The TROPOMI instrument: first H/W results

Robert Voors[a], Johan de Vries[a], Nick C. J. van der Valk[b], Ianjit Bhatti[c], David M. Woods[c], Ilse Aben[d], Ruud Hoogeveen[d], Pepijn Veefkind[e], Quintus Kleipool[e]

[a]Dutch Space B.V. (Netherlands); [b]TNO Science and Industry (Netherlands); [c]Surrey Satellite Technology Ltd. (United Kingdom);, [d]SRON Netherlands Institute for Space Research (Netherlands); [e]Koninklijk Nederlands Meteorologisch Instituut (Netherlands)

ABSTRACT

The Tropospheric Monitoring Instrument, TROPOMI, is a passive UV-VIS-NIR-SWIR spectrograph, which uses sun backscattered radiation to study the Earth's atmosphere and to monitor air quality, on both global and local scale. It follows in the line of SCIAMACHY (2002) and OMI (2004), both of which have been very successful. OMI is still operational. TROPOMI is scheduled for launch in 2015. Compared with its predecessors, TROPOMI will take a major step forward in spatial resolution and sensitivity. The nominal observations are at 7 x 7 km2 at nadir and the signal-to-noises are sufficient for trace gas retrieval even at very low albedos (2 to 5%). This allows observations of air quality at sub-city level. TROPOMI has reached CDR status and production of flight model units has started. Flight detectors have been produced and detector electronics is expected to be finished by mid-2013. The instrument control unit is undergoing extensive tests, to ensure full instrument functionality. Early results are promising and this paper discusses these H/W results, as well as some challenges encountered during the development of the instrument.

Keywords: TROPOMI, air quality, remote sensing, spectrometer, UV-VIS-NIR-SWIR

1. INTRODUCTION

The European Space Agency (ESA) Sentinel-5 Precursor (S-5P) is a low Earth orbit polar mission to provide services on air quality, climate and the ozone layer in the timeframe 2015-2022. The payload is the TROPOspheric Monitoring Instrument (TROPOMI) that will measure key constituents including O3, NO2, SO2, CH4, CH2O, and aerosol properties. TROPOMI will extend the data records of the atmospheric chemistry missions of SCIAMACHY (Envisat) and OMI (Aura) as well as be a preparatory mission for the Sentinel-5 mission planned for 2020 onwards. TROPOMI is a passive UV-VIS-NIR-SWIR spectrograph, which uses sun backscattered radiation to study the Earth's atmosphere and to monitor air quality, on both global and local scale. TROPOMI is currently in its assembly phase and is scheduled for launch in 2015. It follows in the line of SCIAMACHY (2002) and OMI (2004), both of which have been very successful. Compared with its predecessors, TROPOMI will take a major step forward in spatial resolution and sensitivity. The nominal observations are at 7 x 7 km2 at nadir and the signal-to-noises are sufficient for trace gas retrieval even at very low albedos (2 to 5%). This allows observations of air quality at sub-city level.

These instruments measure the combination of Earth and sun spectra. From their ratio – the reflectance spectra – absorptions taking place in the Earth atmosphere are derived. Concentrations of trace gases can be determined because these gases have very specific wavelength-dependent absorption features. Other products, like aerosols, clouds and surface properties, have broader absorption structures and can be derived after accurate radiometric calibration.

Like OMI[1], TROPOMI is a multichannel push-broom spectrometer in a sun-synchronous orbit, which results in daily coverage of nearly the entire globe. However, TROPOMI includes a NIR and a SWIR channel and will also be more sensitive than its predecessors, that is, the signal-to-noise ratio per ground pixel will be higher, and another notable change is a large improvement in ground resolution. OMI was already a big improvement in that sense to SCIAMACHY[2] and GOME[3] and TROPOMI takes this a major step further.

