

MERTIS FM Spectrometer Optical Performance Report

(before/after qualification)

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a – Table of Contents

1	Introduction.....	4
1.1	Purpose	4
1.2	Abbreviations.....	4
1.3	Applicable Documents.....	4
1.4	Reference Documents.....	4
2	Test - Overview	5
3	Data gathering and evaluation approach.....	6
3.1	Measurement Procedures	7
3.2	Image area classification	7
3.3	Scene signal extraction	7
3.4	Determination of the spectral calibration coefficients.....	8
3.5	Radiometric Performance Evaluation.....	9
3.6	Determination of the POI position and repeatability.....	9
4	Test results	11
4.1.1	Radiometric Performance	11
4.1.2	POI position and repeatability before and after vibration.....	12
4.1.3	POI position repeatability for different instrument temperatures done at KT & DLR.....	14
4.1.4	Spectral Calibration Coefficients.....	16
5	Conclusion	18

b – List of Appendixes

Appendix 1: Measurement History / Protocol.....	19
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c – Change Record Sheet, Document History

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1 Introduction

1.1 Purpose

This document contains the description of the test procedures and the corresponding results of measurements done for a radiometric, spectral and partially geometric evaluation of the MERTIS-TIS FM model prior and after qualification tests.

In order enable the investigators to detect and evaluate system changes occurring during the stress tests it is necessary to measure and compare certain radiometric, geometric and spectral key parameters of the system before and after the test runs. These include the spectral assignment coefficients, the image's signal-to-noise-ratios (SNR), and the focus and position of the images in relation to the instruments field of view (FOV). Described here are test measurement procedures and their results from the point of view of possible changes to the system's radiometric, spectral and partially geometric behaviour.

1.2 Abbreviations

BG	Background Signal Portion
DLR	German Aerospace Center, Germany
DM	Development Model (sometimes called Lab-Model)
EM	Engineering Model
FEE	Front End Electronics
FM	Flight Model
FOV	Field of View
ICU	Intelligent Control Unit / Instrument Control Unit
IfP	Institut für Planetologie
MERTIS	ME rcury R adiometer and T hermal I nfrared S pectrometer
OGSE	Optical Ground Support Equipment
PI	Principal Investigator
PIX2PIXBGR	Pixel-to-Pixel Background Removal
SSD	Spectral Sampling Distance
TBC	To be confirmed
TBD	To be determined
TBW	To be written
TIS	Thermal Infrared Spectrometer

1.3 Applicable Documents

N/A

1.4 Reference Documents

RD1 Measurement data, AST

2 Test - Overview

The idea behind the concept introduced is to measure the radiometric, spectral and partially geometric key performance parameters of the system MERTIS-TIS FM before and after the proposed qualification tests. Any possible permanent or temporal change to the system during mechanically and thermally stressing tests which do impact the system performance need to be detected and evaluated. Necessarily basing on those results the qualification status of the instrument can be concluded.

There are three base test procedures which offer the necessary base data for a comprehensive investigation of the spectro-radiometric (and to some degree geometric) system performance:

a.) Spectral calibration using narrow-band spectral features at multiple angular positions within the FOV

In this step a set of narrow band-pass filters (BP) covering the spectral range between 7 μm and 14 μm is measured for three different positions within the FOV. The resulting datasets are the base for determination of the spectral calibration coefficients. The procedure's primary outputs are the calibration coefficients, the spectral sampling distance (SSD) and the BP central positions within each image. The BP positions are chosen relative to the edges of the FOV. The edges are clearly visible in the difference image data. Additionally the relation of the BP – positions in the images to the angular scale of the 2-axis rotary stage in the DLR/IR-Lab can be determined as well.

b.) Measurement of the systems response a static radiometric scene and to the onboard blackbody BB700

Here the signal strength of hot radiometric scenes in difference to a background signal image is determined as well as the systems signal noise strength. The scenes used are generated by the onboard blackbody BB700 and the onboard blackbody BB300. The primary output of this procedure is the systems spectral image SNR related to a 700K-300K difference scene.

c.) Determination of the POI positioning repeatability

In this procedure images are recorded for each of the pointing unit's four positions (Planet View, BB700 View, BB300 View, SpaceView). The measurement is repeated several times. From the gathered data difference images related to the BB300 serving as background radiation reference are calculated. The procedures primary output is the pointing repeatability being evaluated in terms of image feature positions and their distribution over all repetitions for the "BB700 view".

3 Data gathering and evaluation approach

The experimental setup used for the instrument performance examination bases on the opportunities the DLR-IR-Laboratory facilities offer. For a scheme of the experimental setup for measurements under vacuum conditions see

Fig. A radiometric reference scene is generated using a large area OPTRIS-blackbody radiator which is placed in front of an TIR-transparent KRS5 window integrated in a vacuum chamber in which MERTIS is mounted. Using an external flow-through-chiller the instrument can be set at different temperatures ranging between -2°C and 50°C. For the investigations the instrument's planet view is used to couple-in the externally generated radiometric reference scene. For the purpose of capturing images representing the radiometric background an external shutter can be installed between the KRS5-Window and the scene generating external BB. This offers the opportunity to create high SNR-images without changing the system state. Alternatively the instrument-internal BB300 can be used as background reference radiator. This is especially useful for the verification of the pointing repeatability measurements as it will be described in the following chapters.

