Kilohertz Laser Ranging at Graz: Our Plans

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Abstract

At present, SLR Graz is ranging to all satellites with a standard 10 Hz Nd:YAG Laser, using SemiTrain pulses with a total energy of about 30 mJ per shot and 35 ps pulses; we intend to replace this 20 years old system with a diode pumped, solid state laser, operating with 1 kHz repetition rate nominally (10 Hz to 2 kHz specified), with single pulse energy of 0.5 mJ per shot at 532 nm, and a pulse length of 10 ps.

While the present laser system will remain operational for special experiments like MultiColor Ranging etc., the expected advantages of the new laser system are up to kHz return rates for all low satellites, significantly improved return rates from Lageos, and same return rates from high orbiting satellites as now; this should map into much better defined Normal Points for all satellites up to and including Lageos.

First few test passes in December 2002, using a Demo Laser with 80 µJ/Shot, demonstrated return rates of close to 100% from LEOs like TOPEX etc., and significantly improved accuracy and stability.

Introduction

During the last year, SLR Graz has observed more than 5200 passes (until end of October); about 60% of these have been Low Earth Orbiters (LEO's); of the > 100.000 Normal Points of these passes, more than 85% have been measured to these LEO's, and about 10% came from LAGEOS; the remaining NPs are from high flying satellites, like Glonass, GPS etc. We expect, that the percentage of LEO NPs still will increase in the next years, as additional LEO satellites will be launched.

Thus any major upgrade should be mainly for the benefit of LEOs, and also to LAGEOS; in addition, the capability for ETALON etc should at least remain. We have already optimized our system to a large extent: Good single shot RMS, high long and short time stability, minimal pass switching times (e.g. 10 s between tandem satellites), use of Semitrain echoes for maximum return rates etc.; therefore the most promising upgrade is obviously a significant increase of the laser pulse repetition rate.

Specifications of the planned kHz Laser

- The laser is an all solid state, diode pumped Nd:YVO4 (Vanadate) laser, with regenerative amplifier and additional amplifier; the oscillator uses SESAM technology (Semiconductor

Saturable Absorber Mirrors); it is produced by HighQLaser (http://www.highQLaser.at, an Austrian company); it is compact (530 x 530 x 350 mm), and flexible;

- Pulses can be triggered externally via TTL pulses, with ± 6 ns accuracy:
- Allows simple external frequency variations from 10 Hz up to 2 kHz;
- Allows simple pre-trigger pulses to gate C-SPAD at very short (few meters) CAL targets;
- Allows simple frequency adjusting to avoid coincidence of start pulse backscatter with return signals (see below).

Parameter	***Present Laser***	***Planned KHz Laser***
Wavelength	532 nm	532 nm
Repetition Rate	10 Hz	1000 Hz nominal; 10 – 2000 Hz operational
Energy / Shot	35 mJ / SemiTrain, max; 10 mJ / SemiTrain, min;	0.5 mJ / shot, at 1000 Hz; 0.4 mJ / shot, at 2000 Hz
Pulse Length	35 ps	10 ps at 532 nm

