NGSLR: Sharing Eye-safe Kilohertz SLR with Transponder Ranging

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Abstract

NASA's Next Generation Satellite Laser Ranging System (NGSLR) is expected to be operational in early 2009. The system is currently ranging with the eyesafe laser (~100 microJoules at 2 khz) to targets ranging in altitude from Low Earth Orbiting (LEO) satellites to LAGEOS, and has successfully ranged to GLONASS-95 and GLONASS-102. Satellite passes are normally tracked using a tight laser divergence (4 arcsec) with hands-off operation, and requiring no bias correction. Many LEOs have been tracked down below 15 degrees elevation. The telescope is pointed behind, in the direction of the returning light from the satellite, and the Risley Prism wedges are independently controlled to point the laser ahead to where the satellite will be when the laser pulse arrives.

With a simple drop-in mirror, toggle switch, and single cable change, the system can switch from eyesafe laser ranging to ranging with the 50 milliJoule, 28 hz, 6 nanosecond pulsewidth laser. This higher power laser was added to the system to perform uplink-only ranging to the Lunar Reconnaissance Orbiter (LRO-LR). For LRO the laser fire is controlled to ensure that the pulses arrive at the spacecraft when the Range Window is open and can accept events. Ground laser fire times are recorded and transmitted to a central facility where they are matched with the spacecraft events to form ranges.

Introduction

NGSLR is expected to be operational in a few months, performing two-way ranging to satellites and one-way ranging to LRO. This paper describes the current system status, the modifications needed to perform one-way ranging to LRO, and future work to make the system more automated with enhanced performance.

Eyesafe Ranging Configuration and Status

NGSLR is a single photon multi-kilohertz eyesafe satellite laser ranging system (McGarry 2006). NGSLR uses a Q-Peak laser with an original output energy of 120 microJoules per pulse which has degraded over the last several years to less than 100 microJoules per pulse. A 50% transmission loss through the telescope means that the current system is outputting about 50 microJoules per pulse at the telescope aperture in a 37 cm diameter beam.

The current laser pulse width is about 300 picoseconds. The software controls the laser fire rate which is varied between 1.96 khz and 2.0 khz to prevent collisions between outgoing and incoming laser pulses when the detector is gated on. The hardware also provides an added measure of protection by blanking the detector for 50 microseconds after the laser fires.

The laser divergence is currently set at 4 arcseconds (full width) for all satellite ranging. Currently NGSLR receives multi-photon returns from the LEO satellites.
Future plans are to vary the divergence as a function of the satellite. Low earth orbiting (LEO) satellites would have a larger divergence (~8 arcseconds) while the LAGEOS and Global Navigational Satellite Systems (GNSS) would continue with the 4 arcsecond divergence.

The current receiver system is a high quantum efficiency (32%) Hamamatsu four quadrant detector with a constant fraction discriminator (CFD) on each quadrant. The threshold setting on the discriminators is nominally set to < 0.5 photo-electrons.

The telescope is pointed behind to allow the quadrant information to be used for angular correction. The transmitted beam is independently pointed ahead by a Risley Prism pair (Degnan 2008). This allows the system to operate during the daylight with both a narrow beam divergence and a narrow receiver field of view, even when the two do not overlap. The full width fields of view used are 25 arcseconds for night, 16 arcseconds for twilight, and 11 arcseconds for daylight.

The Xybion mount continues to perform well consistently closing the tracking loop to 1 arcsecond. The 22 term mount model provides absolute pointing at the 2-3 arcseconds level after star calibrations.

Over the last several months the system has demonstrated robust tracking of satellites from LEO to LAGEOS in day as well as night, with night tracks of GLONASS-95 and GLONASS-102.

Much of the system is automated, but the station currently requires a single operator to track satellites.

Satellite Laser Ranging Results

The engineering team currently performs the tracking operations for NGSLR which occurs a few hours every week. Over the last two months NGSLR has tracked 27 passes, including AJISAI, BEC, JASON, JASON-2, LARETS, STARLETTE, LAGEOS 1 and 2, and GLONASS-102. Inter-comparison tracks show centimeter level agreement between NGSLR and MOBLAS-7 for all satellites (Dunn 2008).

