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High Stability Laser Control Module

Final Review – 28th February 2023

Agenda

1 Background & Project Plan

2 Technical Outputs

3 Overview and Future Work

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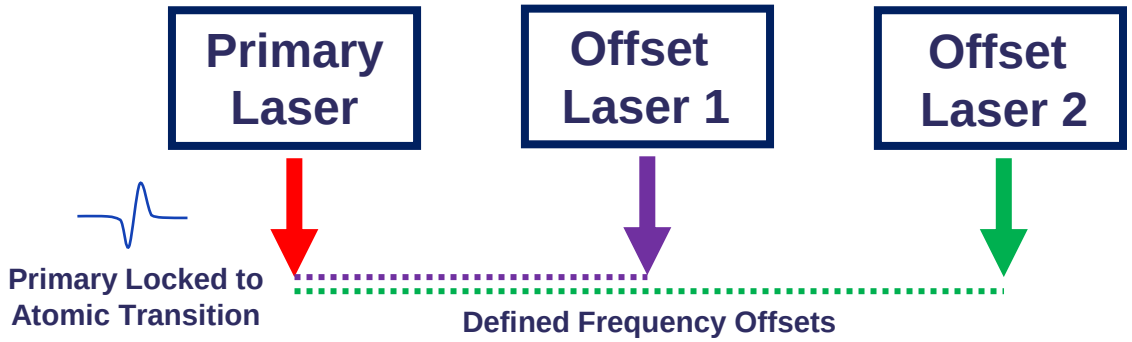
Background

Background

Most quantum technologies depend on reliable, ultra-stable laser light sources. An electronic feedback loop is commonly used to lock the laser to an external reference such as an atomic/molecular spectroscopy line, a stabilised reference cavity or an external reference laser.



For space applications there is a strong need to develop a robust set of electronics, suitable for the space environment, which is able to drive lasers whilst automatically finding and maintaining the required locking frequencies.

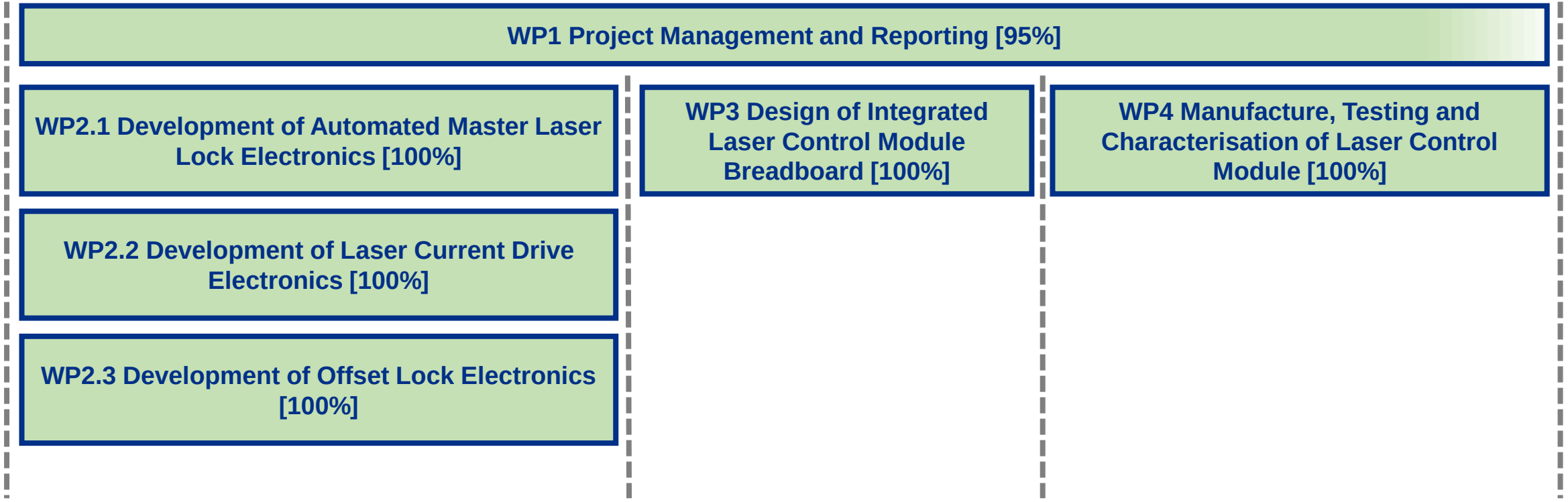
Project Objectives

Develop, test and characterise a laboratory breadboard (TRL 4) integrated laser control module for space applications. Advances in the SWaP and increases to the robustness, automation and usability of the system will open new exploitation opportunities in both space and ground-based environments.

Requirements
The Laser Control Module shall be capable of controlling suitable laser sources with a measured linewidth of < 1 MHz, with a goal of < 100 kHz.
The Laser Control Module shall be capable of automatically locking the master laser frequency to a defined Rubidium transition.
The Laser Control Module shall be capable of locking the slave laser to a defined offset up to 7 GHz from the master frequency, with a goal of up to 10 GHz from the master frequency.

A clear route to space applications shall be defined from the outset with design, architecture and component selections based on the availability of space-qualified devices.

