Laser Ranging At Planetary Distances from SLR 2000

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Abstract

The SLR2000 prototype system will be participating in two separate planetary transponder laser ranging experiments: (1) as one end of the Goddard in-house asynchronous transponder experiment in 2007, and (2) as the primary ground station for one-way ranging to the Lunar Reconnaissance Orbiter (LRO) in late 2008 and 2009.

The modifications to SLR2000 to participate in these projects are relatively few and are very synergistic with the SLR completion effort. This paper describes the transponder experiments and the changes required at SLR2000.

Introduction

SLR2000 is the prototype for NASA's Next Generation of Satellite Laser Ranging (SLR) Systems. It was originally designed to be a completely automated, eye-safe Satellite Laser Ranging System, with a lower cost of operation, a high reliability, and an accuracy comparable to the existing NASA MOBLAS systems [McGarry]. Because of its arcsecond level pointing capability, its timing accuracy (both absolute and relative) and its ability to independently measure fire and return times, this system is an excellent candidate for transponder work.

The 1.2 metre telescope (aka 48 inch telescope) was developed by Goddard in 1974 as a research and development facility. It has hosted many laser ranging and other experiments over the years including the first successful 2-way asynchronous transponder experiment at 24 million kilometres with the Mercury Laser Altimeter (MLA) on the MESSENGER spacecraft in 2005, and the first successful 1-way laser ranging experiment at ~80 million kilometres with the Mars Obiter Laser Altimeter (MOLA) on the MGS spacecraft orbiting Mars, also in 2005. The 1.2 metre telescope is owned and operated by the Laser Remote Sensing Branch (code 694) at the Goddard Space Flight Center.

Both systems are located at Goddard's Geophysical and Astronomical Observatory (GGAO) which has been the site of most of NASA's ground breaking work in laser ranging, including the some of the first laser ranging returns ever recorded, the development and checkout of the MOBLAS and TLRS systems in the late 1970s and early 1980s, and the MLA and MOLA Earthlink experiments described above. It is also home to MOBLAS-7 which is the NASA SLR Network standard for performance.

Two-way asynchronous transponder demonstration

The goal of this in-house Goddard project is to demonstrate two-way asynchronous acquisition and ranging between two ground systems at Goddard's Geophysical and Astronomical Observatory (GGAO). The 1.2 metre telescope will function as the planetary spacecraft and will transmit at 50Hz in the IR (1064nm) and receive SLR2000's green (532nm) returns. SLR2000 will function as the ground station,
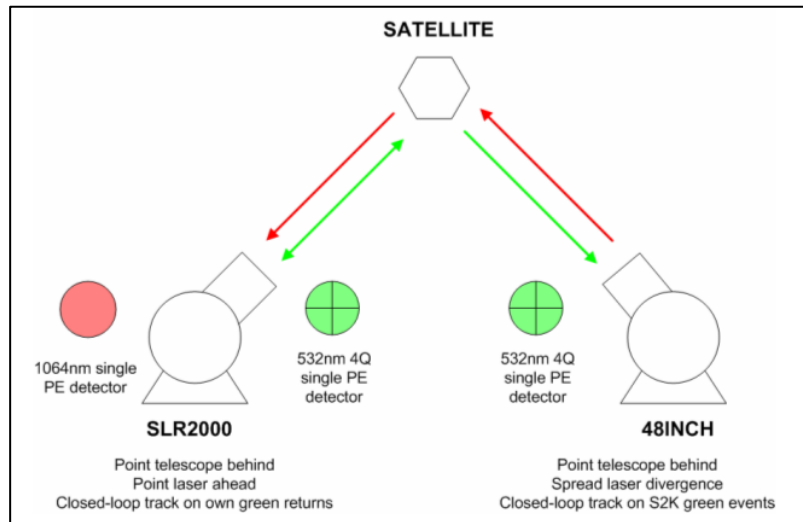
Figure 1: *Two-way asynchronous transponder experiment concept*

firing at 2 khz in the green and receiving the 1.2 metre telescope's IR returns. The laser pulses will be bounced off of retro-reflector equipped satellites to provide the simulation of planetary distances (Figure 1). The stations are sufficiently close that both are within the return footprint from the satellites. SLR2000 will closed-loop track on its own green returns and the 1.2 metre will closed-loop track on the green SLR2000 returns. Fire and return times will be collected by each station. A clock will be used at the 1.2 metre telescope that will simulate the frequency drift of a spacecraft clock. The event information from both stations will be used as input to analysis software that will determine the ranges, clock offset and frequency drift between stations.

