Space Technologies Studies 2016: Results

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Dear reader,

you will find in this document the summary of the twelve projects funded under the call for proposals issued in 2016 by the Swiss Space Office of the State Secretariat for Education, Research and Innovation of the Swiss Confederation (SERI/SSO) to “Foster and promote Swiss scientific and technological competences related to space activities”.

Following the three previous successful editions of the MdP Call for Proposals (Mesure de Positionnement), launched since 2010 to reinforce the technological and scientific capabilities of Swiss entities in the space sector, the SERI/SSO again initiated the MdP Call for Proposals in 2016. The goal of the “positioning measure”, which is part of the National Complementary Activities for space, is to encourage the emergence of projects in space technology. Based on the same principles, it aims to develop niche sectors and to better position Swiss industrial and academic entities, particularly in the frame of ESA activities and other international programmes such as the EU Research Framework Programmes. The SSO mandated the Swiss Space Center to implement the Call for Proposals 2016.

Objectives

The main objectives of this Call for Proposals are to foster and promote Swiss technological and scientific competences that have a clear potential for space products and services/applications. More particularly, this Call for Proposals aims:

- to foster the development of innovative ideas and new products related to the space sector;
- to promote the collaboration between Swiss industrial and academic partners to obtain a more stable and better structured Swiss space landscape;
- to better position Swiss industry with regard to future European and worldwide activities so as to be ready to submit competitive bids when the respective calls are published;
- to increase the technological maturity of ideas developed by academia and to promote competitive space products thanks to partnerships with industry.

List of the projects:

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"xTerm, a miniaturized terminal for machine to machine telecommunications"

Competences:

- **HEIG-VD/IICT** has strong competences in telecommunications, radio frequency electronics up to 24GHz, and on the IoT (Internet of Things), in both the Radiofrequency HW and SW communication protocols. The Advanced Communication Systems Group of the IICT have carried numerous practical applied projects on the IoT field (LoRA, 6LoWPAN, proprietary protocols) and their competences are highly relevant in the Web-of-Things community. We have already connected mattresses, fire extinguishers, medical implants, and other objects!
  When high performance is required, we do designs reaching close to the limits sets by the laws of physics. For IoT, we reach low power through careful SW design.
  The HEIG-VD has also good expertise on the new technology of Software Defined Radio, which allows very flexible operation, as in the project presented.
  The IICT is also designing the RF part of the S-band and X-band service radios (TT&C) of the Astrocast satellites.
- **Astrocast** pushes on the IoT telecommunications through a low-cost space segment, designing, developing and deploying an M2M (Machine-to-Machine) service through nanosatellites in low earth orbit. Astrocast's experience is based on the space segment and on the telecommunication subsystem for spacecraft.

Summary:

As part of the Astrocast's roadmap for the future development of its constellation, this project represents a first prototype of the L-band ground terminal platform. The terminal based on SDR (Software Defined Radio) functionalities will communicate (with a low-data rate) the M2M data to the nanosatellite.
The design, based on a miniaturized RF front-end with 1 Watt transmit power, high-performance transceiver IC and a low-cost FPGA allow the manufacturing of a miniaturized highly flexible satellite communication terminal able to link to 600km low earth orbit. The system can be manufactured in large quantities for less than 100$.

Results:

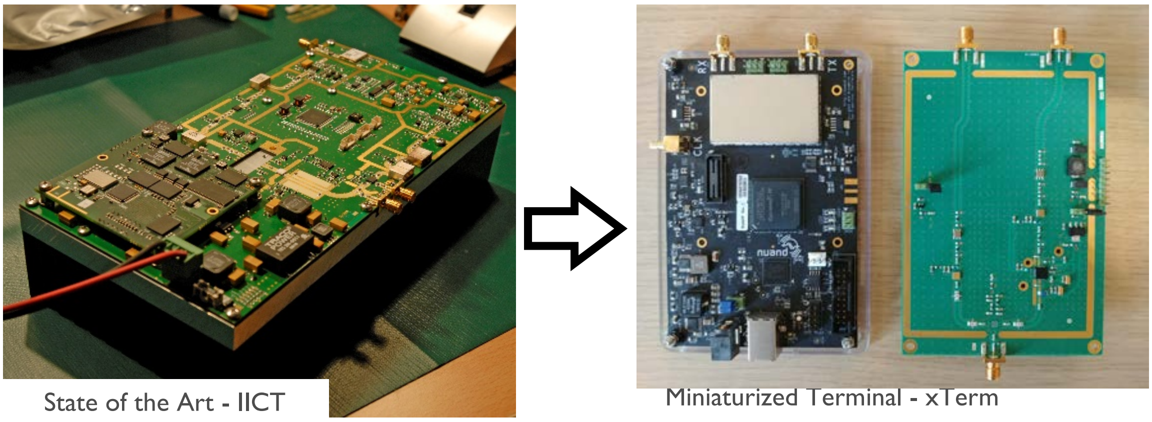

Figure 1: On the right the Phase3 of PocketSat (30cmx10cmx5cm), heritage from IICT project and base for xTerm. On the left the Miniaturized design intended for the xTerm as output from this project (12cmx8cmx5cm).

<u>Miniaturization:</u> The system evolution shown in Figure 1, from State of the art design from IICT (30x10x5 cm^3 and $1500) to the miniaturized design (12x8x5cm^3) realized in this project. There is a path to further miniaturization, down to 6x4x2 cm^3.

<u>Flexibility:</u> The RF front-end can operate in the whole satellite L-band, allowing for communication from ultra-narrow band to wide band communication while respecting spurious emission limits and filtering all possible interferer's signals. The SDR baseband enables total flexibility on the protocol selection: the current system supports QPSK modulation and standard coding; other settings can be enabled by SW update.

Conclusion:

The RF front-end with its 1W transmitting power and excellent receiving front-end, is an ideal complement to the LMS6002 SDR chip.

The terminal will be used during the operations of first Astrocast satellite scheduled Q2-Q3 2018. During this phase the terminal will be used to test and validate the M2M communication link and system. These results are very valuable to Astrocast as the same technology is used for testing and operation of various communication links.

The development of the terminal will continue under ESA ARTES 3-4 funding for the Astrocast precursor mission, among others to optimize the baseband software.

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Software Initiated FPGA Threading SWIFT

Competences:
EPFL LAP has almost two decades of expertise in customized and heterogeneous computing, as well as in the use of reconfigurable components to accelerate embedded processors. In the specific research area of the SWIFT project, EPFL LAP has pioneered since the beginning of the millennium first examples of memory virtualization efficiently adapted to FPGA accelerators and, more recently, has focused on datacenter applications to make FPGA accelerators accessible to software programmers. The industrial partner Syderal is a recognized provider of electronics equipment units for several space missions including Earth observation and space exploration missions. To mention a few, Syderal has successfully delivered the Instrument Control Module for the SAR instrument of the Sentinel-1 mission, the Payload Data Handling Unit for the Gaia Mission, and the Seismometer Electronics for the InSight mission to Mars.

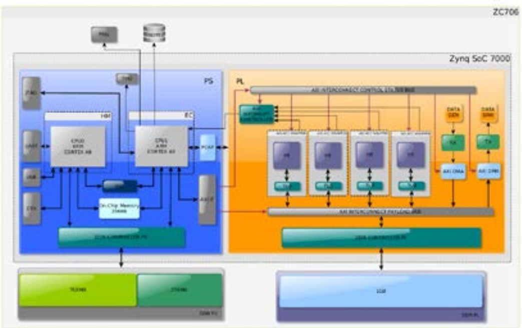
Summary:
FPGA (Field Programmable Gate Array) is an attractive technology for high speed data processing in space missions due to its unbeatable flexibility and best performance to power ratio, in comparison to software. However FPGAs suffer from substantial drawbacks including:

- Higher programming effort with respect to software;
- Static allocation of hardware resources for each implemented algorithm in contrast to running many software algorithms on the same processor hardware.