Work Package Logic



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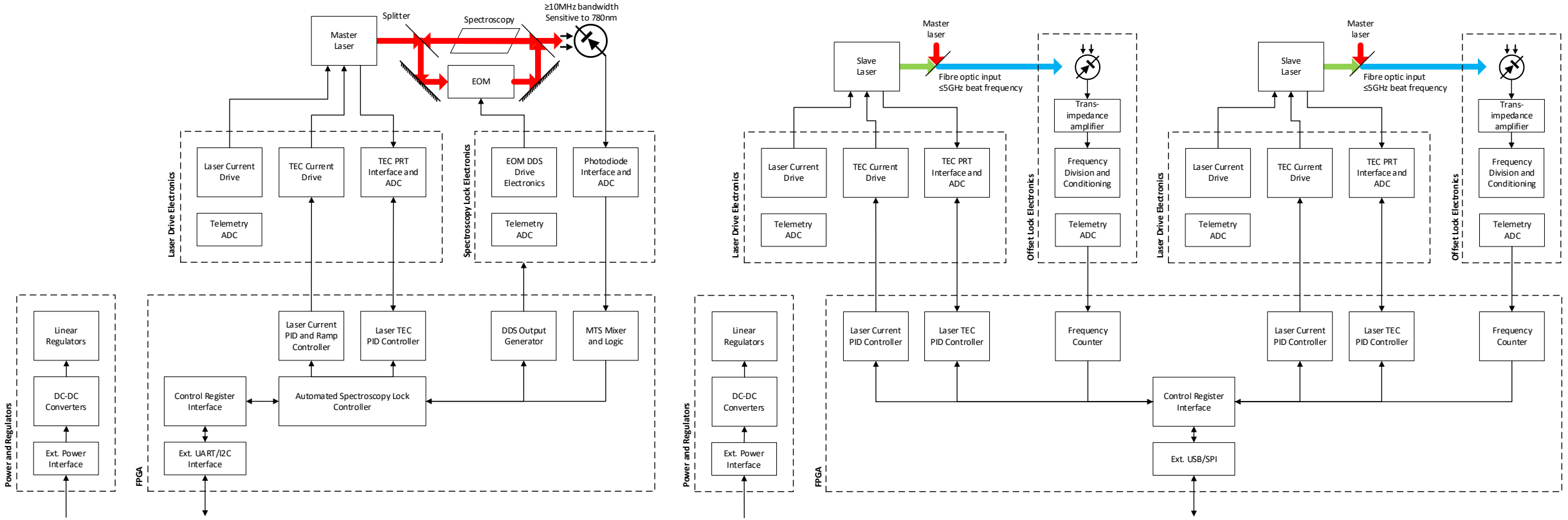
Block Diagram



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Technical Update

Manufacturing and Assembly

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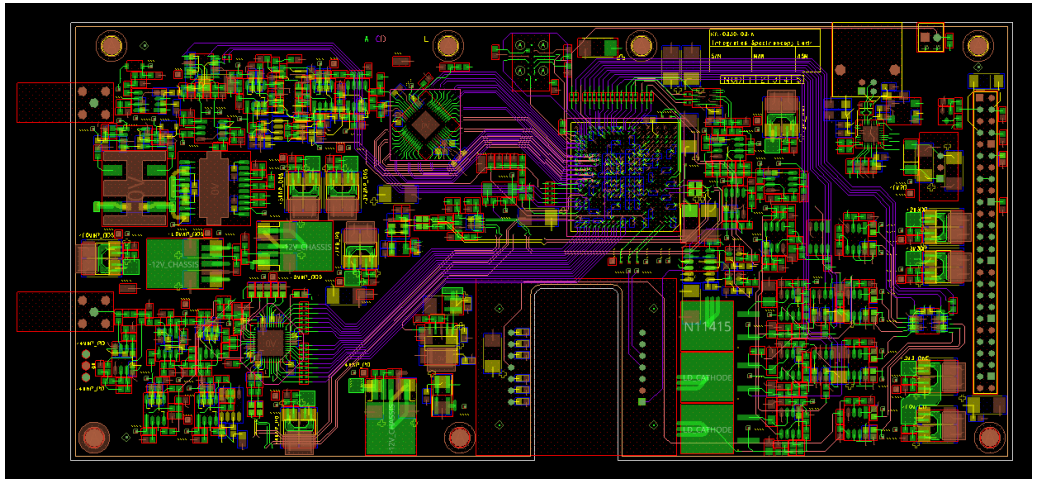

