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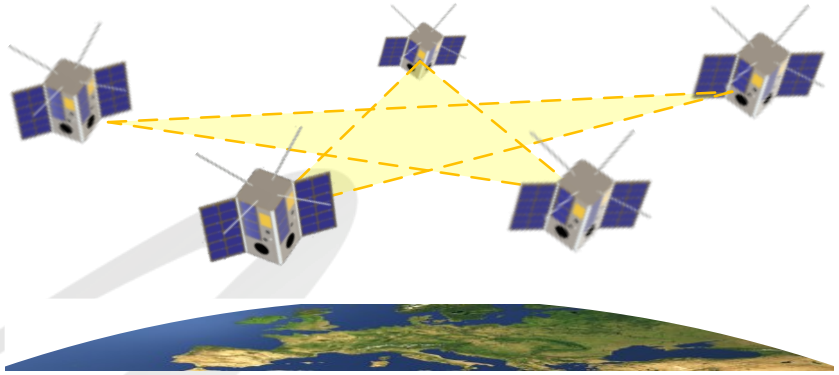
STAR CuCo

Space **T**iming & **A**dvanced **R**anging
for **Cu**beSat **Co**nstellation



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Final Presentation

ESA Contract No.: 4000141195/22/NL/GLC/rk

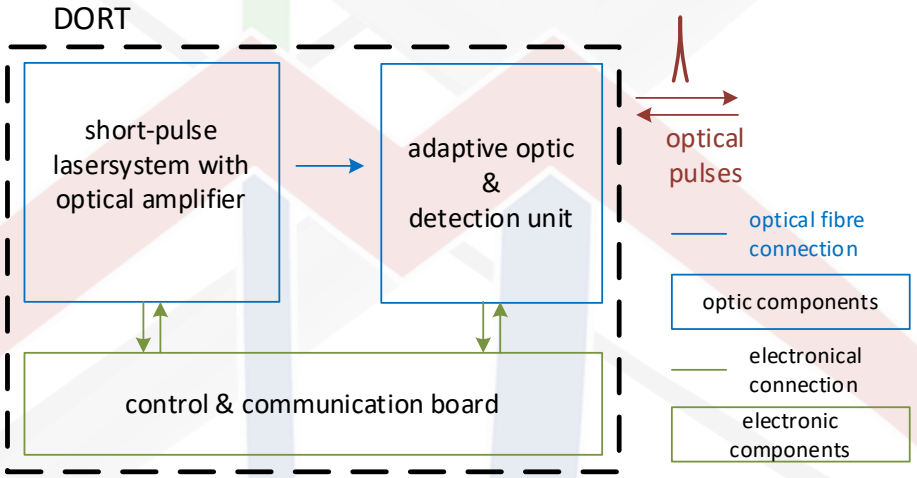
DRAFT

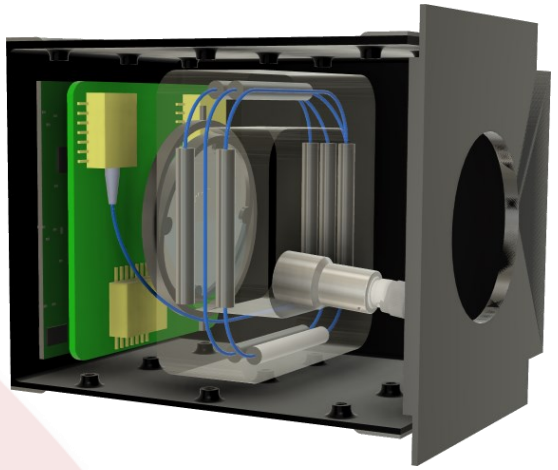
Date: 05 Mar. 2024

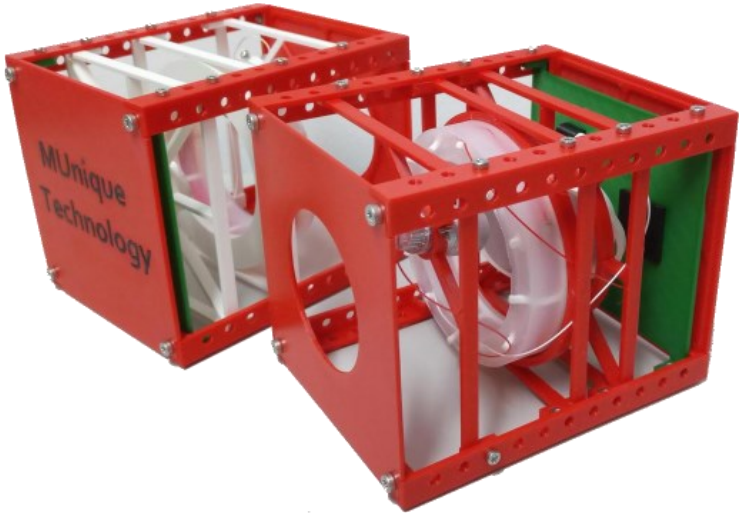
Measurement System DORT

Dynamic Optical Ranging & Timing:

- inter satellite distance measurement (absolute in µm area at >100km distance)
- time distribution (up to 10^{-15})
- applied for patent Aug 2022







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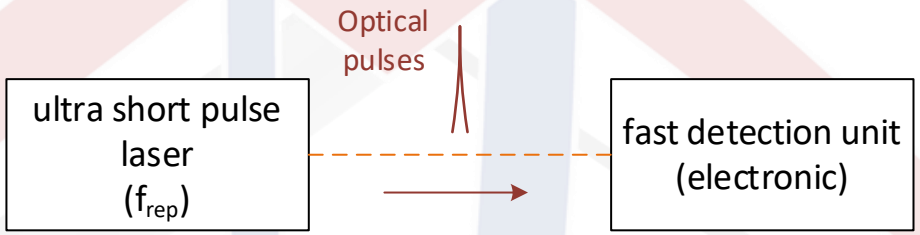
Measurement principle

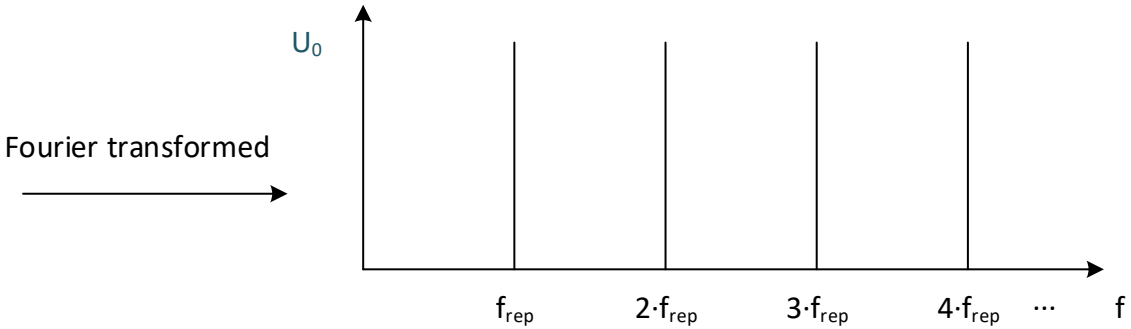
Ultra-short pulse lasers emit pulses in fs- or ps-area

Oscillator frequency (repetition rate) correlates with distance from one pulse to another

Repetition rate can be monitored/controlled very precisely

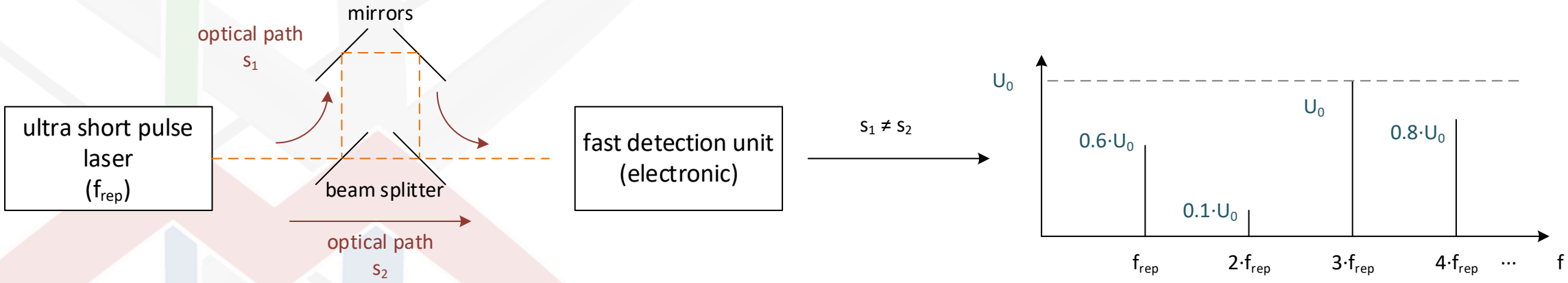
Fourier transformed (from time to frequency domain) a ‘comb’ is generated with multi-harmonics of the repetition rate





Measurement principle

If pulses propagate different optical paths, and are superimposed afterwards, signal in frequency domain varies

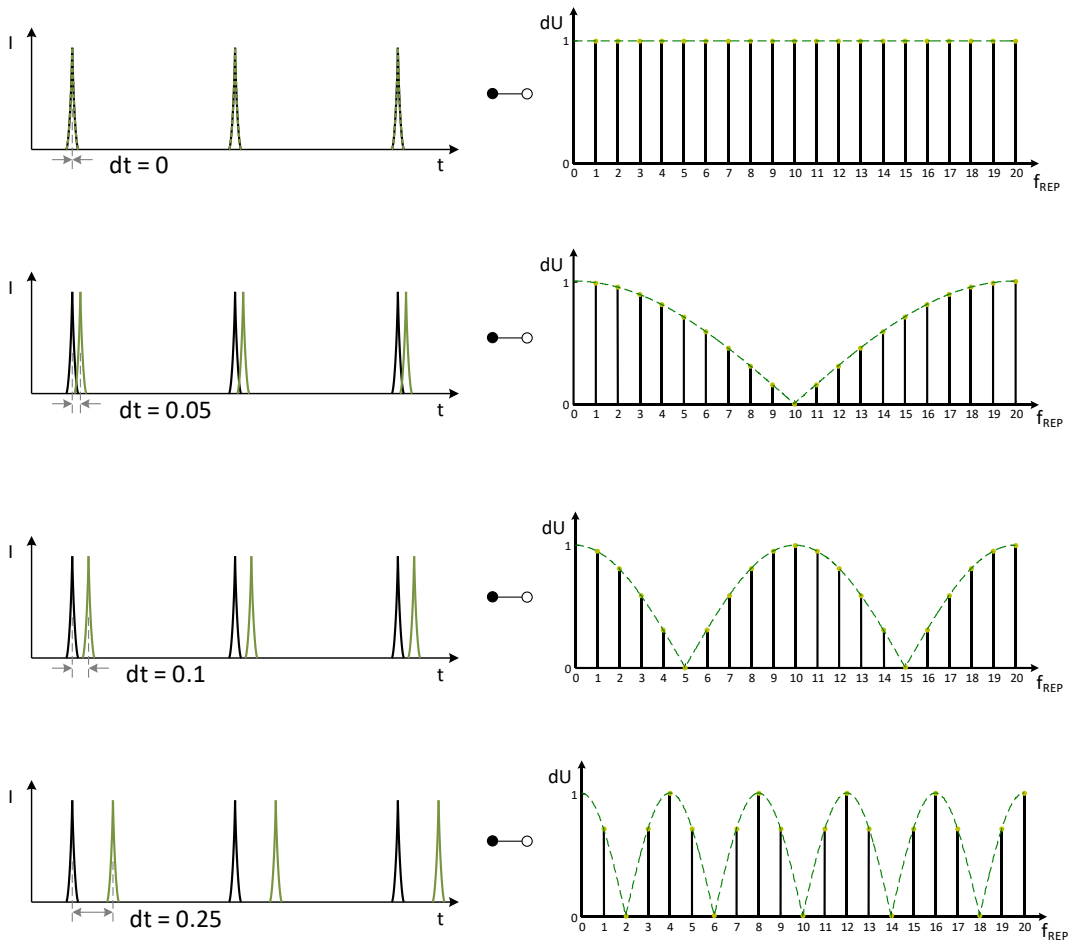


the amplitudes of the harmonic change depends on the difference between optical path 1 and path 2

