Cold Atom Gravity Explorer (CAGE)

NCEO CEOI Conference
Teledyne e2v - Chelmsford
25th July 2020

Project Title: Cold Atom Gravity Explorer (CAGE)
Lead Organisation: Teledyne e2v
Partners:

University of BRISTOL
University of Reading
The University of Nottingham
Newcastle University
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

End User / Science Team

TELEDYNE e2v
Everywhereyoulook™
Science & Technology Facilities Council
RAL Space
UNIVERSITY OF BIRMINGHAM
ThalesAlenia
a Thales / Leonardo company
Space

Technology Team

Presenters: Marton Kiss-Toth (Teledyne e2v), Mike Salter (STFC-RAL)

Project Objectives

- Develop a strong, user driven science case for a cold atom gravity mission.
- Develop a concept design for a cold atom gravity sensor that will address the requirements of the defined science mission.
- Develop a strong and well-aligned UK consortium of partners including science user base, technology developers and platform providers.
- Strong focus on near term solutions using technology/performance assumptions that have already been demonstrated on the ground

Target Missions and Main Benefits

Target Missions

- NGGM
- Future gravity missions
- Potential solutions for sustained observations

Main Benefits

- Cold atom gravity mission could lead to a two-fold improvement (over GOCE) on the gravity field recovery for degrees above 50*
- Many applications and benefits of improved gravity field recovery
- Proposed concepts require significant technology development, are high SWAP and require validation

CAGE Approach

- CAGE set out to identify a pathfinder for a cold atom gravity mission
- Not necessarily step change in performance but a stepping stone to a new technology domain

* A. Trimeche et al 2019 Class. Quantum Grav. 36 215004 based on O. Carraz concept