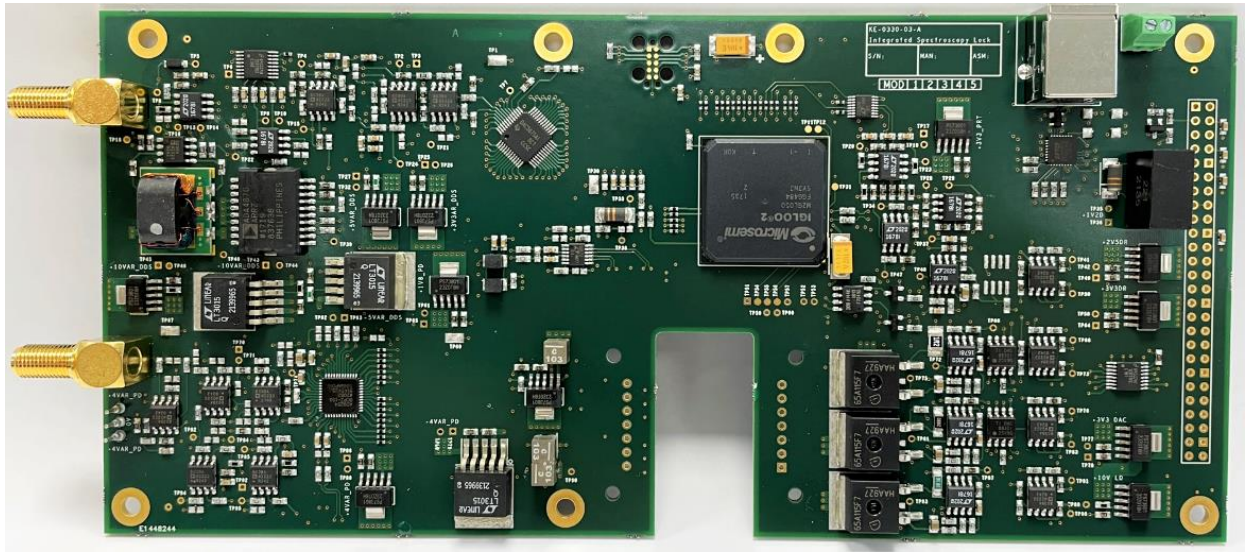

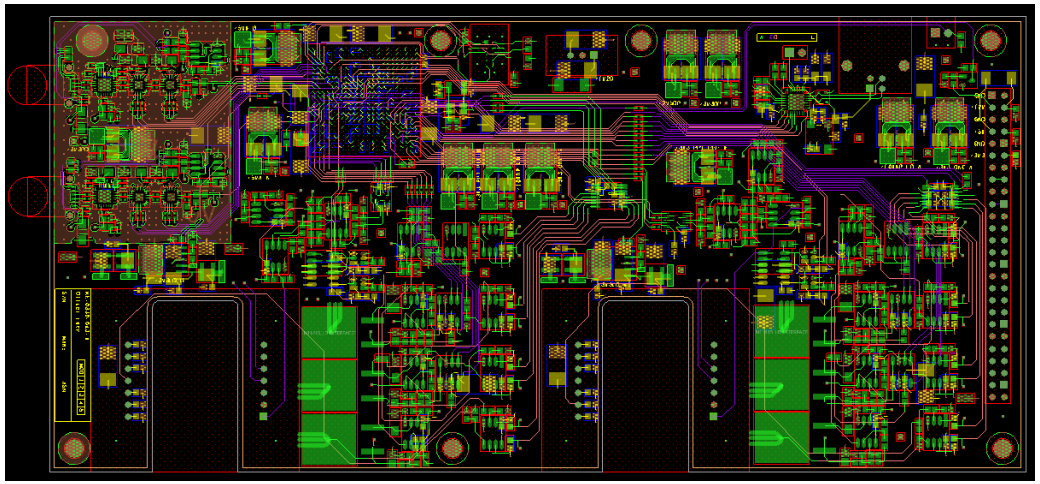

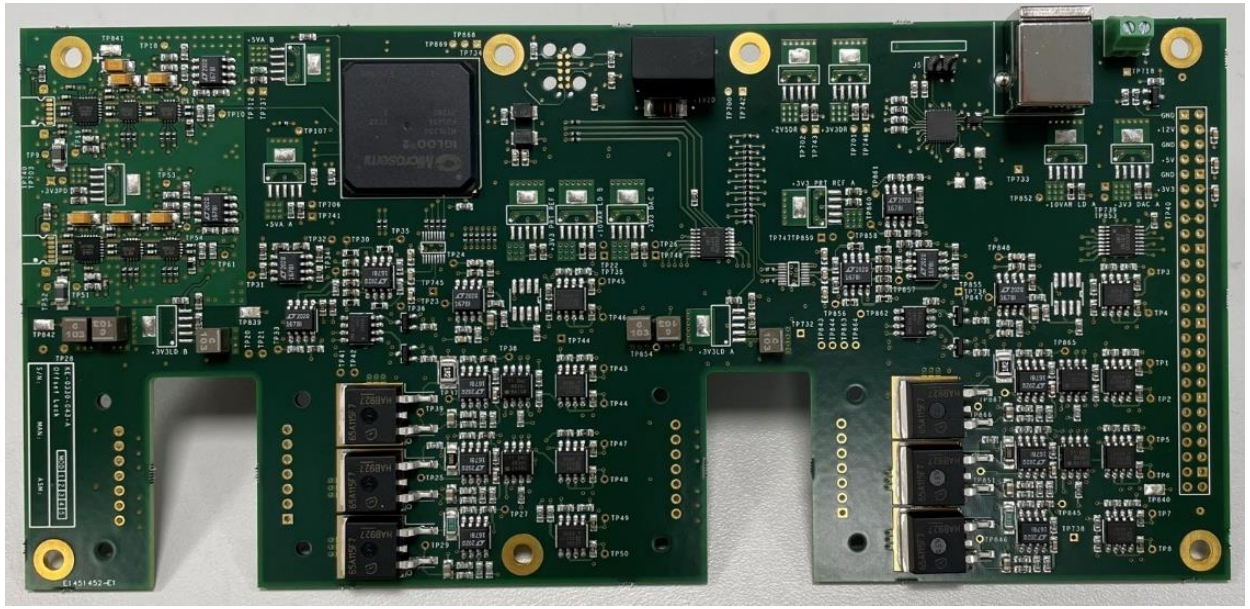

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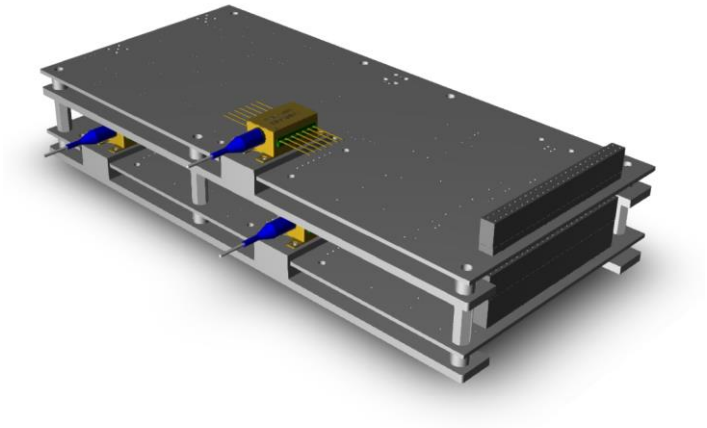

