Admission to 2nd year:

Space systems for optical communications

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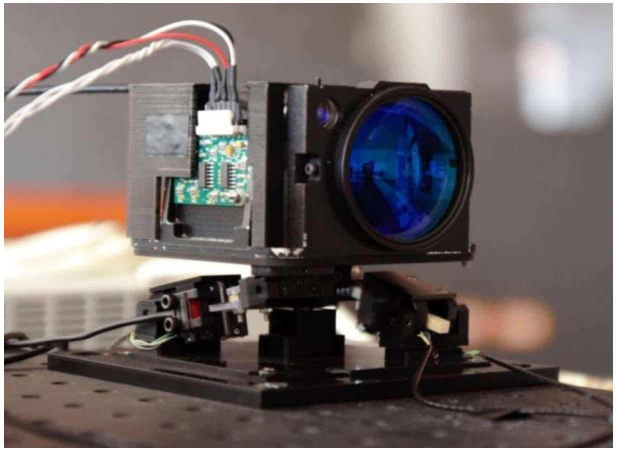
Context

- Apprenticeship contract at Stellar Project, spin-off of University of Padova.
- Startup core project: LaserCube, a miniature optical communication terminal for nano and micro satellites, compliant with CubeSat standards (2U).



LaserCube engineering model.

Laser Cube

Motivation and objectives

- Recent trend: integration of space technologies into private and governmental activities (crop management, forest and biodiversity management, sea traffic management, internet applications, climate monitoring etc).

- Increase in requirements for telecommunication systems in terms of data rate, latency, security and reliability.

- Radio-frequency systems: performance ceiling (R/P_{TX}), spectrum saturation, security related problems.

SOLUTION: Optical wavelengths → Narrow beam → Higher antenna gain

Advantages:

- Higher bandwidth efficiency
- No bandwidth regulation
- Data security
- Quantum applications

Challenges:

- Higher pointing requirements
- Cloud coverage
- Components and systems TRL

Research approach and expected outcomes

Free space optical communication

- Network configurations
  - Constellation design
  - Network (routing) design
  - Latency
  - Throughtput
- Enabling technologies
  - Photonic devices
  - Opto-mechanical devices
  - Sensors and detectors
  - Space qualification

Expected outcomes

- Understanding of satellite optical communications critical aspects
- Technological solutions
- Publications
- Professional education/experience

Network development:

- Analysis of satellite network latency

Ground segment development:

- Start of collaboration with Matera Laser Ranging Observatory
- Design and assembly of PATHOS experiment

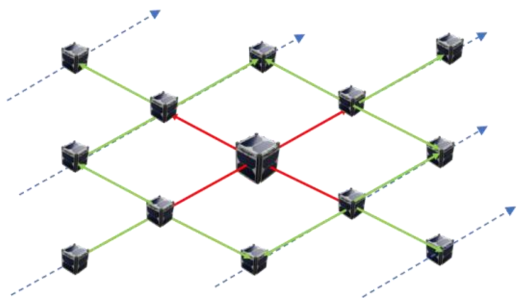
Space terminal development:

- LaserCube's FEM structural analysis
- Launch lock thermal analysis
- Support to LaserCube's vibration tests
- Support to opto-electronic tests

Satellite network latency analysis

Backhaul: part of the network that connects the backbone to the peripheral subnetworks.

Scenario variables:
- Constellations (Astrocast, Telesat, Oneweb)
- User distributions (maritime off-shore, population density)
- Number of ground stations: 5, 20, 50
- Number of inter-satellite links: 0, 1, 2



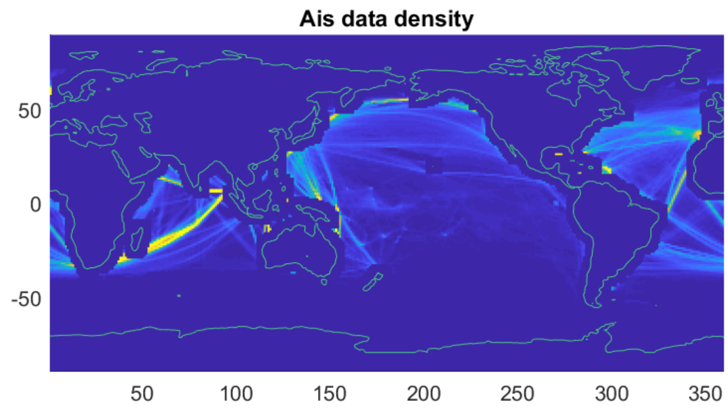
Inter-satellite links in a small satellite constellation.