The SWIFT project aims to minimize the above-mentioned drawbacks by:

- Exploiting dynamic partial reconfiguration capabilities of modern FPGAs to load and execute different processing modules dynamically on the same FPGA hardware;
- Providing abstraction mechanisms to create, execute and join FPGA-based concurrent processing functions under software control.

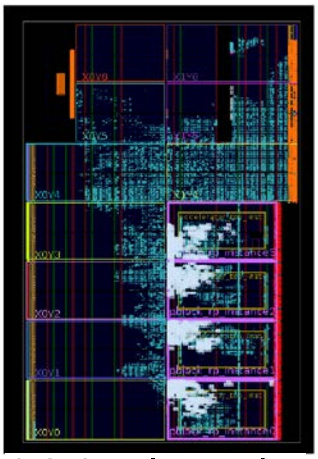
Results:
A functional demonstrator has been developed and implemented on Xilinx Zynq COTS (Commercial Off-The-Shelf) SoC. SWIFT's architecture has been designed to be portable to platforms from multiple vendors: portability and scalability are fundamental principles of the SWIFT design. A proof of concept cloud detection algorithm for Sentinel-2 multispectral images has been implemented and tested on the SWIFT platform to validate the system's design principles and performance.



1. SWIFT Architecture

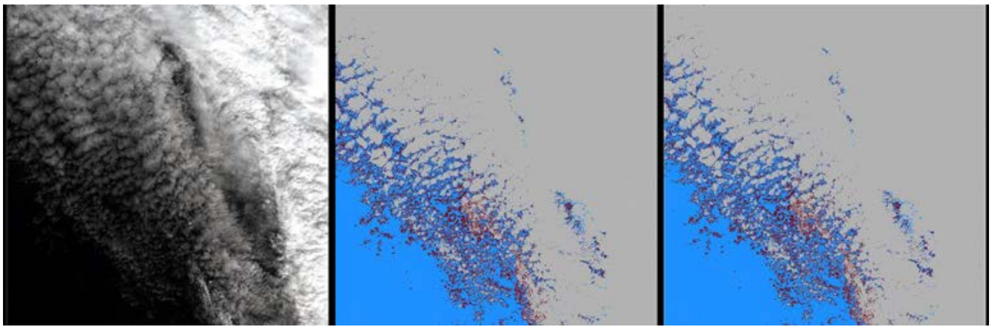
SWIFT achieves the following noteworthy results:

- SWIFT's execution model allows the application to achieve up to 40x speedup over the equivalent software version;
- SWIFT's use of FPGA resources reduces energy consumption by 11x compared to the same algorithm executed on the ARM processor of the Zynq SoC;
- SWIFT's programming model requires no more effort than software threading;
- SWIFT's architecture introduces minimal area and latency overheads.



2. SoC Implementation

The images reported below show the result of a cloud detection algorithm applied to a Sentinel-2 multispectral image (represented in RGB). Execution time and energy consumption are indicated in the caption below the figure for both cases.



3. From left to right: satellite multispectral image (RGB); Classification Mask SW output w/o FPGA threading (5s processing time, 2640 mJ energy); with FPGA threading (120ms processing including configuration time, 221 mJ energy).

Conclusion:

The demonstrator implementation proved that FPGA resources can be managed by software and effectively used for computational tasks in the same way as a central processing unit can be used by an operating system to execute user applications. The FPGA can be initialized for a number of dynamically configurable partitions and make each of them available for running concurrent hardware threads as needed. Additionally, synchronization mechanisms have been implemented and tested to coordinate the execution of the instantiated hardware threads with respect to the main software flow. Finally, the scheduling of hardware threads and allocating them to the available FPGA resources is transparently managed in the background according to dedicated parameters that can be configured by selecting multiple options.

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Spaceborne Autonomous Navigation based on GNSS

"A feasibility study considering the use of GNSS signals as a low-cost solution to autonomously navigate from the Earth to the Moon"

Competences:

The project is a collaboration between the Electronics and Signal Processing Laboratory (ESPLAB) of EPFL and Grosso Link Sarl. EPFL-ESPLAB has over 15 years of research and development experience of novel global navigation satellite system (GNSS) receivers, including the front-end, the baseband, and the navigation solutions, targeting low power and/or high sensitivity and/or high accuracy, with applications ranging from high sensitivity positioning for cars, distress beacons, cellular phones, wrist watches, to GNSS-reflectometry and space exploration.

Grosso Link Sàrl has been founded in 2013 by two graduated PhDs from EPFL. It's focus is on advanced GNSS receiver solutions for niche markets, taking advantage of the new signals transmitted by the modernized GPS satellites as well as the new Galileo and Beidou GNSS constellations that are currently scheduled to become fully operational by 2020.

Summary:

The focus of the project was to demonstrate the feasibility of using GNSS signals received in space for the precise and autonomous on board navigation of a space vehicle traveling on an Earth to Moon transfer orbit.

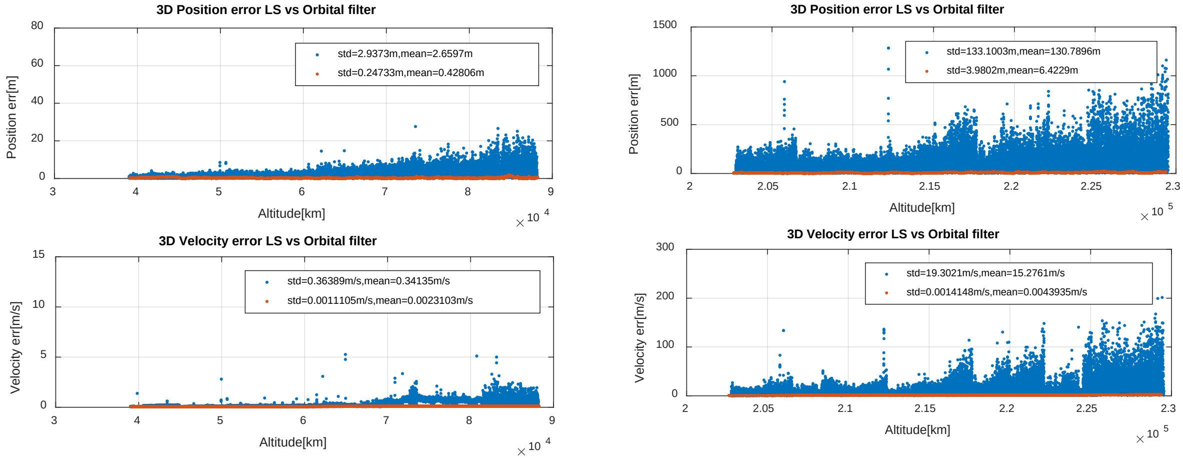
The project involved the following steps:

- Analysis of the visibility of the GNSS signals on a Moon transfer orbit taking into account different realistic antenna patterns for the satellites' transmitters and receiver and definition of the minimum receiver specifications.
- Study of different tracking configurations to combine the received GPS signals on the L1 and L5 frequencies in order to minimize the impact of ionosphere propagation delays on the navigation accuracy.
- Design and realization of a dual frequency radio frequency front-end breadboard built around two radio-frequency down-conversion integrated circuits that were elaborated in a past collaboration project between Grosso Link and EPFL.
- Implementation on a commercial FPGA of the GNSS algorithms, including the acquisition and tracking of the GNSS satellites signals, as well as the navigation algorithms making use of an orbital filter to significantly improve the positioning accuracy.
- Demonstrations of the capabilities of the receiver using a hardware in the loop test-bench making use of a full constellation GNSS simulator feeding the receiver platform with real radio-frequency GNSS signals.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Results:

A direct Earth-Moon Transfer Orbit (MTO) from a LEO parking orbit to the Moon altitude has been considered as representative of all the GNSS signals conditions that characterize the motion of a receiver on the way to the Moon.
The figures below present two examples of the achieved navigation accuracy for two segments of this MTO and comparing the orbital filter solution with a standard least squares (LS) solution.



