ENVISAT-1 GROUND SEGMENT

Michelson Interferometer for Passive Atmospheric Sounding

In-Flight Characterization and Calibration Definition

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Issue Date: 1 May 2001

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<th>Name</th>
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<tbody>
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# DOCUMENT CHANGE RECORD

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<tr>
<td>1(draft)</td>
<td>-</td>
<td>11 January 2000</td>
<td>First draft of document</td>
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<tr>
<td>1</td>
<td>-</td>
<td>24 March 2000</td>
<td>Second draft of document</td>
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<td>1</td>
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<td>19 May 2000</td>
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<td>1</td>
<td>A</td>
<td>3 October 2000</td>
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</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1 May 2001</td>
<td>Updated Issue. Modified IF10 (NESR is computed in time rather than in frequency). Added criteria for considering each test to be successful and added action to be taken after tests. Recomputed data size.</td>
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1. INTRODUCTION

1.1 PURPOSE OF DOCUMENT

This document describes the plan for essential calibrations and characterizations to be performed during the early in-flight operation (commissioning) of MIPAS. The corresponding on-ground data processing and analyses are also described.

1.2 SCOPE

The scope of in-flight tests is to:

- Check and optimize the instrument operation parameters
- Characterize critical performance parameters
- Optimize the calibration scenario (gain, offset, spectral calibration)
- Generate level 1B auxiliary input data sets for calibration, validation, and for IPF processing
- Validate level 1B data products

1.3 DOCUMENT OVERVIEW

The document is organized as follows: important definitions are given in chapter 1, Chapter 2 provides a complete description of the instrument calibrations and characterizations, Chapter 3 gives a summary of the overall calibration and characterization plan in tabular form. Mentions are made where earlier measurements can be used to extract the information necessary to conclude about a specific test without additional experimental measurements.

Chapter 5 gives for each data processing description listed in Chapter 2 the corresponding MIPAS IECF processing chain if any.
1.4 REFERENCE DOCUMENTS

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<th>Reference</th>
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<td>RD1</td>
<td>PO-PL-BOM-MP-0009</td>
<td>1F</td>
<td>MIPAS Instrument Level Calibration and Characterization Plan</td>
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<tr>
<td>RD3</td>
<td>PO-RP-BOM-MP-0030</td>
<td>1-</td>
<td>Instrument FM Data Analysis (1\textsuperscript{st} campaign), 30.07.98.</td>
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<td>RD5</td>
<td>PO-TR-DAS-MP-0143</td>
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<td>MIPAS FM Instrument Performance Verification Test Report (2\textsuperscript{nd} Campaign), 27.08.1999</td>
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<td>RD6</td>
<td>PO-TN-BOM-MP-0016</td>
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<td>PO-PL-DAS-MO-0031</td>
<td>3</td>
<td>In-flight Calibration Plan, 11.11.1998.</td>
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<td>RD9</td>
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<td>Instrument EQM Data Analysis (Cold Case), 15.02.98.</td>
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<td>In-flight Spectral Calibration &amp; Instrument Lineshape Retrieval</td>
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<td>PO-RP-BOM-MP-0007</td>
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<td>MIPAS instrument Assumption on Ground Segment</td>
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<td>PO-ID-DAS-MP-0010</td>
<td>3A</td>
<td>Instrument Measurements Data Definition</td>
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<td>RD17</td>
<td>PO-RS-DOR-MP-001</td>
<td>7</td>
<td>MIPAS Instrument Specifications, 16.10.1995</td>
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1.5 ACRONYMS

ADC  Analog to Digital Converter
CBB  On-board Calibration Black Body
CBE  On-board Calibration Black Body Electronics
DS   Deep Space
FCE  Fringe Count Error
FFT  Fast Fourier Transform
FIR  Finite Impulse Response
FOV  Field of View
FWHM Full Width at Half Maximum
FM   Flight Model
GSE  Ground Support Equipment
IGM  Interferogram
ILS  Instrument Line Shape
INT  Interferometer
IPF  Instrument Processing Facility
LOS  Line Of Sight
MB   Mbytes
MIPAS Michelson Interferometer for Passive Atmospheric Sounding
MPD  Maximum Optical Path Difference
MOB  MIPAS Optical Module Base Plate
OCFB Optical Calibration Facility Black Body
OPD  Optical Path Difference
PFM  Peak Find Method
PRT  Platinum Resistance Thermometer
RMS  Root Mean Squared
SPE  Signal processing Electronics
SNR  Signal-to-Noise Ratio
TBC  To Be Confirmed
TBD  To Be Determined
ZPD  Zero Path Difference
1.6 DEFINITIONS OF TERMS

Accuracy

Accuracy is characterized by uncertainty and repeatability.

Uncertainty: Uncertainty is defined as the closeness of the agreement between the result of a measurement and the value of the measurand. Accuracy is a qualitative concept and is not associated with numbers. When quantifying the accuracy the word “uncertainty” is used (See [RD1]).

All uncertainty values given in this document are stated either as values with standard uncertainty (RMS or $1\sigma$), or as expanded uncertainty (3$\sigma$). Standard uncertainty and expanded uncertainty values are explicitly stated when applicable.

Repeatability: Repeatability is defined as the closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement (See [RD1]).

All repeatability values given in this document are stated either as values with standard uncertainty (RMS or $1\sigma$), or as expanded uncertainty (3$\sigma$). Standard uncertainty and expanded uncertainty values are explicitly stated when applicable.

Calibration Definitions and Grades

Calibration is the procedure for converting instrument measurement output data into the required physical unit with a specified accuracy.

The calibration process is defined by:

- A scenario for measurement data acquisition
- A set of ancillary data acquired during characterization
- A method for computing calibrated data from measurements and ancillary data

In this document the following definitions of the different calibrations are used:

Spectral Calibration: Process of assigning values in cm$^{-1}$ to the wavenumber axis (x-axis) with a specified accuracy.

We will refer to different grades of spectral calibrations. The different grades of spectral calibration indicate the accuracy of the calibration. Some measurements require precise spectral calibration while others require less precise spectral calibration. In this document the following definitions of the different spectral calibrations are used:

Grade I: Spectral calibration is accurate to 0.001 cm$^{-1}$. This is the normal absolute spectral calibration as required by MIPAS.
Grade II: Spectral calibration is accurate to 0.1 cm\(^{-1}\). Many measurements require a minimum of spectral calibration, but not with the full (grade I) accuracy. One example is the radiometric calibration. A radiometric calibration requires some knowledge of spectral registration because a spectral error will induce a radiometric error (e.g. a 1 cm\(^{-1}\) error gives 0.5% radiometric error at 2400 cm\(^{-1}\) for a 220K blackbody). A grade II spectral calibration is sufficient to perform a radiometric calibration.

Note: In the case of a sharp spectral band cutoff of optical component or numerical filtering, applying a spectral correction may cause larger radiometric error due to large variation of spectral response as a function of the spectral frequency, compared to the variation of the Planck distribution for which the correction is intended.

Radiometric Calibration: Process of assigning values in radiance units (W / cm\(^{-1}\) sr cm\(^2\)) to the intensity axis (y-axis) with a specified accuracy. Spectral calibration is prerequisite to the radiometric calibration.

LOS Calibration: Process of assigning, with a specified accuracy, the LOS pointing direction of a given atmospheric spectrum.

**Characterization**

Characterization is the direct measurement or derivation from measurements of a set of parameters, valid over a range of conditions, to provide data necessary for calibration, ground processor initialization, and verification.

Characterization measurements can be classified according to their purposes:

- Characterization for verification: In the context of characterization, verification refers only to performance requirements (verification is defined below).

- Characterization for ground processor initialization: These are the data stored and used by the ground processing. We can distinguish:
  - Pre-flight characterization: Characterization measurements taken on-ground and used in the calibration procedure. The data from these measurements may have been acquired at instrument level using the GSE (e.g. the spectral calibration) or at sub-system level by the sub-system contractor (e.g. the on-board blackbody emissivity coefficients).
  - In-flight characterization: Characterization measurements taken in-flight to optimize the operational scenario when the instrument is subject to the real environmental conditions.

- Characterization for calibration: These are all measurements used in the calibration procedure besides actual scene measurements. These measurements may be acquired on ground or in-flight. Since by definition, the data from these measurements are used in the calibration procedure, they all need to be available to the ground segment.
The Noise Equivalent Spectral Radiance $N_{ESR_T}$ is defined as the standard deviation of the measured single sweep spectral radiance taken over the ensemble of $N$ measurements ($j = 1...N$) for the input signal of a blackbody at temperature $T$ in a stable thermal environment:

$$N_{ESR_T}(\sigma) = \left[ \frac{1}{N-1} \sum_{j=1}^{N} (R_j^T(\sigma) - <R^T(\sigma)>)^2 \right]^{1/2}$$

The Noise Equivalent Spectral Radiance $N_{ESR_0}$ is defined as $N_{ESR_T}$ with $T$ sufficiently small that the noise contribution from input signal becomes negligible to the noise contribution from the instrument itself.

**Transmittance**

Transmittance is a Y-axis unit often used in spectra to express the phenomenon of transmission through a given sample. A spectrum expressed in transmittance unit is a spectrum normalized to the response of the system, i.e. it is independent of the system used. Traditionally the transmittance of a sample, for example a gas, is given by:

$$T_{Sample} = \frac{S_{Sample}}{S_{NoSample}}.$$

where $S_{Sample}$ and $S_{NoSample}$ are the spectra measured in the presence and absence of the sample, respectively. A slightly modified version of the transmittance equation is used in this work to account for the thermal emission of the instrument:

$$T_{Sample} = \frac{S_{Sample} - S_{DeepSpace}}{S_{NoSample} - S_{DeepSpace}}$$

**Validation**

Validation is the process of providing goodness or confidence interval information associated with a particular result. The validation can be provided through an independent check of the parameter (repeating the measurement), an analysis, or against a check of externally provided sources of information, which can be trusted. In-flight tests, when appropriate, are validated against results from the on-ground verification campaigns.

**Verification**

Verification is the sum of all activities performed to demonstrate the fulfillment of a requirement. In principle, verification should be applied to all requirements in MIPAS requirement specifications. There are several types of requirements, for example electrical requirements, mechanical requirements, etc. In the present document, we are only concerned with the instrument performance requirements.

Performance verifications produce outputs in the form of actual numerical values (or vector of values). By comparing these outputs with numerical values representing the requirement, the performance verification process produces binary outputs of the type Pass/NoPass.
Verification activities are generally related to instrument qualification and are thus conducted before launch. In-flight activities are more related to characterization and calibration of the instrument and output of the type Pass/NoPass do not apply. Instead, they generate data to be used by the ground-segment processing.

Other Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Data size</td>
<td>For computer data size, the symbols k, M, and G take the values $2^{10}$, $2^{20}$, and $2^{30}$ instead of the standard SI values ($10^3$, $10^6$, $10^9$). Therefore the data size acronyms have the following meanings:</td>
</tr>
<tr>
<td></td>
<td>1 Byte 8 bits</td>
</tr>
<tr>
<td></td>
<td>1 kByte $2^{10}$ bytes (1024 bytes)</td>
</tr>
<tr>
<td></td>
<td>1 MByte $2^{20}$ bytes (1 048 576 bytes)</td>
</tr>
<tr>
<td></td>
<td>1 GByte $2^{30}$ bytes (1 073 741 824 bytes)</td>
</tr>
<tr>
<td>Interferogram</td>
<td>The sampled intensity $I/n$ of the IR signals I(x), measured by the detector of an interferometer as a function of the moving mirror displacement x.</td>
</tr>
<tr>
<td>Raw interferogram</td>
<td>Interferogram that has not been combined, numerically filtered, or decimated. The signal at the output of the ADC is a raw interferogram.</td>
</tr>
<tr>
<td>Intrinsic line-shape</td>
<td>Contribution to a given line-shape from the natural width of an infrared transition</td>
</tr>
<tr>
<td>Nominal interferogram length</td>
<td>The nominal interferogram length is the number of points for a filtered, decimated and combined interferogram resulting from a measurement in the nominal data mode.</td>
</tr>
<tr>
<td>Raw interferogram length</td>
<td>The raw interferogram length is the number of points for a raw interferogram resulting from a measurement in raw mode.</td>
</tr>
<tr>
<td>Optical Path Difference</td>
<td>The path length difference of the two interferometer arms.</td>
</tr>
<tr>
<td>Sweep</td>
<td>The mechanical motion of the interferometer arm mirrors. A sweep may also refer to the time duration necessary to move the interferometer mirrors resulting in an OPD ranging from -MPD to +MPD. A sweep can be in the reverse or forward direction.</td>
</tr>
</tbody>
</table>
1.7 OVERALL CALIBRATION AND CHARACTERIZATION PLAN

The calibration, characterization, and verification activities are summarized in Figure 1. The activities are grouped in six classes. The classes generally encompass operations of a similar type. The classes are ordered in a hierarchical manner rather than in a strictly chronological manner, for example, the time schedule places some performance verification measurements before some characterization for calibration measurements.

