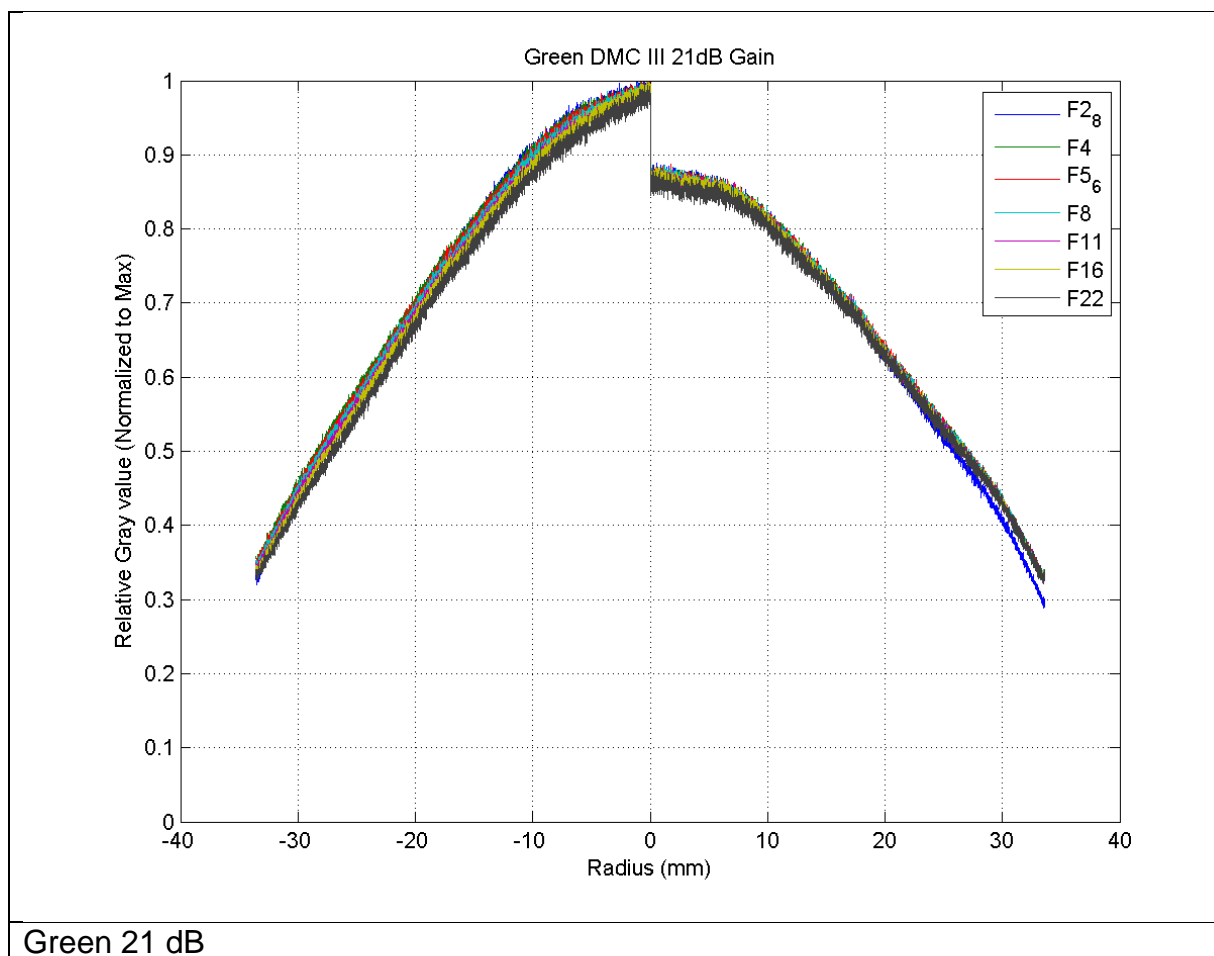
Radiometric Calibration

Aperture Correction

Green (00128807)

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 (00128807)

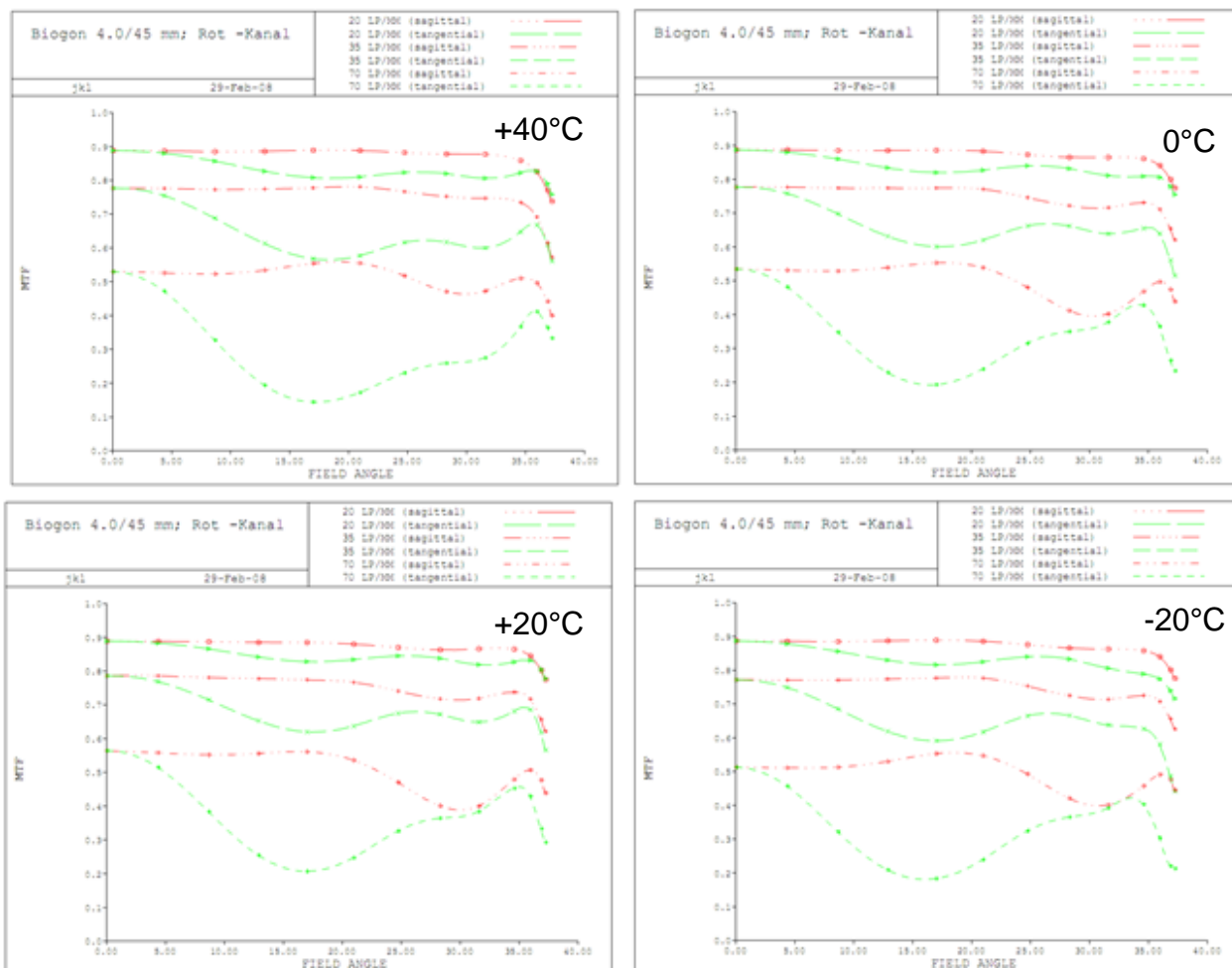
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images.

The quantity and cumulative percentage and specification of defects are described in Appendix “Defect Pixel Recognition” at page 46.

Optical System

Modulation Transfer Function, MTF of Red camera

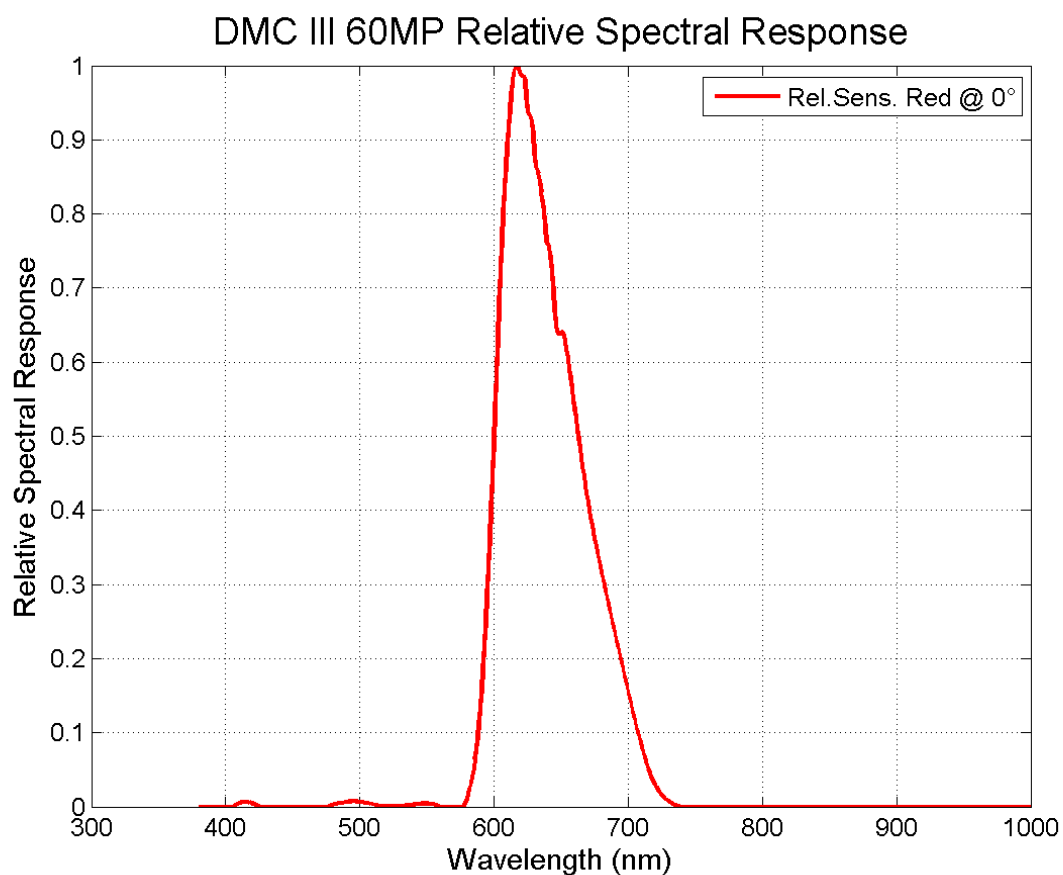
DMC III MS Red – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Red camera

Spectral Response Curves of the single camera head.



