Meteosat Third Generation (MTG)
IRS Overall Design and Performance

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Abstract

The Infra-Red Sounder (IRS) instrument is part of the Meteosat Third Generation (MTG) programme, more precisely part of the MTG-S mission. It is a Fourier Transform infrared spectrometer. It is designed to provide soundings of the Earth every hour in 2 bands; LWIR, 700 to 1210 cm^{-1}, and MWIR, 1600 to 2175 cm^{-1}. Spectral and spatial resolutions are respectively 0.754 cm^{-1} and 4 km (at sub-satellite point) using stares of 640x640 km^2.

Following final consolidation and review of the challenging design, the IRS has now entered manufacturing and testing phases. The instrument STM is being integrated while Engineering Model (EM), and in several cases Proto Flight Model (PFM) equipment, are being manufactured. With results from development model testing, at all levels, the IRS CDR is scheduled to take place in mid 2019. Radiometric, spectral and image quality performance evaluation indicates that the IRS will closely meet its mission requirements.

This paper will briefly recall the overall IRS instrument design and calibration concept. The presentation will provide an overview of performance predictions for the IRS in the geometrical, spectral and radiometric domains. As far as available, it will take into account the latest test results at unit, sub-system and instrument level. Furthermore, the paper will provide an overview of the resulting mission performances up to Level 1b and highlight some of the many challenges and design solutions required to realise this complex programme.

IRS IN MTG

The MTG Programme is being realised through the well-established and successful Cooperation between EUMETSAT and ESA. It will ensure continuity with, and enhancement of, operational meteorological (and climate) data from Geostationary Orbit as currently provided by the Meteosat Second Generation (MSG) system, the last of which, MSG4/MET11, has been successfully launched, commissioned in 2015, and put in orbit storage. The MTG-S mission with its IRS and Sentinel-4 missions will complement the traditional horizontal imaging system with vertical profiling of wind, temperature, and air quality thanks to its sounding capability.

The MTG-I mission, consists of 4 identical satellites (MTG-I1, MTG-I2, MTG-I3 and MTG-I4), having on board the Flexible Combined Imager (FCI) and the Lightning Imager (LI). MTG-S consists of two identical satellites, having on board the IRS and the Ultraviolet Visible and Near-Infrared (UVN) instrument: MTG-S1 and MTG-S2. MTG-S2 will be launched towards the end of MTG-S1 operations. The flight acceptance review (FAR) of MTG-S1 is expected in 2022.

DESIGN FEATURES

The IRS and FCI designs share many similarities: Entrance baffles (see figure 1), pointing mechanisms, telescopes (30cm diameter input beam), cryogenic coolers, on-board blackbody references, main computers, radiator arrangements, etc.

