National Aeronautics and Space Administration

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

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Quantum Sensing for Science Missions
Strategic Initiative Leader: Edward T Chow

Objectives:

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). 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.

This system will operate 852 nm for a Cesium atom interferometer-based gravity gradiometer. It should achieve narrow laser linewidth (<100 kHz), wavelength referencing using a miniaturized atomic vapor cell, wide frequency tunability of >5 GHz, and rapid frequency agility of ~100s of MHz in 1 ms, as well as intensity, polarization, and path control with external modulator/switch components. The initial objective of this work is to demonstrate a functional breadboard based on commercial components, and subsequently to reduce size and power of the system using micro- and integrated-optics technologies to facilitate path to space.

Background:

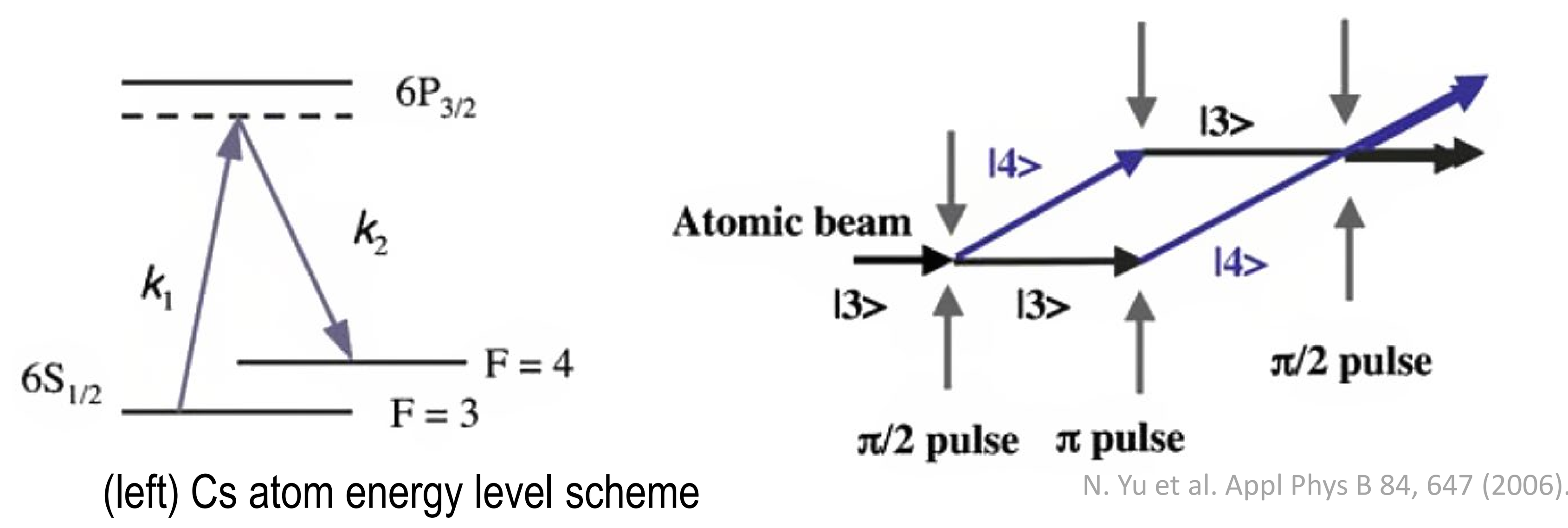
Quantum Information Science (QIS) is a national technology priority. Beyond investments in basic quantum science areas, many agencies' new focus is on moving from lab prototyping to field deployment of quantum sensors as soon as possible. JPL conducted several workshops and developed a Quantum Sensing 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:

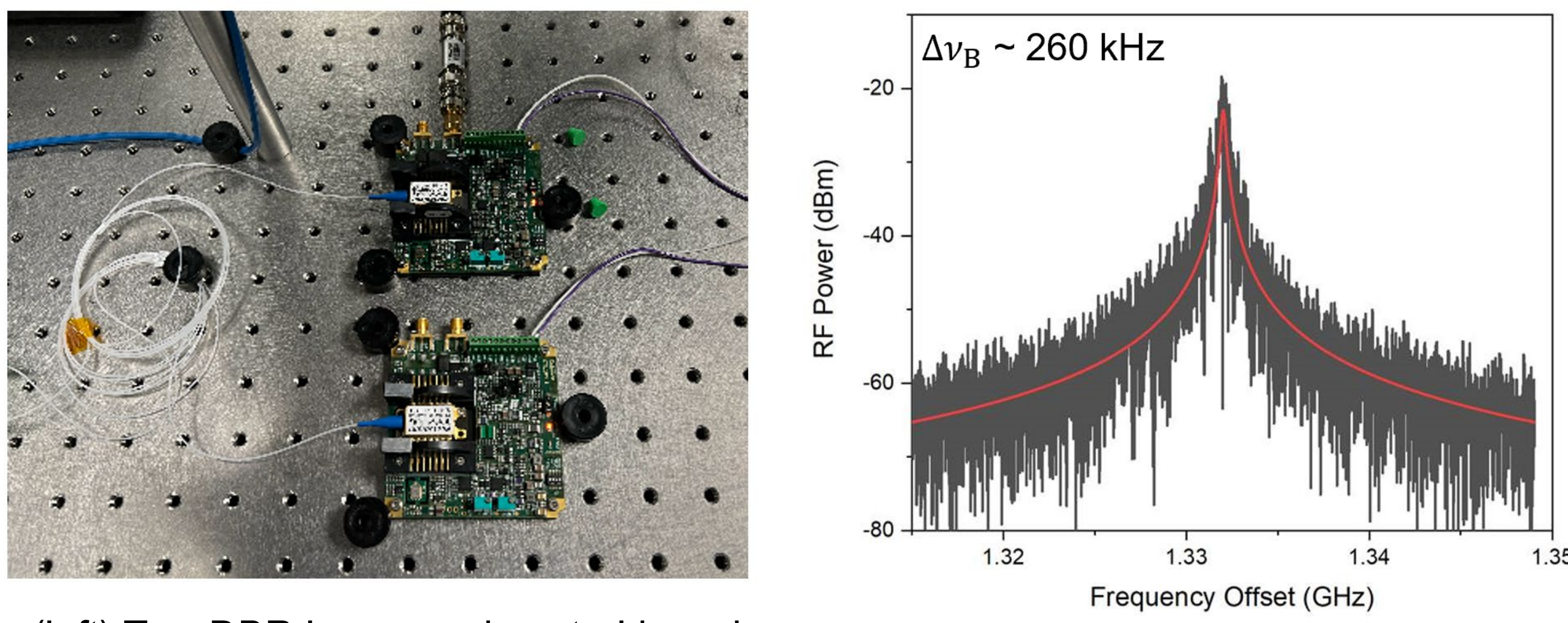
The FY22 SRTD effort has seen good progress toward the development of a functional laser and optical system breadboard incorporating all the necessary functionalities for preparing and performing atom interferometry measurements. This effort culminated in the demonstration of a portable LOS breadboard to create a magneto-optical trap and perform cooling of a cloud of Cs atoms in a vacuum chamber. The development of custom electronic circuitry for control of all components is under way. A prototype electronics control board was fabricated and is currently used for control of the optical amplifiers and MEMS switches.

Significance/Benefits to JPL and NASA:

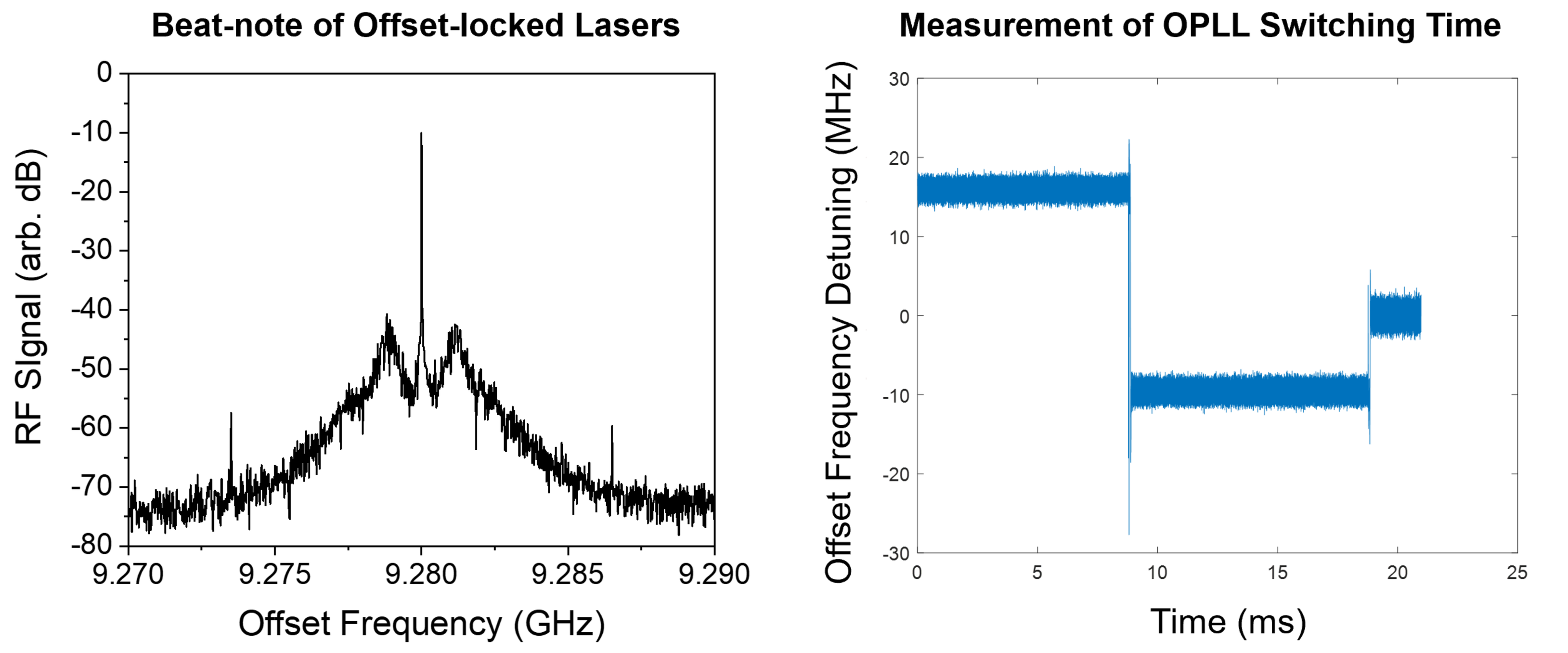
This task focuses on the size-weight-and power reduction and increasing reliability required for space-based quantum sensors. With the bright atom source technology advancement and LOS mass and weight reduction, through this SRTD, JPL will be in a unique position to develop and implement the quantum 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.



