HVI-TEST SETUP FOR DEBRIS DETECTOR VERIFICATION

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ABSTRACT

Risk assessment concerning impacting space debris or micrometeoroids with spacecraft or payloads can be performed by using environmental models such as MASTER (ESA) or ORDEM (NASA). The validation of such models is performed by comparison of simulated results with measured data. Such data can be obtained from ground-based or space-based radars or telescopes, or by analysis of space hardware (e.g. Hubble Space Telescope, Space Shuttle Windows), which are retrieved from orbit. An additional data source is in-situ impact detectors, which are purposed for the collection of space debris and micrometeoroids impact data. In comparison to the impact data gained by analysis of the retrieved surfaces, the detected data contains additional information regarding impact time and orbit. In the past, many such in-situ detectors have been developed, with different measurement methods for the identification and classification of impacting objects. However, existing detectors have a drawback in terms of data acquisition. Generally the detection area is small, limiting the collected data as the number of recorded impacts has a linear dependence to the exposed area.

An innovative impact detector concept is currently under development at the German Aerospace Centre (DLR) in Bremen, in order to increase the surface area while preserving the advantages offered by dedicated in-situ impact detectors. The Solar Generator based Impact Detector (SOLID) is not an add-on component on the spacecraft, making it different to all previous impact detectors. SOLID utilises existing subsystems of the spacecraft and adapts them for impact detection purposes. Solar generators require large panel surfaces in order to provide the spacecraft with sufficient energy. Therefore, the spacecraft solar panels provide a perfect opportunity for application as impact detectors. Employment of the SOLID method in several spacecraft in various orbits would serve to significantly increase the spatial coverage concerning space debris and micrometeoroids. In this way, the SOLID method will allow the generation of a large amount of impact data for environmental model validation. The ground verification of the SOLID method was performed at Fraunhofer EMI. For this purpose, a test model was developed. This paper focuses on the test methodology and development of the Hypervelocity Impact (HVI) test setup, including pretesting at the German Aerospace Centre (DLR), Bremen. Foreseen hardware and software for the automatic damage assessment of the detector after the impact are also presented.

Keywords: Space Debris, SOLID, impact detector, environmental model validation.

1. INTRODUCTION

Space activities over the past 6 decades have led to a progressive increase in the creation of space debris. Impacting debris can damage or even destroy spacecraft and payloads. The mission risk analysis can be performed with space debris environmental models such a MASTER or ORDEM. These models allow the estimation of the space debris flux into the spacecraft. MASTER, for instance, uses mathematical methods in combination with measured data for model generation and validation. There are several databases of space environment data; however the available data is very limited and is valid only for specific objects, orbits and time periods. The Space Surveillance Network (SSN) catalogue contains space debris data for low Earth orbit (LEO), for objects exceeding ~10cm; and geostationary orbit (GEO), for objects exceeding ~1m. Sporadic "spot-check" campaigns are able to provide data in LEO for debris particles exceeding ~2mm, and in GEO for space

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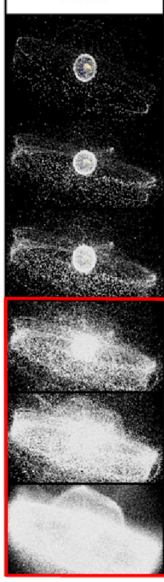
debris larger than ~10cm. These campaigns use a network of radars and optical telescopes to generate snapshots of the space environment. Adequate validation for environmental models can be performed from these campaigns and various catalogues for LEO objects larger than 5mm (from radar measurements), and for GEO objects exceeding 10cm (from optical telescope measurements). Additionally, retrieved hardware provide a representation of space debris smaller than 20µm up to 650km altitude [1].