→ the amplitudes contain distance information

Measurement principle

examples:



the higher the harmonic the higher
the oscillation dependent on distance change

→ best distance resolution at highest frequency

Using special electronic filters
(e.g. surface acoustic wave)
amplitudes can be separated and
measured with high speed (>100kHz)

→ Dynamic movements (e.g. vibrations)

can be measured with high precision and high speed

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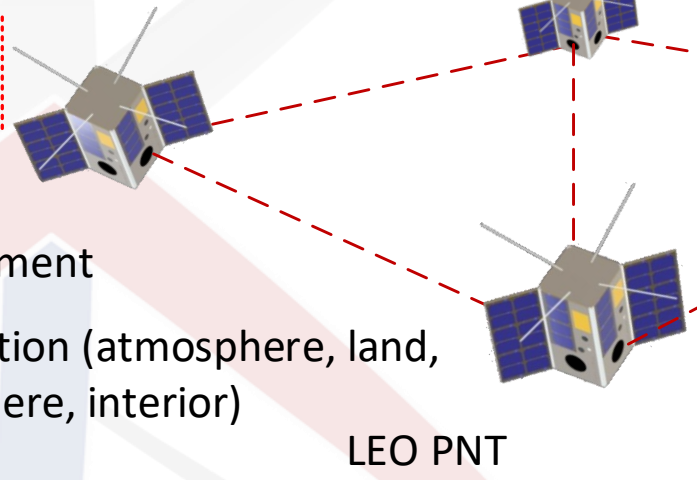
Applications for DORT



secure communication

quantum communication

distributed astronomical instruments

satellite gravimetry

autonomous driving

Disaster management

earth observation (atmosphere, land, ocean, cyosphere, interior)

LEO PNT

telecommunication service (satellite internet)

high frequency trading

(inter)continental time-bridge

space time standard

distributed synthetic aperture

Very Long Baseline Interferometry (VLBI)

lunar/planeatery navigation satellite system

Global Navigation Satellite System (GNSS) enhancement

Reference Mission:
Science Project Satellite Gravimetry

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Cooperation with:

Technical University Munich (Geodesy)

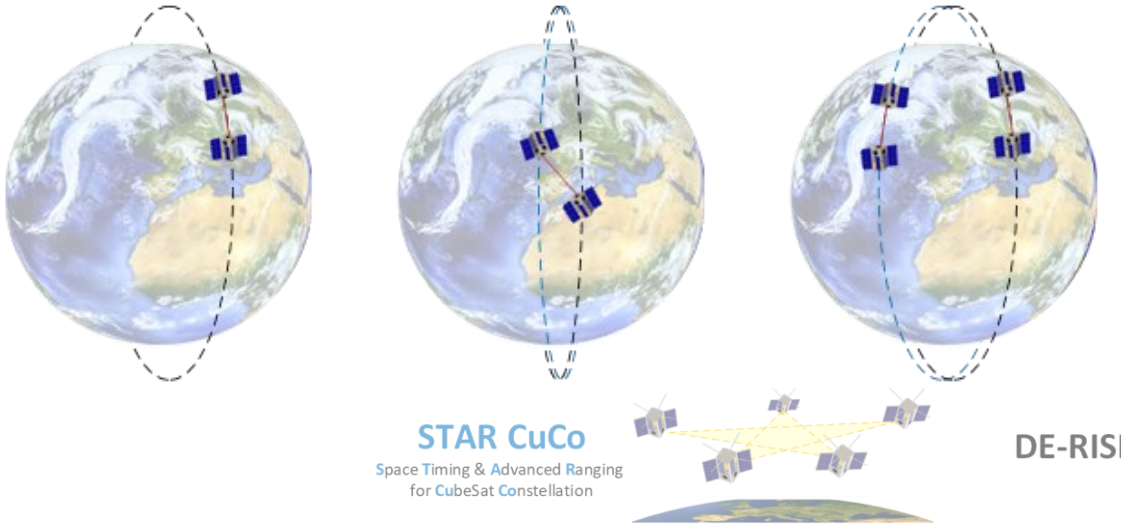
Engineering Minds Munich (electronic development)

Objective:

Study of DORT technology in CubeSat constellations for satellite gravimetry

Mission scenario:

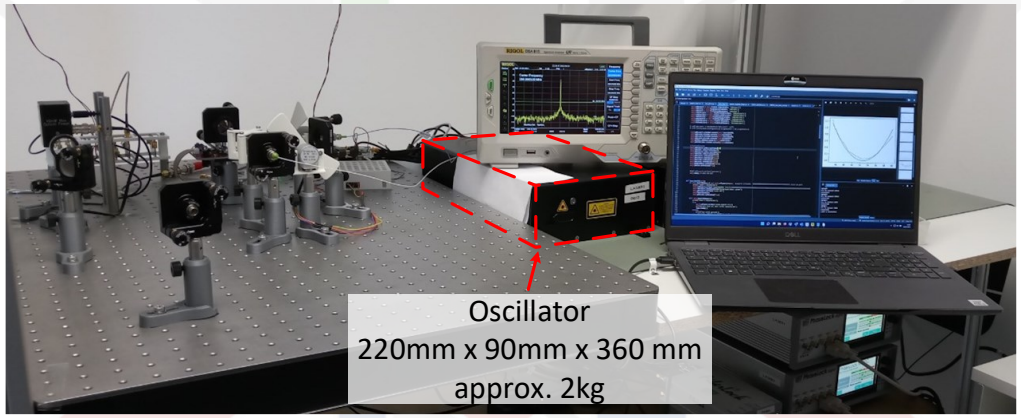
- gravity mission (e.g. GRACE) with CubeSats
- LEO at 400km altitude
- 2 year mission lifetime