Table 1: Main Specifications of planned kHz Laser

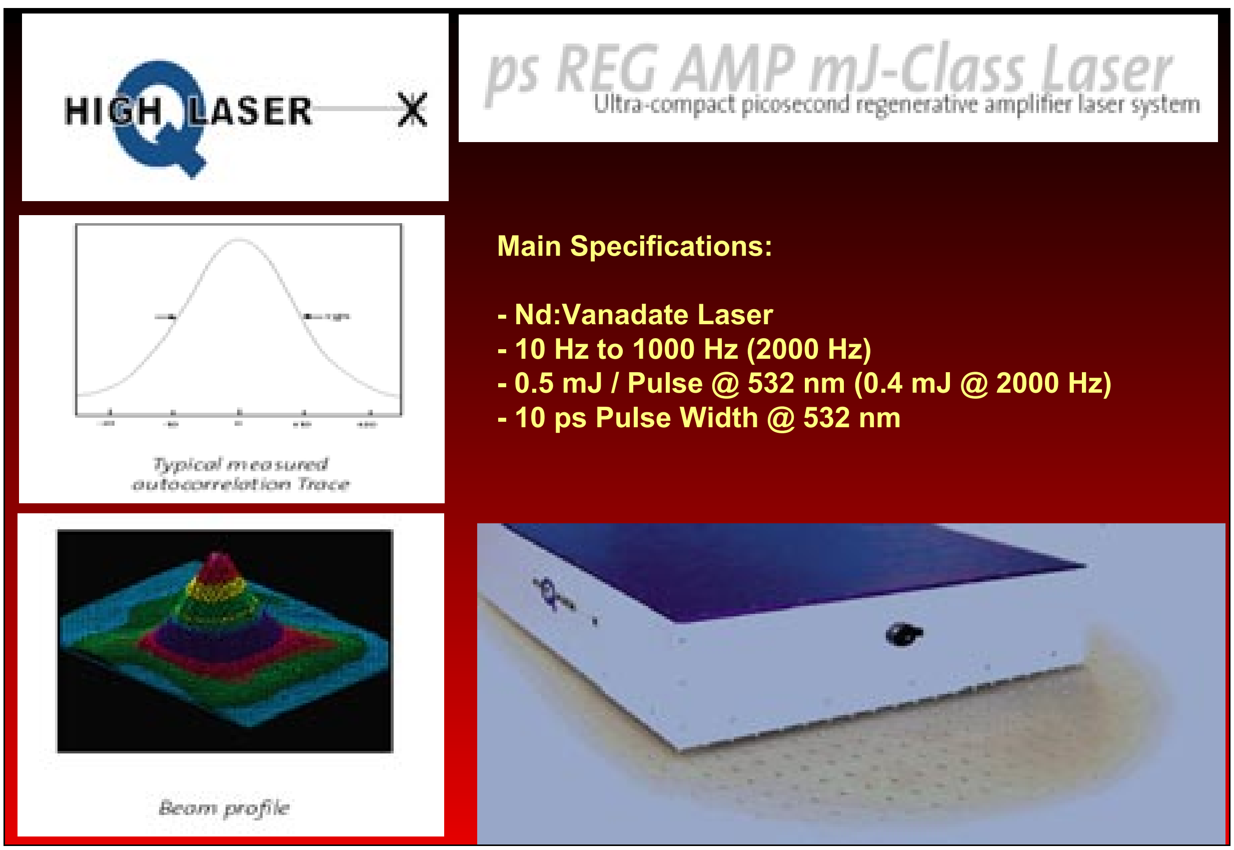

Fig 1: Some parameters of the planned kHz Laser

Expected advantages

For most LEOs, we expect a return rate of up to 1 kHz, in standard meteorological conditions; this should give a dramatic increase in data density within each Normal Point, resulting in much better NP definitions; for LAGEOS, we still expect some increase of return rate; for higher satellites like ETALON, we calculate return rates similar to the present configuration.

- Data density within each Normal Point should increase by a factor of 100 for LEO's; for LAGEOS, we expect a factor of 4 in data density; high satellites, like ETALON, should produce similar data densities;
- All automatic algorithms during tracking (acquisition, return identification, signal strength evaluation, range gate and time bias adjustments etc.) can react much faster and more accurate due to the high return rates;
- Return signal levels could be easier maintained at defined levels (e.g. single photons), and are anyway one order lower;
- Faster acquisition times for difficult LEO targets;
- Short laser pulse length of 10 ps should improve single shot accuracy slightly; tests to target at least could verify the theories …
- Lower operational costs expected: Flash lamps are more expensive than laser diodes …
- Lower maintenance work than with our old laser (has to be confirmed …)