The results clearly illustrate the improvement obtained with the orbital filter solution, reaching for the first segment below 90'000 km sub-m 3-D positioning accuracy, and for the second segment below 230'000 km less than 10 m 3-D positioning accuracy.

Conclusions:

The feasibility of using an autonomous dual-frequency GNSS-based receiver implementing an on-board orbital filter has been successfully demonstrated. Being fully autonomous, characterized by low power consumption, small volume and small mass, and only using the signals transmitted by current and future GNSS constellations, such a navigation device will be particularly suitable for small satellite platforms, such as pico-, nano-, and micro- satellites, and for all kind of space missions which require the autonomy of the spacecraft.

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3D-printed microwave cavities for atomic clock applications

Benefits of additive manufacturing for atomic clocks

Competences:

In order to exploit the potential of 3D-printed (additive manufactured) microwave cavities for highly demanding atomic clock applications, one industrial and two academic partners joined forces:

SWISSto12 SA contributed its considerable experience with design and additive manufacturing of passive microwave components and antennas up to 110 GHz, for aeronautical and space applications.

EPFL Microwaves and Antennas Group (MAG) contributed its expertise in design, simulation, and measurements of microwave devices such as antennas and cavities.

Laboratoire Temps-Fréquence (LTF) at University of Neuchâtel contributed its long-standing expertise on the development and characterization of atomic clocks, including compact vapour-cell clocks.

Summary:

Atomic clocks are the most precise timepieces existing today. A variety of atomic clocks are uniquely provided by Swiss specialized industry and they constitute one of the Priority Areas of the Swiss Space Implementation Plan. The vast majority of today's existing atomic clocks relies on microwave cavity resonators for applying the interrogating microwave radiation in a well-controlled way to the atomic sample serving as ultra-stable time reference. Conventional manufacturing of such cavities generally relies on expensive precision machining and time-consuming assembly of metal parts. In contrast, 3D-printing techniques are known to considerably simplify and accelerate the manufacturing and assembly of the fabricated parts. By using a proprietary SWISSto12 3D-printing process, one completely eliminates the need for the cavity assembly, and significant reduction in cavity mass can be reached as well. In this project we investigated on the suitability of 3D-printing for the manufacturing of microwave cavities with complex geometries, for atomic clock applications.

Results:

For demonstrating the 3D-printing approach, a microwave cavity for compact high-performance vapour-cell atomic clocks was selected. Based on a design previously developed by LTF and MAG for conventional cavities, a design showing a six-electrode geometry was established. Fully operational monoblock cavity structures with electrodes were manufactured, using Stereolithography (SLA) of a polymer followed by metal coating, and using Selective Laser Melting of aluminium (SLM), Figure 1a. These sample structures fulfilled all stringent requirements on the cavities for atomic clocks, such as precise resonance frequency, quality factor, homogeneity and uniformity of the microwave field. Tests in an experimental atomic clock setup showed a fractional frequency stability of $2x10^{-13}$ at one second integration time, which is on the same level as today's best vapour-cell clocks using conventional cavities. A fully monolithic cavity was also designed and realized (Figure 1b), including a 3D-printed coupling loop that further simplifies the cavity assembly and improves reproducibility.

Accelerated aging tests over 800 thermal cycles up to 85°C were performed on test samples produced by SLA. No measurable degradation of RF performance or material integrity was observed, which shows the reliability of the SLA technique and constitutes a first step towards space qualification.

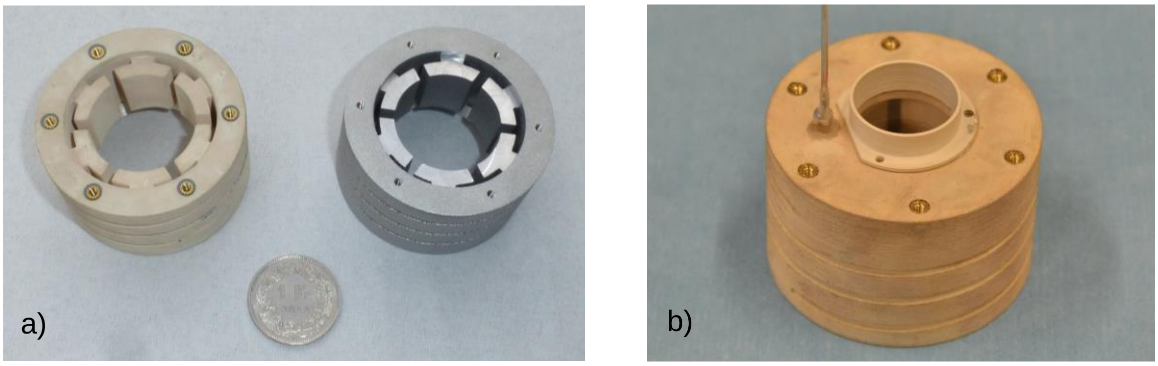

Figure 1: a) Cavity structures manufactured by SLA (left) and SLM (right). b) Fully monolithic cavity manufactured by SLA, including a coupling loop.

Conclusion:

The project has shown that 3D-printing by both SLA and SLM is appropriate for manufacturing complex microwave cavities with stringent dimension tolerances. The approach has the advantages of good reproducibility and strongly simplifies cavity assembly. In the case of SLA, around 30% weight reduction can be obtained.

Tests on clock system level demonstrate that the 3D-printed cavities perform on the same level as conventional ones, shown here for the highly demanding application in a high-performance vapour-cell atomic clock. The 3D-printing approach can also be applied to cavity designs for other clock types with different or relaxed requirements, thus opening a wide application potential in many types of atomic clocks.

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Additive Manufacturing of a SlipRing Assembly Rotor (AMAR)

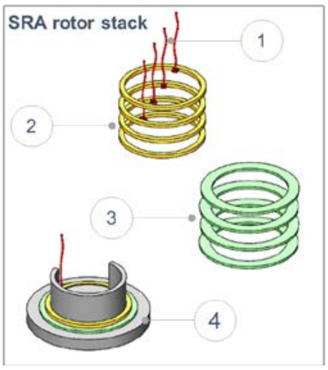
Competences:

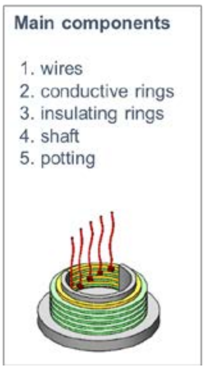
RUAG Space Switzerland Nyon (RSSN) has a large expertise in the field of *SlipRing Assemblies* (SRAs) as well as materials and processes knowledge. For more than 20 years, RSSN has been designing, manufacturing and testing SRAs for the space industry, where environmental, thermal and mechanical specifications are critical. The designers and the production personnel at RSSN have been involved in the production of almost each of the over 100 SRAs currently flying, giving RSSN a unique position to perform the development of these highly complex devices.

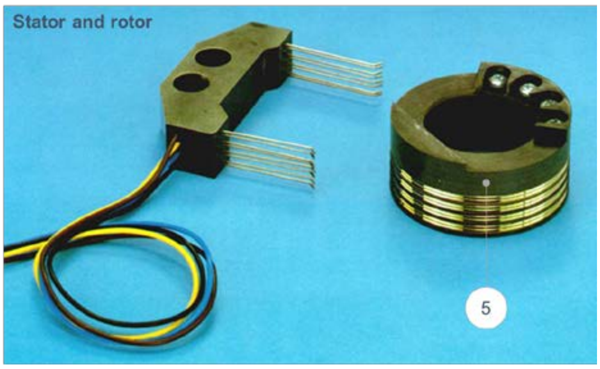
CSEM SA is a private Research and Technology Organization specialized in microtechnology, nanotechnology, microelectronics, systems engineering, and communications technologies. Its mission is to enhance the competitiveness of Swiss and European industry by developing applied technology platforms and transferring them to the industrial sector. In that spirit, CSEM is developing an expertise in product development or re-design, based on Additive Manufacturing (AM) technologies. Recently, CSEM was selected by the European Space Agency to develop a high performance compliant mechanism dedicated to space applications.