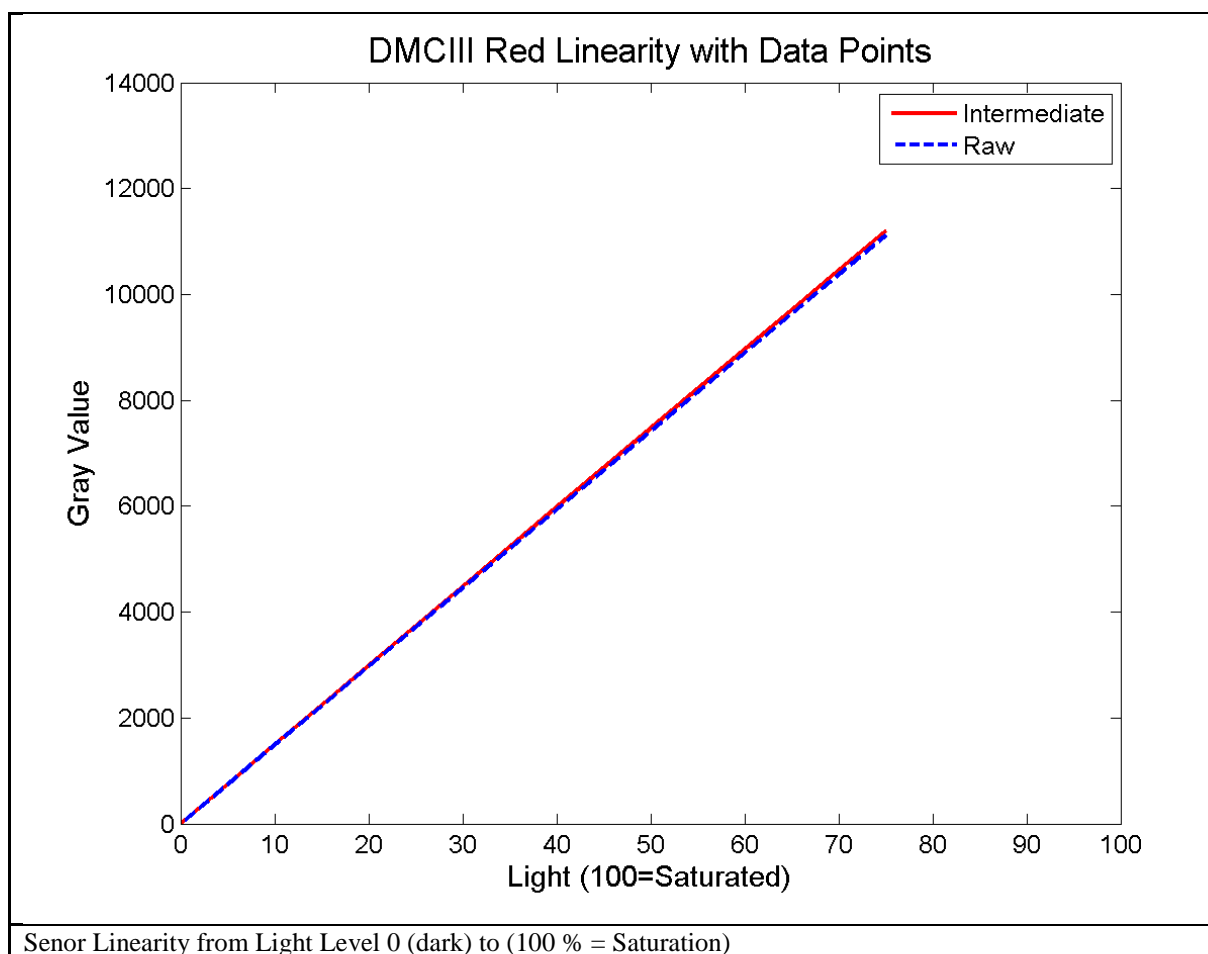
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC III is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera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

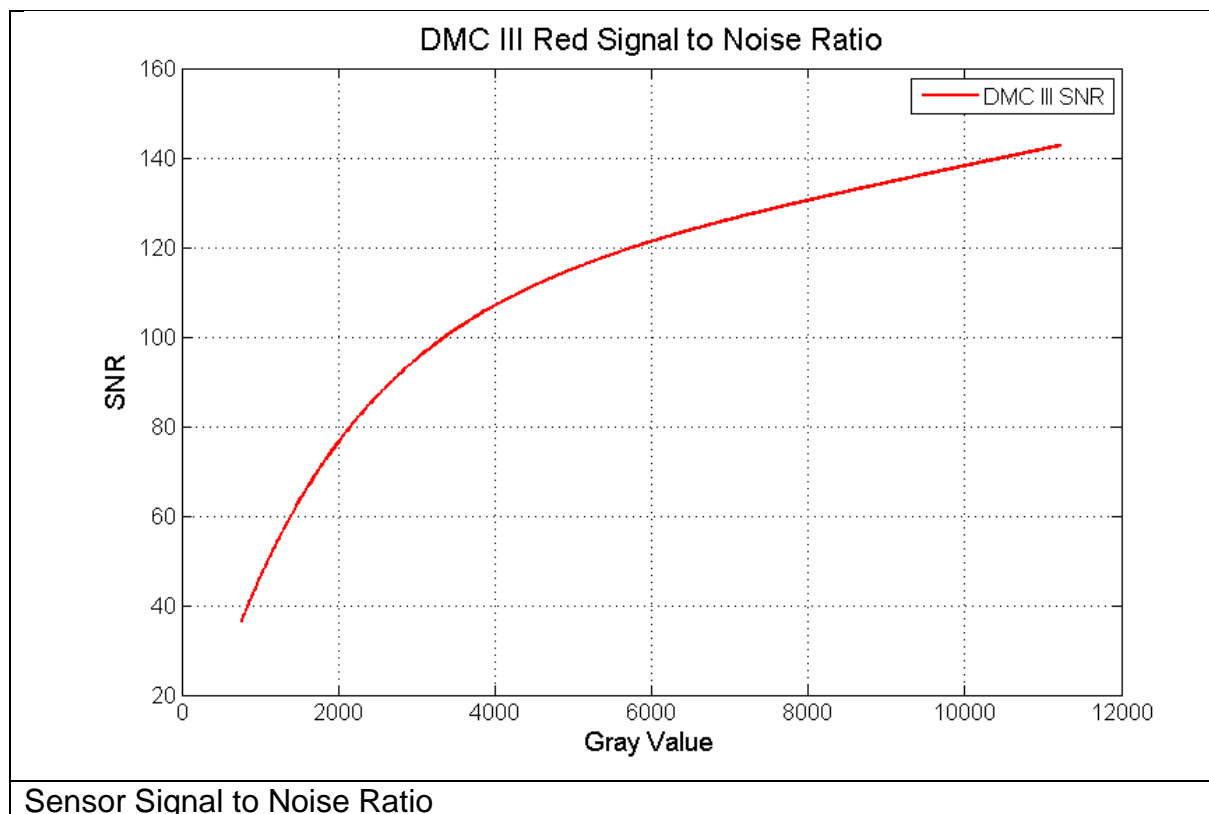


The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 5.6 with exposure time of 10msec.

