National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

Laser and Optical System for Miniaturization and Space Qualification of Quantum Sensors

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Strategic Focus Area: Quantum Sensing for Science Missions **| Strategic Initiative Leader:** Edward T Chow

Objectives:

This effort seeks to build on recent advances in semiconductor lasers and optoelectronic component technology to design and fabricate a low-SWaP, as well as reliable and robust, semiconductor-based laser and optical system (LOS) to support cold-atom quantum sensors. This LOS is targeted for application of an atom-interferometer-based gravimeter, which will enable high-precision gravity measurements outside of the laboratory, looking toward space-based deployment. The target volume is <0.01 m3, and total power consumption of the LOS is envisioned to be less than 100 W, compared to >250 W typically needed in current experiments including NASA/JPL's Cold Atom Lab (CAL).

Through this effort, we have arrived at a notional system design that supplies eight frequency-locked beams for 2D and 3D magneto-optical trap formation and interferometry. Each beam will operate around 852 nm for a Cesium atom interferometer-based gravity gradiometer, and will achieve narrow laser linewidth (<100 kHz), wavelength referencing using a miniaturized atomic vapor cell, frequency tunability of >5 GHz, and rapid frequency agility of ~100s of MHz in 1 ms, as well as intensity and path control, and integration with custom path-to-flight drive electronics.

Background:

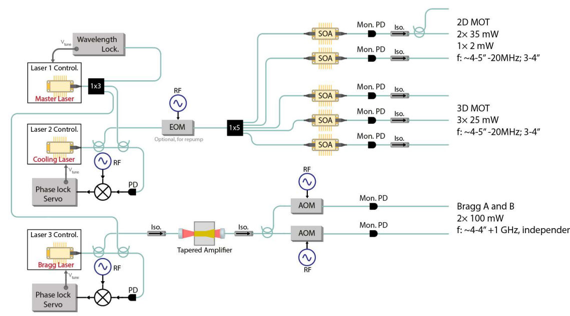
Quantum Information Science (QIS) is a national technology priority. Beyond investments in basic quantum science areas, many agencies' new focus is on moving from lab prototyping to field deployment of quantum sensors as soon as possible. JPL conducted several workshops and developed a Quantum Sensing Technology Development Strategy Study to identify the role it can play in NASA's quantum initiative. Together with discussion with Directorates' scientist and technologist, it became clear that the most promising instrument development would be a compact (i.e., a small suitcase) gravity gradiometer that is space-qualified. Several technology gaps were identified, including (1) achieving high atom source flux for atom interferometers, and (2) developing compact and robust laser optics systems that can support quantum sensor operation in space.

Approach and Results:

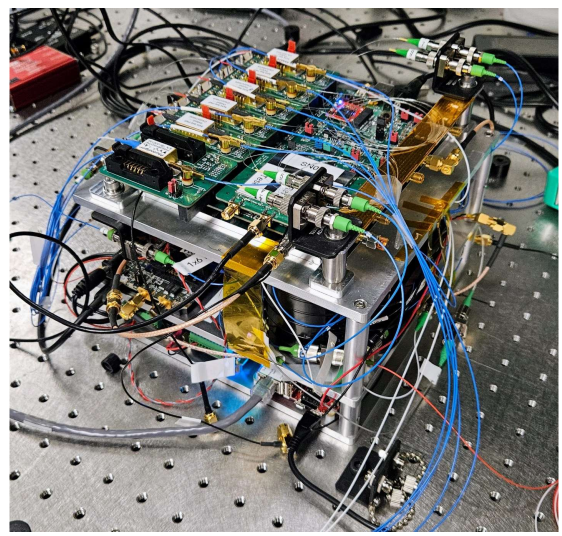
We have validated a novel all-semiconductor approach using semiconductor lasers and semiconductor optical amplifiers to synthesize and manipulate the beams necessary for atom interferometer operation. This architecture eliminates the need for high power lasers that are split among the various paths, reducing SWaP. The FY23 SRTD effort has seen good progress toward maturation and miniaturization of this LOS incorporating all necessary functionalities for preparing and performing atom interferometry measurements. These include including 3D and 2D magneto-optical trap beams with 25 mW power each, higher-power (100 mW) Bragg beams for interferometry, and control electronics in a self-contained system.

Significance/Benefits to JPL and NASA:

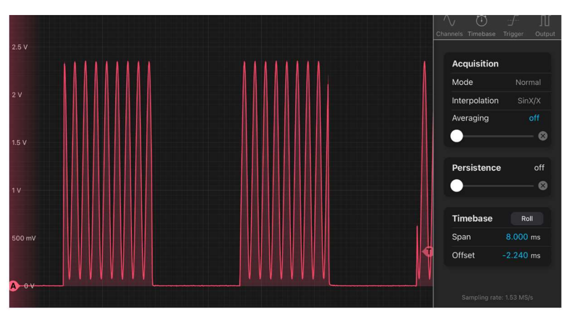
This task focuses on the size-weight-and power reduction and increasing reliability required for space-based quantum sensors. With the bright atom source technology advancement and LOS mass and weight reduction, through this SRTD, JPL will be in a unique position to develop and implement the quantum gravity gradiometer as part of an observing system for Earth mass change, as well as for potential applications in planetary science and astrophysics. Similar LOS architectures are also required by other cold atom quantum sensors, such as Rydberg radar.



Notional block diagram for the laser and optical system.



Photograph of the current system prototype, with custom control electronics.



Temporal interference between the two high-power Bragg beams.

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