![Flowchart of the complete calibration and characterization plan]

The two last classes of operations are to be carried out in-flight. The initial in-flight characterization (IF) includes characterization measurements performed during the commissioning phase. The periodic in-flight verification (PF) is performed periodically during MIPAS's mission when needed.
1.8 ASSUMPTIONS

Change from low- to high-resolution setting introduces fringe count errors (FCE). It is assumed that the software functions implement appropriate handling when manipulating interferograms acquired at different resolution settings. Thus, no FCE processing step is specifically given in this document. Similarly, each time the deep space (DS) measurements are subtracted from CBB or SCENE measurements, or when the radiometric gain is used, the processing described in the Data Analysis section assumes that the FCE is handled properly. The current FCE handling scheme is provided in [RD14].
1.9 MIPAS CONFIGURATION DEFINITION

1.9.1 Definition of modes

Each in-flight characterization requires a specific instrument configuration. These configurations are described here and references are given in the *MIPAS Configuration Requirements* section of each in-flight characterization. Information supplied includes the data transmission mode, detectors used in the measurement, spectral resolution in units of Maximum Path Difference (MPD), the pointing parameters, and the number of interferometer sweeps per acquisition. The MIPAS modes are defined as follow:

RAW data mode: The interferograms are transmitted without any combination, numerical filtering or decimation. The possible detectors are A1, A2, B1, B2, C1, C2, D1, and D2.

NOMINAL data mode: The interferograms are numerically filtered, decimated and combined according to baseline scheme before transmission. The possible bands are: A1, A2, AB, B, C and D. In this document NOMINAL data mode refers only to the data processing of the MIPAS mode. The scan sequencing of the elevation and azimuth mirrors are all commanded using the special event commanding.

LOS data mode: The interferometer slides are locked at the end positions. The detector signals coming from the channels D1 and D2 are fed through digital filters with corner frequencies of 1 Hz and 11 Hz respectively. The data are sampled by the SPE at a rate of 1 kHz. The SPE output data rate, after FIR filtering and sample addition, is equivalent to 100 Hz.
### 1.9.2 Interferogram Length

The number of samples per interferogram are defined in Table 1 (they correspond to the one used during the FM measurement campaign), baseline decimation factor are given in Table 2.

**Table 1: Number of samples in interferograms**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Detector/ Band</th>
<th>Number of Samples (N_j)</th>
</tr>
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<tbody>
<tr>
<td>RAW</td>
<td></td>
<td>2-cm MPD</td>
</tr>
<tr>
<td></td>
<td>A1</td>
<td>(N_{j}^{raw_low} = 30450)</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>D1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td></td>
</tr>
<tr>
<td>NOMINAL</td>
<td>A</td>
<td>(N_{A}^{nom_low} = 1438)</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>(N_{AB}^{nom_low} = 839)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>(N_{B}^{nom_low} = 1373)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>(N_{C}^{nom_low} = 1007)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>(N_{D}^{nom_low} = 2745)</td>
</tr>
<tr>
<td>LOS</td>
<td>D1 and D2</td>
<td>4000 Rearward</td>
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Table 2: Decimation factor for the $j$ channels

<table>
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<th>$j$</th>
<th>Decimation factor ($D_j$)</th>
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<tr>
<td>A1, A2</td>
<td>21</td>
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<tr>
<td>B1</td>
<td>36</td>
</tr>
<tr>
<td>B2</td>
<td>22</td>
</tr>
<tr>
<td>C1, C2</td>
<td>30</td>
</tr>
<tr>
<td>D1, D2</td>
<td>11</td>
</tr>
</tbody>
</table>

1.9.3 Pointing Parameters

Note that angles are given in the $F_{LO2}$ reference frame.

CBB: The MIPAS instrument is pointing to the internal calibration blackbody (113.0 degrees of elevation, 270 degrees of azimuth ([RD8] Fig 5.5-1 ))

DS: The MIPAS instrument is pointing to DS (113.4 degrees of elevation, 80 degrees of azimuth). Table 3 is used by IF9 to optimize DS pointing.

Table 3: Pointing angles for DS pointing optimization

<table>
<thead>
<tr>
<th>$H_k$ (km)</th>
<th>Elevation Pointing Angle (degrees)</th>
<th>Azimuth Pointing Angle (degrees)</th>
</tr>
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<tbody>
<tr>
<td>150</td>
<td>TBD</td>
<td>80</td>
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<tr>
<td>155</td>
<td>TBD</td>
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<td>160</td>
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<tr>
<td>210</td>
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</table>
Table 4: Pointing angles for corresponding tangent height

<table>
<thead>
<tr>
<th>$H_k$ (km)</th>
<th>Elevation Pointing Angle (degrees)</th>
<th>Azimuth Pointing Angle (degrees)</th>
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<tbody>
<tr>
<td>8</td>
<td>TBD</td>
<td>80</td>
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<td>53</td>
<td>TBD</td>
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</table>

1.9.4 CBB baseline temperature

The baseline CBB temperature is 230K ([RD5] section 6.1.3.2.2). The maximum heating temperature is 247K over which the ADC reading the CBB PRTs enters saturation ([RD5] section 6.1.3.2.2).

1.9.5 Instrument Temperature Scenario

Contrary to the temperature scenario defined during ground verification, where the temperature was stabilized at the minimum or maximum orbital temperature, in-flight temperature has no such freedom or constraint but to operate in its environment together with the heating of the metrology detection electronic to operate properly. The only constraint is to allow the instrument to reach its permanent thermal regime before conducting critical characterizations. The MOB baseline temperature is estimated to stabilize to 210K with small orbital variations and seasonal and aging drift.
2. IN-FLIGHT INITIAL CHARACTERIZATION

2.1 IF0 LOS CHARACTERIZATION

**Objective:**

Provide line of sight (LOS) calibration (see [RD9]).

**Approach:**

The LOS calibration channels (detectors D1 and D2) are monitored while stars cross the instrument FOV. The overall data acquisition for a single star is 40 seconds. The measurement is repeated for every available star in one orbit. Note that the number of stars is dependent on the day of the year.

**Accuracy:**

TBD

**Prerequisite measurements or calibrations:**

None.

**MIPAS configuration required:**

LOS data mode, detectors D1 and D2 active, interferometer slides stationary at their opposite end positions.

Instrument pointing at the rear port to the commanded coordinates (rear elevation calibration). See [RD9], section 7.

**Measurement description:**

a) \( I_{\text{Rear}, j,d,i,k}^\text{Rear} [n] \)

- \( j \) = band identification (D1, and D2)
- \( d \) = slides stationary
- \( i \) = star index (select the star with the highest intensity)
- \( k \) = orbit (or repeat) index (0,…, 30)
- \( n \) = sample index \( \left( 0, \ldots, N_{\text{LOS}} - 1 \right) \)

Instrument in LOS mode
Azimuth mirror commanded for multiple star crossings
Instrument pointing at TBD
b) $I_{j,d,i,k}^{\text{Side}}[n]$

- $j$ = band identification (D1, and D2)
- $d$ = slides stationary
- $i$ = star index (0,…, 10)
- $k$ = repeat index (0,…, TBD)
- $n$ = sample index $(0,\ldots,N_{LOS}^{\text{LOS}} - 1)$

Instrument in LOS mode
Azimuth mirror commanded for a constant speed of $V_{\text{ESU}}$
Instrument pointing at TBD

TBC by GPE
2.2 IF1 ANALOG GAIN VERIFICATION

Objective:

Verify that the analog gain settings are correct or can be optimized. The ADC occupation criterion is 85%-100% for CBB at baseline temperature and for minimum tangent height scenes. However, if the ADC has sufficient range to resolve the detector noise with adequate resolution (about 10 levels or 3 bits peak to peak) and to handle to maximum signal without saturation, then it is not necessary to adjust the gain. With the data collected during this verification, an adequate gain setting can be selected.

Approach:

First, the CBB at nominal temperature is measured and the interferogram maximum excursion is determined. The maximum and minimum amplitudes recorded by the SPE may be inaccurate due to the fact that the sampling may miss the real extreme. It is thus necessary to interpolate the interferogram to find the real extremes. This must be done in RAW data mode because filtering removes spectral information thus modifies the ZPD amplitude/shape. 32 sweeps in each sweep direction are acquired to assess the accuracy of the measurements. The first step is repeated until the proper analog gain is found. (To be combined with the LOS characterization measurements)

Second, the measurements are repeated in nominal mode to obtain a correlation between the raw and nominal modes to compare and determine if the raw data mode requires a smaller gain or not. Since decimation and filtering affect the amplitude, the gains setting may be appropriate for nominal mode but not for raw mode. The same interpolation process is performed.

Third, scene measurements are performed at a low tangent height (it is suggested to do the measurements at 5 km) in nominal mode, over several orbits (15 orbits, i.e., covering one earth rotation) to establish the mean and standard deviation of the extreme for each tangent height. The 32-sweep sequence is repeated 20 times per orbits. Again, the interpolation process is performed to find the real extremes. Monitoring of the instrument parameters is also performed during the third step, in particular, all temperature sensors are monitored and recorded.

Note 1: For periodic in-flight verification: Acquire data in nominal scenario, extract the minimum height measurement, and correlate with orbital parameters. This can be performed as standard ground processing, in place of periodic in-flight analog gain verification.

Forth, the analog gain verification may also have to be performed before the non-linearity characterization. This is because the CBB is heated using the maximum heater power and that the nominal gain settings may be too high. Only the raw mode characterization is performed for this purpose.

Note 2: Providing sufficient characterization provides the necessary information for establishing a scenario in which the gain is changed through an orbit. However, this may not be desirable because the radiometric calibration obtained for one gain setting cannot simply be scaled to another gain: a complete new radiometric calibration is required. Performing Radiometric Calibration using different analog gains should be included in the
initial in-flight characterization if this scenario is considered. The goal would be to provide the appropriate calibration gains and offset for each gain setting. Characterize the electrical gain when the CBB is at its minimum temperature. See non-linearity note.

Note 3: Throughout the mission, when operating in nominal mode, the CBB measurement ZPD amplitude should be monitored to detect any significant variations requesting analog gain verification. The trend is monitored by averaging the last 10 interpolated ZPD amplitude measurements and comparing to the 10 averaged interpolated ZPD amplitude measurements following the last Analog Gain Verification. The Analog Gain Verification should be initiated for relative averaged deviation of more than 5%.

Note 4: Analog Gain Verification (the second and third parts) must be repeated if new filters are used as requested by the aliasing verification (IF3).

**Accuracy:**

1% of the ADC dynamic range.

**Prerequisite measurements or calibrations:**

IF0 (LOS required for the 3rd part).

**MIPAS configuration required:**

2-cm MPD, numerical filters as determined from the ground verification.