Sensor Concept Development

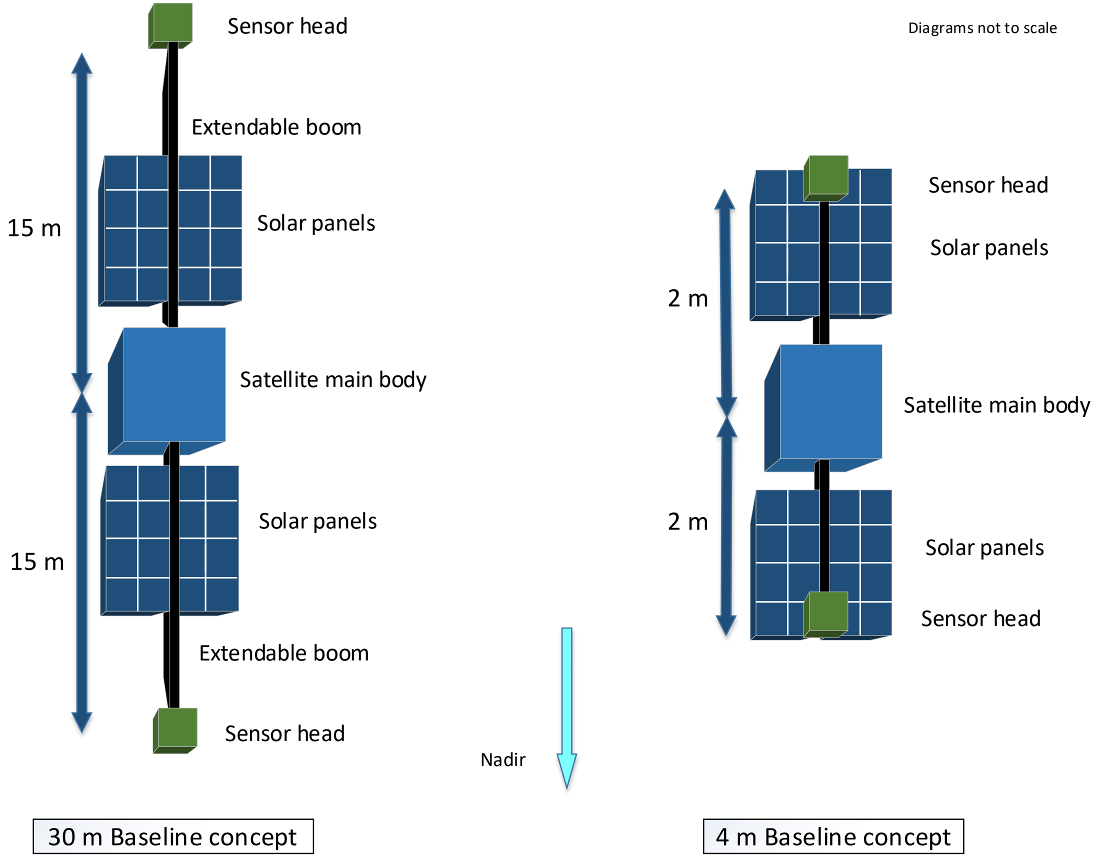
Technology Constraints

No Interleaving	Technology required for this is still low TRL and would significantly increase SWAP
Limited Momentum Transfer	Technology required for higher orders is still low TRL and would increase power requirements
Single Axis Measurement	Single axis measurement only to reduce complexity with gravity vector component calculation done in post processing

Sensor Concept Development

Large Baseline Solution

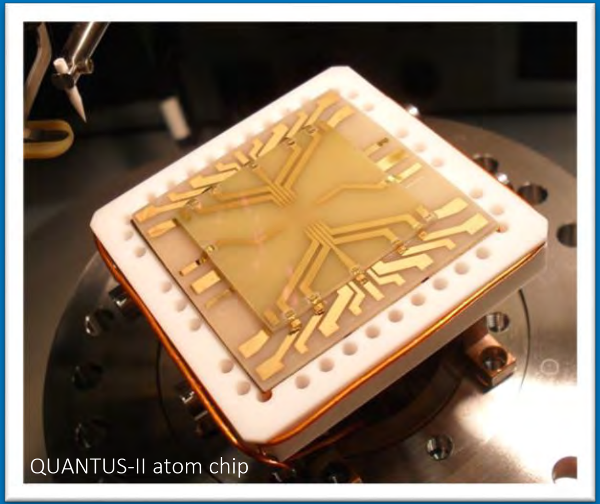
- Baseline of the instrument needs to be increased beyond traditional sizes to achieve scientifically interesting results
- Extendable booms explored for very large baseline but required stability and rigidity is difficult to achieve with current technology
- Instrument concept is scalable beyond fairing limitations for future variants