However, the validity of the data collected is short-lived, due to the dynamic nature of the space debris environment. Additionally, there are some regions where little or even no data exists. The space debris in this region is undetected, as it is too small for ground based radar and optical telescopes. Furthermore, it is large enough that it has a low flux, making detection through impact hardware retrieval rare. This problem is especially the case for space debris ranging in diameter from 20µm to 5mm, where in the case of MASTER2009, only data obtained from the LDEF-CME (Long Duration Exposure Facility – Chemistry of Micrometeoroids Experiment) was available for model validation. In addition, many objects above 650km in altitude and inclinations outside of the range serviced by the space shuttle (typically 28.5°) go undetected [1].

Figure 1 gives an overview of the space debris situation as of 2009. The total quantities for various classes of space debris objects derived from the MASTER2009 model, were provided by Carsten Wiedemann, Technical University of Braunschweig, Germany. Possible options for data acquisition as well as the predicted damage to spacecraft and payloads are outlined. A comparison of four different space debris environmental models is shown to the right of Figure 1 [2], with discrepancies obvious between the models even for well-investigated areas. This is the case particularly for LEO objects >100µm and >1cm. Studies, such as those provided in [2,3], have also uncovered large differences between various models and data. Therefore there is an urgent need for more data, particularly for smaller objects that cannot be tracked (1mm to 1cm) by ground surveillance.

Considering this need, an in-situ impact detector with a large area is proposed. Adaptation of existing spacecraft subsystems for in-situ impact detection allows cost-effective and efficient deployment of detectors into various orbits, providing large spatial coverage of the space environment. Measured data from such detectors can be transmitted real time to ground stations for immediate utilisation in space debris environmental modelling. The Solar Generator based Impact Detector (SOLID) is under development by the German Aerospace Centre (DLR) in Bremen for this purpose. The SOLID detection method was submitted to Hypervelocity Impact (HVI) testing for ground verification. This paper focuses on the test setup and provides an overview of the SOLID concept. More detailed information on the theoretical background, manufacturing, and implementation of SOLID can be found in [5,6,7,8].



2009	Size	Quantity	Comments
			Ground based surveillance (normal) 16.300 Objects within radar catalog (some of them ca. 5cm) Ca. 800 active Satellites Mission lost in case of collision.
	>10cm	29.000	Ground based surveillance (limited) Mission lost in case of collision.
	>5cm	60.000	Ground based surveillance (limited) Mission lost in case of collision.
	>1cm	700.000	1 cm object releases energy equivalent to hand grenade Mission lost in case of collision.
	>1mm	200 million	***Retrieved Surfaces / In-Situ Detectors,*** High probability of spacecraft damage in case of collision.
	>100µm	trillions	***Retrieved Surfaces / In-Situ Detectors,*** Damage /degradation of spacecraft in case of collision possible.

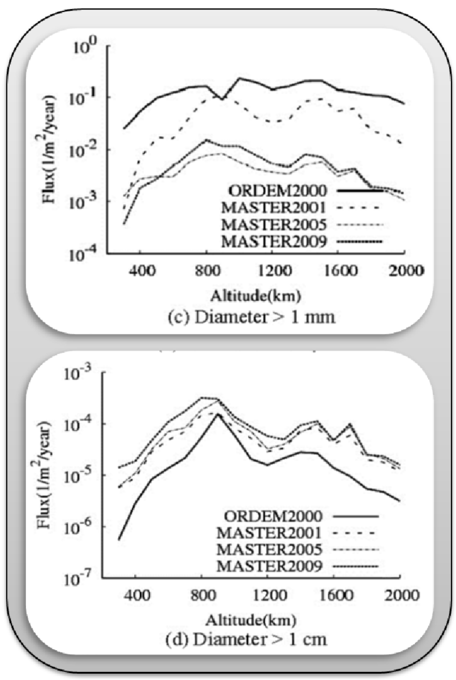


Figure 1: Space debris environment [2,3,4]

2. SOLID IMPACT DETECTOR

The SOLID is a large-area impact detector which can be flown in any orbit. Unlike most conventional detectors, the proposed new concept utilises existing subsystems of the spacecraft bus and adapts them for impact detection, as depicted in Figure 2. The electrical power subsystem (EPS) and the attitude control subsystem (ACS) are used for data acquisition. The data handling subsystem (DH) and telemetry and telecommand subsystem (TM&TC) perform data processing and data transfer to Earth.