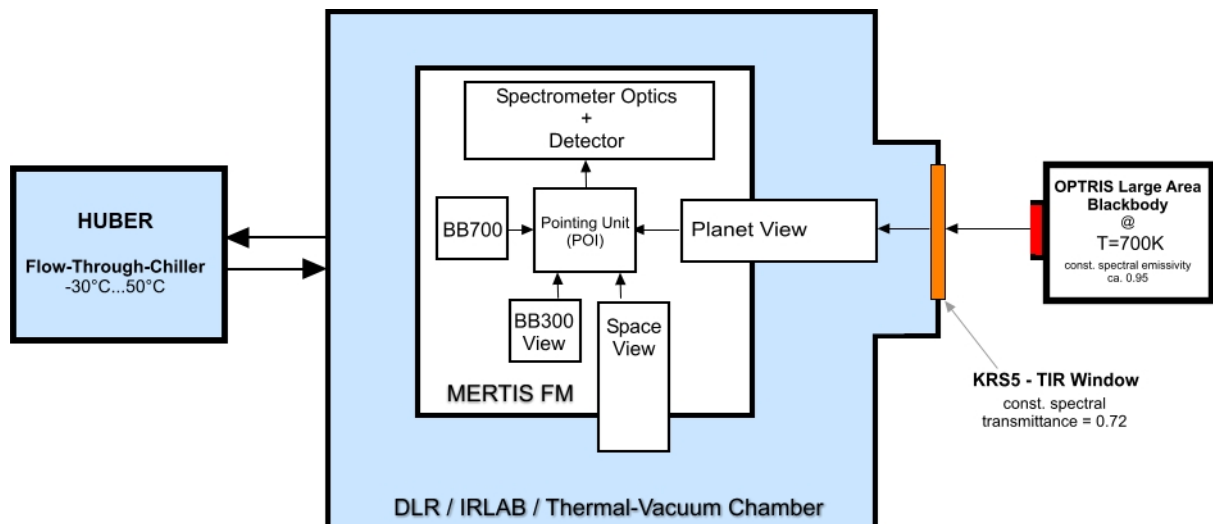


Fig 1: Scheme of the experimental setup for the FM tests under thermal/vacuum conditions. The setup consists of the a vacuum chamber facility with the MERTIS instrument inside. The instrument can be driven to temperatures -1°C up to 50°C. Through a KRS5 window a radiometric reference scene can be seen by MERTIS. The planet baffle is oriented towards the external OPTRIS large area blackbody which can be set to a temperature up to 700K and filling the whole TIS and TIR FOV.

The external OPTRIS blackbody radiator was set to 700K during all TVC measurements. In order to evaluate the radiometric performance of MERTIS-TIS the spectral transmittance function of the KRS5-window has been determined in former measurements (const. 0.72). The emissivity of the OPTRIS BB has a value of ca. 0.95.

For the purpose of measurements of the spectral assignment of the MERTIS-TIS image channels a setup as presented in **Fig. 2** has been used. There MERTIS is placed in front of a high temperature SR20-blackbody which is equipped with a wheel holding a set of IR-narrow band pass filters. The spectral transmittance of the filters and their central wavelengths has been measured in the DLR/PEL before.

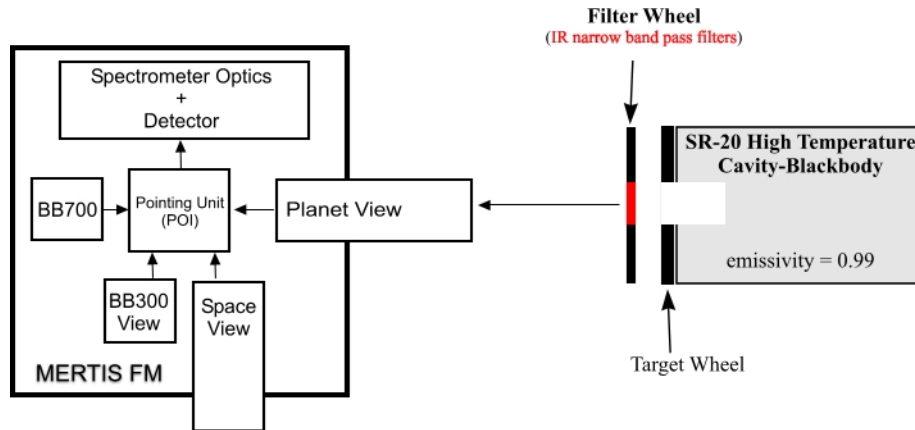


Fig. 2: Scheme of the experimental setup for the FM spectral assignment under air conditions. MERTIS is placed in front of a high temperature SR20-Blackbody which has a filter wheel that hold a set of IR-narrow band pass filters.

3.1 Measurement Procedures

In the following the measurement procedures are described starting with a short introduction into two methods for the extraction of the difference scene signal from the raw data and definitions of the different image areas.

3.2 Image area classification

For the calculations all images have been divided into a rectangular scene area (covering the FOV) and a reference area being the rest of the image. Additionally hot and dead pixels were mapped out and can therefore not contribute any disturbing signal portions to the results to be calculated.

If not indicated differently, the rectangular image scene area is defined as:

$$\text{Rect_Scene_FM} := \{ (x,y) \mid x \in [20 \dots 137] \text{ and } y \in [0 \dots 100] \}$$

which covers the whole FOV and all visible portions of the spectra before the qualification tests. The set of out-mapped pixels is:

$$\text{DeadPixelsSet_FM} := \{ (24,119), (158,110), (158,111), (121,109), (146,37), (133,118), (132..134, 119) \}$$

3.3 Scene signal extraction

In order to reduce the background signal portions (housing radiation / thermal housing drifts, electronical offsets and drifts, thermal detector element drifts etc.), a shuttered measurement mode has been chosen. There are two methods used:

1. Using external shutter

For getting a high SNR measurements using an external shutter are performed. An image series is recorded using the external shutter between the planet view baffle and the external blackbody. Images taken with the shutter as target ("dark") are subtracted from the scene images measured using the external blackbody. The shutter itself has to be regarded as a radiating scene emitting at a temperature of the laboratory (average of 21.5°C). Therefore it can be compared to a 300K scene. The most basic difference image is modelled as:

$$S_{ijts}^{\Delta} := S_{ijt}^{scene} - S_{ijs}^{shutter} \quad (1)$$

where (i,j) addresses the different elements of the image matrices S_{ijts}^{Δ} , S_{ijt}^{scene} and $S_{ijs}^{shutter}$. The index i gives the spatial index of the scene (e.g. the across-track ground pixel direction, that is along 4° FOV) and the index j points to the spectral channels. t is the time the scene signal was determined and s the time the shutter measurement has been done.

In order to improve the SNR by minimization of noise in the resulting difference image, a strong averaging is introduced and (1) becomes more general:

$$\bar{S}_{ij}^{\Delta} := \frac{1}{T_{scene}} \sum_{t=1}^{T_{scene}} S_{ijt}^{scene} - \frac{1}{T_{shutter}} \sum_{s=1}^{T_{shutter}} S_{ijs}^{shutter} \quad (2)$$

Practically the series S_{ijt}^{scene} and $S_{ijs}^{shutter}$ were obtained by a periodical placement and removal of the shutter device during an image series measurement. The resulting scene / background sub-series are extracted algorithmically and are then averaged and subtracted from each other finally.

