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**State Secretariat for Education, Research and Innovation SERI**
Swiss Space Office

swiss space center

# Space Technologies Studies 2014: Results


16 February 2016
EPFL, Lausanne, Switzerland

Welcome to the presentation of the ten projects funded under the call for proposals issued in 2014 by the 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”.

## List of the projects:



The content related to each project is the property and sole responsibility of the corresponding authors. For any questions, you are invited to contact them directly.

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# Carbon-Fibre Heat-Pipe for Spacecraft Thermal Control

*A proposition to overcome the mismatch in coefficients of thermal expansion between aluminium heat transfer structures and carbon-fibre based spacecraft structures*

## The project partners' competences:

The industrial partner Icoflex is one of the very few companies worldwide that has mastered micro powder blasting technologies on hard and brittle materials such as ceramics, glass and fibre reinforced plastics. Its micro-machined products, such as gold through glass vias and quartz-based objects, are currently used in biomedical and aerospace applications. The academic partner, the EPFL's Laboratory of Heat and Mass Transfer (LTCM), is one of the world-leading academic groups in the field of two-phase heat exchange systems such as heat pipes. Their past and on-going research projects span across the design and optimization of innovative two-phase heat exchangers and the development of needed visualisation and characterisation methods.


**Summary**:

Heat-pipes are critical spacecraft parts used to regulate the thermal loads. They run along the spacecraft structure between the heat sources and heat sinks. The heat-pipe design preferred in space application consists in circular tube with inner axial grooves operating as a passive system driven only by temperature differences. To overcome the mismatch of the coefficient of thermal expansion between a standard aluminium heat pipe system and the CFRP spacecraft hull structure, CFRP heat exchange systems are desired to increase reliability and reduce system weight and hence reduce launching costs.

Making full CFRP heat pipes is a challenge from both the manufacturing and the functional optimization points of view. These were overcome by the introduction of an innovative direct powder blasting machining idea by the industrial partner. This was then applied to CFRP material tubes to produce CFRP heat pipes whose thermal performance was subsequently evaluated at the EPFL-LTCM.

## Results:

A powder blasting machining strategy for CFRP tubes was successfully implemented. The absence of critical defects, such as cracks in the CFRP matrix or residual abrasive particles, was confirmed by x-ray tomography analysis of the resulting pieces. This is in contrast to classical CFRP machining techniques, like CNC machining or water-jet cutting, which introduce cracks and humidity typically unacceptable in space applications. The photo shows inside a CFRP tube with 0.7mm wide and deep grooves; these grooves are similar in size to those in standard Aluminium-extruded heat pipes.

*View inside a machined CFRP tube*

## Conclusion:

The project proved that CFRP heat pipes, with internal wicking structures produced by micro abrasion, provide acceptable thermal cooling performance for space applications. For future studies, these devices should be tested with ammonia as the working fluid under typical thermal and pressure loads for space deployment. Structurally, a means to integrate bends in the heat transport assembly has to be developed. Furthermore, CFRP heat exchangers are of interest to many other terrestrial applications where weight and performance are paramount. These include cooling the heat sources of transportation vehicles (cars, trains, planes etc.) and mobile devices incorporating electronics (laptops, mobile phone, drones etc.).

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IcoFlex

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

# Thin-Walled Composite Structures with Improved Damping Properties by using Natural fibre composites and thin ply carbon fibre technology

## Competences:

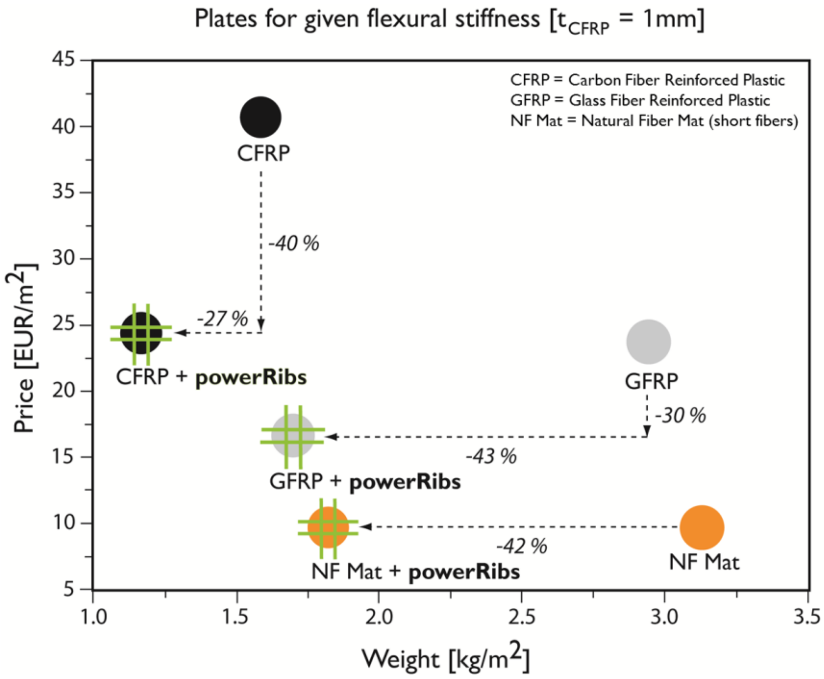
The Institute of Polymer Engineering at FHNW has extensive knowledge in industrial manufacturing technologies of advanced composites for high performance applications. The international group aims to bring high level academic research to industrial applications in various aspects: design, simulation, analytical modelling, tooling, manufacture, joining, nanoparticles/nanostructures, recycling and materials science of thermoset and thermoplastic based fibre reinforced composites.

Since it's founding in 2011, Bcomp has been focusing on the understanding of natural fibres and their composites. They have been developing solutions bringing striking performance benefits in addition to the lower ecological footprint to the end product. Their current focus lies on reducing weight in semi-structural mobility applications and adding manufacturing simplicity to the automotive in the form of powerRibs (Figure 1).

## Summary:


Weight reduction is a substantial driver to achieve higher energy efficiency in launching space structures such as satellites or measurement probes/telescopes. Typically, lightweight structures are however, prone to vibrations, leading to unwanted instability, reduced efficiency or in severe cases, structural failure.

