METEOSAT THIRD GENERATION: SIMULATION AND LEVEL 1 PROCESSING OF INFRARED SOUNDING DATA

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ABSTRACT

The InfraRed Sounding (IRS) instrument of the Meteosat Third Generation (MTG) mission aims at providing unprecedented information on horizontally, vertically, and temporally resolved water vapour and temperature structures of the atmosphere. Both the MTG-S satellite and the IRS instrument are being developed and built under the responsibility of the German space company OHB System AG under the prime contract of Thales Alenia Space France*.

The IRS instrument will deliver hyper spectral sounding information in two bands, a Long Wave InfraRed (LWIR: 700 - 1210 cm^{-1}) and Mid Wave InfraRed (MWIR: 1600 -2175 cm^{-1}) band with a spectral resolution of better than 0.625 cm^{-1}. The instrument is capable of covering the full Earth disc every hour from a geostationary orbit, with a spatial sampling distance of around 4 km.

The IRS is an imaging Fourier transform spectrometer. It converts input spectral radiances to interferograms, which are processed on-board for data rate reduction and then transmitted to ground as compressed interferograms. For each of the two bands, there is a detector of 160 x 160 pixels, leading to more than 50,000 interferograms which are provided every 10 seconds for further on-ground processing. In addition, high resolution images (integrated spectra) composed of 9 subpixels per pixel are sent to ground to support the image navigation and registration process (INR).

In order to meet the stringent performance requirements for this complex instrument (e.g., spectral accuracy, radiometric accuracy, noise), dedicated calibration and Level 1 processing techniques have been developed by OHB and subcontractors. While radiometric calibration is based on dedicated measurements of deep space and of an internal blackbody, the spectral calibration approach relies purely on the data recorded during nominal Earth observation measurements.

For the simulation and analysis of IRS data, dedicated models have been developed in the various project phases. These tools are used by Systems Engineering to support instrument development, e.g. to study the impact of subsystem performances on instrument performance.

Both the Level 1 processing algorithms and the simulation models need to be adapted and extended in phase C/D in order to support the demanding task of on-ground testing, characterisation and performance verification of this data intensive instrument.

In this contribution to the SESP Workshop, an overview of the activities and tools dedicated to the development, characterisation and validation of the innovative IRS instrument is given.

1 INTRODUCTION

After a short summary of the instrument design and the in-flight calibration strategy, the different tools developed in the different phases of the project are described in the following chapters. In phase A, a detailed physical model was needed for the verification of instrument feasibility and the deduction of subsystem specifications. In phase B, the model was adjusted in a way that subsystem performances were defined as input parameters and used to provide instrument performances as output. In this way, instrument performance can be directly assessed based on supplier feedback on subsystem performances. This model is also used for the verification of the requirement breakdown from system to subsystem level. Later in phase B, an instrument simulator was developed in addition to those analytical models. The simulator provides the input to check the developed chain of on-ground (Level 1b) processing, which is necessary to obtain calibration parameters and to correct raw data for instrument inherent errors. For the processing of real measurement data obtained in phases C and D, the tools for Level 1b processing need to be adapted and extended in order to obtain characterisation parameters from the measurements and in order to verify compliance of the instrument to the performance requirements.

1.1 Instrument design

The instrument is based on an Infrared Michelson Interferometer, which includes a detection chain composed of two types of detectors (MWIR and LWIR) located in a cooled cryostat with accompanying processing electronics. Light from the observed Earth is guided by a solar and inner baffle system, scan-mirror assembly (including a mirror) for scanning the Earth and Front Telescope Assembly to focus light into the interferometer and then via the Back Telescope Assembly into the cooled detection assembly (DA).