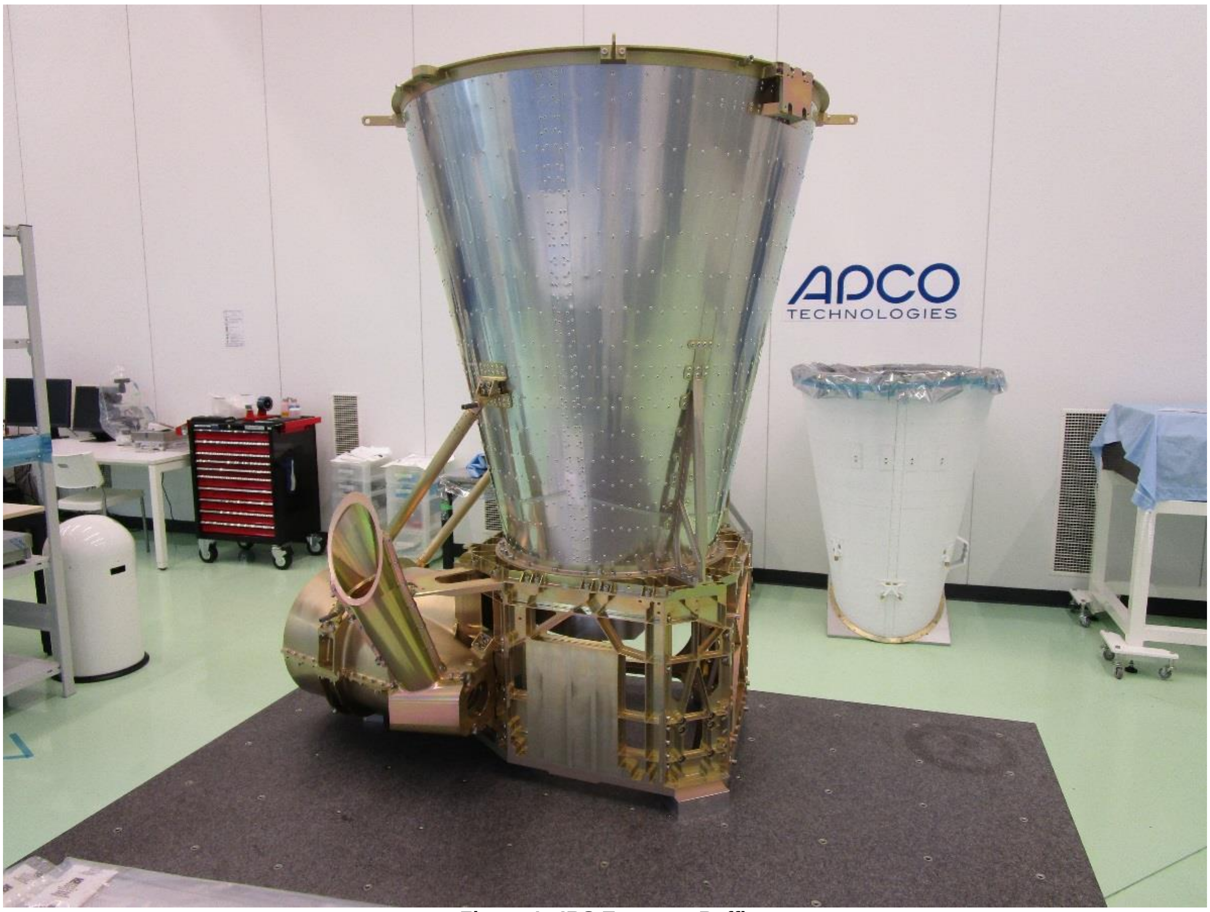

Figure 1: **IRS Entrance Baffle**

The IRS is a Fourier Transform infrared spectrometer. It makes use of a dichroic plate, in its cold optics, to split the signal in two bands: Long Wavelength Infra-Red (LWIR), 700 to 1210 cm^{-1} and Medium Wavelength Infra-Red (MWIR), 1600 to 2175 cm^{-1}. The spectral resolution is 0.754 cm^{-1} over both bands.

The IRS performs imaging by step and stare, each dwell being acquired in about 9.7s, and the step to the next measurement taking about 0.6s. Neither numerical apodization nor Fourier transformation are done on board.

A yaw flip manoeuver is performed twice a year, at the equinoxes. This simplifies the radiator design, avoiding impinging sunlight on one side of the spacecraft.

The weight of the IRS is about 470 kg. The Critical Design Review (CDR) of the IRS is planned for 2019.

The pointing mechanism of the IRS moves a single mirror about two axes. The Earth disk is separated in four zones, each of them covered in 15 minutes. The European zone is revisited every 30 minutes. Each zone is measured with about 75 dwells. Each dwell measures a square area of 640 km x 640 km (when at sub-satellite point) and counts 160 x 160 pixels. The spatial resolution is then 4 km.

A small blackbody reference is incorporated so as to be viewed, via a flip-in mirror, between the telescope and the interferometer. At the same location, the flip-in mirror can provide a view to deep space, through a second baffle.

Two Cadmium-Mercury-Telluride (CMT) detector arrays, having the same geometrical characteristics, co-registrated with one-another, acquire interferogramme samples. They are cooled at 55K by pulsetube cryogenic coolers. To isolate the instrument from microvibrations caused by the cooler compressors, the latter are mounted on an elastomeric suspension. Each detector pixel consists in fact of 3 x 3 de-selectable sub-pixels. This allows much greater operability of the pixels, given that manufacturing defects mostly impact at sub-pixel level.

