SLR 2000: The Path toward Completion

J. McGarry, T. Zagwodzki

1. NASA / Goddard Space Flight Center.

Contact: Jan.McGarry@nasa.gov

Abstract

After years of programmatic and technical issues, SLR2000 is finally receiving the manpower and money needed to solve the final technical challenges. This paper describes the progress that has been accomplished over the past year and discusses the final steps that we will take in the coming year to make the system operational.

Introduction

SLR2000 is the prototype for NASA's Next Generation of Satellite Laser Ranging (SLR) Systems. It was originally designed to be completely automated, eye-safe, with a lower cost of operation, a high reliability, and an accuracy comparable to the existing NASA MOBLAS systems [Degnan(1)]. After many years where funding was low, in 2006 SLR2000 development was given a higher priority and more funding.

Much progress has been made in the last year. The system is now tracking low earth orbiting (LEO) and LAGEOS satellites, able to acquire and track most LEOs relatively easily, although the returns are not yet optimized. The system timing, pointing and ranging capability, and accuracy have been tested using MOBLAS-7 return pulses. The software is more robust and the system is more repeatable. We believe that the system is within a year of final collocation with MOBLAS-7.

Recent system developments.

An optical shutter was designed and built by SigmaSpace and installed in the system to reduce the laser backscatter on the detector [Degnan(2)]. In a single telescope common optics transmit-receive system the photomultiplier tube (PMT) is exposed to a significant amount of laser backscatter within its field of view (FOV) as the pulse leaves the system. Even though the PMT is gated off during the laser fire this illumination stresses the photocathode and may shorten its lifetime. Mechanical choppers or shutters were investigated but deemed too problematic for operation at 2 KHz. The solution was an optical shutter in the form of two liquid crystal (LC) polarizing filters, one installed in each leg of the transmit-receive switch which reduce the backscatter by two orders of magnitude (Figure 1).

A new higher quantum efficiency (QE) quadrant PMT was installed in the system. The comparison with the previous detector is shown in the following table.

	Photek(PMT210)	Ham(R4100U- 74-M004C)
MCP stages	2 plates	2 plates
Active diameter	10mm	6mm
Photocathode	S20	GaAsP
Q.E.*	12%	33%
DC current Gain	1×10^6	2.6×10^5
PMT HV bias	-4700V (nom.)	-2250V (nom.)

The relative sensitivity improvement of the Hamamatsu tube over the Photek tube was estimated during an Etalon track to be approximately 5:1. Additional loss in Photek sensitivity is surmised to be due to aging or degradation of the photocathode over many months of SLR operation.