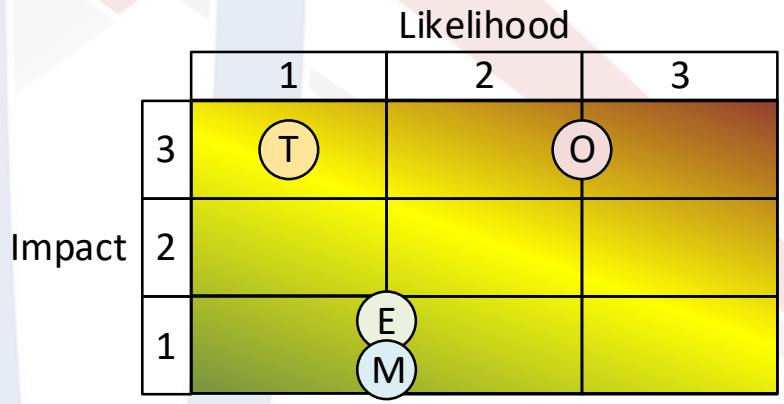


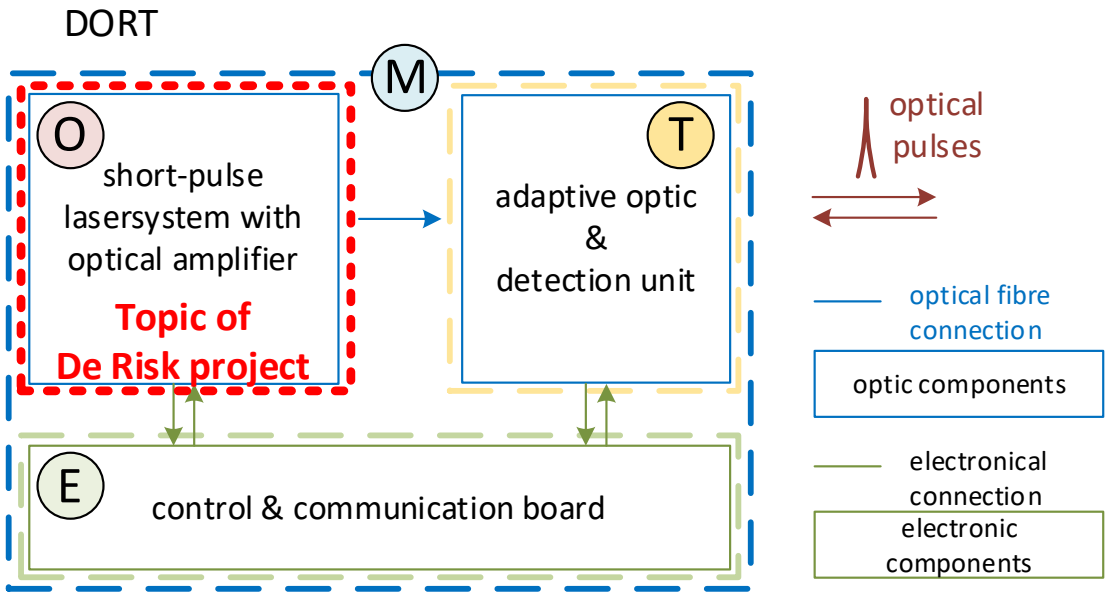
GSTP De-Risk Project

Identification of high-risk part of the System

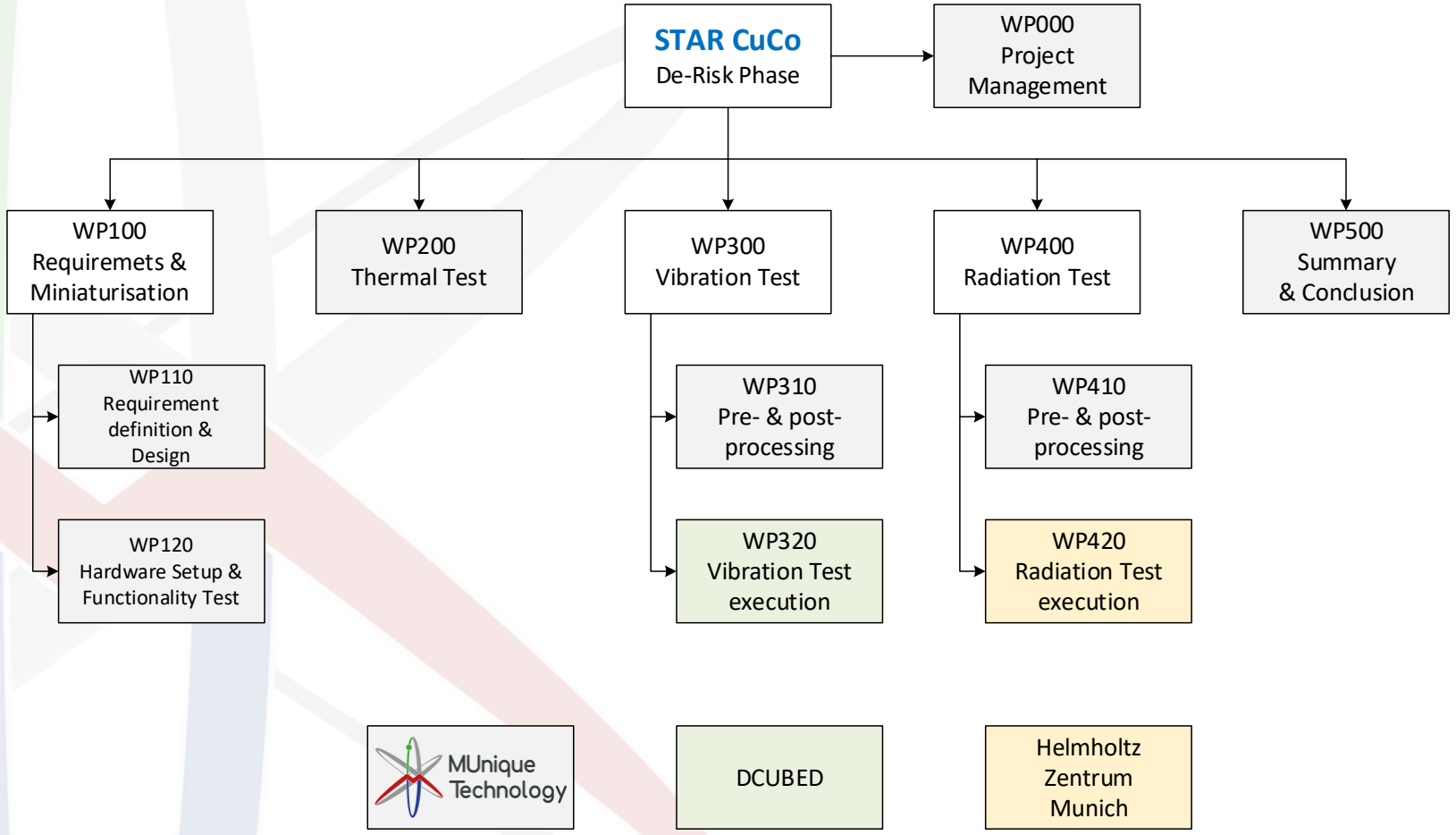
→ Modify and characterize the subsystem to de-risk future developments







Work Breakdown Structure



Requirements definition

Temperature:

Functionality of the optical oscillator defines further requirement for thermal stabilisation

Test environment: **[10°C, 40°C]**

Vacuum:

Pressure during mission	10^{-4} Pa
Depressurising during launch	4.5 kPa/s

Radiation:

One-year mission TID	15 Gy (1.5 krad)

Mechanical: sinusoidal

Frequency range [Hz]	Qualification level (0-peak) [g]
1 – 5	0.50
5 – 45	1.00
45 – 110	1.25
110 – 125	0.25

random:

Bandwidth [Hz]	Overall level [g eff]	PSD [g^2 / Hz]	Time duration
20 - 2000	12	0.0727	1 min

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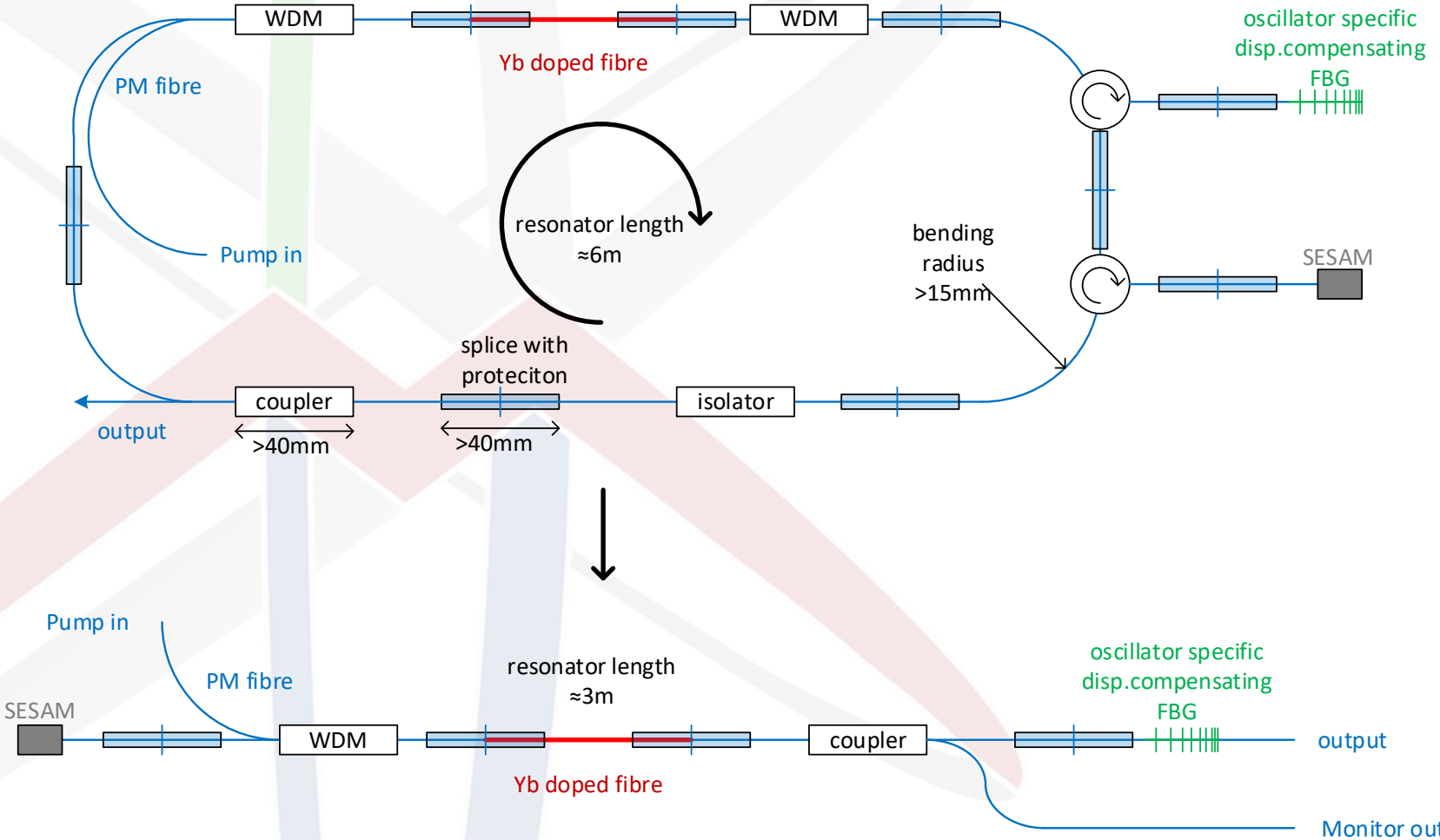
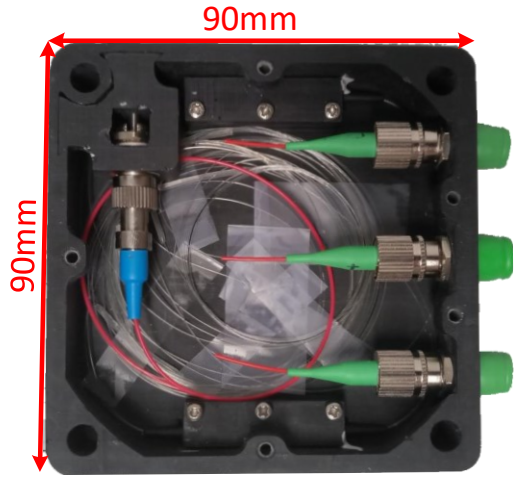
Oscillator design

→ miniaturization





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Increasing mechanical stability

Idea: Oscillator casted in resin → resin selection

Name	Space-tested?	Density [g/cm3]	Viscosity @ 25°C [mPa*s]	Pot life	Hardness [Shore scale]	Th. Conductivity [W m-1 °C-1]	Th. Exp. Coeff. [E-6 K-1]	Other	Suitable for the application?
Araldite CY 205 IN	Yes	1.15-1.20	9000-13000	1 day	?	?	31-36	Cured at 80 °C and 130 °C	No
Epikote 828	Yes	1.16	12000-14000	?	?	?	?	Has an extreme viscosity range depending on the temperature	No
Versamid 140	Yes	0.967	8000-12000	2 hrs	?	?	?	Max. exotherm 150°C	No
RTV 566	Yes	1.5	42700	30 mins	>A61	0.3	200	Very high viscosity	Maybe
RTV S695	Yes	?	66	8 hrs	12 (Unkn. scale)	0.21	320	Low mechanical resistance	No
Solitane 113	Yes	1.07	20000	3 hrs	55-60 (Unkn. scale)	?	126-238	Not resistant to solar UV-radiation; has flammability risk; glass transition at -10°C	Maybe
Stycast 2850	Yes	2.3	70000	45 mins	D92-96	1.02-1.28	31.2-39.4	Extremely high viscosity	Maybe
Stycast 1090	Yes	0.88	30000	30 mins	D75-82	0.19	40	High viscosity	Maybe
Appli-Tec 5051-E	Outgas. Tests	1.15	320	8 hrs	D83	?	?	Low viscosity; transparent	Maybe
Appli-Tec 5108-H	Outgas. Tests	1.07	5000	2 hrs	D80	?	?	High viscosity	Maybe
Appli-Tec 7810-G	Outgas. Tests	0.96	6400	1.5 hrs	A65	0.25	200 (above -74°C)	High viscosity	Maybe
R4GB	No	1	?	3-4 mins	D70	?	?	Extremely short pot life, peak exotherm 45+°C	No
E45GE	No	1.1-1.2	low-viscosity	45 mins	D81	?	80	Low viscosity; transparent, peak exotherm 25°C	Maybe
PX700K-1/BK/500	No	1.66	5000-9000	2 hrs	D70-80	1	40-50	High viscosity; peak exotherm 40 °C; flame retardant; operating temperature range: -40 to +150 °C	Maybe
EL116F/GY	No	1.47	5000	25 mins	A70-80	0.6	50-75	High viscosity; relatively short pot life; peak exotherm 60°C	Maybe
EL171LF/BK/270	No	1.51	3500	15 mins	D60	0.55	75-100	Hard to degas; short pot life; relatively low viscosity; non-toxic; flame retardant	No

