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Upgrade of the NGSLR Optical Bench and the Resulting Performance Improvement

Howard Donovan[1*], Jan McGarry[2], T. Zagwodzki[4], J. Annen[2], J. Degnan[3], J. Horvath[1], F. Hall[1], D. Patterson[1], J. Cheek[3], A. Nelson[1]

[1]Honeywell Technology Solutions Inc., Lanham, MD
*howard.donovan@honeywell.com
[2]NASA Goddard Space Flight Center, Greenbelt, MD
[3]SigmaSpace Corp, Greenbelt, MD
[4]Cybioms Corp, Greenbelt, MD

Abstract

After several years of field development and satellite laser ranging operations, the optical bench has undergone many incremental changes to accommodate increased demands on the capabilities of the NGSLR. Initially designed for low energy, eye-safe laser ranging, the optical bench has been modified to handle energies needed to perform daytime GNSS tracking as well as meet newly developed American National Standards Institute (ANSI) and Federal Aviation Administration (FAA) safety requirements.

In time, it was realized that an overall design change was essential to better accommodate iterative upgrades, allow for full use of increased laser power, provide more precise and efficient optical alignments, and incorporate lessons learned thus far from SLR operations. We will review the initial design of the optical bench and its implementation as well as discuss the upgrades, the supporting reasons, and the improvements in system performance because of this upgrade.

Introduction

NASA's Next Generation Satellite Laser Ranging (NGSLR) system, located at the Goddard Space Flight Center, was designed in the mid-1990's and was originally intended for automated, eye-safe SLR operations. As the requirements for NGSLR were later expanded to include GNSS daylight ranging and increased levels of automation and performance, it became apparent that the NGSLR optical bench would need an upgrade to accommodate the new requirements.

NGSLR First Generation Optical Bench

The first NGSLR optical bench was designed as an eye-safe system that would support tracking of all satellites from low earth orbit (LEO) to the orbit of LAGEOS (Figure 1). The Q-Peak laser used in this design (350 ps pulse width/120 µJ energy/2 kHz fire rate) precluded the use of optics with a high power AR coating. There were no requirements for GNSS tracking, and because of the eye-safe laser specified, no requirement for radar or aircraft monitoring. The ANSI

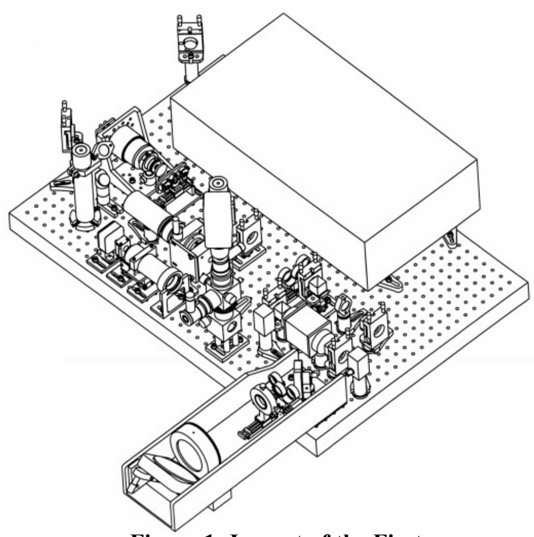

Figure 1: Layout of the First Generation Optical Bench

startle, glare, and flash blindness requirements had not yet been implemented, therefore the system was not originally designed with aircraft avoidance in mind.

As the requirements changed, the first optical bench design was unable to adequately perform the new work. The optical alignment was unstable and the configuration of the bench was not optimal for efficient alignment. Components such as the laser and the star calibration leg, which needed minimal adjustment, were closest and easiest to access, while components requiring frequent adjustment, such as the transmit and receive optical legs, were not very accessible. The complexity of the alignment was exacerbated by the fact that beam paths were at different heights across the optical bench. Unfortunately, the original space allocated to the optical bench did not allow for much expansion or optimization of the design at the time.

In addition to issues relating to the layout of the optical bench, it was also noted that the power output of the Q-Peak laser slowly began to degrade over time, resulting in greater difficulty tracking. It was for these reasons that a second generation design was desired.

NGSLR Second Generation Optical Bench

In 2009 the NASA requirements for NGSLR changed to include tracking GNSS during daylight. It soon became clear that a new laser with increased laser energy would be necessary to range to GNSS altitudes. Because of the stringent laser specifications needed, and the lack of a viable candidate laser on the market at the time, it was decided that NASA would build the laser in-house. This laser (200 ps pulse width/2 kHz fire rate) was installed in 2010 and provided variable laser energy from eye-safe levels to 1 mJ.

