# ICSO 2016

# International Conference on Space Optics

Biarritz, France

18–21 October 2016

*Description and performance of the OGSE for VNIR absolute spectroradiometric calibration of MTG-I satellites*

*W. Glastre*

*J. Marque*

*E. Compain*

*A. Deep*

*et al.*

# DESCRIPTION AND PERFORMANCE OF THE OGSE FOR VNIR ABSOLUTE SPECTRORADIOMETRIC CALIBRATION OF MTG-I SATELLITES

W. Glastre[1], J. Marque[1], E. Compain[1], A. Deep[2], Y. Durand[2], D. M. A. Aminou[2]
*[1] Bertin Technologies, 155 Rue Louis Armand, 13290 Aix-En-Provence, France*
*[2] European Space Agency, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands*

## I. ABSTRACT

The Meteosat Third Generation (MTG) Programme is being realised through the well-established and successful Cooperation between EUMETSAT and ESA. It will ensure the future continuity of MSG with the capabilities to enhance nowcasting, global and regional numerical weather prediction, climate and atmospheric chemistry monitoring data from Geostationary Orbit.

This will be achieved through a series of 6 satellites named MTG-I and MTG-S to bring to the meteorological community continuous high spatial, spectral and temporal resolution observations and geophysical parameters of the Earth based on sensors from the geo-stationary orbit. In particular, the imagery mission MTG-I will bring an improved continuation of the MSG satellites series with the Flexible Combined Imager (FCI) a broad spectral range (from UV to LWIR) with better spatial and spectral resolutions. The FCI will be able to take high spatial resolution pictures of the Earth within 8 VNIR and 8 IR channels. As one of the mission of this instrument is to provide a quantitative analysis of atmosphere compounds, the absolute observed radiance needs to be known with a specified accuracy for VNIR as low as to 5% at k=3 over its full dynamic. While the FCI is regularly recalibrated every 6 month at equinoxes, it is however requiring initial ground calibration for the beginning of its mission.

The Multi Optical Test Assembly (MOTA) is one of the Optical Ground Support Equipment (OGSE) dedicated to various missions necessary for the integration of the FCI . This equipment, provided by Bertin Technologies, will be delivered to TAS-F by the end of 2016. One of its mission, is the on-ground absolute calibration of VNIR channels. In order to handle this, the MOTA will be placed in front of the FCI under representative vacuum conditions and will be able to project a perfectly known, calibrated radiance level within the full dynamic of FCI instrument. The main difficulty is the very demanding calibration level with respect to primary standards down to 3% (k=3) coupled with constraining environment (vacuum), large dynamic (up to factor 100), high spectral resolution of 3 nm. Another main difficulty is to adapt the specific MOTA etendue (300 mm pupil, 9 mrad field) to available primary standards. Each of these constraints were addressed by specific tool design and production, a fine optimization of the calibration procedure with a large involvement of metrology laboratories.

This paper introduces the missions of MTG satellites and particularly of the FCI instrument. The requirements regarding the absolute calibration over the different spectrometric channels and the global strategy to fulfill them are described. The MOTA architecture and calibration strategy are then discussed and final expected results are presented, showing state of the art performances.

## II. MOTA OGSE MISSION OBJECTIVES

*A. MTG Context*

The MTG Programme includes MTG-I and MTG-S satellites series [1]. This programme is being realised through the well-established and successful cooperation between EUMETSAT and ESA. It will ensure the future 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 and commissioned in 2015.

The MTG space segment activities are now entering the manufacturing and testing phases from equipment levels to the platform and instrument assemblies. For the platform and instruments, the Structural and Thermal Models (STM) hardware is being manufactured, with initial integration activities of the Platform core structure on-going. At equipment level, most of Engineering Model (EM) units are available and platform EM integration will start in Q3/2016.