Summary:

The objective of AMAR was to develop, manufacture and test prototypes of cylindrical SRA rotors made by 3D Additive Manufacturing (AM). An SRA is a continuity device which aims at transferring electrical signals and/or power from a stationary member to a rotating member. In space, SRAs are recurrent device being present in many satellite sub-systems such as Solar Arrays Drive Mechanisms (SADMs), Antenna Pointing Mechanisms, Control Momentum Gyroscopes and other instruments. The aim is to simplify the current manufacturing and assembly sequence, which is currently a very delicate and tedious process. This shall allow reducing manufacturing and assembly costs by more than 40%, whilst improving the overall reliability and repeatability of the product. The re-design is also awaited to enable a mass decrease for the rotor and to avoid the use of cables which are part of the current physical architecture.

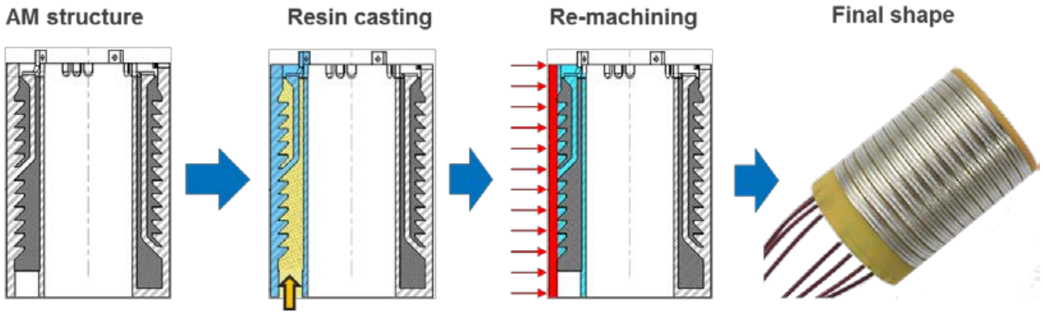






Results:

The developed rotor consists of a 3D printed monolithic structure made of aluminium, which includes conductive rings and electrical wires. The structure comprises a sacrificial shell which allows to cast the inner volume with resin and therefore creating the insulating barriers between each ring. The shell is removed, giving the rotor its final shape. As for common rotors, plating treatments are finally applied and the rotor is cabled to integrate it on the validation test bench.



The rotor was manufactured and validated by means of electrical performances and lifetime testing. The current performances are compatible with the SADM LEO and GEO applications. The new concept allows significant mass reduction, since the central shaft can be removed or optimized. Considering a number of 24 tracks, the new concept enables a reduction of the components from more than 70 parts to a single one, inducing a drastic decrease of the manufacturing and assembly costs. The preliminary analysis indicates that the objective of 40% is realistic. To consolidate this value, *the development shall be further continued in order to fully define the design geometries and the process parameters. The final prototype shall then be fully qualified with respect to the application requirements foreseen.*

Conclusion:

Thanks to the very close cooperation between RSSN and CSEM, the project outcome is considered as very successful by both partners. *Protoshape* and *3D Precision* are thanked for their implication on Additive Manufacturing for these prototypes.

A common development roadmap involving the whole SRA was elaborated, targeting ESA development programs. Moreover, the original concept developed and patented to avoid the use of cables in the SRA can be advantageously applied to other electro-mechanical components and assemblies, with the same potential for costs reduction and reliability improvement.

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Part integrity monitoring during Selective Laser Melting

Background

Existing part-quality and process monitoring solutions for laser powder bed fusion processes, such as melt-pool monitoring, are not sufficient to directly certify the produced components for certain demanding applications, such as those in the Space Industry. Therefore, new monitoring solutions are needed, complementing current ones. The current feasibility study aimed at demonstrating the performance of a new advanced part-quality monitoring solution which can be integrated into the SLM-process. The in-depth expertise and know-how of the consortium's members in their respective fields was key to the success of the present study.

Competences

This project is a common initiative of Sensima Inspection, inspire AG – icams, and hepia.

Sensima Inspection was in charge of developing a new implementation (sensors and acquisition electronics) based on its extensive knowledge in non-destructive testing of metal components.

The Innovation Centre for Additive Manufacturing Switzerland (inspire – icams) integrated the aforementioned monitoring technology into a R&D SLM-setup, to test the technology on additively manufactured samples.

The Haute École du Paysage, d'Ingénierie, et d'Architecture (hepia) performed CT-scanning of SLM-manufactured samples and brought its expertise in analysing it, thereby allowing the correlation between material defects and Sensima's sensor data.

Summary

Metal Laser Powder Bed Fusion (LPBF) processes, such as Selective Laser Melting (SLM), have been of high interest for the last two decades, owing to their potential to revolutionize manufacturing. However, the LPBF processes still present several drawbacks, such as a lack of consistent manufactured part quality assessment, thus requiring expensive post-process analysis. In order to overcome this problem and to enable a direct qualification of SLM manufactured parts for demanding industrial applications, it is necessary to develop technologies able to deliver fast and reliable build quality assessment.

In the project, a non-destructive testing (NDT) electromagnetic (EM) technique is applied, taking advantage of the normative framework developed for industries such as power generation or aerospace. The technology has been adapted to match the AM requirements. The developed solution will allow reaching the next level of SLM-process- and parting qualification, requested by many applications.

Through a two-phase project the NDT technique was tested and calibrated in order to detect typical material defects such as cracks, connections defects and porosity. The applied methodology was to correlate spatially resolved defect imaging from EM sensors with the results from CT-scanning. The first phase, "off-line", permitted to evaluate the capabilities of the NDT technology and design a SLM-oriented sensor, whereas the second phase demonstrated a successful integration of this technology into a R&D SLM machine, allowing on-line monitoring of manufactured part quality.

SENSIMA inspection

hepia
Haute école du paysage, d'ingénierie et d'architecture de Genève

inspire

Results

The off-line measurement of samples with different porosity levels showed that it is possible to identify a drift in the porosity in a SLM sample (Figure 1). Such a drift is critical in AM as it could occur due to unstable machine conditions (i.e. filter condition). CT scanning confirmed this porosity drift as well as the presence of other designed defects.

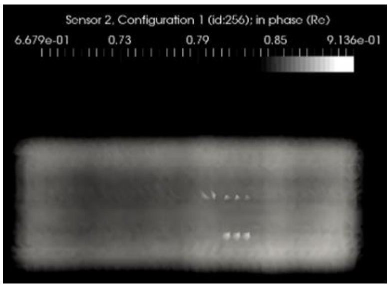

Figure 1 : Drift in porosity over a SLM sample of SS316L

The integration of the sensing technology into the R&D SLM setup allowed a layer-wise 2D scanning of the sample’s top surface throughout the build process. Different 2D scanning parameters (e.g. pitch, speed) have been investigated and optimized. In order to approach a near-certification level, the defects used to calibrate the sensor were designed according to the ISO standard 15548 for non-destructive testing. The technology developed in the frame of this study enabled detecting defects down to a typical size of 0.5mm. The detection was successful for additively processed SS316L and a R&D-type Al-alloy, proving the versatility and potential of the technology. The correlation with the CT scans permitted to generate the first 3D consistent file coupling: CAD, layer wise part quality monitoring and CT scanning (Figure 2).