Bcomp has been developing powerRibs technology, a natural fibre mesh creating ribs on composite shells, which allows outperforming carbon fiber composite in term of specific bending stiffness of thin shells at a lower price (Figure 2) whilst adding valuable damping functionality with our newest results demonstrating 14 fold increase on the coupon scale.

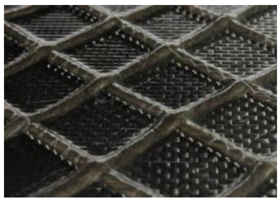



**Figure 1: Carbon powerRibs**

**Figure 2: Price-weight comparison at a given flexural stiffness for different standard composite materials with- and without powerRibs, respectively.**

University of Applied Sciences and Arts Northwestern Switzerland

Bcomp®

In order to better understand the damping phenomena, a systematic study of damping as a function of fibre orientations and frequencies was conducted on flax fibre composites combined with carbon fibre composites made of thin plies. These new design freedoms provide valuable stiffness and damping via pre-programmed microstructures. Damping modelling based on an extension of the classical laminate theory was also conducted to learn from our experiments and create predictions for a multitude of new designs. This modelling approach uniquely allows for damping by design, which could deliver tremendous gains in efficiency and weight when designing parts for any application where mobility and accelerations are a consideration: since the damping is already considered in the design phase. Furthermore, a new impregnation method has been developed using powerRibs to shorten process cycle (50 times faster) whilst adding specific stiffness and damping.

## Results:

The measurements confirmed the superior damping of flax, which was generally more than twice as high as for carbon fibre composites. The fibre angle and frequency dependency were modelled, allowing good prediction of damping for a random laminate (Figure 3). This modeling has been verified on micro-mechanical scale measurements and using beams on the macro-mechanical level.

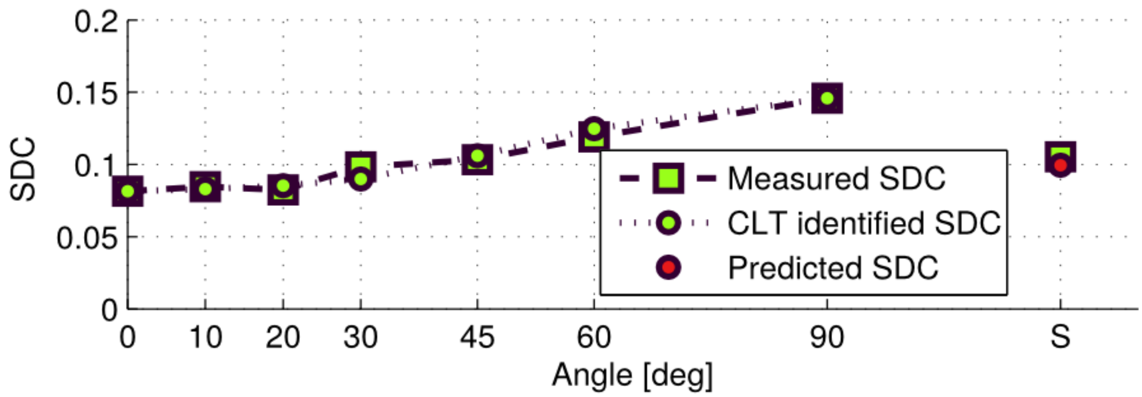



**Figure 3: Measurements with DMA at 1Hz of the damping (SDC) of angle ply flax laminates as a function of fibre angle and identification of the damping coefficients (SDC). A single prediction is shown for any arbitrary example laminate, S, on the graph, demonstrating tremendous accuracy of the developed method.**

## Conclusions:

This study highlights the outstanding damping performance of flax and allowed a better understanding of damping phenomena, confirming the high potential for using flax layers or the flax powerRibs technology to gain stiffness and damping simultaneously while reducing cost. It also confirmed the need to conduct further characterization (fatigue, long –term behavior, radio-transparency) to reach TRL4 and then evaluate it for the use in thin light shells applications such as RF-shielding, sun shielding or closing parts in satellites. Importantly this study demonstrates that natural fibre materials are viable, add value and are a credible clean alternative in tomorrow's space endeavors.

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# Artificial Muscles for Reconfigurable Millimeter-wave Antennas (AMRA)

**Competences**:
This project has put together two EPFL laboratories, the *Laboratory of Electromagnetics and Antennas* (LEMA) and the *Microsystems For Space Technologies Laboratory* (LMTS), together with the company *ViaSat Antenna Systems, S.A.*, based in EPFL Scientific Park. ViaSat focuses on the design and development of commercial antenna systems for satellite telecommunications, both in the space and ground segments. Therefore it was the ideal industrial partner to support a prospective research on a new type of antenna, which could be made possible by the combination of the LEMA experience on innovative antennas design and the LMTS expertise on the miniaturized actuators expected to be one key component for these new antennas.

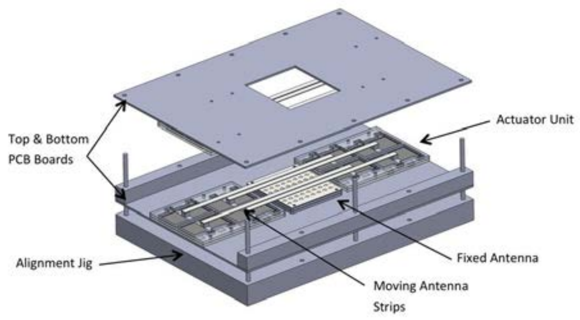
**Summary**:
Antennas are ubiquitous devices in our wireless connected world. However, the classic antenna used to be a device with fixed characteristics and performances. This is no longer neither satisfactory nor acceptable in modern telecommunication systems, where a given antenna should be able to change dynamically its characteristics and adapt dynamically to both external commands or variations in their external environment. In other words, antenna should be able to “reconfigure”.
Dynamic reconfiguration of antennas is becoming a prime need in space-related applications centered around the Ka frequency band (26-40 GHz). Reconfigurable antennas are needed for spacecraft antennas but even more in ground terminals. Here, new satellites will afford soon the possibility of providing broadband communications and services to at least 2 millions of residential and enterprise users of satellite Internet. To exploit this increased bandwidth, the market demands consumer terminals, whose price and easiness of installation should be comparable to those of current TV-satellite terminals. A simple but efficient reconfigurable antenna, able to dynamically steer its beam, would be the key element in these new terminals. One possible solution, whose feasibility has been investigated in this project, is to use a reflectarray antenna (RA) where the reconfiguration properties are obtained by the use of Dielectric Elastomer Actuators (DEAs), also known as artificial muscles.
This was the goal of the AMRA project. Reflectarray antennas combine the advantages offered by more traditional antennas like parabolic reflectors and active phased arrays. They are flexible, easily to fabricate using inexpensive technologies and well adapted to reconfiguration. On the other hand, artificial muscles offered a very interesting and unexplored alternative to the current devices used to reconfigure Ka-band antennas (micromotors, MEMS, diodes and related active electronic components, liquid crystals, graphene...). This solution was considered very