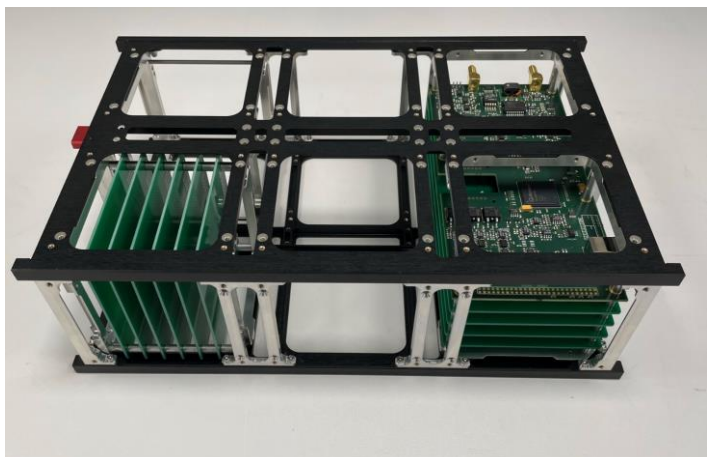

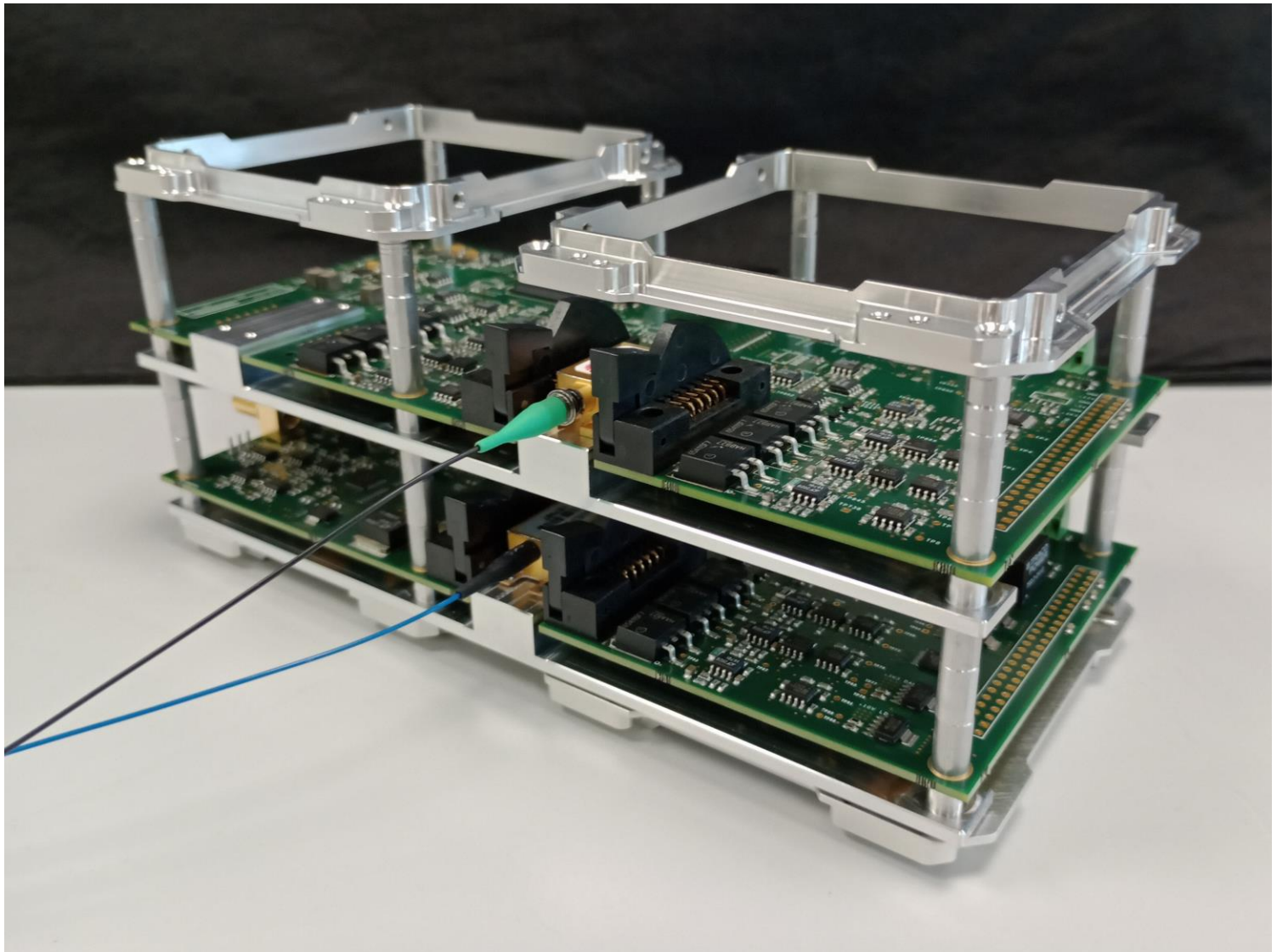

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Technical Update

Characterisation Results

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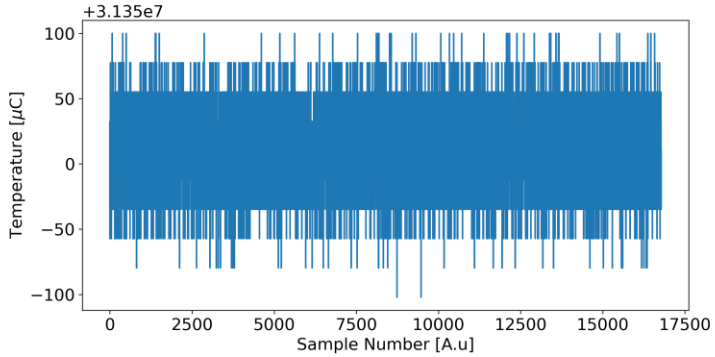
Laser Drive

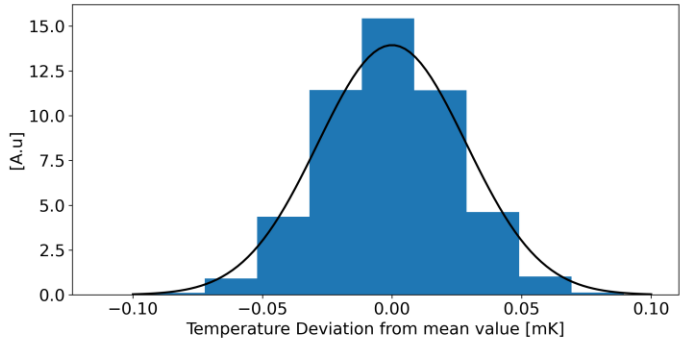
- Laser current drive with both fixed analogue set point and digital controllable modulation.