→ **epoxy resin E45GE** with similar characteristics is suitable COTS equivalent

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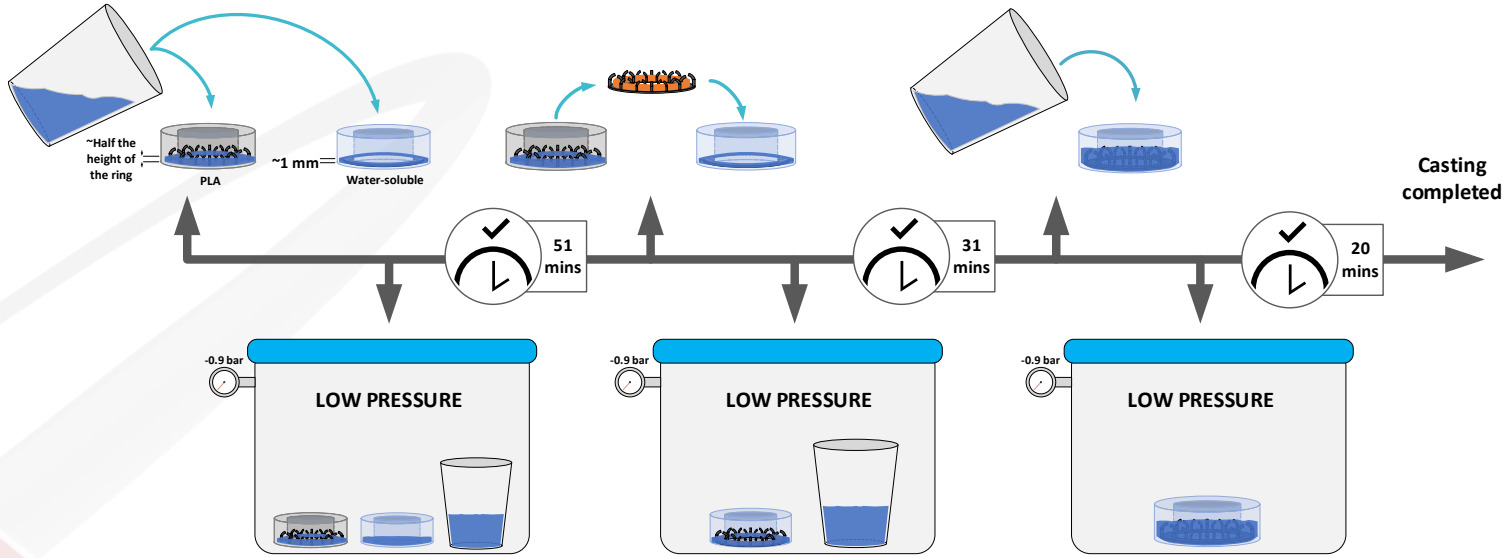
Castin Process



Non-processed casting

processed casting

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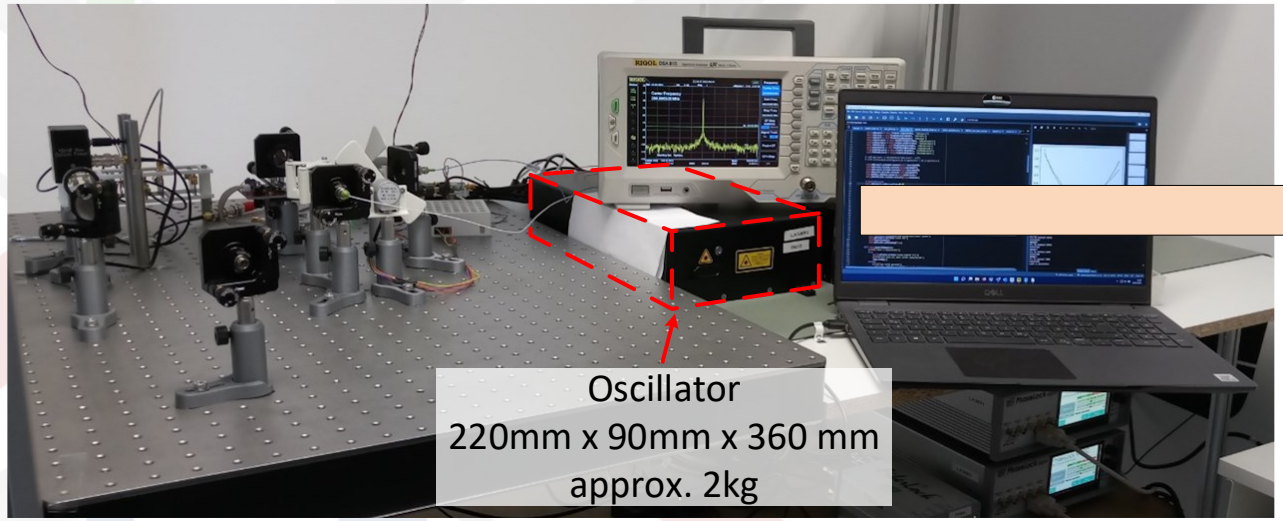
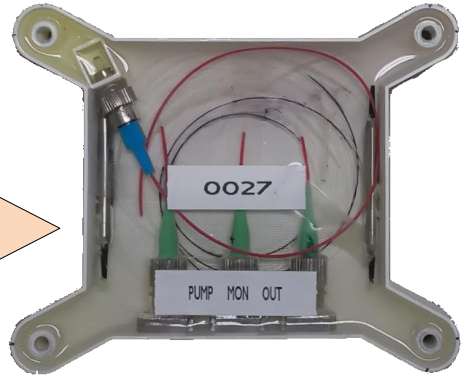
New oscillator design

WP100 ✓





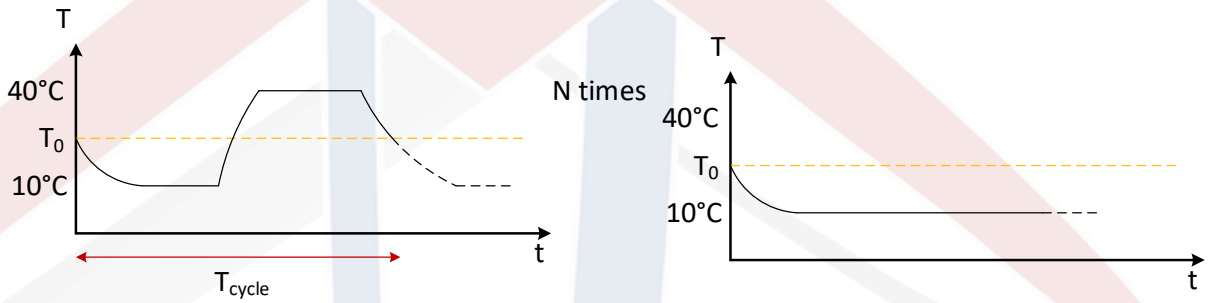
Oscillator
80mm x 80mm x 20 mm
approx. 150g

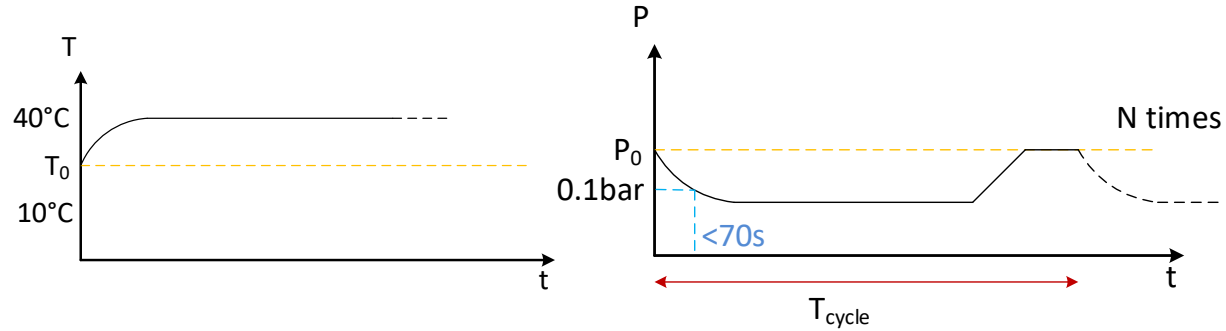
Thermal Vacuum Test

Questions:

- survives the oscillator all loads?
- in which temperature range is mode lock possible?

