ÖAW – AUSTRIAN ACADEMY OF SCIENCES

CONTRIBUTIONS TO SUB-MHZ SLR IN GRAZ

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Ultra-high repetition (≥100 kHz) rate ranging is one of the most promising strategies for future SLR, and few stations have already started such experiments. In August 8th-10th, 2019, SLR Graz tested the 500 kHz ranging, using a demo laser provided by IPG, single photon detector and some technical updates of hardware and software. Finally, returns were received successfully at 500 kHz from several LEO satellites (return rate about 2%). Meanwhile to verify accuracy and ranging performance of the laser, we ranged up to GNSS satellites with the same laser (2 kHz / ~7μJ / 515nm) and our routine setup.

1 Key equipment and techniques

1.1 MHz laser

- IPG Photonics: **YLPP-25-3-50-R**
- Pulse length: 2 ps
- Energy: 25.9μJ (@ 1030 nm)/shot
- Rep. rate ≤2 MHz

- Spectral bandwidth (14.1nm) might prohibit daylight ranging due to the necessary 0.15~0.3 nm filter
- At 14 nm bandwidth, the atmospheric refraction would spread the final ranging RMS to > 21 mm which is much too large for a modern mm (single shot RMS) SLR level

1.2 Single photon detector

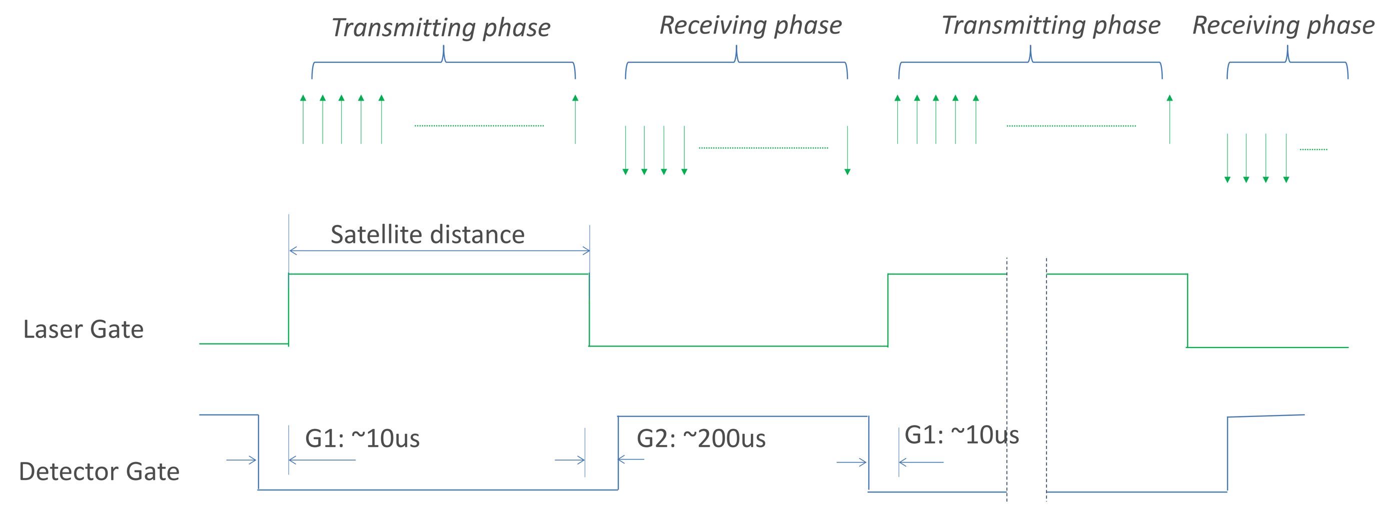
- SAP500 / free running or gated mode/ up to 6 MHz/ active quenching
- Dark counts: 2,000 Hz
- With partial overlap of laser back scatter: 200,000 Hz; must run in burst mode

1.3 Event timer A033-ET/USB

- Max. average rate: 1 MEPS (million events per second)
- Max. burst rate: 20 MEPS for 2 600 sequential events
  12.5 MEPS for 16 000 sequential events

1.4 Burst mode: Laser triggering and range rate

- Burst intervals updated every 100 μs FPGA, according to the distance to the satellites
- Four phases burst mode:
  - **Transmitting phase:** laser fires continuously until echo of first pulse approaching
  - Gap phase 2 (G2): wait till the back scatter of last laser pulse pass by
  - **Receiving phase:** enable the detector, get stop pulses
  - Gap phase 1 (G1): Disable the detector, wait for 10 μs, re-start transmitting phase



MHz SLR Burst mode, Laser and detector gate generation

2. Experiments and results

2.1 kHz SLR with LPG laser(7μJ/shot / 2 kHz / 515nm)