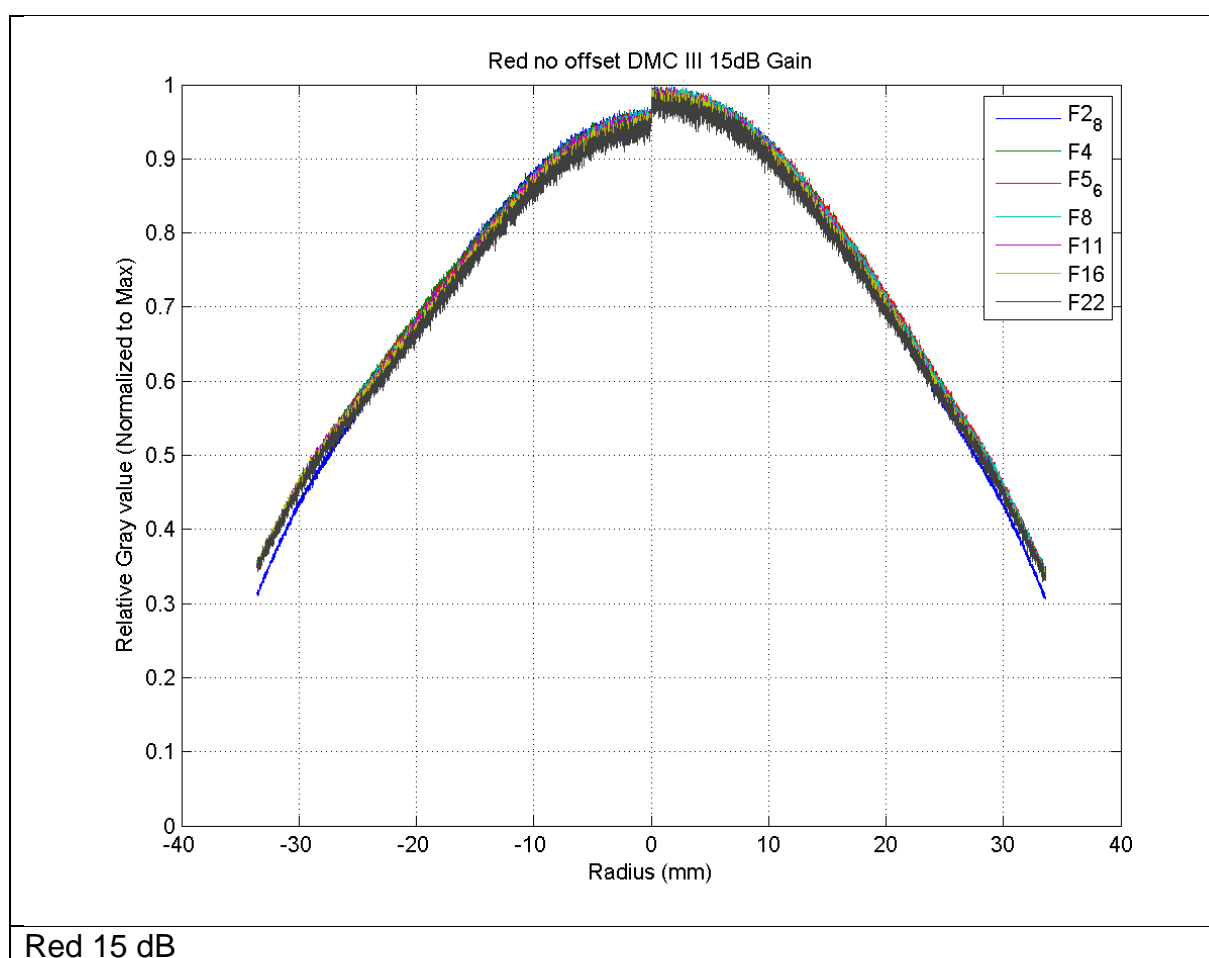


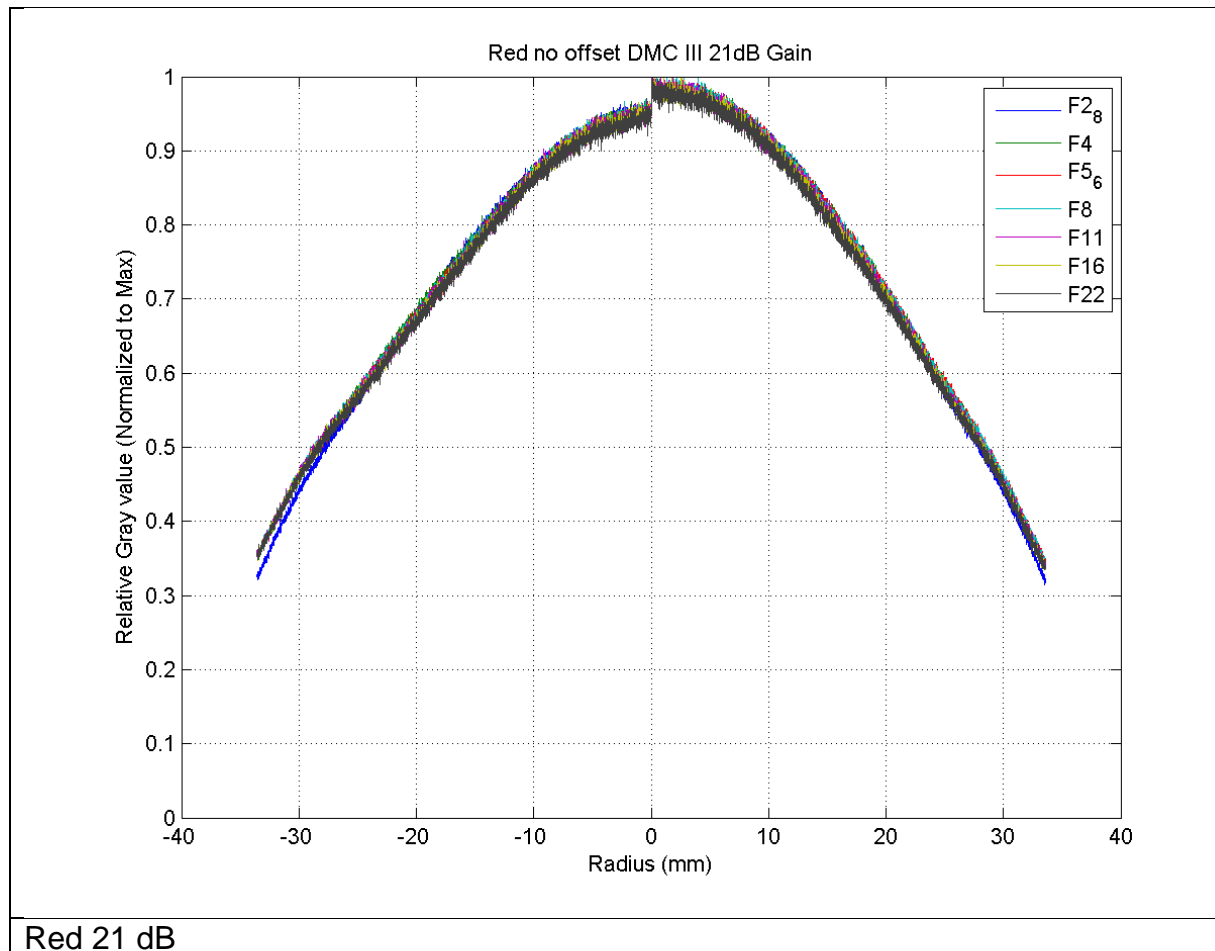
Radiometric Calibration

Aperture Correction

Red (00127981)

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 (00127981)

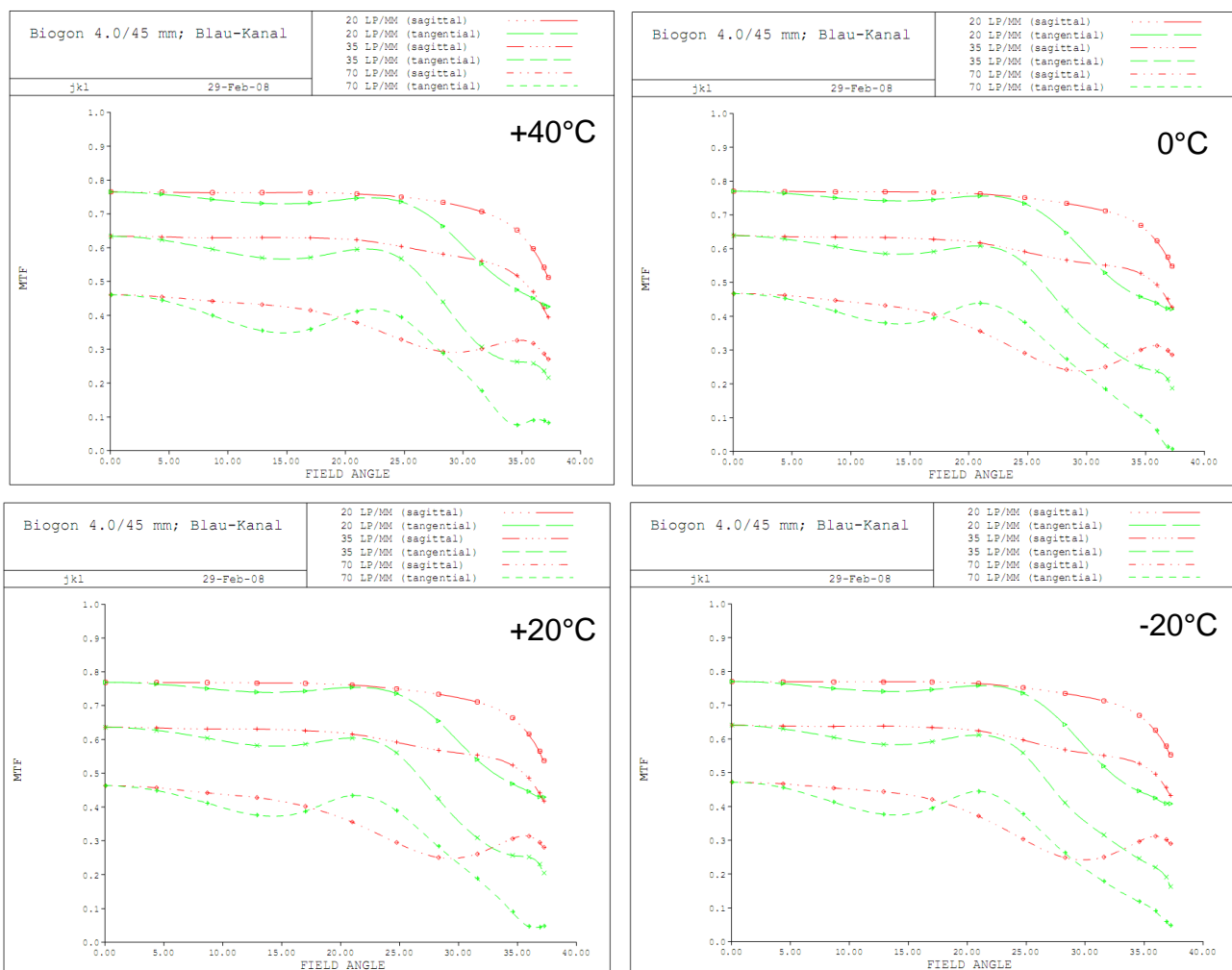
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images.