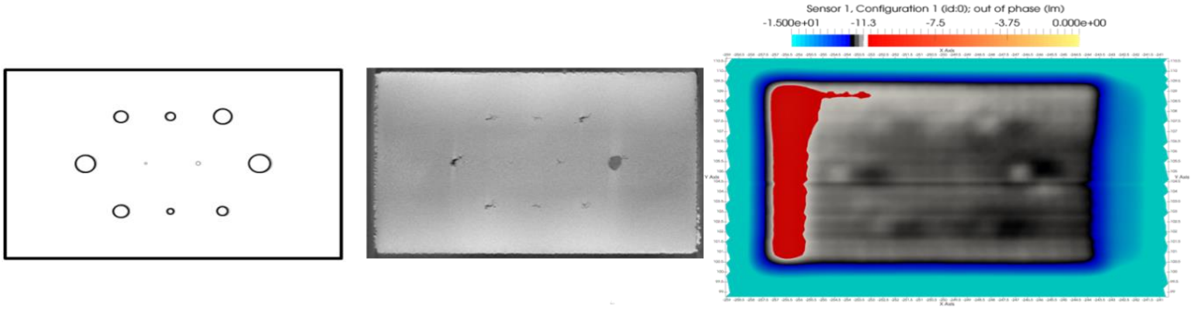

Figure 2 : One layer representation of comparison between three 3D files. From left to right CAD according to ISO 15548, CT scanning, electromagnetic NDT technique part quality monitoring

These results also enabled the development a software framework permitting the precomputation and the evaluation of metallic components manufactured by the SLM process, which will allow better and easier detection of the defects during the built-process.

Conclusion

A new in-process part quality monitoring solution for metal laser powder bed fusion processes was successfully demonstrated. The feasibility study reached a TRL-level between 4 and 5. The demonstrated solution is considered as a major step towards an easy and cost-effective qualification of metallic components produced by LPBF-processes. By this, the technology complements existing qualification approaches, such as melt-pool monitoring.

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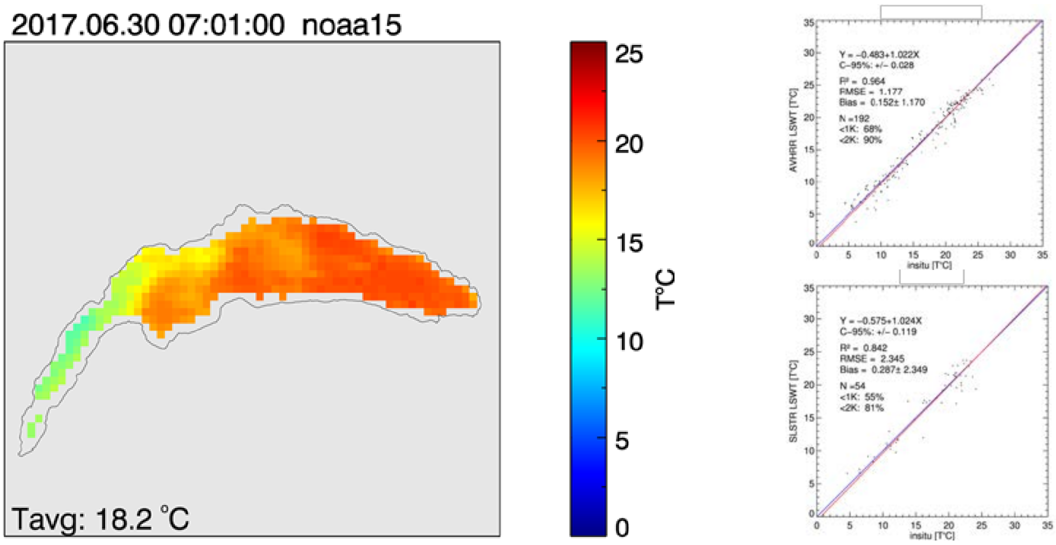
Multi-Sensor Application for LSWT Processing (MuSenALP)

Competences:

The MuSenALP project is a collaboration between the University of Bern's Remote Sensing Research Group (RSGB) and Odermatt & Brockmann GmbH. Both partners share a strong interest in remote sensing of surface waters. RSGB services one of the largest historical Earth observation data archives in Europe, extended by their 24/7 receiving facilities. This record covers observations of the AVHRR sensors onboard NOAA and EUMETSAT satellites over Europe and Northern Africa since 1981. It is used for near-real time Lake Surface Water Temperature (LSWT) retrieval for hydrodynamic modelling as well as in long-term climate studies. Odermatt & Brockmann facilitated the first decade-long inland water biodiversity data archive from ENVISAT data, and using ESA's open source image processing software toolboxes.



Left: LSWT map, retrieved from NOAA-AVHRR sensor and processed with MuSenALP; Right: Comparison of AVHRR LSWT (top) and SLSTR LSWT (bottom) with in-situ measurements at Lake Geneva.

Summary:

Our shared goal is the development of a multi-sensor application for LSWT retrieval with ESA's Sentinel Applications Platform (SNAP), based on the AVHRR prototype processing chain of RSGB. This SNAP plugin can be deployed in advanced processing environments and enables the usage of the RSGB prototype processor in operational services. It ensures the continuation of the AVHRR Lake Surface Water Temperature climate record with 1 km resolution data from ESA's Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR), but allows also for the use of sensors with better spatial resolutions (e.g. Visible Infrared Imaging Radiometer Suite (VIIRS) I-channels). This consolidated application will foster improvements towards the usage of LSWT as Essential Climate Variable, and strengthen Switzerland's competence and presence in an expanding application field.

The MuSenALP plugin is based on SNAP's Python library snappy, and it enables the use of several different input data types from different spaceborne thermal radiometers, and different retrieval algorithms depending on the number of thermal bands available from these radiometers. Indispensable auxiliary data from radiative transfer simulations can be ingested in various manners, including approximation through a regionalization concept. A quality level procedure is included that allows for the improvement of retrieval accuracy through selection of favourable observations. The plugin experienced initial testing and bugfixing in the scope of several application studies, and will be assessed and developed further in the scope of the project partner's research and service activities.

Results:

The plugin's multi-sensor capabilities and the adequacy of the regionalization concept are verified at the example of Lake Geneva. We compared LSWT from several hundred Sentinel-3 SLSTR datasets to the AVHRR long-term climate time series, with reference to in situ measurements provided by the Aquatic Physics Group of EPFL and for quality levels optimized for AVHRR. The resulting performance for SLSTR is already quite robust and will further improve once sensor-specific qualiy level optimization is available for SLSTR.
Using the MuSenALP plugin, LSWT at improved spatial resolution of 375 m is available from a single band (I-channel) of the VIIRS sensor onboard the SUOMI NPP and NOAA-20 satellites. Given that single band LSWT is expected lower accuracies than split-window retrieval, we compared with the standard Environmental Data Record skin temperatures provided by NOAA. Biases between the two product types for small lakes in Switzerland (Greifensee and Lake Sils) were 1.4 °K and 0.9 °K, respectively, which is considered a good agreement.
Further testing included the use of 100 m Landsat-8 TIRS data, which have recently undergone a recalibration process for the correction of straylight artifacts. However the LSWT output was still subject to prominent banding effects and a significant bias from ferry measurements on Lake Constance. It is thus still not recommended using Landsat-8 for LSWT retrieval, but it is anticipated that the availability of a high-resolution thermal radiometer on Sentinel-8 (currently in phase A) might lift the remaining resolution limitations.

Conclusion :

The MuSenALP project produced the first multi-sensor LSWT retrieval plugin for the open source SNAP toolbox. This plugin enables a variety of downstream usages for climate impact and ecosystem monitoring, but it also consolidated a long-term effort by different scientists at RSGB, and allowed Odermatt & Brockmann to build competence in the implementation of SNAP plugins. In this sense, it improves our capability for future investigations and further developments in related fields for both partners.

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CORDET Extension Project

Development of a Software Framework for On-Board PUS Application

Competences:
The CORDET Extension Project was done jointly by P&P Software GmbH of Switzerland and the Department of Astrophysics of the University of Vienna. P&P Software have specialized in the application of software re-use techniques to mission-critical embedded applications, notably in the space domain. The Dept. of Astrophysics in Vienna have extensive experience in the development of software for satellite payloads.

Summary:
Virtually all space-based applications developed in Europe are based on the Packet Utilization Standard (PUS). The PUS is a standard introduced by ESA to define the protocol through which on-board applications make their services available to each other and to the ground.