**Measurement description:**

a) \( I_{j,d,i}^{CBB_{-230_{-RAW}}}[n] \)

\( j = \) band identification (A1, A2, B1, B2, C1, C2, D1, and D2)
\( d = \) sweep direction identification (FORWARD and REVERSE)
\( i = \) sweep index (0, ..., 31)
\( n = \) sample index \( \left(-\frac{N_j^{raw\_low}}{2}, ..., \frac{N_j^{raw\_low}}{2} - 1\right) \)

Instrument pointing at CBB
CBB at baseline operation temperature
Instrument in RAW mode

b) \( \tilde{I}_{j,d,i}^{CBB_{-230_{-NOIMAL}}}[n] \)

\( j = \) band identification (A1, A2, B1, B2, C, and D)
\( d = \) sweep direction identification (FORWARD and REVERSE)
\( i = \) sweep index (0, ..., 31)
\( n = \) sample index \( \left(-\frac{N_j^{nom\_low}}{2}, ..., \frac{N_j^{nom\_low}}{2} - 1\right) \)

Instrument pointing at CBB
CBB at baseline operation temperature
c) $\tilde{I}_{j,d,i,k}^{SCENE}[n]$

- $j = \text{band identification (A1, A2, B1, B2, C, and D)}$
- $d = \text{sweep direction identification (FORWARD and REVERSE)}$
- $i = \text{sweep index (0, ..., N_{SWEEP}=31)}$
- $k = \text{sequence index (0, ..., 299)}$
- $n = \text{sample index } \left(-\frac{N_{j,\text{nom}}}{2}, \ldots, \frac{N_{j,\text{nom}}}{2} - 1\right)$

Instrument pointing at minimum tangent height

Instrument in NOMINAL mode

\[I_{j,d,i}^{\text{CBB}_245_{\text{RAW}}}[n]\] for non-linearity characterization only.

- $j = \text{band identification (A1, A2, B1, B2, C1, C2, D1, and D2)}$
- $d = \text{sweep direction identification (FORWARD and REVERSE)}$
- $i = \text{sweep index (0, ..., N_{SWEEP}=31)}$
- $n = \text{sample index } \left(-\frac{N_{j,\text{raw}}}{2}, \ldots, \frac{N_{j,\text{raw}}}{2} - 1\right)$

Instrument pointing at CBB

CBB at 245K

Instrument in RAW mode

d) Other inputs:
- Specified bracket of ZPD amplitude within ADC range
- ADC range
- Analog gain settings

**Data processing description:**

The processing is performed separately for each detector $j$ and sweep direction $d$.

1. Peak height evaluation. The result is a scalar amplitude for each interferogram noted $A_{j,d,i}^{\text{CBB}_230_{\text{RAW}}}$, $A_{j,d,i}^{\text{CBB}_230_{\text{NOMINAL}}}$, or $A_{j,d,i}^{\text{CBB}_245_{\text{RAW}}}$ depending on the experimental setup. As the interferogram has positive and negative values only the maximum absolute amplitude is taken.

2. Averaging of the $i$ measurements of each type is done. The result is a scalar value for each channel, direction, and experimental setup.

3. Standard deviation of the $i$ measurements of each type is done. The result is a scalar value for each channel, direction, and experimental setup.
4. Peak height evaluation of the different height scene measurements. The result is a scalar amplitude for each interferogram noted $A_{j,d,i,k}^{\text{SCENE}}$. As the interferogram has positive and negative values only the maximum absolute amplitude is taken.

5. The average and standard deviation of the peak height evaluation of the scene measurements are computed. The results are average $A_{j,d,k}^{\text{SCENE}}$ and standard deviation $D_{j,d,k}^{\text{SCENE}}$ for each channel, sweep direction, and orbital sequence.

6. The temperature sensors are averaged over the sweeps, direction and tangent height sequence. The results are $T_{k}^{\text{sensor}_x}$ where $\text{sensor}_x$ refers to temperature parameters listed in Appendix B of [RD15].

7. Both the forward and reverse standard deviations are inspected to assess that the ADC occupation criterion is met.

**Outputs:**

1. Average ZPD amplitudes: $A_{j,d}^{\text{CBB}_230\_RAW}$, $A_{j,d}^{\text{CBB}_230\_NOMINAL}$, $A_{j,d}^{\text{CBB}_245\_RAW}$, and $A_{j,d,k}^{\text{SCENE}}$.

2. Standard deviation of ZPD amplitudes: $D_{j,d}^{\text{CBB}_230\_RAW}$, $D_{j,d}^{\text{CBB}_230\_NOMINAL}$, $D_{j,d}^{\text{CBB}_245\_RAW}$, and $D_{j,d,k}^{\text{SCENE}}$.

3. Temperature sensor orbital variations: $T_{k}^{\text{sensor}_x}$.

**Pass criteria:**

N/A.

**Action to be taken:**

TBC.
2.3 IF2 SPECTRAL CHARACTERIZATION

**Objective:**

Characterize the MIPAS in-orbit spectral stability. This test also checks the spectral linearity, spectral resolution, and the spectral calibration.

**Approach:**

The following measurements are performed: First, with the instrument pointing at TBD km altitude, sweeps are collected during a period corresponding to the stability interval. The atmospheric measurements are performed at high resolution. Second, the same number of sweeps are acquired with the instrument pointing at the DS altitude. The DS measurements are performed at low resolution.

It is necessary to repeat the measurements around several orbits to derive the long term spectral stability. Polar and equatorial measurement sequences (4) are performed and repeated for 8 orbits.

The spectral linearity, spectral resolution, and the spectral calibration are derived from these measurements.

**Short-term Spectral Stability**

All possible sources of spectral instability affect all bands equally and the effect is relative to the actual wavenumber. Therefore, the spectral instability need only be verified in one band. However, to increase the accuracy several atmospheric emission lines are used.

The averaged offsets are subtracted from each measured atmospheric emission spectrum, then the interferograms are Fourier transformed, the amplitude extracted, and the frequency of each peak computed. The peaks are scaled to the upper frequency limit of band D and the RMS variation is evaluated to produce the short-term instability. The short term variation is evaluated for each orbital measurement set.

**Long-term Spectral Stability**

For each orbital measurement set, the atmospheric emission spectra are averaged and the average of the offset is subtracted. As for the short-term verification the interferograms are Fourier transformed, the amplitude extracted, and the frequency of each peak computed. The peaks are scaled to the upper frequency limit of band D, then the RMS variation is evaluated over the orbital sequences to produce the long-term instability.

The non-linearity correction assumes that the spectral drifts are negligible. The non-linearity characterization scenario may have to be revisited if spectral stability reveals to be significant.

**Spectral Linearity**

Spectral linearity can be derived using one of the short-term measurement sets.
Spectral Resolution

Spectral resolution can be derived using the highest frequency peak of one of the short-term measurement sets. The resolution obtained is compared to the MIPASILS model.

Spectral Calibration

Spectral calibration can be derived using one of the short-term measurement sets.

Accuracy:

Accuracy of spectral stability measurement to better than 0.001 cm\(^{-1}\) (Grade I).

The [RD13] document describes the approach used to perform the spectral calibration. The analysis of the PFM Method Accuracy section shows that with a SNR of 15 (see table 3.1 of RD13), the standard deviation on the spectral position can be determined with a standard deviation of 0.00035 cm\(^{-1}\) (see Figure 4.2 of RD13).

From [RD10] LL5, WRK:BNOHP0015.SNR the single-sweep SNR (at 20 cm MPD) is 1 in the upper end of band D, therefore, 225 sweeps full resolution measurements would produce the required SNR. Unfortunately, this does not allow to determine the short-term spectral stability. For this reason spectral region with higher SNR is used; this condition is meet in band D at around 1800 cm\(^{-1}\) and anywhere in band C. Averaging the result from several lines should help to increase the confidence in the result.

The standard deviation is performed using 32 spectral frequency evaluations. The standard deviation on the evaluation of the standard deviation is estimated to 13% of the spectral instability when using 32 spectral frequency evaluations.

Prerequisite measurements or calibrations:

IF0 and IF1.

MIPAS configuration required:

- NOMINAL data mode.
- Coefficients of numerical filters as determined from the ground verification: \(\tilde{F}_{j}[c]\)
  \[ c = \frac{N_{nf}}{2}, \ldots, \frac{N_{nf}}{2} - 1, \text{ with } N_{nf} = 256. \]
- Decimation factors as determined from the ground verification: \(D_{j}\)

Measurement description:

a) \(\tilde{I}_{\text{scene}, j,d,i,k,l}[n]\)

20-cm MPD
Instrument pointing at TBD km altitude
\(j\) = band identification (A1, A2, AB, B, C, and D)
\(d\) = sweep direction identification (FORWARD and REVERSE)
\(i\) = sweep index (0,..., \(N_{\text{sweep}}=31\))
\[ k = \text{sequence index in orbit (0,…,4)} \]
\[ l = \text{orbital position index (0,…,7)} \]
\[ n = \text{sample index } \left( -\frac{N^\text{nom\_high}}{2}, \ldots, \frac{N^\text{nom\_high}}{2} - 1 \right) \]

b) \( \tilde{T}_{j,d,i,k,l}^{DS}[n] \)

2-cm MPD
Instrument pointing at DS
\[ j = \text{band identification (A1, A2, AB, B, C, and D)} \]
\[ d = \text{sweep direction identification (FORWARD and REVERSE)} \]
\[ i = \text{sweep index (0,…, N_{SWEEP}=31)} \]
\[ k = \text{sequence index in orbit (0,…,4)} \]
\[ l = \text{orbital position index (0,…,7)} \]
\[ n = \text{sample index } \left( -\frac{N^\text{nom\_low}}{2}, \ldots, \frac{N^\text{nom\_low}}{2} - 1 \right) \]

d) Other inputs:

- On-ground spectral calibration: \( \sigma^\text{laser} \)
- Spectral lines identifications \( \sigma^\text{True\_Frequency}_u \) for \( u = 0 \) to \( U-1 \)

**Data processing description:**

The processing is performed separately for each detector \( j \) and sweep direction \( d \). The short-term spectral stability is first described.

1. All offset measurements are coadded together over the \( i \) index producing \( \tilde{T}_{j,d,k,l}^{DS}[n] \).
2. Subtract \( \tilde{T}_{j,d,k,l}^{DS}[n] \) from each of the \( \tilde{T}_{j,d,i,k,l}^{\text{Scene}}[n] \) interferograms producing \( \tilde{T}_{j,d,i,k,l}^{\prime}[n] \).
3. The offset corrected interferograms are zero padded and Fourier transformed to produce the \( \tilde{S}_{j,d,i,k,l}[m] \).
4. The amplitude is extracted to produce un-calibrated emission spectra \( S_{j,d,i,k,l}[m] \).
5. The frequencies of the lines are extracted. The LineFrequency removes the ILS shift contribution:

\[
\sigma^\text{measured}_{d,j,k,l,u} = \text{LineFrequency\{S}_{j,d,i,k,l}[m]\sigma^\text{True\_Frequency}_u}
\]

**Spectral Calibration**

6. The spectral calibration is extracted from the first measurement set (or one of the measurement sets) by averaging over the \( i, d \) and \( u \) indices:
\[
\sigma_{\text{scaling}} = \frac{1}{U} \sum_u \left( \frac{\sigma_u^{\text{true, frequency}}}{1 \cdot \left( N_{\text{Sweep}} + 1 \right) \cdot \sum_{i,d,j,k=0,j=0,u} \sigma_{\text{measured}}^{\text{measured}}} \right)
\]

**Short-term Stability**

7. The short-term stability is derived from the scaled and averaged spectral line frequencies:

\[
\sigma_{\text{measured}}^{\text{measured}} = \frac{1}{U} \sum_u \sigma_u^{\text{measured}} \cdot \sigma_{\text{max}}^{\text{true, frequency}}
\]

8. The spectral calibration is applied to all measurement sets:

\[
\sigma_{\text{measured}}^{\text{measured}} = \sigma_{\text{sampling}}^{\text{measured}} \cdot \sigma_{\text{scaling}}^{\text{measured}}.
\]

9. The standard deviation is computed over the \(i\) index producing the spectral stability \(\Delta \sigma_{\text{short, term}}^{\text{measured}}\).

**Long-term Stability**

10. All scene measurements are coadded together over the \(i\) index producing \(\tilde{T}_{\text{Scene}}^{\text{Scene}} [n]\).

11. Subtract \(\tilde{T}_{\text{DS}}^{\text{DS}} [n]\) from each of the \(\tilde{T}_{\text{Scene}}^{\text{Scene}} [n]\) interferogram producing \(\tilde{T}_{j,d,k,l}^{j,d,k,l} [n]\).