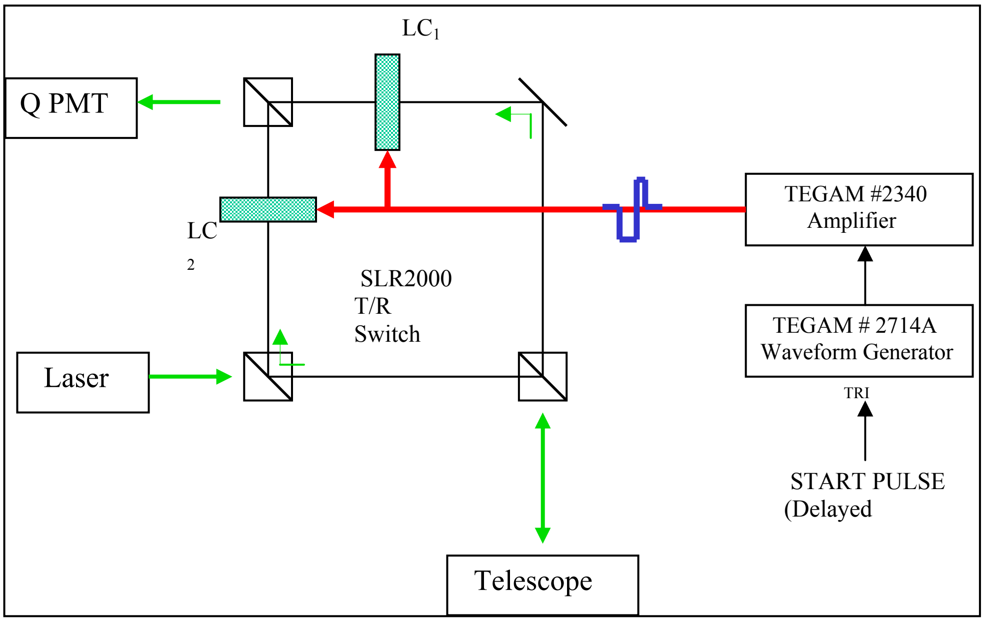

Figure 1: *Optical bench with Liquid Crystal Shutter in both legs of T/R switch*

A laser beam expander was replaced in the system to both control the laser divergence and to give adequate knowledge of the divergence setting. This expander was designed and built by SigmaSpace [Degnan(3)]. Originally the laser transmitter beam divergence could not be adjusted without de-focusing the common beam expander for the receiver. The resultant FOV change in the receiver adversely effected control of background noise and vastly complicated tracking. The solution was to develop a beam expander mechanism which operates solely on the laser transmit beam (independent of the receive path) and which could be focused to accommodate the 10 to 30 arcsecond (full angle) desired beam width.

The Risley prism laser point-ahead optics are now operational in the system [McGarry]. The Risley wedge pair is used to steer the transmit beam ahead of the telescope receive path and put the center of the transmit laser beam directly on the target. The telescope can then be pointed behind to center the receive FOV about the return light. This then allows the FOV to be closed to 10 arcseconds, which reduces the optical noise and allows use of the quadrant detector information to correct the telescope pointing. The Risley optics have successfully undergone testing with an off-line software package. The operational software package interface to the Risleys will be verified in the next few months.

The software now controls the Laser Pulse Repetition Frequency (PRF) to avoid fire/return collisions [Titterton]. This is needed due to the common optics design of the system. Only two different fire intervals are needed for any of the ILRS tracked satellites. The values of the two fire intervals are dependent upon altitude:

- Low Earth Orbiting (LEO): 500 and 510 microseconds
- LAGEOS: 500 and 502 microseconds
- High Earth Orbiting (HEO): 500 and 501 microseconds

The PRF switching is currently being successfully used in all satellite ranging. Figure 2 shows how the laser PRF changes during the course of a LEO (left plot) and LAGEOS (right plot) pass.

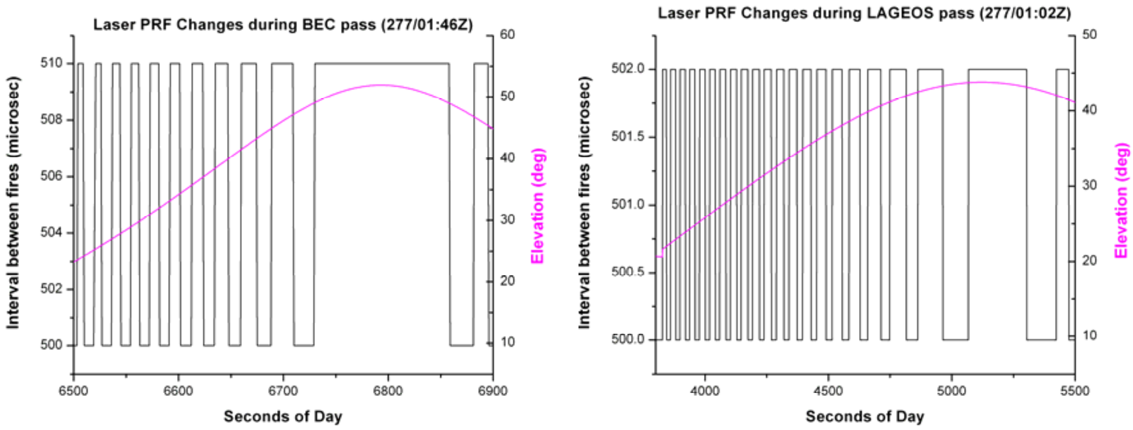

Figure 2: *Examples of laser PRF changes during two passes. The left plot is BEC and the right plot is LAGEOS.*

The new Q-Peak laser was installed into the system. The energy of the previous laser (an earlier Q-Peak version) had degraded to the point where it was transmitting only about 60 microJoules per pulse. The newer laser transmits approximately 120 microJoules per pulse.

Both the star camera (for star calibrations) and the sky camera (for sky condition) failed during 2006 and have been replaced. The star camera had been in use for approximately ten years. The new star camera is the Santa Barbara Instrument Group (SBIG) ST-402ME CCD imaging camera. The CCD chip is 9 microns square with 765 x 510 pixels. It is a low noise, high QE camera with a USB 2.0 interface. It greatly increases the star sensitivity from our old camera, where the dimmest useable star was around magnitude 3.5. The SBIG camera in SLR2000 can resolve better than 8^{th} magnitude stars. The new star camera has been installed and is operational.