- TEC current drive with 20-bit PRT ADC and digital PID control.

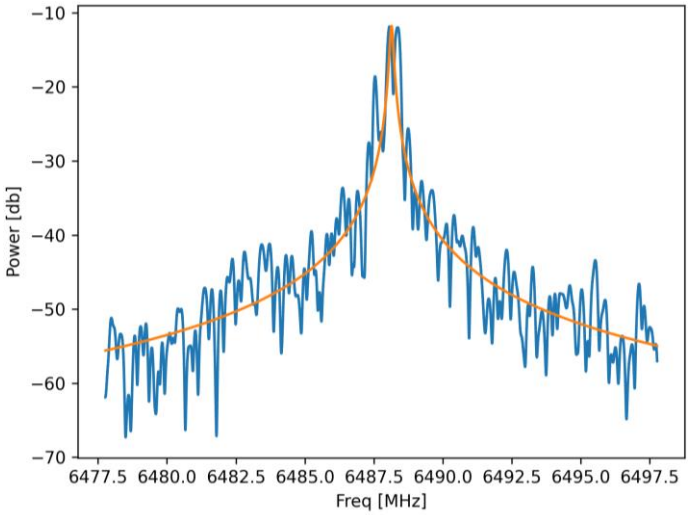
- Temperature Stability = **0.029mK**

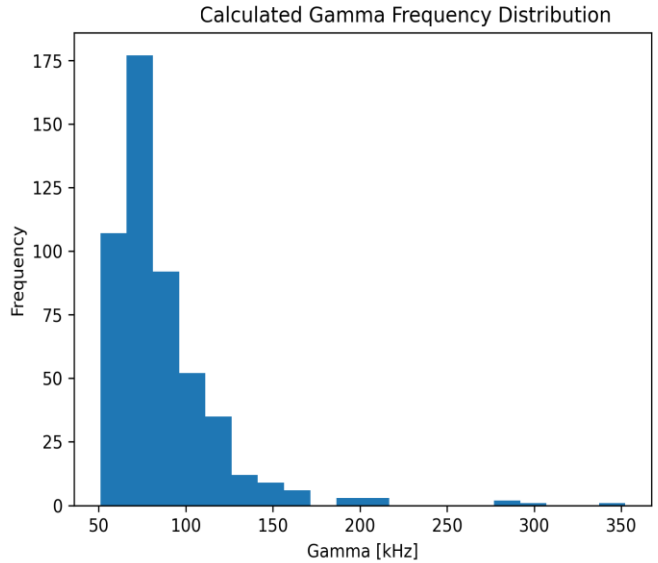
- Linewidth (1ms) < **73.54kHz**

Design outputs from this activity have already been incorporated into HIROS instrument baseline on ESA SCOUT CubeMAP programme.