12. The offset corrected interferograms are zero padded and Fourier transformed to produce the \(\tilde{S}_{j,d,k,l}^{j,d,k,l} [m]\).

13. The amplitude is extracted to produce un-calibrated emission spectra \(S_{j,d,k,l}^{j,d,k,l} [m]\).

14. The peak frequencies of the lines are extracted and scaled to band D upper spectral limit.

\[
\sigma_{\text{measured}}^{\text{measured}} = \text{LineFrequency}\{S_{j,d,k,l}^{j,d,k,l} [m]\} \cdot \sigma_{\text{max}}^{\text{true, frequency}} \cdot \sigma_u^{\text{true, frequency}}
\]

15. Spectral calibration is applied:

\[
\sigma_{\text{measured}}^{\text{measured}} = \sigma_{\text{scaling}}^{\text{measured}} \cdot \sigma_{\text{scaling}}^{\text{measured}}.
\]

16. All frequencies are scaled to the upper limit of band D:
17. The scaled peaks are averaged over the \( u \) index producing \( \sigma_{scaled, d,k,l,u} \).

18. The standard deviation is computed over the \( k \) and \( l \) index producing the long-term spectral stability \( \Delta \sigma_{d, long\_term} \).

### Spectral Linearity

19. The spectral linearity is computed on each measurement set:

\[
\Delta \sigma_{linearity, d,k,l} = \sqrt{ \frac{1}{U-1} \sum_{u=0}^{U-1} \left( \sigma_{measured, d,k,l,u} - \sigma_{True\_Frequency, u} \right)^2 }.
\]

### Spectral Resolution

20. Spectral resolution is derived using the highest frequency peak for each of the orbital measurement sets:

\[
\Delta \sigma_{resolution, f,d,k,l} = \text{GetResolution}\left\{ m \right\}_{U=0}^{U=1} \sigma_{True\_Frequency, u}.
\]

21. The resolution obtained is compared to the MIPASILS model.

### Outputs:

- **Sort-term spectral stability:** \( \Delta \sigma_{d, short\_term} \)
- **Long-term spectral stability:** \( \Delta \sigma_{d, long\_term} \)
- **Spectral Linearity:** \( \Delta \sigma_{d, linearity} \)
- **Spectral Resolution:** \( \Delta \sigma_{f,d,l, resolution} \)
- **Spectral Calibration:** \( \sigma_{d, sampling} \)

### Pass criteria:

The values obtained have to be in agreement with the values from the table below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement (from RD17)</th>
<th>Measured with FM (RD5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \sigma_{d, short_term} )</td>
<td>&lt; 0.001 cm(^{-1}) over 165 s</td>
<td>0.00028 cm(^{-1}) (worst case)</td>
</tr>
<tr>
<td>( \Delta \sigma_{d, long_term} )</td>
<td>&lt; 0.001 cm(^{-1}) over 24 h</td>
<td>-</td>
</tr>
<tr>
<td>( \Delta \sigma_{\text{linearity}} )</td>
<td>(&lt; 0.001 \text{ cm}^{-1} )</td>
<td>0.00098 cm(^{-1})</td>
</tr>
<tr>
<td>( \Delta \sigma_{\text{resolution}} )</td>
<td>(&lt; 0.035 \text{ cm}^{-1} )</td>
<td>0.034 cm(^{-1}) in band D</td>
</tr>
</tbody>
</table>

*Action to be taken:*

N/A
2.4 IF3 ALIASING VERIFICATION

Objective:

The laser wavelength may drift with time. Since it is optimized for one sampling frequency, the efficiency of the numerical filter might be affected. Aliasing would then reduce the radiometric accuracy. It is thus necessary to verify that the filter rejection factor still remains within the requirements.

Principle:

Raw interferograms are acquired and downloaded to ground. The interferograms are then filtered using the current numerical filter coefficients. Then a copy of each filtered interferogram is decimated. Both interferograms are then Fourier transformed and the difference compared to the budgeted aliasing error.

Accuracy:

Accuracy of spectral aliasing to 1/10 of the radiometric accuracy.

The NESR vs. radiometric accuracy for a source at 230K is given in [RD5] (Annex C, H1 to H10). The worst case is a NESR two times better than the radiometric accuracy budget. Therefore, to obtain an accuracy of one fifth of the radiometric accuracy budget, the number of sweeps required is about 25 sweeps \((0.5 \times 10)^2\). Taking 100 sweeps at low resolution produces a more accurate result for a still reasonable amount of data.

We do not expect spectral features to be finer than 1 cm\(^{-1}\) in presence of a CBB, justifying the choice of low resolution (this is verified in 2.12).

Note: Section 2.12.3 of [RD10] also points out that band D does not have an optical filter to filter out the frequencies above 2410 cm\(^{-1}\) and that the numerical filter of band D could possibly be optimized.

Prerequisite measurements or calibrations:

IF0, IF1, and IF2.

MIPAS configuration required:

Raw mode, 2-cm MPD, CBB at baseline operating temperature.

Measurement Description:

a) \(I^{CBB}_{j,d,i}[n]\)

Instrument pointing at CBB
\[j = A1, A2, B1, B2, C1, C2, D1 and D2.\]
\[d = \text{FORWARD and REVERSE}\]
\[i = 0, \ldots, 99\]
\[ n = \text{sample index} \left( -\frac{N_{j}^{\text{raw},\text{low}}}{2}, \ldots, -\frac{N_{j}^{\text{raw},\text{low}}}{2} - 1 \right) \]

b) Other inputs:

- Radiometric accuracy budget: \( B_j[\sigma(\sigma)] \)
- Coefficients of numerical filters numerical filter as determined from the ground verification: \( \tilde{F}_j^{nf}[c] \)
  \[ c = -\frac{N^{nf}}{2}, \ldots, -1, \text{ with } N^{nf} = 256. \]
- Decimation factors: \( D_j \)

**Data processing description:**

The processing is performed separately for each detector \( j \) and sweep direction \( d \).

1. Interferogram coaddition is performed producing \( I_{j,d}^{\text{CBB}}[n] \).

2. A copy of the coadded interferogram is filtered and decimated:
   \[ \tilde{I}_{j,d}^{fd}[n'] = \text{Filter} \left[ I_{j,d}^{\text{CBB}}[n], \tilde{F}_j^{nf}[c], D_j \right] \]

3. Zero padding and Fourier transform of the filtered and decimated interferogram is done producing \( \tilde{S}_{j,d}^{fd}[m^{fd}] \).

4. The original coadded interferogram is filtered (but not decimated):
   \[ \tilde{I}_{j,d}^{\text{und}}[n] = \text{Filter} \left[ I_{j,d}^{\text{CBB}}[n], \tilde{F}_j^{nf}[c], 1 \right] \]

5. Zero padding and Fourier transform of the filtered interferogram is done producing \( \tilde{S}_{j,d}^{\text{und}}[m^{\text{und}}] \).

6. Spectral interpolation is done to evaluate the non-decimated spectrum at the wavenumber values of the spectrum of the decimated interferogram:
   \[ \tilde{S}_{j,d}^{\text{und}}[m^{fd}] = \text{Interpolat} e \left[ \tilde{S}_{j,d}^{\text{und}}[m^{\text{und}}], \Delta\sigma^{\text{und}}, \Delta\sigma_0^{\text{und}}, N^{\text{und}}, \Delta\sigma^{fd}, \Delta\sigma_0^{fd}, N^{fd} \right]. \]

7. Calculation of the radiometric error using the following equation:
   \[ A_{j,d}[m^{fd}] = \frac{\tilde{S}_{j,d}^{\text{und}}[m^{fd}] - \tilde{S}_{j,d}^{fd}[m^{fd}]}{\tilde{S}_{j,d}^{fd}[m^{fd}]} \]

8. Visual inspection of the results. Compare to the radiometric accuracy budget. Decide if new filters need to be provided. Note that Analog Gain Verification (the second, third and forth parts) must be repeated if new filters are used.
**Outputs:**

Radiometric error due to aliasing $A_{j,d} \left[m_{jd}^{fd} \right]$ (for each channel and direction).

**Pass criteria:**

The radiometric errors must not be higher than the values listed in the following table:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Maximum allowed radiometric error</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>%</td>
</tr>
<tr>
<td>A1</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td></td>
</tr>
</tbody>
</table>

**Action to be taken:**

In case of non-compliance, the numerical filter must be reprogrammed.
2.5 IF4 NON-LINEARITY CHARACTERIZATION

**Objective:**

Characterize the non-linearity of the MIPAS detectors. The product of this characterization is a series of coefficients used in the radiometric calibration equation. Even if only the detectors from band A, AB, and B are thought to be affected by non-linearity, the characterization is performed on all detectors.

**Approach:**

The non-linearity of the instrument as function of input radiance is determined using measurements taken at different but known input radiance levels. A series of CBB measurements with the CBB set to different temperatures is acquired for this purpose.

Due to the thermal characteristics of the CBB, the measurement sequence is realized in a dynamic way by viewing the CBB continuously while it is being warmed up by its dedicated heater circuit or whilst it is cooling down (with the heater circuit disabled). See section 5.2.2.4.5 of [RD8] for justification.

Firstly, the instrument is commanded to heater mode. With this setting, the CBB is heated using the maximum heater power. It will take around 8 – 10 hours for the CBB to reach a temperature of 245K. Note that the limit of 245K is imposed by the CBE, above this temperature the ADCs of the CBB temperature readout are saturated. When the limit of 245K is reached, the CBB heater power level is set to zero by direct command. It is estimated that the cool down will last at least 20 hours.

Measurements to characterize the non-linearity are required at different temperatures (minimum of five) over a range of CBB temperatures from 210 to 245K. The temperatures are selected to produce evenly distributed integrated intensity over the temperature range for the band A, i.e. for the 685-970 cm\(^{-1}\) spectral range. The measurements are made at the following suggested CBB temperature: 210, 222, 233, 242 and 245K. Note that it would be desirable to extend the range to lower temperature.

Before the non-linearity characterization can start the analog gain must be verified. This is described in the forth step of IF1 (raw mode only).

For each CBB temperature, each measurement consists of a single CBB sweep and 200 DS sweeps (100 sweeps in each sweep direction). Note that a DS measurement sequence is taken for each CBB measurement sequence since the instrument temperature, thus the self emission, may change due to the different CBB heat loss, which was not the case for on-ground verification since OCFB was used instead of CBB. During 200 sweeps the radiance of the CBB will change by up to 1.2%; it is expected that the impact of the instrument offset will be less. Otherwise, the number of DS measurements can be reduced to 32, reducing the radiance variation of the CBB to less than 0.2%.

Because the CBB temperature may not be precisely predicted the CBB and DS measurements sequences are repeated frequently and the sequence closest to the desired temperature is selected during ground processing via the PRT readings in the auxiliary data stream. It is suggested that the measurements be taken every hour, until the CBB reaches 245K.
Because the CBB heating may affect the instrument temperature spectral drift may occur. For this reason spectral characterization is performed regularly, i.e., before each CBB non-linearity characterization measurement sequence.

Also, to minimize orbital effects, the non-linearity characterization always starts at the same orbital position.

In principle, the non-linearity is expected to be very stable with time, but there may be some long-term (aging) effects that affect the responsivity. For this reason, it is proposed to perform the characterisation twice per year.

Note: Once the CBB is at its minimal temperature, analog gain could be characterized to be used for gain switching. This is described in IF1.

**Accuracy:**

The goal of the non-linearity measurement accuracy is taken as 0.2% of the signal measured. A detailed description of the accuracy of the non-linearity correction is given in [RD11] and [RD12].

**Prerequisite measurements or calibration:**

IF0 to IF3 with IF1 repeated with CBB at maximum heating power.

**MIPAS configuration required:**

Nominal data mode, 2-cm MPD, Equatorial orbital position.

