EPSC Abstracts
Vol. 10, EPSC2015-850, 2015
European Planetary Science Congress 2015

Solar Irradiance Sensor on the ExoMars 2016 Lander

I. Arruego, V. Apéstigue, J. Martínez, J.J. Jiménez, J. Rivas, M. González, J. Álvarez, J. Azcue, I. Martín, R. Canchal.

Instituto Nacional de Técnica Aeroespacial (INTA), Spain (arruegori@inta.es).

Abstract

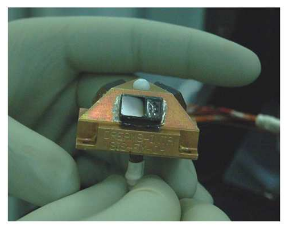
DREAMS-SIS is a radiometer designed to provide in-situ measurements of the Sun irradiance on Mars surface, as well as to estimate the opacity of the Mars atmosphere, due to the suspended dust. It will be included in the DREAMS package (Dust characterization, Risk assessment and Environment Analyzer on the Martian Surface), payload of the EDM (Entry and Descend Module) for the EXOMARS 2016 ESA mission [1]. We report on the development and characteristics of this miniature sensor.

1. Introduction

DREAMS-SIS is a kind of evolution/simplification of a previous development (MetSIS), built for a different mission called Mars MetNet Lander [1]. The incorporation of this sensor to DREAMS was decided in an advanced stage of development of DREAMS and EDM. When it was done, the mass of MetSIS was not acceptable, given that the mast on top of which the sensor is lo be located, was not prepared to accommodate more than 25 g, with an extremely reduced volume envelope.

Due to that, a new SIS called DREAMS-SIS was developed. The unit was separated into 2 parts: Optical Head (OH) Processing electronics (PE), and the mechanical interfaces were defined so as to be adapted to the existing Mast. The OH contains the detectors and front-end conditioning electronics. The PE includes digital conversion, data handling/storage and communications capabilities with the DREAMS Central Electronics Unit (CEU). The OH will operate outside any warm box, with an operational temperature requirement going down to -120ºC.

The complete re-design, manufacturing, calibration and qualification, was done in only 10 months, due to system-level schedule requirements. 5 models have been manufactured (Engineering or EM, Qualification or QM, Flight or FM, Spare or SP and “Field-Test” for field campaigns, or FC).



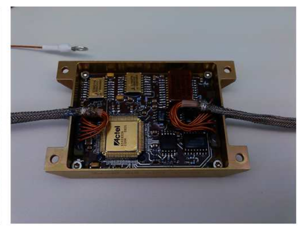


Figure 1. Left: Optical Head (OH). Right: Processing Electronics (PE)

2. Instrument design

The high level of integration of the sensor, and very specially the OH, was possible thanks to the use of commercial parts (COTS: Commercial Of The Shelf) previously selected, qualified (radiation and temperature) and screened thanks to the MetNet developments and an internal initiative for the development of miniature instruments developed during the past years, as described in [3].

2.1 Materials, Components and COTS selection.

DREAMS-SIS benefits from the previous work done mainly for MetNet, where an intensive radiation and extreme temperature qualification campaign was developed for different materials and parts.

As stated, especially for the OH some COTS had to be used, as no adequate space-grade parts are available for some of the functionalities, with the required mass and volume constraints. This applies to optoelectronic and optical parts, as well as the amplifiers used for the front-end electronics. All of them have been tested under Gamma radiation for TID, and protons for DD/SEE, depending on the kind of component.

Finally, those COTS have undergone adequate screening and qualification processes according to the next diagram (and following [4] to [7]):

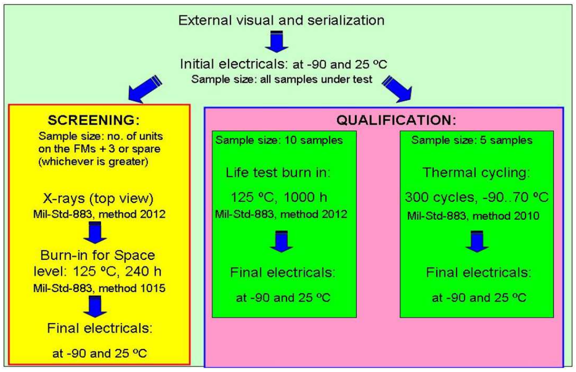


Figure 2. Flow diagram of the screening and reliability qualification processes adopted for Plastic COTS

2.2 Optical Head (OH) design

The adopted solution consists in a truncated tetrahedron with face inclination angles of 60º (to reduce the dust deposition on the sensors active area). On each "lateral" face there are 2 detectors with different optical filters (assembly 1 in Fig. 3). A seventh detector was added on top that includes no optical filter.