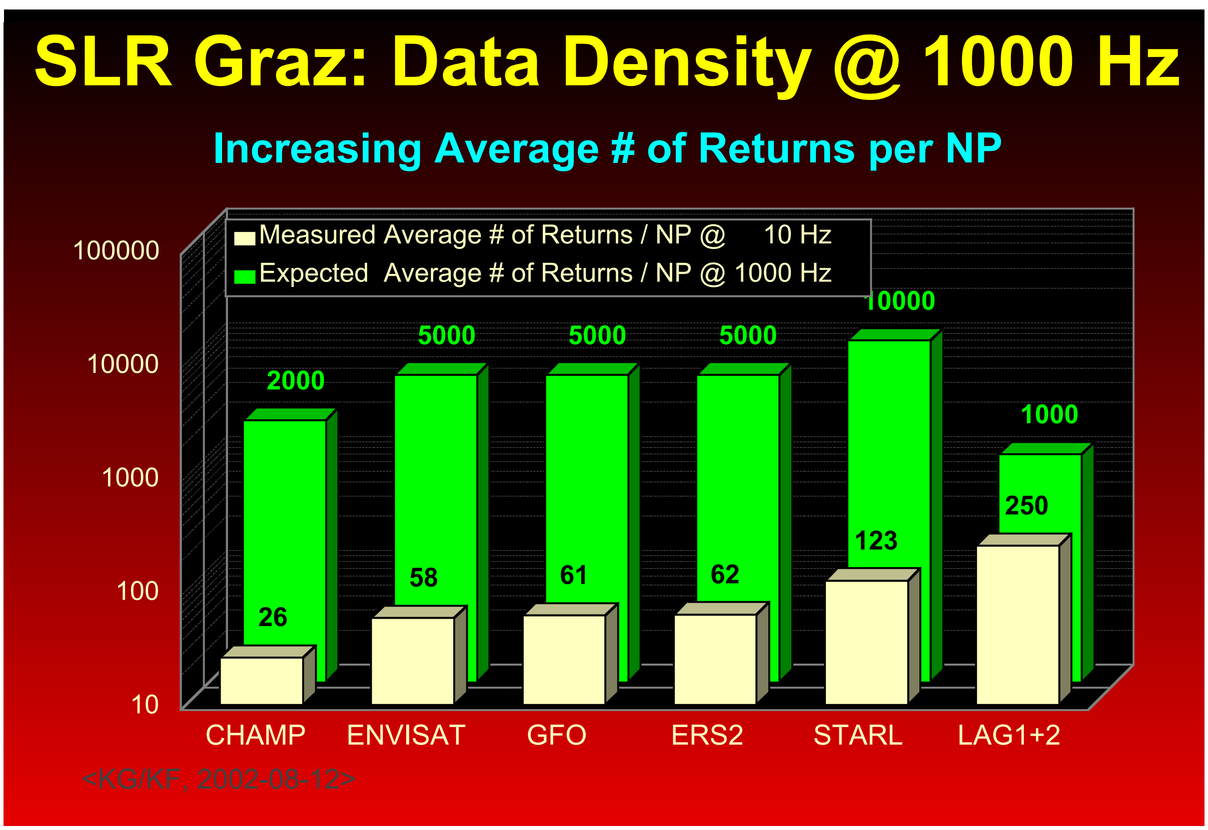

Fig. 2: Present average data density within Normal Points, and expected increase due to kHz

Start / Stop coincidence problem

One of the problems of kHz laser systems arises from the backscatter of the laser pulse crossing the lower part (up to about 5 km altitude) of the atmosphere; this loads significant optical noise on the detector during the first 200 µs after laser firing; any single photon return during this time might get lost within this backscatter; for a 1 kHz system, this will be the case for 20% of all shots (40% for a 2 kHz system).

The problem can be avoided completely by appropriate shifting of laser firing times; we are considering 2 methods; one of them is varying the laser firing frequency within a ± 10% band around the selected center frequency (e.g. 1000 Hz ± 100 Hz); doing it on a shot-by-shot basis or each n-th shot only (where n is a function of the rate of approach for the tracked satellite and the center frequency; e.g. n = 80 for LAGEOS at 1 kHz) keeps any expected return well outside of this 200 µs post-firing-slot.

The second method involves insertion of a 200 µs delay into to Fire Time Counter, whenever a Return is predicted within the next 200 µs; this will be necessary again as soon as this shift becomes effective in the return times; for LAGEOS, this will cause such additional delays each 40-60 shots (at 1 kHz), thus applying only minimal changes on the average laser frequency; for CHAMP, it would be applied each 3rd or 4th shot at minimum distance, thus reducing a 1 kHz firing to about 930 Hz at worst case (or 2 kHz to about 1.76 kHz).

Practical implementation of this scheme will be simple: We will use part of the FPGA chip, which is now used within our range gate generator: A down-counter will trigger the laser firing, when reaching ZERO, than re-load with a preset value (e.g. 1 ms for 1 kHz) and so on; the register holding the preset value will be changed in proper intervals, to adjust the frequency accordingly; or the clock pulse of this down-counter will be delayed for 200 µs if a return is expected here.