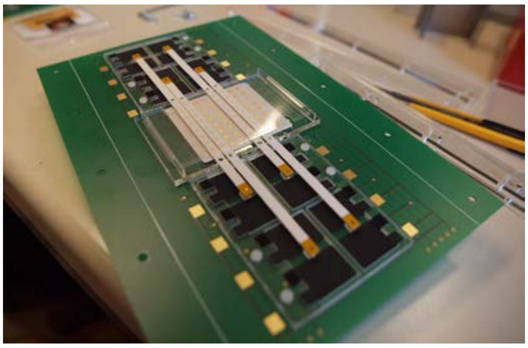
interesting and full of potentialities by ViaSat. On the other hand it corresponded to the core competences of the two EPFL Laboratories, LEMA (antenna design and characterization) and LMTS (miniaturized actuators).

The basic idea was to consider separately the different antenna elements of a planar reflectarray and to reconfigure them by introducing small displacements, made possible by attaching planar DEAs to the reflectarray elements. DEAs appear as a technology of choice for achieving mechanical reconfiguration in reflectarray systems, due to their appealing properties, that include inexpensive materials and fabrication process, relatively large (at least for Ka band) displacement easily controlled by a DC voltage, and very low DC power consumption. The combination of the RA concept and DEA actuation has the potential to provide a low-cost and pseudo-planar device with very low-loss, low power consumption, and able to achieve the sought-after beam-scanning reconfiguration. The ultimate objective of this project was to demonstrate at a proof-of-concept level that the combination of an emerging technology, dielectric elastomer actuators, and the reflectarray concept can provide antenna reconfiguration.

## Results:

Thanks to the efforts of the LMTS and LEMA teams working in excellent coordination, the design proposed at the beginning of the project and consolidated after the first six months of intensive work, has been able to be prototyped and measured. The figure shows the successful transformation of a computer-generated design into a real-life working prototype. The measurement results confirm the theoretical expectations. Under the effect of the actuators, a deflection of the antenna beam up to 30 degrees was conclusively observed.



## Conclusion :

The project has been highly successful and the constructed prototype is a solid proof of principle for the concept of using DEAs to reconfigure antennas. Due to the limited resources, the prototype is only able to deflect the beam in one direction. Currently, a mechanical rotation of the antenna should be used to achieve 2D beam steering. Also, the original design needs a dedicated vacuum system for a correct performance of the actuators. This unexpected complication could be solved by a proper redesign ab initio of the antenna elements

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# hybSat

*"Hybrid lightweight and flexible circuit boards (FCBs) for satellites and space"*

## Competences:

**HIGHTEC MC AG** is a privately owned microelectronic manufacturer SME located in Lenzburg specialized in development and production of thin films on substrates (e.g. $Al_2O_3$, AlN, and glass), flexible multilayer circuits on polyimide (PI), assembly of microcircuits, and packaging of dies, sensors and MEMS.
**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 in micro-/nanotechnologies and ICT, and transferring them to the industrial sector.


## Summary:

The objective of the **hybSat** project was to position the Swiss industry (HIGHTEC MC AG) and a Swiss Research and Technology Organization (CSEM SA) as leaders in smart flexible circuit boards (FCBs) offering key advantages compared to today's printed circuit boards in terms of reduced weight, increased flexibility, added functionality and small footprint. This will be achieved by the combination of inkjet printed passive and active electrical components (e.g. resistors and capacitors and organic photodiodes (OPDs)) on a FCB with integrated high-end SMDs, e.g. amplifier. The gain in smaller footprint, lower mass, added functionality will be a key asset for applications in the space domain.


## Results:

To fully demonstrate the potential of this hybrid technology the hybSat project has developed a hybrid FCB-based Sun Sensor (extremely thin and light weight, < 2g.).

A sun sensor currently used in the SwissCube pico-satellite is shown in Figure 1 (top left). It is made of two printed circuits boards connected by (red) wires: one for the sensor and one for signal processing. The hybSat mock-up shown in Figure 1 integrates inkjet printed resistors, capacitors and the light sensors e.g. OPDs (CSEM) on one PI foil that is folded up using the flip-chip-like concept (HIGHTEC).

## Conclusion:

The main lesson learnt from the hybSat project is that every components required in the hybrid sun sensor is demonstrated at the stand-alone level with printed techniques thus showing no "red brick wall" for the fully printed sun sensor demonstrator.

Secondly the connection-on-demand approach probing SMD versus printed resistors/capacitors turned to be a key enabling system integration approach for smart FCBs.