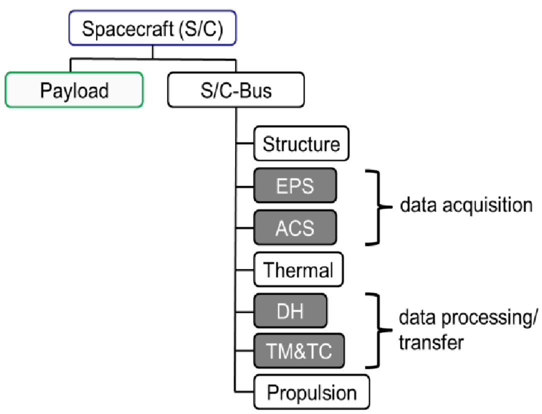


Figure 2: Spacecraft subsystems adaptation

The functional principle of SOLID is illustrated in Figure 3. The core component of the system is a solar generator (S/G) with photovoltaic cells (PV). An autonomous electronic box (E-BOX) is also implemented in the interior of the spacecraft. A particle impacting the solar generator can create an anomaly in power supply. The E-BOX monitors the EPS for these events and compares them to predefined impact disturbance behaviour. Once the anomaly was identified as an impact, the solar generator structure (SGS) is analysed for damage. From this analysis, the impact location and damage of the SGS caused by impact is determined. The magnitude of the damage enables estimation of the incident particle diameter. The ACS data is also analysed within a predefined time after the impact in order of the damage to ascertain the momentum transfer to the spacecraft from the space debris or micrometeoroid impact. The combination of the known impact position, the particle diameter from SGS analysis and the momentum transfer from ACS subsystem enables the determination of the particle velocity.

The principal adaptation method of the standard SGS for the purpose of impact detection is depicted in Figure 4. The SOLID concept modifies the insulation layer behind the solar cells of commonly used S/G. The modified S/G integrates two layers of copper lines between the insulation layers (usually Kapton). The two copper layers are aligned in perpendicular directions, forming a detection grid. In an impact event, the colliding particle causes damage which can range in depth from the cover glass layer down to the detection layer (DL). Consequently cuts several copper lines in the grid. The number and position of the severed strips can be identified by the analysis electronics and software (see the E-BOX, Figure 3). The damage equations provided in [6, 7, 12, 13] can be used to estimate the diameter of the incoming particle.