Sensors, Systems, and Next-Generation Satellites XVII, edited by Roland Meynart, Steven P. Neeck, Haruhisa Shimoda, Proc. of SPIE Vol. 8889, 88890Q · © 2013 SPIE · CCC code: 0277-786X/13/$18 · doi: 10.1117/12.2028848

2. THE INSTRUMENT DESIGN

The TROPOMI instrument consists of five hardware modules: (1) the UV-VIS-NIR (UVN) Module, (2) Short Wave Infra-Red (SWIR) Module, (3) the Instrument Control Unit (ICU), (4) the Telescope Support Structure (TSS), and (5) the Radiant Cooler (RC). The UVN Module consists of a telescope shared with the SWIR Module, the three UVN Spectrometers including three Detector Modules (DEMs), and a Calibration Unit (CU). The SWIR Module consists of the SWIR Spectrometer, the SWIR Detector Module (SWIR-DEM), and the SWIR Front End Electronics (SWIR-FEE). The UVN and SWIR Spectrometers house the optics, mechanisms and structural parts that comprise the optical system. The SWIR module interfaces with relay optics at the UVN Module to receive light from the telescope and the CU. The SWIR side of this Relay Optics interface is part of the SWIR spectrometer development.

The UVN and SWIR Modules will be mounted on the Telescope Support Structure (TSS) that ensures stable alignment of the two and allows integral testing. The UVN and SWIR detectors, electronics and optical benches will be cooled to operational temperatures by the Radiant Cooler. The heat load of the instrument is transported via the Thermal Bus Unit (TBU), which is part of the TSS, to the Radiant Cooler. The instrument is operated through the Instrument Control Unit, which is located inside the spacecraft. The ICU is connected to the UVN and SWIR Modules mainly through the Connector Bracket, located on the TSS.

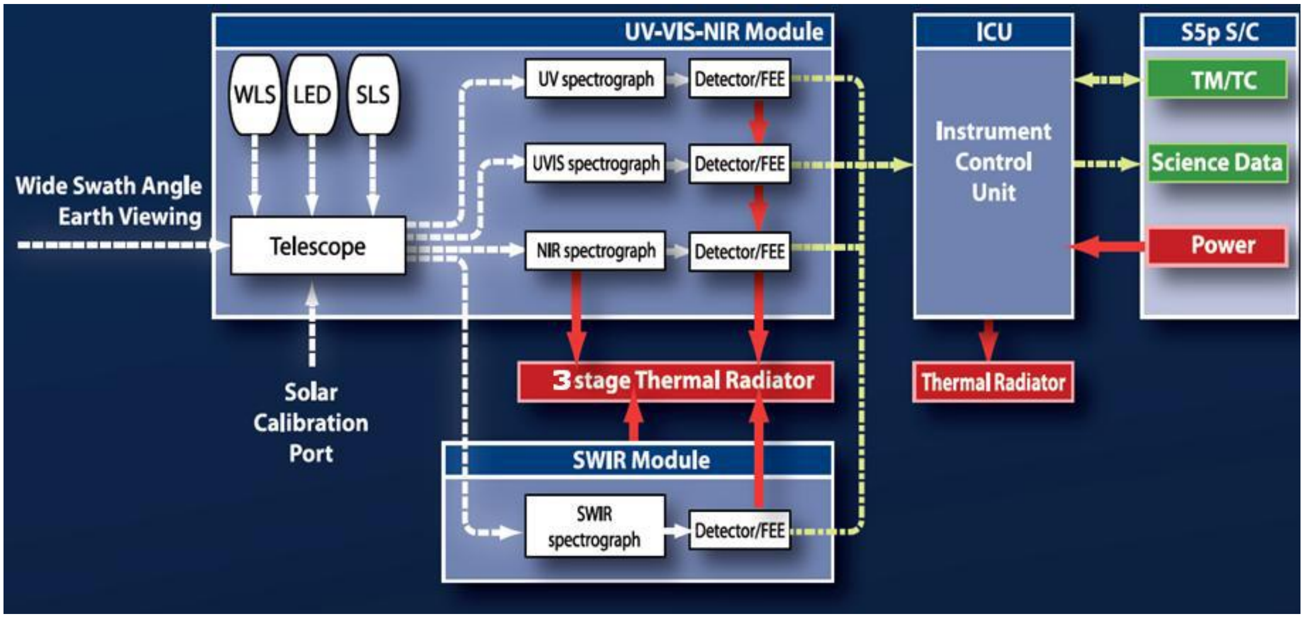

Figure 2.1 Conceptual layout of the TROPOMI instrument.

