

Improvements at NASA's NGSLR in Support of GNSS Ranging

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ABSTRACT

The NASA Space Geodesy Program (SGP) requires day-night ranging to Global Navigational Satellite System (GNSS) satellites. To meet this new requirement, the NGSLR eye safe laser was replaced with a NASA GSFC-built 1 milliJoule (mJ) 200 picosecond (ps) laser and the ~10% Quantum Efficiency (QE) quadrant anode Photek MCP-PMT was replaced with a high QE (40%) single anode GaAsP MCP-PMT from Hamamatsu. This improved transmitter-receiver combination is estimated to yield a link augmentation of 30X over the previous configuration. NGSLR tracks with fine pointing using a tight laser beam divergence of ~4 arcseconds (FWHM) and a narrow receiver field of view (FOV) of ~11 arcseconds enabled by a Risley Prism pair for laser point-ahead. Further reduction in day time optical noise and laser backscatter is planned by adding a telescope sun shield, narrowband spectral filter, and a gated optical shutter. The improvements in the signal to noise ratio (SNR) as well as the link margin should significantly enhance the NGSLR GNSS tracking and operations automation efforts. System configuration and early operational results are discussed.

Introduction

NASA's Next Generation Satellite Laser Ranging (NGSLR) system was originally designed for eyesafe day-night satellite laser ranging to Low Earth Orbiting (LEO) satellites and LAGEOS [1] [2]. The maximum laser energy exiting the 40cm telescope system was limited to ~60 microJoule at 532 nm for a pulsewidth of 300 picoseconds. This laser configuration met the stringent radiation safety requirements of the US Federal Aviation Administration (FAA) for autonomous operations by being eyesafe at all times and operated without the need for any safety monitoring mechanism. During the last few years, many technical challenges unique to the eyesafe laser were solved and system issues pertaining to the eye-safe laser configuration and operations automation were addressed.

Eyesafe Laser Configuration and Performance

The laser was developed by Q-Peak under a NASA Small Business Innovative Research (SBIR) program and was used for many years in NGSLR. The beam divergence control, as low as 4 arcsec, was accomplished via computer control of a Special Optics Beam Expander which changed the spacing among a lens triplet to maintain the beam size while changing the beam divergence.

A passive polarization T/R switch, interfaced to two orthogonally polarized receive optical paths, combined the return signal efficiently in space and time at the receiver. Two configurations employing quadrant anode MCP-PMT detectors were used for single photoelectron detection: the first involved a Photek MCP-PMT with a Quantum Efficiency (QE) of ~ 12% and the second used a Hamamatsu Quadrant anode MCP-PMT with a QE of ~35%, almost a 3-fold improvement in QE. The latter device was damaged after several years of operations and was replaced by the Photek MCP-PMT. The four outputs of the detectors, when combined with the four separate channels of the Constant Fraction Discriminator (CFD) and the Event Timer (ET), can provide an equal number of precise simultaneous range measurements. This approach was in the works for near real-time tuning of the telescope pointing via spatial discrimination of the received photon, but was not fully implemented.

To reduce the solar background for daylight ranging, the receiver field of view (FOV) is kept at ~ 11 arcseconds enabled by laser point-ahead using a pair of Risley Prisms. External day time background optical noise is further suppressed via a narrow band (0.3nm) spectral filter. Since NGSLR uses a common transmit-receive telescope optics, the backscatter is an issue. This is attenuated over the initial 70 microsecond period of the atmospheric propagation by a blanking circuit for the receive detector, which proved to be adequate under eyesafe laser transmission. The pulse repetition frequency (PRF) of the laser was dynamically modulated under software control from 2 kHz to 1.96 kHz to avoid collisions of transmit and receive pulses [2]. Precise telescope pointing and tracking were enabled by an effective mount model that often provides a global RMS fit as low as 1.5 arcseconds using star calibration (nominally 50 stars).

In this configuration, NGSLR has successfully tracked LEO satellites and LAGEOS during day and night. Tracking to 20 degrees elevation was consistently achieved for LAGEOS, while lower elevation (down to 10 degree) tracking was routinely performed on LEO satellites. There was also success with GLONASS and ETALON ranging. In this case, tracking was successful only above 60 degrees elevation, where the link is better due to the shorter range and reduced atmospheric losses.

NGSLR Augmentation for Daylight Ranging to GNSS

NASA formulated an integrated multi-technique Space Geodesy Program (SGP) to set the directions for the global space geodesy efforts. A key SLR requirement that emerged from this new program was the need for day-night ranging to Global Navigational Satellite System (GNSS) satellites. The link to 20,000 km GNSS satellites is weak for daylight ranging using the eye-safe laser and the previous detector configuration. A stronger (an order of magnitude greater) link margin configuration was required at the station to meet this new requirement. It was recognized that the best way to accomplish this was by boosting the laser energy and increasing the QE of the receive detector.