MTG-I mission is a continuity of the MSG satellite series carrying as a main payload the SEVIRI radiometric imager. The FCI as a MTG main payload is an improvement of SEVIRI and it is designed to provide images of the Earth every 10 to 2.5 minutes in 16 spectral channels between 0.44 and 13.3 μm, with a ground resolution ranging from 0.5 km to 2 km. It is to be noted that SEVIRI IR channels' calibration is based on an on-board blackbody (absolute accuracy of 0.7K at end of life) [2] and a vicarious calibration is used for the solar channels (with no specification). In the contrary to the SEVIRI instrument, the FCI solar channels' calibration is based on an innovative end-to-end full entrance aperture on-board VIS/NIR calibration. It is performed by inserting a

Metallic Neutral Density (MND) at the telescope exit pupil. As a consequence the on-board calibration requirements are also more demanding than the SEVIRI ones, and especially in the VIS/NIR domain for which an absolute calibration is required to fulfill climatology needs. Overall, the instrument calibration will be performed by inserting in the useful beam path a black body for IR channels in addition to the deep space for offset correction and a diffuser target plate illuminated by the Sun through the front optic for VIS/NIR channels. Both are full pupil coverage.

Overall, the performance predictions for the satellites/instruments are very encouraging, and are confirmed in several critical areas by good early test results (particularly with respect to the detector chain and related cryogenic performances). A very high level of compliance, to the very stringent satellite system/mission requirements, can be confidently expected for both imaging (MTG-I) and sounding (MTG-S) missions promising state of the art performances when the first satellites are launched in the 2020 timeframe.

*B. The FCI: an absolute VNIR radiometer*

The FCI being an absolute radiometer, it must be able to perform in-flight radiometric calibration both for solar channels grouped in 5 VIS channels and 3 NIR channels (VNIR or VIS/NIR) and thermal channels grouped in three focal planes (IR1, IR2, IR3). The detailed design of the FCI and its calibration are discussed elsewhere [3]. Tab. 2 indicates the calibration improvement from SEVIRI to FCI instruments as specified by the end users.

**Tab. 1.** Absolute calibration & stability requirements comparative between SEVIRI (MSG) and FCI (MTG) instruments.

| RADIOMETRIC CALIBRATION Performance | MSG | | MTG (*) |
|---|---|---|---|
| Absolute Accuracy | None specified | Absolute Accuracy | VNIR 5% (~4.5% from source error) IR 0.7K |
| Mid-Term drift | VNIR 0.1% [≤ 24h] IR 0.05 to 0.1 K [≤ 4h] | Mid-Term Stability | VNIR 0.1% [≤ 24h] IR 0.1K [≤ 24h] |
| Bias & long term drift [<1year] | VNIR 2% IR 0.7 to 1 K | Long-Term Stability [≤ Lifetime] | VNIR 2% IR 0.3K |

(*) Spectral bandwidths narrowed vs MSG

The FCI radiometric accuracy is defined as the mean radiometric error associated with a spectra channel, within a temporal repeat cycle. It is specified below 5 % for the VNIR channels and below 0.7 K for the IR channels. When the FCI operates in the High Resolution Fast Imagery, the absolute accuracy is relaxed to 10 % and 1 K for VNIR and IR respectively.

Besides, the FCI must maintain its radiometric stability over a day below 0.1 % for the VNIR channels and below 0.1 K for the IR channels. The radiometric stability over the entire instrument lifetime amounts to 2 % for the VNIR channels and to 0.3 K for the IR ones.

For the IR channels an approach similar to the one implemented for SEVIRI is followed: the signal offset, including stray-light, instrument thermal background and detection dark signal is measured at each scan line during deep space imaging and subtracted to the Earth acquisitions. A well characterized radiance source is introduced to calibrate the gain fluctuation which is due to instrument ageing and thermal fluctuations. This source is a black body which is periodically inserted in the optical path between M2 and M3, near the intermediate focal plane. The black body is cross calibrated with a large black body on-ground and only its drifts contribute to the calibration budget. To cope with the fact that the entrance mirrors M0, M1 and M2 are not directly calibrated, the temperature of the black body can be adjusted.