The quantity and cumulative percentage and specification of defects are described in Appendix “Defect Pixel Recognition” at page 46.

Optical System

Modulation Transfer Function, MTF of Blue camera

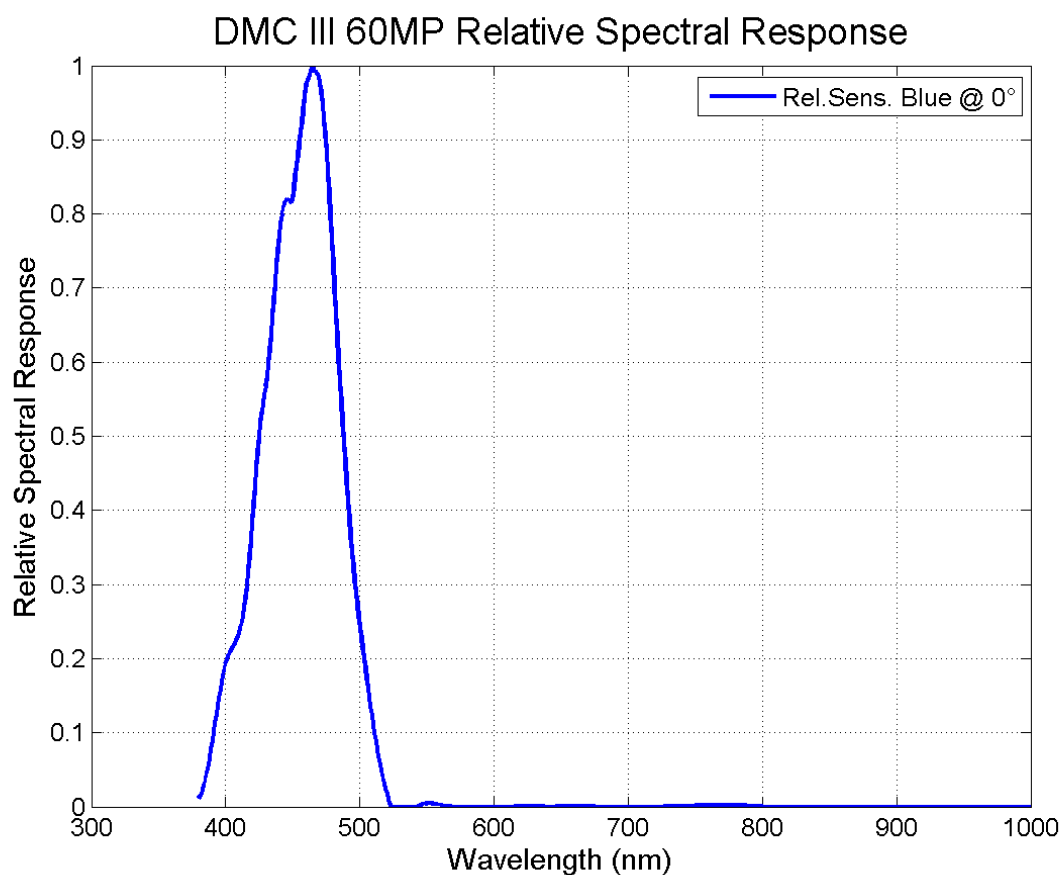
DMC III MS Blue – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of Blue camera

Spectral Response Curves of the single camera head.

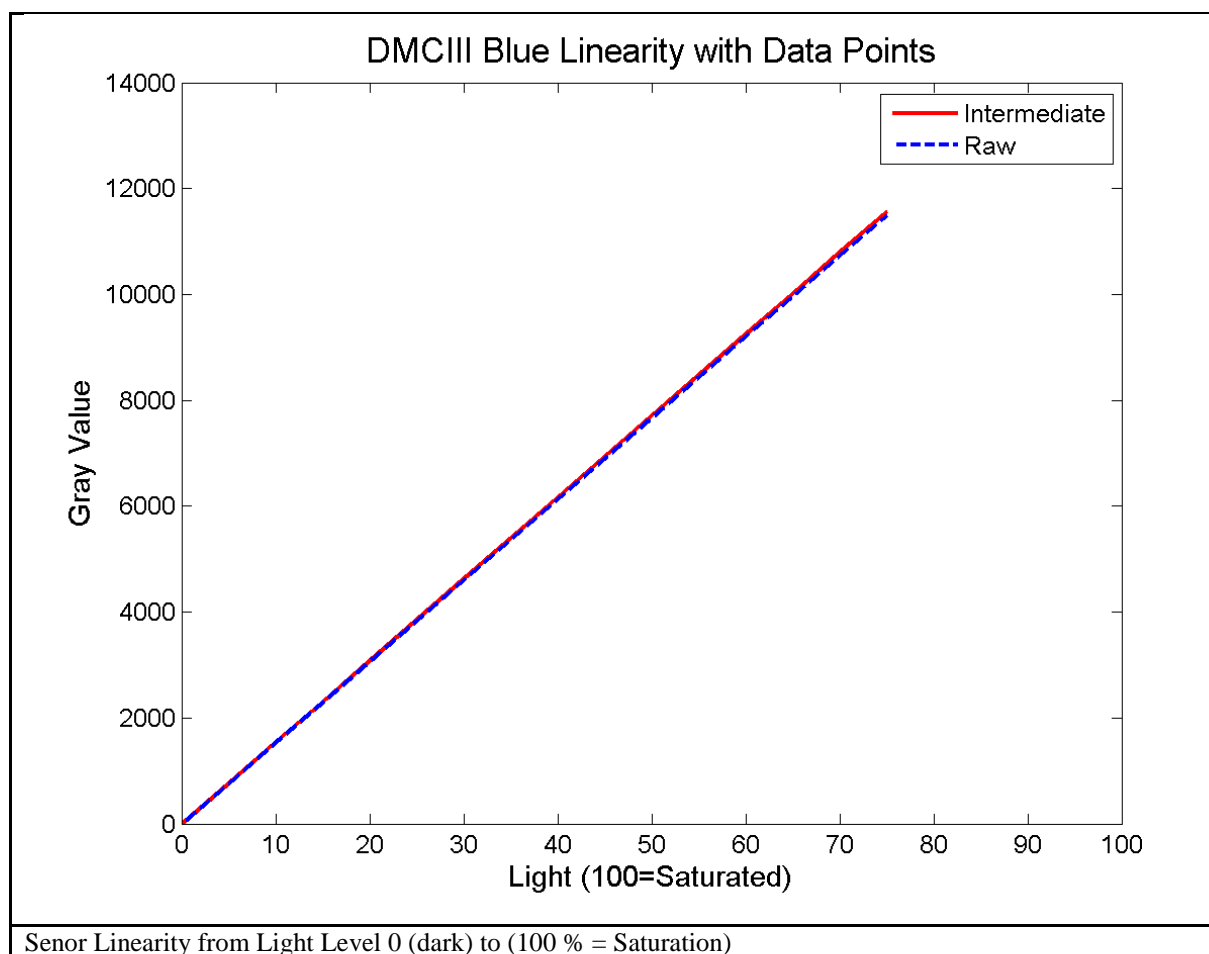


The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC III is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera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

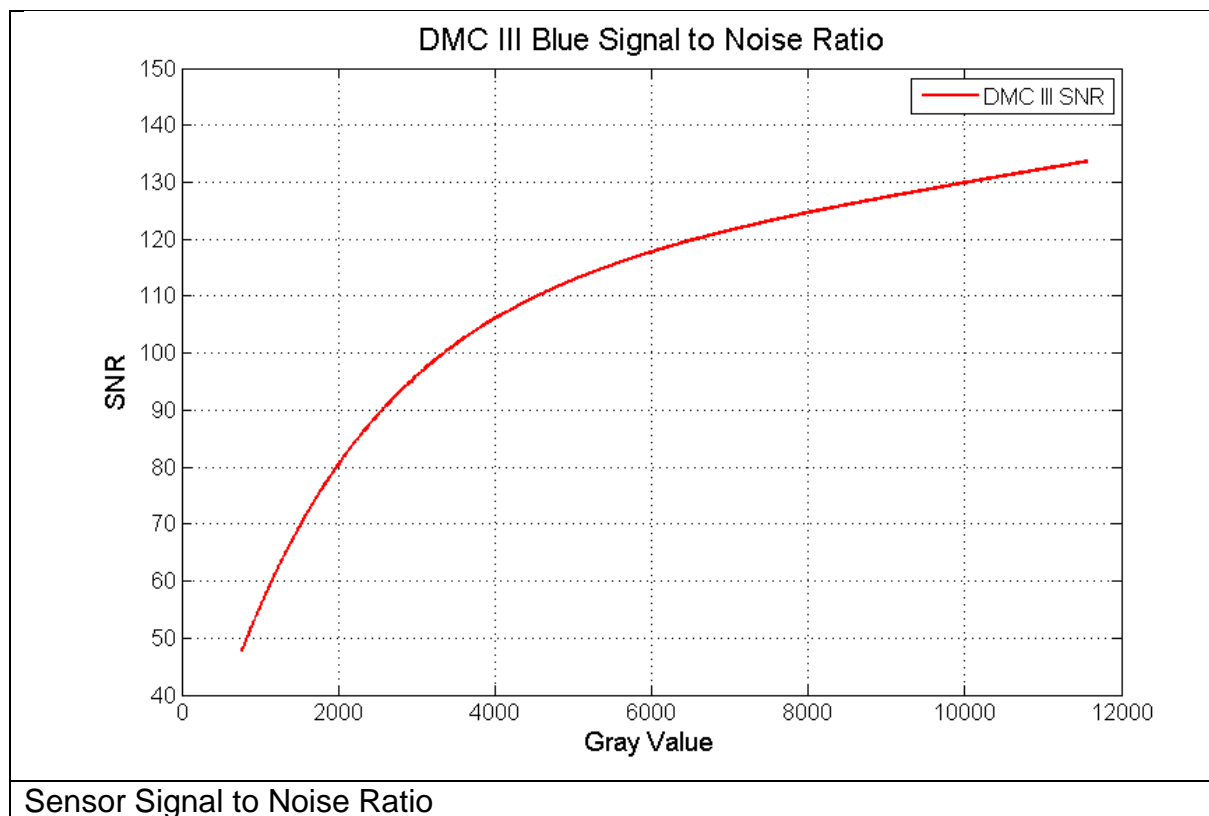


The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 5.6 with exposure time of 10msec.