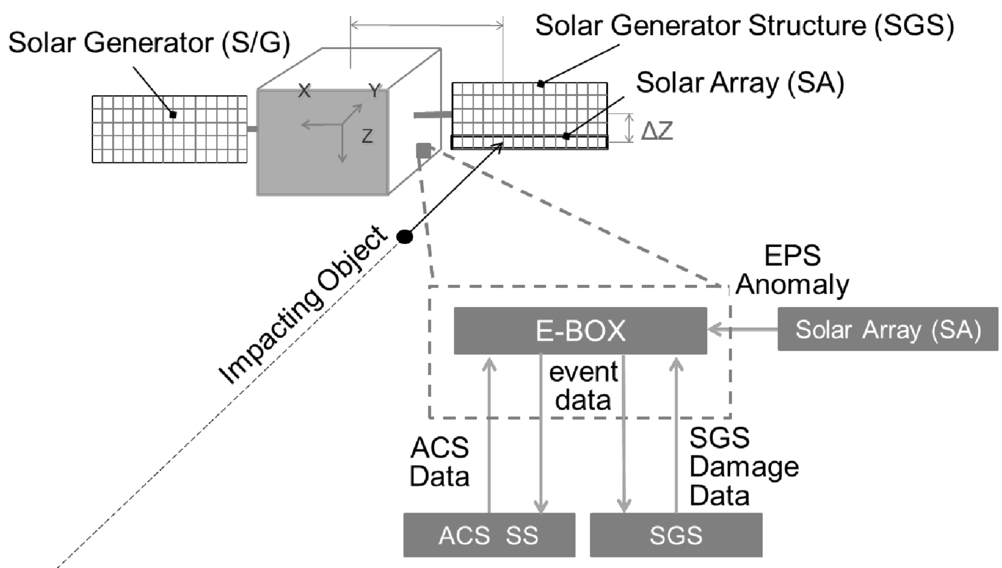


Figure 3: Functional principle of SOLID concept

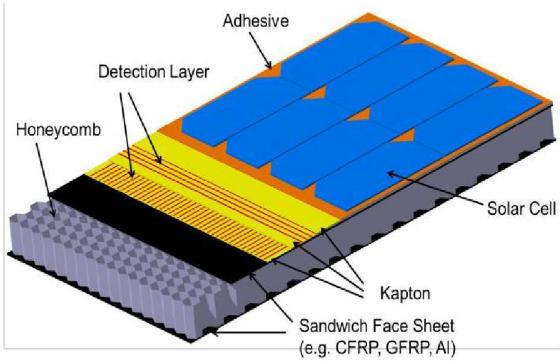


Figure 4: SG adaptation for SOLID concept

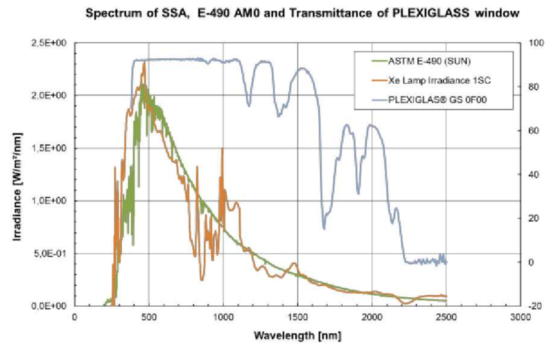


Figure 6: Spectrum of the sun, of the SSA and the transmittance of the target chamber window [14,15,16]

3. HVI TEST SETUP

Figure 5 shows the foreseen HVI-test setup. The SOLID (including electronics system) is placed within the target chamber. The oscilloscope, transient recorder, PC (software interface), power supply, and sun simulator (SSA) are placed outside the target chamber. Electrical interfaces from the interior to the exterior of the target chamber are provided by vacuum-convenient connectors. The communication between the software on the PC and the SOLID electronics occurs via an RS232 interface. The power supply provides the detection electronics with a voltage of 7V.

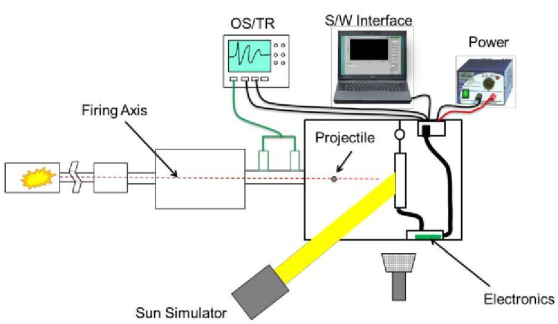


Figure 5: HVI test setup

Plexiglass windows are used for high speed photography, video and for illumination of the solar cells with solar light. One target chamber window is used for high speed cameras, and the second for the SSA. The SSA light spot of ca. 200mm in diameter is conducted through the 8mm plexiglass window and illuminates the solar cells on the test panel. Figure 6 contains the solar spectrum (ASTM E-490; American Society for Testing and Materials), the spectrum of the SSA (Xe-Lamp) and the transmission of the Plexiglass window foreseen for the HVI tests.

