

## THE SOS-W - A TWO COLOUR KILOHERTZ SLR SYSTEM.

Stefan Riepl<sup>(1)</sup>, Wolfgang Schlüter<sup>(1)</sup>, Reiner Dassing<sup>(1)</sup>, Karl-Heinz Haufe<sup>(1)</sup>, Nikolaus Brandl<sup>(1)</sup>, Pierre Lauber<sup>(2)</sup>, Alexander Neidhardt<sup>(2)</sup>

(1) Bundesamt für Kartographie und Geodäsie. D-93444 Koetzting, Germany

(2) Technische Universität München. Fundamentalstation Wettzell. D-93444 Közting, Germany

### Abstract

*This paper presents the design of the newly envisaged SLR system termed Satellite Observing System Wettzell (SOS-W). The key idea behind the project is to provide support especially for low earth orbiting satellites, a kilohertz laser transmitter and a detection package being capable to perform two colour laser ranging. On completion the new system is mentioned to decrease the workload and configuration diversity of the WLRS, which, in turn, will be optimized for high altitude satellites and lunar laser ranging only. The SOS-W will be set up at the existing SLR facility building of the Fundamentalstation Wettzell, which already hosted the Satellite Ranging System (SRS) two decades ago. As the rough design of the transmit and receive optics is terminated, plans for modifying the building and dome installation are set up, which will allow a site installation and successive operation of the system during 2006.*

### Introduction

The design of the Satellite Observing System (SOS-W) attempts to integrate to best knowledge the requirements for SLR systems at least for the current and upcoming decade, which in our view can be cast into the following items:

- Minimization of all systematic error sources at or even below the millimeter level.
- Permanent two colour operation during day and nighttime conditions to strive against the elimination of the most potential systematic error source remaining in the SLR data, the atmospheric refraction.
- Capability of monitoring local baselines to support intertechnique combined solutions.
- Support of LEO gravity \_eld missions with an adequate data rate.
- Support of navigation satellite missions.
- Highly autonomous or even totally automatic system operation.

To realize these goals the design is driven in order to match the following constraints:

- Operation in single photoelectron mode introducing the least systematic biases, especially space segment induced biases.
- Utmost timing precision and reproducibility.
- Utmost spectral and spatial filtering improving the signal to noise ratio.
- External calibration with parallax compensation, which is indispensable for local baseline monitoring.

- Internal calibration at any pointing direction allowing for interleaved calibration e.g. whilst satellite switching.
- Beam pointing verification at any pointing direction to maximize data acquisition periods.
- Point ahead mode (aberration compensation) to enhance the maximum target distance and signal to noise ratio.
- Support of kilohertz repetition rates minimizing the random error which is especially required for low altitude satellites.
- Closed and pressurized optical chain to protect the coated surfaces.

### **Laser Specification**

Within the last ten years, vast progress has been achieved in laser technology. Especially the mode locking techniques for picosecond pulse lasers have been revolutionized by Semiconducting Saturable Absorber Mirrors (SESAM), which are commercially available nowadays. In contrast to Kerr lens and acousto-optic mode locking the SESAM technique works as well with femtosecond and picosecond pulses, i.e. it offers a broad operating bandwidth ensuring Fourier limited pulse generation. Moreover it is preferable to dye cell modelocking due to the lower service requirements arising from the solid state design. The laser output will be polarized circular at 850nm and 425nm, ensuring the least wavelength dependent systematic error in terms of center of mass correction (see [3]).

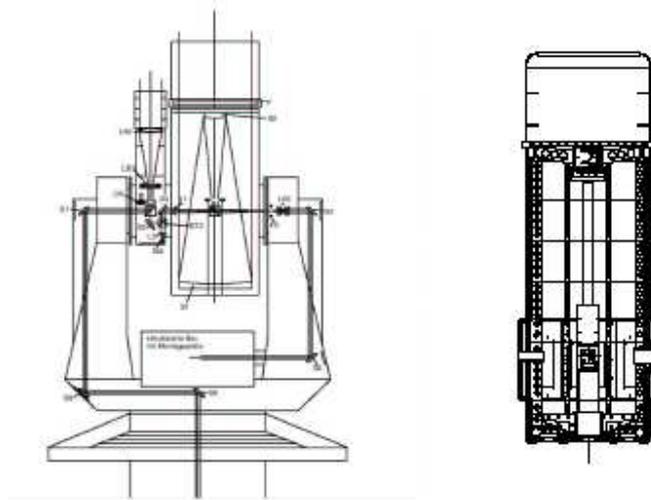
- 850nm/425nm Ti:SAP CW oscillator, passive modelocking by SESAM
- pulselength shorter than 50ps at 850nm, time band width product  $< 1$
- pulse to pulse jitter  $< 1$  ps
- active oscillator length control referenced by frequency standard down to  $\pm 4$ Hz
- frequency stability  $< 4$ GHz
- regenerative and linear amplifier generating 1W CW-power at 1kHz repetition rate
- contrast ratio  $< 1:1000$
- variable SHG conversion rate
- $M^2 < 1.5$  at both harmonics
- output power  $< 2$  percent rms
- circular polarization at both harmonics