The on-board calibration equipment benefits from field-stop and exit pupil proximity and both MND and black-body are carried on the same calibration wheel mounted on the optical bench. The switching between different positions will be done by rotation of the multifunction wheel. The rotation axis is parallel to the chief ray direction between M3 and M4 to ensure a parallel placement of the metallic neutral density filters into the optical beam.

The VIS/NIR calibration principle is based on 3 steps:

-       An on-ground radiometric characterisation phase using MOTA OGSE which illuminates the FCI with a source block located at the focal plane of a collimator placed in front of the instrument entrance. Due to the radiance limitation of the source, the MND will be removed during the on-ground calibration phase. Image acquisitions will be done in this configuration at different optical source radiances. The processing of these video data will provide for all VNIR spectral channels: the offset and gain calibration coefficients and the absolute calibration coefficient. Multiple order calibration coefficients can also been calculated. The optical source used during on ground tests will cover the specified dynamic of all solar channels and will be calibrated by its supplier, Bertin Technologies, for an accurate knowledge of its absolute radiance.

-       An in-flight offset acquisition phase, which consists in deep space acquisitions at the end of each swath, equivalent to dark conditions. These measurements will be processed to update the offset calibration coefficients.

-       An in-flight gain acquisition phase, which consists in the acquisition of images when the instrument is observing the sun through the MND. Equinox periods occur twice a year and last 1.5 months. In this temporal windows two calibrations will be performed. These measurements will be processed to update the gain calibration coefficients and the absolute accuracy coefficient.

The IR calibration principle is based on 3 steps:

-       An on-ground radiometric characterisation phase using an optical test configuration based on the illumination of the instrument with two large black-bodies placed in front of its entrance. One black-body will be set to variable temperatures and the other will be set at a fixed cold temperature for deep space simulation. Image acquisitions will be done in this configuration at different black body temperatures. At the same time, acquisition on the internal black body will be done at temperatures between 20 and 40°C. The processing of these video data will provide for all IR spectral channels: the offset and gain calibration coefficients, the correction coefficients for nominal and calibration optical path difference compensation and the absolute calibration coefficient. Multiple order calibration coefficients can also be calculated if deemed necessary. The on-ground black-bodies temperature range will cover the dynamic range of all IR channels (165 to 350 K) and will be calibrated for an accurate knowledge of their temperature and emissivity. They will serve as a reference source to calibrate the internal black-body in order to optimize the radiometric accuracy.

-       An in-flight routine calibration phase, which consists in acquiring every 10 minutes two images: one on the internal black body at a floating but well known temperature (between 15 and 22°C) and one when the instrument entrance is illuminated by deep space (dark conditions). These images will be processed to update the calibration coefficients acquired during the on ground test phase. As for VNIR, deep space acquisition is done at each swath end to update the offset calibration coefficient.

-       An in-flight absolute calibration phase, which consists in the acquisition of internal black-body images at a different temperature. During this phase, the instrument temperature must remain constant. These data will be processed to update the absolute accuracy coefficient.

*C. The MOTA OGSE: an initial on-ground spectroradiometric absolute reference*
The MOTA (Fig. 1) is an OGSE, designed and developed by Bertin Technologies which will be positioned in front of the FCI. The whole set-up can work either in air or in vacuum. The MOTA allows to simulate objects at infinite under FCI representative environment. The measurements performed from the MOTA emission allows to adjust the FCI and to characterize its optical and radiometric performances. Among the main mission of the MOTA (detailed description of MOTA missions are presented in [4]) one can list:

- Knife Edge Function/Line Spread Function/Modulation Transfer Function measurements ; these measurements will be used for the fine optical adjustment of the FCI but also for its MTF characterization,
- Registration and alignment tests,
- Straylight tests
- Absolute radiometric calibration (in the VNIR range) which is the purpose of this paper
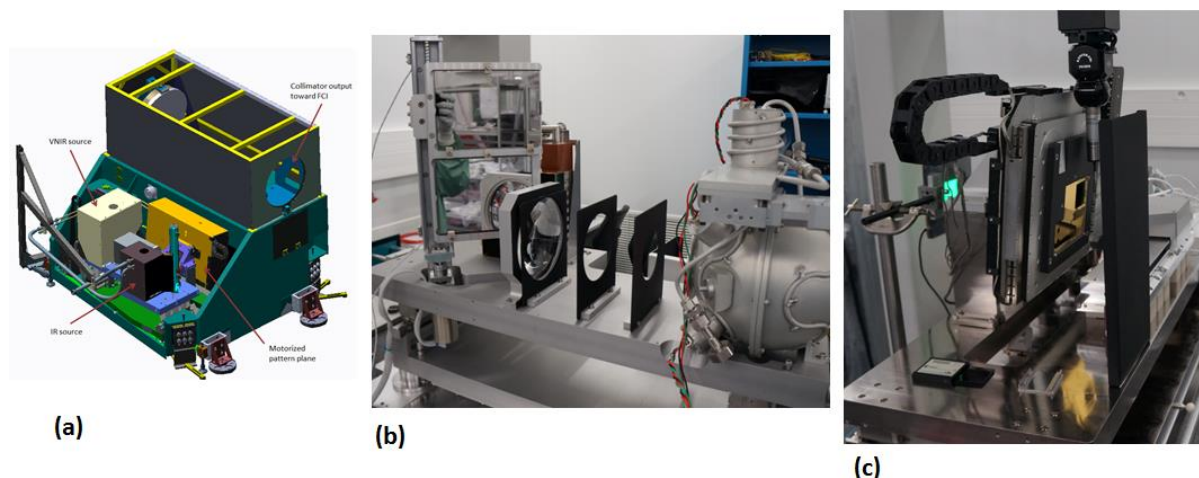
**Fig. 1.** The MOTA configuration. (a) General view: with the SA (Source Assembly) on the bottom and the HRC (High Resolution Collimator) on the top. The SA, itself, is made of a (b) Pattern Plate carriage which can move in X,Y and Z directions and of (c) VNIR (adjustable integrating sphere) and IR sources (cryogenic Black Bodies) to cover FCI 16 spectral channels. The pattern plate is imaged by highly stable HRC onto a collimated 300 mm diameter pupil and 9x9 mrad square angular field in order to match with the FCI.

As indicated above, one of the main missions of the MOTA is to provide an adjustable and calibrated radiance in order to be used as a reference for the FCI before its first calibrations in flight. Here are the MOTA requirements regarding absolute calibration:

- In order to respect the absolute radiometric accuracy of 5% at 3σ at satellite level [2], the MOTA allocation in the budget is only 3% at 3σ for each channel.
- The VNIR spectral range covers 8 channels from 440 to 2250 nm with high spectral resolution: 3,5 nm in visible, 10 nm between 1000 nm and 1800 nm (NIR 1) and 7 nm between 1800 nm and 2250 nm (NIR 2).
- The dynamic range is wide: 2 orders of magnitude.
- The radiance must be measured integrated at the center of field (which is narrow) and on the large 300 mm diameter pupil.
- The absolute calibration must be provided for satellite environment.
- For acceptable operability, the calibration shall be valid during several months under vacuum without requiring any recalibration at atmospheric pressure.

The complexity of the MOTA calibration is thus due to the combination of cutting edge performances and flexible operability.

III. CALIBRATION PROCEDURE
*A. Overview*
The global logic of the calibrations steps with description of the different environments and configurations is presented in Tab. 2.

**Tab. 2.** Complete absolute calibration flowchart from primary laboratory to the MOTA under its final operational environment.

| Step # | Current standard | Details on transfer operation to next standard |
|---|---|---|
| 1 | Primary source | At primary laboratory, high spectral resolution, reference radiance level |
| 2 | Portable secondary source | In clean room, atmospheric pressure, high spectral resolution, reference radiance level |
| 3 | Spectrometer | In clean room, atmospheric pressure, high spectral resolution, reference radiance level |
| 4 | MOTA | MOTA inside vacuum vessel in air, measurement through optical fiber, low spectral resolution, reference radiance level |
| 5 | Spectrometer | MOTA inside vacuum vessel under vacuum, measurement through optical fiber, low spectral resolution, variable radiance level |

| 6 | MOTA | - |
|---|------|---|

As indicated in Tab. 2, the main steps of the calibration are:

- Calibration transfer from Primary laboratory to portable secondary standard: because of the impossibility to regularly transport the complete MOTA in national metrology laboratory for direct calibration, it has been decided to use a portable secondary standard in order to transfer the calibration from the primary sources to the MOTA. Because the CMC (Calibration and Measurement Capabilities) of this initial calibration is significant in global budget (up to 2% at 3σ compared to the 3% specification), the choice of the laboratory is very important. After discussions with main European metrology laboratories (NPL, PTB & LNE), it has been decided to make the absolute calibration at NIST which presents the best performances and that is the only one which covers all spectral channels.
- Calibration transfer from secondary standard to the MOTA using a high resolution spectrometer. Because of hardware constraints, high spectral resolution was possible only at AP (Atmospheric Pressure). During these measurements, the radiance of the MOTA is tuned on an intense reference level to maximize SNR. At this stage the MOTA is absolutely calibrated with high spectral resolution but at AP at this fixed radiance level.
- Transfer of calibration from the MOTA to the spectrometer: this is made with a lower resolution.
- Regular monitoring of the MOTA with spectrometer: the spectrometer is able to perform monitoring of radiance variations of the MOTA for its different channels through vacuum vessel. The absolute calibration of MOTA is then followed whatever its radiance level is.

As it can be noticed, this procedure has been optimized in order to provide both high radiometric performances and high operability.

*B. Calibration transfer tools*
In order to be able to carry out with the best performances the complete calibration procedure described in Tab. 2, it was necessary to design or carefully select commercial tools. Here is the description of these key elements:

- Secondary standard: a baryum sulphite 65 mm diameter output port integrating sphere was selected. The main reason is its ease of use, its ability to provide high radiance levels when seeded with one 150 W internal QTH (Quartz Tungsten Halogen) lamp and its immunity to possible pollution when output port is covered (ensuring stability during transport or long term storage). The only possible issue was regarding possible water adsorption on inner coating surface which could impact the 1380 nm channel. However some measurements have demonstrated that water is quickly evaporated after few minutes of operations.
- Secondary standard power supply: In order to have repeatable and stable radiance levels at secondary standard sphere output, a specific power supply is required. Bertin has selected a 150 W high performance current supply both stabilized and absolutely calibrated with an accuracy down to +/- 0.06% (at 3σ). This ensures that radiance variations & drifts due to power supply is less than 0,37% at 3σ for all channels.
- Homemade radiometer: MOTA and secondary standard have very different *etendue* geometries. In order to ensure calibration transfer from the integrating sphere to the MOTA specific radiometer has been designed. It is composed of one 50 mm diameter, off-axis parabolic mirror in order to image MOTA field on a square bundle of fibers used as spectrometer input. This radiometer measures average radiance integrated over the complete field and the central part of the pupil. In order to extrapolate measurements to the total pupil and central field (as required), complete mapping of field and pupil has been carried out (with other secondary tools not described in the paper). The two measurement configurations at MOTA and secondary standard output are shown on fig. 2.
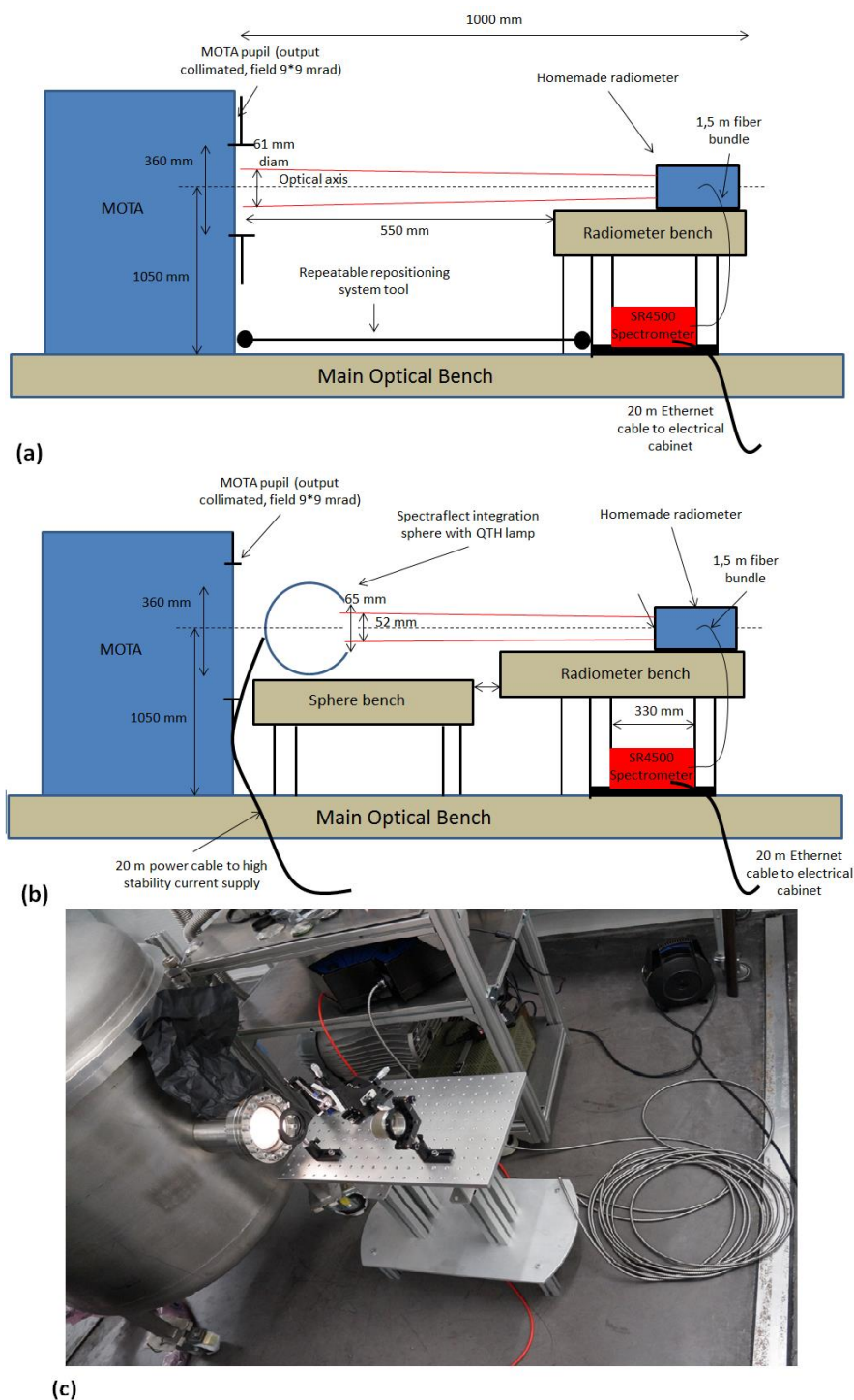
**Fig. 2.** Setup for calibration transfer from NIST calibrated secondary standard to the MOTA. (a) Measurement of the MOTA output radiance and (b) comparison to calibrated secondary standard output radiance. (c) Picture of the homemade radiometer during measurement of integrating sphere behaviour under vacuum.

- Spectrometer: The driven elements for the choice was the photon collection efficiency, and the spectral range and resolution (from 440 to 2300 nm at least to cover all spectral range with resolution of 2.5 nm in VIS, 10 nm in NIR 1 and 7 nm in NIR 2 regions). Another crucial parameter was the long term stability as it acts as the calibration reference during the last monitoring step when the MOTA is under vacuum vessel. Finally, the best compromise was to select the SR4500 spectrometer from SpectralEvolution which exibits efficient collection, high stability over the wide 400-2500 nm spectral range and low straylight. The reason is its design with no moving part based on 3 high performances VIS, NIR 1 and NIR 3 TE cooled linear CDD. This provide stability down to 0.3% over several months

can be achieved. Another is its high linearity without any gain calibration: the absolute calibration is determined over a wide dynamic without distorsion.

