STAR CuCo

Space Timing & Advanced Ranging
for CubeSat Constellation

DE-RISK

Executive Summary Report

Topic:

Executive Summary Report of the project

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Prepared by:	Bastian Eder
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Executive Summary:

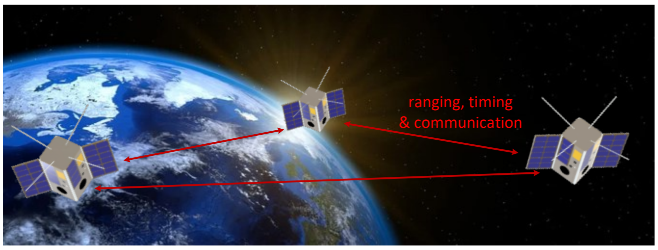

Figure 1: CubeSats with optical links for ranging, timing & communication in a formation flight

Satellite-based navigation, satellite internet or satellite data for climate research, these are just a few examples of how satellite-based applications have become an integral part of our daily lives. In the classical space industry, the development of conventional satellites takes decades and is associated with costs in the range of several hundred million euros. Due to the commercialisation of the space industry, the so-called 'New Space', small satellites (CubeSats) are coming to the fore. By implementing Commercial off-the-shelf (COTS) components and standardisation, the complexity, development times and costs are enormously reduced. When using multiple satellites, they can be interlinked to produce a common data product or function. This allows missions to be carried out with greater flexibility (adaptability, scalability, evolvability, and maintainability) and robustness (reliability, survivability, and fault tolerance) compared to a large monolithic satellite. Examples are XEUS with a too long focal length for a single satellite, or interferometry based payloads with a very important measurement basis, such as CODRIS, Darwin or LISA.

Crucial points for the performance of such a system are:

- distance measurement to control the relative position of the satellites
- time synchronisation between the individual satellites
- inter-satellite communication for networking, onboard fusion, and processing of data

Advancing the above issues is also described within the Technology Harmonisation Roadmap from the European Space Agency (ESA), which is prepared by ESA experts in collaboration with scientists and companies. The urgency and importance of this is highlighted. **So far there is no technology that fit into a CubeSat and can solve these three tasks with sufficient performance.**

Our company **MUnique Technology (MUT)** is developing the DORT (Dynamic Optical Ranging & Timing) technology. The DORT system is a disruptive technology for which the process to **patent** is already ongoing. DORT is an ultrashort pulse laser system that uses a novel mathematical algorithm. This innovation can be used for **long-distance measurement** as well as for very precise **optical time synchronisation** and **communication**. A laboratory setup for the verification of the technical feasibility of the DORT measurement principle is already established at MUT.

The first project planned is a gravity field measurement using CubeSat constellation flights. MUT is already in the planning phase together with satellite geodesy of the Technical University of Munich. Satellite gravity field missions offer a unique opportunity to continuously and globally observe climate-relevant mass transport and mass redistribution processes in the Earth system. Examples include the monitoring of sea level rise and ocean currents, the melting of ice masses, e.g. in Greenland and Antarctica, and the monitoring of changes in the global water cycle. In this context, gravity field missions represent the only available measuring technology that is sensitive to changes in groundwater levels. Against the background of an increased public interest in climate-relevant processes and as a central contribution to operational service applications such as the monitoring of droughts and floods, a large number of scientific studies for new satellite gravity field missions have been carried out on the basis of the successfully completed missions CHAMP, GRACE, GOCE and the current mission GRACE-FO. In particular, feasibility and economic efficiency play an important role for future missions, with the focus on increasing spatio-temporal resolution while reducing error effects.
MUT has a reference measurement system installed in their laboratory. Roughly summarised, the system consists of 4 components:

- mechanical setup (M)
- electronic setup (E)
- optical oscillator (O)
- optical transceiver (T)

The laboratory setup overview is shown in Figure 2 together with an illustration of the possible final setup for CubeSat applications.