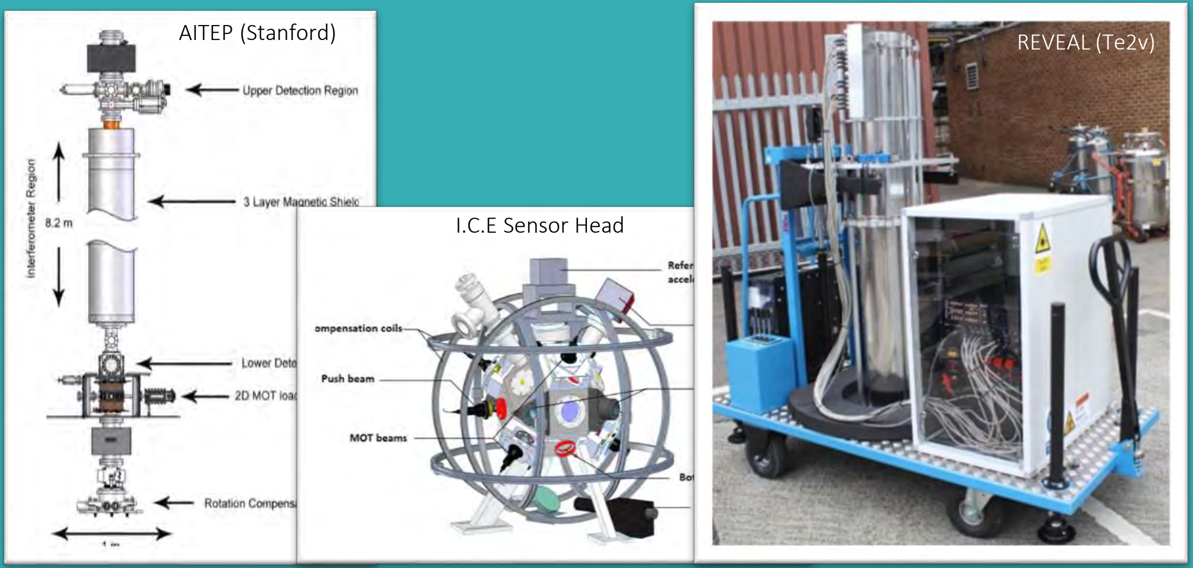
Diagrams not to scale

Design Trade-off

Atom Chip


QUANTUS-II atom chip

Non-Atom Chip



Advantages

Lower SWAP

Better space applicability – atom chip can be utilised for all cooling stages

Disadvantages

Atom cloud generated very close to chip surface

Relatively new technology

Advantages

Extensive heritage

In-house expertise

Disadvantages

Higher SWAP

Most instruments are terrestrial

Ultra-cold cooling methods may not be micro-gravity compatible

Final Concept

Operational Parameters

Parameters	Values
Interferometry Duration 2T (s)	8
Baseline (m)	4
Number of atoms	10^3
Preparation Time (s)	2.7
Atom Temperature (nK)	1
Diffraction Order	2
Total Noise (E)	0.0485

Additional Systems

Michelson Interferometry for active baseline measurement, platform vibration correction and rotation compensation.

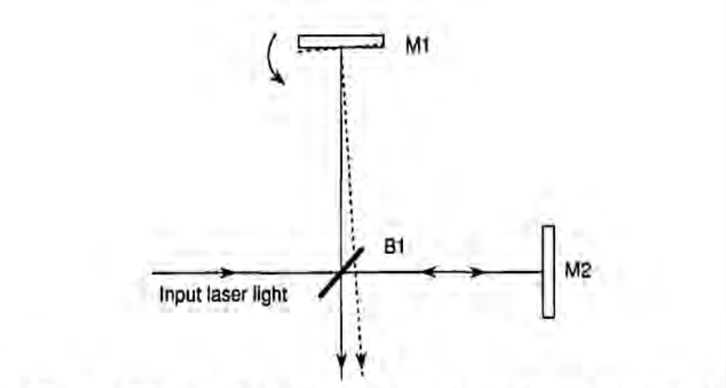


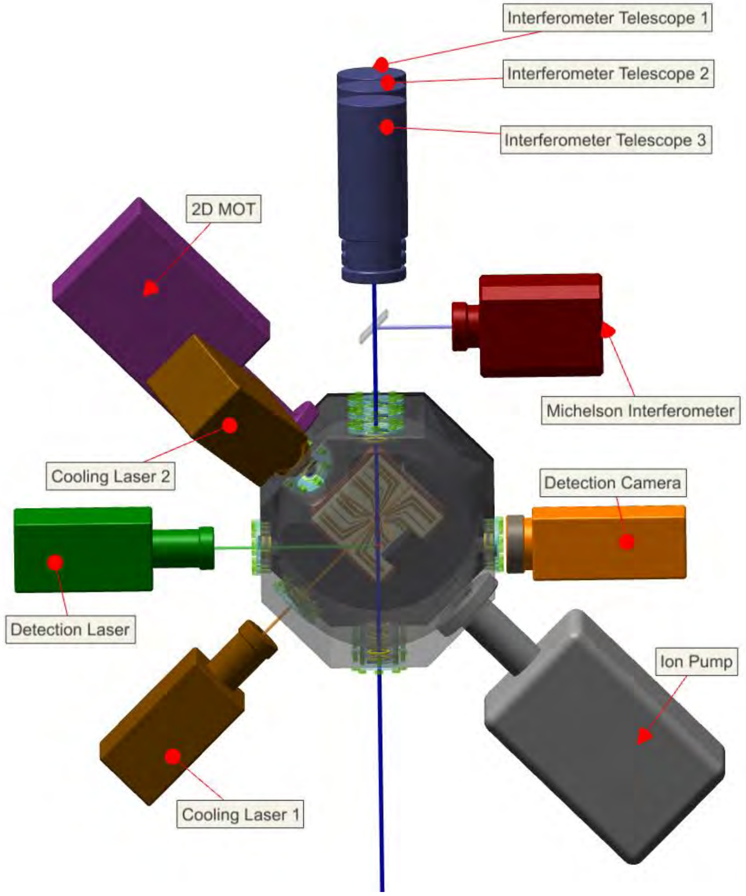
Fig. 1. Effect of misalignment of one of the mirrors in a simple equal path-length Michelson interferometer.

doi: 10.1364/ao.33.005041.

