

Fast Light Optical Gyroscopes

Project Manager(s)/Lead(s)

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Sponsoring Program(s)

Space Technology Mission Directorate
Game Changing Development

Project Description

Next-generation space missions are currently constrained by existing spacecraft navigation systems which are not fully autonomous. These systems suffer from accumulated dead-reckoning errors and must therefore rely on periodic corrections provided by supplementary technologies that depend on line-of-sight signals from Earth, satellites, or other celestial bodies for absolute attitude and position determination, which can be spoofed, incorrectly identified, occluded, obscured, attenuated, or insufficiently available. These dead-reckoning errors originate in the ring laser gyros themselves, which constitute inertial measurement units.

Increasing the time for standalone spacecraft navigation therefore requires fundamental improvements in gyroscope technologies. One promising solution to enhance gyro sensitivity is to place an anomalous dispersion or fast light material inside the gyro cavity. The fast light essentially provides a positive feedback to the gyro response, resulting in a larger measured beat frequency for a given rotation rate as shown in figure 1. Game Changing Development has been investing in this idea through the Fast Light Optical Gyros (FLOG) project, a collaborative effort which began in FY 2013 between NASA Marshall Space Flight Center (MSFC), the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC), and Northwestern University. MSFC and AMRDEC are working on the development of a passive FLOG (PFLOG), while Northwestern is developing an active FLOG (AFLOG). The project has demonstrated new benchmarks in the state of the art for scale factor sensitivity enhancement. Recent results show cavity scale factor enhancements of ~100 for passive cavities.

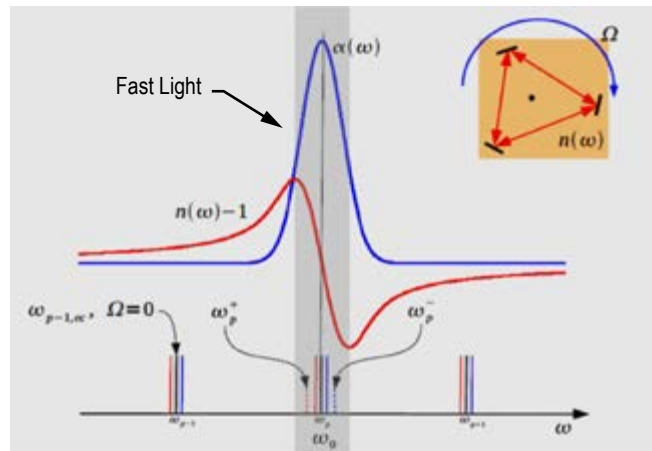


Figure 1: Illustration of how the response of a gyroscope is enhanced by fast light. The cavity modes are split by the rotation of the gyro. In the fast light region, the refractive index $n(\omega)$ decreases with frequency, which pushes on the modes and further increases the splitting.

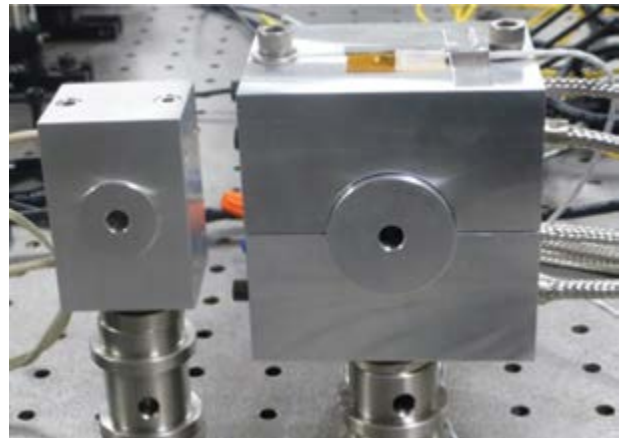


Figure 2: Temperature-stabilized atomic-vapor oven for tuning the PFLOG sensitivity: left—miniaturized version 2.0 and right—version 1.0.

Anticipated Benefits

FLOG addresses a critical need for navigation technologies that can meet the complexities of next-generation space missions, which will involve a diverse set of navigational challenges that cannot be supported with current methods. The development of onboard autonomous navigation technologies is critical to meeting these challenges, which range from cooperative flight to rendezvous with asteroids and other small bodies. FLOG is an entirely onboard technology that does not

rely on the reception of signals external to the spacecraft, extending the time for standalone navigation and reducing the need for updates from startrackers.