The 2 detectors of each "lateral" side (1.f) provide signal for the next bands: UVA (315-400nm) and NIR (700-1100nm). To discriminate these bands interference filters are used (1.d, 1.e). To avoid the widening of the spectral response of these filters at incidence angles superior than 30º, an opto-mechanical FoV-shaping element (sometimes referred to as "collimator") was added to correct the FoV of the photodiodes, on each lateral side (1.c).

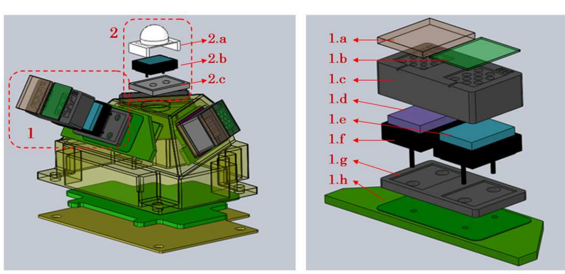


Figure 3. SIS OH Assembly. Opto-mechanical Set Assembly

The set is finished on top by two filters, an UG11 on the UV channel (1.a), and a transparent Teflon on the IR one (1.b), that were used to enhance the optical response of the detectors and to avoid the dust deposition inside the collimators.

On the other hand, the opto-mechanical set is finished on the bottom side (the one facing towards the inside of the OH box) with a "radiation shield" (an aluminum plate) to complete a 1 mm shielding protection of the box in any direction (element 1.g in Fig. 3). The whole assembly is attached to a PCB (1.h) that, on the bottom side, contains the signal amplifier electronics. To avoid electrostatic charging, the radiation shield and the collimators are later glued with a conductive glue (ECCOBOND 56C) to the OH structure.

The detector on top is a "total luminosity" Si detector (2.b) that incorporates no filter (i.e., its detection band is 200 – 1100 nm approximately) and is covered by a semi-spherical diffusing element (2.a) that helps minimizing the impact of the Sun position on the overall response and provides protection against dust deposition. On the bottom of the photodiode, another "radiation shield" was installed (2.c), again wired to the structure to avoid electrostatic charging.

The resultant geometry of SIS for DREAMS ensures that there will be measurements of both global and diffuse light contributions, with independence of the landing position. At almost any moment, one of the faces will be receiving direct plus diffuse light, whereas the others will only receive diffuse one.

SIS OH incorporates inside 4 different printed circuit boards (PCB). There is a main board located in the base of the OH that contains a multiplexer, power filter and buffering amplifier, to send the already-amplified photocurrent values to the PE. There is also a temperature sensor (platinum resistor) and a dark-current reference photodetector to measure the radiation accumulated (through Displacement Damage effect on the increase of dark current) during the flight to Mars. This main PCB also receives and conditions the photocurrent from the top detector (i.e. the total luminosity one). The multiplexer receives signals from the other 3 PCBs located on the lateral sides of OH. Connection between PCBs is done by means of wires.

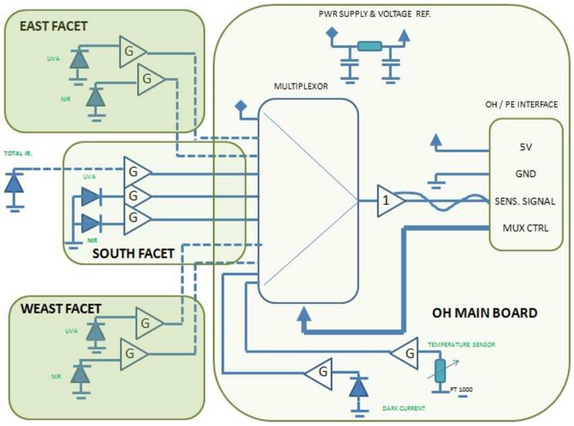


Figure 4. SIS OH Electronics diagram

Each one of these lateral PCBs contains the 2 aforementioned photodiodes and their corresponding transimpedance amplifiers that deliver voltage signals.