The interferometer mechanism (see figure 2) has a double parallelogram configuration and is a design evolution from the IASI instrument. One cube corner is fixed while the other one is moving linearly at a mechanical speed of about 1 mm/s. Time sampling is used, and interferogrammes are resampled on board on a regular optical path difference grid. This is done thanks to the laser 3D metrology in the interferometer, measuring the relative movements of the cube corners not only along the optical axis but also across both orthogonal axes.

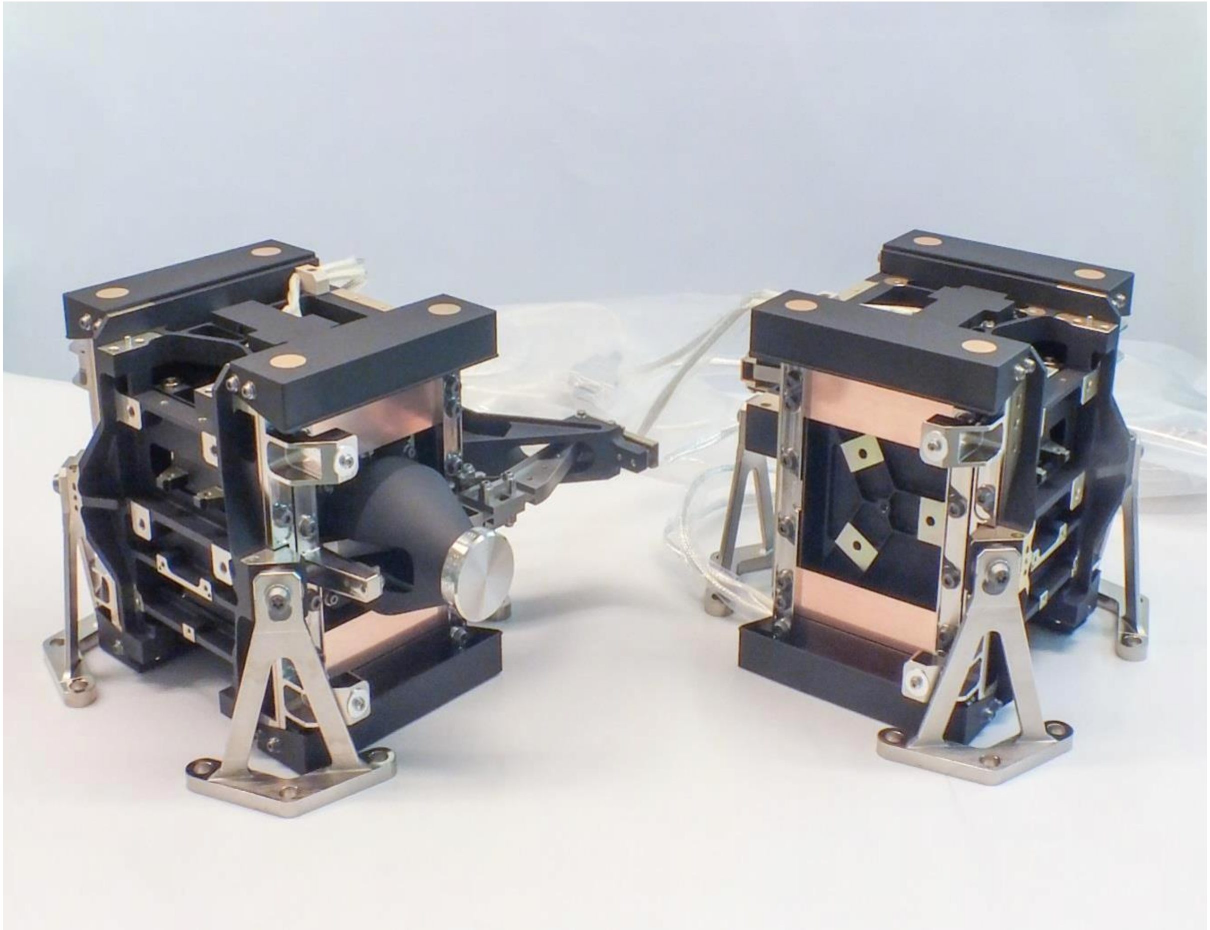

Figure 2: **Interferometer Mechanism**

Due to the very slow cube corner movement and the proximity of the cryogenic coolers, and despite the elastomeric suspension, the scanning speed experiences significant instability, on the order of 20% peak. An integration window compensation method using a 3-tap numerical filter is used before resampling. Otherwise, the speed instability would be a dominating error term.

RADIOMETRIC CALIBRATION

The IRS radiometric calibration is based on a 2-point characterization. The blackbody reference temperature is not controlled and will be close to ambient.

As explained before, a flip-in mirror allows to select between telescope input, blackbody reference and intermediate deep space view. These views allows to calibration the core part of the instrument, ie not including the telescope. This partial gain calibration is performed every 15 minutes.

Offset characterization is done about every 3 minutes, ie at the end of every east-west line of dwells, through the main telescope.

Since the gain characterization has to be completed by an estimation of the telescope total reflectivity, the emissivity of the telescope is monitored in flight. Scan mirror reflectivity, as a function of the pointing angle, is also to be characterized in flight.

SPECTRAL CALIBRATION

To achieve spectral calibration, the spectral shift is continuously characterized (48 times per day) on dwells taken over the North Atlantic. This region was chosen for its reasonable surface and atmospheric variability. It was statistically studied for all seasons, through simulation of about 2000 different atmospheric conditions.