Potential Applications

In addition to the benefits for navigation, the improvements in gyro sensitivity open up new science possibilities such as ground-based measurements of the general relativity Lense-Thirring frame dragging effect, tabletop gravitational wave detection, and enhancement of the sensitivity-bandwidth product for interferometric gravitational wave detectors under development by the Laser Interferometric Gravitational-wave Observatory project. The increase in sensitivity can also be traded off against system size which could benefit other applications that place a premium on compactness such as pointing and tracking, high bandwidth satellite and interplanetary laser communications, vehicle motion compensation for synthetic aperture radar, automatic rendezvous and docking systems, and rover/lander localization in non-GPS environments.

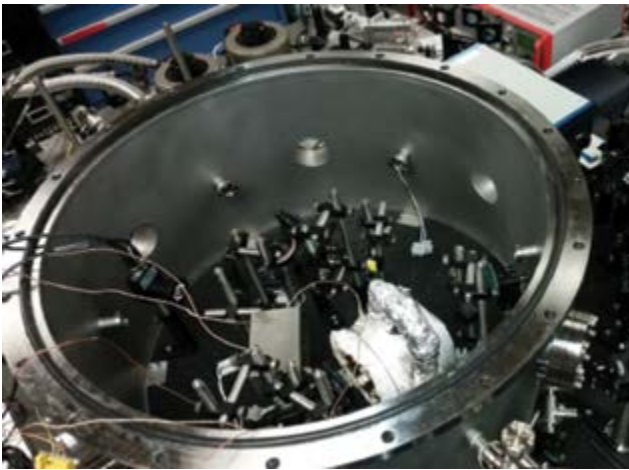


Figure 3: AFLOG custom vacuum enclosure containing shared-cavity, dead-band-free DPAL gyroscope.

Notable Accomplishments

PFLOG accomplishments for FY 2014 include the following: (1) Invented improved method for measuring cavity scale factor which substantially reduces the effect of cavity noise without the need for a hardened cavity, (2) Miniaturized and tested a compact, rugged, inexpensive, and frequency-stable laser source leveraged from the Army as low noise input to PFLOG, (3) Constructed a temperature-controlled atomic vapor

oven (fig. 2) to tune to an optimal fast light condition (first demonstration of temperature tuning to control the sensitivity of an optical cavity, first demonstrated scale factor enhancement in a ring cavity using atoms, and largest cavity scale factor enhancement measured in any system), (4) Demonstrated narrow atomic resonances in high finesse cavity output by velocity selective optical pumping, (5) Achieved first scale factor enhancement in high finesse cavity by polarization mode coupling, and (6) Developed an error model to determine the effect of temperature/mechanical fluctuations on a gyro sensitivity enhancement.

AFLOG accomplishments for FY 2014 include the following: (1) Eliminated beat-note noise in a previously constructed dead-band-free, shared-cavity, diode-pumped alkali laser (DPAL) ring laser gyro by placing it in a custom vacuum enclosure (fig. 3), (2) Constructed and demonstrated the operation of a dual-pumped Raman ring laser as an alternative AFLOG design that could be easier to miniaturize, and consume less power, (3) Invented and implemented a method for stabilizing the Raman probe laser of the superluminal DPAL to an absolute frequency by locking it to a serendipitous resonance in Rb87 to make the AFLOG function in a more robust manner, (4) Invented a design for overlapping bidirectional self-biased AFLOG with no gain competition or lock-in, by using dual isotope cells with different Raman pumps, (5) Significant progress on miniaturization was made: building custom compact diode laser controllers, and compact offset phase locked laser boxes to replace all AOMs and tapered amplifiers. A single high-power DBR laser for pumping to replace bulky pump lasers is being implemented.

References

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2. Smith, D.D.; Chang, H.; Myneni, K.; and Rosenberger, A.T.: "Fast-light enhancement of an optical cavity by polarization mode coupling," *Physical Review A*, Vol. 89, 053804, 2014.
3. Smith, D.D.; Chang, H.; Myneni, K.; and Rosenberger, A.T.: "Fast light enhancement by polarization mode coupling in a single cavity," *Proc. SPIE 8998*, in *Advances in Slow and Fast Light VII*; M.S. Shahriar and F.A. Narducci (eds.), 2014.