Optical breadboard space has been added to SLR2000 to support this experiment along with a dichroic beam splitter (532nm / 1064nm) for the receive channel, beam reduction optics, a narrow band pass filter, and a fiber optic delivery to the 1064nm photodetector (Figure 2). The candidate detector is a Perkin Elmer model SPCM-AQC(4) photodetector with a quantum efficiency of ~2% and better than 500 picosecond jitter. An additional discriminator will be added and one additional event time channel will be used (for the 1064nm returns). There are minimal software changes required to the operational software at SLR2000 to perform this experiment.
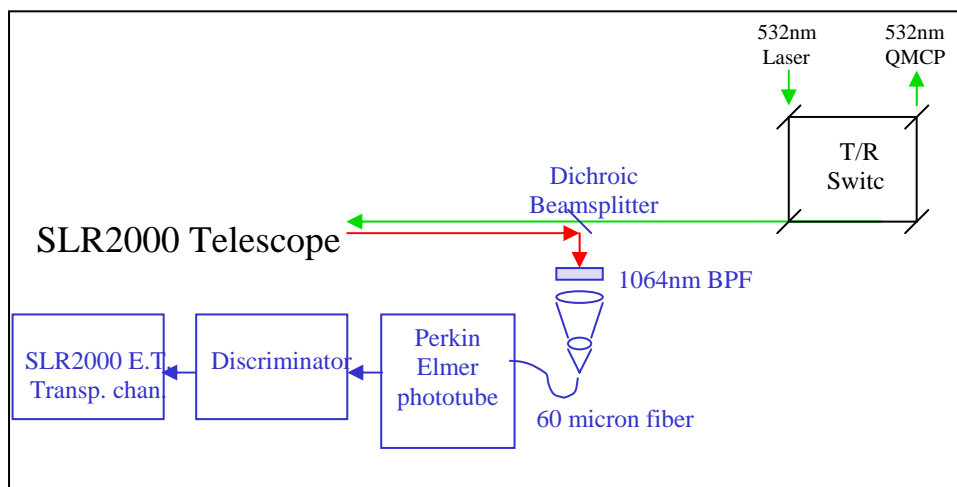

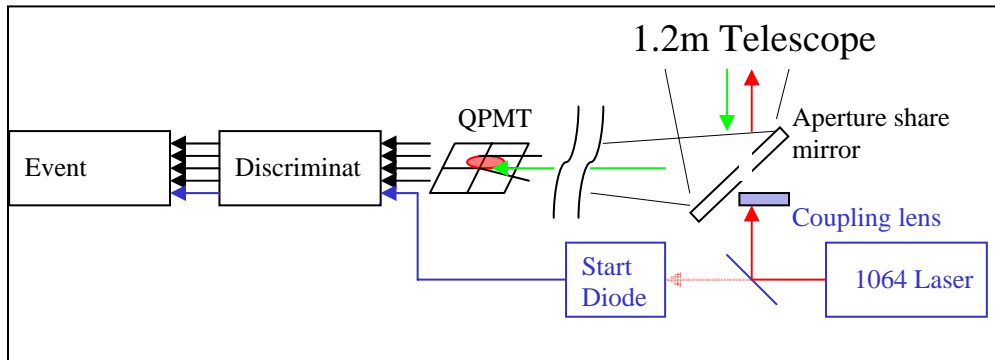*Figure 2:* *Additions for 1064nm transponder returns at SLR2000*

Figure 3: 1.2 meter telescope configuration for transponder experiment

Modifications to the 1.2 metre telescope configuration include the addition of a 532nm ungated single photon quadrant detector (Hamamatsu metal channel dynode PMT) and four discriminators, along with a band pass filter for the 532nm events from SLR2000 and a 1064nm blocking filter to prevent backscatter from local laser (Figure 3). Much of the configuration used for the MLA-Earthlink and MOLA-Earthlink experiments will be used for this project including the computer, the Time-to-Digital Converter (TDC), the Continuum Inlite II-50 laser (up to 50 Hz at 1064nm with a 6 nanosecond pulse width), and aperture sharing of the transmit-receive. Software modifications include handling of the four quadrant channels for closed-loop tracking.