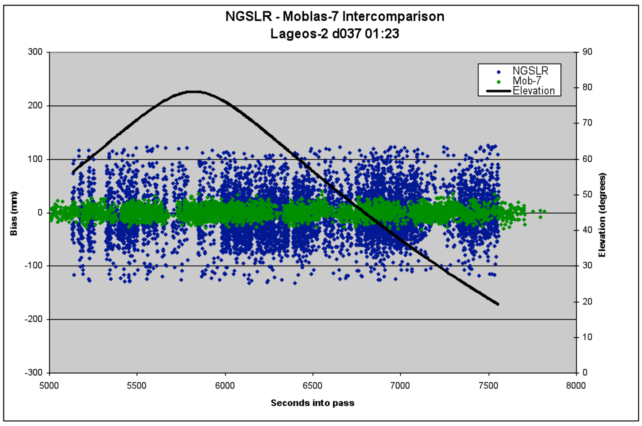

Figure 1: NGSLR full-rate ranges (blue: wide envelop) versus MOBLAS-7 ranges (green: narrow envelop) for a February 6th, 2009 LAGEOS-2 pass.

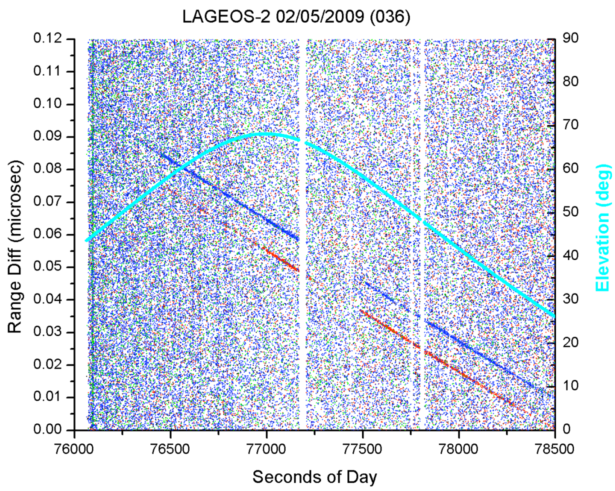

Figure 2: Daylight LAGEOS-2 OMC plot showing returns in two of NGSLR's four quadrants. Length of tracking segment is ~ 40 minutes.

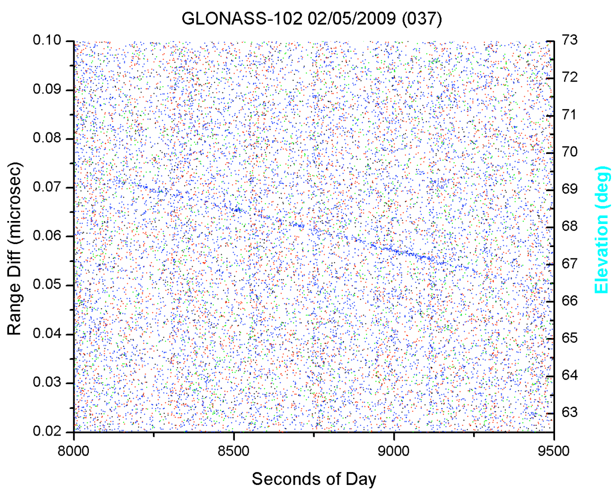

Figure 3: Night GLONASS-102 pass with returns in single quadrant. Length of tracking segment is ~ 30 minutes. Elevation of mount was > 60 degrees.

Accommodating Laser Ranging to LRO

Laser ranging to LRO requires a 28 hz 30+ milliJoule laser with a wavelength that is matched to the center of the spacecraft's 3 Angstrom LR bandpass filter. The pulse width is required to be less than 8 nanoseconds (FWHM). Two lasers were purchased from Northrop Grumman Space Technology Cutting Edge Optronics and characterized. They have a wavelength of 532.2 nm and an output energy capability of up to 50 milliJoules with a pulse width of 5.5 nanoseconds. One laser was installed in NGSLR and the other is the system spare. The onboard LR filter was tilt tuned to center it around the 532.2 nm wavelength.