12 h	8 h	8 h	4 h
Ramp test	Low temp test	High temp test	Vacuum test





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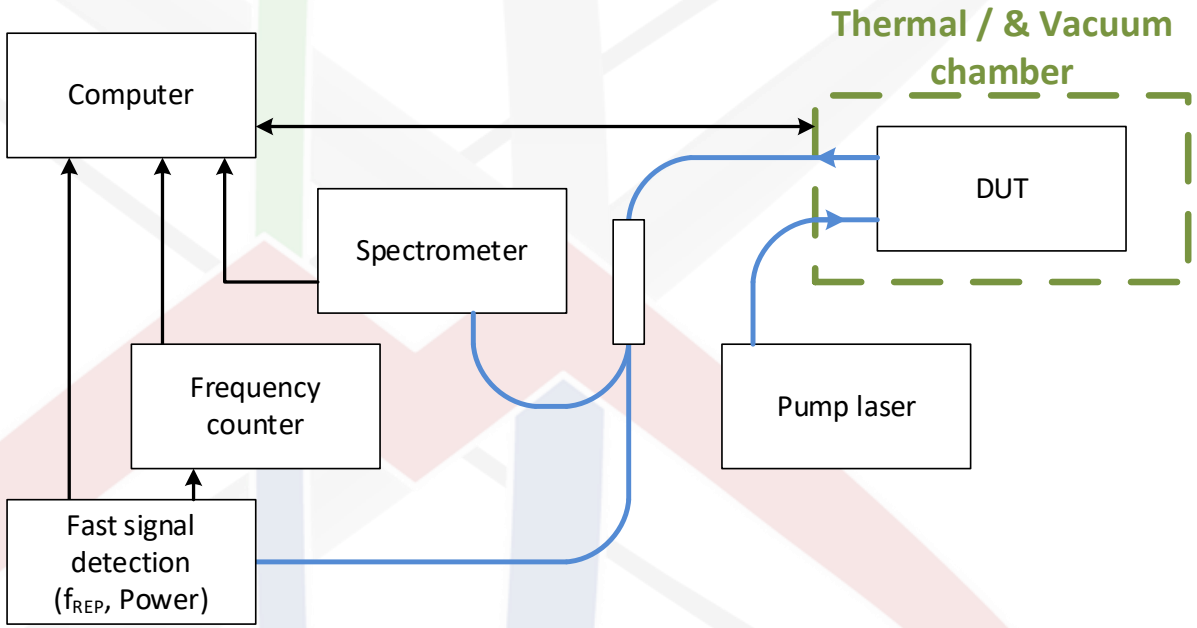
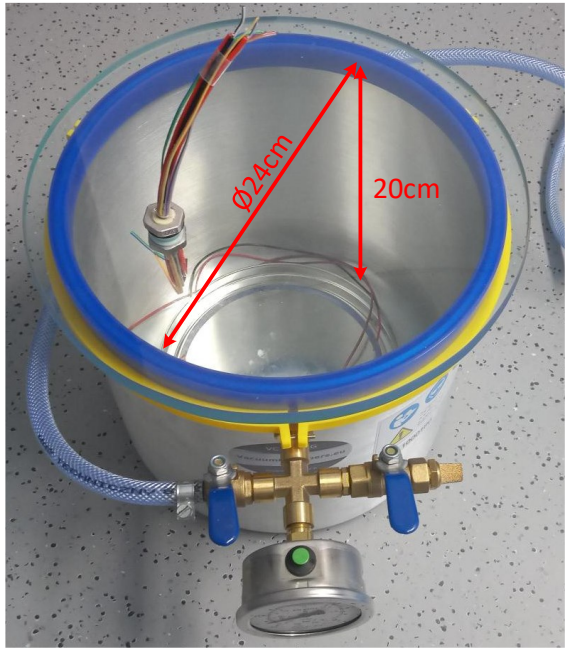
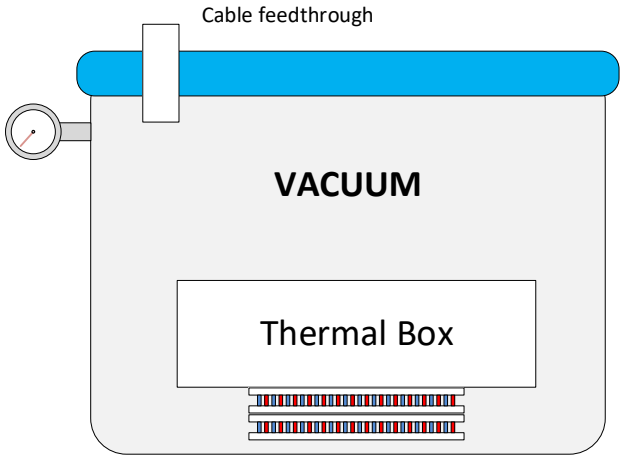
Thermal Vacuum Test

Setup allows online measurement during all tests



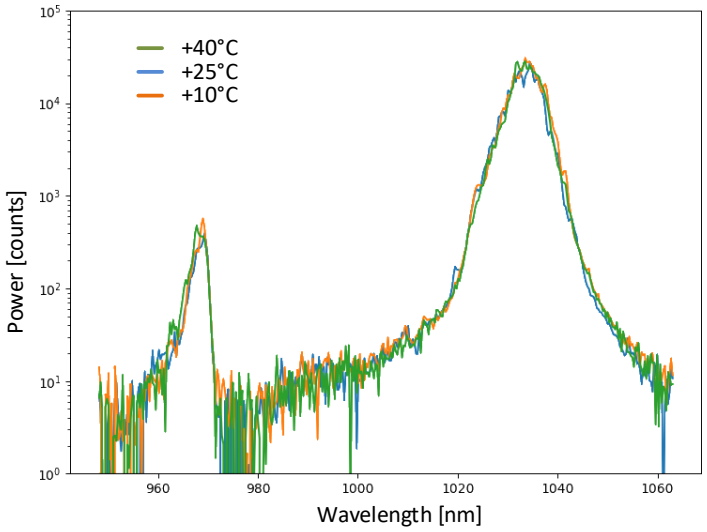


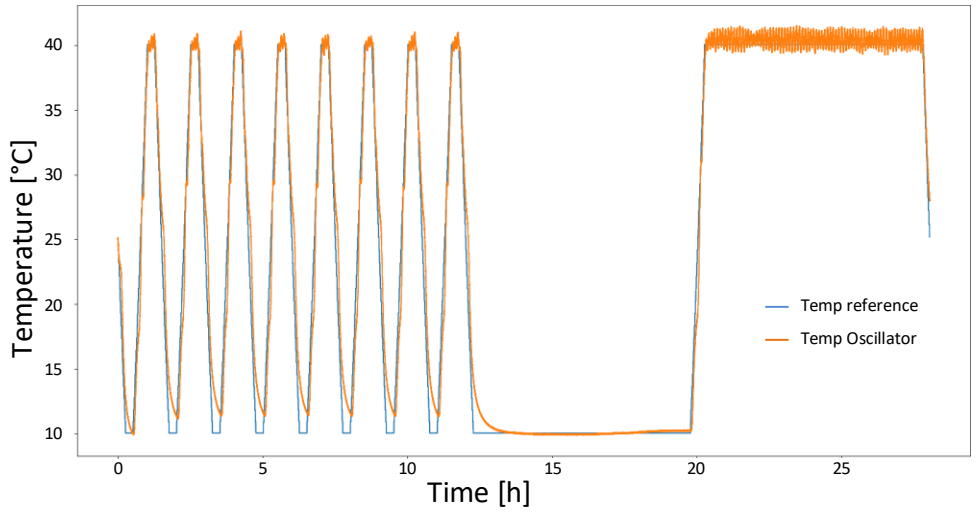


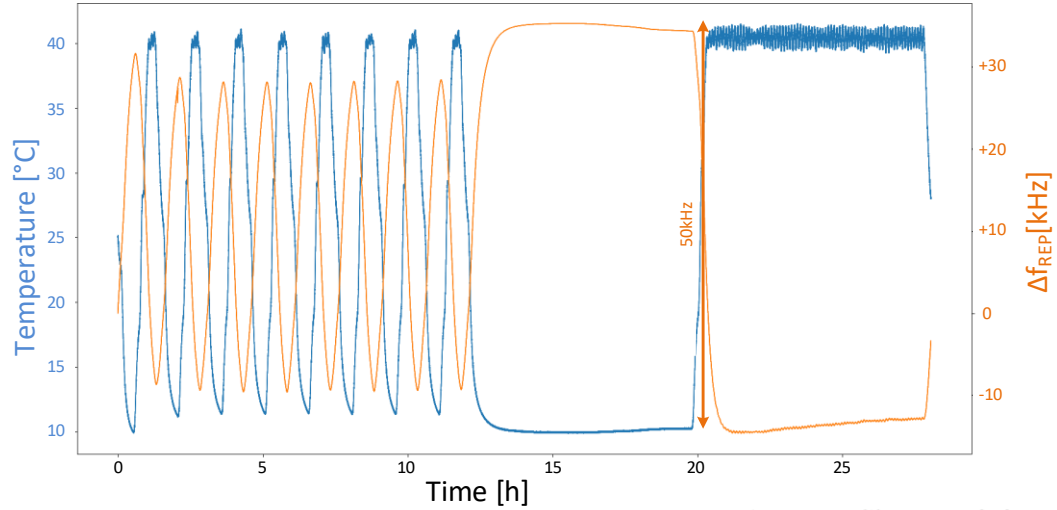
Thermal Vacuum Test

- Oscillator survives thermal/vacuum loads
- Oscillator in mode lock state all time
- Optical spectrum constant at all time
- output power varies with ±10%

(can be compensated with pump power)







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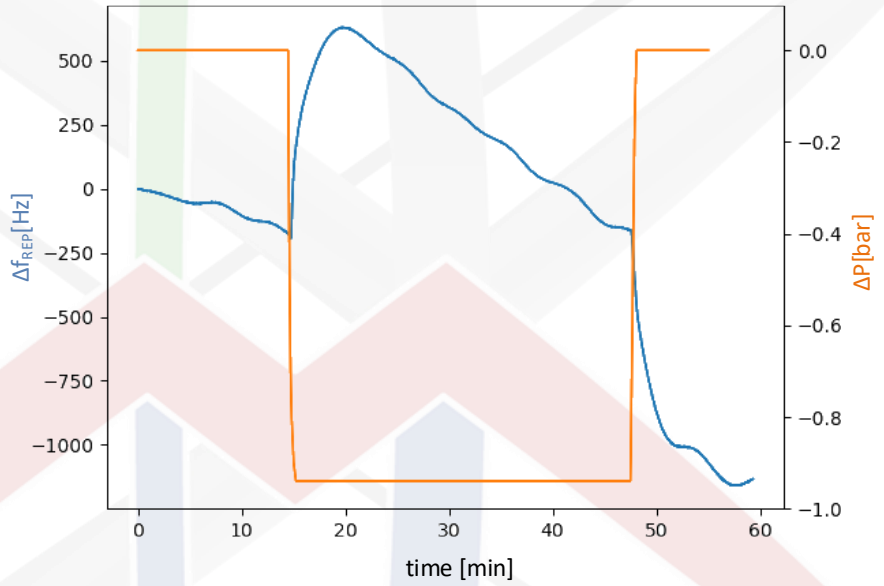
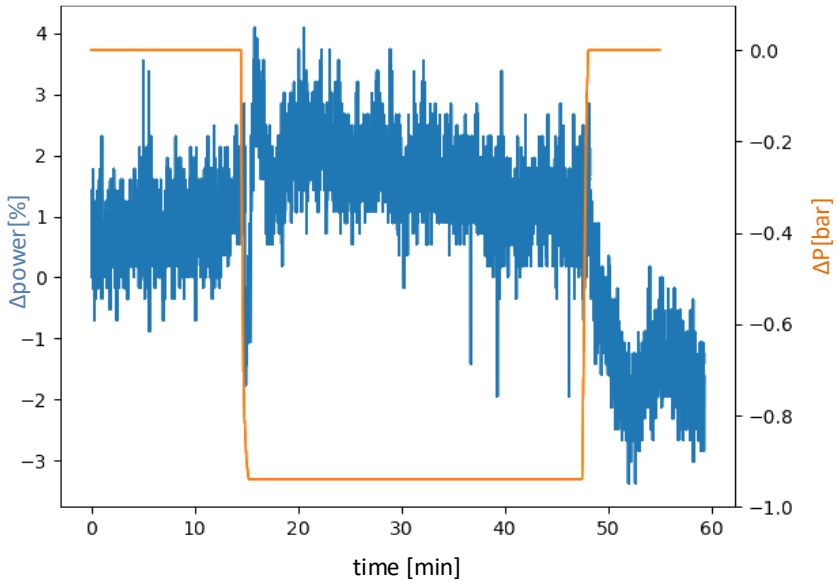
Thermal Vacuum Test