The sky camera failed after about five years of more or less continuous operation. The new sky camera is the Jenoptik VarioCam InfraRed (8 – 13 μm) camera. It has an uncooled sensor with a 320 x 240 pixel resolution and a Fire-Wire interface. The new sky camera is installed and working but has not yet been incorporated into the operational software.

Testing with MOBLAS-7

To checkout the system timing, pointing and receive electronics, we took many passes with MOBLAS-7 acting as the transmitter for SLR2000. These tests took two forms: (1) transferring the receive time from the MOBLAS-7 discriminator to the SLR2000 event timer with a cable running between the systems (start/stop via cable), and (2) receiving the actual return light with the SLR2000 quadrant detector. In both cases the MOBLAS-7 fire time was transferred to SLR2000 via cable.

Analysis showed (1) good pointing for SLR2000 (these tracks required no biases to maintain the returns), (2) comparable results between MOBLAS-7 and SLR2000 for data RMS when the cable was used to transfer the MOBLAS-7 fire times, and (3) in general a higher return rates for HEO satellites at SLR2000, due to its singe photon detection capability. Examples of the full rate data RMS for various passes are given in the table below.

Figure 3 shows an example of the LAGEOS return rates for MOBLAS-7 and SLR2000 with MOBLAS-7 providing the fires for both systems and SLR2000 receiving the return light with the quadrant detector.

LAGEOS RMS (mm)
MOBLAS-7 Start/Stop via cable: 10
SLR2000 quadrant detector: 25 – 40
ERS-2/ENVISAT RMS (mm)
SLR2000 quadrant detector: 20 – 25
GLONASS-87 RMS (mm)
MOBLAS-7 Start/Stop via cable: 15
SLR2000 quadrant detector: 35 - 45
ETALON RMS (mm)
SLR2000 quadrant detector: 50 – 60

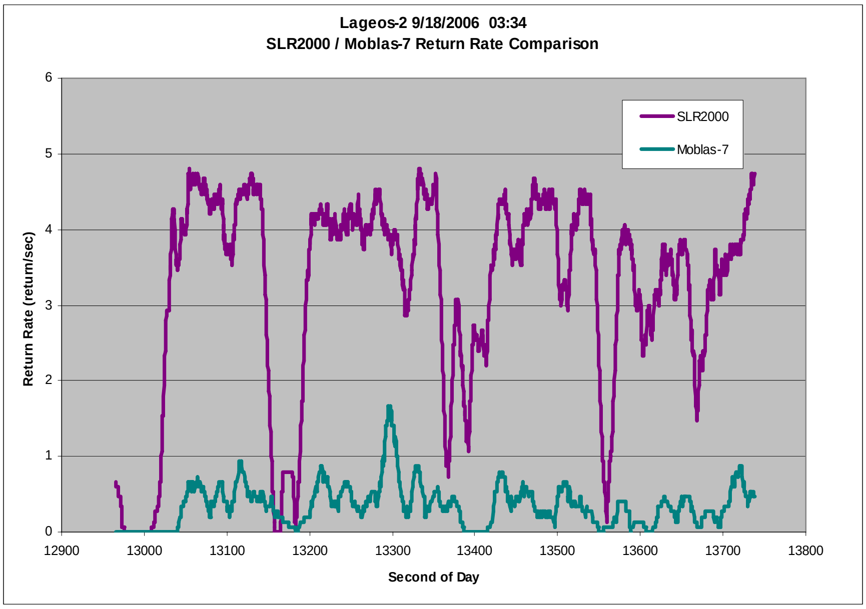

Figure 3: *LAGEOS return rates for SLR2000 (top curve) and MOBLAS-7 (bottom curve) when MOBLAS-7 was used as laser transmitter (5Hz) for both systems.*

Satellite ranging with the 2 kHz eyesafe laser

In the last several months SLR2000 has been ranging to satellites using its own eye-safe 2 kHz laser and pointing the telescope ahead. This configuration removes the need for the Risleys to point the laser ahead, but prevents daylight operation due to the need to keep the receiver field of view open to 25 arcseconds to cover the point-behind angular deviation from the point-ahead.

We have tracked many low earth orbiting satellites as well as a portion of a few LAGEOS passes. The pass RMS values remain relatively high due to our relatively wide pulse width laser (250 picoseconds). An example of the raw data from a STARLETTE pass is shown in Figures 4.

Path to Completion

Our immediate goal for 2007 is to increase our return rate from LAGEOS when ranging with our 2 khz eye-safe laser. We also need to return to our operational configuration where the telescope is pointed behind (toward the receive light) and the Risleys are used to point the laser ahead of the target. In this configuration we will work on finishing the closed-loop tracking. We expect our return signal rate to increase measurably when the system is closed-loop tracking.