2.1 The UVN Module

The UVN module consists of the telescope – which is shared by the UVN and the SWIR – and the 3 UVN spectrometer channels (UV, UVIS and NIR) each equipped with individual detector units. The telescope has a very wide field-of-view of 108 degrees. A polarisation scrambler is placed in the optical path to make the measurements insensitive to the polarisation state of the incoming light. The light from the telescope is separated in the flight direction by a reflective slit. That is, the VIS/NIR channels have a transmissive slit and the UV and SWIR a reflective slit just next to the transmissive slit. This means that the UV and SWIR channels will see a slightly shifted part of the Earth than the UVIS and NIR channels. The UVIS and NIR bands make use of the same spectrograph slit whereas the UV and SWIR have separate slits. This allows having a wider slit for the UV to compensate for the lower radiance for these wavelengths and for the SWIR it means that the slit can be included in the cooled SWIR module. The different slits result in slightly different viewing angles in the flight direction.

2.2 The SWIR Module

The SWIR Module is composed of the Spectrometer, the Detector Module (DEM) and the Front End Electronics (FEE). The main function of the Spectrometer is to receive the light transferred to the SWIR module by the UVN relay optics and to image this light onto the detector. The Detector Module houses the detector, which is controlled by the Front End Electronics.

2.3 The Instrument Control Unit

The Instrument Control Unit (ICU), located inside the spacecraft, controls the TROPOMI instrument. The ICU is the electrical interface between the spacecraft and the TROPOMI instrument. The main functions of the ICU are:

- Receive and condition spacecraft power and provide it to the UVN and SWIR modules
- Handle telecommands and generate telemetry
- Handle science measurements and package science data
- Temperature control by using local heaters and Peltier coolers
- Control of calibration sources and mechanisms

Physically the ICU consists of a single box, mounted on the inside of the spacecraft. The ICU itself consists of two Processor Modules, two Power and Heater Driver Modules, and four Instrument Specific Modules (one for each detector). These modules are mounted on a motherboard, which provides the electrical connections between these boards.

2.4 The Telescope Support Structure

The TSS and ancillary items consist of the TSS baseplate and kinematic mounts, the Connector Bracket, and the Thermal Bus Unit (TBU) with a ‘warm’, an ‘intermediate’ and a ‘cold’ stage. An MLI Thermal Tent and support structure will also be mounted on the TSS.

The TSS baseplate design is based on an Aluminium sandwich panel which is mounted isostatically to the spacecraft top floor using three Kinematic Mounts. The flat Base Plate offers good structural support to all optical instruments and it provides easy access to all thermal and electrical interfaces.

The Connector Bracket is used to electrically connect the items on the TSS to the ICU, which allows for convenient integration of TROPOMI on the spacecraft.

2.5 The Radiant Cooler

The Radiant Cooler will be used to cool both the UVN and SWIR modules of the TROPOMI Instrument. The Radiant Cooler is the sole means for cooling TROPOMI and therefore shall serve to cool and maintain the different temperature levels which apply for the UVN and SWIR Optical Benches and detectors, including Front End Electronics. The Radiant Cooler consists of a 3-stage Radiator Unit; a ‘warm’ (room temperature), ‘intermediate’ (~180K) and a ‘cold’ stage (~125K), each with a separate set of heat pipes making the thermal connections to a Thermal Bus Unit (TBU) mounted on the TSS. The TBU serves to distribute the cooling to the UVN and SWIR module.

The ‘warm’ stage of the RC provides cooling for the UVN-DEMs, the SWIR-FEE, and the UVN-OBM. The ‘intermediate’ stage of the RC provides cooling for the UVN detectors and the SWIR-OBM, both to around 200K. The ‘cold’ stage of the RC is connected to the SWIR detector via a TBU cold stage assembly which is supported from the ‘intermediate’ stage of the Radiant Cooler. The Radiant Cooler is dynamically isolated from the TBU and TSS through the inherent flexibility of the heat pipes connecting the warm and intermediate stages of the TBU to the RC.

3. RECENT INSTRUMENT DEVELOPMENTS

3.1 The UVN Module

OBM

All mechanical parts have been procured and nearly all optical components are available for integration as well. The assembly of the UVN optical bench has started at TNO in the Netherlands (see Figure 3.1). The design of the optical bench has been optimized for compactness (in view of optimal weight and thermal stability). This complicates the integration of the optical elements but no major issues have been encountered so far.