One of the mirrors is mounted on a refocusing

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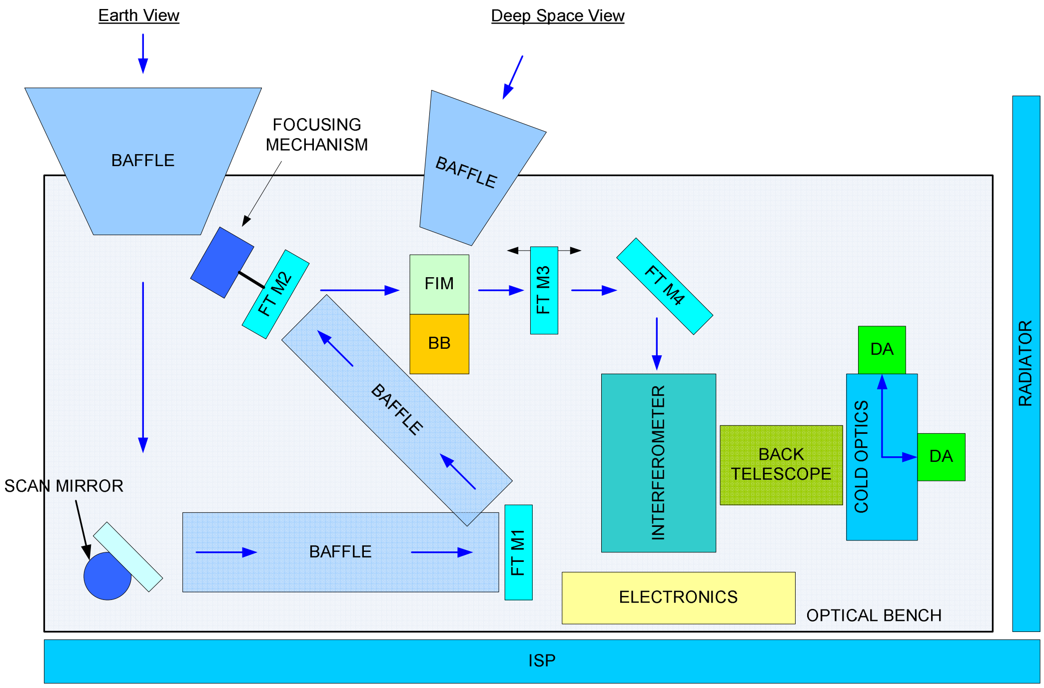

Figure 1: IRS functional sketch.

mechanism (REM) which can be used to optimise the mirror position. A special flip-in mirror (FIM) provides the options to observe the on-board blackbody or deep space through a dedicated calibration baffle for obtaining parameters for radiometric calibration. When no calibration is required, the FIM is removed from the light path and Earth observation is performed.

The interferometer utilizes corner cubes and a linear moving mechanism. The interferograms are acquired at equal time intervals. A dedicated laser metrology system accurately measures the corner cube position. This information is used for interferogram resampling from equal time steps to equal optical path difference (OPD) steps. The sampling is performed on-board together with other corrections (e.g., non-linearity) and data compression. A functional sketch of the IRS is shown in Fig. 1.

1.2 ON-GROUND DATA PROCESSING

On-ground, the Level 0 data as obtained from the instrument are processed to correct each pixel individually for instrument errors (radiometric, spectral and geometric). The processing is needed to meet the stringent instrument performance requirements, which are defined on Level 1b data. The Level 1b processing chain consists of the following main blocks:

- pre-processing: interferogram decompression, numerical apodisation, Fourier transform
- radiometric correction: offset correction, correction for the radiometric response of the core section (after the FIM) , correction for the transmission of the front section (before the FIM, dependant on the scan angle), sun straylight correction (dependant on the line of sight angle towards the sun)
- spectral correction: correction for spectral scale shifts (composed of a wavelength dependent, but temporally stable shift and a shift constant over the spectral axis, but varying with time)
- geometric correction: INR using high spectral resolution and high spatial resolution data

1.2.1 Radiometric calibration

Instrument background (offset) is determined for each pixel using so-called DS2 (deep space 2) measurements. These measurements are taken through the main entrance baffle by pointing the scanner to the deep space to the West (or East) of the Earth, before or after a scan line. They are taken frequently (about every 3-4 min) in order to account for the high temperature variations in the front telescope.

The radiometric response of the core section for each pixel is determined from measurements of the on-board blackbody and measurements of deep space through the calibration baffle (so-called DS1 measurements) by changing the position of the FIM. Blackbody and DS1 measurements are taken regularly (every 15 min) in order to account for temperature drifts. The transmission of the front section is characterised separately and taken into account in the radiometric correction, as the front section contribution is not covered with the blackbody and DS1 measurements via the FIM.

A dedicated processing for noise reduction is applied to calibration measurements, combining temporal and spatial averaging of calibration measurements.

1.2.2 Spectral calibration

The spectral scale factor for each pixel is determined using operational observations of the atmosphere over a so-called spectral calibration zone, which is an area over the North Atlantic Ocean. An innovative approach is used to accurately estimate and predict the scale factor using a set of peaks in the atmospheric spectrum after applying a dedicated apodisation function.

Several options for prediction of the scale factor have been developed, either short-term (over some hours) or medium-term (over several days) in order to account for temperature dependent drifts.

2 PHASE A: PHYSICAL PERFORMANCE MODELING

In the early project phase, a first analytical performance model was developed based on detailed descriptions and models of all components of a first system design. The parameters were derived from supplier feedback and working assumptions. The main purpose of the model was the verification of instrument feasibility.