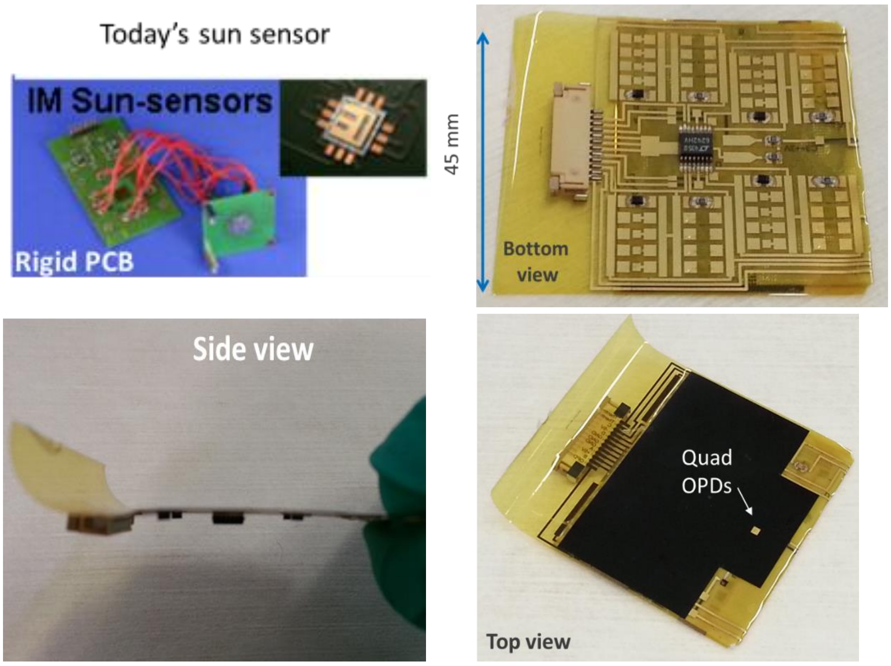


**Figure 1. Top-left: SwissCube's sun sensor. Top-right and bottom row: hybSat assembled and folded mock-up with inkjet printed resistors, capacitors, OPDs and SMD amplifier.**

Thirdly the developed hybrid technology (printed passive/active components monolithically assembled with high end SMD components on FCB) offers new possibilities to the system designers (smart PCB), material providers (printable functional inks) and extends the current range of products.

Fourthly CSEM's technology in hybrid electronics is transferable to HIGHTEC production line (inkjet printer) thus enlarging their product/service portfolio.

Finally out of this hybrid technology a wide range of smart FCB-based products are expected such as: health monitoring sensors (heartbeat, temperature sensors, etc.), environment monitoring sensors (pressure, irradiation, etc.), etc.

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# Mid-Infrared Antennas and Graphene Detector Arrays (MAGDA)

*"A road-map towards graphene-based detectors"*

**Competences**:

The two partners for the project "MAGDA (Mid-infrared Antennas and Graphene Detectors Arrays)" are Empa, the Swiss Laboratory for Material Science and Technology in its Reliability Science and Technology laboratory, and Micos Engineering GmbH. Reliability Science and Technology laboratory at Empa performs reliability and failure analysis investigations both as direct services for industry and on a basis of research projects. One of the core expertise of the laboratory is the development of methods for structuring and characterization of optical and electronic devices at the micro- and nano-meter level. For the MAGDA activity, the access to the Electron Beam Lithography (EBL) facilities at FIRST Lab of ETH Zürich and to the Gallium Focused Ion Beam and the more recently installed Helium Ion Microscope Zeiss Orion were provided. This equipment is a very unique combination and represent key elements to enable reliable and reproducible prototyping of the nanostructures with sub-30 nm dimensions on top of the waveguides. In particular, the laboratory has a solid experience in manufacturing and handling graphene technology.

Funded in December 2010, Micos Engineering GmbH is a new player acting on the European space market. Micos, as a company is aiming at positioning itself as a reference for remote sensing instrumentation engineering with a clear focus on spectroscopy. Its profile and capabilities are closely related to the profiles of its founders and key employees. Micos has been initiating a series of R&D activities aiming at developing highly 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 nanoantennas, a necessary building block for waveguide spectrometers, and an industrial PhD thesis funded by ESA/NPI program supporting WIS miniaturization activities.

From a product development perspective, being waveguide spectrometer an innovative concept based on breakthrough developments starting from low TRL, a number of pitfalls have been encountered. Micos mid-term goal is to manufacture a product line of miniaturized imaging spectrometer products and to support with excellence the implementation of space-borne missions for remote sensing applications.

## Summary:

The focus of MAGDA is investigating the feasibility and capabilities of graphene detection arrays as key enabling technology also in combination with nano-antennas to enhance the response of graphene by mean of Plasmon resonance. The scope was to investigate alternative detection capabilities in the IR spectral range while allowing integration of the detection circuits directly on substrates of interest in a very compact architecture. Alternative to traditional sensing techniques nowadays available, graphene detectors in fact allow firstly a high degree of miniaturization and on-wafer integration, secondly, a common architecture covering the sensing of the electromagnetic spectrum from x-ray to sub-mm waves. This features of a graphene-based detector enables the possibility to implement state of the art imaging spectrometer units in a volume of few cubic centimetres, electronics included.

## Results:

A breadboard demonstration of graphene nano-detectors integrated on waveguides, aimed at testing the performance of graphene photodetectors in real spectrometer configuration has been carried out. In addition, a preliminary demonstration of a functional fully-static SWIR spectrometer was achieved in the course of MAGDA activity.

## Conclusion:

By means of the previous MdP2012 NAOMI Micos had identified a manufacturing principle for waveguide-based sensors, particularly suitable for waveguide-based spectrometers but not only. With MAGDA that concept has been brought further in its feasibility, while investigating other aspects critical for the achievement of miniaturized, fully integrated, optical sensors. Despite the positive outcome of MAGDA's activity, further research and development work is required to optimize and bring forward several aspects in view of a functional breadboard and of a successive productisation.

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# ADULA

*AD-converter With PLL for Space Applications*

**Competences**:
The ADULA project is a collaboration between Saphyrion Sagl and the Advanced Learning and Research Institute, Faculty of Informatics, Università della Svizzera Italiana, Lugano (USI-ALaRI). Saphyrion was in charge of the design, manufacturing, test and industrialization of the ADULA ASIC, USI-ALaRI's contribution to the ADULA project was mainly the design and synthesis of the digital block that includes a serial interface and a register array with Hamming error correction.
The ADULA ASIC was implemented using design techniques for radiation tolerance developed by Saphyrion for its space-borne ASIC products, which are flying already in some ESA Earth Observation missions.

**Summary**:
The main goal of the ADULA project was to design and implement a radiation-hardened, dual channel 3-bit AD-converter, 8-bit DA-converter and PLL for Space applications. This chip is mainly meant to complement the DiReRa ASIC, currently in development in a parallel project, although other applications in various telecommunications purposes can be envisaged.