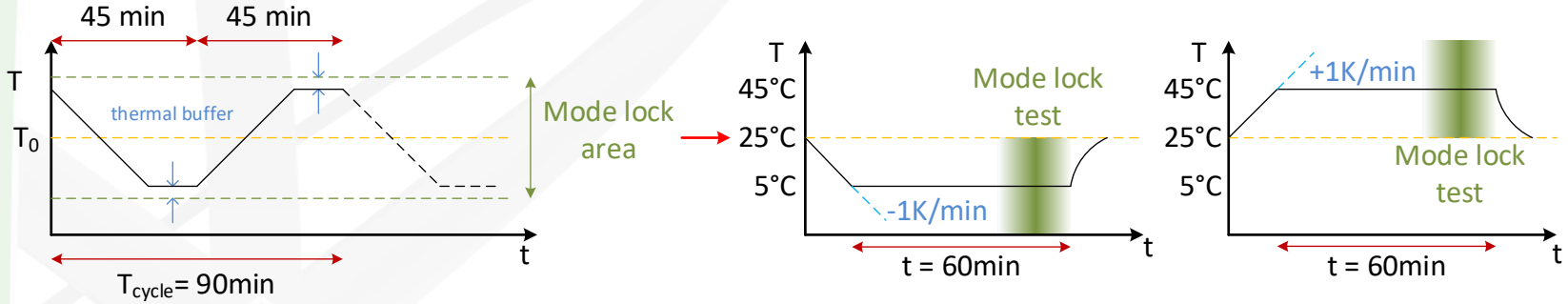
- vacuum has no major impact on setup

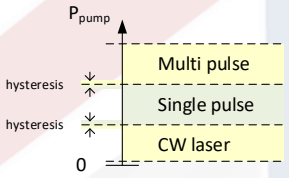


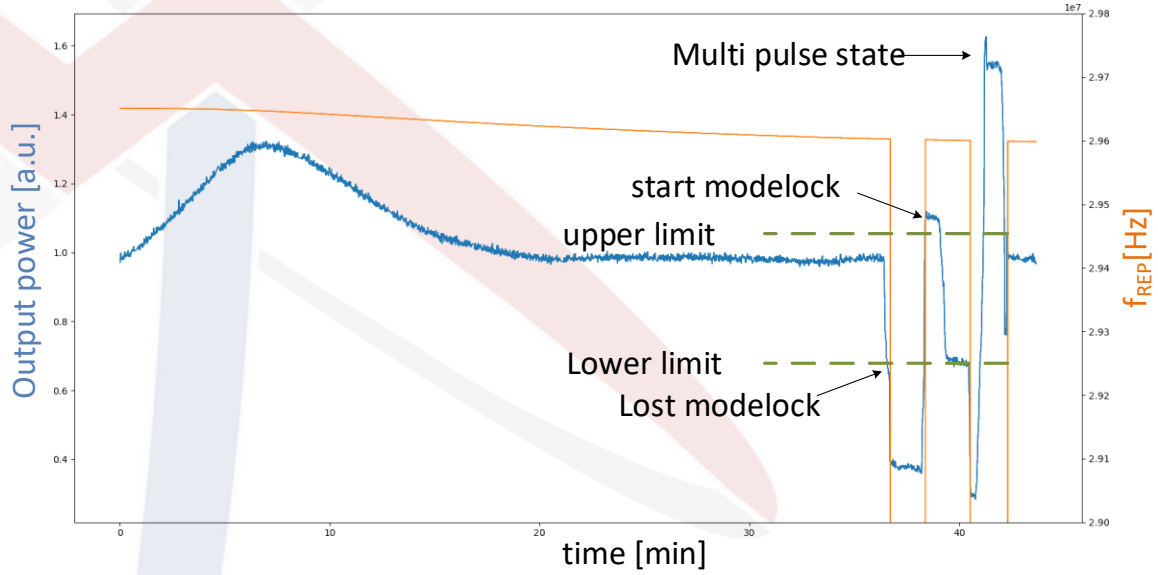


Thermal Vacuum Test

Since mode lock is during all tests, mode lock is tested by varying the pump power at higher/lower temperatures







	5°C	45°C
Multi pulse	1.70 ± 16%	1.33 ± 2%
Upper limit	1.00 ± 6%	1.00 ± 5%
Lower limit	0.61 ± 4%	0.60 ± 2%

Thermal Vacuum Test

WP200 ✓

- Oscillator survives all tests
- thermal range for full functionality is defined to [5°C, 45°C]

→ Requirements on thermal control (electronic) not challenging

- vacuum has no major impact on system
- space proven resin with similar characteristics exists

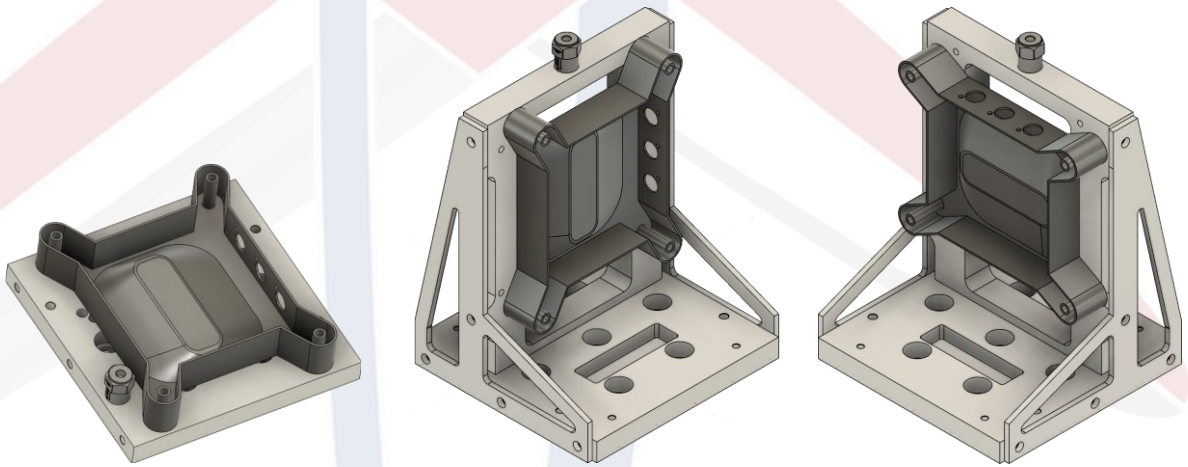
→ No outgasing issues

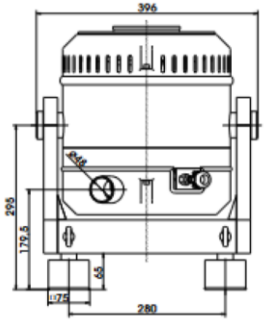
Vibration Test

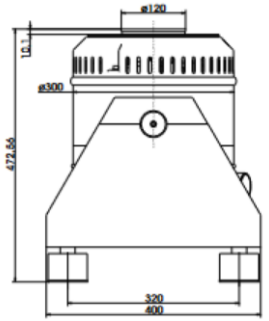
Preparation:

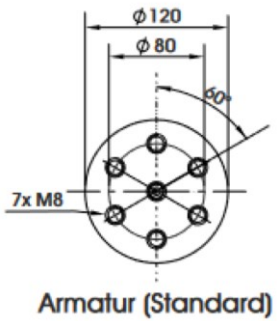
- mech. adapter for out-of-plane (z) and in plane tests (x,y)
- reference accelerometer on test adapter
- probe accelerometer mounted on oscillator by adhesive mass
- mass of oscillator approx. 150g

→ Shaker with less load applicable









Armatur (Standard)

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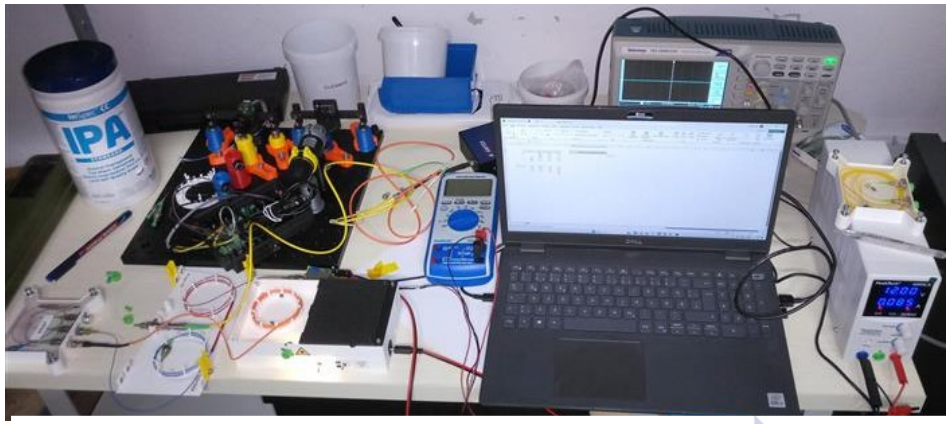
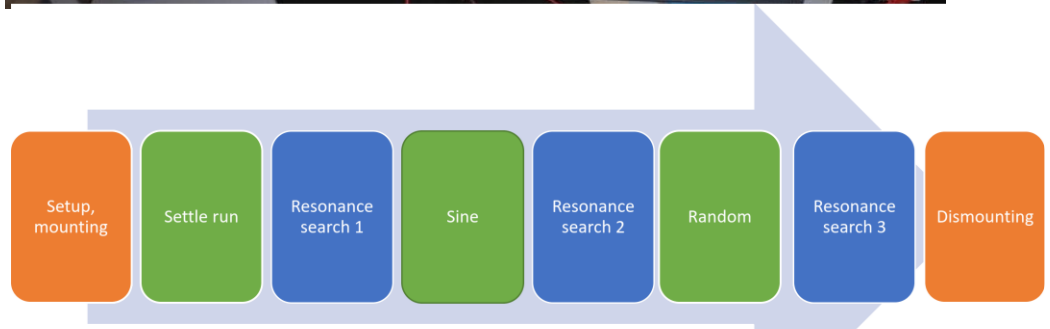
Vibration test