Under laboratory conditions, this method delivers high SNR values easily since there is no need to change the radiometric state of the instrument itself. That would be the case as soon as the internal shutter or the POI is moved, producing heat loads changing the intrinsic radiometric regime of the spectrometer and causing strong signal offset drifts.

2. Using BB300 and reference pixel values

For the test of the BB700 blackbody a shutter between detector and radiator is not available because both devices are instrument-internal. Nevertheless the background signal portion has to be removed as well if the BB700-scene signals shall be regarded. For that purpose a method has been developed that makes it possible to obtain knowledge about the background signal portions with a minimum of inner instrument heat-up. The concept makes use of the fact that due to the optic design the outer image regions do not receive radiation from the scene but from the full background. The corresponding pixel signal values can be related to the background signal portions that can be expected in the scene regions of the images. If the background radiation is sufficiently flat, the following relation defines the connection of the signals of both image areas:

$$S_{ij}^{BG} = S_{mn}^{BG} d_{mnij} + c_{mnij} \quad (3)$$

where (i,j) index image elements in the image scene area and (m,n) elements in the rest of the image. BG refers to “background” and consequently S_{ij}^{BG} to the background signal portion in the scene image area and S_{mn}^{BG} the background signal in the non-scene image area. The relative offset and sensitivity coefficients (c_{mnij} , d_{mnij}) can be determined from separate flat-field image measurements, e.g. with the POI pointing at the BB300 device prior and after to the scene measurements. The desired difference image S_{ij}^{Δ} can be determined using (3):

$$S_{ij}^{\Delta} = S_{ij} - (S_{ij}^{BG} = S_{mn}^{BG} d_{mnij} + c_{mnij}) \quad (4)$$

3.4 Determination of the spectral calibration coefficients

For the determination of the instrument’s spectral calibration a plane fit calculation through spectral – spatial sampling points has been defined. The base data for that calculation are difference images of IR band pass filters discretely covering the whole spatial and spectral range MERTIS-TIS offers. Having measured the sample points at three different positions within the FOV and for six spectral positions, a plane can be fitted through the set of $3 \times 6 = 18$ points. The following plane equation was used to connect pixel coordinates (i,j) with a channel’s central wavelength λ :

$$\lambda(i, j) := \lambda_0 + s * i + t * j \quad (5)$$

The set (λ_0, s, t) are the spectral calibration coefficients. From these results the image clocking angle ϕ and the spectral sampling distance SSD can be calculated and verified as well. Furthermore a fit-error is given.

3.5 Radiometric Performance Evaluation

For the qualification tests possible changes in the radiometric performance are to be detected. The radiometric performance is here regarded in terms of a difference image SNR. The corresponding difference image is calculated from a single BB300 image and a single BB700:

$$\bar{S}_{ij}^{\Delta} = S_{ijt}^{BB700} - S_{ijs}^{BB300} \quad (6)$$

For a calculation of the SNR the image noise has to be determined. Here, the noise $\bar{\sigma}^{\Delta}$ is defined as the spatial average of each pixel's temporal noise value:

$$\bar{\sigma}^{\Delta} := \frac{1}{MN} \sum_{ij} \sigma_{ij}^{\Delta} = \frac{\sqrt{2}}{MN} \sum_{ij} \sigma_{ij}^t \quad \text{with} \quad \sigma_{ij}^{\Delta} := \sqrt{2} * \sigma_{ij}^t \quad (7)$$

where σ_{ij}^t denotes to the temporal noise of a single pixel (i,j) as a standard deviation. An estimate of σ_{ij}^t will be calculated from the datasets measured using 50 temporal samples.

For a graphic representation the SNR values from the image column i containing the maximum difference signal values are chosen. The SNR graphics are shown as a spectral value distribution:

$$SNR_i(j) := \frac{\bar{S}_{ij}^{\Delta}}{\bar{\sigma}^{\Delta}} \quad (8)$$

3.6 Determination of the POI position and repeatability

Goal of the measurement is to determine the positioning error of the pointing mirror unit. The positioning error will be determined from a series of BB700 difference scenes. The results are to be expressed in terms of a standard deviation and in units of pixel coordinates.

To determine the error a long image sequence is recorded. During the measurement the POI position is changed to the four viewports periodically. Each period takes 30 seconds (see Fig. 3). The BB300 view will be used as background reference in order to calculate the difference images for the BB700 and the planet view according to formula (4). The planet view is pointing to the AFT having a 700K scene.

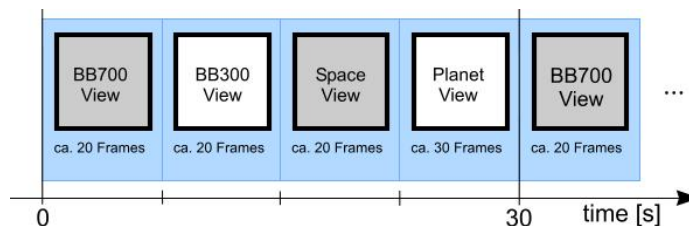


Fig. 3: POI positioning cycle for the position repeatability measurements. One period takes 30 seconds