Figure 3.1 Main mechanical housing of the UVN optical bench.

UVN Detectors

The UVN detectors for the three channels are back-illuminated frame transfer CCDs and are basically identical in design. The detectors have been produced by e2v in the UK. The image area has 1024x1024 26 µm square pixels, the line transfer time is 0.75 µs and the readout frequency is 5MHz. The UVIS and NIR detectors have a graded AR coating. During the development, production and testing of the detectors a number of issues have been identified, which have all been solved. The electrical isolation of the storage section from the silicon was not always adequate and this has led to a change in the design of the electrical insulating layer. This design change has shown to have the desired result. At a later stage, during testing, some issues concerning the charge transfer efficiency and the register full well capacity were observed. These were caused by too short rise and fall times of the register clocks. This issue was solved by minor modifications to the readout electronics.

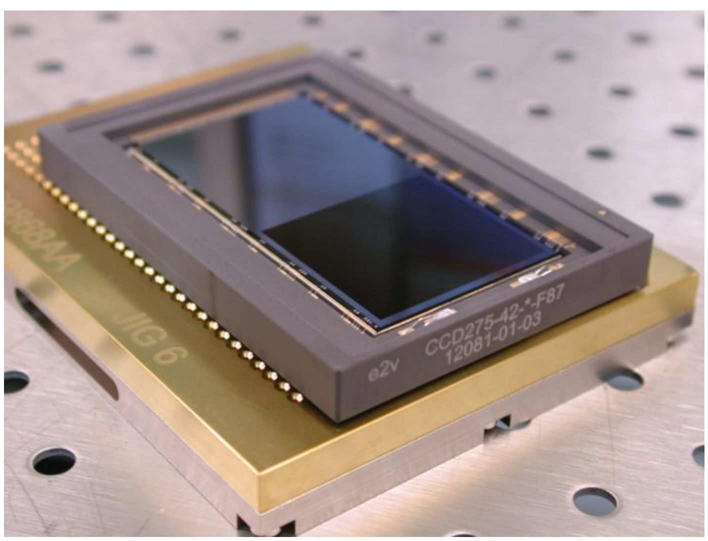

Figure 3.2 CCD detector intended for the UVIS channel.

All flight detectors have been produced and acceptance testing by e2v shows that the performance of these detectors is largely within specification, where certain performance parameters (e.g. dark current and readout noise) are significantly better than specified. All detectors, including 2 flight spares, have been delivered to RUAG Switzerland for integration into the Detector Electronics Modules.

UVN-DEM

The detector modules that house the UVN detectors are all nearly identical in design. The assembly of the flight units of the Detector Modules has started and at the same time the qualification program is nearing its completion. A key result is that the readout noise of the integrated DEM is significantly below the specified limit. Full EMC and ESD testing was performed successfully on the engineering model and EMC test will be repeated on the flight model. Thermal testing is underway.

