Recent Achievements in mono-static, high-repetition rate ranging at the WLRS

J. J. Eckl[1], K. U. Schreiber[2]

1 Federal Agency for Cartography and Geodesy, Geodetic Observatory Wettzell, Sackenrieder Strasse 25, 93444 Bad Kötzting, Germany, johann.eckl@bkg.bund.de.

2 Technical University of Munich, Geodetic Observatory Wettzell, Sackenrieder Strasse 25, 93444 Bad Kötzting, Germany.

Abstract

The Wettzell Laser Ranging System is a mono-static third generation SLR-System, which was specifically built to allow Lunar Laser Ranging. Therefore, it was designed to provide the highest possible signal to noise ratio, a high pointing accuracy and a smooth tracking precision. As a result, a mono-static setup, with a mechanical transmit-receive switch was chosen, which precludes higher laser repetition rates above 20 Hz. However, in order to reach sub millimeter normal point precision newer SLR-systems are ranging with significantly higher repetition rates in the regime of hundreds of Hz up to more than 2 kHz. In order to increase the repetition rate of the WLRS, while the HEO and lunar ranging capability is fully maintained, we can switch the optical configuration towards a new transmit-receive-switch via a motor driven opto-mechanical assembly. The high-repetition rate configuration provides an additional advantage, because it is inherently eye-safe. The paper describes the concept and realization of our new transmit-receive switch.

Introduction

Upgrading a low repetition rate SLR-system to a several hundred or kHz repetition rate-system can be considered as a step towards the latest generation of SLR-systems. This latest generation of Satellite Laser Ranging facilities operates high repetition rate lasers with single pulse energies of only about 0.5 mJ. The usage of such kind of lasers is possible nowadays, thanks to new computer generations. The benefits of an upgrade to higher repetition rates is an increased data yield in combination with a low signal level at the receiver side. This leads to reduced systematic errors of few millimeters in the measurement and a confidence in the statistics up to a level of below 1 mm, which is close to the goals of contemporary geodesy [PLAG] and therefore desirable to achieve. However, in the case of the WLRS this is not the only motivation. On the one hand, it can be pointed out, that there is no need for a flash lamp pumped post amplifier stage any more. This reduces maintenance costs and provides the possibility for freely triggering the laser source, which is again important for upcoming time-transfer experiments, like ELT. Especially for that kind of experiments it is also of big importance to know the system specific system delay. To determine this delay it is common practice to measure the distance to a target at a well-known distance. This is difficult to achieve with a bi-static (separated transmit and receive telescopes on the same mount) telescope setup, because due to the geometry of that setup, corner cube reflectors cannot be used. The advantage of using corner cube reflectors is that their position can easily be monitored by means of local tie surveys. Therefore, one design goal for the upgrade was to maintain the monostatic design. Furthermore, in case of the WLRS, with its 0.75 m optical telescope an upgrade to a repetition rate of 2 kHz would even allow for eye-safe Satellite Laser Ranging (Figure 1) at least at the primary laser wavelength of 1064 nm without losses in the transmit signal strength. Since the goal was to accomplish all the ideas mentioned, the upgrade encompasses:

- The reinstallation of our NIR-SPAD for permanent usage
- An upgrade of our Event-timer to support kHz operation and Time Transfer Experiments
- An upgrade of the transmit-receive optics for a faster switching time