From this first system design, subsystem requirements were derived. This set of requirements had to be as unspecific as possible in order not to impose any specific technical solution on the suppliers, but detailed and precise enough in order to ensure unambiguity and completeness. Whereas, for example, in the detailed physical model all noise contributions from the retina, the read-out electronics and the processing chain were included individually, the respective specification towards the supplier of the detection electronics assembly was reduced to a signal-to-noise ratio covering all contributions. This methodology was applied to other requirements as well in order to give to the suppliers maximum freedom for design solutions.

3 EARLY PHASE B: REQUIREMENT ORIENTED PERFORMANCE MODELING

In phase B, another model was developed which is closely linked to the performance requirements defined in the User Requirements Document (URD). The aim was to verify the sub-system contract specifications (URD/IRD) and check for their completeness. This model is also used later to elaborate the effects of potential supplier non-compliances on instrument level.

All performance relevant specifications listed in URDs/IRDs are considered and incorporated into the simulation model. The model is an analytical model, which considers all contributors to each performance budget, including statistical effects. Different cases (e.g., with regard to temperature conditions, aging effects) can be simulated.

An example is shown in Fig. 2 for the analysis of the NEdT (noise equivalent delta temperature) performance.

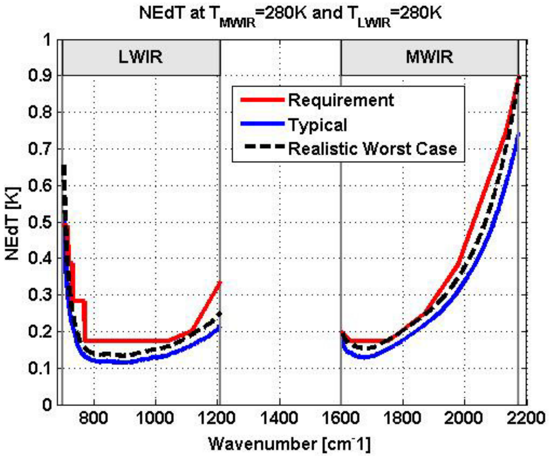

Figure 2: Example output of requirement oriented modeling: NEdT performance for the reference scene (blackbody scene of 280K) for different cases.

4 LATE PHASE B: SIMULATION OF INSTRUMENT RAW DATA

Later in phase B, a complete simulator of instrument raw data was developed to support detailed analyses and processing simulation. For example, the simulator was used to support the consolidation of detector design, as it allowed to validate the allocation in the radiometric performance budget for detector non-linearity. Its performance impact strongly depends on the exact shape of the non-linearity and of the measured interferogram, which could both be simulated using the raw data simulator.

For an arbitrary pixel on the detectors, any arbitrary input spectrum is transformed into a raw interferogram, taking into account all relevant radiometric and spectral errors due to the instrument design. These include, for example, the transmissions of optical elements, the detection system‘s spectral response, gains and offsets introduced by the electronics, etc. Also, calibration measurements of the on-board blackbody and deep space can be simulated.

For simulations, various cases can be selected regarding boundary conditions (e.g., typical temperature environment, hot case) and instrument aging (e.g., different parameters for beginning of life and end of life). The same parameters and properties are used as for the analytical models described in Chapter 3. In fact, the noise level on simulated interferograms is consistent with the noise predicted by the analytical model. An example for output of the simulator is shown in Fig. 3.

Despite its advantages in terms of producing realistic instrument output, the simulator does not render the analytical tools unnecessary. They are still mandatory to evaluate statistical effects (e.g., for requirements on stability), which are not part of the simulator, and to evaluate the impact of subsystem performances as announced by suppliers as they detail their design and manufacture their hardware. In the meantime, the raw data simulator is also used for the development and validation of the algorithms and tools which are necessary for the evaluation of real measurement data during on-ground tests on instrument level. These are the tools described in the next chapter.