Satellite network latency analysis

Methodology (Monte Carlo):

- Sample space generation from user distribution
- Ground station subset selection
- Orbit propagation and wait time computation

Key findings:
- ISL is always useful in terms of latency reduction
- Many hops can compensate for few ground stations
- ISL are more useful for off-shore users



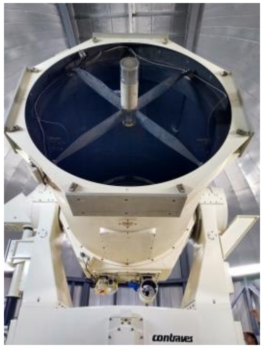
Example of user distribution (off-shore ship routes).

IAC 2020 conference paper
'Analysis of the impact of inter-satellite links on the performance of backhaul satellite networks based on small satellites'

Collaboration with ASI's Matera Laser Ranging Observatory (MLRO)

- Centro di Geodesia Spaziale 'Giuseppe Colombo', Matera.
- 1.5 m telescope, primarily used for laser ranging activities dedicated to geodesy research.
- MLRO telescope selected as possibile candidate for LaserCube's In-Orbit Demonstration (IOD) ground facility.
- The IOD is intended to demonstrate LaserCube's capability to perform pointing acquisition and tracking operations and to communicate with the ground station.

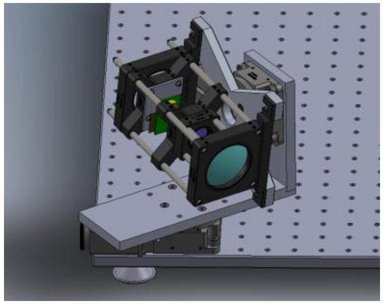
Telescope dome at Matera Space Centre.



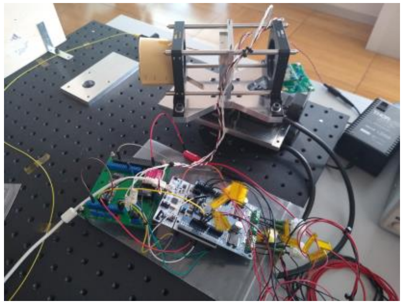
MLRO telescope.

PATHOS
(Pointing Acquisition and Tracking Hemispherical Optical System)

- Design and assembly of a laboratory setup simulating a small optical ground station.
- The setup is intended to functionally replicate the IOD ground station.
- Objective:
  - PAT procedures simulation and tests
  - Hardware and software development
  - Educational activities



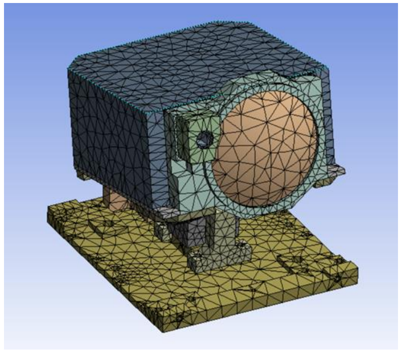
PATHOS CAD in the two degrees of freedom (azimuth and elevation) configuration.



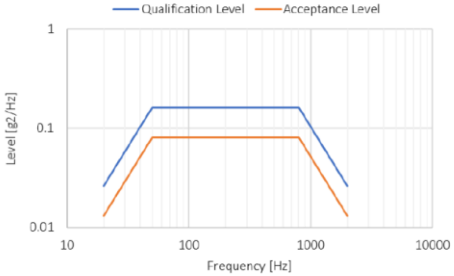
Picture of current PATHOS setup in its single degree of freedom (azimuth) configuration. Evaluation electronic hardware is also shown.

LaserCube's FEM structural analysis

- Objective: create a complete structural model in order to simulate natural frequencies and stresses due to expected launch loads.
- FEM model (Ansys) with geometry defined directly from production CADs.
- Loads derived as an envelope of loads specified by relevant launch and platform providers (NASA GEVS, Falcon, D-Orbit).



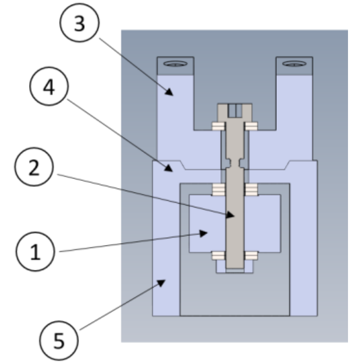
LaserCube's meshed geometry.



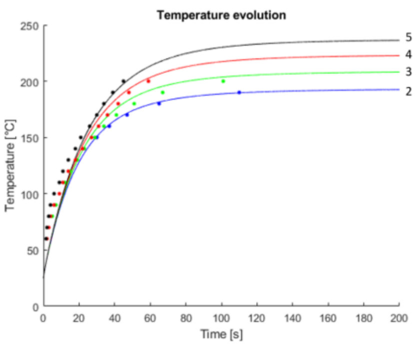
Vibrations tests acceleration levels.