P&P Software GmbH have developed the *CORDET Framework* as a software framework for PUS-compatible on-board applications. The CORDET Framework pre-defines an architecture for handling PUS service requests and provides a set of C-language components which implement this architecture. The components are offered with a Qualification Data Package which provides the verification evidence normally required by ESA for level B space applications and normally required by other industrial standards for mission-critical applications.

In order to foster its use, the CORDET Framework is available on a free and open source licence (see: https://www.pnp-software.com/cordetfw/).

The Department of Astrophysics has demonstrated the benefits of the CORDET Framework. It has used it for the development of the payload software of the CHEOPS satellite and has found that this resulted in an accelerated implementation process and in simpler implementation and configuration for the payload services.

This project had two objectives:

1. To extend the usability of the CORDET Framework by developing the *CORDET Editor* as a GUI-based environment to automate its instantiation, and
2. To extend the scope of the CORDET Framework by providing a *Service Extension* to implement the most commonly used PUS services

P&P | software

institut für astrophysik
UNIVERSITÄTSSTERNWARTE WIEN

Results:

Both project objectives have been met. A prototype version of the CORDET Editor is available as a web-based tool at: https://www.pnp-software.com/cordetfw/editor. Users can access it after registering with their e-mail address (registration is free). Local installations on a company server can be obtained by applying for a commercial licence from P&P Software GmbH.

The tool can be used to define the commanding and reporting interfaces of one or more PUS applications. The interface information is entered in a set of tables and is then stored in a database. Facilities are provided to navigate and edit this information and to generate from it items such as an Interface Control Document (ICD), a C-language implementation of key application components, and configuration files for the instantiation of the CORDET Framework. The generators are implemented as simple python scripts which users can modify to suit their needs.

The PUS Extension of the CORDET Framework is available as a public GitHub project at: https://github.com/pnp-software/cordetfw. It has been developed using a full model-driven approach and it currently supports the following PUS services:

- Service 1: Command Verification
- Service 3: Housekeeping Reporting
- Service 5: Event Reporting
- Service 13: Large Packet Transfer
- Service 17: Test

A test suite with a coverage level close to 100% is provided with the framework.

Conclusion:

The CORDET Framework is a flight-proven product which has demonstrated its potential for reducing cost and development times for on-board PUS applications. This project has extended it with tool support and with an implementation of key PUS services. Both the tool and the PUS service implementations are expected to be used for the payload of the SMILE satellite. Both items – the CORDET Editor Tool and the PUS Extension – will be further extended and in the near future.

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Superlative Wideband Waveguide Imaging Spectrometer (SWWIS)

"Breakthrough realization of fully integrated waveguide spectrometer"

Competences and Background

The two partners for the SWWIS project are ETH Zürich, the Optical Nanomaterial Group (ONG) within the Institute for Quantum Electronics, and Micos Engineering GmbH.

The ONG is part of the department of physics, located at the ETH Hönggerberg campus. The goal of the ONG is to understand the behaviour of metal-oxide materials at the nanoscale for developing compact devices for optoelectronics or imaging applications. The research focuses on strategies to enhance nonlinear optical signal in nanostructures as well as imaging techniques based on multiphoton process for developing new microscope designs.

Micos is an SME devoted to the engineering of optical instrumentation for space applications, while having in clear focus the development of forefront technologies for spectroscopy. Micos has been active in a series of R&D activities aiming at developing integrated Waveguide Imaging Spectrometers (WIS) including an ESA TRP activity in response to the feasibility demonstration of an innovative spectrometer operating in the NIR region, the MdP2012 study "NAOMI" aiming at the study of nano-antennas for VIS and NIR, a necessary building block for waveguide spectrometers, and the MdP2014 study "MAGDA" which proved the potential of highly integrated mono-layer graphene detectors and the performance of nano-antennas in the infrared.

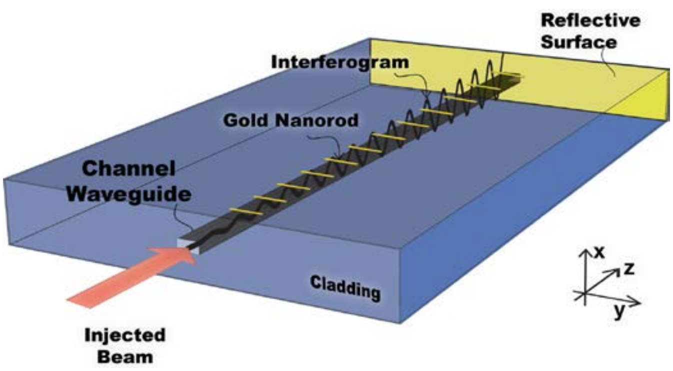

Figure 1 Illustration of a Lippmann waveguide spectrometer based on single-mode waveguide [*Source: M. Madi, et al. "Lippmann waveguide spectrometer with enhanced throughput and bandwidth for space and commercial applications," Opt. Express 26, 2682-2707 (2018)*].

Summary

The SWWIS work was inspired by the activities of Micos aiming at the achievement of highly miniaturized spectrometers and is based on a Micos/ESA patent application filed in July 2016. The ETH team's expertise in electro-optical materials to achieve an integrated device complemented well the goal of the MdP2016.

The baseline concept firstly conceived in MdP2012 and its successive architecture implementation identified in MdP2014 allowed to identify the SWIR/MWIR spectral range as a range for several applications for spectroscopy (analogies with SWIR-

1, -2 and SWIR-3 channels studied in CARBONSAT, TROPOMI and Sentinel 5 form mentioning some examples) but also telecommunication applications (optical fiber based telecommunication products operate on SWIR- 1 like wavelengths).

The SWWIS study targets the concept-proof of a novel interferogram scanning technique for waveguide spectrometers. A successful realization of this concept yields a fully integrated device for extremely miniaturized and solid spectroscopy without any moving parts. The new concept allows for instance to compress bulky classical imaging spectrometers into a very compact focal plane array. The proposed interferogram scanning technique is based on electro-optical/thermal effect in waveguide material to realize a broadband waveguide-based interferogram acquisition system, which is suitable for applications in dynamic Fourier Transform spectrometers or others.

The bandwidth of current Fourier transform waveguide spectrometers is limited since the interferogram samplers are spatially distributed on the waveguide with relatively large sampling distance compared to the guided-wavelength. In addition, the state-of-the-art technologies in Lippmann configuration are unable to recover the interference information of a broadband signal stored at the edge of the reflective surface. The innovative solution explored in SWWIS is to scan the interferogram below the fixed samplers using the electro-optical effect of lithium niobate waveguide material within the waveguide itself. This is done by varying the index of refraction of the waveguide module while applying an electric field. The change in the refractive index of the waveguide modifies the effective path length resulting in scanning the interferogram in front of the fixed samplers.

Conclusion

The SWWIS team has demonstrated that an interferogram can move in front of nano-samplers, which are at fixed positions on the waveguide core, by using the electro-optic effect. We have overcome the traditional problem of the state-of-the-art waveguide spectrometer devices without amending any external mode or adding moving parts such as a piezo-actuated mirror, which has been lately proposed to overcome similar problems. The breakthrough outcome of the SWWIS activity opens the way towards commercialization of highly integrated waveguide spectrometers with largely enhanced spectral performance.

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Thermo-Mechanical Virtualization of Hybrid Flax/Carbon Fiber Composite for Spacecraft Structures (THERMICS)

"A project to improve thermo-mechanical testing of powerRibs composite plates for validation and calibration of high-fidelity multi-axial constitutive material models."