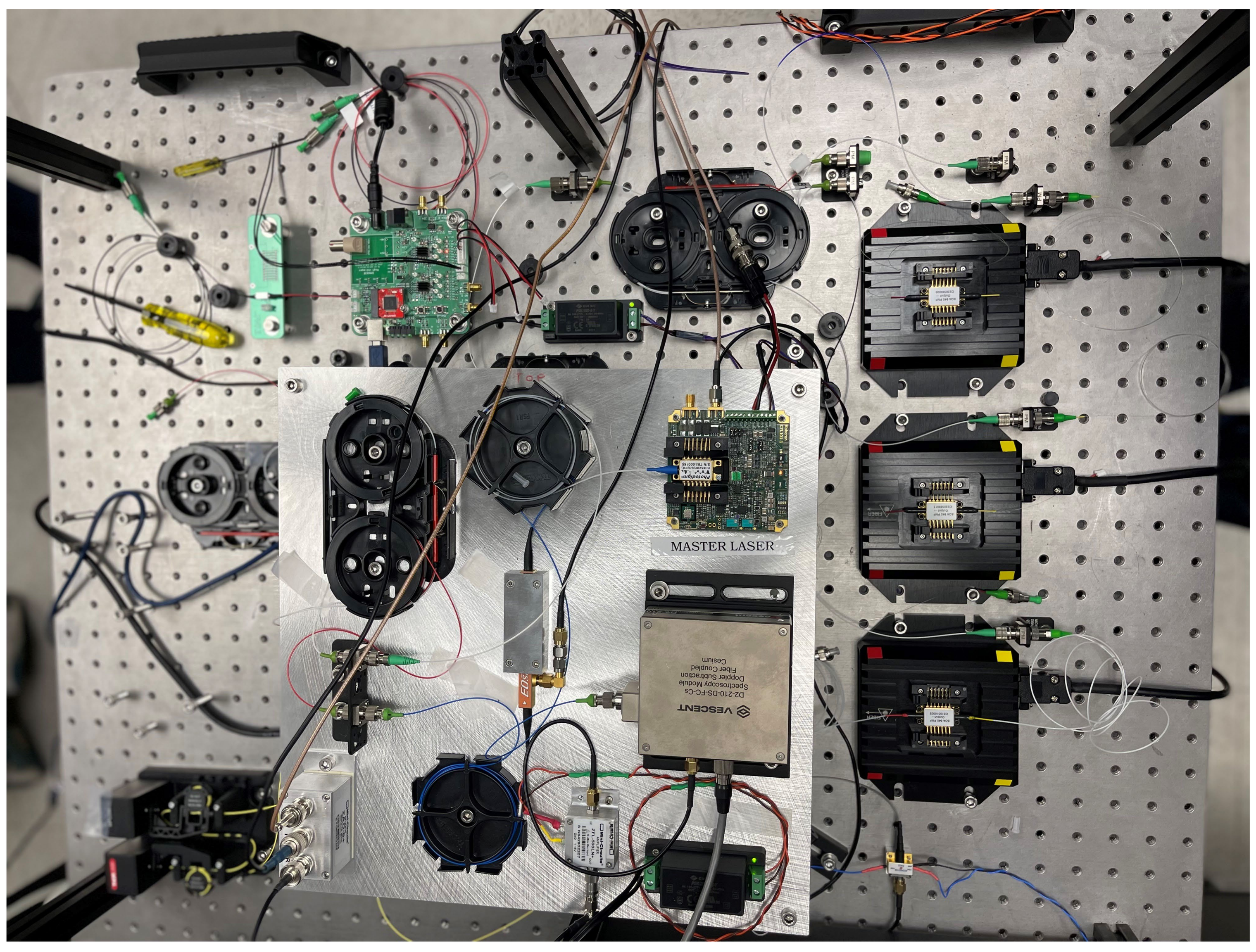
(left) Cs atom energy level scheme
(right) Schematic of an atom-wave interferometer using laser light pulses



(left) Two DBR lasers and control boards
(right) Beat-note of two independent lasers, demonstrating linewidth ~130 kHz



Offset locking using an optical phase-locked loop (OPLL) at frequencies above 9 GHz



Photograph of first-generation LOS breadboard using commercial and custom components.

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