Launch lock thermal analysis

- Launch lock working principle: temperature activated SMA (Shape Memory Alloy) actuator.
- Numerical thermal analysis (lumped parameters).
- Tests: temperature evolution and activation.
- Model validation (parameters tuning).
- Design outcomes:
  - Launch lock material (titanium)
  - Washers number (5)
  - Activation temperature (150 °C)



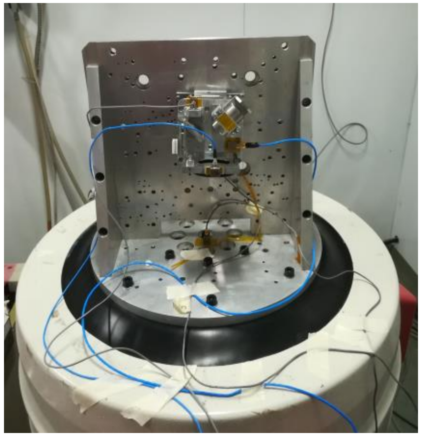
Launch lock components: 1) SMA actuator, 2) notched screw, 3) upper part, 4) contact surfaces, 5) lower part.



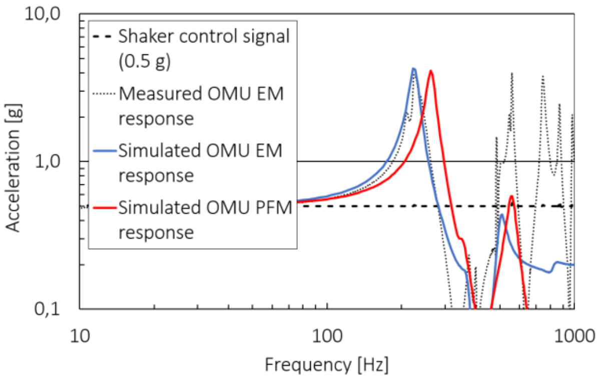
Comparison between test results and modelled temperature evolution.

Support to LaserCube's vibration tests

- Test setup: shaker table, monoaxial and triaxial accelerometers.
- Resonance search performed in order to find first natural frequencies of the system.
- Engineering model results: 1st 200 Hz, 2nd 370 Hz.
- Vibration tests have allowed to validate the FEM model.
- Flight model simulations results: 1st 240 Hz, 2nd 350 Hz.



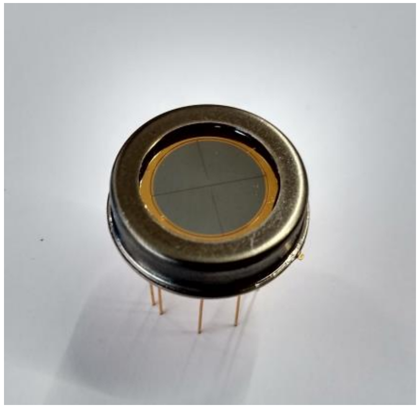
Shaker table test setup.



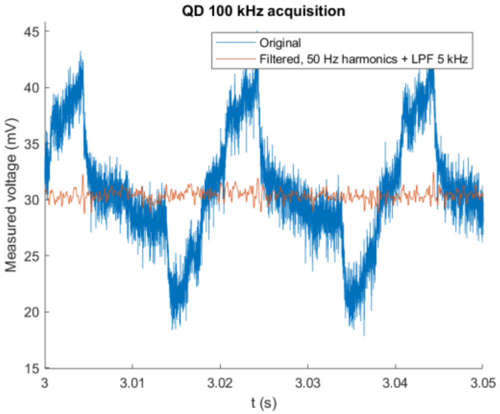
Comparison of vibration tests and FEM simulation results.

Support to opto-electronic tests

- Opto-electronic tests have been performed in order to assess the correct operation of the optical transceiver at system and component level.
- Tests have been performed both on the transmission and reception side.
- A numerical analysis has been carried out in order to identify and cancel potential sources of noise.



Tested quadrant detector.

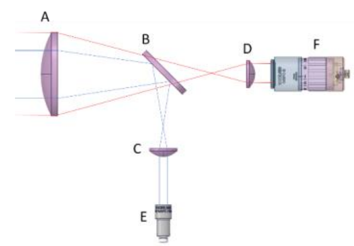


Dark noise direct acquisition compared with digitally filtered signal.

Functional and qualification tests setup design

- A functional test setup has been designed and assemblied in order to replicate the orbital configuration from an optical point of view.
- The setup will contribute to a series of tests that are going to be performed durig the next months (thermal-vacuum, vibrational, transmission/reception)

Test setup: the assembly works as beam expander, telecom reception segment and beacon transmission segment.



Main optical components: A) 75 mm lens, B) dichroich mirror, C-D) 25 mm lens, E) fiber coupling collimator, F) laser source collimator

Next activities:

- Analysis of constellations in terms of throughput
- Development of ground station solutions
- Support to functional and qualification tests

Startup project milestones:

- LaserCube Downlink TRR: 10/2020
- LaserCube Inter-satellite link CDR: 10/2020
- LaserCube Downlink In-Orbit Demonstration: Q2 2021

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Feel free to ask questions or make suggestions!!!