Reference accelerometer

probe accelerometer

Test setup





Vibration test

WP 300 ✓

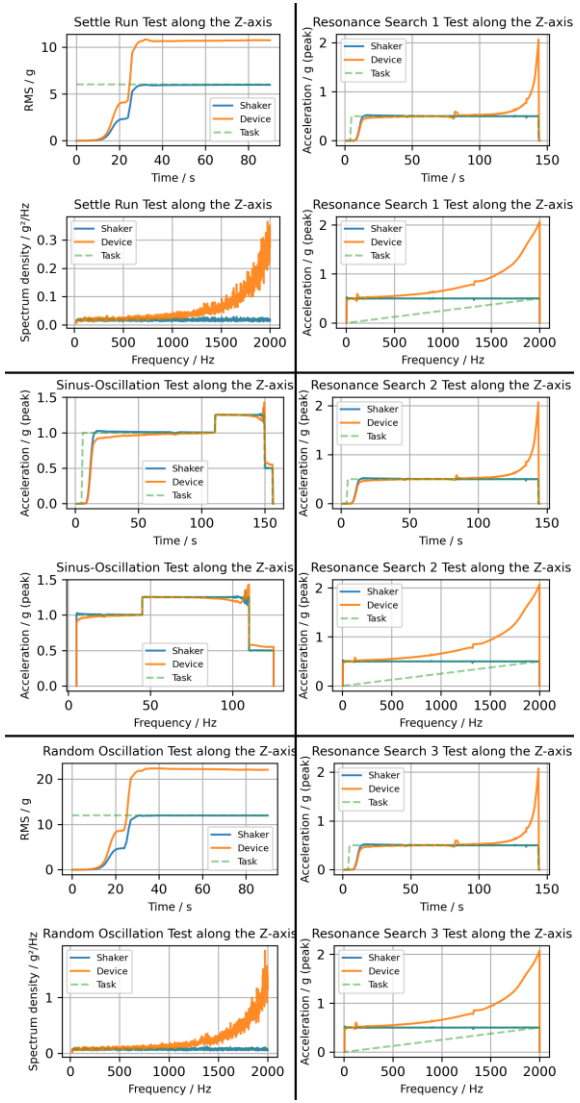
- after each test cycle oscillator is tested for functionality
- no specific behaviour measurable during and after test
- at higher frequencies, adaption would be necessary

→ Oscillator survives complete vibration test

- basic mech. design enough to survive vibration test

→ Still space for improvement, if necessary

→ All-in-fibre setup, casted in resin promises large variety of applications in space (compact, robust, low weight)



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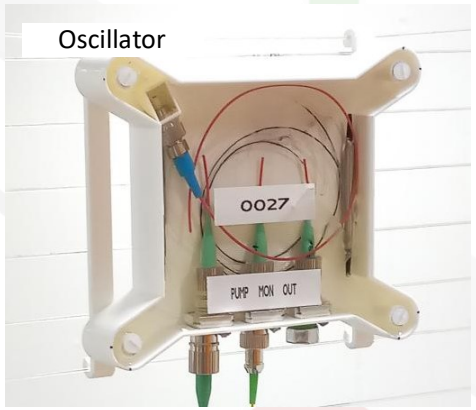
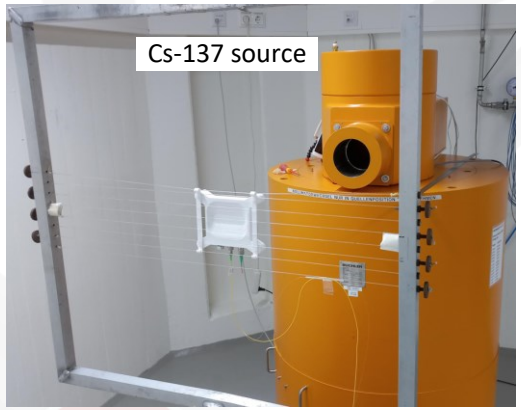
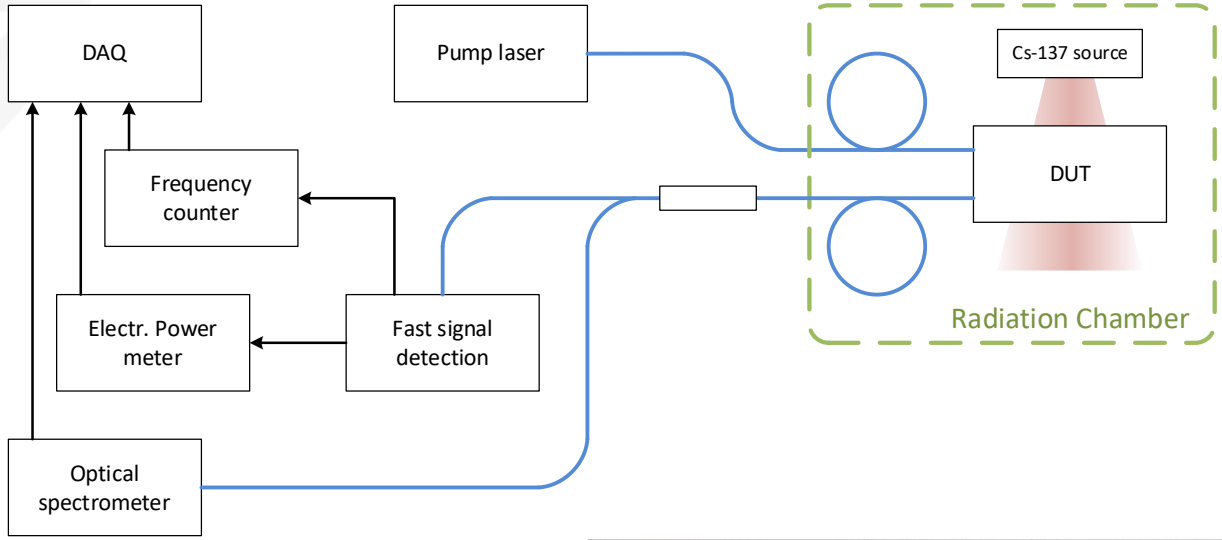
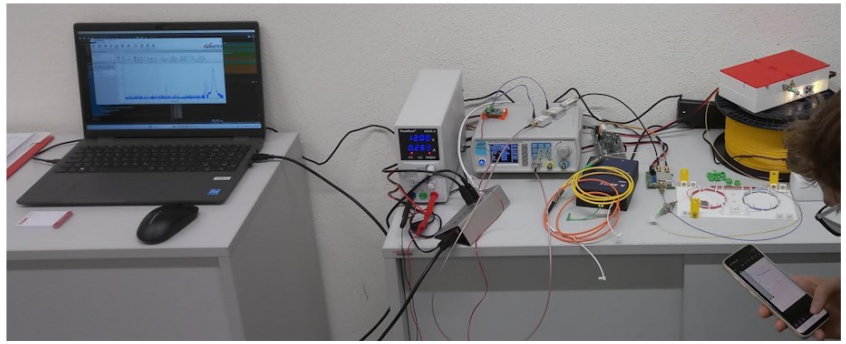
Radiation test

Test setup









Using PM and SM fibre spools of approx. 1km length online measurement possible

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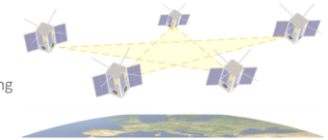
Space Timing & Advanced Ranging for CubeSat Constellation



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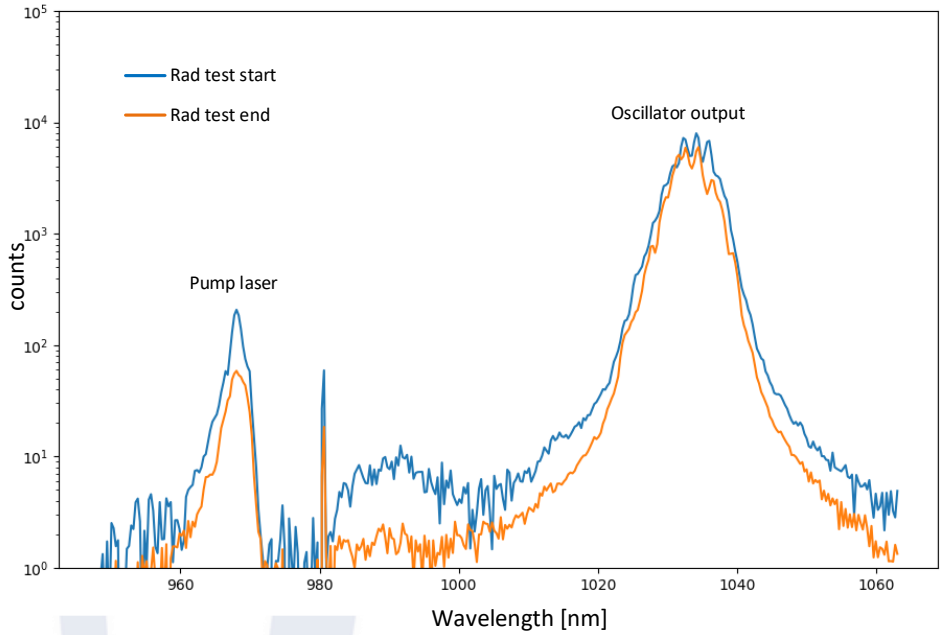
Radiation test

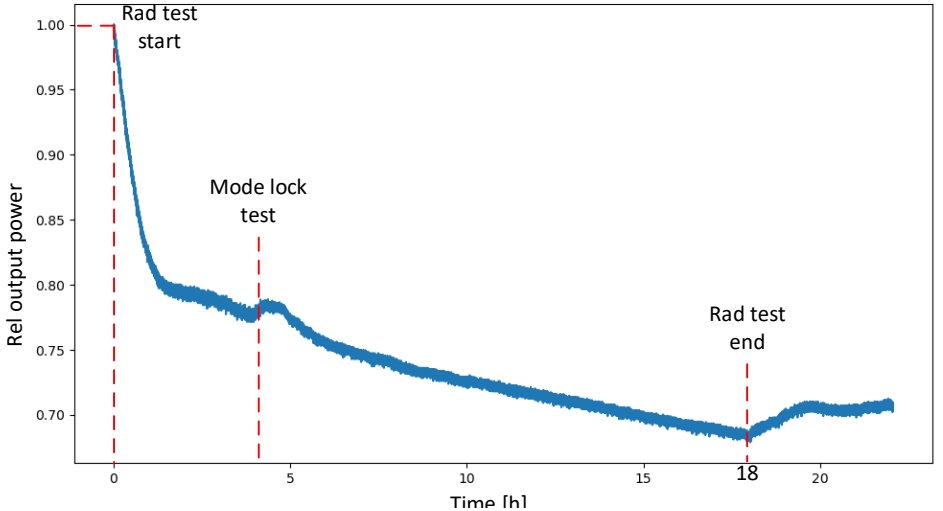
- in total oscillator irradiated with 30Gy (3krad)
- output power decreased to 70% of start value