The LRO laser is mounted on an upper level breadboard above the NGSLR optical bench and coupled into the telescope with a removable aperture share mirror. This mirror allows for easy switching back and forth between the eyesafe 2khz laser and the LRO laser and permits use of common receiver and alignment optics and electronics, allowing the system to track satellites with either laser. The two lasers also share a common start diode. A single cable swap is required to move from one laser to the other on the start discriminator.

Because the LRO laser is not eyesafe, an aircraft avoidance radar and associated electronics were added to NGSLR. This Laser Hazard Reduction System (LHRS) provides a means of detecting aircraft and shutting off the laser before the aircraft intersects the transmitted laser beam. The radar can detect aircraft out to a range greater than the nominal ocular hazard distance. It is the same unit used on the NASA MOBLAS and TLRS systems.

The software must control the time of the laser fire to ensure that each pulse arrives at the spacecraft when the Earth detector gate is open (McGarry 2008). NGSLR uses the Range Gate Generator (RGG) to command the laser fire times. The HTSI built RGG outputs at a 2 khz frequency with the software commanding (1) the delay of the outgoing pulse from the start of each 2khz interval and (2) the width of the outgoing TTL pulse to the laser. The software modulates the width of the RGG output pulse to provide an approximately 28 hz frequency to the laser.

Because of the critical nature of the timing measurement it was determined that the Truetime GPS steered Rubidium station timing was not an adequate source for the 10 Mhz external input to the Event Timer. This is because the steering puts jumps in the otherwise smooth fire time differences when the GPS steering occurs. To eliminate this issue a Cesium Oscillator (Symmetricom model 4310) was added to the system. This unit now provides the 10 Mhz input to the system Event Timer for all operations (SLR and LRO), while the Truetime continues to provide station time-keeping. Special processing for LRO ensures that only the Cesium drives the timing for the hour long LRO passes.

The block diagram in Figure 4 shows the NGSLR system with the additions for LRO.

Operations during LRO-LR

NGSLR is expected to operate whenever the moon is above 20 degrees elevation, LRO is on the near side of the moon, the spacecraft High Gain Antenna (HGA) is pointed at earth, and there is no precipitation. This implies operational shifts that would need to cover as much at 10 hours per day 7 days a week. Operations are expected to last for over a year. We are still working on the shift scheduling, but we will have 3 trained operators to cover NGSLR and one MOBLAS-7 shift, and we will have multiple people from the engineering development team to fill in for sick days, holidays, and other times.

The period of LRO's orbit is approximately 2 hours. Passes last for approximately one hour. The alternate hour will be used at NGSLR to do eyesafe satellite laser ranging.