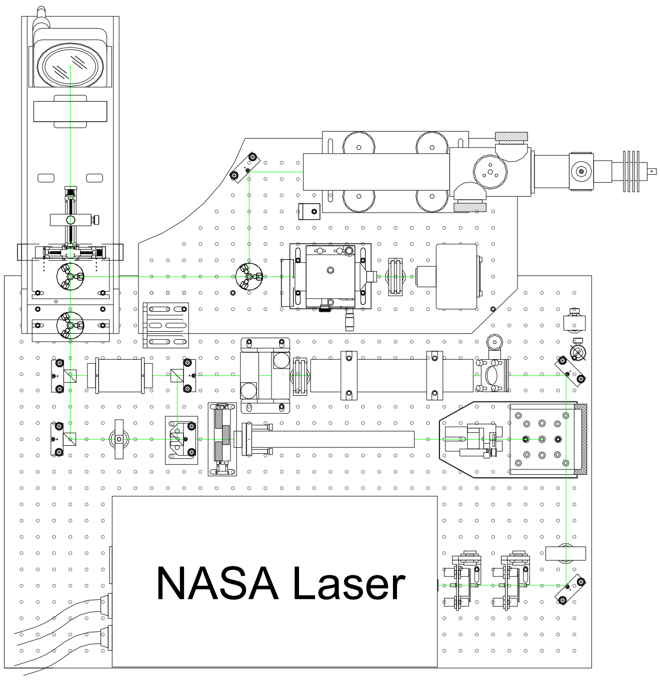

Figure 2: Layout of the Second Generation Optical Bench

A radar-based laser hazard reduction system (LHRS) had already been installed at NGSLR during 2007 to support another experiment using a co-located laser. In 2010 the LHRS was integrated into SLR operations allowing the NGSLR to meet the new FAA requirements for laser safety. The LHRS and laser interlock system of the NGSLR provides automated termination of the beam upon aircraft detection, compliance with laser transmission regulations in the Laser Hazard Zones (LHZ) surrounding local airports, and re-enabling of the laser interlock by the operator.

Several challenges were identified with the second generation optical bench design. The higher energy of the NASA laser began to cause distortion of the ND filters used during ground calibration and was also close to the damage threshold of many of the optics in the transmit path. These optics were designed for a lower energy laser with a wider pulse-width and risked damage during operation of the system. In addition, the backscatter produced by the higher power beam became problematic for exposed optics in the receive path. Initally, the laser itself was found to work well, but was not easily automated and began to degrade in power over a period of time. In the end, NASA desired a COTS solution to focus resources on system development.

Alignment continued to prove challenging on the second generation optical bench. The configuration was still not optimal for efficient alignment, and the space on the optical bench had become cramped with very little room for expansion or modification, including adding necessary monitoring equipment like a power meter or a beam profiler. Manual insertion of optics, such as the pellicle for the star camera and a turning mirror for the autocollimator introduced error into the alignment process. This augmented design was not yet fully automated, and required a fair amount of user interaction for operation. Due to the limitations of the second generation design and the acquisition of a more capable COTS laser, a third generation design was developed to accommodate the increased project requirements.

NGSLR Third Generation Optical Bench

The new design sought to incorporate a new laser that could be easily automated, replace/protect low power optics, provide greater automation capability, increase alignment stability, and increase the ease of alignment (Figures 4 and 5).

The capability of an upgraded laser system was a core consideration in the development of the next generation design. It was deemed necessary to use an easily automated COTS laser with increased laser energy, shorter pulse width, and increased stability. Figure 3 illustrates the progression in laser specifications from the original design to the current iteration.

Q-Peak laser	NASA laser	Photonics laser
350 ps Pulse Width	200 ps Pulse Width	50 ps Pulse Width
120 μJ Energy	>1000 μJ Energy	2,800 μJ Energy
240 mW Power	>2 W Power	5.6 W Power
2 kHz Repetition Rate	2 kHz Repetition Rate	2 kHz Repetition Rate

Figure 3: Progression of Laser Upgrades

To accommodate the demands that this new laser would introduce, a number of upgraded optical layouts were developed. As space is at a premium inside NGSLR, a larger custom optical table was selected to accommodate the new design, as well as to provide room for future expansion.