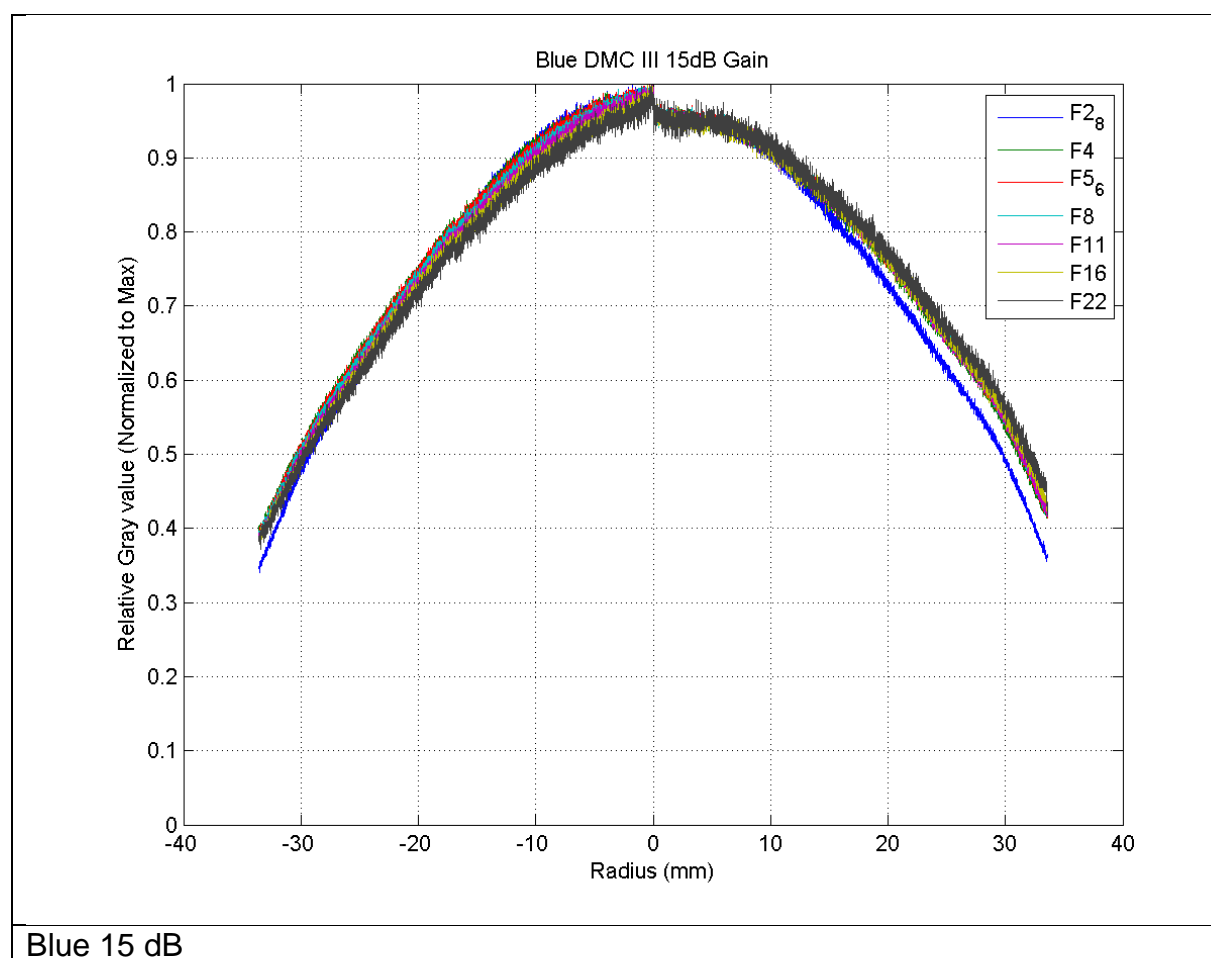


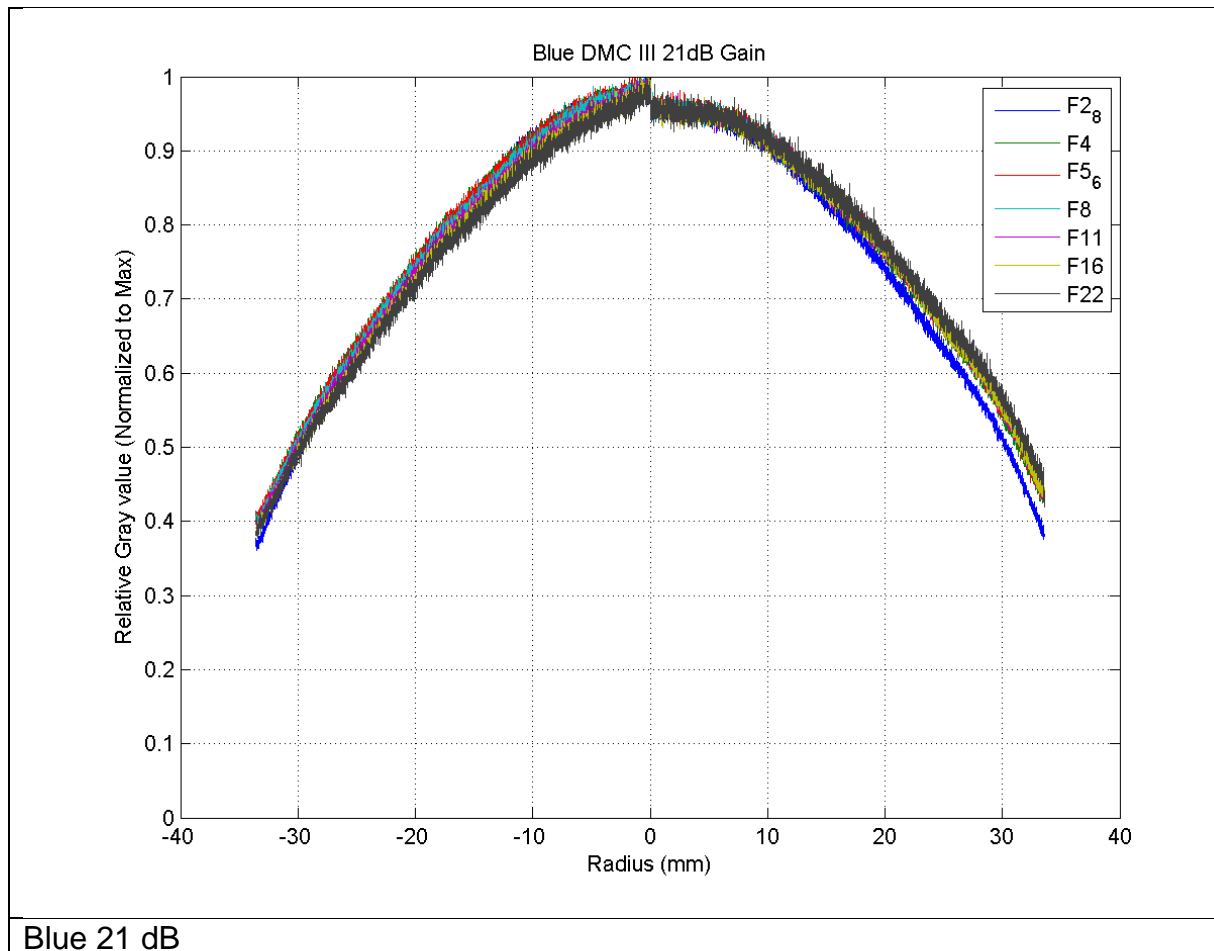
Radiometric Calibration

Aperture Correction

Blue (00128804)

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 (00128804)