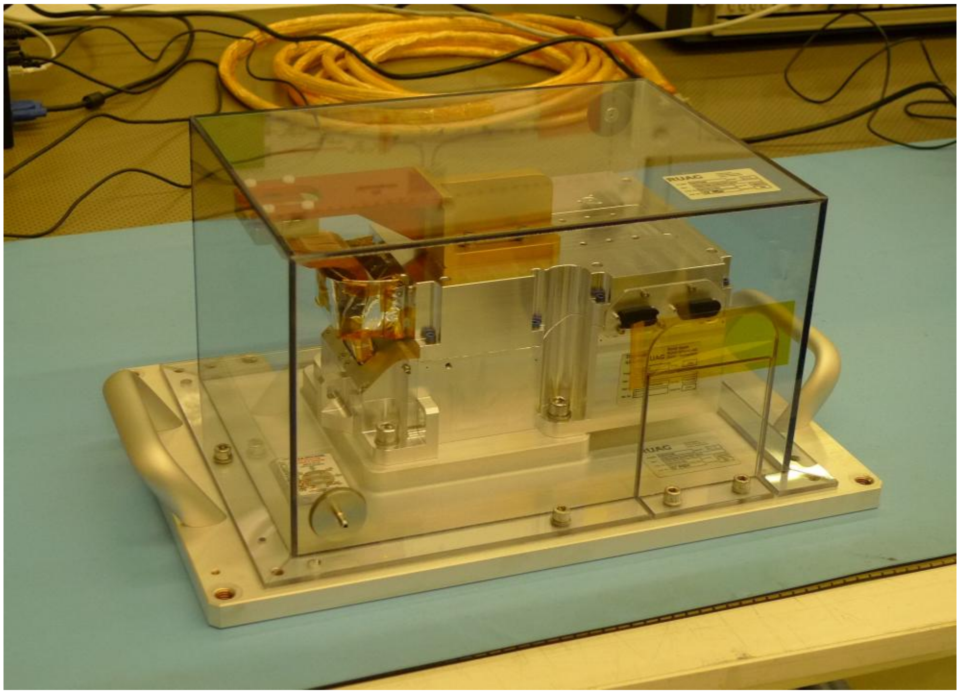

Figure 3.3 Engineering model of the UVN-DEM.

3.2 The SWIR Module

OBM

After extensive breadboarding of critical items and a number of qualification steps, the assembly of the optical bench of the flight unit has started at SSTL, who are responsible for the development of the SWIR unit. Expected completion of the unit is expected in the 3rd quarter of 2013. After this, the SWIR unit will be tested at MSSL. A key factor in the testing of the SWIR unit is that in-flight it will be operated at low temperatures, thus requiring a thermal vacuum environment. The optical bench will be operated around 200K and the detector at 140K.

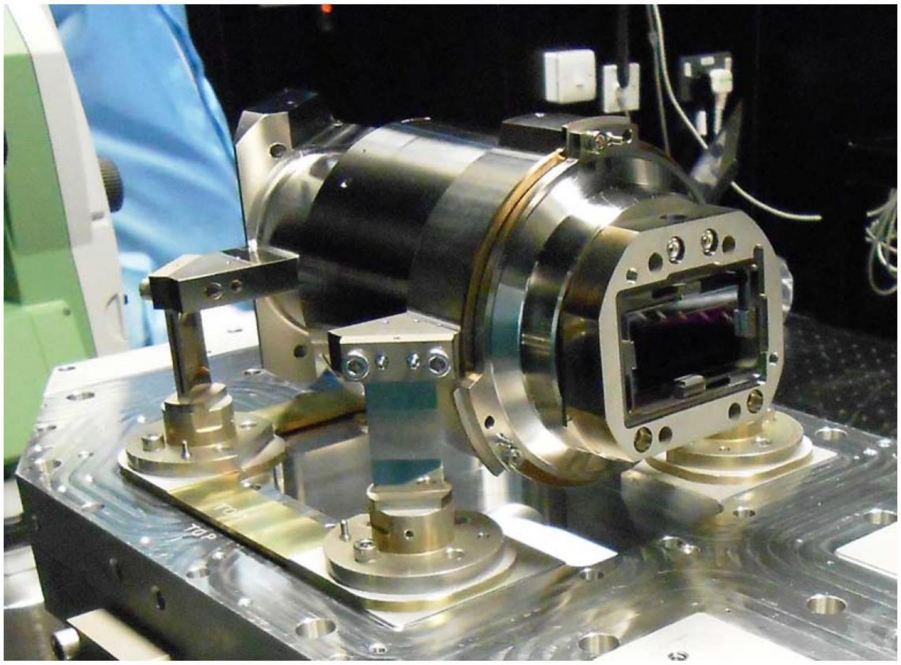

Figure 3.4 Housing of the camera lens of the SWIR optical bench during alignment.