The central positions (i_p^c, j_p^c) of the difference scenes are calculated and collected for each period p of the measurement. $P > 2$ periods are to be driven in order to determine a standard deviation positioning error. The central scene difference image positions (i_p^c, j_p^c) are calculated component-wise as:

$$i_p^c := \frac{\sum_{ij} S_{ijp}^{\Delta} i}{\sum_{ij} S_{ijp}^{\Delta}} \quad \text{and} \quad j_p^c := \frac{\sum_{ij} S_{ijp}^{\Delta} j}{\sum_{ij} S_{ijp}^{\Delta}} \quad (9)$$

where c indicates that it is a central position and p is either the time index for single images for a fixed POI position or it indicates the period an average image was taken in. I.e. the central positions $\{(i_p^c, j_p^c)\}_{p \in \{1 \dots P\}}$ can be related to the individual difference images within all periods or p can index the period itself within which all positions (which are calculated from those images taken at a fixed POI position) were averaged resulting in a single average value. That makes it possible to get an impression on how strong the calculated positions depend on the system noise rather than on the mirrors repositioning errors. The positioning errors σ_{ipos}^c and σ_{jpos}^c are calculated as:

$$\sigma_{ipos}^c := \sqrt{\frac{1}{P-1} \sum_p (i_p^c - \bar{i}^c)^2} \quad (10.1)$$

$$\sigma_{jpos}^c := \sqrt{\frac{1}{P-1} \sum_p (j_p^c - \bar{j}^c)^2} \quad (10.2)$$

where P is the total number of (average) positions. In the case of averaged central positions $\langle (i_p^c, j_p^c) \rangle$ P corresponds to the total number of periods, since exactly one averaged position sample will be taken per period p . The total positioning error σ^c is defined as:

$$\sigma^c := \sqrt{(\sigma_{ipos}^c)^2 + (\sigma_{jpos}^c)^2} \quad (11)$$

4 Test results

Here the test results are presented for both measurement campaigns before and after the qualification tests of the MERTIS-TIS FM.

4.1.1 Radiometric Performance

For the determination of the radiometric system performance the QM-BB700 and the BB300 as shutter have been measured.

For each image of the BB700 the background signal contribution was determined and removed using 152 reference pixel values outside the image scene area according to formula (4). The reference pixels were arranged in a 5x5 grid structure. The base dataset keeping the reference flat-field images is consisting of two average images which have been calculated from the first 15 and the last 15 images having the BB300 scene.

The row and column offsets have been removed from the resulting difference images before further processing and according to the windowing definition in 3.2.

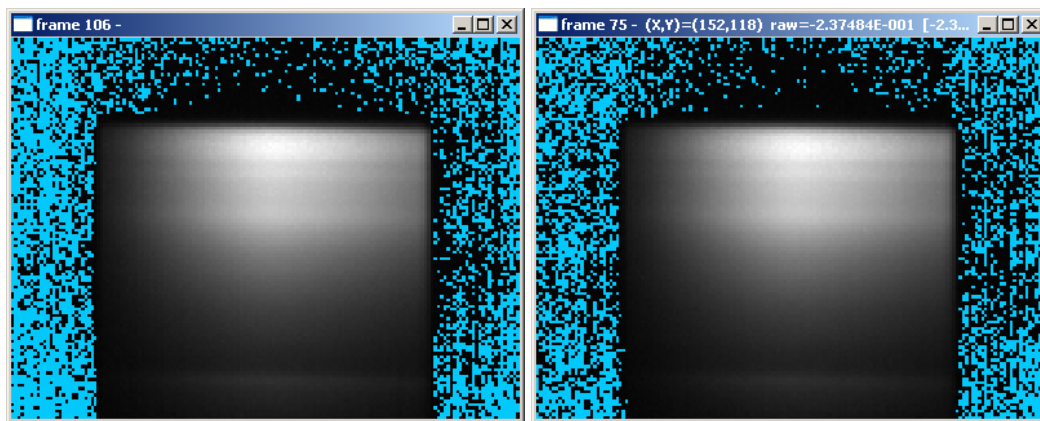


Fig. 4: left: Difference image of the BB700K scene before vibration **Right:** difference image of BB700 after vibration. No value distribution changes can be seen as well as there are no ghosting effects.

The noise strength $\bar{\sigma}^A$ of a basic difference image was determined according to formula (7) and has a value of $5.25 * \sqrt{2}$ DN. The spectral SNR determined according to formula (8) is given in Fig. 5. The measurement data sets used for the radiometric performance evaluation were taken in the measurement session "FM_8_POI_Position_Stability" on 4/December/2012.

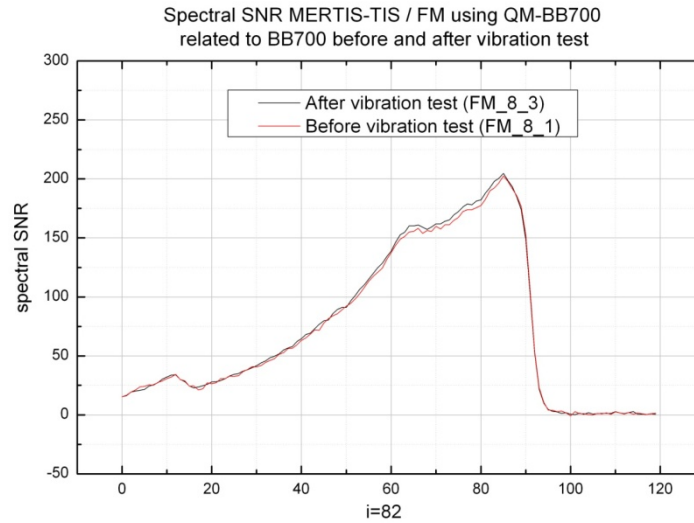


Fig. 5: Spectral SNR for the BB700 radiator before (red line) and after (black line) vibration tests. The SNR values are related to a difference image calculated from two single raw images. Both graphs show nearly identical SNR values. It is suggested that residual differences are results of noise strength variances.

4.1.2 POI position and repeatability before and after vibration

For the determination of the POI position and repeatability before and after vibration tests very large image series (FM_8_1 and FM_8_3) have been recorded keeping totals of ca. 7000 images each. During the measurement the POI was periodically driven to all 4 positions according to Fig. 3. One period took ca. 30 seconds so that there are 28 periods usable for the data processing. The images were taken within time intervals of 100 ms or 800 ms for the planet view position. For each image the background signal contribution was determined and removed using 152 reference pixel values outside the image scene area according to formula (4). The reference pixels were arranged in a 5x5 grid structure. For each measurement file the base dataset keeping the reference flat-field images is consisting of two average images which have been calculated from the first 15 and the last 15 images showing the BB300 scene.

For the position measurement evaluation the image scene area rectangle (see chapter 3.2) has been expanded to:

$$\text{Rect_Scene_FM} := \{ (x,y) \mid x \in [10 \dots 149] \text{ and } y \in [0 \dots 109] \}$$

Basing on that windowing definition the background-free difference images were additionally stabilized by cleaning them from drifting row, column and image offset structures. For the resulting image data cube the scene's central positions (i_p^c, j_p^c) were calculated for the BB700. The central position results

can be seen in Fig. 6. The positioning error σ^c has been determined for both the single and averaged positions.