Laser upgrade

A new laser was built by a NASA GSFC laser group [Coyle and Poullos] that has built many lasers for NASA airborne and spaceborne applications. The original NGSLR eyesafe laser was a 1064nm passively Q-switched microchip laser (Northrop Grumman Synoptics) with 15 microJoule energy per pulse. A proprietary diode pumped multi-pass Q-Peak amplifier scaled the output energy producing ~250 microJoule/pulse at 532nm. The table below summarizes the characteristics of the two lasers.

	Q-Peak	GSFC mJ
Energy	~0.1mJ	~ 1mJ
Pulsewidth	350 ps	< 200 ps
Wavelength	532nm	532nm
PRF	2 KHz	2 KHz
Divergence	5-8 arcsec	4 arcsec

The new laser utilizes a regenerative amplifier seeded by a 200 ps gain-switched diode laser. The regenerative amplifier cavity is 1.5 m long and utilizes a pair of Nd:YAG zigzag slabs in a crossed-head configuration as the gain medium. The regenerative amplifier system is designed to run at a repetition rate of 2 kHz with ~1 mJ/pulse at 532 nm and a ~200ps pulse width. A pulse from the diode seeder is trapped in the regenerative amplifier cavity using a Pockels cell, where it can make many passes through the gain medium. When the pulse reaches its maximum energy, it is then switched out and directed through a KTP frequency doubler. The folded 1.5m long stable resonator cavity design enabled a package size small enough to fit within the Q-Peak footprint and avoid a NGSLR system redesign. This laser has the PRF flexibility from 1–2000 Hz. The upgraded laser needed further technical work to improve the pulse amplitude stability and is currently removed the station. It is expected back at the station by the end of August 2011.

Detector upgrade

The quadrant Photek detector (gain $\sim 3.0 \text{ E}+5$, rise time $\sim 180 \text{ ps}$, transit time spread $\sim 45 \text{ psec}$) will be replaced with a higher QE Hamamatsu single anode GaAsP detector. This single element Hamamatsu model R5916U has a 40% QE, rise time of 178 ps, gain of $3.0\text{E}+5$, and a transit time spread of $\sim 136\text{psec}$. The improvements to the laser transmitter and receiver configuration should provide a significant enhancement (factor of 30) to the link budget.

Noise reduction

NGSLR uses common transmit-receive optics and consequently backscatter from the optical surfaces as well as the atmosphere is a serious problem. To eliminate as much backscatter as possible, all optical surfaces in the transmit path (after the harmonic generator) are AR coated for 532nm and are kept optically clean. Backscatter into the MCP detector is also minimized by a very small angular tilt of all transmitting optics. Efficient beam dumps ($>99\%$ absorption) are used, where needed, and beam paths are baffled to improve optical isolation. Further reduction in back scatter should be possible by the use of a liquid crystal optical gate developed for NASA by Sigma Space [3]. Additional optical noise reduction is expected through the use of a narrower range gate, a solar shield on telescope, a narrow (0.1nm) spectral filter bandwidth, and a spatial filter operating at $\leq 11 \text{ arcsec}$.

Laser Hazard Reduction System (LHRS)

The new NGSLR configuration needs a Laser Hazard Reduction System (LHRS) for aircraft avoidance. A LHRS, which uses a 9.4GHz X-band radar transceiver and discriminating electronics to inhibit the laser from radiating the aircraft, is in place. This system, co-aligned with the laser beam, works automatically for aircraft detection, target discrimination, and laser beam inhibit.

Preliminary Results

Very preliminary tracks of GLONASS-102 and GLONASS-120 show the system now has the ability to track GNSS to below 40 degrees elevation at night. Initial LAGEOS passes show a higher return rate than previously achievable.

Conclusions

A systematic engineering upgrade effort is in progress to transition NGSLR station from its eyesafe configuration to a higher power laser configuration for increased link margin on high earth orbiting satellites. This link margin is further augmented by a high quantum efficiency high gain receive detector and a receive electronics system with a single photoelectron threshold. Significant SNR enhancement is also sought using a variety of optical noise filtering and isolation techniques. This new system configuration should provide a strong link budget to consistently track GNSS (using the ILRS standard array lidar cross section of $1\text{E}+8 \text{ m}^2$) during night or day. The suite of engineering developments, now underway, will offer full compliance with SGP needs for GNSS tracking and operational automation while meeting the ILRS performance standards for SLR.

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