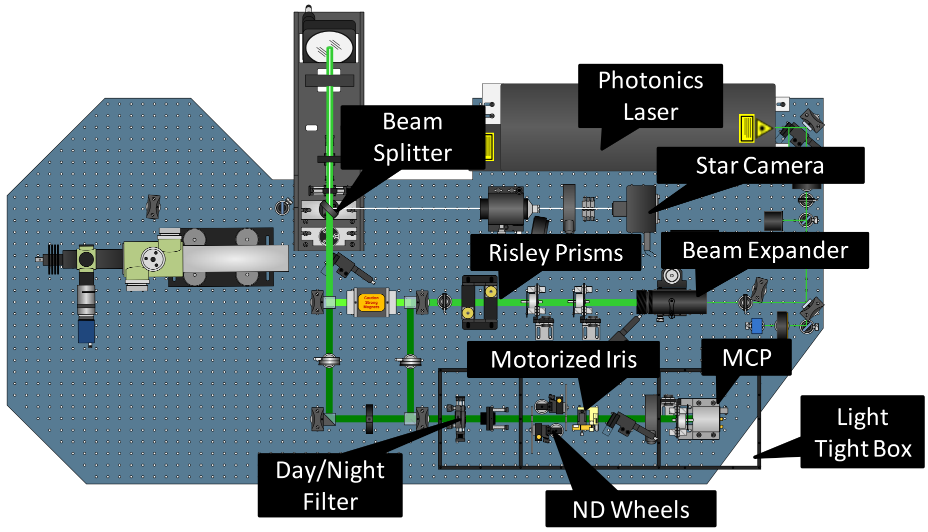

Figure 4: Layout of the Third Generation Optical Bench

The higher energy level of the COTS laser posed a number of challenges to the new design. The original optics in the transmission path were at risk of damage with the higher power and short pulsewidth. Optics at risk for damage were identified and were replaced with optics using high power optical coatings, or were placed after the beam expander where the expanded beam did not exceed the damage threshold of the unit. The higher energy levels also produced higher levels of backscatter, increasing noise in the detected signal. Two methods were used to address this problem. The entire receive optical path was isolated using a baffled, light-tight box, which served to filter out off axis light. In addition, a Liquid Crystal Rotator Assembly was introduced to filter out backscatter for 70 μs around the laser fire.

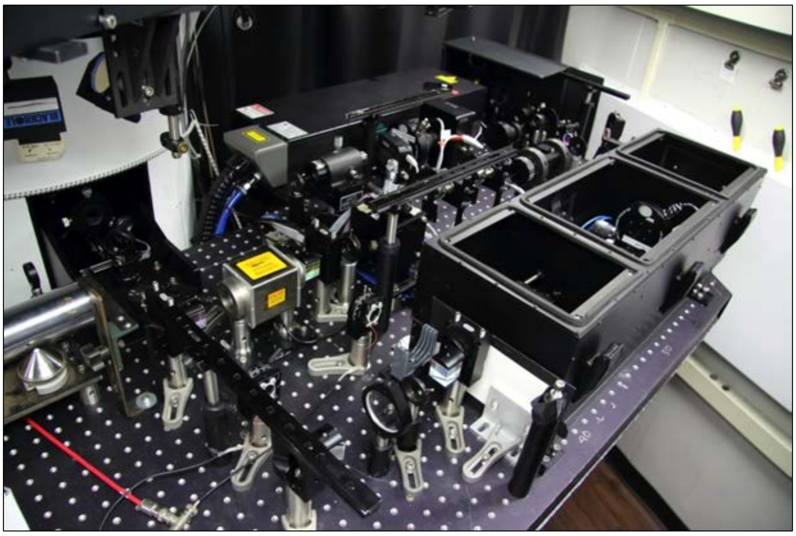

Figure 5: Photo of the Third Generation Optical Bench

Other enhancements to the optical bench include the permanent addition of a beam profiler and power meter. The beam profiler proved particularly useful as it not only allows for monitoring the laser in real-time, but also as a sensitive alignment aid to align the expanded beam in the far field. Improper alignment of the beam expander not only affects the steering of the beam, but the shape of the beam in the far field (Figure 6).