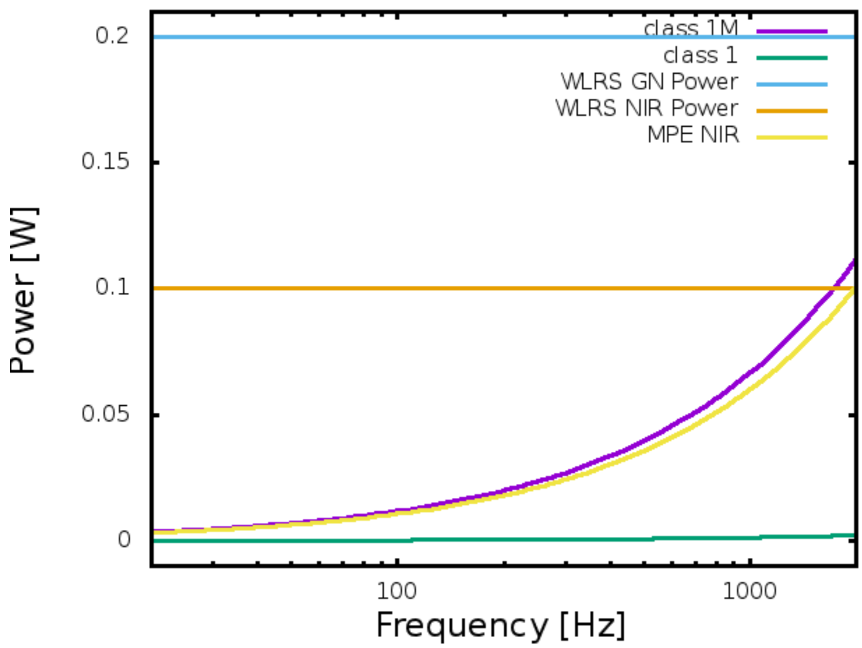

Figure 1. Horizontal lines: Mean power levels currently used for SLR at 532 nm and 1064 nm at the Wettzell Laser Ranging System. Purple, yellow, green: Maximum mean power level for a class 1M laser, the maximum permissible exposure and a class 1 laser as a function of the pulse repetition rate in the case of the Wettzell Laser Ranging System.

Receiver upgrade

From Figure 1 it can be seen, that eye-safe SLR is possible in the infrared regime at 1064 nm only, when the mean laser power should be preserved at the same time. Therefore, an InGaAs/InP-Single Photon Avalanche Diode, namely a Princeton Lightwave PGA-200-1064 was installed and investigated for its suitability for Satellite Laser Ranging. With its active area of just 80 µm the diode provides a field of view of only 18 arcsec in case of the WLRS, which is sufficient for SLR, but requires careful alignment. For satellite laser ranging applications, the diodes detection efficiency and its timing-properties are of interest. Ranging is usually performed close to the single photoelectron level, which ensures low systematic effects in the measurement. For the single photoelectron timing, a FWHM value of 75 ps was found, which is close to that of the best currently available single photon counting devices [PROCHAZKA]. Even though the dark count rate of the diode of 180 kHz is pretty high, the diode provides best in class detection efficiency when the signal is expected to be close to the gate on time. This was experimentally verified during ranging an IRNSS1B satellite, which is one of the most demanding targets in SLR. During the measurement, both laser wavelength, the fundamental at 1064 nm and the second harmonic at 532 nm with a similar laser pulse energy, were used. For easier adjustment of the laser pulse energy at the different wavelengths two laser sources were employed. On the receiver side the ordinary WLRS receiver, a LaserComponents SAP500 Single Photon Avalanche Diode, was utilized at 532 nm and compared to the new receiver, which is working at 1064 nm. During the measurement, the signal was alternately optimized for 1064 nm to 532 nm and back to 1064 nm. The result of this measurement can be seen in Figure 2. It was found, that the signal rate was increased by a factor of almost 10 in favor of the diode working at 1064 nm.