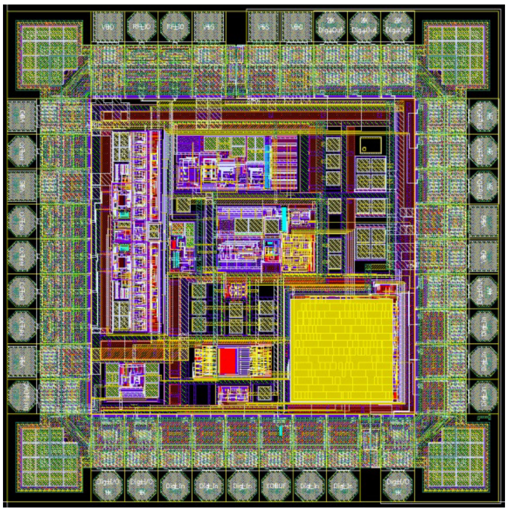
The 3-bit AD-converter is based on a Flash architecture, which is the most efficient architecture for the very low resolution required for these AD-converters. A sampling frequency of up to 130MHz (100MHz performance guaranteed under worst-case conditions) is supported. Since the design of the AD-converter is static, a wide range of sampling frequencies down to ideally 0Hz is supported.

The 8-bit DA-converter is meant principally to drive a VCA gain control input of the companion DiReRa chip, i.e. a DC voltage. No particular speed requirements therefore exist. In order to obtain good linearity without requiring calibration, a two-stage resistive divider architecture has been used. Such architecture in fact provided a DNL = ±0.1LSB and INL = ±0.2LSB, making this DA-converter interesting also for different applications that require an 8-bit low frequency high linearity DA-converter.

The frequency synthesizer is an integer-N PLL with on-chip ring VCO able to generate frequencies from 20MHz to 130MHz in two ranges. Its main purpose is to generate the sampling clock for the 3-bit AD-converters.

Since PLL output and sampling clock input of the AD-converters are independent, the frequency synthesizer can be used also for applications unrelated to the 3-bit AD-converters, as long as its requirements and limits are respected.

The ADULA ASIC is configured by programming its register array via a synchronous serial interface, which partly conforms to the SPI specification. As a means to prevent registers corruption during write under a high radiation environment (heavy ions), parity check is used. The registers control power modes, main divider of the PLL and the 8-bit DA-converter. Their contents is protected against single event upset (SEU) errors with Hamming error correction able to correct up to one SEU error per register per clock cycle.



The ADULA prototypes, manufactured by means of Multi Project Wafer runs, were tested and characterized extensively; all circuits operate properly and fulfil the requirements, in some cases (e.g. VCO's phase noise) with a quite large margin.

## Conclusion:

The ADULA chip is the result of a collaborative effort between Saphyrion and USI-ALaRI that proved quite effective. The design required just about one year of work and was completely successful. Thanks to the good results achieved by these prototypes, Saphyrion decided to proceed with the industrialization of the ASIC. At the end of this still quite long and mainly self-financed process, the ADULA device will be ready to be sold to customers and will be introduced in Saphyrion's product catalog of Space-qualified ASICs.

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# Improvement of GNSS kinematic positioning with low-cost receiver clocks

## Competences:

The project is a joint effort between the Institute of Geodesy and Photogrammetry (IGP) at ETH Zurich and the company Spectratime in Neuchâtel. The consortium joins its very complementary expertise for the first time for this proposal in order to open a new field of applications for low-cost, miniature but high-stability clocks, as developed by Spectratime, in the area of positioning and navigation. IGP at ETH Zurich has a strong background in high-precision Global Navigation Satellite System (GNSS) positioning and navigation and the use of high-precision clocks for geodetic applications, whereas Spectratime has already realized miniature atomic clocks in the frame of the ARTES program. In view of the upcoming European GNSS Galileo, the use of high-precision clocks to improve positioning and navigation may become a very important aspect with a potentially large future market.

## Summary:

In this project we assessed the benefits for positioning and navigation applications connecting the low-cost high-stability clocks provided by Spectratime to low-cost GNSS receivers (e.g. u-blox receivers). The project studied the appropriate modeling of the low-cost but high-stability receiver clocks to improve the kinematic pseudorange Precise Point Positioning (PPP) suffering from very high correlations between clock and height estimates. The studies were performed in three steps:

- Study and clock modelling using simulated and real IGS data
  A low-order polynomial and relative clock constraints between subsequent and near-subsequent epochs with different weights were applied as clock model and tested in simulations with different measurement scenarios. Apart from that, real IGS data was also used to test the influence of different clock models on kinematic PPP solutions in post-processing and real-time mode.
- Hardware preparation and field experiments
  The low-cost rubidium clocks (GRClock 1500) from Spectratime were successfully connected to low-cost u-blox receivers. Static experiments on the roof of our ETH building and kinematic experiments onboard an airplane, a ship and a car were performed during summer 2015 using the combined low-cost receiver-clock units.
- Analysis of the experimental results
  The results of the field experiments were analyzed with the Bernese GNSS software in post-processing mode and a real-time software package in real-time mode. The influences of the different clock models on the kinematic code positioning solutions were studied with respect to the clock quality, the applied clock models and the measurement condition.

## Results:

The results of the field experiments show that the modelling of the low-cost but high-stability clocks provided by Spectratime can improve the vertical component of the kinematic PPP solutions by a factor of 1.5 to more than 10.

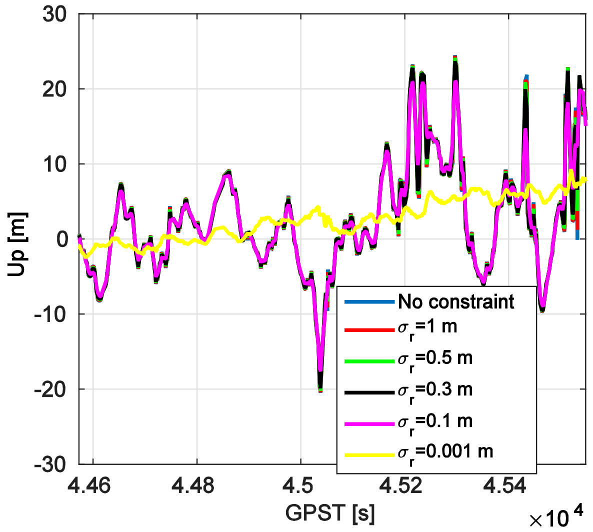


**Figure 1: Height differences between the receiver-clock unit and the ground truth during the field experiment on a car applying different clock constraints $\sigma_r$.**

The improvement achieved in kinematic heights is strongly influenced by the clock stability, the measurement noise and the measurement conditions. In general, applying clock modelling to better clocks leads to larger height improvements. It was also found that a larger measurement noise and worse measurement conditions, e.g., in urban areas with a lot of obstructions and multipath, lead to a larger potential to improve the kinematic height estimates.