- Custom input fiber: As an input of the SR4500 spectrometer, two custom optical fibers were designed by Bertin. The reason was the need to optimize SNR and spectral resolution for each calibration step. As shown in Fig. 2, the firsts steps needs high spectral resolution at atmospheric pressure, a bundle of fiber of size adapted to the MOTA field of view was then selected. For the lasts steps, it was necessary to optimize SNR under vacuum conditions, but with less constraints on spectral resolution (only monitoring on channels variations is performed). A large silica fiber compatible with the use of vacuum feedthrough was selected.

*C. Hygrometry management*

When measuring under atmospheric pressure, specific attention has to be paid on the 1380 nm channel as it is impacted by gas water attenuation. This phenomenon is ruled by Beer-Lambert law:

$$T(\lambda) = \exp(-\alpha(\lambda).H.L) \tag{1}$$

In (1), T is the transmission through a propagation distance L (m) under an hygrometry level of H (%) at 20°C. $\alpha(\lambda)$ is the attenuation coefficient given in $m^{-1}.\%^{-1}$ which may depend on the wavelength λ. The issue with calibration procedure is that, depending on the configurations and moment of measurement both the hygrometry level and the propagation distance can change which results in attenuation varying up to several tens of %. This value is not in line with required calibration accuracy of 3% (which must be given under vacuum), correction is thus necessary.

The final selected strategy is to measure the attenuation spectrum $\alpha(\lambda)$ with both high accuracy and spectral resolution. This spectrum was obtained by measuring, at a known hygrometry level, the radiance from a source with the high resolution spectrometer at two different distances. For this last measurement, a specific care was required in the selection of hygrometer which needed to be absolutely calibrated down to 0.5% at 3σ, this was done directly at the Swiss primary laboratory. Using this attenuation spectrum, the exact propagation distances for each measurement configuration (at NIST and at TAS/Bertin: Fig. 2), the hygrometry level in room during measurements, and the attenuation law (1), it was then possible to eliminate the impact of water attenuation down to residual error of 1.7% at 3σ.

*D. Extreme channels specific optimization*

Despite the optimization of the hardware and of the process, the channel at higher wavelength (2250 nm at center) is suffering of bad SNR when used at the lowest radiance levels. This is both due to poor transmission of silica fibers, important noise of NIR 2 InGaAs linear detector of SR4500 spectrometer and very low specified radiance level. In order to enhance the SNR, the implemented solutions were to:

- Optimize the fibers lengths and material purity.
- Extrapolate 2250 nm variations from 1600 nm channel during the last steps of calibration procedure, when operating through vacuum feedthrough and long attenuating fiber. Indeed 1600 nm is the closest channel which is not subjected to fiber attenuation. This strategy however required to carefully make a prior measurement of the non linearities between the two channel when changing the radiance levels. Regular monitoring of the color temperature changes when the MOTA is under vacuum is also necessary.

The 3 channels situated in the 400-700 nm range are strongly impacted by the color temperature drift of the QTH lamp which causes large variations of the blue channels of the secondary standard integration sphere with time. This specific sensitivity in blue is due to the slope of the spectrum in this region (radiance of QTH lamp is approximately a black body at 3000 K). In order to avoid too often unacceptable recalibrations at NIST, the radiance drift is monitored using a comparison with measurements at 1000 nm which is a much more stable region (maximum radiance spectrum) and corrected. Regular calibrations of the sphere every 50 hours of use are however still necessary to preserve calibration performances (limitations of the drifts to 1% at 3σ).

IV. ACHIEVED RADIOMETRIC ACCURACY

*A. Theoretical budget*

The final theoretical performance has been calculated from the complete calibration procedure, it is presented in a simplified way on Tab. 2.