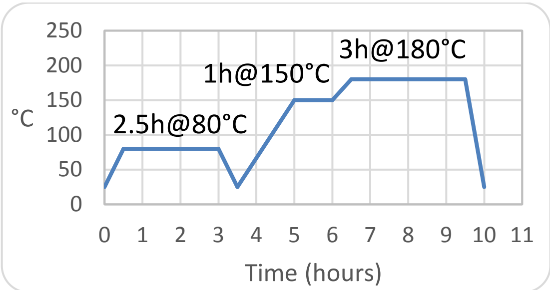
Competences:

Bcomp (industrial partner) develops innovative reinforcement solutions based on flax fibre ribs for composite materials, namely powerRibs, which are renewable and recyclable and thus less harmful to the environment. Bcomp has a solid experience on sport and automotive applications where it's active since 2003. More recently, Bcomp entered the aerospace business where thermal loads pose new challenges to powerRibs. The Chair of Structural Dynamics and Earthquake Engineering of ETH Zürich (academic partner) pioneered the development of thermo-mechanical hybrid testing, a simulation paradigm where a computational environment provides realistic loadings and feedbacks to the tested structural component in a virtual co-simulation.

Summary:

Weight reduction still represents the key challenge in space. Nevertheless, the traditional way of developing spacecraft still tends to address structural and non-structural functions separately, resulting in suboptimal load-bearing elements with add-on attachments performing non-structural functions with penalizing added weight. The increased interest in multifunctional materials (MFM) is driven indeed by the need to develop multifunctional structures (MFS) that simultaneously perform (a) multiple structural functions e.g., stiffening and damping (b) combined non-structural functions e.g., thermal and damping control or (c) both e.g., stiffening and thermal control. Along this line, the powerRibs technology already demonstrated superior performance in term of specific bending stiffness while increasing damping and lower price compared to carbon fibre composite. With the objective in mind of developing a high-fidelity constitutive material model of powerRibs to be used for the purpose of structural modelling/optimization, we developed a thermo-mechanical test rig (TMTR) that enables thermo-mechanical characterization tests of composite plates subjected to realistic multi-axial and thermal loadings. The calibration of a refined constitutive models of powerRibs composite solutions based on flax fibres paves the way to real applications on spacecraft structures.

a



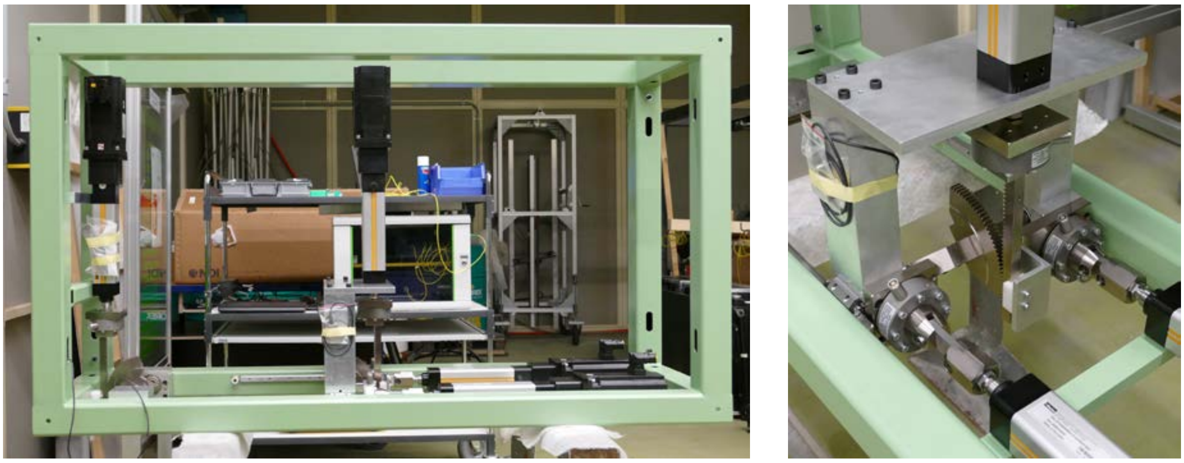
b

PowerRibs sample: a) 200x600x0.5mm plate b) curing process.

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Results:

The TMTR combines a mechanical loading system based on four linear electromechanical actuators equipped with load cells, laser position sensors and angular resolvers and a thermal loading system based on infrared lamps and Peltier modules. A real-time computer programmed via MATLAB/SIMULINK controls the experiment, acquires the data and interfaces to numerical simulation platforms.



a *b*

Mechanical loading system: a) steel frame; b) kinematics of the clamp.

a *b* *c* *d*

Main components of the thermal loading system: a) infrared lamp; b) heat flux gauge; c) infrared camera; d) Peltier module.

Conclusion:

This study tackled the fundamental challenge in conducting thermal structure testing, that is, the application of realistic thermal and mechanical boundary conditions covering the expected operating range of the specimen. The need of minimizing mechanical fixtures, which inevitably perturb the thermal response, along with tight integration of thermal and mechanical loading systems limit the geometrical complexity of the tested specimen. As main conclusion, testing of relatively simple structural components under complex loading conditions represents the optimal trade-off between complexity of testing equipment and relevance of measured data to model validation and calibration.

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Flexible Optical Solar Reflector

Involved Partners

APCO Technologies:

APCO Technologies SA is a renowned PME active in different engineering domains with more than 25 years' experience in space. The lead role in MGSE design and manufacturing and the high number of flight hardware projects, ranging from satellite structures to space mechanisms, makes APCO Technologies one of the most important actors in the domain: thanks to it, R&D is enhancing the improvements high quality products already offer on the market.

Empa – Material Science and Technology

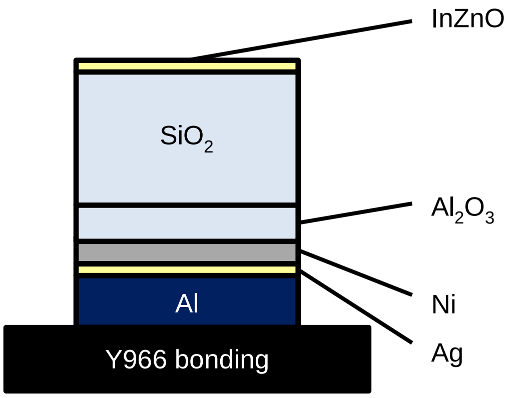
The coating competence center (CCC) at Empa gains expertise in various state-of-the-art surface technologies such as magnetron sputtering, E – beam evaporation and 3D – printing. The purposes are to perform cutting – edge research and to translate the scientific discoveries into innovative products.
The Laboratory for Thin Films and Photovoltaic under the lead of Prof. Dr. A.N. Tiwari has been involved and lead numerous research and industry oriented projects. The group has extensive knowledge on the deposition and characterization of thin films.

Project Summary

The objective of this study was to develop an innovative flexible optical solar reflector, whose installation would be much easier than the classic OSR, and however presenting same or better thermo-optical properties, and to reach a TRL level 3 or 4.

FOSR Design

The FOSR is designed such that a high emittance (ε) and at the same time a low absorptance (α_S) can be ensured. To prevent electrostatic effects, a sheet resistivity r_s < 2.0 kΩ/sq is needed. Following structure was determined and the layers were deposited by E-beam evaporation or magnetron sputtering respectively.



Material	Function
Al	Substrate
Ni	Adhesion
Ag	High reflectivity
Al_2O_3	Transition layer
SiO_2	Emittance layer
InZnO	Conductivity

APCO TECHNOLOGIES

Empa
Materials Science and Technology

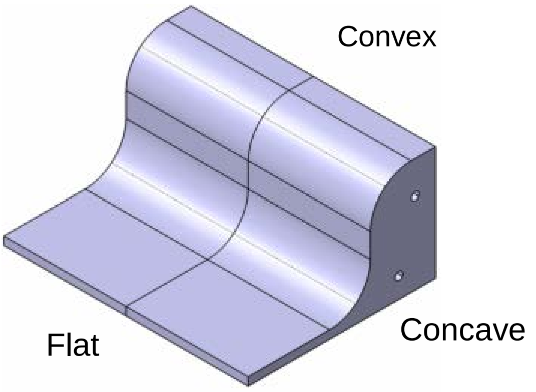
FOSR Performance

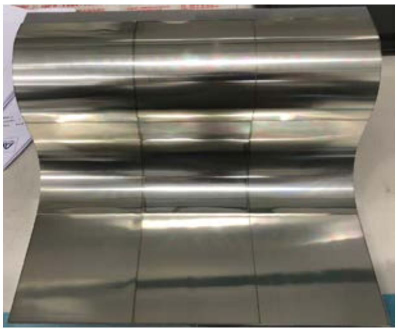
The FOSR was subjected to 100 thermal cycles between -70°C and +100°C in vacuum. Absorptance, emittance, sheet resistivity and minimal radius of curvature, were the coating is still functional was determined before and after thermal cycling. The performance of the champion device is summarized in the following:

Property	Before thermal cycling	After thermal cycling
Absorptance	0.065	0.066
Emittance	0.803	0.801
Sheet resistance	1.12 kΩ/sq	0.96 kΩ/sq
Radius of curvature	40.41 mm	34.58 mm

Demonstrator

The demonstrator is composed of 9 FOSR units that are bonded on an aluminium support, which present a flat, a concave and a convex surface in order to simulate all the possible cases.