Figure 1 shows the deviations of the heights estimated by the combined receiver-clock unit using L1-only pseudorange observations from the ground truth during a field experiment on a car in the city of Zurich. A quadratic polynomial and relative constraints with different weights were applied for clock modelling. We see that appropriate clock modelling significantly reduces the large deviations in the kinematic heights.

## Conclusion:

In this project, low-cost but high-stability rubidium clocks provided by Spectratime were successfully connected with low-cost GNSS receivers. Applying an appropriate modelling for these clocks significantly improves the kinematic height estimates and is especially helpful in bad measurement conditions with large multipath effects or low number of available satellites. Present-day clocks, as those used in our experiments, have not yet reached the level of miniaturization that is required for the most widespread applications like smart phone positioning and car navigation. For scientific applications and for applications, where a very reliable determination of the height is key and where costs, power, size and weight may not be as important, there may be a market for such a combined system consisting of a low-cost GNSS receiver connected to a low-cost high-precision clock. The miniaturization of clocks and the associated costs reduction is on-going and, in the future, such technology will become as competitive as alternate navigation enhancement technologies like integrated IMU systems.

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# Phase Unwrapping Parallel Accelerator (PUPAx)

**Competences**:
sarmap (www.sarmap.ch) is a Swiss company founded in 1998 that builds and provides sophisticated and innovative remote sensing software products. sarmap is at the forefront of technology in terms of signal and image processing related to the topic of Earth's natural/environmental resources observation.

ICS (www.ics.usi.ch): the Institute of Computational Science (ICS) hosts eight research groups and is regarded as one of the largest institutes in Switzerland devoted to computational science. Its aim is to exploit the capabilities of modern numerical methods and supercomputers, in order to tackle problems of increasing complexity – from exact and natural sciences to economics and social, bio-medical, environmental, materials, and engineering sciences.

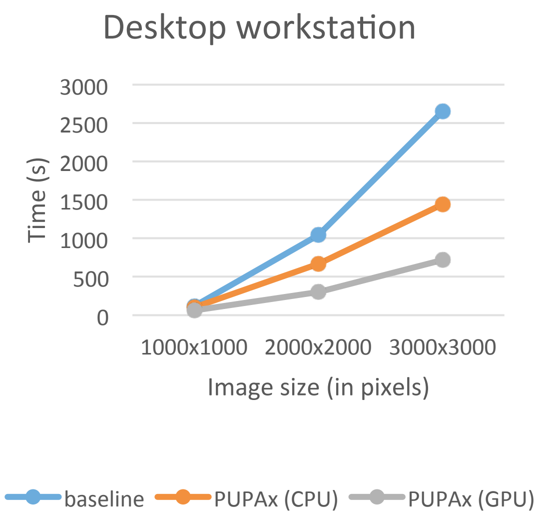
**Summary:**
PUPAx is a multidisciplinary project aiming to provide a new sophisticated product for Synthetic Aperture Radar (SAR)-based imagery that takes advantage of modern parallel computational means.

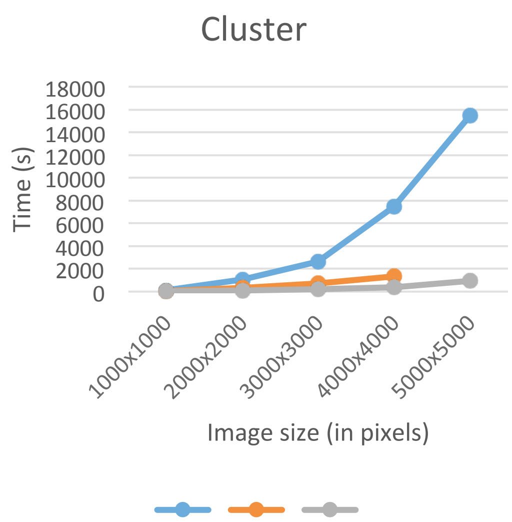
The target of PUPAx is to provide a faster software module for the computation of phase unwrapping, which is a complex key-algorithm widely used in SAR-imagery that requires up to several days of processing to converge to a solution. Achieving an efficient, state-of-the-art software implementation of the phase unwrapping algorithm on modern computational hardware, such as multicore and Graphics Processing Units (GPUs), is a challenging task, that needs a significant amount of knowledge and experience in the fields of computational mathematics, parallel computing, software engineering, and remote sensing. Through this project, we propose to fill the gap between the algorithmic maturity of phase unwrapping and the spread of massively-parallel devices, with a competitive new product that the remote sensing community demands.

**Results:**
The core of the phase-unwrapping algorithm requires the computation of the Minimum Cost Flow (MCF) over a large graph with up to few billions nodes and arcs. We reformulated the MCF problem through the Interior Point Method, an iterative approach mainly based on vector and matrix operations, which can be efficiently parallelized and executed both on multicore and GPUs.

We implemented two new software modules, one on top of OpenCL (to support CPU- and GPU-accelerated processing on desktop workstations) and one based on the scientific computation library PETSc for cluster execution.

Both modules provide a significant speedup over the previous implementation (baseline) in terms of speedup and scalability. According to the following charts, the OpenCL-based module is about 40% (on multicore CPU) and 70% (on GPU) faster than the baseline, while its PETSc counterpart scored an impressive scalability when used on a distributed configuration with variable number of nodes:




The current generation of GPUs (left chart) cannot (yet) directly compete to supercomputers, but things are rapidly evolving and the right chart shows that we already have the technology to exploit the next-generation of graphics adapters.

## Conclusion:

The project has identified a new class of algorithms with a good potential for an efficient parallel implementation. In this way, we are able to take advantage of the multiple cores of the machines and to exploit GPGPU technology.

The phase unwrapping problem has been expressed as a more general problem that can be solved mostly through typical BLAS functions, for which a faster evolution of the base solvers and APIs can be expected.