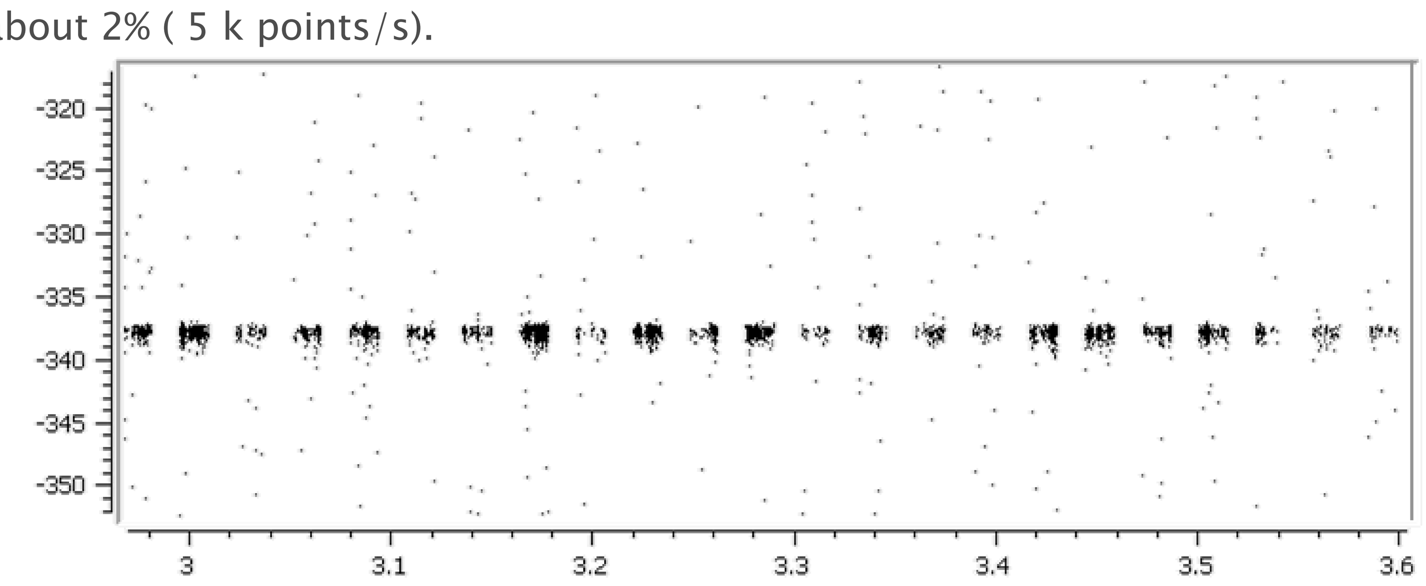
With LPG laser and Graz ***2 kHz*** routine setup (C-SPAD, Dassault ET, Graz start pulse detector, external gate), it was demonstrated that with an energy of ~7μJ/shot SLR Graz could range up to GNSS satellites, with an acceptable return rate of >1%.

Table 1: IPG @ 2 kHz/ 515nm, to different cooperative satellites

Satellite	Distance when reach max return rate (km)	Max. Return rate (%)	Single shot RMS (mm)
Sentinel3a	1195.5	55.6	2.6
Lares	1669.9	38.2	3.2
Jason2	2501.9	3.0	2.4
Lageos-1	6472.9	7.9	CCR signature visible
Glonass-134	19459.5	1.3	

2.2 500 kHz SLR with LPG laser

Due to the limits of ET-a033, SP detector and software, IPG laser was operated at 500 kHz; effectively we had 250 kHz shots per second (burst mode). 3 LEO passes (Jason-2, Sentinel 3a, Sentinel 3b) were tracked successfully; return rates were about 2% (5 k points/s).



Burst mode, 500 kHz/ 515nm, O-C residuals; Jason-2

3. Conclusions

- The compact IPG demo laser was used for first tests of sub-MHz SLR in Graz (at 515 nm); and we successfully tracked cooperative targets up to GNSS satellites at 2 kHz and LEOs at **500 kHz** repetition rate.
- The 2 kHz tracking demonstrated that with an energy of ~7μJ/shot SLR Graz could range up to GNSS satellites, with an acceptable return rate of >1%.
- Theoretically, the maximal possible power of this laser (40 W / 2 MHz / 1030 nm) would allow also space debris laser ranging (Graz operates a 16 W debris laser); however, this was not tested, mainly due to the lack of an operational IR detector channel and other hardware.

4. New ideas

❑**Aircraft/ Clouds laser detection:** Together with "Smart Transmit Telescope" (see Tuesday 09:06 presentation, Kirchner Georg), fire weak/low repetition laser pulses at the very beginning of each burst; derive ≤ 60 km clouds and aircraft detection from scattering photons.

❑**Repetition-rate-independent RG (range gate generator):** Nearly impossible for each start pules at MHz rate (1 μsec each) to calculate laser time of flight (ToF) and then set RG FIFO. However the distance change rate of any satellite is always < 10 km/s. So updating every 100 μsec ToF (interpolation by FPGA hardware) is precise enough to implement a resolution of a few ns resolution **RG.** Therefore the MHz SLR will not be limited by RG setting procedure.

Reference

1) https://www.ipgphotonics.com/de/147/FileAttachment/YLPP-25-3-50-R+Datasheet.pdf

2) Mendes, V.B., Prates, G., Pavlis, E.C., Pavlis, D.E., Langley, R.B., 2002. Improved mapping functions for atmospheric refraction correction in SLR. Geophys. Res. Lett. 29, 53-1-53–4. doi:10.1029/2001GL014394

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