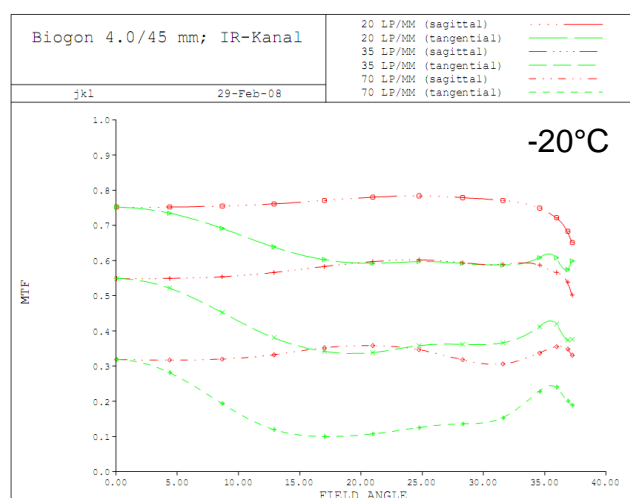
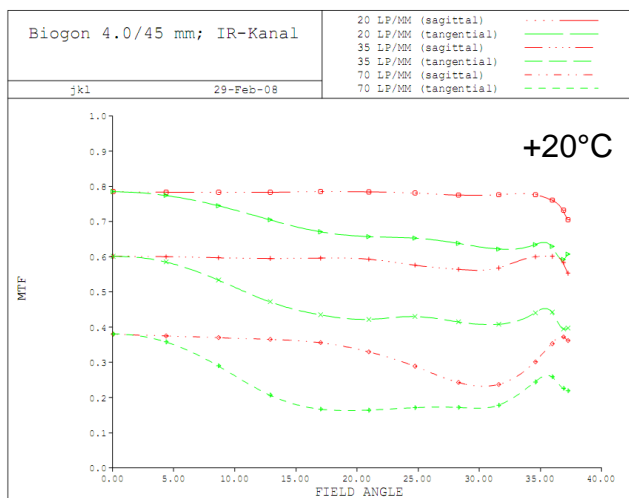
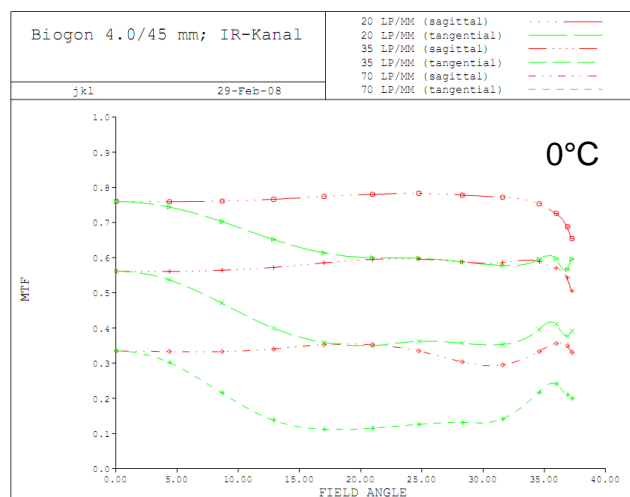
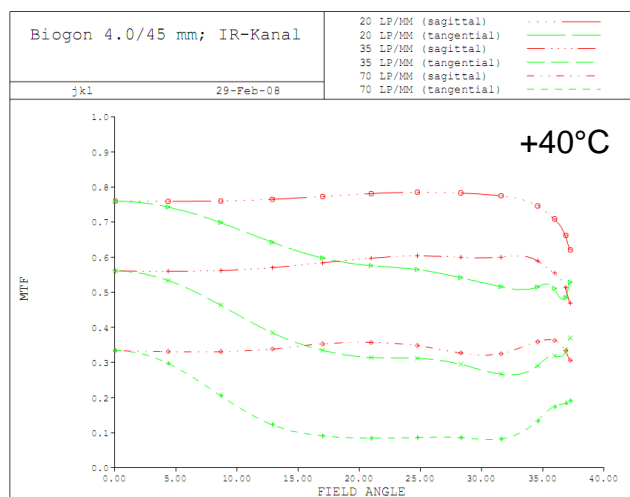
Defect pixels are detected during radiometric calibration and will be corrected during radiometric processing of the images.

The quantity and cumulative percentage and specification of defects are described in Appendix “Defect Pixel Recognition” at page 46.

Optical System

Modulation Transfer Function, MTF of IR camera

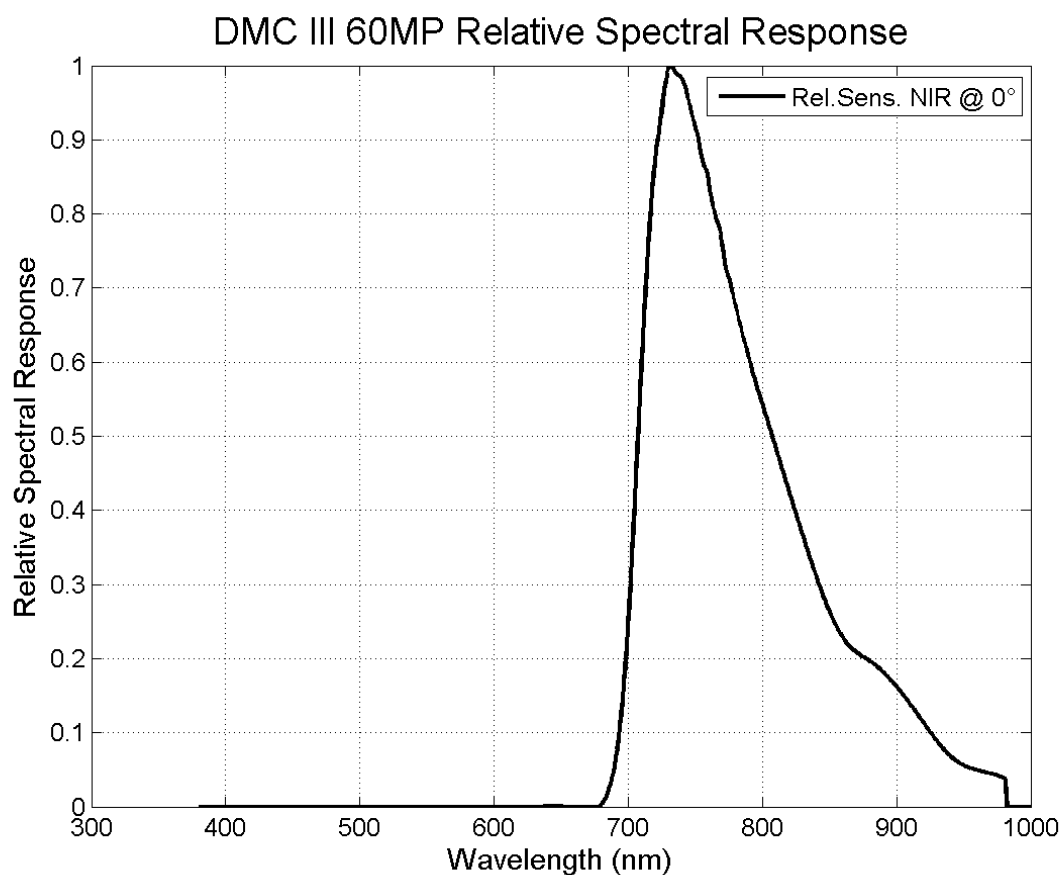
DMC III MS IR – MTF F/4.0 ; 45 mm– Temperature Stability



Radiometric Calibration

Sensitivity of NIR camera

Spectral Response Curves of the single camera head.



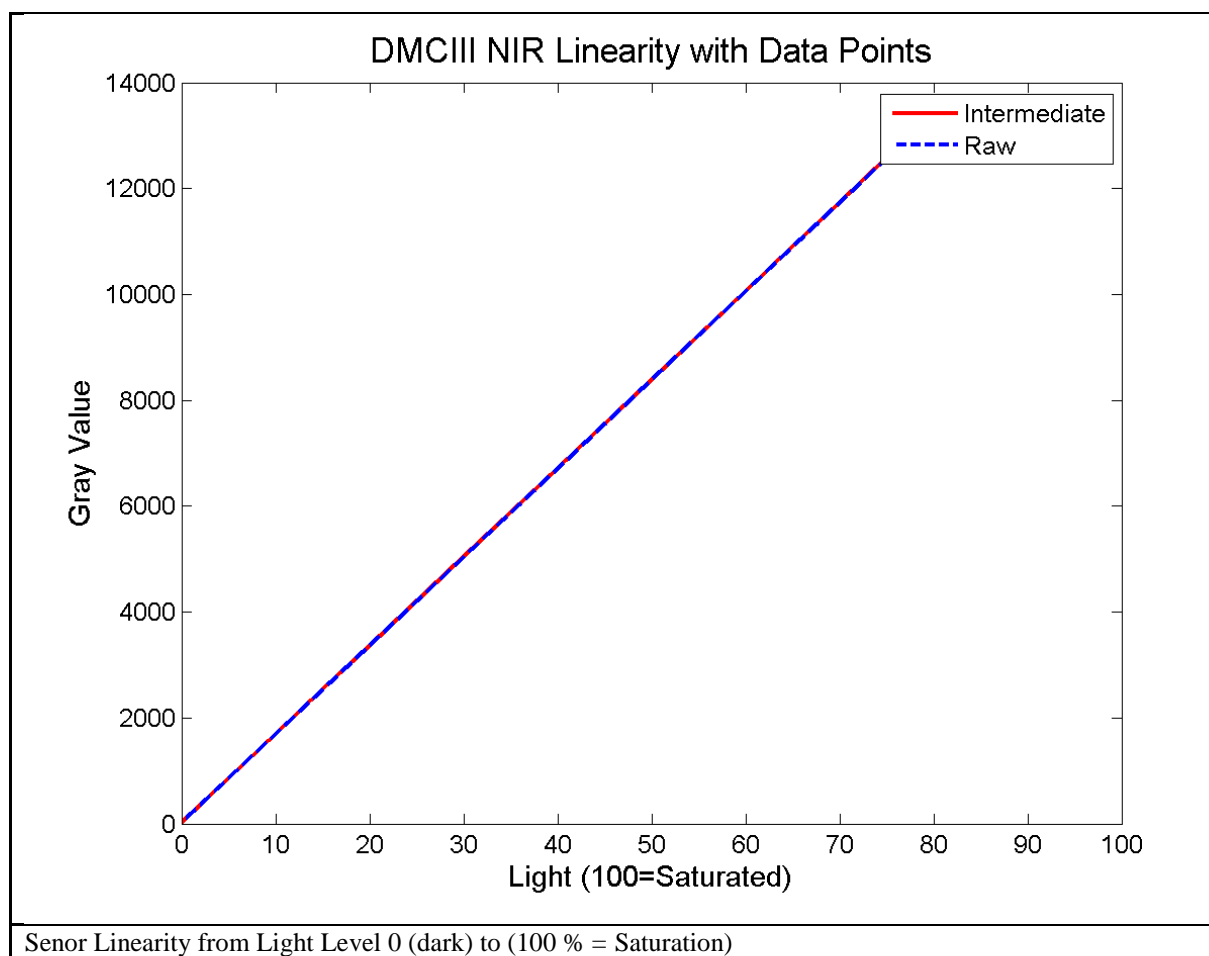
The sensitivity shows the spectral response curve of the single camera head including the optical system (optics, filter) and the sensor response. The DMC III is calibrated with respect to the absolute spectrometer. This allows computing pixel radiance values from pixels digital numbers and is a camera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