The measurement data sets used for the spectral calibration / evaluation were taken in the measurement session "FM_8_POI_Position_Stability" on 4/December/2012.

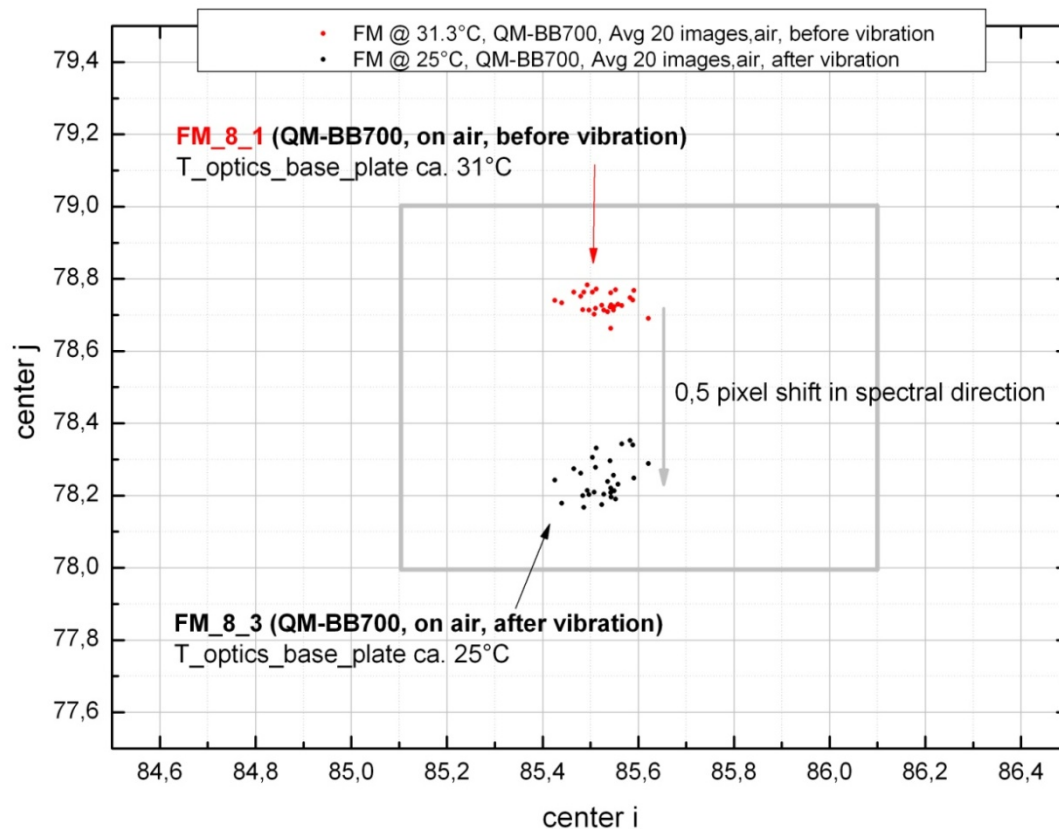


Fig. 6: Scene central positions calculated from difference images for BB700 view for both measurements before and after vibration tests. **Black** dots: positions over all 28 measurement periods after vibrational tests. **Red** dots: positions over all 28 measurement periods before vibrational tests.

The resulting positioning errors are far below an image pixel's size as it can be seen in **Table 1** and **Table 2**. Between the measurements before and after vibration tests there is a slight shift of the image detected, having a difference position value of ca. 0.5 pixel in spectral direction j and 0.1 pixel in FOV-direction i .

POI positioning error before vibration, FM_8_1	Standard deviation in FOV-direction σ_{ipos}^c	Standard deviation in spectral direction σ_{jpos}^c	Total position error σ^c	Central position in FOV direction i^c	Central position in spectral direction j^c
Single position	0.074	0.065	0.099		
Period position average	0.046	0.280	0.053		
Over-all position average	0.008	0.006	0.01	85.526	78.734

Table 1: POI repositioning results before FM vibration tests. The total position error is far below a pixel size with a value of <0.1 pixels.

POI positioning error after vibration, FM_8_3	Standard deviation in FOV-direction σ_{ipos}^c	Standard deviation in spectral direction σ_{jpos}^c	Total position error σ^c	Central position in FOV direction i^c	Central position in spectral direction j^c
Single position	0.082	0.101	0.130		
Period position average	0.050	0.054	0.074		
Over-all position average	0.009	0.010	0.013	85.42	78.26

Table 2: POI repositioning results after FM vibration tests. The total position error is far below a pixel size with a value of <0.1 pixels.

4.1.3 POI position repeatability for different instrument temperatures done at KT & DLR

For the determination of the POI position and repeatability for different instrument temperatures two measurement campaigns are compared. These tests were performed in the DLR / Berlin / IRLab and at KT - both under TV conditions. The series (FM_13_1, FM_14_1 and FM_15_1) belongs to the DLR measurements covering a thermal interval [13.7°C...41.9°C] of the optic's base plate while the measurements series (2013_01_12_Phase_I_MODE4_RED and 2012_01_10_Phase_F_Mode4_red) refer to KT covering the thermal interval [-1.9°C...43.7°C].

At the time of the measurements the **FM-BB700** has already been reintegrated into the instrument.

During the DLR measurement the POI was periodically driven to all 4 positions according to Fig. 3. One period took ca. 30 seconds so that there are ca. 70 periods usable for the data processing. The images were taken within time intervals of 100 ms or 800 ms for the planet view position. Between each period there were ca. 5 minutes. For the KT measurements there were for each period only one BB700 image available. For the lower base plate temperature there was additionally an instrument heater driven, being not properly controlled and therefore causing thermal oscillations which is problematic for the background signal estimation and removal.

For each image the background signal contribution was determined and removed using 152 reference pixel values outside the image scene area according to formula (4). The reference pixels were arranged in a 5x5 grid structure. For each measurement file the base dataset keeping the reference flat-field images is consisting of two average images which have been calculated from the first 15 and the last 15 images showing the BB300 scene.