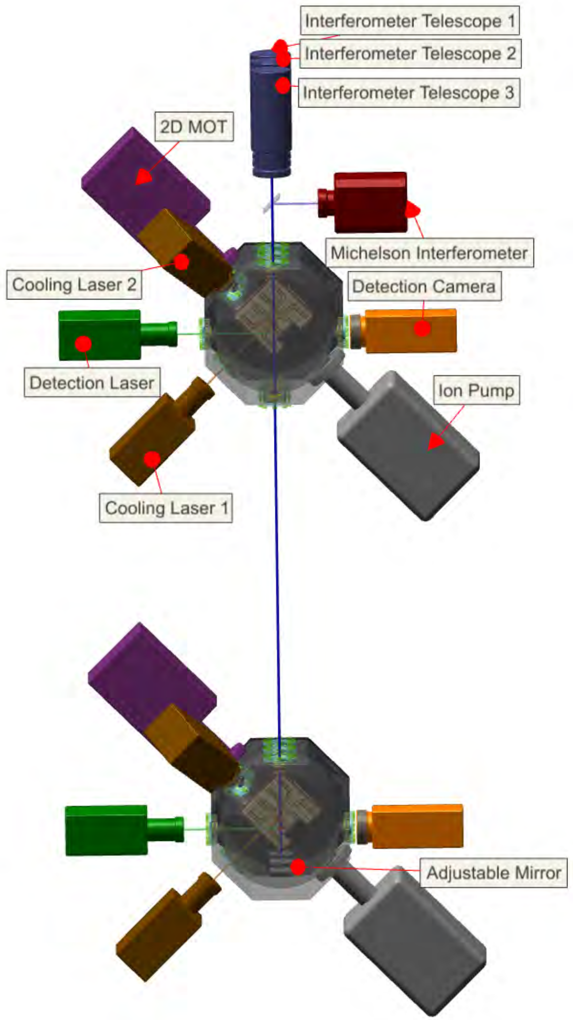
Sensor Configuration

- Atom chip design using 2 cooling lasers, both retroreflected
- Magnetic trapping using the chip and external bias coils only (not shown)
- 2D MOT to increase loading rate
- Michelson Interferometer for active baseline measurement and alignment/ compensation
- Detection via direct imaging of atom cloud fringes