In order to simulate the solar spectrum at operational conditions, the illumination of the solar cells for the HVI testing should occur within the light spectrum ca. 300-1800nm [8,9]. For the HVI testing GS0F00 Plexiglass was selected, despite the spectral transmission variation with the wave length, with some frequencies transmitted only few percent. Figure 6 shows the spectrum of a comparable Plexiglass, for which the spectral transmission was provided by the manufacturer.

Figure 7 depicts the SOLID prototype manufactured for concept verification through HVI testing. The SOLID detection layer is made of polyimide, with dimensions of 380mm x 255mm. Diodes were implemented on the top side of the detection layer. The detection area was covered by six solar cells, covering an area of 160.5mm x 121mm. These dimensions are marginally smaller than the foreseen dimensions of the detection grid for impact detection (168mm x 120mm).

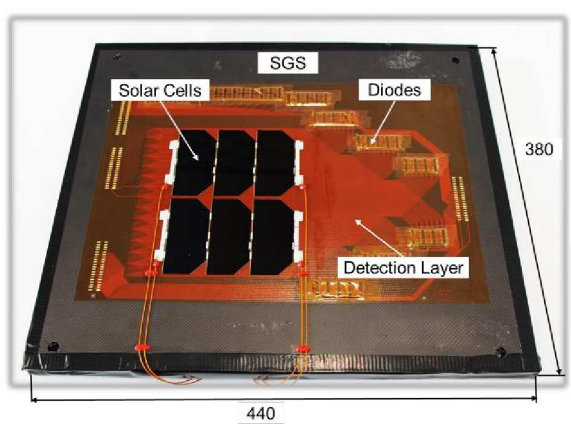


Figure 7: SOLID prototype for HVI testing

This discrepancy was caused by size limitations of the polyimide used for detection layer manufacturing. The detection layer is applied to the carbon-fibre-reinforced polymer/aluminium (CFRP/Al) primary structure (sandwich). The aluminium honeycomb was perforated to allow venting of the encapsulated air, as the tests are performed in vacuum environment.

The automatic damage assessment on the solar panel after the impact is performed by the SOLID electronics. The electronics can be subdivided into two functional units: the pulse detection unit, which identifies the impact; and the analysis unit, which performs the damage analysis on the structure. Figure 8 shows the functional principal of the pulse detector for ground testing.

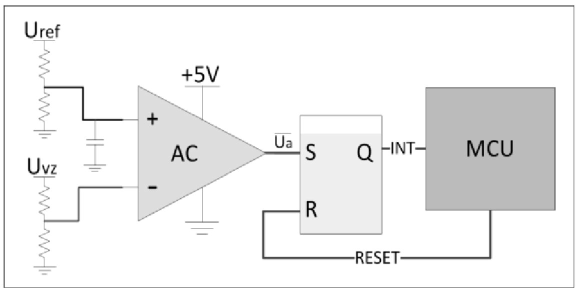


Figure 8: Schematic principal of pulse detector

The voltage provided by solar cells (U_{vz}) is compared to predefined reference voltage (U_{ref}). In the event that the solar cell voltage drops below the reference voltage, the comparator provides the flip-flop with output signal (Ua) and the flip-flop is switched from reset (R) to set (S). If the flip-flop is set to (S), the output signal (Q) of the-flip flop sets the interrupt (INT) on the microcontroller unit (MCU). After the triggering by the INT and following a predefined time period, the MCU starts to analyse the detection layer behind the solar cells. The MCU checks the existence of all conductive lines by switching the multiplexers (MUX) to the defined state of the particular line. Figure 9 shows the schematic principal of the analysis unit.