The interface with PE includes, as inputs, the 5V power supply and ground, received by means of a twisted pair, and 4 multiplexer selection lines received as single-ended signals (filtered at OH input). As out-puts, the OH delivers in a twisted pair the output signal from the multiplexer and its local ground, to allow for pseudo-differential reception on PE side.

2.3 Processing Electronics (PE) design

In this case the mechanical design is much simpler than OH's one. It has been designed in aluminum of 1mm thickness and it has no lid in order to be as light as possible. The CEU structure itself is used as lid.

The unit contains a unique PCB where the core is an ACTEL antifuse RTSX FPGA that controls the op-eration of the instrument: sequential acquisition of channels, averaging of multiple samples, calculation of standard deviation values, temporal storage on memory and communication with CEU.

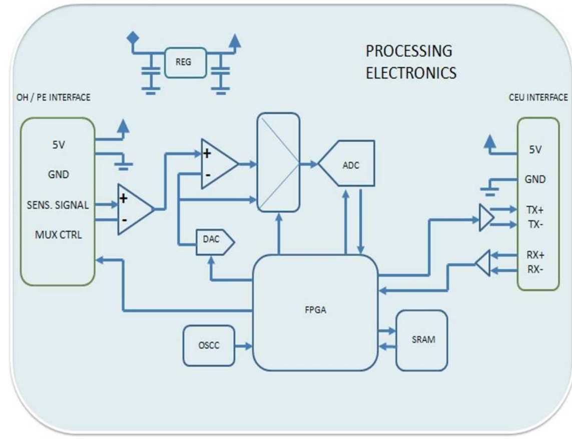


Figure 5. Fig. 1 SIS OH Electronics Schematics

PE receives the pre-amplified signals from OH with a differential amplifier. It receives only one signal from OH, which is the output of the OH multiplexer, whose active channel is selected by the PE FPGA, which controls the selection lines. Another multiplexer exists in the PE, to incorporate new housekeeping signals (PE temperature, power voltage and some voltage references).

The output of this PE multiplexer enters a subtraction and post-amplification scheme, prior to final digitalization, which allows a sub-ranging Analog-to-Digital (A/D) conversion. This means that, through a Digital-to-Analog (D/A) converter, the FPGA generates a voltage close to the value of the signal entering the post-amplifier, which is subtracted from the signal. After that subtraction, a new amplification takes place, and the A/D conversion is applied to the resulting signal. With this scheme we increase the dynamic range, while maintaining the linear response, in opposition to other classical logarithmic amplification solutions. The DAC being used to generate the subtracting signal has a resolution of 12-bit, although only the 6 MSBs are really used. The ADC is 16 bit.

A 128 bit Rad Tolerant SRAM memory is added to the system. It allows to perform some intermediate calculations (for example, to perform pseudo-noise estimation by computing a pseudo-sigma of a number of samples that are averaged). It also allows the sensor to operate in an autonomous mode, with no intervention of the CEU.

The basic operation mode is a “manual” one, in which CEU interrogates the sensor each and every time a new measurement is desired (which includes samples from all the channels). The aforementioned “automatic” mode, however, is an autonomous mode. At the beginning of an automatic session, the CEU just tells the instrument to go to this mode with a particular sampling period (configurable from seconds to minutes). When desired, the CEU commands the stop of the acquisition, and the internal memory can be dumped with a dedicated command.

3. Calibration

The method for the optical calibration of the SIS OH is based on the spectro-radiometric transfer from a standard lamp and a standard detector in well-controlled laboratory conditions.

The current generated by the photo-detector depends on its responsivity and on the incident optical power. Both parameters are a function of the wavelength and the relation is an integral. The responsivity depends on the temperature and also on the light incident angle, so the integral relation can be written:

$$I(T,\theta) = \int_0^\infty r(\lambda, T, \theta) E(\lambda) d\lambda \tag{1}$$

Where I(T,θ) is the current generated in the photo-detector and depends on the temperature and the light incident angle, r(λ,T,θ) is the spectral responsivity of the photodiode plus filters assembly. It depends on the wavelength, the temperature and the light incident angle. And E(λ) is the spectral incident light power.