The method to retrieve the spectral shift uses strongly apodized spectra. It computes a weighted average of over 100 spectral feature shifts in each band. Validity checks, averaging and prediction algorithms are used to yield the best current estimate.

A correction for chromatism is needed. Characterization of this effect will be done on ground and is expected to remain valid until end-of-life.

GEOMETRIC PERFORMANCE

Nominal sampling distance is 4km between spatial samples. Typically, 90% of these distances should be within 200m of the nominal value. In the worst case, 80% is expected.

Line of sight instability during the acquisition of a dwell is driven by microvibrations. Expectation is a root mean square fluctuation of 380m.

The absolute knowledge of a spatial sample position is expected to be about 1.2km. Between 2 dwells, the error is expected to be about 1.1km. Between two measurements of the same spatial sample, 30 minutes apart, the expected error is expected to be 2.6km.

Within the same band, LWIR or MWIR, the co-registration error is expected to be about 350m in worst case assumptions. Between the two bands, the error is expected to be typically about 540m, and in worst case 1120m.

SPECTRAL PERFORMANCE

A spectral resolution (full width at half maximum) of 0.747cm^{-1} is expected. It is the result of combining a maximum optical path difference of 0.828m with a very weak apodization. The apodization function is the result of a convolution of a boxcar with a Gaussian curve.

The spectra will be delivered with a 0.625cm^{-1} sampling interval. Spectral accuracy will be about 1ppm.

The uncertainty on the spectral response function of the IRS is separated in a daily average error and a short term (dwell to dwell) variability. The first term is expected to be equivalent to a 10 to 20mK noise temperature, while the second one is expected to be at a level of 30mK. These values are small, compared to the minimum noise level of 200mK.

RADIOMETRIC PERFORMANCE

The measurement range of the IRS is from 180K to 313K in LWIR, and 180K to 280K in MWIR.

The noise level is nearly compliant with the sensitivity requirements (see figure 3), but this will not be achieved near the lowest frequency of 700 cm^{-1}. The cutoff of the CMT detector is responsible for the sharp decrease of responsivity in this region. A non compliance by a factor 2 is expected but only at this extremity of the LWIR band.