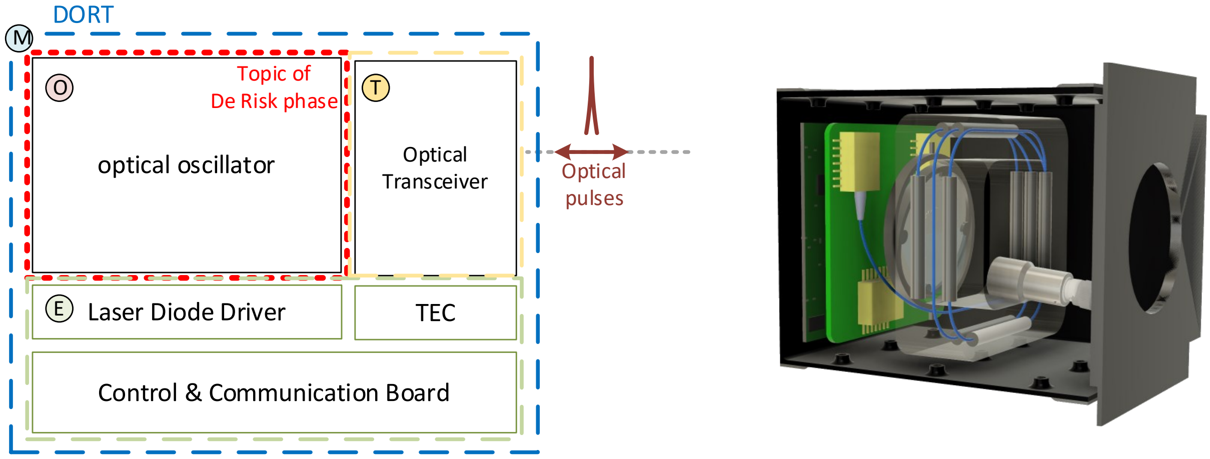

Figure 2: DORT system overview (left) and 3D simulation of setup (right)

The heart of the measurement system is the short pulse laser / optical oscillator. The oscillator is also the weak point for further space developments. The mechanical fragility as well as the special non-linear properties pose a challenge.

During the De Risk Phase, primarily the miniaturisation and the environmental impact on the laser system is investigated. Since the optics are special non-linear fibre optics, vibration and/or irradiation will also cause some limitations in the lifetime. Thus, in the first move, a mechanical adjustment is made to bring the system into the dimension of a CubeSat.

The second step is temperature. Since CubeSats do not have the same thermal stabilisation capabilities as science satellites, the temperature range that occurs for the payload will be considerable. The functionality of the optics will show changes, or the system may only be operational in a specific area. This has to be characterised.

In the third step, the mechanical loads during a rocket launch are then simulated on the system by means of a vibration test.

Radiation loads are an important influencing factor for glass fibres, as they strongly affect the quality of a glass fibre resonator. The fibre is darkened by the radiation load and the quality decreases. The radiation dose that can affect a system must be defined in order to calculate the average service life.

Miniaturisation and casting in resing:

By a new design of the laser oscillator, there is a first all-in-fibre setup available. Free beam parts e.g. for mode locking are adapted to be fibre coupled. Also, the optical part for dispersion compensating (crucial for ultra short pulses) is designed to fit within an optical fibre. The complete optical fibre setup has a length of approx. 3m, with only two optical coupling parts. One optical input for light pumping is available, and two outputs (monitoring and main output).

The size of the oscillator is then about 80mm x 80mm x 20mm, which fits in any CubeSat setup. This all-in-fibre setup enables to cast the complete system within resin. There are already space proven resins, which are applicable to use for the laser. After research, two promising candidates for the future tests are: **epoxy resin E45GE** from bredderpox and **epoxy resin PX700K-1** from Robnor. Their space-proven analogues in some properties are Appli-Tec 5051-E and Appli-Tec 5108-H respectively. Stycast 1090 is another space-proven candidate that shares some of the properties with the available resins.

A procedure is created to obtain reproducible results in the casting of different resins with space proven analogues. This procedure is not only important for the further development steps of the project. Since further optical subcomponents of the system are also to be cast in resin, this is a very important step for product development. Likewise, this document is a know-how gain for the company.

Thermal & Vacuum Tests:

Oscillator not only survived the test, but the mode lock state is more stable as originally expected. The temperature range is expanded to [5°C,45°C] and even within these new limits, the mode lock state is continuously available.

This lowers the requirements on the outer control electronic dependent on temperature stabilization. Additionally, since the DORT system does not require specific frequency stability, the requirements on control electronics is to start the laser in mode lock with single pulses only, and to adjust the output power continuously by increasing or decreasing the pump laser output.

The vacuum test shows no major impact on the setup.

The complete in-fibre oscillator casted in resin is applicable to fulfil the mission scenarios, without modification. Requirements on the outer control unit are decreased.

Vibration tests:

The oscillator embedded in resin managed to withstand the mechanical loads and the stress during the test showing that the resin casting could be used to provide mechanical stability and protection for the fragile optical elements. Hence, this method can be further used in the development of the DORT-System.

Radiation Tests:

The oscillator survived the radiation impact of a LEO mission scenario and a lifetime of 2years. Thus the minimum requirement of 1year lifetime is exceeded by factor 2.

The laser is in mode lock all time. The mode lock state changes are below the uncertainty limit.

The output spectrum does not change, which means no change in performance change of the DORT system.

The darkening of the fibre lowers the output power of the oscillator to 70% of the starting value. This can be compensated by increasing the optical power of the pump laser. This must be considered, when planning the laser driver of the oscillator.

The current all-in-fibre setup is suitable for applications for the planned mission scenario, with better performance as originally expected. All requirements are fulfilled.