Top Sensor Head

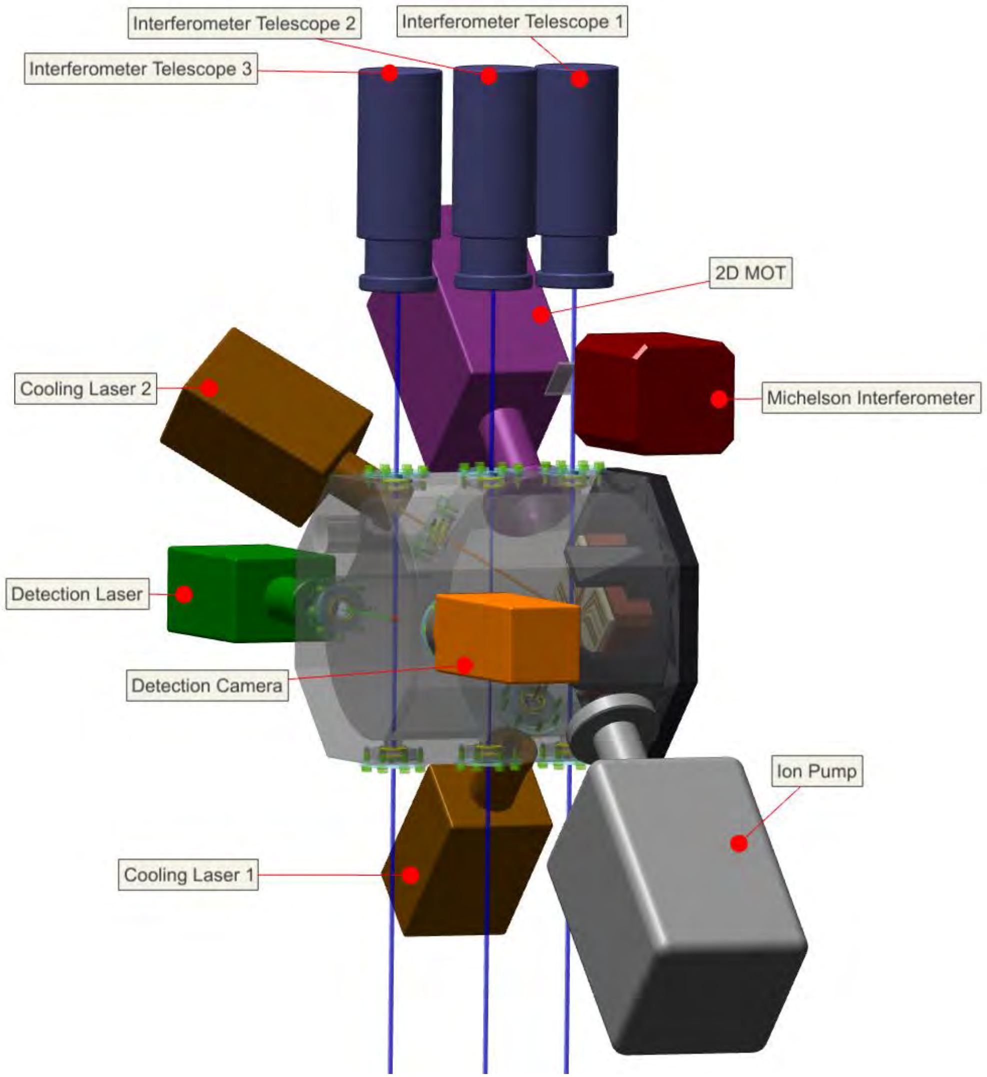


Full Sensor



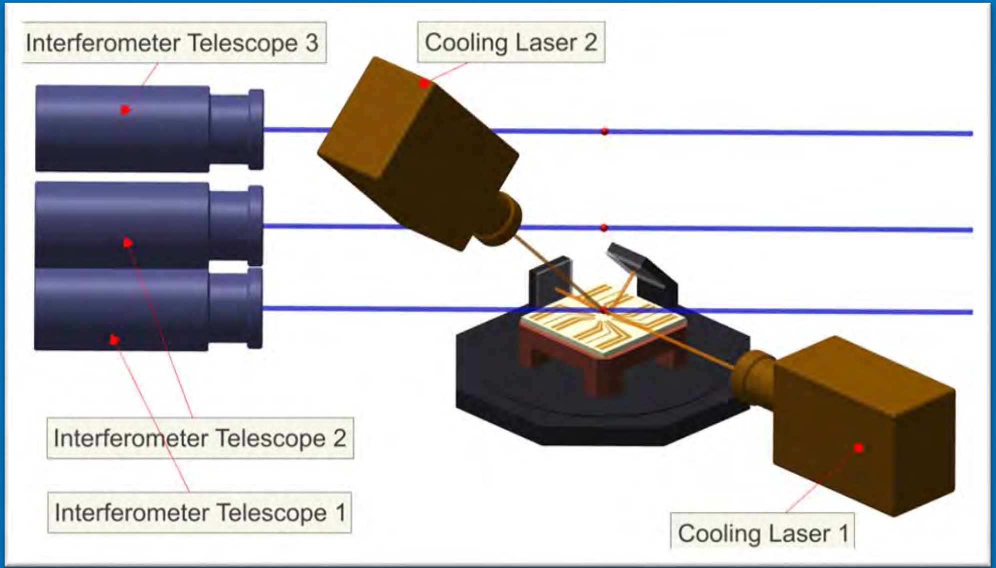
Extended Chamber

- Atom cloud is generated very close to surface
- The atom cloud must be moved away from the surface of the chip to achieve reasonable beam width
- Distance to which the atom cloud must be moved makes re-capture technically challenging
- Atom cloud is launched away and interferometry takes place in 3 spatially spread out locations