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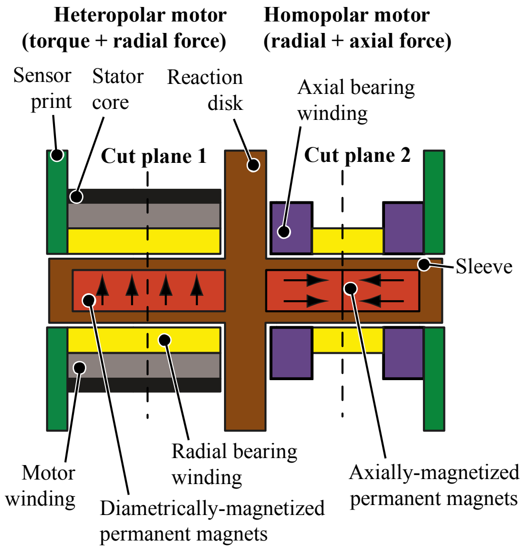
# Miniature high-speed magnetic bearing reaction/inertia wheel for small satellites

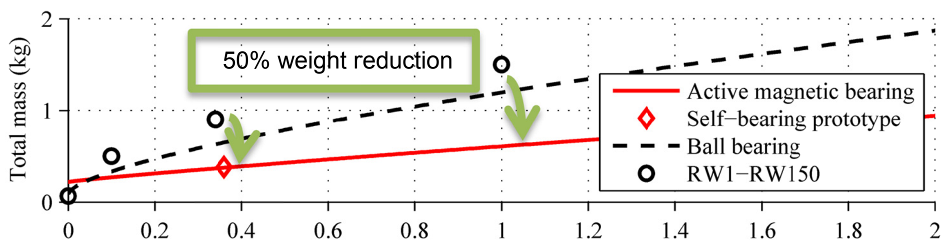
## Introduction

Lorentz type magnetic bearings have many advantages compared to ball bearings in space applications such as:

- No bearing speed limit → Allows for 50% weight reduction reaction wheels
- Low micro vibrations → Major benchmark criteria for all space actuators
- Increased lifetime → Major benchmark criteria for all space actuators
- Vacuum operation

In this study applying the Lorentz type magnetic bearing to a reaction wheel application is investigated.

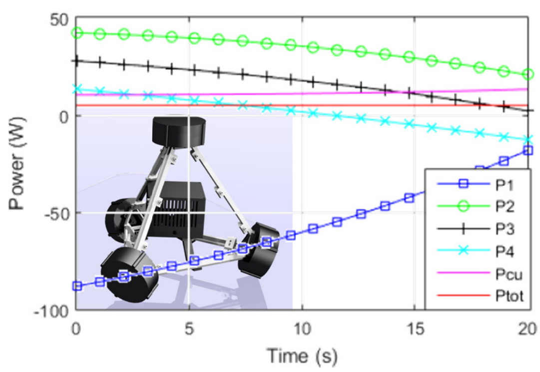



## Results

**Torque generation and power recirculation in a reaction wheel assembly**

A simulation model of a 2- and a 4-reaction wheel assembly is used to determine the optimum torque profiles for the individual wheels. As a result, the required angular momentum change can be generated while the electrical power extracted from the decelerating wheel is used by the accelerating wheels, keeping the external power requirement (Ptot) of the reaction wheel assembly to a minimum.




ETH
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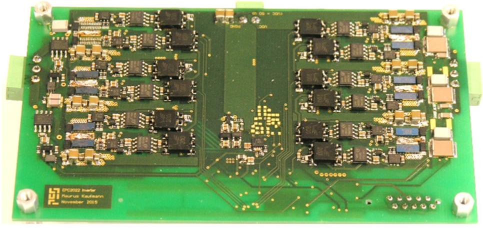
Power Electronic Systems Laboratory

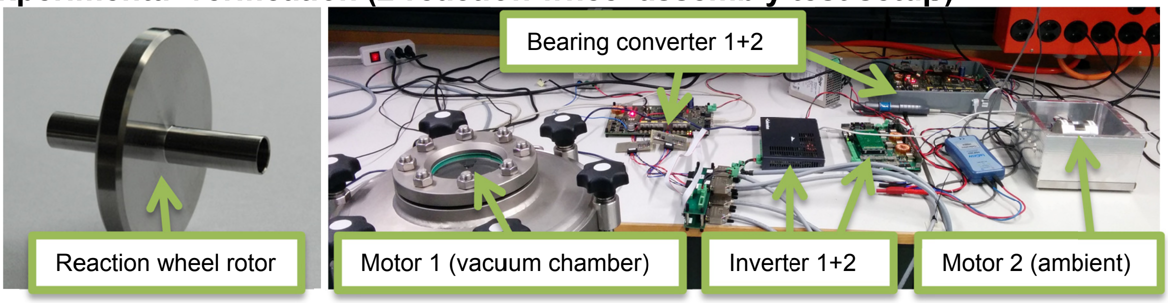
Celeroton
ultra-high-speed electrical drive systems

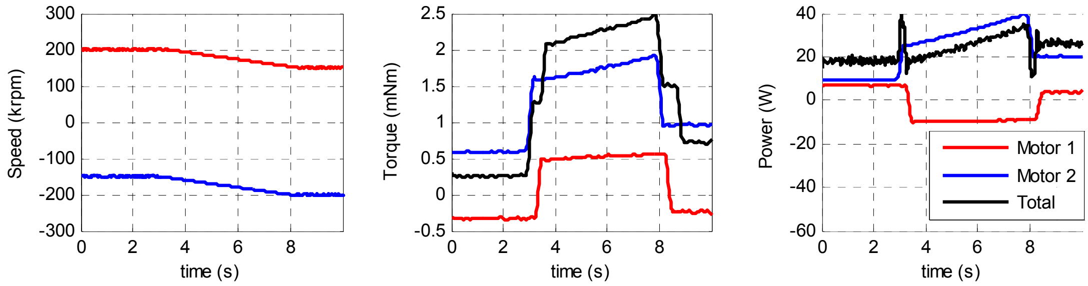
## Inverter design and realization



High (>200 W) power is circulated between accelerating and decelerating wheels, therefore a high efficiency and high power density inverter is required. Following a comparison of topologies and operating modes, a 6-phase inverter featuring 3.4 kW/dm$^3$ power density and 96.5% efficiency is designed and realized.