**Measurement description:**

a) \( \tilde{T}_{j,d,i,k}^{CBB}[n] \)

Instrument pointing at CBB

- \( j \) = band identification (A1, A2, B1, B2, C, and D)
- \( d \) = sweep direction identification (FORWARD and REVERSE)
- \( i \) = sweep identification in the sequence (0,…,199)
- \( k \) = measurement sequence (0,…,20)
- \( n \) = sample index \( \left\{ - \frac{N_{j}^{\text{nom,low}}}{2}, \ldots, \frac{N_{j}^{\text{nom,low}}}{2} - 1 \right\} \)

b) \( \tilde{T}_{j,d,i,k}^{DS}[n] \)

Instrument pointing at DS

- \( j \) = band identification (A1, A2, B1, B2, C, and D)
- \( d \) = sweep direction identification (FORWARD and REVERSE)
- \( i \) = sweep identification in the sequence (0,…,199)
- \( k \) = measurement sequence (0,…,20)
- \( n \) = sample index \( \left\{ - \frac{N_{j}^{\text{nom,low}}}{2}, \ldots, \frac{N_{j}^{\text{nom,low}}}{2} - 1 \right\} \)
c) Other inputs:

- Spectral band limits: $\sigma_j^{\text{min}}$ and $\sigma_j^{\text{max}}$
- Spectral calibration: TBD

**Data Analysis:**

A complete description is presented in [RD6] and [RD7]

1. Separate averaging of CBB and DS measurements producing $\tilde{I}_{j,d,k}^{\text{DS}}[n]$ and $\tilde{I}_{j,d,k}^{\text{CBB}}[n]$.
2. Apply spectral calibration.
3. Zero padding to a power of two and FFT producing $\tilde{S}_{j,d,k}^{\text{DS}}[m]$ and $\tilde{S}_{j,d,k}^{\text{CBB}}[m]$.
4. Subtract $\tilde{S}_{j,d,k}^{\text{DS}}[m]$ from $\tilde{S}_{j,d,k}^{\text{CBB}}[m]$ spectrum producing $\tilde{S}_{j,d,k}'[m]$.
5. Select the measurement sequence closest to the specified nominal CBB temperatures and compute CBB true radiance using $CbbTruRad$ function (at the actual CBB temperature) for each CBB sweep $L_{j,i}^{\text{true}}[m]$.
6. Average the true radiance producing $L_{j}^{\text{true}}[m]$.
7. Compute the gain spectrum using the coadded CBB sequence for which the temperature is closest to the nominal CBB temperature:

$$\tilde{G}_{j,d}[m] = \frac{L_{j}^{\text{true}}[m]}{\tilde{S}_{j,d}[m]}.$$  

8. Use the Simplex method to optimize non-linearity coefficients that minimize the residue (see [RD11] and [RD12]).

**Outputs:**

Non-linearity coefficients $d_{j,0}$ and $d_{j,1}$

**Pass criteria:**

N/A

**Action to be taken:**

Use coefficients for non-linearity correction.
2.6 IF5 CHANNEL COMBINATION CHARACTERIZATION

Objective:

Verify and/or generate the channel combination coefficients.

Principle:

The principle of the test is to determine the signal to noise ratio, for a representative source radiance, in each individual channel to be combined. Raw interferograms are acquired while pointing at the internal blackbody. Signal and noise levels are evaluated for each channel. The optimum combination ratio is then derived.

Accuracy:

The number of scans can be derived as follows. Assuming similar SNR for the two ports of each band, combining them with the same proportion increases the SNR by a factor of 1.4. Changing the proportion would reduce the optimum SNR. Allocating a degradation of 2% of the optimum SNR to the optimum combination factor, yields a deviation from the optimum factor of 22%. For SNR > 1 the variance of the combination ratio is given by:

$$\sigma_{\text{Ratio}} \approx 4\sqrt[707.4]{n-1}. $$

$n$ must be larger than 163 (evaluated from numerical analysis) to obtain a relative deviation of the ratio evaluation lower than 0.22. Acquiring 200 sweeps provides better accuracy.

Prerequisite measurements or calibrations:

IF0 to IF4.

MIPAS configuration required:

Raw mode, 20-cm MPD, CBB at baseline operating temperature.

Measurement description:

a) $I_{j,d,i}^{\text{CBB}}[n]$

Instrument pointing at CBB

$j = \text{A1, A2, B1, B2, C1, C2, D1, and D2}$

$d = \text{FORWARD and REVERSE}$

$i = 0,...,199$

$$n = \frac{N_{\text{raw\_high}}}{2}, \ldots, \frac{N_{\text{raw\_high}}}{2} - 1$$

b) Other inputs:

- Spectral band limits: $\sigma_{\text{min}}^{j}$ and $\sigma_{\text{max}}^{j}$
Data processing description:

The processing is performed separately for each detector $j$ and sweep direction $d$. Detectors B1 and B2 are not processed.

1. Numerical filtering (without decimation) of the interferogram. The filter coefficients are those with equalization coefficients not incorporated.

$$
\tilde{I}_{j,d,i}^{\text{CBB}}[n] = \text{Filter}\{I_{j,d,i}^{\text{CBB}}[n], \tilde{F}_j^{nf}[c]\}
$$

2. The non-linearity correction is applied on non-linear detectors to be combined, i.e., $j = A1$ and $A2$:

$$
\tilde{I}_{j,d,i}^{\text{CBB}}[n] = \text{CorrectNL}\{I_{j,d,i}^{\text{CBB}}[n], ADC_{\text{min}}, ADC_{\text{max}}, d, d_{q,j}\}
$$

3. Zero-padding and Fourier transform producing the $\tilde{S}_{j,d,i}^{\text{CBB}}[m]$ complex spectrum.

4. Calculation of the module to produce the $S_{j,d,i}^{\text{CBB}}[m]$ spectrum.

5. Compute the standard deviation over the $i$ index for each $m$ spectral frequency index (cumulative method for computation efficiency). The results are representative of the source noise:

$$
S_{j,d,i}^{\text{Noise}}[m] = \sqrt{\frac{1}{l-1} \left[ \sum_{i=0}^{l-1} (S_{j,d,i}^{\text{CBB}}[m])^2 - \frac{\sum_{i=0}^{l-1} S_{j,d,i}^{\text{CBB}}[m]^2}{l} \right]^2}.
$$

6. Calculation of the average spectra over the $i$ index. The results are representative of the source signal (note that the signal is derived from the previous step):

$$
S_{j,d}^{\text{Signal}}[m] = \frac{\sum_{i=0}^{l-1} S_{j,d,i}^{\text{CBB}}[m]}{l}.
$$

7. Determination of the amplitude of the spectral equalization vectors is done using the following equation.
\[ k_{j',d}[m] = \frac{S_{j,d}^{\text{signal}}[m] \cdot \left(S_{j,d}^{\text{noise}}[m]\right)^2}{S_{j,d}^{\text{signal}}[m] \cdot \left(S_{j',d}^{\text{noise}}[m]\right)^2} \]

where

\[ j = A1, C1, D1 \]

\[ j' = A2, \quad \text{for } j = A1 \]

\[ j' = C2, \quad \text{for } j = C1 \]

\[ j' = D2, \quad \text{for } j = D1 \]

8. Produce the average complex spectrum \( \tilde{S}_{j,d}[m] \) from the initial complex spectrum \( S_{j,d}[m] \).

9. Determination of the phase of the spectral equalization vectors is done using the following equation:

\[ \varphi_{j',d}[m] = \arg(\langle \tilde{S}_{j,d}[m]\rangle) - \arg(\langle \tilde{S}_{j',d}[m]\rangle) \]

10. The equalization filter is obtained as follows:

\[ \tilde{F}_{j,d}^{eq}[m] = k_{j,d}[m] \cdot e^{\varphi_{j,d}[m]} \]

11. The results from the two sweep directions are averaged producing \( \tilde{F}_{j}^{eq}[m] \).

**Outputs:**

Combination (equalization) spectral vectors \( \tilde{F}_{j}^{eq}[m] \) for each band, i.e. \( j' = A2, C2 \) and \( D2 \).

**Pass criteria:**

N/A.

**Action to taken:**

The combination factor found should be compared to the combination factor in use. The later should be updated if it deviates by more than 5%.
2.7 IF6 CBB AND DS SNR CHARACTERIZATION

**Objective:**

Determine the optimum number of sweeps for the CBB and the DS measurement types for the radiometric calibration.

**Principle:**

The instrument is successively pointed at the CBB and DS and a number of sweeps are acquired for each target. The noise contribution of each target is evaluated and the optimum number of CBB sweeps with respect to DS sweeps for the radiometric calibration is derived.

For $\text{Noise}_{\text{CBB}}$ twice as noisy than $\text{Noise}_{\text{DS}}$, we get the same noise contribution if we do 4 times the number of sweeps for CBB than for DS. This having been said, it is not the optimum ratio because if one sweep is removed from the CBB sequence and added to DS sequence it degrades CBB noise less than it improve DS and the resulting combination improves. At a single wavenumber, and for a constant total number of sweeps, the optimum ratio is for:

\[
\frac{N_{\text{CBB}}}{N_{\text{DS}}} = \frac{\text{Noise}_{\text{CBB}}}{\text{Noise}_{\text{DS}}}. 
\]

Because of spectrally dependent noise, the optimum ratio will likely have a spectral dependence. The choice of the optimum ratio will depend on which spectral band one wants to optimize.

**Accuracy:**

To contain the SNR of the combined CBB and DS measurements to within 2% of the optimum SNR, with a confidence of 95% (2σ), the ratio must not deviate by more than 25% of the optimum ratio within the same confidence. The standard deviation of the ratio is given by:

\[
\sigma_{\text{Ratio}} = 2 \cdot \frac{0.707}{\sqrt{n - 1}}.
\]

33 sweeps is thus required to obtain the ratio at ± 25% accuracy. Acquiring 200 sweeps in each sweep direction allows more accurate evaluation. In addition, since the ratio will be derived for each spectral frequency of each detector, additional averaging is available.

**Prerequisite measurements or calibrations:**

All IF above.

**MIPAS configuration required:**

Nominal mode, 2 cm MPD, CBB at baseline operating temperature.
**Measurement description:**

a) \( I_{j,d,i}^{CBB}[n] \)

Instrument pointing at CBB

\( j = \) band identification (A1, A2, B1, B2, C, and D)
\( d = \) sweep direction identification (FORWARD and REVERSE)
\( i = \) sweep identification in the sequence (0,…,199)
\( n = \) sample index \( \left[ -\frac{N_j^{nom\_low}}{2}, \cdots, \frac{N_j^{nom\_low}}{2} - 1 \right] \)

b) \( I_{j,d,i}^{DS}[n] \)

Instrument pointing at DS

\( j = \) band identification (A1, A2, B1, B2, C, and D)
\( d = \) sweep direction identification (FORWARD and REVERSE)
\( i = \) sweep identification in the sequence (0,…,199)
\( n = \) sample index \( \left[ -\frac{N_j^{nom\_low}}{2}, \cdots, \frac{N_j^{nom\_low}}{2} - 1 \right] \)

c) Other inputs:

- Spectral band limits: \( \sigma_{j}^{\text{min}} \) and \( \sigma_{j}^{\text{max}} \)
- Non-linearity coefficients: \( d_{q,j} \)
- Equalization coefficients: \( \tilde{W}^{eq}[n^{eq}] \)

**Data Analysis:**

1. The non-linearity correction is applied on the non-linear A1, A2, AB and B channels:

\[
\tilde{I}_{j,d,i}^{CBB}[n] = \text{CorrectNL}\left[ I_{j,d,i}^{CBB}[n], ADC_{j}^{\text{min}}, ADC_{j}^{\text{max}}, d_{q,j} \right]
\]

\[
\tilde{I}_{j,d,i}^{DS}[n] = \text{CorrectNL}\left[ I_{j,d,i}^{DS}[n], ADC_{j}^{\text{min}}, ADC_{j}^{\text{max}}, d_{q,j} \right]
\]

2. Equalize and combine the A1 and A2 channels:

\[
\tilde{I}_{j,d,i}^{A_1,d}[n] = \text{EquilizeCo mbine } \left\{ \tilde{I}_{j,d,i}^{CBB}[n], \tilde{I}_{j,d,i}^{CBB}[n], \tilde{I}_{j,d,i}^{DS}[n], \tilde{I}_{j,d,i}^{DS}[n], \tilde{W}^{eq}[n^{eq}] \right\}
\]

3. Compute the spectra using the FFT function for each measurement type producing \( \tilde{S}_{j,d,i}^{CBB}[m_j] \) and \( \tilde{S}_{j,d,i}^{DS}[m_j] \).