In a first approximation, we can assume that the wavelength (λ), the temperature (T) and the light incident angle (θ) are independent variables. Then, we can write:

$$I(T,\theta) = r_T(T) r_\theta(\theta) \int_0^\infty r_\lambda(\lambda) E(\lambda) d\lambda \tag{2}$$

Where rθ(θ) is the Angular Response Function (ARF), rT(T) is Temperature Response Function (TRF) and rλ(λ) is the spectral responsivity under a perpendicular incident light at room temperature. We can write rλ as:

$$r_\lambda(\lambda) = R(\lambda_0) \cdot r'(\lambda) \tag{3}$$

Being r´(λ) the normalized responsivity with regard to a reference λ0, and R(λ0) a constant that represents the responsivity at λ0. Then, we can write:

$$I(T,\theta) = R(\lambda_0) \cdot TRF(T) \cdot ARF(\theta) \cdot \int_0^\infty r'(\lambda) E(\lambda) d\lambda \tag{4}$$

During the calibration process, E(λ) is known. r´(λ) is also known (after ad-hoc characterization done by the manufacturer and verified by INTA). We can solve the integral and get its value. This value (IE) is the amount of current generated in the hypothetical case that the detector had a responsivity of 1 at λ0. In this way, we can write:

$$I(T,\theta) = R(\lambda_0) \cdot TRF(T) \cdot ARF(\theta) \cdot I_E \tag{5}$$

This value (IE) depends on the optical channel, on the distribution of the input light spectrum and on the total incident optical power. The signal of a specific optical channel under the illumination of a specific spectral lamp with a determined light spectrum depends only on the incident optical power.

The TRF is defined to be equal to 1 at room temperature and the ARF is defined to be equal to 1 for a perpendicular light incidence. After these definitions, we can fix the temperature and the incident angle and we can change the optical power of the lamp. In this way, the experimental data can be fit in order to get the responsivity (R). Results for the FM model are shown in the next figure.

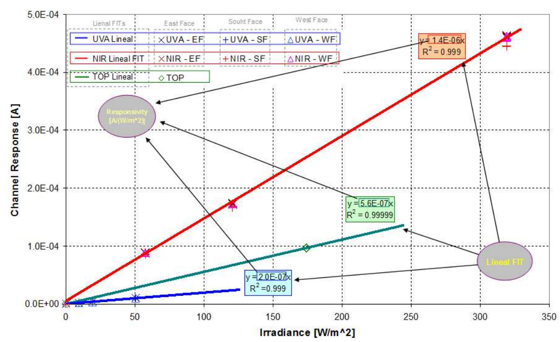


Figure 6. SIS FM responsivity calibration

Additionally, we can fix the optical power and the temperature and change the angle. In this way, we evaluate the ARF.

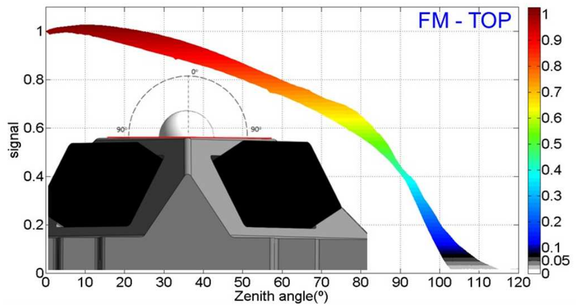


Figure 7. SIS FM "total light" (top) channel angular calibration

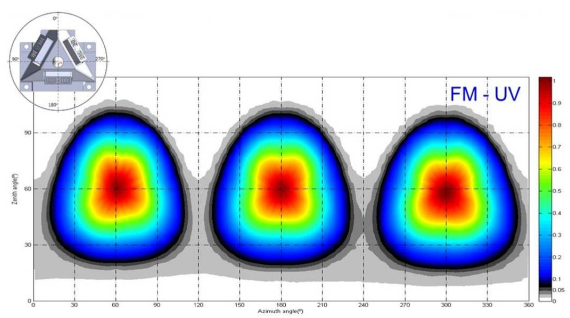


Figure 8. SIS FM UVA channels angular calibration

Finally, if we fix the optical power and the angle, we can get the TRF. In this case, we can calibrate the response of the temperature sensor as well. This was done in a vacuum chamber with optical window to allow excitation from the outside.