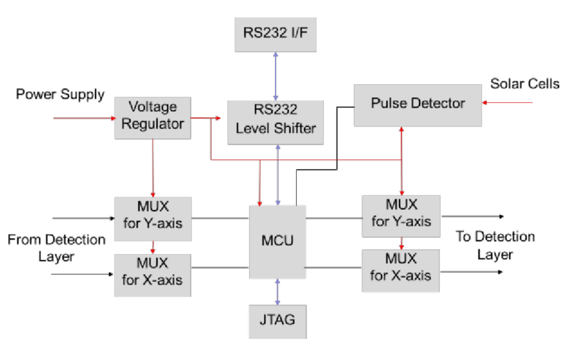


Figure 9: Schematic principal of analysis unit

Figure 10 illustrates the SOLID electronics manufactured for the HVI testing. The PCB comprises of an RS232 interface for data exchange, connectors for power supply, an interface for detection analysis and electronics components for impact detection and damage analysis. The analysis software was realised in Labview [11]. The software is capable of performing all necessary steps foreseen for autonomous HVI testing. Furthermore, it allows the user to check the voltage and current of the solar strings and the reference voltage prior to the HVI testing. The string voltage can be measured manually, as well as being visually represented. Additionally, the detection layer state can be analysed manually. A reset button is foreseen in order to restart the MCU and set all settings into initial condition.

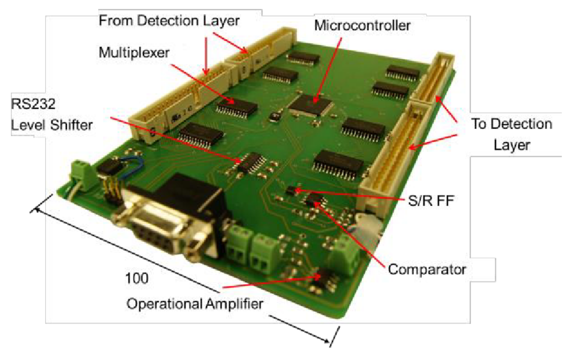


Figure 10: Electronics for HVI-tests

4. PRETESTING AT DLR BREMEN

Pretesting at system level was performed at DLR Bremen. This testing was performed in order to ensure that the HVI tests at EMI could be successfully accomplished, and was executed in addition to the component testing. The geometrical arrangements of the testing equipment were made analogous to the anticipated HVI test setup at EMI's SpaceGun. This allowed a fit-check of all components foreseen for planned tests. This comprised of (amongst others):

- implementation of all necessary cables to the safety hoses, which protect the cables against the released ejecta at HVI testing,
- wire routing of components such as solar cells, detection layers and power supply to the electronics,
- verification of alignment of solar cells to the firing axis and mounting of the SOLID prototype, and
- testing of the electronics at normal operational conditions.

After each HVI firing, the testing SOLID prototype was analysed outside of the target chamber. For this purpose, disconnection components for the SOLID / target chamber and SOLID / electronics interfaces were foreseen and incorporated into the pretesting setup.