4. Extract the real part of each measurement producing \( S_{j,d,i}^{CBB}[m_j] \) and \( S_{j,d,i}^{DS}[m_j] \).
Note that, even if there is no phase correction performed the noise is the same for both the real and imaginary parts. Applying the phase correction would not change the noise distribution and is thus not required.

5. Compute the standard deviation over the \( i \) index for each \( m \) spectral frequency index for each target (cumulative method for computation efficiency):

\[
\text{Noise}_{j,d}^{CBB}[m_j] = \sqrt{\frac{1}{I-1} \sum_{i=0}^{I-1} \left( S_{j,d,i}^{CBB}[m_j] \right)^2 - \frac{\left( \sum_{i=0}^{I-1} S_{j,d,i}^{CBB}[m_j] \right)^2}{I}},
\]

\[
\text{Noise}_{j,d}^{DS}[m_j] = \sqrt{\frac{1}{I-1} \sum_{i=0}^{I-1} \left( S_{j,d,i}^{DS}[m_j] \right)^2 - \frac{\left( \sum_{i=0}^{I-1} S_{j,d,i}^{DS}[m_j] \right)^2}{I}},
\]

6. Compute the number of sweeps ratio that minimizes the gain noise contribution:

\[
R_{j,d}[m_j] = \frac{\text{Noise}_{j,d}^{CBB}[m_j]}{\text{Noise}_{j,d}^{DS}[m_j]}
\]

7. Compute the number of sweeps for the CBB, assuming the total number of sweeps (DS + CBB) is 600:

\[
N_{j,d}^{CBB}[m_j] = \frac{R_{j,d}[m_j]}{R_{j,d}[m_j]+1} \cdot 600,
\]

\[
N_{j,d}^{DS}[m_j] = 600 - N_{j,d}^{CBB}[m_j].
\]

8. Inspect the result for each band and each sweep direction and determine the appropriate number of sweeps for the CBB.

**Output:**

The number of sweeps for the DS target is \( N_{DS} \) and the number of sweeps for the CBB target is \( N_{CBB} \) that optimizes the SNR if the total number of sweeps allocated to calibration is 600.

**Pass criteria:**

N/A
**Action to be taken:**

Use the determined number of coadded sweep for DS and CBB measurements.
2.8 IF7 PHASE CHARACTERIZATION

Objective:

Characterize the phase relationship between the CBB and DS measurements (see [RD8], Section 5.2.2.4.3.) This phase characterization step is used to check that no FCE occurs during CBB and DS radiometric gain characterization, or correct any FCE, which occurrence is non-negligible.

Principle:

The initial phase relationship between the CBB and the DS is established by repeatedly switching (10 times) between DS and CBB sources and acquiring a single low-resolution interferogram in each sweep direction. The phases of the CBB measurements are compared to establish that there is no phase difference between them. The phases of the DS measurements are also compared between themselves. When the concurrent set of CBB and DS measurements is found in which no phase difference occurs, these two sets are coadded separately and used to provide phase reference data. If a phase difference is detected the whole data set is discarded and a new measurements sequence acquired.

Accuracy:

Single sweep measurement provide adequate SNR to detect FCE’s.

Prerequisite measurements or calibrations:

IF0 to IF5.

MIPAS configuration required:

Nominal mode.

Measurement description:

a) \( \overline{I}_{j,d,i}^{\text{CBB}}[n] \) Instrument pointing at CBB

\[ j = \text{band identification (A1, A2, B1, B2, C, and D)} \]
\[ d = \text{sweep direction identification (FORWARD and REVERSE)} \]
\[ i = \text{sweep identification in the sequence (0,…,9)} \]
\[ n = \text{sample index } \left( -\frac{N_j^{\text{nom\_low}}}{2}, \ldots, \frac{N_j^{\text{nom\_low}}}{2} - 1 \right) \]

b) \( \overline{I}_{j,d,i}^{\text{DS}}[n] \) Instrument pointing at DS

\[ j = \text{band identification (A1, A2, B1, B2, C, and D)} \]
\[ d = \text{sweep direction identification (FORWARD and REVERSE)} \]
\[ i = \text{sweep identification in the sequence (0,…,9)} \]
c) Other inputs:

- Spectral band limits: $\sigma^\text{min}_j$ and $\sigma^\text{max}_j$

**Data Analysis:**

1. FCE detection algorithm is performed, for $j = A1, A2, AB, \text{and } B$, to detect any FCE:

   $FCE^\text{CBB}\_{j,d,i} = \text{FceDetect}\{\vec{\tau}^\text{CBB}\_{j,d,i \neq 0}, \vec{\tau}^\text{CBB}\_{j,d,i=0}\}$

   $FCE^\text{DS}\_{j,d,i} = \text{FceDetect}\{\vec{\tau}^\text{DS}\_{j,d,i \neq 0}, \vec{\tau}^\text{DS}\_{j,d,i=0}\}$

2. All FCE shall be zero. If any FCE occurs, i.e. one of several FCE is not equal to zero, then the data set is rejected and the measurements repeated. If no FCE occurs the reference phase is constructed to be used during radiometric characterization. The CBB and DS measurements are coadded separately producing $\vec{\tau}^{\text{DS}}\_{j,d}[n]$ and $\vec{\tau}^{\text{CBB}}\_{j,d}[n]$. Low-resolution interferogram may be extracted depending on the FceDetect algorithm (TBC).

**Outputs:**

CBB and DS phase reference $\vec{\tau}^{\text{DS}}\_{j,d}[n]$ and $\vec{\tau}^{\text{CBB}}\_{j,d}[n]$.

**Pass criteria:**

**Action to be taken:**
2.9 IF8 RADIOMETRIC CALIBRATION CHARACTERIZATION

**Objective:**
Characterize the radiometric calibration scenario.

**Principle:**
Perform successive radiometric calibration over several orbits and extract orbital variations and long term drift for both the radiometric offset and the radiometric gain. Correlate/parameterize the variations to orbital and long-term parameters.

The measurement consists of a radiometric calibration repeated during one orbit per day, over a period of at least 15 days. One nominal calibration takes 17.35 minutes (see [RD4], section 6.1.2.1.1) allowing 6.34 calibration per orbit. This gives too little calibration points and could underestimate the peak variations. For this reason the number of sweeps is reduced from 600 to 150 sweeps in both the blackbody and deep space sequence, allowing 24 calibration sequences of 1.6 minutes each. Applying spectral averaging on the radiometric gain and offset compensates for the SNR loss.

This verification can be repeated if significant changes of the environment or instrument are suspected.

**Accuracy:**
Accuracy of radiometric calibration to 1/10 of the specified radiometric accuracy requirement.

The NESR vs. radiometric accuracy for a source at 230K are given in [RD5] (Annex C, H1 to H10). The worst case is a NESR two times better than the radiometric accuracy budget. Therefore, to obtain an accuracy of one third of the relative radiometric accuracy budget, the number of sweeps required to measure the expected high resolution features, with the CBB source at nominal temperature, is about \((0.5 \times 10)^2\) or 25 sweeps. Taking 75 sweeps produces more accurate result for a still reasonable amount of data.

**Prerequisite measurements or calibrations:**
CBB Self Calibration
IF0 to IF7.

**MIPAS configuration required:**
Nominal mode, number of interferometer sweeps derived from IF5.

**Measurement description:**

a) \(\tilde{T}_{j,d,k,l}[n]\) Instrument pointing at CBB

\(j = \) band identification (A1, A2, B1, B2, C, and D)
$d$ = sweep direction identification (FORWARD and REVERSE)

$i$ = sweep identification in the sequence (0, ..., 74)

$k$ = sequences identification in an orbit (0, ..., 23)

$l$ = orbit index (0, ..., 14)

$n$ = sample index \[ \left( -\frac{N_j^{\text{nom\_low}}}{2}, \ldots, \frac{N_j^{\text{nom\_low}}}{2} - 1 \right) \]

b) $\tilde{I}^{DS}_{j,d,i,k,l}[n]$ Instrument pointing at DS

$j$ = band identification (A1, A2, B1, B2, C, and D)

d = sweep direction identification (FORWARD and REVERSE)

$i$ = sweep identification in the sequence (0, ..., 75)

$k$ = sequences identification in an orbit (0, ..., 23)

$l$ = orbit index (0, ..., 14)

$n$ = sample index \[ \left( -\frac{N_j^{\text{nom\_low}}}{2}, \ldots, \frac{N_j^{\text{nom\_low}}}{2} - 1 \right) \]

c) Other inputs:

- Geo-location: $O_l = (TBD)$
- Instrument temperature: $T_{k,l}^{\text{MOB}}$
- Spectral band limits: $\sigma_{j}^{\text{min}}$ and $\sigma_{j}^{\text{max}}$
- Non-linearity coefficients: $d_{q,j}$
- Equalization coefficients: $\tilde{W}^{eq}[n^{eq}]$
- CBB emissivity data TBD.

**Data Analysis:**

1. Separate averaging of CBB and DS measurements producing $\tilde{I}^{DS}_{j,d,i,k,l}[n]$ and $\tilde{I}^{CBB}_{j,d,i,k,l}[n]$.

2. Correct non-linearity for $j = A1, A2, AB, and B$:

\[
\tilde{I}^{CBB}_{j,d,i,k,l}[n] = \text{CorrectNL}\left\{ \tilde{I}^{CBB}_{j,d,i,k,l}[n], ADC_{j}^{\text{min}}, ADC_{j}^{\text{max}}, d_{q,j} \right\}
\]

\[
\tilde{I}^{DS}_{j,d,i,k,l}[n] = \text{CorrectNL}\left\{ \tilde{I}^{DS}_{j,d,i,k,l}[n], ADC_{j}^{\text{min}}, ADC_{j}^{\text{max}}, d_{q,j} \right\}
\]

3. Equalize and combine for $j = A1$ and A2:

\[
\tilde{I}^{CBB}_{A,d,i,k,l}[n] = \text{EquilizeCo\, mbine} \left\{ \tilde{I}^{CBB}_{A1,d,i,k,l}[n], \tilde{I}^{DS}_{A2,d,i,k,l}[n], \tilde{W}^{eq}[n^{eq}] \right\}
\]

\[
\tilde{I}^{DS}_{A,d,i,k,l}[n] = \text{EquilizeCo\, mbine} \left\{ \tilde{I}^{DS}_{A1,d,i,k,l}[n], \tilde{I}^{DS}_{A2,d,i,k,l}[n], \tilde{W}^{eq}[n^{eq}] \right\}
\]
4. Zero padding to a power of two and FFT producing $\tilde{S}_{j,d,k,l}[m]$ and $\tilde{S}_{j,d,k,l}^{CBB}[m]$.

5. Compute CBB true radiance using $CbbTruRad$ function for the CBB temperature producing $L^{true}_{j,k,k,l}[m]$.

6. Compute the gain:

$$\tilde{G}_{j,d,k,l}[m] = \frac{L^{true}_{j,d,k,l}[m]}{\tilde{S}_{j,d,k,l}^{CBB}[m] - \tilde{S}_{j,d,k,l}^{DS}[m]}$$

7. Perform moving spectral averaging over 20 spectral bins for each gain producing $\tilde{G}_{j,d,k,l}[m']$.

8. Average $\tilde{G}_{j,d,k,l}[m']$ and $\tilde{S}_{j,d,k,l}^{DS}[m']$ over the $l$ orbit index and $k$ sequence index producing $\tilde{G}_{j,d}^{average}[m']$ and $\tilde{O}_{j,d}^{average}[m']$.

9. Compute $\tilde{G}_{j,d,k,l}[m']$ and $\tilde{S}_{j,d,k,l}^{DS}[m']$ standard deviation over the $l$ orbit index and $k$ sequence index producing $\tilde{G}_{j,d}^{stdev}[m']$ and $\tilde{O}_{j,d}^{stdev}[m']$.

10. Inspect visually and determine if orbital compensation is required.

Data Analysis:

Mean value of spectral gain and offset. Standard deviation of spectral gain and offset.
2.10 IF9 OFFSET TANGENT HEIGHT ALTITUDE DETERMINATION

**Objective:**

Determine the minimum tangent height required for acquiring DS measurements to minimize wear out of the elevation scanning mechanism.