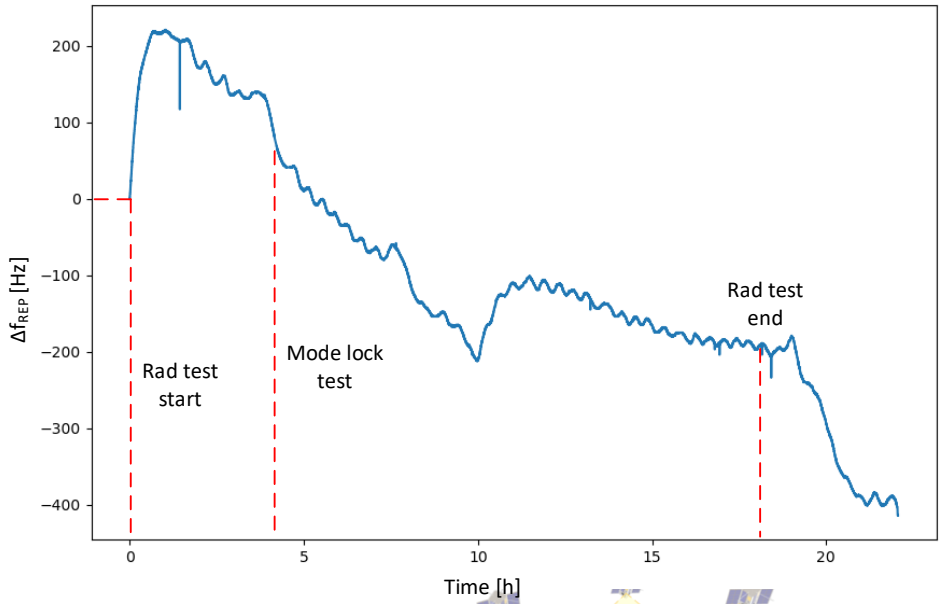
→ Can be compensated by increasing pump power

- optical spectrum shows no change

→ Pulses are still in the same shape







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Radiation test

WP 400 ✓

- Oscillator survives radiation load of 2 year mission lifetime

(1 year minimum required)

- power loss can be compensated without major effort

→ Low requirements on electronics and Satellite Shielding (2mm Aluminum)

- no impact on optical output

→ No performance loss

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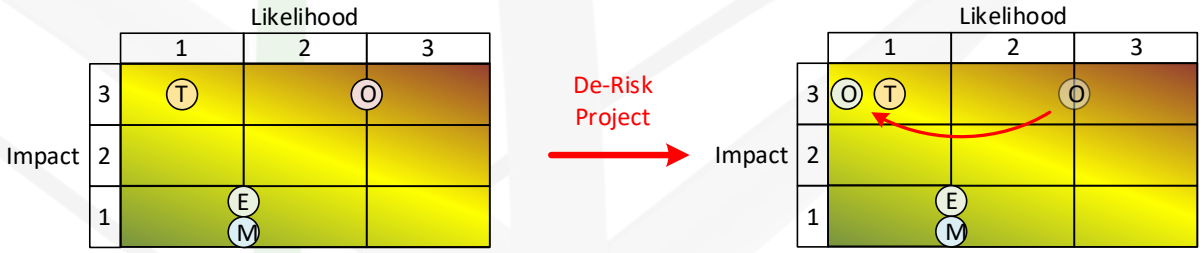
Summary

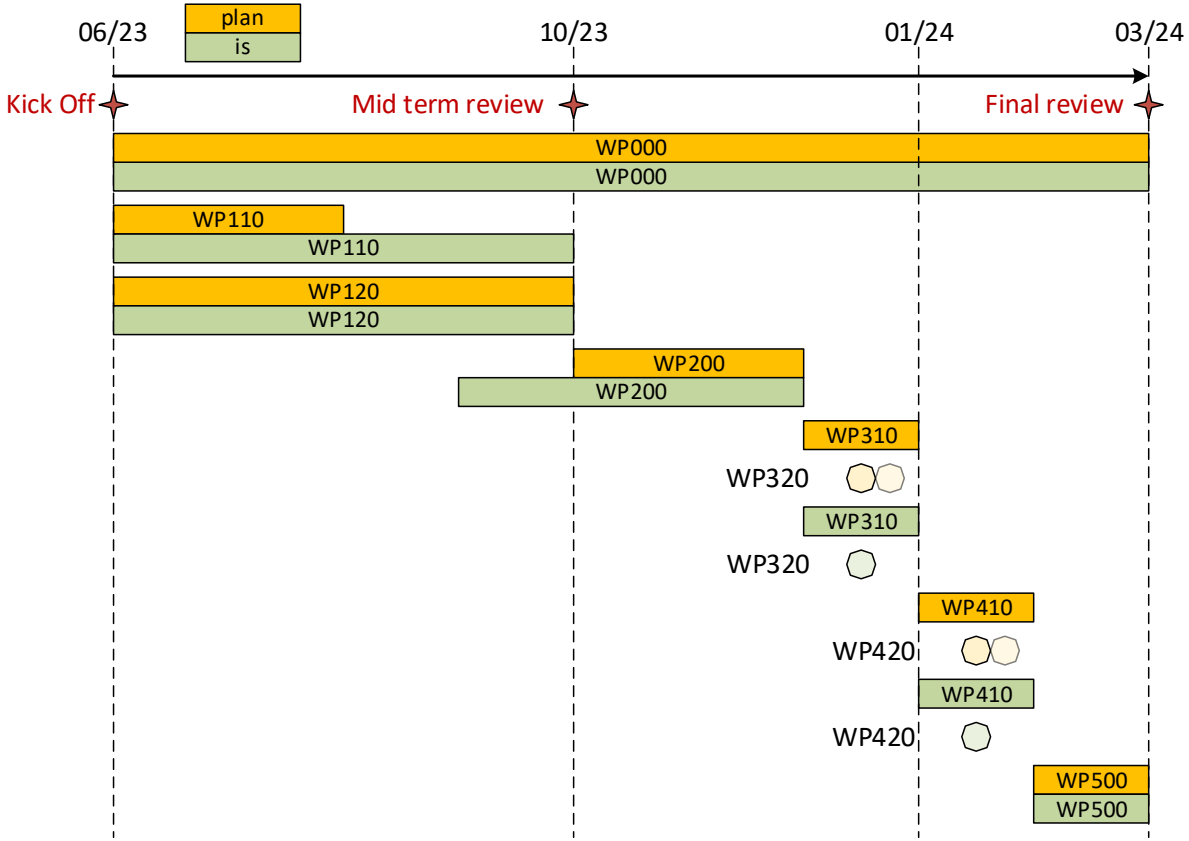
- Oscillator design updated to fit within 80mm x 80mm x 20mm mould
- full in-fibre-setup enables casted in resin
- casting procedure created to ensure proper resin homogeneity
- oscillator in resin shows high mechanical robustness
- thermal loads within [5°C,45°C] possible without losing mode lock state
- vacuum has no impact on fully casted device
- vibration loads on oscillator shows no impact
- radiation impact on power loss can be compensated with increasing pump power

Summary

- De-Risk project completed without major changes
- oscillator de-risk successful

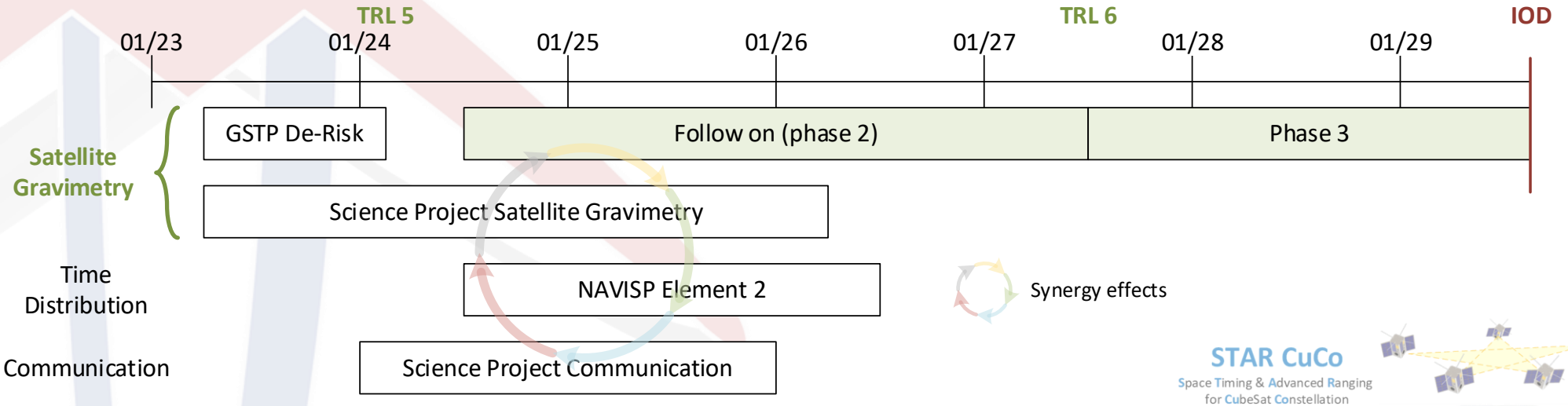


- project in time
- no finance change
- outcome more promising as expected



Next steps

- → Satellite gravimetry as most promising mission for demonstration (highest requirements on distance measurement)
- → Further technical development necessary for high precise distance measurement
- → **<u>Engineering Model of complete DORT system is the next step</u>**
- → INCUBED?
- → Synergy with other projects lowers time and financial investments



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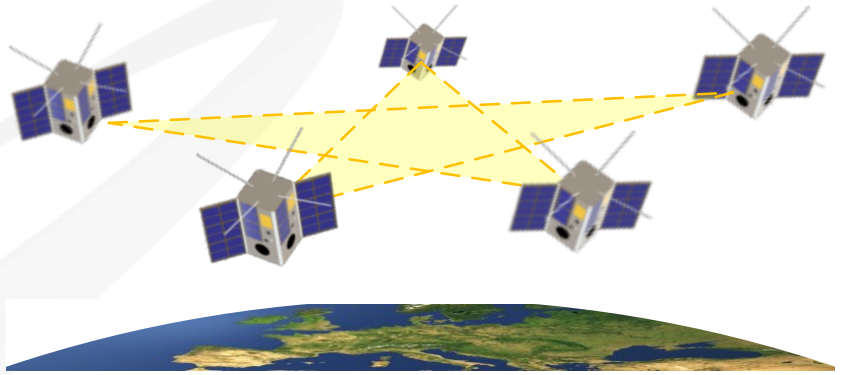
for **Cu**beSat **Co**nstellation



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Thank you!