The transmit and receive times from both SLR2000 and the 1.2m telescope will be processed to remove the noise. The clock bias and drift can be modeled as a linear function of the 1.2 metre telescope's time. The range error can be modeled as a quadratic equation in time. A least squares fit of the fire and receive event data to the resulting equations (shown below in Figure 4) would then provide the ranges as well as the relative clock offset and drift.

Both systems are nearing completion of the required modifications and both have tracked green returns from MOBLAS-7's fires. The 1.2 metre telescope's mirrors are in the process of being recoated in preparation for an upcoming laser communications experiment. When the recoating is complete in the spring of 2007 the two-way asynchronous transponder data collections will begin.

One-way laser ranging to the Lunar Reconnaissance Orbiter

The function of the Earth to LRO laser link is to achieve the mission's precision orbit determination requirement. The requirements on the SLR2000 ground station to accomplish this are:

1. Between 1 and 10 femtoJoules per square centimetre of signal must be delivered to the LRO-LR receiver aperture. For the SLR2000 laser with a 55 microradian laser divergence, this implies 30 milliJoules per pulse.

2. The wavelength must be 532 nm and the 3 Angstrom LRO-LR filter will be tuned to the actual SLR2000 laser in the lab.

3. The laser pulse width must be less than or equal to 8 nanoseconds FWHM.

4. Laser pulses must be delivered into the LOLA earth window at 28Hz.

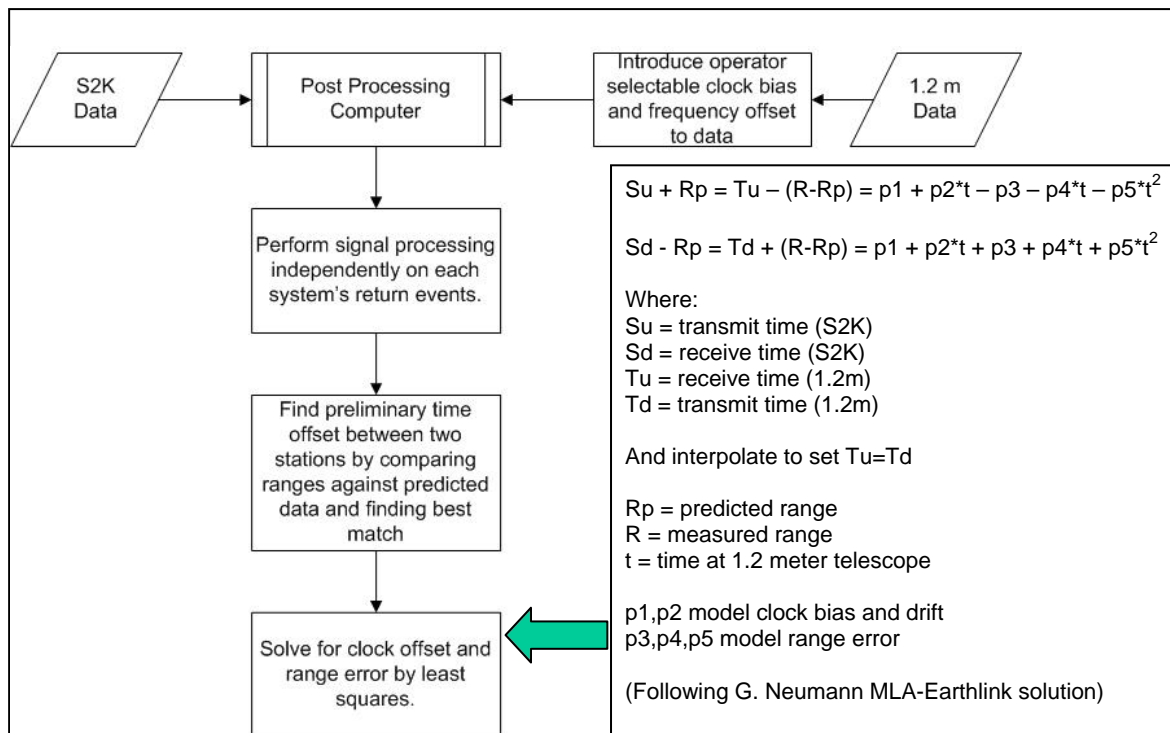5. The transmitted pulse time stamp accuracy must be maintained within 100 ns of UTC.