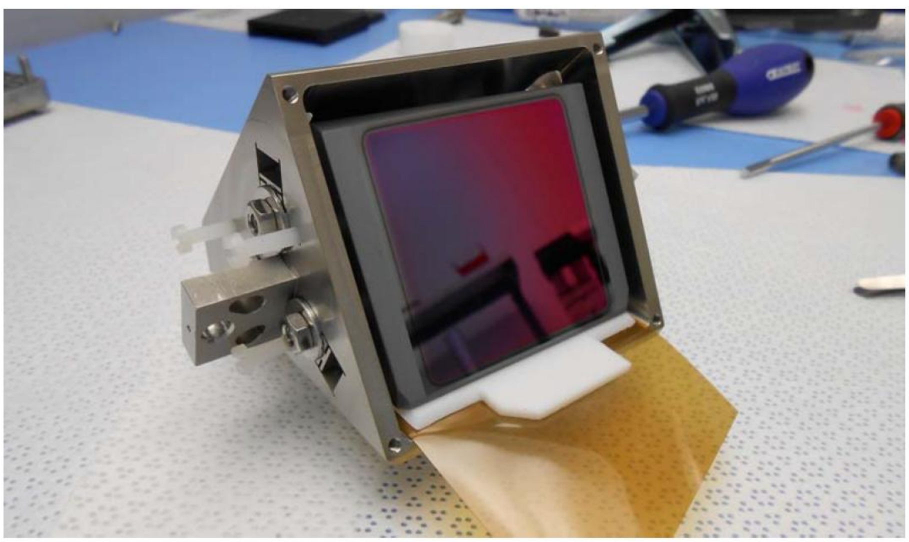

Figure 3.5 SWIR immersed integration in its housing during integration.

Detector and FEE

The flight device was delivered beginning of 2013 by Sofradir to SSTL, to be integrated into its housing. Subsequently the unit has been tested extensively with the flight detector and Front End Electronics at SRON in the Netherlands. After these tests the FEE and detector were returned to SSTL, where they are now in the process of being integrated in the focal plane array. This will subsequently be integrated onto the SWIR optical bench.

A dedicated paper on the test results of the performance of the SWIR FEE plus detector is presented by Hoogeveen et al, during this conference[4].

3.3 The Instrument Control Unit

The engineering model of the ICU has been delivered to DS by RUAG Sweden and has been integrated in the Electrical Functional Model. On the EFM the ICU is controlled by the EGSE and it has been connected with several other engineering models for functional testing. These tests have shown that some modifications to the flight H/W were required and these changes are currently being implemented.

3.4 The Telescope Support Structure

Integration of the TSS flight model is well under way. Construction of the main structural component – the baseplate – has been completed. Manufacturing of the harness, the flex links and also the EGSE are ongoing at Astrium in Germany. After completion the TSS will be delivered to Dutch Space for integration with the optical bench.

3.5 The Radiant Cooler

The radiant cooler is built by Astrium, Friedrichshafen. The detailed design of the cooler has been finalized. An important milestone will be the fitcheck of the cooler with the instrument. This is planned for the start of 2014. The delivery of the cooler for final integration with the instrument is expected in the first half of 2014.

4. INSTRUMENT CHARACTERIZATION AND CALIBRATION

4.1 EFM characterization at DS

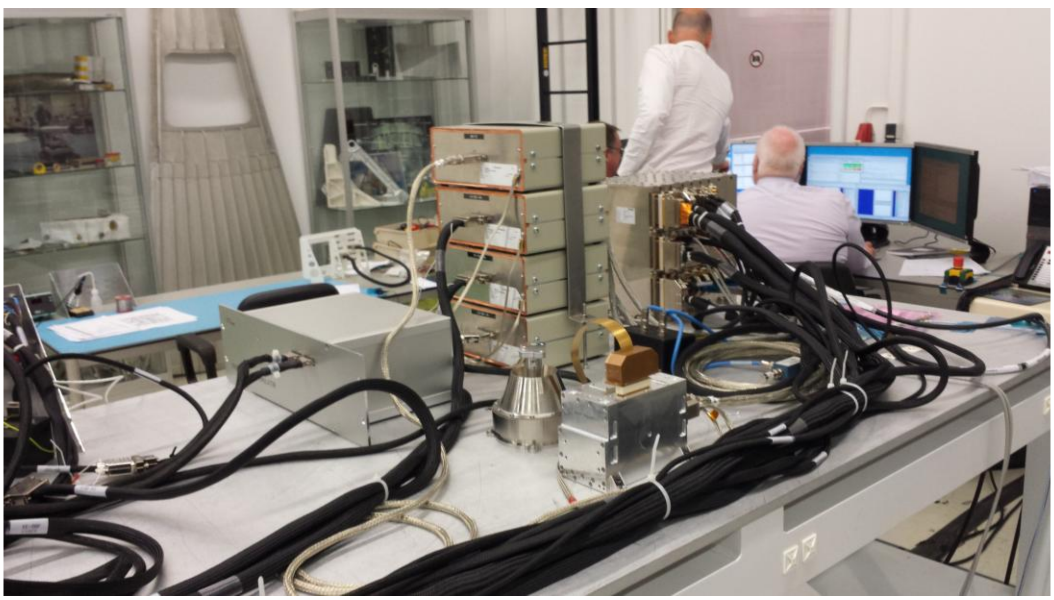

Figure 4.1 An early setup of the EFM test bench at Dutch Space.