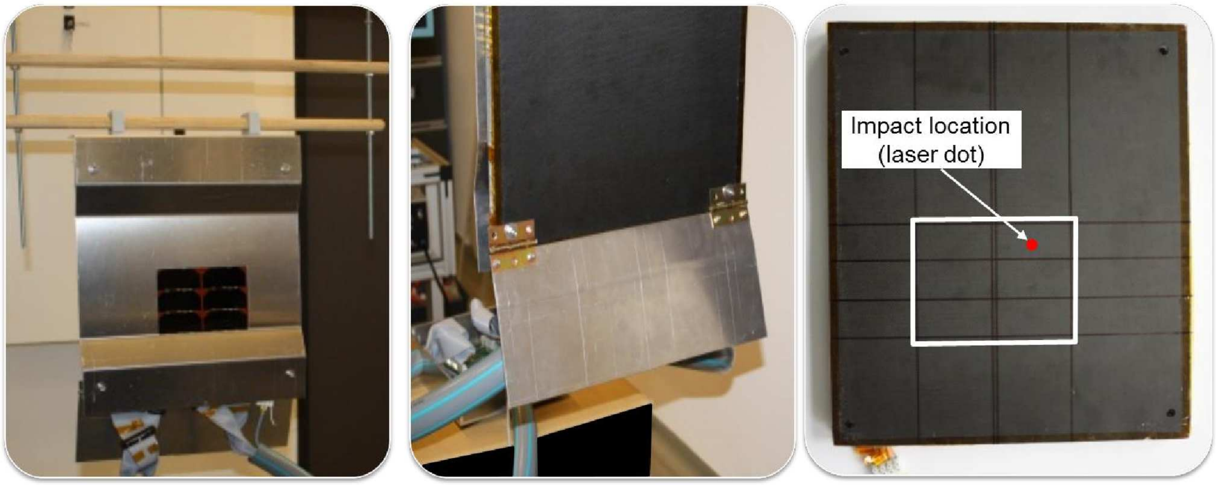


Figure 11: SOLID adjustment to the shut axis

The rear of the test panel was covered by pivoting aluminium sheet (Figure 11, centre). This panel protected the electronic connectors and wire from released secondary ejecta after the impact, and allowed fast disconnection of SOLID from the electronics.

The front side was also covered by aluminium sheet, to avoid damage to the used diodes (see Figure 7). The vertical and horizontal adjustment of the SOLID was performed by a threaded rod and a sliding rod, according to Figure 11 (right). The solar cell geometry was projected to the back side of the CFRP/Al sandwich to allow external adjustment of the impact target position.

The sun simulator was placed both frontally and at an angle to the solar cells. The latter was also the case for tests at EMI's SpaceGun. In both cases, the sun simulator power was adjusted to one solar constant (~1370W/m²) normal to the detector surface, by using air mass filter AM0. The sun simulator provided a sunlight spot of approximately 200mm in diameter, covering all six solar cells.

The EBOX was placed inside the SpaceGun chamber to shield the electronics from electromagnetic noise of the sun simulator. This solution yielded further challenges. The HVI tests required particle velocities of approximately 5kms-1, therefore the ambient pressure of the SpaceGun chamber needed to be set to at least to 100hPa. Consequentially, the already-manufactured electronics components had to withstand the defined ambient pressure within the target chamber. The electronics systems were comprised of commercial off-the-shelf (COTS) components, for which information concerning operation at 100hPa was not available. Therefore, vacuum testing of the electronics was performed at DLR in Bremen. Figure 14 illustrates the electronics testing setup for rough vacuum conditions. The SOLID test panel, including the electronics, was placed inside the vacuum chamber. The connection to the power supply as well as to the PC was routed to connectors on the front side of the vacuum chamber.

The test was performed by reducing the ambient temperature, while operation of the electronic systems. The ambient pressure was reduced in two steps:

- 1.025hPa to 500hPa, then held constant for approx. 2h,

- 500hPa to 100hPa, then held constant for approx. 3h.

The functionality of the electronics was observed for the duration of the test. No difference to the normal operation at ambient pressure of 1.025hPa could be identified.

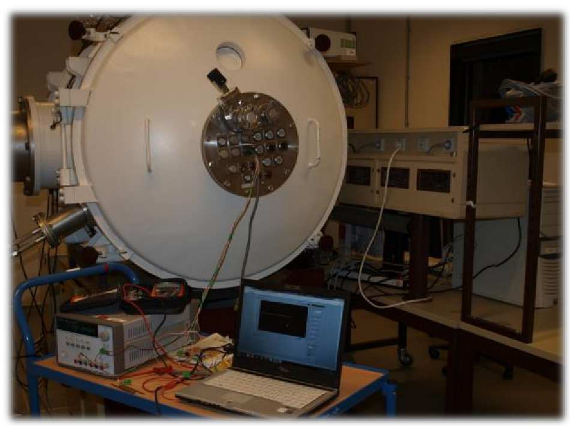


Figure 12: Electronics testing at vacuum chamber at DLR Bremen

The pretests helped in the preparation of the HVI tests at Fraunhofer EMI. These tests were undertaken successfully in February 2013. The corresponding results will be presented at IAC2013.

5. ACKNOWLEDGEMENTS

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