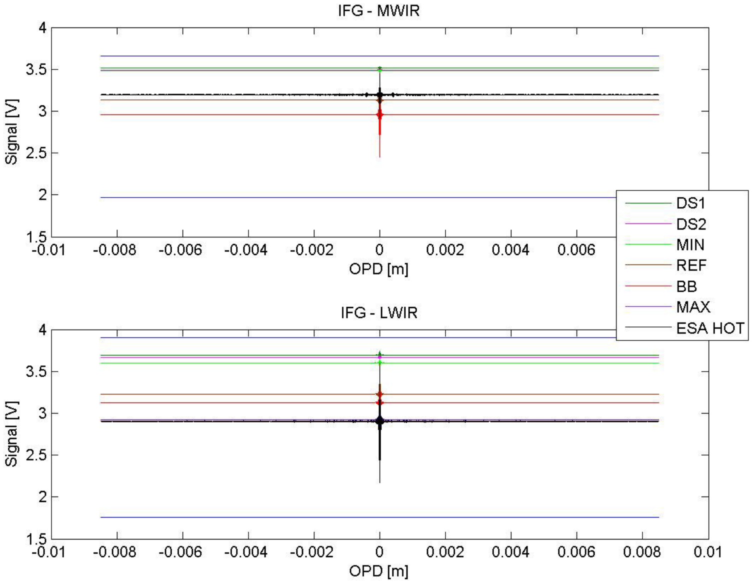

Figure 3: Example output of the instrument simulator, showing interferograms for MWIR (above) and LWIR (below) for various input scenes (DS1 = deep space observation through calibration baffle, DS2 = deep space observation through main baffle, MIN = minimum flux, REF = typical flux, BB = blackbody observation, MAX = maximum flux, ESA HOT = hot scene provided in ESA specifications).

5 PHASE C/D: ON-GROUND CHARACTERISATION AND PERFORMANCE VERIFICATION

For on-ground characterisation and performance verification of the instrument, a dedicated software is needed to evaluate the measurement data from the instrument. This software, called PASS (Performance Assessment Software Suite) includes parts of Level 1 processing (pre-processing, radiometric calibration and correction), but also additional functionalities to derive characterised parameters and check whether performance requirements are met. Each performance requirement in the URD is linked to performance requirements and characterisation requirements in the TRD. From there, the verification module links to the relevant test specifications. For each of these tests, PASS needs to process the data in order to

- derive the needed quantity (e.g., derive wavenumber dependent, but temporally stable spectral shifts from dedicated gas cell measurements) or
- provide a statement on compliance to the tested performance requirement (e.g., calculate the noise level to be compared to the NEdT requirement). In some cases, analytical assumptions need to be incorporated in order to account, e.g., for launch effects.

The set-up for performance verification, including the role of PASS, is shown in Fig. 4.

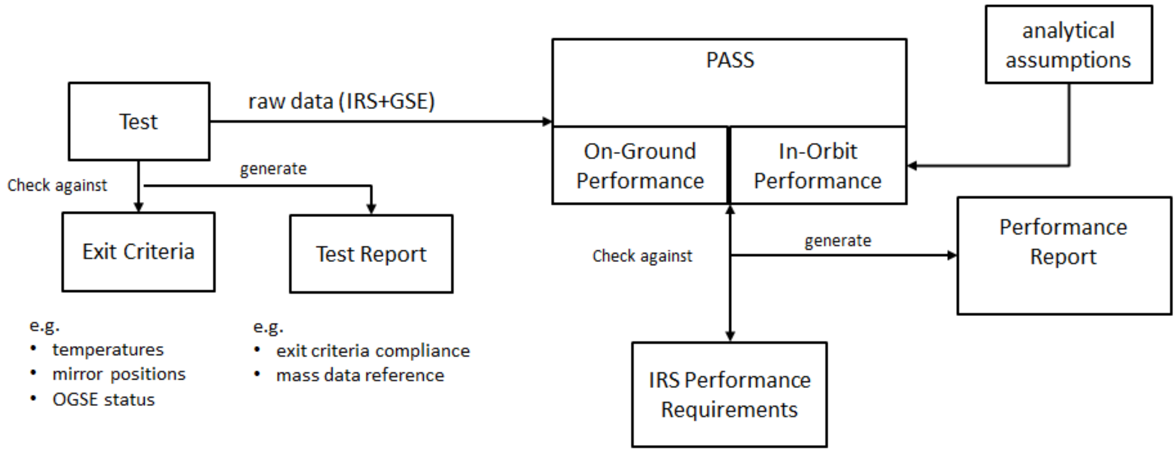

Figure 4: Set-up for performance verification and tasks for PASS.

5 CONCLUSIONS

The InfraRed Sounder developed for the Meteosat Third Generation mission is a highly complex instrument with demanding performance requirements. As complex as the instrument development itself is the developed processing chain for Level 1 processing, calibration and performance assessment. These tasks could only be addressed through the development of different tools which give answers to different questions, but are all based on the same physics and the same instrument design. The developed tools support the requirement breakdown to instrument subsystems, the evaluation of supplier feedback on instrument level, but also the validation of the processing chain and the verification of instrument performance during on-ground testing.