The engineering model at Instrument level is the Electrical Functional Model (EFM), which contains no optics. It consists of the qualification model of the ICU and when available, extended with engineering and/or qualification models of the UVN-DEM and SWIR-DEM. Before availability of the UVN-DEM E(Q)Ms, the EFM will be equipped with the so-called "Demulator", which is a functionally representative breadboard model of the DEM, equipped with a front-faced BB detector. The EFM provides the opportunity of early interface testing and "instrument like" electrical behaviour. The EFM is also used for final validation of test facilities and GSE and the related procedures. Its main objective is to increase the confidence in the electrical design, and to reduce the risk of unexpected functional problems during the (P)FM programme.

4.2 Instrument assembly and calibration

As prime contractor of TROPOMI, Dutch Space leads the final assembly and integration of the instrument out of the different subassemblies. The UVN-OBM, SWIR, connector bracket and TBU will be mounted on the TSS, together with thermal hardware, purging equipment, cables and cable harnesses. The SWIR will be aligned with regards to the UVN-OBM, based on sub-assembly alignment and alignment cubes. In parallel, the ICU will be integrated with the EGSE and together these will be integrated to the instrument. The final integrated instrument will then undergo a series of electrical, functional and performance tests. After a mass properties measurement at Dutch Space and a fit check of the Radiant Cooler with door release and functional test, the instrument will move to CSL. Here environmental, performance and verification tests and calibration will be performed, after which the instrument is ready for delivery and integration on the spacecraft.

5. CONCLUSION

One of the most exciting stages of the project is well underway: the integration and testing of the flight H/W. After years of planning, lots of paperwork, and of course testing at component level the final instrument is coming together. Despite the constraints of the program, the TROPOMI instrument promises to live up to its expectations in that it will exceed the performance of its predecessors in all its aspects. For the next SPIE remote sensing conference we expect to present the results of the flight instrument tests in detail.

REFERENCES

[1] Levelt, P. F., van den Oord, G. H. J., Dobber, M. R., Malkki, A., Visser, H., de Vries, J., Stammes, P., et al. (2006). The ozone monitoring instrument. IEEE Trans. on Geosc. and Rem. Sens., 44(5), 1093-1101.

[2] Bovensmann, H., Burrows, J. P, Buchwitz, M., Frerick, J., Noël, S., Rozanov, V. V., Chance, K. V., et al. (1999). SCIAMACHY: Mission Objectives and Measurement Modes. Journal of the Atmospheric Sciences, 56(2), 127-150.

[3] Burrows, J.P., Richter, A., Dehn, A., Deters, B., Himmelmann, S., Voigt, S. and Orphal, J., J. Quant. Spectrosc. Radiat. Transfer Vol. 61, No. 4, pp. 509-517, 1999

[4] Hoogeveen, R. Voors, R., Robbins, M., Tol, P., Ivanov, T., "Characterization results of the TROPOMI SWIR detector", 2013, Proc SPIE, paper 8889-38.

This document has been produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union and/or ESA. The Sentinel 5 Precursor mission, a collaborative effort of ESA and the Netherlands Space Office (NSO), is part of the GMES Space Component Programme. ESA and the Netherland Space Office share the procurement of the TROPOMI payload and its processing software, whilst ESA is responsible for the procurement of the platform and the development of the ground segment. The consortium composing the mission comprises Astrium Ltd (Stevenage - UK), as Mission Prime, and an integrated team of Dutch Space (Leiden - NL) and TNO (Delft - NL) is responsible for the Payload. Major subcontractors are SSTL (Sevenoaks – UK) for the development of the SWIR Channel, and RUAG (Switzerland and Sweden) for the Payload electronics. The Royal Netherlands Meteorological Institute (KNMI) and the Netherlands Institute for Space Research (SRON) are the Principal Investigator institutes on behalf of the Netherlands' national programme.