For the position measurement evaluation the image scene area rectangle (see chapter 3.2) has been expanded to:

$$\text{Rect_Scene_FM} := \{ (x,y) \mid x \in [10...149] \text{ and } y \in [0...109] \}$$

Basing on that windowing definition the background-free difference images were additionally stabilized by cleaning them from drifting row, column and image offset structures. For the resulting image data cube the scene's central positions (i_p^c, j_p^c) were calculated for the BB700. The central position results

can be seen in Fig. 7. The positioning error σ^c has been determined for both the single and averaged positions.

The resulting positioning errors for both measurement campaigns the DLR measurements are below an image pixel's size as it can be seen in Table 3,

Table 4 and

Table 5. During the instrument heating measurements at the DLR there is no shift of the image detectable. For the KT measurements a shift of <2 pixels is visible in spectral direction and <0.2 pixels in FOV direction.

The DLR measurement data sets used for the evaluation were taken in the measurement session “FM_13, FM_14, FM_15” on 12-13/December/2012.

The KT measurement data sets used for the evaluation were included using the session number “FM_17” being taken at KT during the FM-TVC measurement campaign in January / 2013.

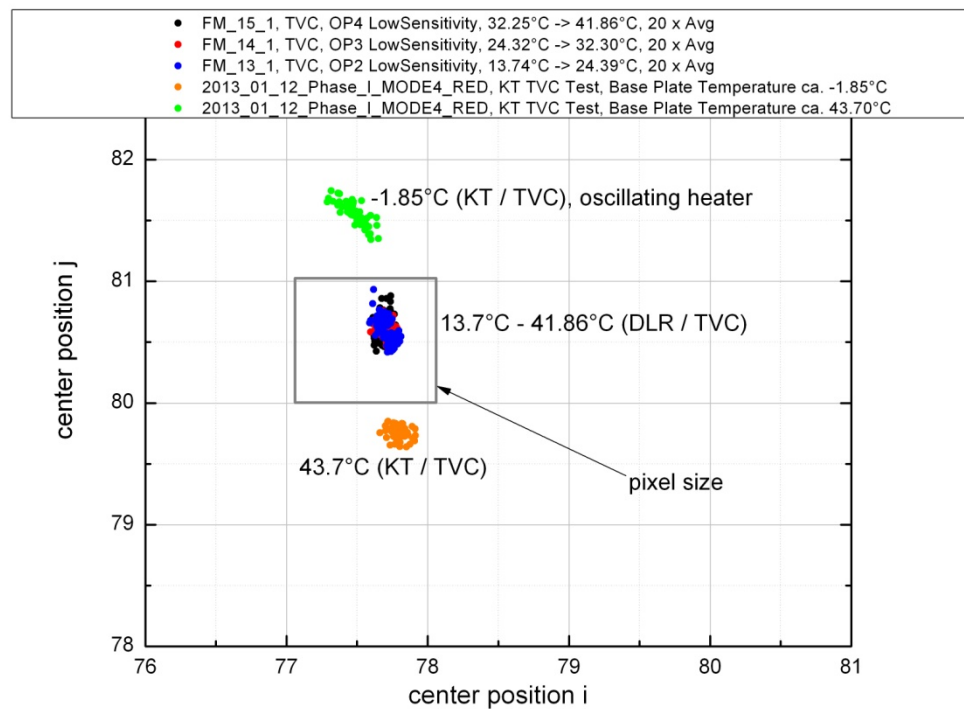


Fig. 7: Scene central positions calculated from difference images for BB700 view for instrument heating measurements after vibration tests done in the DLR/Berlin and KT both in TV conditions. At that time the FM-BB700 was reintegrated in the instrument. The measurements cover a thermal interval between 13.7°C and 41.9°C for the DLR measurements and -1.9°C and 43.7°C for KT measurements. There is no image significant position shift visible for the DLR measurement campaign. For the KT measurements there is a strong shift of nearly 2 pixels in spectral direction and a low shift of ca. 0.2 pixels in FOV direction visible.

POI positioning instrument temperature ramp: 13.7°C -> 24.4°C, FM_13_1, 74 periods	Standard deviation in FOV-direction σ_{ipos}^c	Standard deviation in spectral direction σ_{jpos}^c	Total position error σ^c	Central position in FOV direction i^c	Central position in spectral direction j^c
Single position	0.086	0.215	0.232		
Period position average	0.053	0.100	0.114		
Over-all position average	0.007	0.011	0.013	77.70	80.61

Table 3: POI repositioning results after FM vibration tests performed at the DLR and for an instrument temperature interval of ca. 14°C to 24°C. The total position error is far below a pixel size with a value of <0.1 pixels.

POI positioning instrument temperature ramp: 24.3°C -> 32.3°C, FM_14_1, 76 periods	Standard deviation in FOV-direction σ_{ipos}^c	Standard deviation in spectral direction σ_{jpos}^c	Total position error σ^c	Central position in FOV direction i^c	Central position in spectral direction j^c
Single position	0.083	0.190	0.207		
Period position average	0.043	0.061	0.075		
Over-all position average	0.010	0.022	0.023	77.690	80.614

Table 4: POI repositioning results after FM vibration tests performed at the DLR and for an instrument temperature interval of ca. 14°C to 24°C. The total position error is far below a pixel size with a value of <0.1 pixels.

POI positioning instrument temperature ramp: 32.3°C -> 41.9°C, FM_15_1, 100 periods	Standard deviation in FOV-direction σ_{ipos}^c	Standard deviation in spectral direction σ_{jpos}^c	Total position error σ^c	Central position in FOV direction i^c	Central position in spectral direction j^c
Single position	0.078	0.205	0.219		
Period position average	0.038	0.089	0.097		
Over-all position average	0.004	0.009	0.010	77.690	80.625

Table 5: POI repositioning results after FM vibration tests performed at the DLR and for an instrument temperature interval of ca. 32°C to 42°C. The total position error is far below a pixel size with a value of <0.1 pixels.

4.1.4 Spectral Calibration Coefficients

The spectral calibration measurement has been done according to 3.4 after the qualification test procedures. The differences of the spectral central positions of the BP sample points in the image and the calculated plane are shown in Table 6. From these a spectral calibration error σ_{fit} is given as a standard deviation. Furthermore the image clocking angle ϕ , the spectral sampling distance SSD and the spectral calibration coefficients (λ_0, s, t) are given in Table 7.