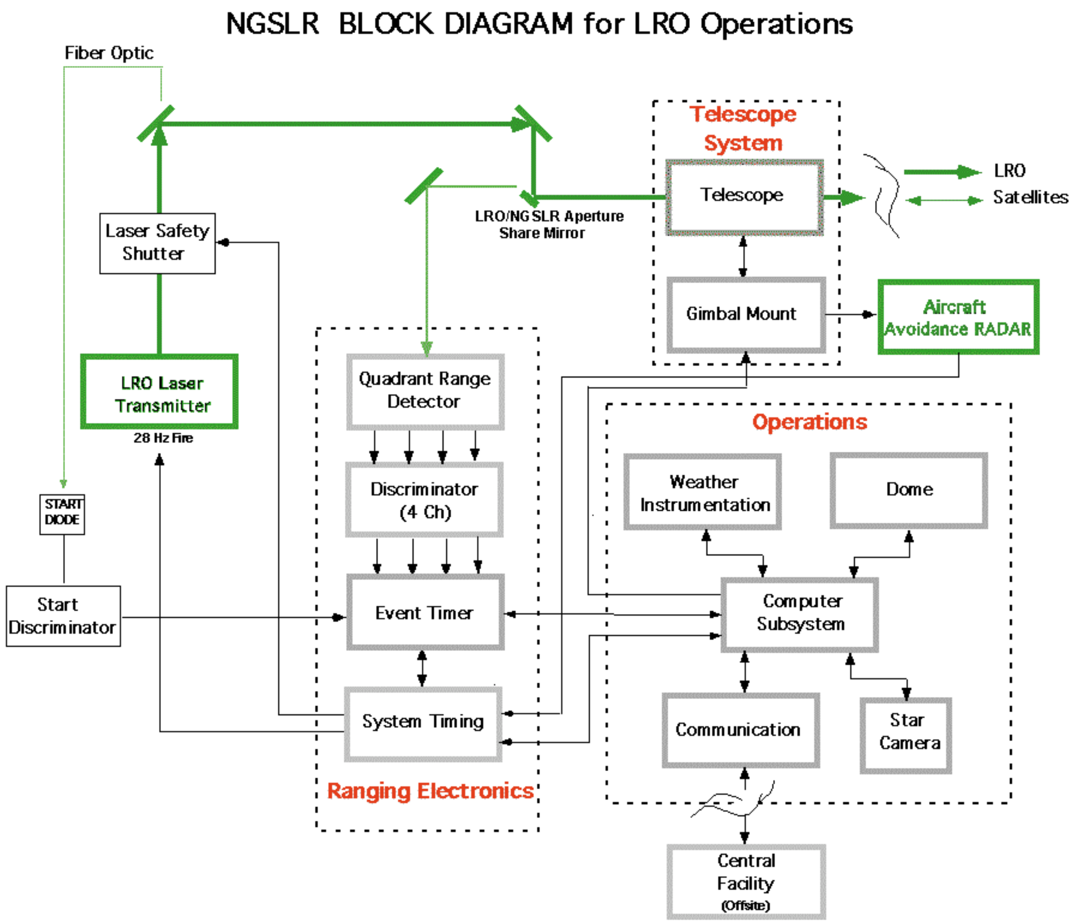

Figure 4: Block diagram of NGSLR system. Changes for LRO-LR include additional laser (28hz) with software control of fire via RGG, aircraft avoidance radar, and drop in mirror to allow switching between LRO and eyesafe lasers.

Remaining to Complete at NGSLR

To complete the automated eyesafe satellite laser ranging at NGSLR, we will be replacing the Q-Peak laser with a new laser designed and built in-house at GSFC by D. B. Coyle based on his previous work on the injection seeded ring cavity (Coyle 2008). This laser will give us a variable energy output level from eyesafe to up to 2 milliJoules of output energy per pulse, allowing us to more easily range to the navigational satellites such as GPS and GLONASS while maintaining our ability to do eyesafe ranging. This laser will be tested in NGSLR during the month of March and will be completed and installed permanently later in 2009.

Automated closed-loop tracking of satellites will be the focus of our efforts after NGLSR completes collocation with MOBLAS-7 in the next couple of months. Included in this work is equalizing the quadrant noise counts, upgrading the signal processing, and completing the algorithms to convert the quadrant signal counts to mount drive information. We expect to have this work completed in late 2009 or early 2010.

Several of the optics on the transceiver bench have been automated, but the rest also need to be added to the software control, as do the detector and camera shutters.

The modifications required for LRO-LR are complete and successfully tested (Mallama 2008).

Summary and Acknowledgements

NGSLR has been in development since the late 1990s utilizing many novel technologies that required in depth analysis and engineering. This last year has seen the fruition of this development work. We have made great strides in system robustness, daylight ranging capability, and data accuracy, and we expect to be operational in a few months. The system is capable of being completely automated and we will continue to work toward this end.

At the same time, we have performed the required system modifications for LRO-LR and successfully tested them. We will begin operational ranging to LRO later this year, demonstrating that NGSLR is capable of both earth orbiting satellite and planetary transponder laser ranging.

NGSLR SLR development is being funded by the NASA/HQ Science Mission Directorate. Funding for LR modifications and operations is provided by the LRO Project. The authors would like to thank John LaBrecque of NASA/HQ for his continued support of the SLR work. We would also like to thank David Carter of NASA/GSFC code 450 for all of his efforts on behalf of NGSLR.

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