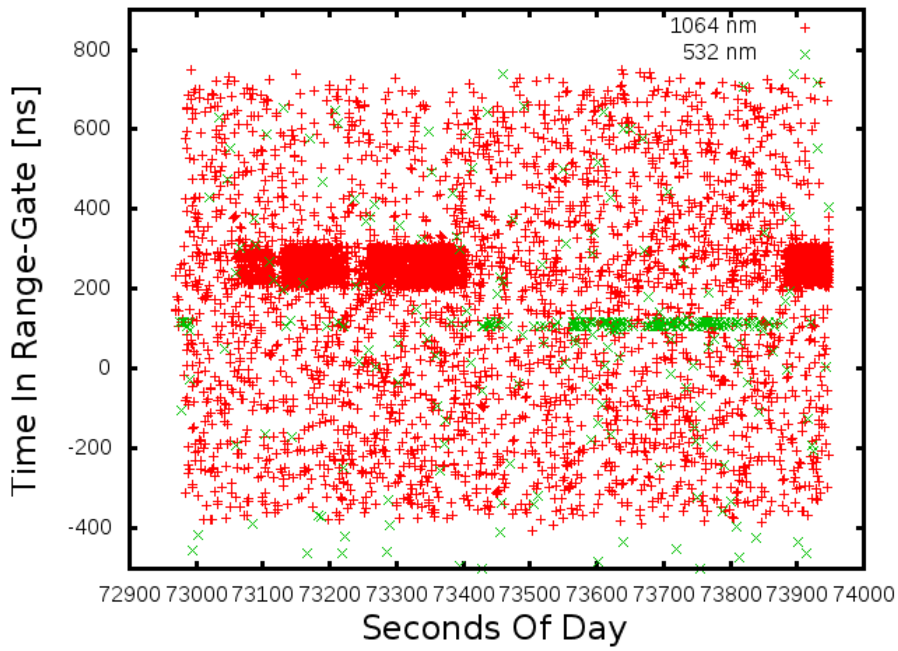

Figure 2. Residuals from ranging to the IRNSS1B satellite and alternately optimizing from 1064 nm to 532 nm to 1064 nm. The large scatter in the 1064 nm data arises from the fact, that two different laser sources were used in the measurement.

Event-timer upgrade

To prepare our Event-Timing device to support kHz operation and Time-Transfer experiments the analog input board and the data evaluation PC including the software package, had to be upgraded. The components that remained are the Thales Event Timing Modules, the power supply unit and the mechanical housing. Thereby, the analog input board was acquired from the Czech Technical University in Prague. The new input board provides a stability in the epoch of about 16 ps, when the epoch is repeatedly set using the PPS output signal of a Time Systems Technology, INC. Model 6460 clock module as a time reference and a common clock frequency is provided to both devices. This is an improvement by more than 2 orders of magnitude compared to the former input board and is expected to improve even more, when a more sophisticated signal source is used. An estimation of this can be derived from the channel to channel jitter, which is slightly below 2 ps for the new analog input board in combination with the Thales Event Timing Modules. For data evaluation a ZEDBOARD FPGA development environment for XILINX ZYNQ chips was chosen. The device provides an ARM-processor in combination with an FPGA-chip. For data acquisition, the readout process of the Thales Timing Modules is programed on the FPGA-side, while the data processing is performed on the ARM-side with a Linux operating system. On the other side, the interface to the WLRS operation system is made using idl2rpc [NEIDHARDT], which is based on Ethernet communication and provides a C-code header file, that may be implemented in any software package. Design goals of the software were, among others: kHz support of course, a hit-detection for satellite echo detection, a Normal-Point finished indicator based on evaluating the ranging precision and evaluation algorithms for the calibration signal. Each of them on a shot by shot basis.

Optics & T/R upgrade

The most demanding problem to support kHz ranging for the WLRS is its monostatic design. This means, that a single telescope is used for transmitting and receiving the signal. Considering the high sensitivity of the receivers in satellite laser ranging, which is down to single photons and the large number of photons transmitted in a single laser pulse of about 10^{15}, an attenuation of about 160 dB is needed, if single photons should be prevented from reaching the receiver side during the laser pulse transmission. The drawback of leakage light reaching the receiver side is an increased dark noise or even a damage of the receiver. Since the high amount attenuation needed cannot be achieved with optical components, a rotating mirror is used for that purpose at the moment. Because it is a heavy mechanical construction with sensitive optical elements mounted, the rotation frequency is restricted to 20 Hz. To overcome these restrictions, it was decided to split this construction into two parts: an optical transmit-receive-switch and a mechanical beam block. In order to maintain the operational status of the WLRS, both of these devices are installed in parallel to the existing T/R-switch by means of flip mounts. While the mechanical beam block is so far only set up in the laboratory, the optical T/R-switch, on the other hand, is implemented and tracking attempts were performed with reduced laser pulse energy. The T/R-switch consists of a half-wave-plate, a thin-film-polarizer and a quarter wave plate. The working principle is as follows: Rotating the half wave plate changes the direction of the polarization axis of the linear polarized laser-light. In this way, the laser light can be optimized for maximum reflection at the thin film polarizer. From that point, the light is guided towards the quarter wave plate, which turns linear polarization into circular polarization. Afterwards, the light is propagating towards the satellite. There, the signal is reflected back to the telescope and again passing the quarter wave plate. Thereby, the light becomes linear polarized again with the polarization axis shifted by 90 degree, which enables the light to transmit the thin film polarizer and reaching the receiver-side of the WLRS. First measurement with this transmit-receive-switch where carried out to the AJISAI satellite with a repetition rate of 200 Hz and a laser pulse energy of 1 µJ. During the measurement, a return rate of up to 40% was observed. Compared to the IRNSS1B passage, which was measured at a repetition rate of 20 Hz, the AJISAI passage shows strong noise. This arises from the fact, that no mechanical beam block was installed in this “first light” measurement. However, one design goal was to achieve the ability to freely trigger the pulse-laser for time-transfer-experiments, especially for the ELT experiment. Since the satellite response is expected to be in the same order of magnitude for ELT and AJISAI, the results prove, that ELT is possible, even without an additional mechanical beam block.