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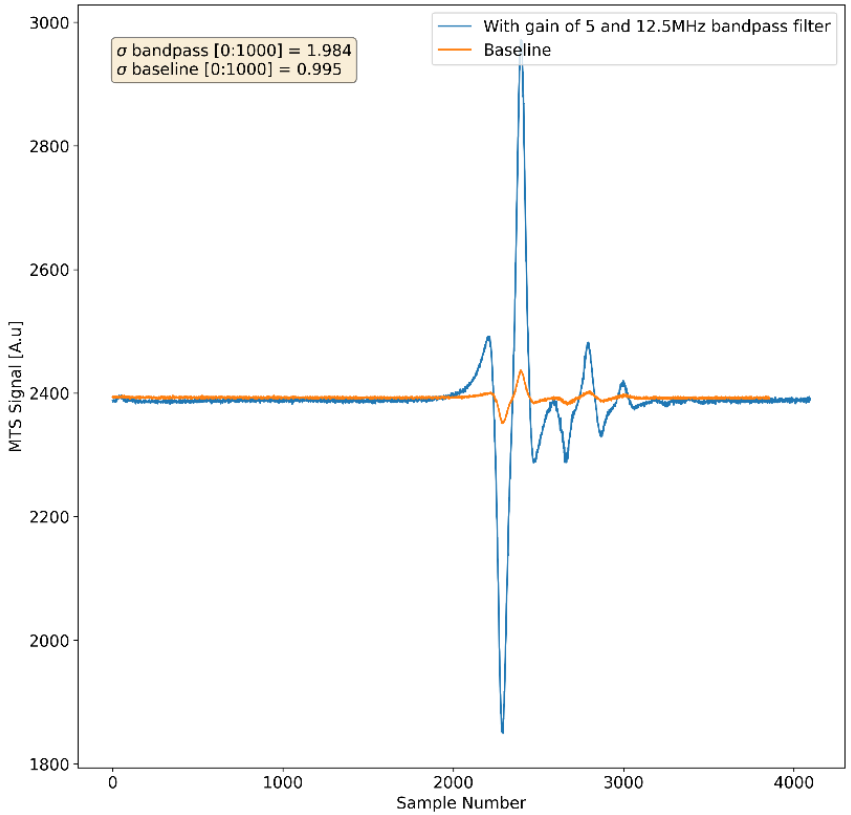
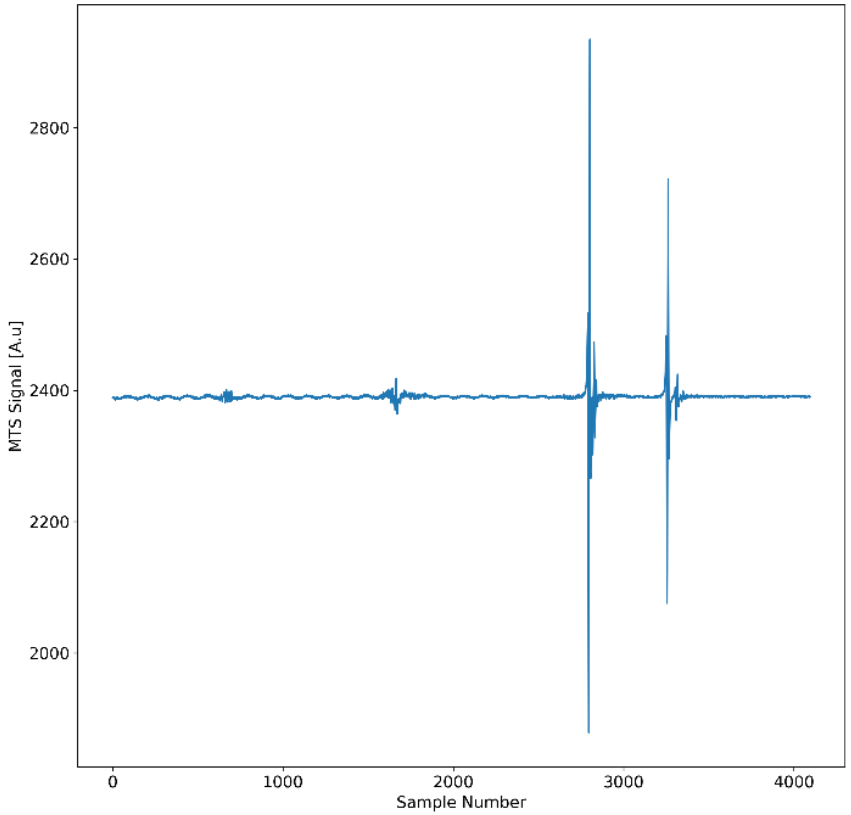
Spectroscopy Lock

- Introduction of bandpass filtering on PD input has significantly improved MTS signal to noise ratio.





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Spectroscopy Lock

- FPGA-based PID control gives robust spectroscopy lock, demonstrated for 12+ hours.
- Frequency deviation (σ) exceeds wavemeter measurement capability, estimated in the region of **75 kHz to 150 kHz.**