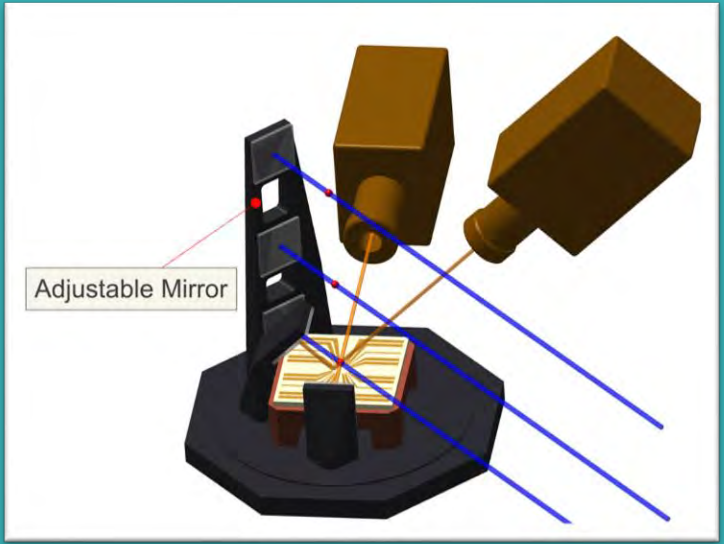
Inside The Chamber

Top Sensor Head



- Mirrors and atom chip rigidly mounted to the base plate for easier alignment
- Atom cloud generated close to the chip surface and then moved away for interferometry