Conclusion:

FOSR is a new promising product able to be installed on different geometries and surfaces with one axes of curvature thanks to the demonstrated flexibility and resistance of the stack. It is easy to apply on the target surface and it already demonstrated the strong stability of its state of art performances for thermal-vacuum space environment, ensuring potential stability to its function all along space structure operative life.

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Lightweight Ceramic Foam Composites and Novel Environmental Testing for Space Applications

A feasibility study of lightweight ceramic foam behaviour in various space environments

Competences

The Laboratory of Renewable Energy Science and Engineering (LRESE) at EPFL aims to advance renewable energy conversion and storage through research into production of renewable fuels, power and materials. Experimental and numerical work in thermal sciences is particularly applicable to space technology and porous material research. de Cavis AG offers a combined 20+ years of experience in technical ceramics processing and manufacturing. A novel foaming technology enables production of porous ceramics with properties tailored to various applications. de Cavis' main activities focus on material and process development, prototyping and upscaling.

Scope and Results of the Project

The aim of the project was to develop layered lightweight ceramic foam composite panels and test their fitness for various space applications like satellite shielding, heat exchange and storage systems. Extensive material characterization and post-test analysis were performed at LRESE in existing or newly designed experimental facilities. Various numerical models were utilized to support the design of experimental setups or to enable a deeper understanding of the material behavior.

Topics	Methods	Measured Key Properties / Aim
Mechanics	3/4-point bending Sine/random vibration	Bending strength (*S*) and modulus (*E*) Vibration resistance, fundamental modes
Thermal testing	HFSS & environmental chamber Plasma torch	Low (on-orbit) & high flux (demise/re-entry) Thermal cycling/thermal shock
Thermo-mechanical testing	Thermal cycling followed by 4-point bending	Bending strength after thermal shock
Post-test analysis	Light/electron microscopy UV-NIRS spectroscopy	Microstructural changes Changes in optical properties
Simulation techniques	Finite element for mechanics Heat transfer and CFD Illumination and ATOX erosion	Design factors for test equipment Confirmation of experimental results Material modeling for potential applications

The high flux solar simulator (HFSS) with >20 MW/m^2 maximum flux and the newly developed environmental chamber were used to test material samples and components in a controlled environment (at different temperatures, pressures and gas atmospheres), coupled to a shutter for thermal cycling and a UV-filter for isolating the effect of high energy photons. The capabilities of the HFSS facility are:

Experiment	Flux Levels/Modes	Environment	Sensors
Low flux (on orbit) and high flux (demise/re-entry) Thermal cycling/shock	Magnitude: 14 - 1300 kW/m^2 (up to 20 MW/m^2); UV filters Shading (up to 3 cycles/min) Exposure times: 10 min – 8 h	Pressure: 1atm - 1 Pa Temperature: up to 2000 K Various atmospheres/ gases	IR camera CCD camera Thermo-couples

de Cavis developed also layered foam composite panels with dimensions and mechanical properties as listed below. In HFSS demise experiments at fluxes of 1300 kW/m^2, 40x40x20 mm^3 pure foam and Design 1 panels show local melting only and

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE crack formation in the peak flux area, despite of heating rates up to 140 K/s.

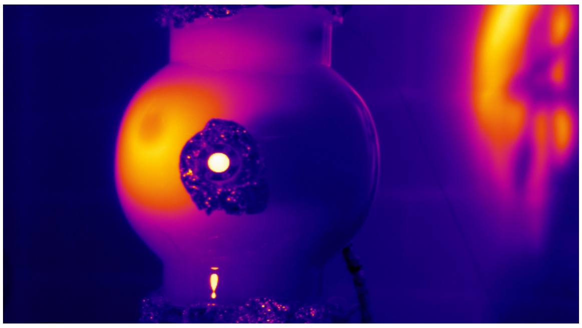

Figure 2: Experimental chamber with window for temperature recording during a low-flux experiment in the HFSS at EPFL/LRESE

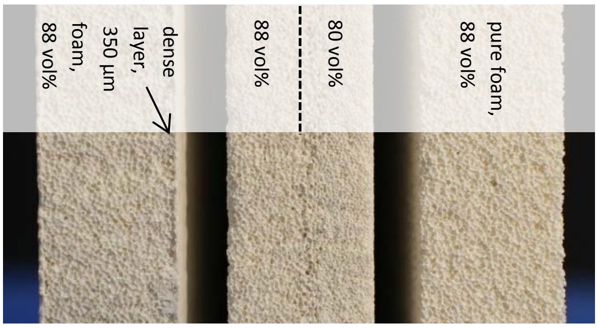

Figure 1: de Cavis aluminosilicate foam and composite panels. Design 1 (left), Design 2 (middle), pure 88 vol% porous foam (right)

Label	**Layer 1 (density, porosity) (g/mL, vol%)**	**Layer 2**	**Dimensions (mm^3)**	***S* (MPa)**	***E* (GPa)**	**Random Vibration**
Pure foam	0.33, 88 0.54, 80 0.68, 75	n/a	100x20x5	1.4±0.0 2.5±0.1 2.9±0.4	1.0±0.4 2.1±0.1 2.7±0.2	n/a
Design 1	0.33, 88	dense, 350 µm	100x100x10	1.9±0.1	2.2±0.2	5 g pass
Design 2	0.33, 88	0.54 g/mL, 80 vol%	100x100x10	1.9±0.2	1.3±0.2	5 g pass

Thermal cycling at 1000 kW/m^2 with 5 cycles and 10 min on/off time at atmospheric pressure did not reveal changes in the thermal response. However, a reduction of the bending strength was observed after treatment at 136 to 520 kW/m^2. Steady state sample temperatures and thermal gradients are listed below. In plasma torch experiments, demise conditions with T >1700 K were not achieved at 600 A maximum current and pressure of 2 mbar. During post-testing, small cracks are observed on the surface. FE simulations confirm that the materials can bare quasi-static and random vibrations required for a launch. The natural frequencies are above the critical interval.

Material	**Flux (kW/m^2)**	**T_{max} (K)**	**T_{min} (K)**	**Difference (K)**	**Gradient (K/mm)**
pure foam 88 vol%	136 / 1000	700 / 1545	349 / 404	351 / 1132	18
pure foam 80 vol%	1000	1500	419	1079	54
pure foam 75 vol%	1000	1450	427	1021	51
Design1	1000	1390	391	987	49

Conclusion

de Cavis' lightweight ceramics fulfil the mechanical criteria of ASAP-S for a launch, and the strength of the materials is resisting large thermal shocks and thermal cycling at high temperature gradients. Demise is possible at high thermal fluxes. Potential applications are high temperature shielding, heat exchange and storage.

The HFSS facility at EPFL/LRESE enables testing of space materials at low (on-orbit) and high flux (demise/re-entry), thermal shock and cycling conditions at flexible heat fluxes (full spectrum or UV-only). Using the environmental chamber, experiments can now be conducted at various temperature, pressure, and gas atmospheres.

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