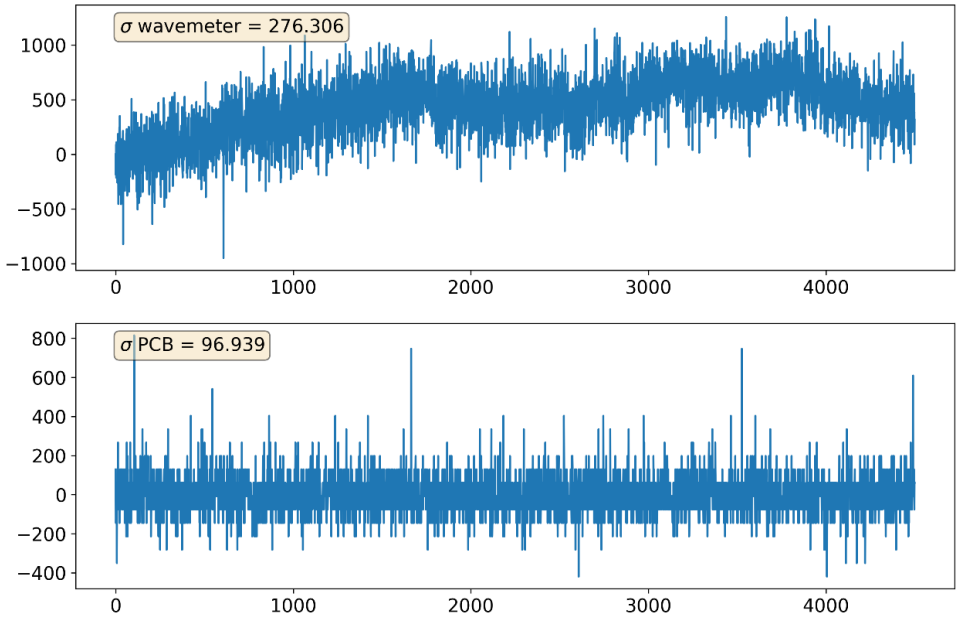

Figure 5: PID Lock Frequency Deviation (kHz) - No Bandpass Filter

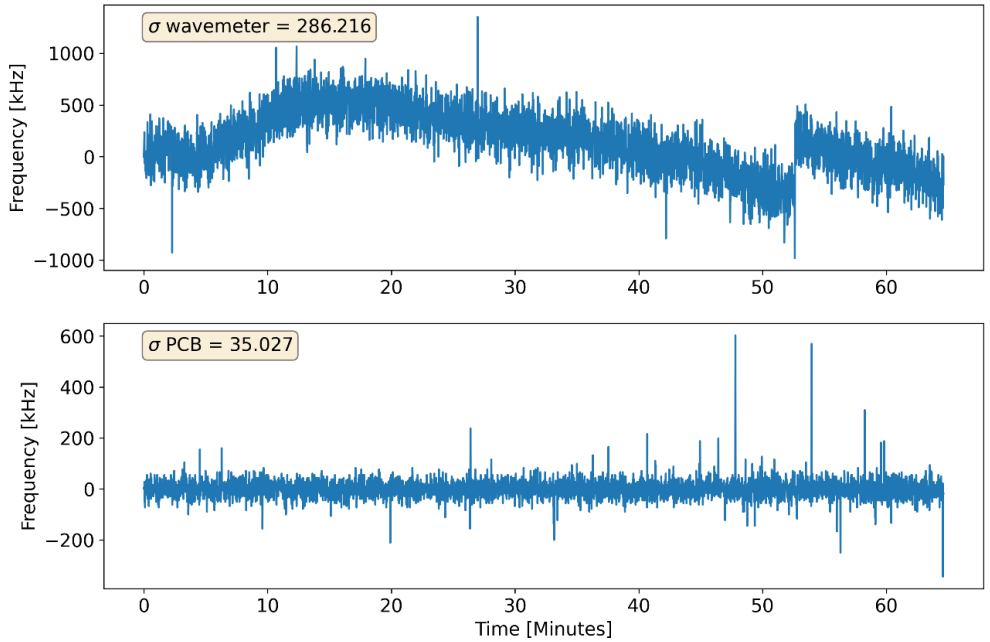

Figure 6: PID Lock Frequency Deviation (kHz), with Bandpass. [File - PID_tracking_bandpass_7]

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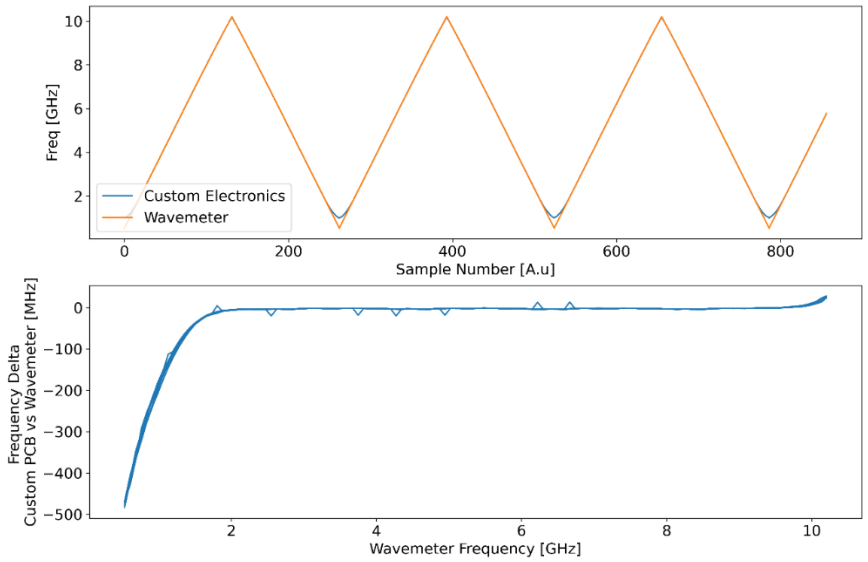
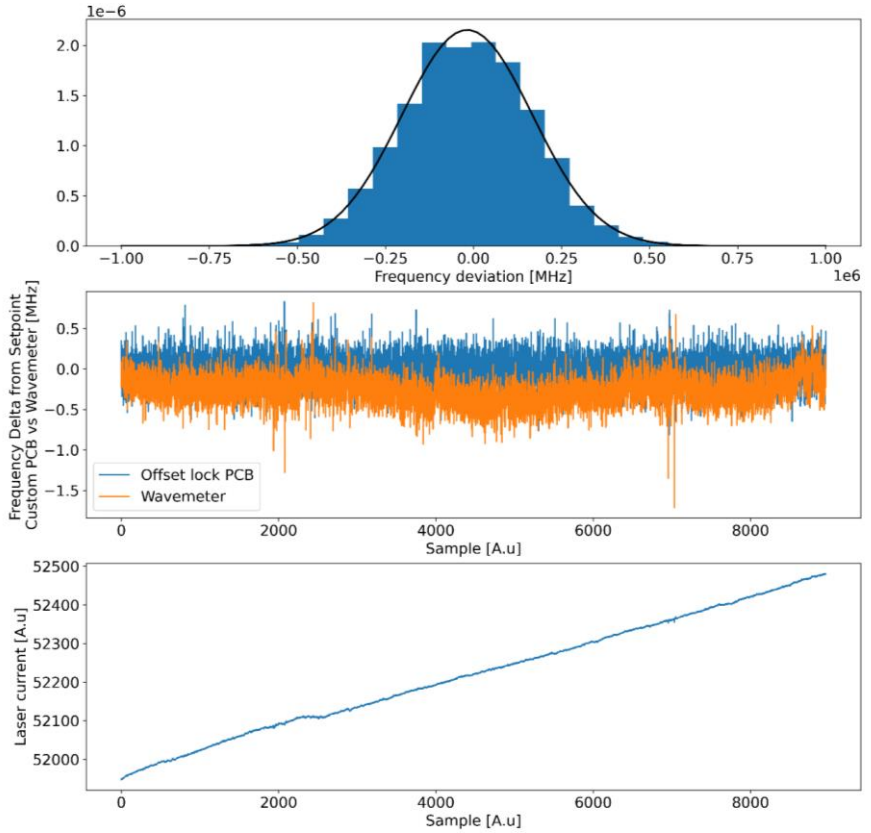
Offset Lock