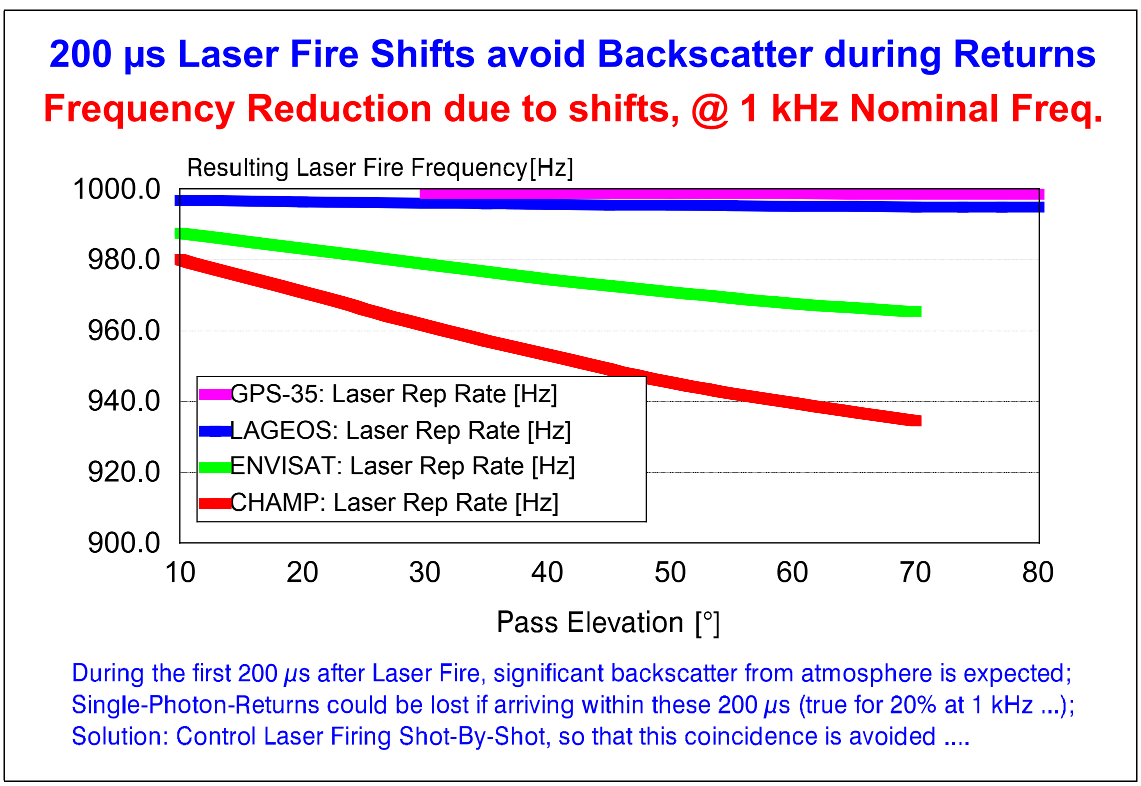

Fig. 3: Shifting Laser Fire Pulses, to avoid return photons during backscatter …

What else is needed ?

- Since end of 2000, we are using already our Event Timer (E.T.), which allows pulse rates of up to 2.5 kHz, for both start and stop event channels (Kirchner et al, 2000);
- During 2002, we have designed, built and implemented a new range gate generator (RGG) which offers repetition rates of some kHz, a resolution of < 500 ps, and is fully programmable via a standard 16-bit interface; it is implemented with an FPGA chip (Field Programmable Gate Array), which allows a high degree of flexibility (e.g. for later add-ons like the planned variable laser start pulse generation); this RGG already allows now the use of 10 Hz - from our standard laser – to ALL satellites, including GPS, ETALON and GLONASS (Kirchner et al., 2002)
- Software: Has to handle up to 300 pulses simultaneously on flight to or from the satellite; the main parts of it are already finished, and part of the passes delivered during the last months have been tracked already with it; although it was written and tested on our standard real time PC – a very old 486, running at 66 MHz – we simulated successfully 100 Hz laser pulses with it.
- Observer Interface: Has to be changed for 1 kHz returns ….

Present Status

In December 2002, we had a demo laser for 2 weeks installed in Graz SLR; this Demo Laser from HighQLaser had the same specifications as our planned one, but with only about 80 μJ @ 532 nm per shot (in our final version - with an additional amplifier - we will have about 500 μJ/shot); the laser itself allows repetition rates between 10 Hz and 2 kHz, but our present real time PC is limiting this at the moment only up to 125 Hz repetition rates.

Because of fog, we could range only few passes; nevertheless, we demonstrated return rates of close to 100% for LEOs like TOPEX etc., and we could exceed all our stability and accuracy goals as expected due to the high repetition rate and the short laser pulse (10 ps).

Money for this project has been applied for already in summer 2002, and the project was selected in autumn; we expect to sign all necessary contracts early next year, and the new laser to be delivered in summer 2003.

Conclusions

Fig. 4: ☺☺☺☺☺☺☺

References

Kirchner, G.; Koidl, F., 2000, *„Graz Event Timing System: E.T."* Matera, Proceedings

Kirchner, G.; Koidl,F., Steindl, M.: *„Hardware-Entwicklung eines Rangegate-Generators"* Diploma Work / Cooperation Fachhochschule Deggendorf (BRD), & Institut für Weltraumforschung der ÖAW; betreut von P. Sperber (FH) / G. Kirchner, F. Koidl