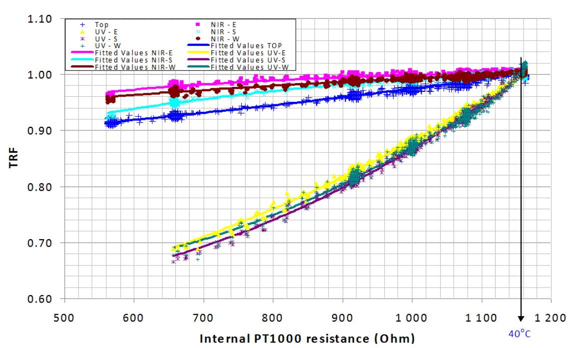


Figure 9. SIS OH FM thermal calibration

4. Qualification

The DREAMS SIS QM, FM and SPARE have passed the corresponding qualification and acceptance test levels according to the mission requirements. These test involve vibration (sine and random), thermal-vacuum, SRS shock and DHMR. For each model, optical characterization before and after the test campaign were done to verify the optical integrity of the instrument. Functional test and less intensive optical test were applied as well between tests (e.g., different axis of a vibration test) with the same aim.

All the assembly of the unit was done inside a laminar-flux cabinet in an ISO-6 facility, and observing Planetary Protection rules. The qualification campaigns were developed at corresponding INTA's facilities, but not always these facilities were compliant with the Planetary Protection requirements. In those cases, to avoid contamination of the units, special bagging procedures where applied to the transportation and for the test itself.

5. On-going activities

At present we are focused on the scientific retrieval algorithms. There are two main areas on which work is being developed:

5.1 Determination of Sun relative position

A priori it is not guaranteed that the Lander will provide information about its final attitude, once landed. The inclination of the horizontal plane on which the SIS lies, as well as its orientation within that plane, is of utmost importance in order to retrieve any information for which the relative position of the sun is relevant.

Due to this, during the last quarter of 2014 a big effort was done to qualify a miniature COTS accelerometer, accommodate it into SIS-PE box, and to acquire its signals at the expenses of removing some previously existing housekeeping signal. Only X and Y axis will be acquired. If the lander final inclination is moderate/high, with these signals we will recover the complete attitude information with a small error. In case it is small, the orientation of the sensor within the X-Y plane must be evaluated by other means.

We will do it by finding the time of the day for which the derivative of the signal provided by each detector is zero. This moment is related to the relative orientation of the Sun, and is found to show little dependence with the state (opacity) of the atmosphere. Next figure shows how the zero-value happens at the same moment regardless of the Optical Thickness (OT) value:

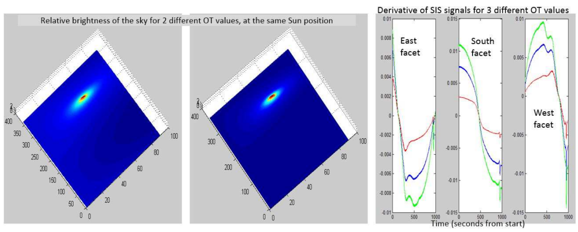


Figure 10. Left: Two different sky brightness models corresponding to 2 OT values. Right: Derivative of SIS signals for 3 different OT values from 0.1 to 2.2.

5.2 direct irradiance measurement and OT estimation

In July 2014 a measurement campaign was carried-out in a representative environment (Sahara Desert). An important set of reference instruments was carried to the dessert to be able to inter-compare their data with DREAMS-SIS: two pyranometers, one for measure the global irradiance and the second one to measure the integrated diffuse light (with a shadowing ring), one spectral-radiometer ASD-FS3 and one photometer CIMEL 318.