**Principle:**

Interferograms are acquired with the elevation mirror pointed so as to view several (say 10) tangent heights in the range of 150 to 210 km at different positions within an orbit (say 8 positions covering the polar, equatorial, and mid latitude of day and night orbital positions).

**Accuracy:**

Accuracy to 1/10 of the specified radiometric accuracy budget.

The NESR vs. radiometric accuracy for a source at 230K are given in [RD5] (Annex C, H1 to H10). The worst case is a NESR two times better than the radiometric accuracy budget. Therefore, to obtain an accuracy of one third of the relative radiometric accuracy budget, the number of sweeps required to measure the expected high resolution features, with the CBB source at nominal temperature, is about \((0.5 \times 10)^2\) or 25 sweeps. Taking 25 sweeps will produce more accurate result for a still reasonable amount of data.

Performing the measurement at each height and at selected in orbit positions allows establishing at which tangent height the Offset and Deep Space measurements should be made in the operational case. Spectral averaging is not allowed.

**Prerequisite measurements or calibrations:**

IF0 to IF8

**MIPAS configuration required:**

Nominal mode, 2-cm MPD.

**Measurement description:**

\[ \tilde{I}^{DS}_{j,d,i,k,l}[n] \]

\(j\) = band identification (A1, A2, B1, B2, C, and D)
\(d\) = sweep direction identification (FORWARD and REVERSE)
\(i\) = sweep identification in the sequence (0,...,24)
\(k\) = height index (0,...,9)
\(l\) = orbital position index (0,...,7)
\(n\) = sample index \(\left( -\frac{N^{\text{nom low}}}{2}, \cdots, \frac{N^{\text{nom low}}}{2} - 1 \right) \)
c) Other inputs:

- Spectral band limits: $\sigma_{j}^{\text{min}}$ and $\sigma_{j}^{\text{max}}$
- Non-linearity coefficients: $d_{q,j}$
- Equalization coefficients: $\tilde{W}_{eq}[n_{eq}]$
- Radiometric Gain: $\tilde{G}_{j,d}[m]$
- Tangent Heights: $H_{k} = (150, 155, 160, 165, 170, 175, 180, 190, 200, 210)$ km (to be converted to pointing angle TBD)
- Geo-location: $O_{l} = \text{TBD}$

Data Analysis:

1. Average all sweeps within a height and orbital position configuration producing $\tilde{I}_{j,d,k,l}^{DS}[n]$.

2. Correct non-linearity for band A1, A2, AB, and B.

$$\tilde{I}_{j,d,k,l}^{\ast DS}[n] = \text{CorrectNL}\{\tilde{I}_{j,d,k,l}^{DS}[n], ADC^{\text{min}}, ADC^{\text{max}}, d_{q,j}\}$$

3. Equalize and combine A1 and A2 channels

$$\tilde{I}_{A,1,d,k,l}^{DS}[n] = \text{Equilib} \begin{cases} \{\tilde{I}_{j,d,k,l}^{DS}[n], \tilde{I}_{A,2,d,k,l}^{DS}[n], \tilde{W}_{eq}[n_{eq}]\} \end{cases}$$

4. Compute spectra using FFT function producing $\tilde{S}_{j,d,k,l}^{DS}[m]$.

5. Subtract the DS acquired at the highest height from each of the other heights, calibrate and extract the real part.

$$D_{j,d,k,l}^{DS}[m] = \text{Re}\{\tilde{S}_{j,d,k,l}^{DS}[m] - \tilde{S}_{j,d,0,l}^{DS}[m]\} \tilde{G}_{j,d}[m]$$

6. Inspect visually and determine for which height spectral features begin to appear. As a guideline, spectral features can be considered important if they have an amplitude higher than the nominal NESR$_o$.

Output:

Selected height.

Pass criteria:

N/A.

Action to be taken:

Use selected height.
2.11 IF10 NESR₀ VERIFICATION

Objective:

Verify the NESR₀ levels. The specified noise includes the noise contributions of the Gain and the Offset.

Principle:

The principle of NESR₀ verification is fairly simple. Having performed a radiometric calibration measurement set, a series of measurements with a scene of negligible radiance (DS) are acquired. The noise is calculated from the standard deviation of these spectra after radiometric calibration. This approach assumes that drifts during the acquisition are smaller than the noise.

Accuracy:

Accuracy of NESR₀ measurement to about 10% of NESR₀ specification. The variance of a variance estimation is given by [RD16]:

\[ \sigma^2 = \sigma^2 \cdot \frac{1}{\sqrt{2(n-1)}} \]

To obtain a 10% variation of our estimation we must have at least 51 samples.

Prerequisite measurements or calibration:

IF0 to IF9. DS data from IF4 can be used instead of acquiring new data.

MIPAS configuration required:

Nominal data mode, orbital coordinate generating maximum offset contribution (see IF8).

Measurement description:

b) \( \tilde{T}_{DS,j,di}^n \)

- Instrument pointing at DS
- Low resolution setting
- \( j \) = band identification (A1, A2, AB, B, C, and D)
- \( d \) = sweep direction identification (FORWARD and REVERSE)
- \( i \) = sweep identification in the sequence (0,…,51)
- \( n \) = sample index \( \left( -\frac{N_{j\_nom\_low}}{2}, \cdots, \frac{N_{j\_nom\_low}}{2} - 1 \right) \)

b) Other inputs:

- Spectral band limits: \( \sigma_{j\_min} \) and \( \sigma_{j\_max} \)
• Non-linearity coefficients: \( d_{q,j} \)
• Equalization coefficients: \( \tilde{W}^{eq} [n^{eq}] \)
• Radiometric gain: \( \tilde{G}_{j,d}[m] \)

**Data processing description:**

For each detector and each sweep direction:

1. Apply calibration, non-linearity correction, and every other regular processing steps used to convert NOMINAL mode data to calibrated spectral radiance so as to generate \( L_{j,d,i}^{DS}[m] \).

2. Extract the real part

\[
L_{j,d,i}^{DS}[m] = \text{Re} \{ L_{j,d,i}^{DS}[m] \}
\]

3. Calculate the standard deviation of all the samples:

\[
\text{NESR}_{0,j,d}[m] = \text{StdDev} \{ L_{j,d,i}^{DS}[m] \}
\]

**Outputs:**

Measured NESR\(_0\) spectral vector.

**Pass criteria:**

NESR smaller than the specified values.

<table>
<thead>
<tr>
<th>Wavenumber (cm(^{-1}))</th>
<th>Specified NESR(_0) (nW/cm(^2) sr cm(^{-1}))</th>
<th>Min Measured Cold Case(^1) NESR(_0) (nW/cm(^2) sr cm(^{-1}))</th>
<th>Min Measured Hot Case(^2) NESR(_0) (nW/cm(^2) sr cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>685-970</td>
<td>50</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>1020-1170</td>
<td>40</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>1215-1500</td>
<td>20</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>1570-1750</td>
<td>6.0</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>1820-2410</td>
<td>4.2</td>
<td>2.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Action to be taken:**

N/A

1 F-1 of [RD5]
2 F-2 of [RD5]
2.12 IF11 ABSENCE OF HIGH RESOLUTION FEATURES VERIFICATION

Objective:

Verify the absence of features due to intrinsic characteristics of the interferometer blackbody and system self-emission for resolution finer than that used during characterization for radiometric calibration (0.25 cm⁻¹).

In the MIPAS standard data processing, the characterization for radiometric calibration is performed at a reduced resolution in order to obtain radiometric gains and offsets with reasonable SNR in a reasonable amount of time. This test verifies that a characterization for radiometric calibration performed at a reduced resolution does not under-resolve higher resolution features that could cause radiometric errors.

The verification is performed in-flight to check that no contamination occurred since the ground verifications and that no residual gas surrounds the spacecraft.

Principle:

The test consists in inspecting the differences between a spectrum at full resolution (0.025 cm⁻¹) and a spectrum at low resolution (0.25 cm⁻¹). The low-resolution spectrum is generated using the same data as the full resolution spectrum to avoid seeing the effect of radiometric instabilities in the results. The verification is performed using the CBB and DS types measurements.

Accuracy:

Check accuracy of relative high-resolution features to better than 1/10 of the actual radiometric accuracy as determined in section H-1 to H-5 of [RD5].

The NESR vs. radiometric accuracy for a source at 230K are given in [RD5] (Annex C, H1 to H10). The worst case is a NESR two times better than the radiometric accuracy budget. Therefore, to obtain an accuracy of one tenth of the relative radiometric accuracy budget, the number of sweeps required to measure the expected high resolution features, with the CBB source at nominal temperature, is about \((0.5 \times 10)^2\) or 25 sweeps. Taking 200 sweeps produces more accurate result for a still reasonable amount of data.

Prerequisite measurements or calibration:

IF0 to IF5.

MIPAS configuration required:

Nominal data mode.

Measurement description:

a) \(\tilde{I}_{j,d}^{\text{CBB}}[n]\) Instrument pointing at CBB

\(j = \text{band identification (A1, A2, B1, B2, C, and D)}\)
\[ d \text{ = sweep direction identification (FORWARD and REVERSE)} \]
\[ i \text{ = sweep identification in the sequence (0,…,199)} \]
\[ n \text{ = sample index } \left( -\frac{N_{j}^{\text{nom\_high}}}{2}, \ldots, \frac{N_{j}^{\text{nom\_high}}}{2} - 1 \right) \]

b) \[ \tilde{t}_{j,d}^{DS}[n] \]
Instrument pointing at DS
\[ j \text{ = band identification (A1, A2, B1, B2, C, and D)} \]
\[ d \text{ = sweep direction identification (FORWARD and REVERSE)} \]
\[ i \text{ = sweep identification in the sequence (0,…,199)} \]
\[ n \text{ = sample index } \left( -\frac{N_{j}^{\text{nom\_high}}}{2}, \ldots, \frac{N_{j}^{\text{nom\_high}}}{2} - 1 \right) \]

c) Other inputs:
- Actual radiometric accuracy as given by H-1 to H-5 of [RD5].
- Spectral band limits: \( \sigma_{j}^{\text{min}} \) and \( \sigma_{j}^{\text{max}} \)
- Non-linearity coefficients: \( d_{q,j} \)
- Equalization coefficients: \( \tilde{W}_{eq}[n_{eq}] \)
- Radiometric gain: \( G_{j,d}^{\text{DS}} \)

**Data processing description:**

For each detector and each sweep direction:

1. First the interferograms acquired with the DS and CBB are coadded separately producing \( \tilde{t}_{j,d}^{DS}[n] \) and \( \tilde{t}_{j,d}^{CBB}[n] \).

2. Correct non-linearity for band A1, A2, AB, and B for both DS and CBB measurements:

\[
\tilde{t}_{j,d}^{DS}[n] = \text{CorrectNL}\left[ \tilde{t}_{j,d}^{DS}[n], ADC_{j}^{\text{min}}, ADC_{j}^{\text{max}}, d_{q,j} \right]
\]

\[
\tilde{t}_{j,d}^{CBB}[n] = \text{CorrectNL}\left[ \tilde{t}_{j,d}^{CBB}[n], ADC_{j}^{\text{min}}, ADC_{j}^{\text{max}}, d_{q,j} \right]
\]

3. Equalize and combine A1 and A2 channels:

\[
\tilde{t}_{A,d}^{CBB}[n] = \text{EqualizeCombine}\left[ \tilde{t}_{A_{1},d}^{CBB}[n], \tilde{t}_{A_{2},d}^{CBB}[n], \tilde{W}_{eq}[n_{eq}] \right]
\]

\[
\tilde{t}_{A,d}^{DS}[n] = \text{EqualizeCombine}\left[ \tilde{t}_{A_{1},d}^{DS}[n], \tilde{t}_{A_{2},d}^{DS}[n], \tilde{W}_{eq}[n_{eq}] \right]
\]

4. The DS’s are then subtracted from the CBB’s.

\[
\tilde{t}_{j,d}^{\text{high}}[n] = \tilde{t}_{j,d}^{CBB}[n] - \tilde{t}_{j,d}^{DS}[n]
\]
5. Compute spectra using FFT function producing $\tilde{S}_{j,d}^{\text{high}}[m]$

6. $\tilde{I}_{j,d}^{\text{high}}[n]$ is then reprocessed after properly setting the interferogram wings to zero to produce $\tilde{I}_{j,d}^{\text{low}}[n]$ simulating a resolution degradation to 0.25 cm$^{-1}$.