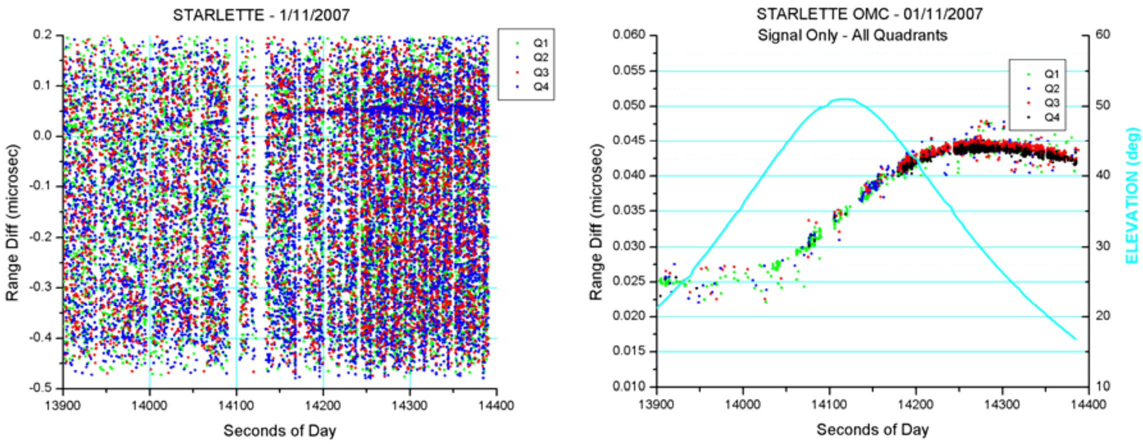

Figure 4: *STARLETTE pass on 1/11/2007. Left plot shows entire range window with signal and noise. Right plot is of signal only (as determined by signal processing).*

Along with this work, a new in-house laser is being built by Barry Coyle and colleagues. This 2 khz laser is expected to have a less than 200 picosecond pulse width with a 100 microJoule to 2 milliJoule variable per pulse output energy. This laser, which will enable us to track the higher satellites (in particular GPS), is expected to be delivered near the end of 2007. Our goal is to complete the SLR2000 prototype system in calendar year 2007 and perform a collocation with MOBLAS-7 in early 2008.

Acknowledgements

The authors would like to thank John Degnan, who developed the concept of SLR2000 and who led the development of this system until recently, for both his original idea and for his continued and unfailing support of this effort. We would also like to thank the SLR Network Manager, David Carter, for his support of our work, and Michael Pearlman who, as chairman of the ILRS Central Bureau, has been a steadfast proponent of SLR2000. We would also like to acknowledge the SLR2000 team, whose efforts were instrumental in SLR2000's progress: Christopher Clarke, John Cheek, Peter Dunn, Howard Donovan, Mike Heinick, Julie Horvath, Anthony Mallama, Anthony Mann, Donald Patterson, Mike Perry, Randall Ricklefs, Mark Torrence, Susan Valett, and Thomas Varghese. This work is being performed with funding from NASA's Science Mission Directorate.

References

[1] Degnan, J., J. McGarry, and T. Zagwodzki, "SLR2000: An Inexpensive, Fully Automated, Eyesafe Satellite Laser Ranging System," Proceedings of 10th International Laser Workshop on Laser Ranging Instrumentation, Chinese Academy of Sciences, Yang Fumin (ed.), 367-377, Shanghai, 1996.

[2] Degnan, J., and D. Caplan, "Performance of Liquid Crystal Optical Gate for Suppressing Laser Backscatter in Monostatic Kilohertz SLR Systems", in this Proceedings.

[3] Degnan, J., G. Jodor, and H. Bourges, "Adaptation of a Commercial Beam Expander for Automated Transmitter Beam Size and Divergence Control in the SLR2000 System", in this Proceedings.

[4] McGarry, J., T. Zagwodzki and J. Degnan, "SLR2000 Closed Loop Tracking with a Photon-Counting Quadrant Detector," Electronic Proceedings of 13th International Workshop on Laser Ranging, Ron Noomen (ed.), Automation and Control Session, Washington, DC, 2002.

[5] Titterton, P., H. Sweeney, and D. Leonard, "System/Usage Impact of Operating the SLR2000 at 2 kHz," Proceedings of the 11th International Workshop on Laser Ranging, 426 – 437, Deggendorf, 1998.