### **Telescope and Mount Design**

In contrast to the SLR2000 design [1] which is based on a monostatic telescope configuration, the SOS-W employs a separate transmit and receive telescope. Due to the fact that the chosen continuous wave mode locked oscillator pollutes the optical path with its constant emission of the high repetition rate pulse train (typically 100 MHz), it is mandatory to provide the utmost optical isolation between the transmit and receive optical path, which can be met only by a bistatic configuration. Moreover the bistatic design isolates the high sensitive photon counting detectors from optical splashes caused by backreflection from the optical surfaces which is a known problem in every monostatic SLR system. The remaining backscatter in the atmosphere in a bistatic system can be diminished

very effectively by proper spatial filtering. Figure 1 shows a preliminary design of the telescope mount and tube. The beamsplitter in the transmit path, realized by a highly reflective dichroic laser line mirror, enables for

- internal calibration to the flipable calibration reflector (CR),
- parallax compensated external target calibration through the transmit telescope,
- and star observations through the transmit telescope by guiding the backward light leakage through the subsequent mirror assembly S3, ST3 and S4 to a focusing lens L1 in the elevation axis. Passing through a second dichroic beamsplitter (coude mirror in the receive telescope), the two telescope optical paths are unified and propagated to the adjustable field stop.
- aperture (1 to 120 arcseconds) and recollimating optics (LA3) after which they are guided to the receiver box.



**Figure 1:** The SOS-W telescope according to a preliminary design by Baader-Planetarium

As the ordinary mount modeling procedure is assumed to be realized by pointing optimization of the receive telescope, residual deviations of the transmit telescope pointing direction as a function of elevation can be compensated by transversal adjustment of LA1 which is mounted on a piezo translation stage. Moreover mirror S7 is vernier controlled in two axes to realize the point ahead mode (aberration compensation) for the transmit optical path.

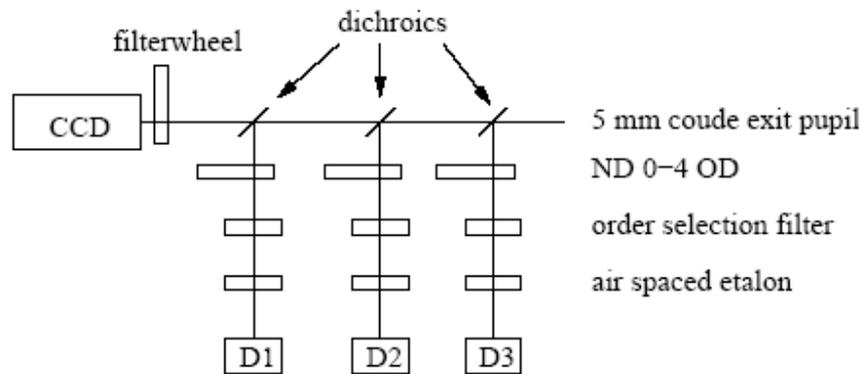
### **Detection Package**

To fully exploit the lightweight telescope tube and main mirror construction, the detection package will be housed in a hermetically sealed and climatized receiver box located on the Nasmyth (Azimuth-) platform of the telescope. The housing is designed to host two standard and one auxiliary detection channel with individual spectral filtering and attenuation devices as illustrated by figure 2. Moreover a CCD camera with a special filter wheel is installed for mount modeling, beam pointing and beam quality analysis as well as

autoguiding with sunlit satellites during night time. Table 2 summarizes the design guidelines for the detection package.