**Tab. 3.** Final expected absolute calibration performances (given in % at 3σ) for complete radiance dynamic. Final performance for restricted radiance dynamics (10% to 100% of maximum radiances) is given too.

| Channels (nm) | 444 | 510 | 640 | 865 | 914 | 1380 | 1610 | 2250 |
|---|---|---|---|---|---|---|---|---|
| CMC | 1,7 | 1,5 | 1,1 | 1,1 | 0,8 | 2,0 | 1,8 | 2,0 |
| SNR at 1% of the dynamic | 0,3 | 0,3 | 0,1 | 0,2 | 0,2 | 0,8 | 0,9 | 6,2 |
| Stability & accuracies | 1,3 | 1,1 | 1,1 | 1,1 | 1,1 | 1,0 | 0,9 | 0,9 |
| Hygrometry | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 1,7 | 0,0 | 0,0 |
| Others | 1,3 | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 |
| **Final performances 1% of dynamic** | **2,5** | **2,2** | **1,9** | **1,9** | **1,7** | **3,1** | **2,4** | **6,6** |
| **Final performances 10% of dynamic** | **2,5** | **2,2** | **1,9** | **1,8** | **1,7** | **3,0** | **2,3** | **2,5** |
| **Specification** | **3** | | | | | | | |

From Tab. 3 it can be noticed that the most relevant contributors to the final calibration accuracy are CMC, stabilities & accuracies of the different tools and hardwares, hygrometry (for 1380 nm channel only) and the SNR at the lowest radiances levels (mostly for NIR channels).

Compliance is expected for all channels except for 1380 and 2250 nm. The non-conformances are mainly due to hygrometry and spectrometer noise respectively. It is however important to underline that for the 1380 nm channel, performance is very close to the specification and that for 2250 nm channel, bad figure is expected for the lowest radiances only.

*B. Experimental qualification*

Beside this pure theoretical analysis, important experimental validation work at subsystem level has been carried out to assess the figures in Tab. 3. More precisely it has been checked that all most critical parts (except CMC which is based on NIST statement, regularly validated by BIPM) are within theoretical expectations, this includes:

- Noise measurements on all dynamic
- Parasitic straylight in homemade radiometer.
- Drifts, stability & stabilization time of secondary standard integrating sphere and of the MOTA
- Stability & stabilization time of secondary standard integrating sphere and of the MOTA
- Measurement of hygrometry lineic attenuation spectrum

This experimental work confirms that theoretical analysis is correct and that the expected final performances will be met.

V. CONCLUSION

In this paper it has been shown both theoretically and experimentally, that, by using a relevant calibration procedure, by choosing and designing calibrations tools perfectly suited to requirements and hardware, it is possible to achieve cutting edge absolute calibration performance of the MOTA OGSE. These figures, in line with the requirements for more than 98% of the dynamic range and channels, are obtained without sacrificing the operability of the system which was difficult to address (vacuum, geometry of the measurement, several months validity without recalibration, impossibility to move the OGSE to primary laboratories). These successful results paves the way for FCI final on-ground calibration performances and for the success of one of the major MTG-I satellite mission.

REFERENCES
[1] Donny M., *et al.* "Meteosat Third Generation, Space Segment Status and Performance," *EUMETSAT Meteorological Conference Toulouse 21-25 September 2015.*
[2] D.M.A. Aminou, A. Ottenbacher, B. Jacquet, and A. Kassighian, "Meteosat Second Generation: On-Ground Calibration, Characterisation and Sensitivity Analysis of SEVIRI Imaging Radiometer," *Proceedings of SPIE "Earth Observing Systems IV", Volume 3750, pp. 419-430 (September 1999).*
[3] Y. Durand, *et al.*, "The Flexible Combined Imager on board MTG: from design to calibration," *Proc. of the Sensors, Systems, and Next-Generation Satellites XIX conference*, vol. 9639, 963903 (2015).
[4] E. Compain, *et al.*, "VNIR, MWIR, and LWIR source assemblies for optical quality testing and spectro-radiometric calibration of earth observation satellites," *Proc. of Optical Design and Engineering VI*, vol. 9626, 962626 (2015).