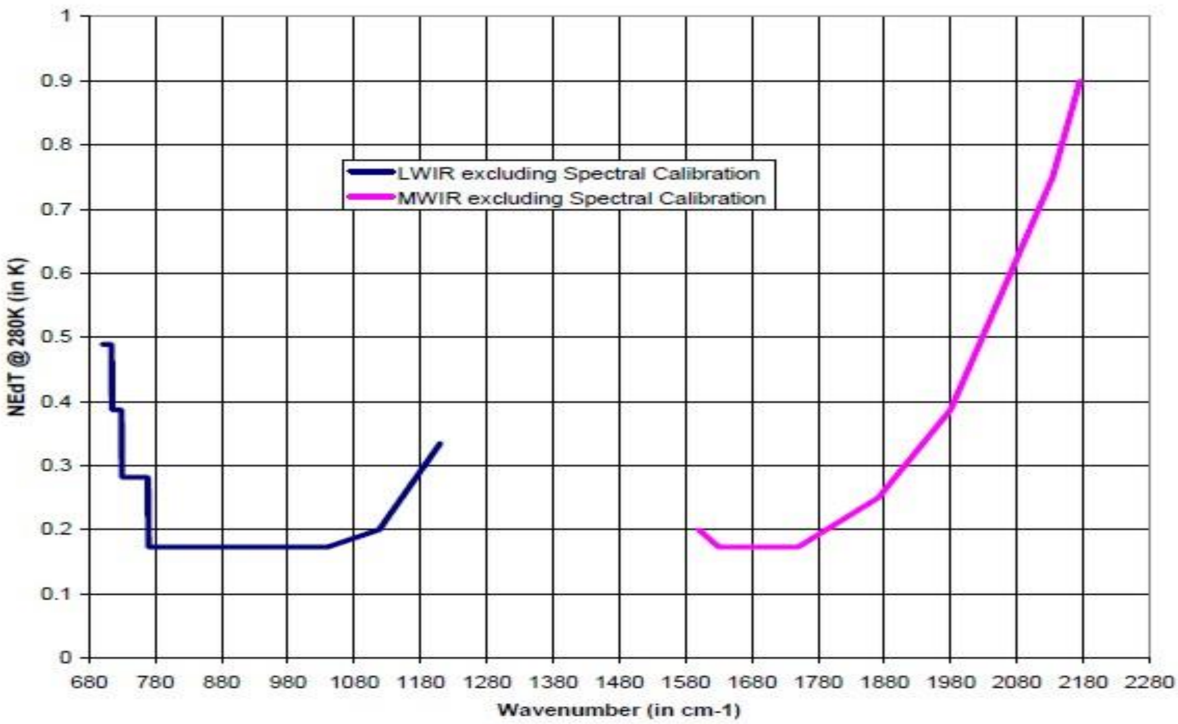

Figure 3: **IRS Sensitivity Requirement**

The IRS is expect to have an absolute radiometric accuracy of about 0.5K. The radiometric stability is expected to be about 0.1K on a daily basis, and 0.3K over the mission duration.

CHALLENGES

A number of IRS challenges are shared with the FCI. The pointing mechanism and the coolers are completing their qualification. The thermo-elastic stability has been demonstrated with the FCI Structural and Thermal Model (STM). FCI telescope stability tests will take place next year. The IRS STM and the IRS Engineering Model (EM) are being produced, to be also tested next year. The LWIR detector feasibility has been demonstrated, but the production yield is critical for the schedule. Microvibration control is involving comprehensive Finite Element Model (FEM) and performance simulations. The efficiency of the elastomeric suspension for the coolers will be demonstrated with an end-to-end test with the IRS STM next year.

Specific to the IRS, the 3D interferometer metrology and the data acquisition will be tested on the IRS EM next year. On-board processing performance has been comprehensively simulated with bit-to-bit accuracy.

CONCLUSION

The IRS is a large FTIR instrument with many common technologies with the FCI. The IRS Critical Design Review (CDR) is planned for 2019. The MTG-S1 FAR is expected in 2022.

Very good performance is expected for the IRS, and risks associated with the main challenges are being retired.

IRS STM and IRS EM are being produced, and testing is to be done in 2019.