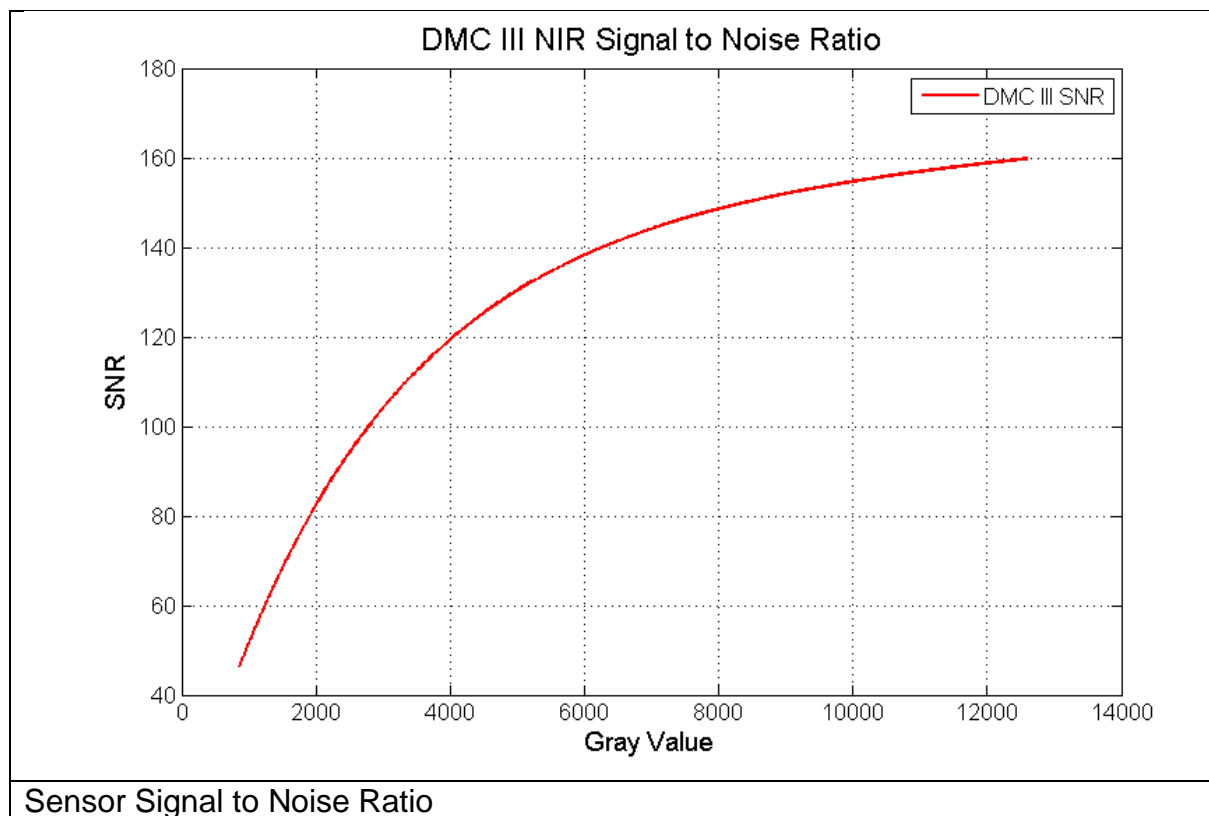


The deviation from the linearity is below 1%.

Radiometric Calibration

Sensor Noise (Reference)

Sensor noise shows image noise with respect to the image center measured at an aperture of 5.6 with exposure time of 10msec.