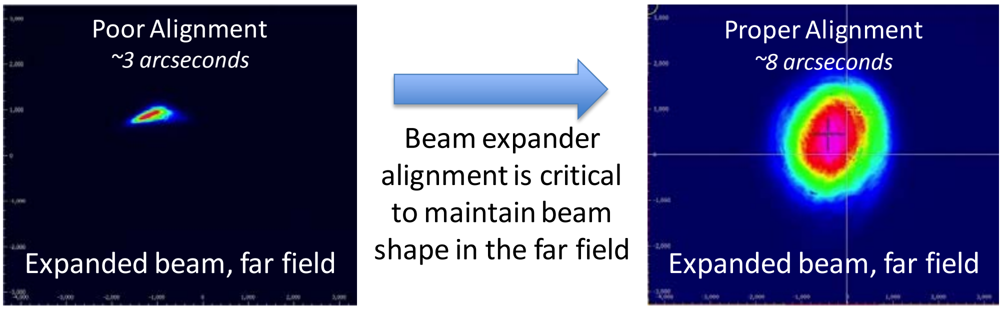

Figure 6 – Using the Beam Profiler to verify the alignment of the Beam Expander

The stability and ease of alignment are dramatically improved in the third generation of the optical bench. The layout of the optical bench is optimized, so that optics requiring frequent alignment are easily accessible from the perimeter of the optical bench. A number of reference irises have been placed along the beam path to define the optical axis of the beam and assist in the alignment process. These are essential in consistently achieving the orthogonality of the beam during alignment procedures. In addition, tools such as alignment lasers, beam path cameras and alignment targets have been incorporated to simplify the alignment process. One aspect that affected the stability of the alignment in past designs was the manual insertion/removal of the pellicle beam splitter and the turning mirror for the autocollimator. The pellicle has been replaced with an etalon beam splitter that remains in place permanently, and the autocollimator is re-located such that the manual insertion of a mirror is not required. The alignment has proven to be quite stable as adjustment of the optical bench was not required during the collocation between May 29th and July 5th.

The installation of a new beam expander and mount provides solutions to challenges in the old design. The original beam expander is replaced with a unit that can withstand the high power beam, and is secured in a mount that allows x/z and tip/tilt adjustment to align the unit with the optical axis. Precision hinges on the mount are used to allow the device to rotate in and out of the beam path during alignment procedures, allowing the raw beam alignment to be compared with the beam passing through the device.

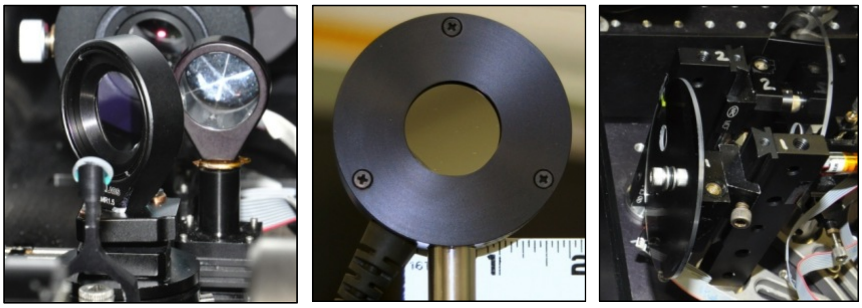

Figure 7 - Additions to the Optical Bench

To allow for automation of configuration changes between satellite tracking, ground calibration and star calibrations, motor controllers have been added to the optics on the bench to allow for complete control by the software. This includes the addition of an automated iris, automated ND filter wheels for ground calibration, and the daylight filter. Automated safety features have been integrated into the design with the addition of the IO Chassis which controls a beam block device, shutters for the MCP and the Star Camera, automated ND filter, and the laser fire trigger. The operation of the COTS laser is now automated, with software controlling the configuration of the laser.

Testing of the Third Generation Optical Bench

The upgrades to the optical bench were validated during collocation testing with the MOBLAS-7 system in May through July of 2013. All changes to the optical bench, including alignment, were frozen during this time, allowing system performance and stability to be tested in a particular configuration. The results of the collocation indicated that the upgrades to the optical bench increase system stability, enhance optical isolation of the receive path, provide the capability to track GNSS during daylight, and offer greater automation capability. For a detailed analysis of the collocation results, see McGarry, et al. (2013) and Horvath et al. (2013).

Summary

The iterative upgrades to the optical bench have been part of a learning process in the development and optimization of NGSLR. The improved layout of the optical bench has proven stable, with a streamlined alignment process. All of the critical optical mounts are easily accessible, and permanently mounted irises allow for quick verification of the alignment. The hinge system under the beam expander allows it to be easily removed from the beam path to aid in the general alignment process, while the beam profiler has proven to be the most useful tool for far field optical alignment of the beam expander. The COTS laser proved stable during collocation and is configured and controlled by the software system in NGSLR. The updated design of the optical bench provides a stable, efficient platform for the transmit and receive subsystems, provides ease of use through automation, and has been optimized to support high performance, high yield satellite laser ranging.

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