50cm f/3 primary mirror, light weight construction, centric mount
f/11 secondary focus
lightweight telescope tube sealed sealed BK7 front window
16cm transmit achromat
pointing accuracy < 1 asec
pointing correction devices
direct drive
max. velocities 20deg/sec in azimuth, 10deg/sec in elevation
open cable wrap

**Table 1:** Specifications for the SOS-W telescope, which will be constructed by Baader-Planetarium.



**Figure 2:** The schematic setup for the detection package

Narrow air-spaced FP Etalon (bandwidth < 0.05nm, transmission > 90%)
High transmission (approx. 80%) high blocking (5 OD) order selection filter
Return rate control by variable ND filter (0-4 OD)
MCP detectors at both wavelengths (Transit Time Spread < 30ps)
Housed in climate box on Nasmyth (Azimuth) platform
Custom discriminators at detectors
Realized with OEM components

**Table 2:** Specifications and guidelines for the detection package

Baader Planetarium guarantees 10 years serviceless operation
Turbulence/seeing limiting design
High quality surface finish
Up to 30 deg/sec Velocity
Sustains harsh environmental conditions
Hermetically sealed (when closed)
Ambient dry air system keeping outdoor temperature to avoid temperature gradients
Integrated heavy duty lifter (for Telescope)

**Table 3:** Features of the Baader-Planetarium Dome

### **Dome Features**

The company Baader-Planetarium being in charge of the dome manufacturing for the SOS-W has gathered thorough experience in serviceless design and dome operation in harsh environmental conditions. This is proven by dome installations ranging from Spitzbergen to Teneriffa and even in stringent environments of high mountains, where the dome mechanics are frequently confronted with ice coverage. The features of the dome for the SOS-W are summarized in table 3.

### **Software Development**

Within the in house control software development for the WLRS and the TIGO SLR system vast experience has been gained regarding this issue. Based on the achieved software efforts in these two systems, the existing control system software will be upgraded and improved in order to support kilohertz repetition rates as well as autonomous operation. To realize this goal it is planned to adapt the VLBI- field system software philosophy for this project, since it enables for e.g. support of diverse observation hardware, processing of system independent observation schedule and allows a manual intervention of an automatically processed observation schedule. It should be pointed out that the VLBI-field system as well as the TIGO SLR control system operate with Linux. The realtime extension for Linux RTAI offers even support for time critical software problems arising in SLR systems. The goal of the SOS-W software project is to realize a counterpart of the VLBI Field System, the SLR Field System which should be adaptable to any existing SLR systems.

### **Outlook**

The SOS-W comprises a kilohertz capable two color laser ranging system designed at the utmost but achievable limits of nowadays technology. It represents an up to now unique approach to two wavelength ranging using single photon counting techniques. Moreover the project aims to operate the SLR system autonomous or remote. The expectations on normal point accuracy scaled by error budget, return rate and link budget considerations respectively are in the submillimeter range, i.e. internal accuracy excluding to date unmodeled error contributions.

In terms of refraction correction derived from the measurements in the two wavelength domains an evaluation of the two colour capability of the TIGO SLR system [0] scaled top the SOS-W system parameters leads to approximately 3mm obtained within a normal point interval of 120 seconds, if one assumes perfect modelling of the wavelength dependent center of mass correction. For quasi single reflector targets like STARLETTE the obtainable accuracy for the refraction correction within a normal point interval should be at the millimeter level. Due to the envisaged spatial filtering at the seeing limit, a minimum sun proximity of 20 degrees should be achieved. The control system software will support global coordinated experiments, e.g. time transfer and transponder missions for which a mandatory observation schedule has to be processed, similar to the VLBI-Field-System capabilities. The software will be developed using open source code standards which will facilitate the portability and application to other SLR systems. Throughout the development of the SOS-W control system we will approach solutions entirely based on software from the Free Software Directory, which is a joint project of the Free Software Foundation and the UNESCO. The system is expected to be operational in early 2007.

## References

- [1] John Degnan, *SLR2000: Progress and Future Applications*, Proceedings of the 13th International Laser Ranging Workshop, Washington D.C., 2001
- [2] U. Keller, K. J. Weingarten, F. X. Kärtner, D. Kopf, B. Braun, I. D. Jung, R. Fluck, C. Hönninger, N. Matuschek, J. Aus der Au, Invited Paper, *Semiconductor saturable absorber mirrors (SESAMs) for femtosecond to nanosecond pulse generation in solid-state lasers*, IEEE J. Selected Topics in Quantum Electronics (JSTQE), vol. 2, pp. 435-453, 1996.
- [3] D. Arnold, *Wavelength Dependence of Range Correction*, Proceedings of the 13th International Laser Ranging Workshop, Washington D.C., 2001.
- [4] S.Riepl, D.Ramirez, C.Guaitiao, *Validation of Mapping Functions*, Proceedings of the 13th International Laser Ranging Workshop, Washington D.C., 2001