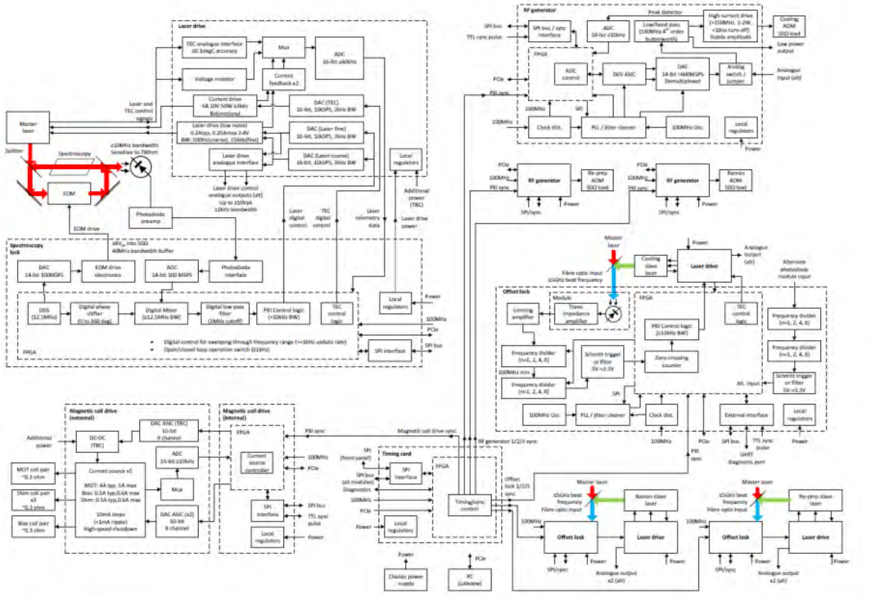
Bottom Sensor Head



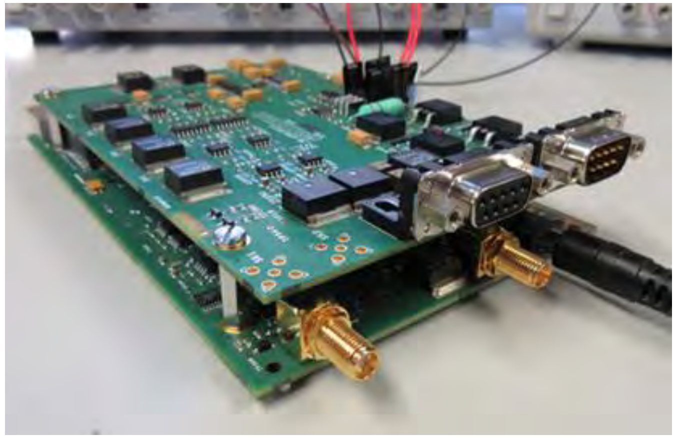
- 3 mirrors for reflecting the interferometer beams
- Mirrors controlled by a piezoelectric actuators to re-align the interferometer beams to compensate for rotation and platform vibration, and active baseline measurement

Cold Atom Electronics for Space Applications

- Concept architecture draws on previous MCLAREN Cold Atoms electronics development
  - Innovate UK/EPSRC - EP/R019304/1

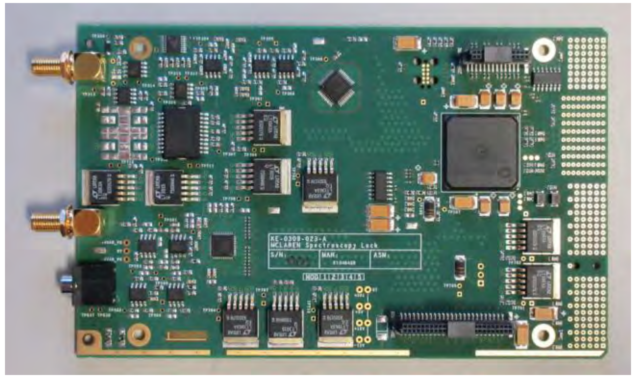


MCLAREN Cold Atoms System Overview

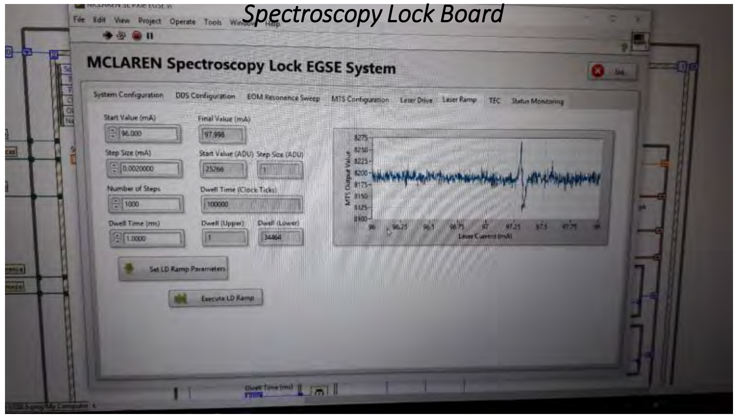


Laser Drive Board mounted on the Spectroscopy Lock

LabVIEW Toolkit example VIs



Spectroscopy Lock Board



MCLAREN Spectroscopy Lock EGSE System

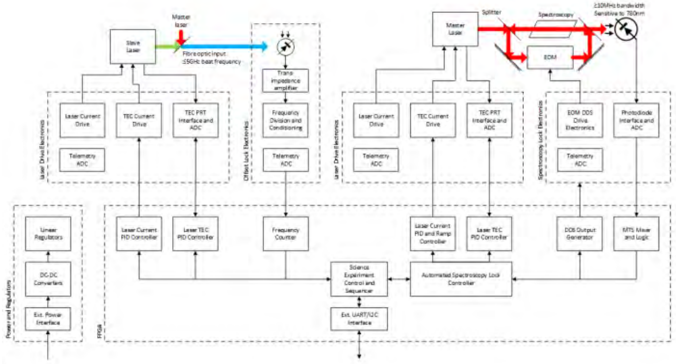
Start Value (mA): 96.000
Final Value (mA): 97.998
Step Size (mA): 0.0020000
Start Value (ADU): 25266
Step Size (ADU): 1
Number of Steps: 1000
Dwell Time (Clock Ticks): 100000
Dwell Time (ms): 1.0000
Dwell (Upper): 1
Dwell (Lower): 34464

Error signal obtained using the Spectroscopy Lock Board

Cold Atom Electronics for Space Applications

- The Electronics and Laser Control concept design considers how to implement the system in a representative way within spacecraft constraints.
  - Explores the parameter space to consider overall practicalities as opposed to defining single detailed proposal.
  - Flexibility to adapt to differing priorities and requirements, depending on future mission direction.