7. Compute spectra using FFT function producing $\tilde{S}_{j,d}^{\text{low}}[m]$.

8. Compute the CBB radiance producing $L_{j,d}^{\text{high}}[m]$.

9. The relative radiometric error due to the high-resolution features of the gain is given by:

$$R_{j,d}^{\text{gain}}[m] = \left(1 - \text{Re}\left\{\frac{\tilde{S}_{j,d}^{\text{high}}[m]}{\tilde{S}_{j,d}^{\text{low}}[m]}\right\}\right) \cdot L_{j,d}^{\text{high}}[m]$$

10. As the offset is also taken at low resolution additional error may be introduced. Using the high-resolution offset measurements $\tilde{I}_{j,d}^{\text{DS}}[n]$, generated in Step 3 above, set to zero all interferogram samples corresponding to the low-resolution interferogram samples, producing $\tilde{I}_{j,d}^{\text{DS, high}}[n]$.

11. Compute spectra using FFT function producing $\tilde{S}_{j,d}^{\text{DS, high}}[m]$.

12. Generate a high-resolution gain:

$$\tilde{G}_{j,d}^{\text{high}}[m] = \frac{L_{j,d}^{\text{high}}[m]}{\tilde{S}_{j,d}^{\text{high}}[m]}$$

13. Apply radiometric calibration

$$\tilde{L}_{j,d}^{\text{DS, high}}[m] = \tilde{S}_{j,d}^{\text{DS, high}}[m] \cdot \tilde{G}_{j,d}[m]$$

14. The presence of high-resolution features from the offset can be detected by inspecting the following result:

$$R_{j,d}^{\text{offset}}[m] = \text{Re}\left\{\tilde{L}_{j,d}^{\text{DS, high}}[m]\right\}$$

Outputs:

The presence of high-resolution features from the gain and offset:

$$R_{j,d}^{\text{gain}}[m]$$

$$R_{j,d}^{\text{offset}}[m]$$
**Pass criteria:**

The amplitude of high-resolution features should be smaller than:

\[ \frac{N_{ESR}}{\sqrt{N_{DS}}} \]  
for deep space measurements where \( N_{DS} \) is the number of coadded DS measurements during calibration sequence.

\[ \frac{N_{ESR}}{\sqrt{N_{CBB}}} \]  
for calibration blackbody measurements where \( N_{CBB} \) is the number of coadded CBB measurements during calibration sequence.

**Action to be taken:**

If high-resolution features are found their impact on the radiometric error budget must be assessed. The result of this analysis may lead to the suggestion of a different calibration strategy.
3. IN-FLIGHT TEST SEQUENCES

The in-flight test sequence is performed in the order presented Figure 2. The following remarks can be made.

IF0: The LOS Characterization is subject to stars availability and is likely to be repeated through the commissioning phase. The accuracy of the LOS calibration will increase as the in-flight commissioning proceeds.

IF1: The first and second steps of the Analog Gain characterization may be performed right from the beginning of the commissioning phase. The third step requires some form of LOS calibration to provide proper tangent height for atmospheric limb measurements. As this characterization is needed only for establishing a gain-switching scenario for the operational phase the third step can be performed late in the commissioning phase.

IF7: Phase characterization must not be interrupted by other measurements. It must be performed before any CBB and DS are combined.

IF2: Spectral Characterization Requires DS measurements. In the early commissioning phase, residual gas and contaminant may still be present in the vicinity of the platform and affect the DS with high-resolution features. What is really needed first is to have a coarse spectral calibration for IF3 and IF4.

IF4: Non-linearity requires that the CBB be boosted heated and then the heater turned off during cool down. This will slightly affect the instrument radiometric offset contribution.

IF5: Channel Combination requires non-linearity correction thus must be performed after IF4. Because the measurement time exceeds the time window for direct transmission to ground (required for the RAW transmission mode) the measurement can be divided into several sequences, which are combined before processing.

IF6: CBB and DS SNR characterization requires channel combination thus must be performed after IF5.

IF8: Radiometric Calibration needs the phase characterization and the number of sweeps determined in IF6.

IF9: Offset Tangent Height requires the Radiometric Calibration determined in IF8.

IF10: NESR0 Verification requires Radiometric Calibration determined in IF8.

IF11: High Resolution Features is performed after the Offset Tangent Height is determined (IF9).

The total duration should be less than 20 days.
<table>
<thead>
<tr>
<th>Test ID</th>
<th>Duration</th>
<th>Resource Usage</th>
<th>Timeline (not to scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF0</td>
<td>TBD</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>IF1 (steps 1 and 2)</td>
<td>2 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF7</td>
<td>0.6 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF2 (coarse cal.)</td>
<td>5 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF3</td>
<td>3 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF4</td>
<td>40 hours</td>
<td>&lt;20%</td>
<td></td>
</tr>
<tr>
<td>IF5</td>
<td>30 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF6</td>
<td>10 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF8</td>
<td>15 days</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>IF1 (step 3)</td>
<td>1 Day</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>IF9</td>
<td>100 min</td>
<td>66%</td>
<td></td>
</tr>
<tr>
<td>IF10</td>
<td>8 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF11</td>
<td>30 min</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IF2</td>
<td>3 hours</td>
<td>23%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: In-flight test timeline (not to scale)
4. IN-FLIGHT PERIODIC VERIFICATION

In-flight periodic verification shall be a subset of and similar to in-flight initial characterization tests. The exact frequency shall be defined during the initial characterization tests in-light of the results. The following verification are proposed:

- PF3 High Resolution Feature Verification
- PF4 NESR₀ Verification
- PF5 Aliasing Verification
- PF6 Channel Combination Verification
- PF7 Non-Linearity Verification
- PF8 Radiometric Calibration Verification
5. CORRESPONDING IECF PROCESSING CHAIN

IF0 LOS Characterization
  None

IF1 Analog Gain Verification
  UR-MI-2.18 Analysis of the On-board Analog Gain Setting

IF2 Spectral Characterization
  None

IF3 Aliasing Verification
  UR-MI-2.10 Aliasing Verification

IF4 Non-Linearity Characterization
  UR-MI-3.3 Generation of the Non-Linearity Coefficients

IF5 Channel Combination Characterization
  UR-MI-5.1 Generation of the Channel Combination

IF6 CBB and DS SNR Characterization
  None

IF7 Phase Characterization
  None

IF8 Radiometric Calibration Characterization
  UR-MI-3.5 Radiometric Gain Calibration

IF9 Offset Tangent Height Altitude Determination
  None

IF10 $\text{NESR}_0$ Verification
  UR-MI-2.7 $\text{NESR}_0$ Verification

IF11 Absence of High Resolution Features Verification
  UR-MI-2.2 High Resolution Features Verification
6. ANNEX A

Table 5 below presents the measurement configurations with the data size and acquisition time required. L0 data size is expressed in MB of compressed data. Compression rate was estimated from FM data measurement files. Uncompressed data size for L1A are given for data not coadded and in float (4 bytes) format as it will be in MICAL.
## Table 5: In-flight data summary

<table>
<thead>
<tr>
<th>Verification ID</th>
<th>Description</th>
<th>Measurement ID</th>
<th>Instrument Mode</th>
<th>Resolution</th>
<th>Instrument Poling</th>
<th>Target Characteristics</th>
<th>Notes</th>
<th>Number of Sweeps per Direction</th>
<th>Number of Sweep Directions</th>
<th>Sequence</th>
<th>Number of Times Along the Orbit</th>
<th>Orbital Revolution</th>
<th>Number of Orbits</th>
<th>Estimated Measurement Time (min)</th>
<th>Ladar Product Data Size (MB)</th>
<th>L1A Product Data Size (MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF0</td>
<td>LOS</td>
<td>n/a</td>
<td>STAR</td>
<td>&gt;2 D.U.</td>
<td>1, 2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>10</td>
<td>n/a</td>
<td>n/a</td>
<td>10</td>
<td>15</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>IF1</td>
<td>Analog Gain</td>
<td>a) RAW LOW CBB</td>
<td>220 K</td>
<td>3</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.9</td>
<td>23.8</td>
<td>59.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) NOM LOW CBB</td>
<td>220 K</td>
<td>3, 4</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.9</td>
<td>1.9</td>
<td>4.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) NOM LOW SCENE</td>
<td>5 km</td>
<td>3, 4</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>20</td>
<td>n/a</td>
<td>15</td>
<td>272</td>
<td>582.7</td>
<td>1456.8</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d) RAW LOW CBB</td>
<td>245 K</td>
<td>3</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.9</td>
<td>23.8</td>
<td>59.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IF2</td>
<td>Spectral</td>
<td>a) NOM HIGH SCENE</td>
<td>TBD km</td>
<td>3, 4</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>1</td>
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<td>8</td>
<td>151.9</td>
<td>626.2</td>
<td>1565.5</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>b) NOM LOW DS</td>
<td>210 km</td>
<td>3, 4</td>
<td>32</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>n/a</td>
<td>8</td>
<td>29.0</td>
<td>62.2</td>
<td>155.4</td>
<td></td>
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</tr>
<tr>
<td>IF3</td>
<td>Aliasing</td>
<td>a) RAW LOW CBB</td>
<td>220 K</td>
<td>3</td>
<td>100</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>2.8</td>
<td>74.3</td>
<td>185.9</td>
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<tr>
<td>IF4</td>
<td>Non-Linearity</td>
<td>a) NOM LOW CBB</td>
<td>Heat to 245 K/</td>
<td>200</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Equatoria</td>
<td>20</td>
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<td>Cool to TBD K</td>
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<td></td>
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<td>20</td>
<td>113.3</td>
<td>242.8</td>
<td>607.0</td>
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<tr>
<td>IF5</td>
<td>Combination</td>
<td>a) RAW HIGH CBB</td>
<td>220 K</td>
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<tr>
<td>IF6</td>
<td>SNR</td>
<td>a) NOM LOW CBB</td>
<td>220 K</td>
<td>3, 4</td>
<td>200</td>
<td>2</td>
<td>1</td>
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<td>n/a</td>
<td>n/a</td>
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<td>12.1</td>
<td>30.3</td>
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</tr>
<tr>
<td>IF7</td>
<td>Phase</td>
<td>a) NOM LOW CBB</td>
<td>220 K</td>
<td>3, 4</td>
<td>200</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>n/a</td>
<td>n/a</td>
<td>5.7</td>
<td>12.1</td>
<td>30.3</td>
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<td></td>
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<tr>
<td>IF8</td>
<td>Radiometric</td>
<td>a) NOM LOW CBB</td>
<td>220 K</td>
<td>3, 4</td>
<td>75</td>
<td>2</td>
<td>1</td>
<td>24</td>
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</tr>
<tr>
<td>IF9</td>
<td>DS Tangent Height</td>
<td>a) NOM LOW CBB</td>
<td>220 K</td>
<td>3, 4</td>
<td>75</td>
<td>2</td>
<td>1</td>
<td>24</td>
<td>n/a</td>
<td>15</td>
<td>765.0</td>
<td>1638.9</td>
<td>4097.2</td>
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<tr>
<td>IF10</td>
<td>NERF</td>
<td>a) NOM HIGH DS</td>
<td>210 km</td>
<td>3, 4</td>
<td>51</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>7.6</td>
<td>31.2</td>
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<td>IF11</td>
<td>High-Res Features</td>
<td>a) NOM HIGH CBB</td>
<td>220 K</td>
<td>3, 4</td>
<td>200</td>
<td>2</td>
<td>1</td>
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<td>122.3</td>
<td>305.8</td>
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**Notes**

1: PAW settings (Current baseline for star measurements)
2: SPE Filters, Decimation factors (Current baseline for LOS mode)
3: PAW settings (Current baseline for interferogram)
4: SPE Filters, Decimation factors (Current baseline for nominal mode)
5: Data from IF11 b) can be used instead