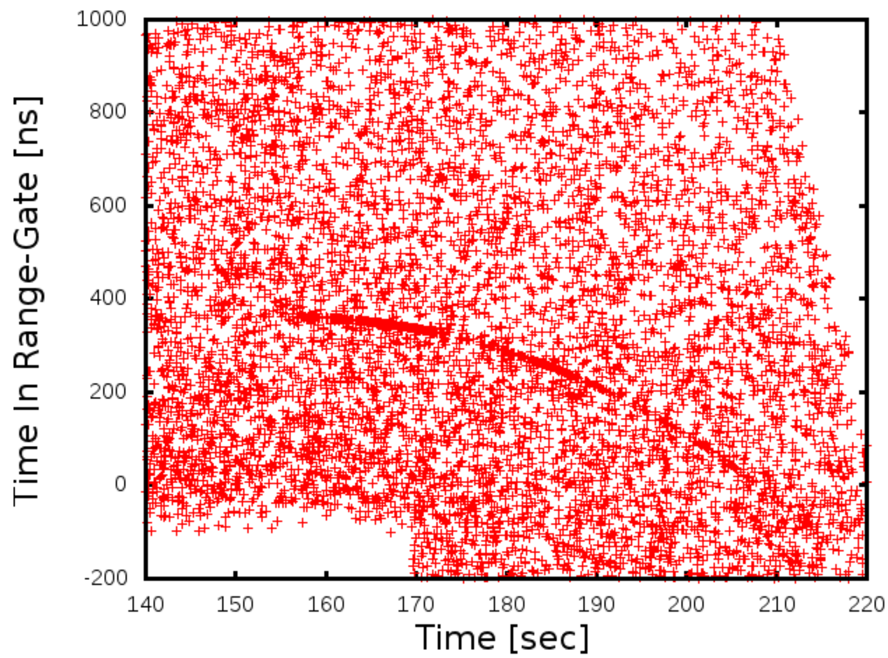

Figure 3. Residuals from ranging to AJISAI satellite at 200 Hz with the WLRS using the new T/R-switch. A return rate of up to 40 % was obtained.

Conclusion

The Wettzell Laser Ranging System was prepared to support high repetition rate ranging. First results could be achieved with reduced laser pulse energy, allowing for high repetition rate ranging to low earth orbiting satellites. In combination with an upgrade of our event-timer the system was prepared for best support of the ELT time-transfer experiment. However, to gain all of our design goals, an additional mechanical beam block has to be installed in the future.

References

Neidhardt, A., Ettl, M., Dassing, R., Hase, H., Mühlbauer, M., Plötz, Ch., Sobarzo, S., Herrera, C., Alef, W., Rottmann, H., *The interface generator idl2rpc.pl and ideas for the automation of VLBI telescopes,* 8th RadioNet Engineering Workshop, 2008.

Plag, H., P., Pearlman, M., *Global Geodetic Observing System,* Springer Verlag Berlin, Heidelberg, 2009.

Prochazka, I., Schreiber, K., U., Kodet, J., Panek, Petr, Eckl, J., J., *Recent achievements in detector and timing technology for SLR and laser time transfer,* Proceedings of the 18th International Workshop on Laser Ranging, 2013.