- Modular system allows flexibility for evolving sensor concept.
  - Laser Control Board (Current and TEC stabilisation)
  - Spectroscopy and Offset Lock Control Board
  - Isolated Atom Chip Current Drive
  - Non-isolated Coil Current Drive
  - RF Generator and Amplifier
  - Detection/Imaging Subsystem
  - Central Timing and Experiment Control Module

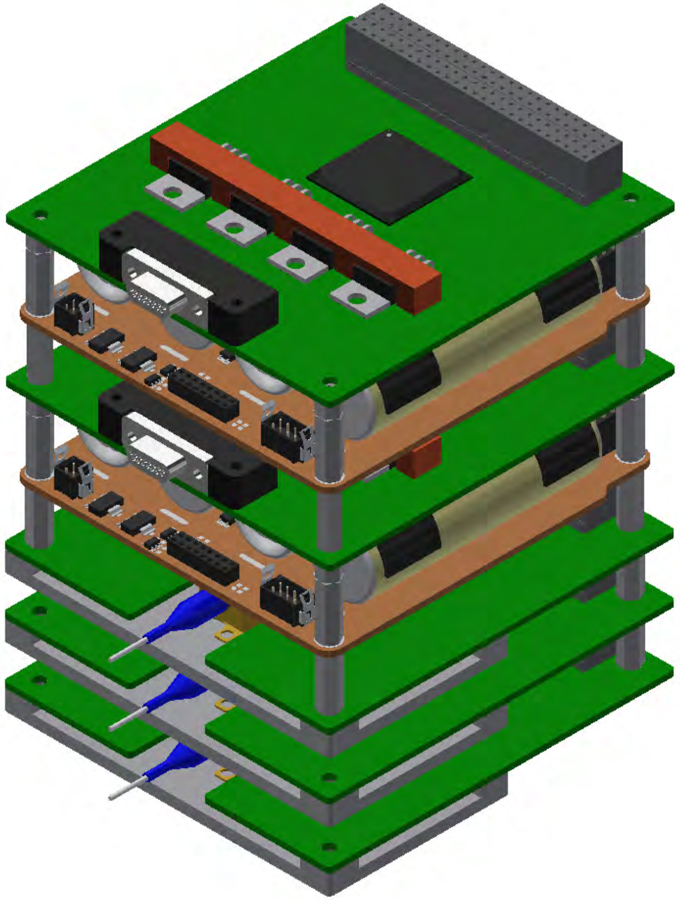


Concept system for fully-automated laser locking.

Cold Atom Electronics for Space Applications

- Focus is on assessing feasibility within the size and power constraints of typical platforms.
  - Coil drives, atom chip drives, AOM drives and laser amplifiers have largest influence on overall power budget.
  - Changes to requirements around these systems in a payload have a significant impact on what's achievable on a given platform.
- Consideration is given to different architectures for low-cost technology demonstration vs. flagship mission.
  - Design focussed on delivering a development roadmap for future missions.
  - High-reliability components increase volume.
  - Increased cost FPGAs pushes architecture towards more centralised controller with less modularity.
  - Power increase vs. mission type is less significant.

Design focus is on identifying initial concepts and a development roadmap for future missions.



Technology Demonstration Concept Atom Chip and Laser Electronics Stack

GOMSpace BPX Batteries included for reference.

Performance and Technology Timeline

Technology Timeline

GOCE

10 mE/√Hz in 2 axis

20 mE/√Hz in radial direction

CASPA-ADM

CAI Technology Demonstrator

CAGE

84 mE/√Hz

Future CAI

5 mE/√Hz*

* Based on numbers from A. Trimeche et al Class. Quantum Gravity, vol. 36, no. 21, 2019