## Experimental verification (2-reaction wheel assembly test setup)




# Outlook

### Identified main requirement for future reaction wheels:

- Analysis and optimization of low microvibrations
- Investigation in subsequent projects (NPI, ITI)

### Identified challenges for future integration in reaction wheel:

- Dipole of motor: torque by stray field interaction with geomagnetic field
- Power loss during operation: touchdown
- Launch: vibrations

## Contacts/Competences:


**Academic Partner:**
Power Electronic Systems Laboratory
ETH Zurich, www.pes.ee.ethz.ch
Physikstrasse 3, 8092 Zurich


Multi-domain simulation, design, construction and testing of very high efficiency and low weight/volume power electronic systems and electrical machines. PES has broken world records for highest speeds in electric machines utilizing both mechanical and magnetic bearings.


**Industrial Partner:**
Celeroton AG, www.celeroton.com
Industriestrasse 22, 8604 Volketswil


Development, production, sales and complete solution provider of ultra-high-speed electric machines, optimized converters and turbo compressors. Celeroton replaces volume and weight with rotational speed across all industries.

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Power Electronic Systems Laboratory

ultra-high-speed electrical drive systems

# Lightweight Deployable Solar Array

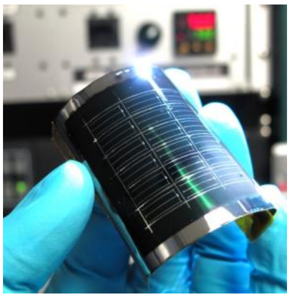
## Competences:

**APCO Technologies SA** is an independent Swiss company, specialised in the design and manufacture of high quality mechanical and electromechanical equipment for the Space and Nuclear industries.

**EMPA** Laboratory for Thin Films & Photovoltaics is doing research and development of highly efficient thin film solar cells, mainly focussing on novel concepts to improve the performance of solar cells. EMPA concentrates on simplification of production processes and improvement of the device structure of next generation solar cells with higher efficiency at lower cost for terrestrial as well as for space applications.

## Summary:

Future satellite power subsystem will be designed to achieve higher power level, higher launch packaging densities (kW/m3) and lower unit costs ($/kW). Increasing power could be achieved by a scale-up of the current and most common technologies, such as rigid flat panel solar array, but are likely to be very expensive and require larger launch vehicles due to their inherent packaging limitations and low mass efficiency. Flexible CIGS solar cells offer the potential for providing very high power levels in a lightweight configuration that can be compactly packaged for launch. However, the lower power-conversion efficiency of flexible CIGS solar cells compared to existing multi-junction photovoltaic technology means that larger deployed areas are required to provide a given total power.

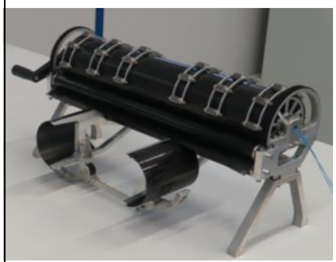


The objective of this project was to develop lightweight deployable support structure equipped with EMPA's latest high efficiency flexible solar cells and to demonstrate its technical and economic efficacy.

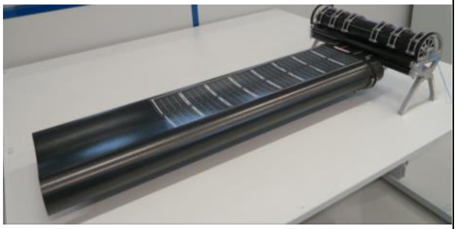
## Results:

During the project, the maximum allowable deformation of the CISGS cells was defined by various mechanical tests combined with electronical performance. We were able to define a safe operating environment for the cells in the foreseen application.

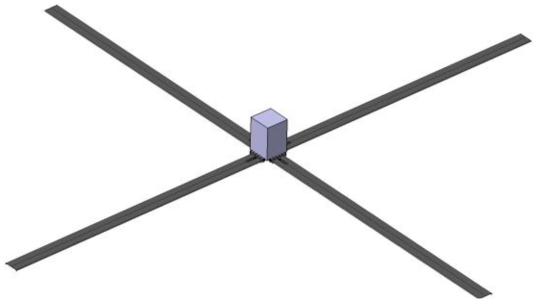
The thermal experiments and theoretical assessments showed that thermomechanical stress between CFRP laminate and the solar cell structure does not lead to delamination or cell damage in the temperature range from -150°C to 200°C. No failure could be detected so far within the thermal environment.



A complete demonstrator was built and tested, combining the solar cell development, the structure support and the electrical architecture, within the project framework.



Based on the demonstrated technical feasibility, performance evaluations were performed for a given spacecraft with 4x4kW 25x1.2m deployed solar array considering EOL performance.



| | LDSA concept | Standard technologies |
|---|---|---|
| **Cost to power ratio** | 150 €/W | 500 to 1500 €/W |
| **Stowage density** | 28 kW/m$^3$ | 10 kW/m3 |
| **Power to weight ratio** | 147 W/kg | 50-100 W/kg |

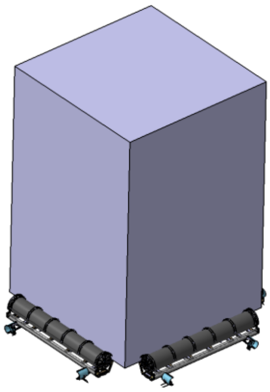
The presented concept is very cost effective.

This estimation is highly encouraging, when compared with traditional hinged solar array equipped with triple junction GaAs solar cells.

## Conclusion :

EMPA and APCO Technologies successfully achieved the objectives of the project:

- ✓ modification of the solar cells to improve resistance to cracks,
- ✓ development of the structure molding and of the deployment mechanism,
- ✓ development of the encapsulation of the complete structure/cell/array current collection.



The development successfully demonstrated that

- ✓ CIGS cells could be integrated on thin CFRP substrates,
- ✓ the assembly could survive the harsh space thermal environment observed on solar arrays,
- ✓ a flexible current collection can be integrated

The project did not only establish the principles of flexible solar arrays but also demonstrated that the manufacturing process from individual Photo-voltaic cells to complete solar array is feasible, at low cost, with very advantageous power-to-mass and cost-to-power ratios. As final achievement, a complete demonstrator was manufactured and tested.

Some technical aspects remain, on process side to improve performance, on design side to integrate the by-pass diodes and on test side to qualify the assembly against radiation.

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EMPA Materials Science & Technology

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