- Consistent Offset locking up to **8 GHz** demonstrated. Capability to 10 GHz, but not fully repeatable.
- Outstanding design issue limits effectiveness below 2 GHz, likely due to variation in input optical power.
- Frequency deviation (σ) in region of **200 kHz**





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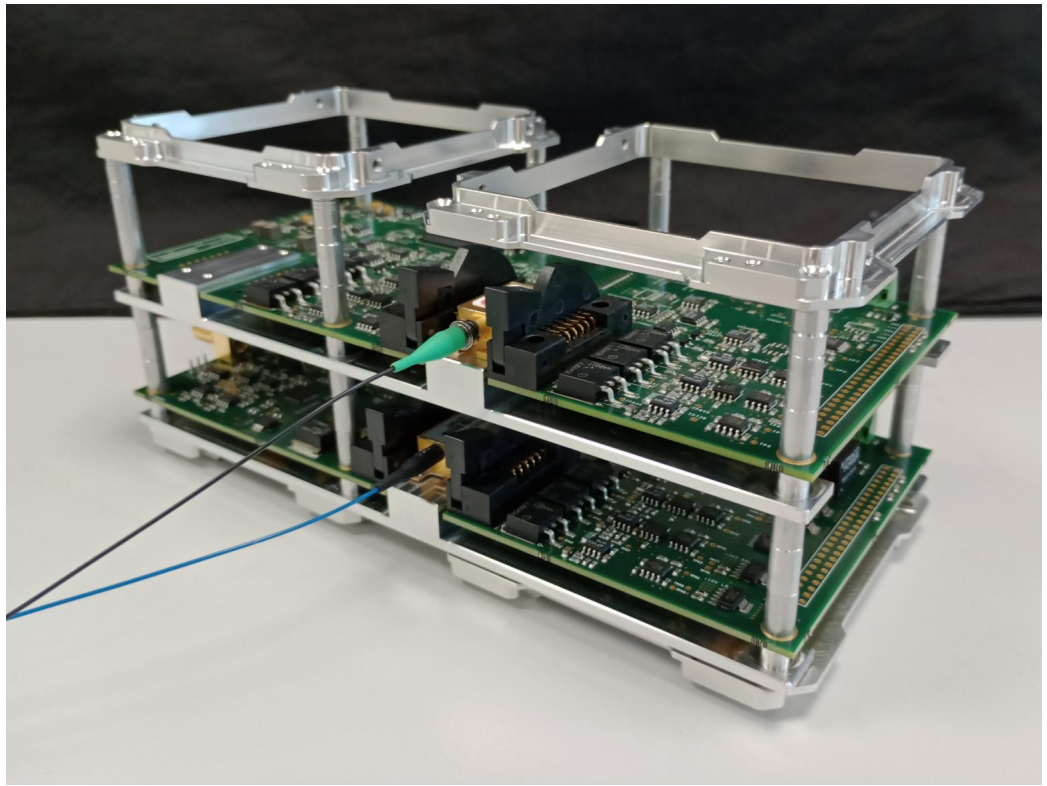
Overview & Future Work

Overview & Future Work

- High Stability Laser Control Module breadboard assembled and characterised in a laboratory environment.
  - Provides single spectroscopy-locked primary laser output, with two (+) additional lasers offset-locked up to 8 GHz.
- Component choices mapped to space-applications, with clear areas to focus up-screening efforts.

Next Development Steps:

- **Compact Spectroscopy Bench** – providing a robust optical setup for spectroscopy, significantly improving repeatability.
- **Integration into instrument/measurement sensor concept** – to enable optimisation of performance for specific application with clear development of requirements.
- **Instrument Control Software System** – forms a key part of automated atomic transition identification algorithms, but closely linked to overall instrument architecture.



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Thank you

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