An image showing all bandpass measurements as a sum image is given by Fig 1 Fig. 8.

The measurement data sets used for the spectral calibration / evaluation were taken in the measurement session "FM_18" on 29/January/2013.

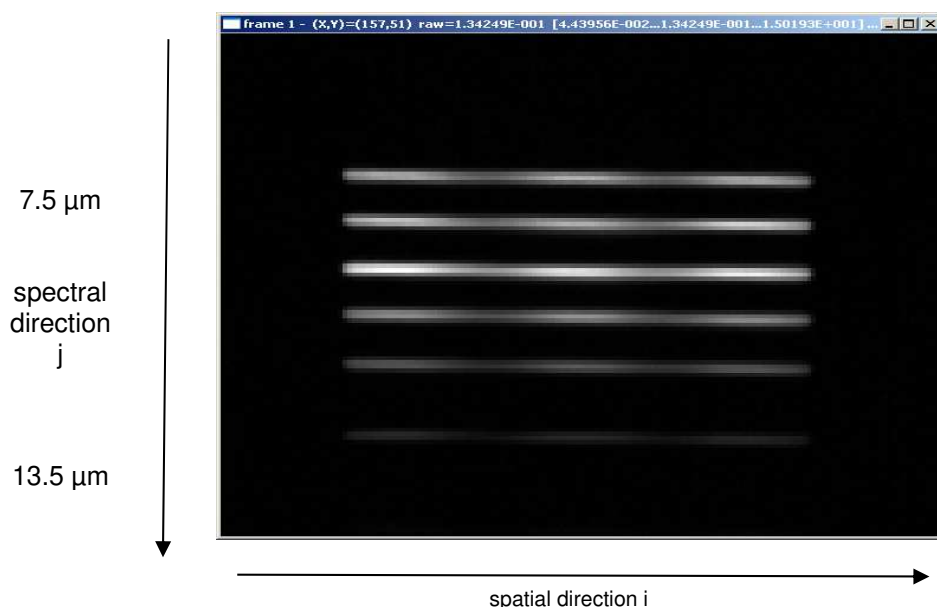


Fig. 8: Sum of all difference images of the IR-narrow band pass filter set measured using the MERTIS-FM after vibrational tests. The set covers the spectral range between 7.5 μm and 13.5μm.

Filter Name	λ_c [m] PEL	λ_{plane_fit} [m] Plane Fit	$\Delta\lambda = \lambda_{plane_fit} - \lambda_c$ [m] (PEL vs. Plane Fit)	σ_{fit} [m]
BP 7.5 μm	7.508189E-06	7.509928E-06 7.500119E-06 7.500752E-06	-1.738542E-09 8.070253E-09 7.436687E-09	
BP 8.5 μm	8.471418E-06	8.494111E-06 8.467947E-06 8.471366E-06	-2.269240E-08 3.471142E-09 5.270368E-11	
BP 9.5 μm	9.497802E-06	9.507104E-06 9.496916E-06 9.499150E-06	-9.302047E-09 8.859198E-10 -1.348062E-09	
BP 10.5 μm	1.047755E-05	1.047302E-05 1.045785E-05 1.048352E-05	4.529269E-09 1.970422E-08 -5.964155E-09	
BP 11.5 μm	1.153172E-05	1.153946E-05 1.151999E-05 1.153749E-05	-7.741103E-09 1.172662E-08 -5.773941E-09	
BP 13.0 μm	1.301154E-05	1.300358E-05 1.303024E-05 1.300212E-05	7.959471E-09 -1.869582E-08 9.419780E-09	
All Filters				1.061719E-08

Table 6: Spectral central positions of the IR BP filter set measured in the DLR/PEL and their deviations from the plane used as base model for the spectral calibration of MERTIS-TIS, central BP position values were calculated using bounding boxes of 12x3 (pre-centering) and 10x7 pixels (final centering) around the BP intensity maximum positions. The shuttering sequence was estimated using an intensity threshold value of 0.6.

SSD [m]	Clocking [°]	f_0 [m]	s [m / index]	t [m / index]
8.904449E-08	7.552717E-01	1.517173E-05	-1.173749E-09	8.903675E-08

Table 7: Spectral Sampling Distance (SSD), image clocking angle ϕ relative to the (almost spectral) image direction j and the spectral calibration coefficients (λ_0, s, t)

5 Conclusion

No relevant radiometric or spectral degeneration during or after the qualification test could be observed. The radiometric performance appears to be invariant against the strong mechanical stress the instrument was set under.

Thermal tests show a position shift of the image observed during KT thermal tests but these results cannot be confirmed from DLR measurements where no instrument heater has been used. The heater used in the KT measurement campaign caused temperature oscillations of the instrument housing for the cold case impacting the efficiency of the background signal reduction which is important for a proper scene signal extraction and therefore for a valid position determination of the BB700 features. It is highly suggested to perform POI positioning measurements using equal measurement procedures and instrument conditions if possible.

Anyways it is not expected to have an impact on the overall spectro-radiometric performance of the instrument since a possible position change can be tracked in-flight using the BB700 radiator delivering a feature-rich scene which is used for shift-compensation by modifying the spectral calibration coefficients.

Appendix 1: Measurement History / Protocol

FM_8_POI_Position_Stability:

4.Dezember.2012 - Emanuel Kopp

- * Model : FM , Komponenten komplett integriert (mit QM-BB700)
- * Session# : 8
- * Session-Name: "FM_8_POI_Position_Stability"
- * Ziele:
 - * Bestimmung der Positioniergenauigkeit des POI VOR UND NACH FM-Vibration-Test, QM-BB700 wurde zuvor in das FM integriert
- * Messung an Luft
- 1. Messung:
 - * file = "FM_8_1_Planet_BB700_BB300_SpaceView_OnAir_Before_Vibration.tdat"
 - * Originalmessung liegt unter "M:\MERTIS_SVN\FM\FM-System-Tests\Mechanical Test\POI_Rep_Test" und trägt den Namen "mer_kopp_em_FM_MAIN_LFT_Before_Mech_TEST_POI_Rep.tdms"
 - * größter Teil der Messung besitzt Bilder, die Teilweise Werte im nicht nutzbaren Dynamikbereich besitzen
 - * für Auswertung Bilder 0...7000 genommen
 - * VOR VIBRATION-TEST
- 2. Messung:
 - * file = "FM_8_2_Planet_BB700_BB300_SpaceView_OnAir.tdat"
 - * Originalmessung liegt unter "M:\MERTIS_SVN\FM\FM-System-Tests\Mechanical Test\POI_Rep_Test" und trägt den Namen "mer_kopp_em_FM_MAIN_LFT_Before_Mech_TEST_MODE29.tdms"
 - * VOR VIBRATION-TEST
- 3. Messung:
 - * file = "FM_8_3_Planet_BB700_BB300_SpaceView_OnAir_After_Vibration.tdat"
 - * Originalmessung liegt unter "M:\MERTIS_SVN\FM\FM-System-Tests\Mechanical Test\POI_Rep_Test" und trägt den Namen "mer_kopp_em_FM_MAIN_LFT_After_Mech_TEST_POI_Rep.tdms"
 - * BOL_CHIP_TEM = 25°C;
 - * SKIM = 4,581V;
 - * FID = 4,504V;
 - * BOL_TIMING_MODE = Low (123,8us Integrationszeit)
 - * 20 Bilder pro Target
 - * NACH VIBRATION-TEST

"FM_13, FM_14, FM_15":

12.Dezember.2012 - Thomas Säuberlich

- * Model : FM , Komponenten komplett integriert (mit FM-BB700 reintegriert)
- * Session# : 13
- * Session-Name: "FM_13_LONG_TIME_SERIES_TVC_HUBER_from_-13_5_to_-2_5_degC"
- * Ziele:
 - * Bestimmung von Arbeitsbereichen für MERTIS FM - TVC - Testphase
 - * OP2
- * Messung in TVC
- * OPTRIS BB@700K@PlanetView
- 1. Messung:
 - * file = "mer_f_mertis_FM_13_1_OP2_LONG_TIME_SERIES_TVC_HUBER_from_-13_5_to_-2_5.tdat"
 - * [V_fid = 2.398V, V_skim = 3.821V, t_int=123µs, T_TEC=15°C]
 - * Oversampling OFF
 - * Wechsel: T_HUBER_SET = -13.5 °C auf T_SET_HUBER = -2.5°C
 - * 1 Bild / 10s
 - * Calib. Cycle mit BB300,SpaceView,BB700 alle 300s = 5 min, 20 Bilder Pro Viewport (BB300,BB700,SpaceView)
 - * HK Period = 10s
 - * Messung Start 11:00 Uhr
 - * Histogramm linke Kante @ PlanetView bei 2000 DN
 - * Histogramm Mitte @ PlanetView bei 2870 DN
 - * T_optics_base_plate = 13.74°C
 - * 11:05: T_HUBER_SET = -2.5°C (-3,5 im VTK-VI ;)

* 17:19: T_optics_base_plate = 24.39°C, Histogramm Mitte @ PlanetView bei 7581 DN
* Messung Beendet, kann um 1K extrapoliert werden, da Histogram-Fuß rechts, bei 8931 DN

12.Dezember.2012 - Thomas Säuberlich

* Model : FM , Komponenten komplett integriert (mit FM-BB700 reintegriert)
* Session# : 14
* Session-Name: "FM_14_LONG_TIME_SERIES_TVC_HUBER_from_-2_5_to_7_5_degC"
* Ziele:
 * Bestimmung von Arbeitsbereichen für MERTIS FM - TVC - Testphase
 * OP3

* Messung in TVC
* OPTRIS BB@700K@PlanetView

1. Messung:

* file = "mer_f_mertis_FM_14_1_OP3_LONG_TIME_SERIES_TVC_HUBER_from_-2_5_to_7_5.tdat"
* [V_fid = 2.398V, V_skim = 3.818V, t_int=123µs, T_TEC=25°C]
* Oversampling OFF
* Wechsel: T_HUBER_SET = -2.5 °C auf T_SET_HUBER = 7.5°C
* 1 Bild / 10s
* Calib. Cycle mit BB300,SpaceView,BB700 alle 300s = 5 min, 20 Bilder Pro Viewport (BB300,BB700,SpaceView)
* HK Period = 10s
* Messung Start 17:25 Uhr
 * Histogramm linke Kante @ PlanetView bei 2443 DN
 * Histogramm Mitte @ PlanetView bei 3894DN
 * T_optics_base_plate = 24.37°C
 * T_HUBER_SET = 7.5°C
* Messung Ende 23:50 Uhr:
 * T_optics_base_plate = 32.30°C

12.Dezember.2012 - Thomas Säuberlich

* Model : FM , Komponenten komplett integriert (mit FM-BB700 reintegriert)
* Session# : 15
* Session-Name: "FM_15_LONG_TIME_SERIES_TVC_HUBER_from_7_5_to_19_0_degC"
* Ziele:
 * Bestimmung von Arbeitsbereichen für MERTIS FM - TVC - Testphase
 * OP4

* Messung in TVC
* OPTRIS BB@700K@PlanetView

1. Messung:

* file = "mer_f_mertis_FM_15_1_OP4_LONG_TIME_SERIES_TVC_HUBER_from_7_5_to_19.tdat"
* [V_fid = 2.398V, V_skim = 3.819V, t_int=123µs, T_TEC=35°C]
* Oversampling OFF
* Wechsel: T_HUBER_SET = 7.5°C °C auf T_SET_HUBER = 19°C
* 1 Bild / 10s
* Calib. Cycle mit BB300,SpaceView,BB700 alle 300s = 5 min, 20 Bilder Pro Viewport (BB300,BB700,SpaceView)
* HK Period = 10s
* Messung Start 00:00 Uhr
 * Histogramm linke Kante @ PlanetView bei 2261 DN
 * Histogramm Mitte @ PlanetView bei 4120 DN
 * T_optics_base_plate = 32.27°C
 * T_HUBER_SET = 19.0°C
* Messung Ende 8:30 Uhr:
 * T_optics_base_plate = 41.85 °C
 * Histogramm rechter Fuß @ ca. 12000 DN

“FM_17” is actually part of a measurement campaign done by KT on the FM in 2013