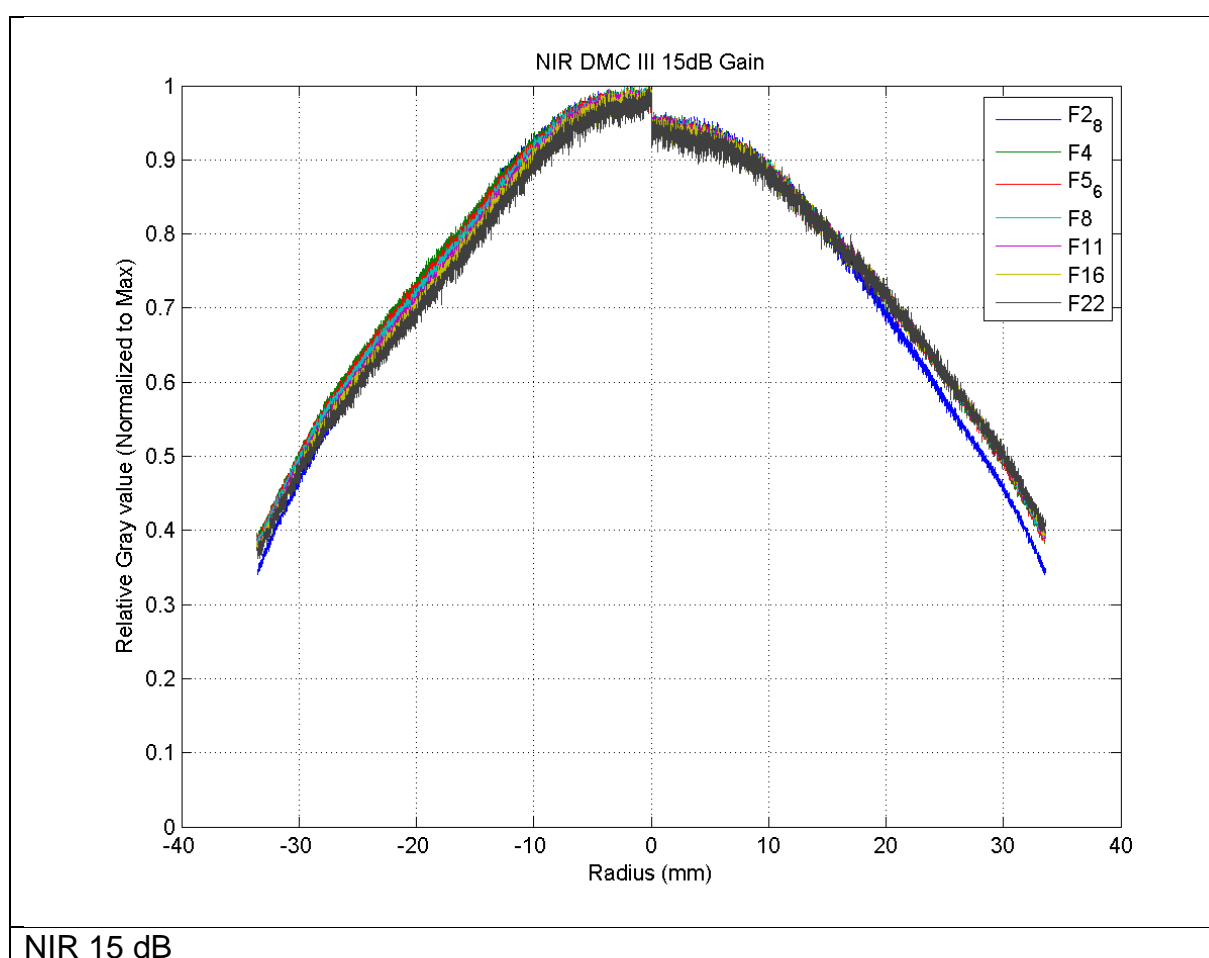


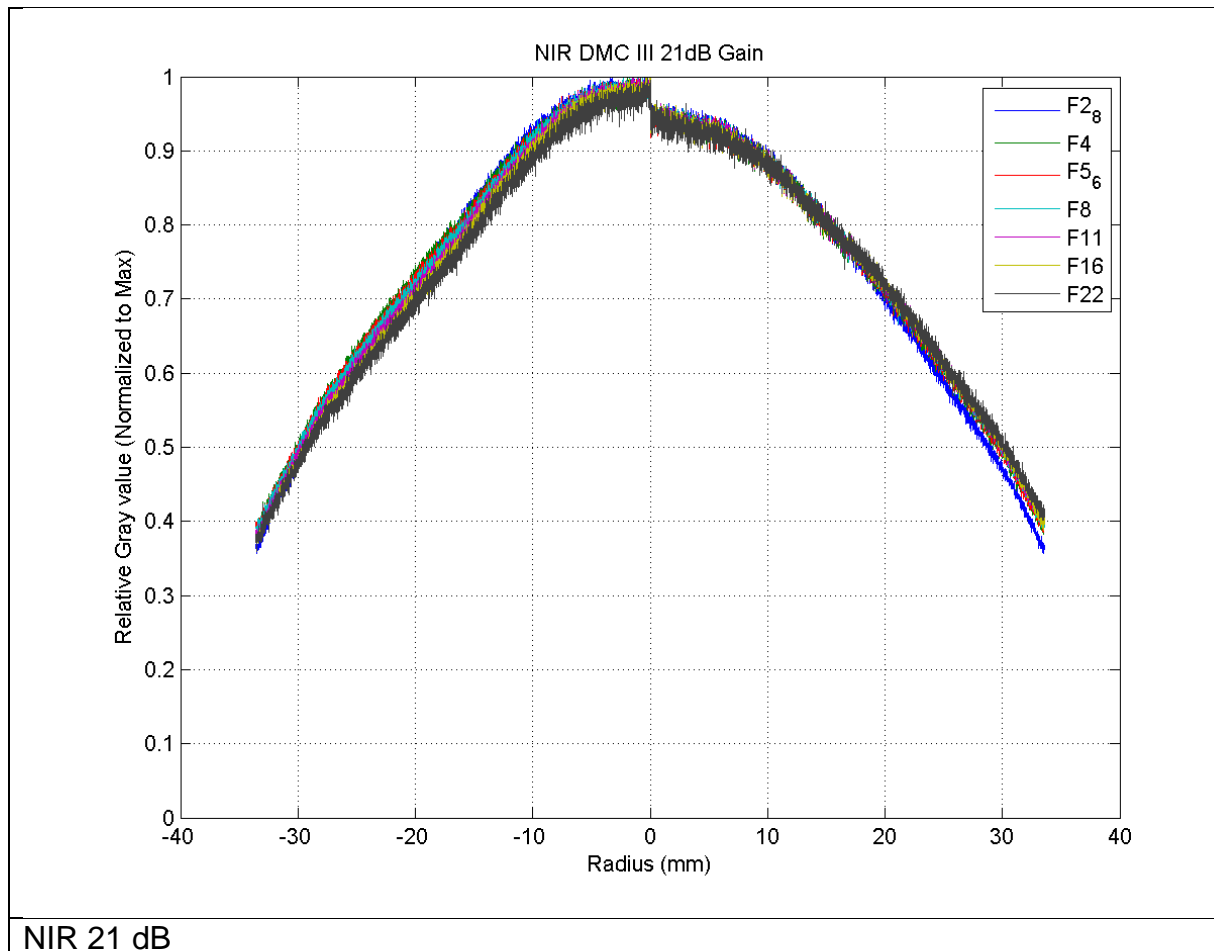
Radiometric Calibration

Aperture Correction

NIR (00128786)

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

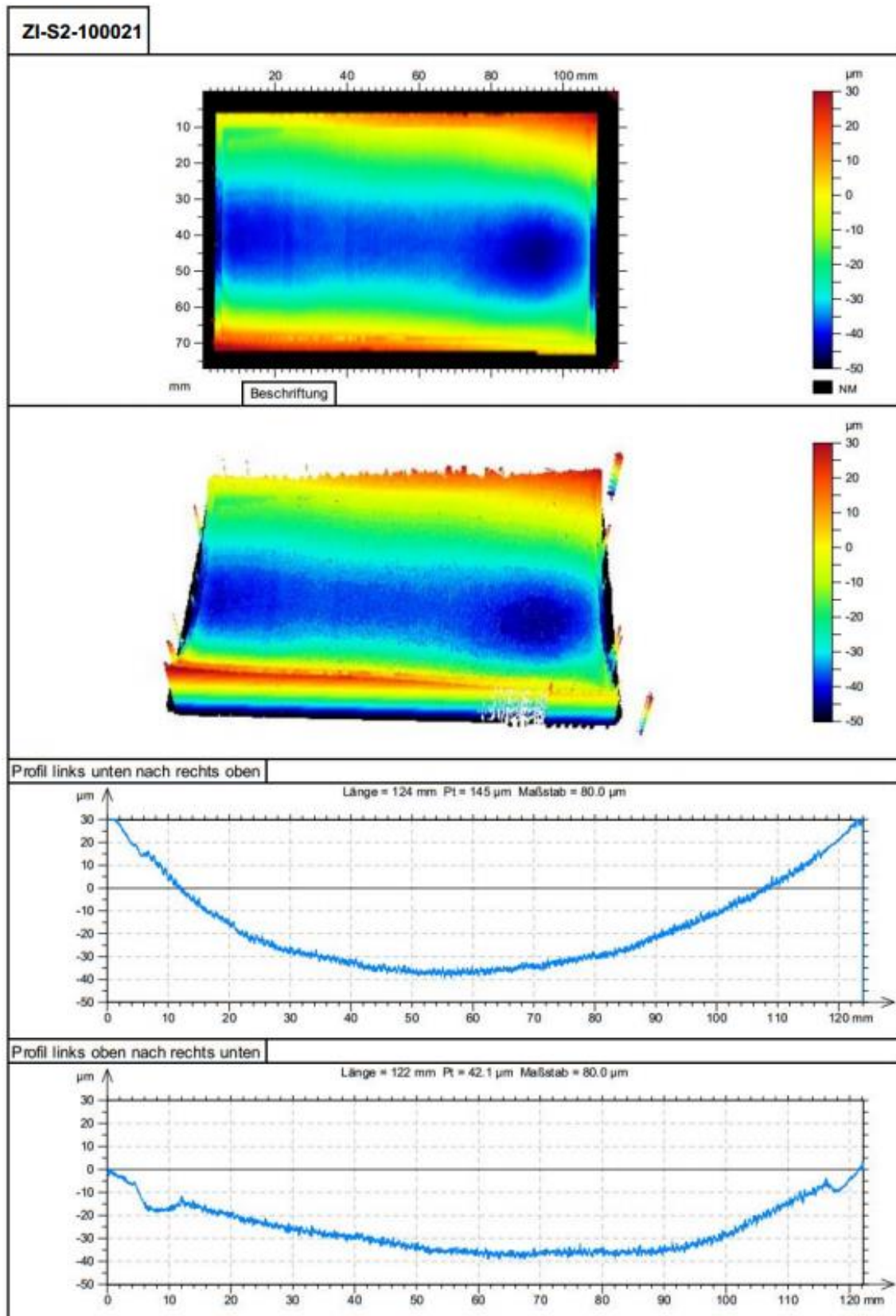
Defect Pixel

NIR (00128786)

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 are described in Appendix “Defect Pixel Recognition” at page 46.

Sensor Geometry



Radiometric Reference Camera Calibration

The DMC III absolute radiometric calibration uses a reference camera to produce consistent DN and radiance values from all cameras systems. The application of the reference camera values occurs within PPS, when color balancing output is selected. Then, a single set of calibration coefficients, along with the current acquisition F# and exposure time, may be used to convert the color balanced (radiometric corrected) DN values to radiance.

A single, reference camera absolute radiometric calibration coefficient is provided for each camera band. For the multispectral cameras, which have variable gains, the calibration is provided at a single reference gain. These calibration coefficients are applied to image DN values that have been corrected within PPS to match the reference camera. In PPS, the uncorrected, raw DN values are dark image subtracted and flat fielded using the current camera's calibration files. Then the DN values are scaled to the reference camera maximum DN value for the current acquisition F-stop, and if appropriate, scaled to account for differences in gain. Once these corrections have occurred, the DN values are representative of the reference camera. Then, the corrected DN values can be converted to radiance using the following equation:

$$L = C_{ref} \cdot DN' \frac{F\#^2}{\tau}$$

Where: **C_{ref}** -- calibration coefficient (in $\mu\text{W ms} / (\text{cm}^2 \cdot \text{sr} \cdot \text{nm})$)
F# -- current aperture or f-number
 τ -- current exposure time (in ms)
DN' -- radiometric corrected DN value output from PPS

Defect Pixel Recognition

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

Description		CMOS/CCD Spec s/n	PAN 00126502 meet spec	GREEN 00128807 meet spec	RED 00127981 meet spec	BLUE 00128804 meet spec	NIR 00128786 meet 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 ≤ 15000	yes	---	---	---	---
		MS ≤ 500	---	yes	yes	yes	yes

Description		CMOS/CCD Spec s/n	PAN 00126502 meet spec	GREEN 00128807 meet spec	RED 00127981 meet spec	BLUE 00128804 meet spec	NIR 00128786 meet spec
Column/Row	Definition	A column which has more than 8 pixel defects in one 1x12 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	yes	---	---	---	---
		MS ≤ 20	---	yes	yes	yes	yes
	Max double Column	PAN ≤ 40	yes	---	---	---	---
		MS ≤ 6	---	yes	yes	yes	yes
	Max Single Row	PAN ≤ 140	yes	---	---	---	---
	Max double Row	PAN ≤ 40	yes	---	---	---	---

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

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

Bibliography

Brown D. C. Close-Range Camera Calibration, Photogrammetric Engineering 37(8) 1971

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Fraser C., Digital Camera self calibration. ISPRS Journal of Photogrammetry and Remote Sensing, (1997, 5284): 149-159

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Ryan R., Pagnutti M. (2009): Enhanced Absolute and Relative Radiometric Calibration for Digital Aerial Cameras, in: Fritsch D. (Ed.), Photogrammetric Week 2009, Wichmann-Verlag, pp. 81-90.

Doering D., Hildebrand J., Diete N. (2009): Advantages of customized optical design for aerial survey cameras, in: Fritsch D. (Ed.), Photogrammetric Week 2009, Wichmann-Verlag, pp. 69-80.

Stoldt, H. (2010): DALSA Ultra large CCD technology Customized for Aerial Photogrammetry. At: ASPRS 2010, San Diego, USA, p. 15.