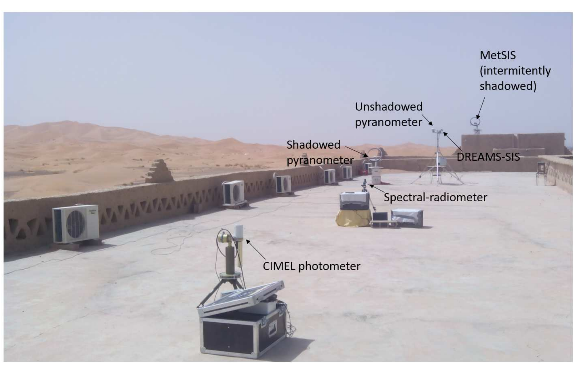


Figure 11. Image of the different instruments during the Sahara Desert campaign.

On one side, as shown in figure 12, the Sun irradiance value as recovered from SIS "Top" detector (hemispherical FoV, broadband: 200-1100 nm) is in very good agreement with the values provided by the pyranometers. The small differences (below 10% for Sun elevations above 40º) observed (Figure 12, bottom left) are due to the different angular responsivity of SIS and a pyranometer, which is uncorrected for the diffuse light.

On the other side, we estimate the OT value by doing as follows: (A) Compute the quotient between two signals of SIS (usually, the 2 biggest ones). (B) Simulate the sensor response for different sky brightness maps, corresponding to different OT's. (C) Calculate the same quotient from the simulations and identify the OT value that provides the closest result to the measured one. Radiation transfer models are needed for this.

In this way, SIS only makes use of relative measurements (quotient of 2 signals). If we assume, as per a random process, that the dust that will be deposited on each detector will produce approximately the same decrease of signal on each one, and giving that the measurement principle is fully differential, the degradation due to dust (or others, such as radiation) is negligible. At the same time, given that the measurements are simultaneous, we can obtain a "real time" estimation of the OT, instead of a daily average.

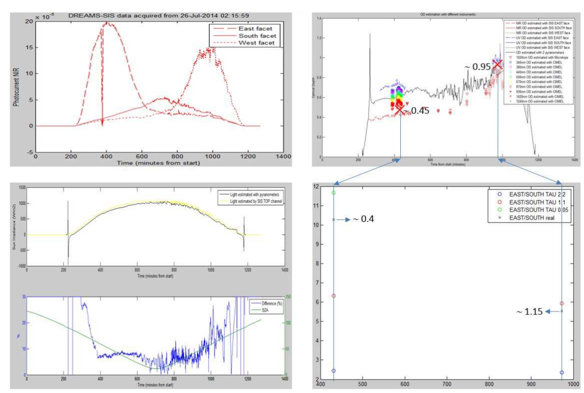


Figure 12. Left, top: real signals obtained from SIS in Sahara. Bottom: Sun irradiance calculated by SIS and pyranometer, and difference. Right, bottom: comparison of real signal quotients with simulated ones and identification of the estimated OT. Top: Measurements of OT for the same day and time, with different reference instruments.

6. Summary and Conclusions

The Solar irradiance Sensor on board the ExoMars 2016 Lander (as part of the DREAMS package) has been presented. It is a extremely miniaturized, low power and versatile (fully digital and autonomous) sensor, whose development was only possible thanks to the big effort done in qualification and screening of COTS parts.

It will allow obtaining direct Sun irradiance measurement and continuous OT estimation, with a full availability along the mission.

At present, the flight unit is already integrated in DREAMS, and being integrated in ExoMars Lander.

Acknowledgements

Part of this work has been funded with the help of the Spanish National Research, Development and Innovation Program, through the grant AYA2011-29967-C05-01.

References

[1] F. Esposito et al. (2014) 8th International Conference on Mars, #1246.

[2] A.-M. Harri et al. (2014) 8th International Conference on Mars, #1458.

[3] I. Arruego (2014) A Roadmap for the Development of Miniature Instrumentation for Mars Exploration. Second International Workshop on Instrumentation for Planetary Missions (IPM2014).

[4] MIL-STD-883H, method 2009.10, “External visual”.

[5] MIL-STD-883H, method 2012.8: "Radiography".

[6] MIL-STD-883H, method 1015.8: "Burn-in test".

[7] MIL-STD-883H, method 1010.8: "Temperature cycling".