S2K Data → **Post Processing Computer** ← **Introduce operator selectable clock bias and frequency offset to data** ← **1.2 m Data**

Perform signal processing independently on each system's return events.

Find preliminary time offset between two stations by comparing ranges against predicted data and finding best match

Solve for clock offset and range error by least squares.

$$Su + Rp = Tu - (R-Rp) = p1 + p2*t - p3 - p4*t - p5*t^2$$

$$Sd - Rp = Td + (R-Rp) = p1 + p2*t + p3 + p4*t + p5*t^2$$

Where:
Su = transmit time (S2K)
Sd = receive time (S2K)
Tu = receive time (1.2m)
Td = transmit time (1.2m)

And interpolate to set Tu=Td

Rp = predicted range
R = measured range
t = time at 1.2 meter telescope

p1,p2 model clock bias and drift
p3,p4,p5 model range error

(Following G. Neumann MLA-Earthlink solution)

Figure 4: Post processing of fire and receive event times at two stations

6. The relative laser time of fire must be measured to better than 200 picoseconds (1 sigma) shot-to-shot over a 10 second period. The laser fire time must be recorded to better than 100 picosecond resolution.

7. The frequency stability of the station's clock must be equal or better than 1.e-12.

8. The system must provide better than 407 hours of ranging data to LRO during year after launch. This number is achievable and takes into account the LRO visibility from the station, the outages due to weather, system failures, as well as aircraft avoidance outages.

To accomplish these requirements SLR2000 is purchasing a 28 Hz diode pumped Nd:YAG master oscillator power amplifier (MOPA) laser that can deliver up to 50 milliJoule per pulse at 532 nm in a 6-8 nanosecond pulse. It is a turn-key system with a projected lifetime of greater than 1 year of continuous use. Additional optical table space has been added for the laser and a removable kinematic mirror mount will be inserted to launch the LRO transmit beam and ensure an easy transition between SLR and LRO lasers. Because this laser is not eye-safe, an aircraft avoidance radar is also being added to the system.

The software for SLR2000 is being modified to handle the new laser parameters, to control the laser fire to hit the earth window on the spacecraft, to take new operator commands for control of the new laser, and to handle predictions for non-earth-orbiting satellites.

LRO-LR will be launched in late 2008. SLR2000 will be staffed to support the mission 10 hours a day, 7 days a week to cover those times when the moon is above 20 degrees elevation. LRO is visible to earth about one hour out of every two.

During the hour that the spacecraft is behind the moon SLR2000 will range to earth orbiting satellites with the eye-safe 2 khz SLR laser.

Summary

Transponder experiments will extend capabilities of SLR2000 and demonstrate the system's ability to do planetary ranging which is the future of laser ranging. Earth orbiting satellite laser ranging and planetary transponder ranging can co-exist in SLR2000 and transitioning between the two will be seamless. The in-house Transponder experiment will complete in late 2007. The LRO mission will run from Fall 2008 through January 2010.

Acknowledgements

References

[1] Degnan, J., "Simulating Interplanetary Transponder and Laser Communications Experiments via Dual Station Ranging to SLR Satellites," in this Proceedings.

[2] McGarry, J., and T. Zagwodzki, "SLR2000: The Path Toward Completion," in this Proceedings.