The New 100–Hz Laser System in Zimmerwald: Concept, Installation, and First Experiences

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Evaluation of the new laser

- Higher repetition rate: 100Hz to few kHz
- Pulse length < 40ps
- Participation in one-way ranging and transponder experiments
  - → back to Nd:YAG (532 nm)
  - → single pulse energy not too low

- Call for tender December 2006 for Nd:YAG–System
- Four offers:
  - 3 kHz systems (High Q, Time Bandwidth, Expla)
  - 1 100 Hz system (Thales)

- Decision: 100 Hz system by Thales with Time Bandwidth Oscillator
Rationale for Decision

- **100 Hz good compromise**
  - Limit number of returns to strong targets
  - Total energy: >800 mJ per second (532 nm)
  - Single-shot applications still possible (8 mJ per pulse)
  - Flexibility in applications (firing rate, synchronization)
    - E.g., 28 Hz for LRO
  - Diode-pumped. Promises very stable operation
  - Monostatic system: Protection of the receiver against backscatter (rotating shutter possible: modulation 100%)

- **Two-color ranging: Outcome was not overwhelming**
  - Still possible at 1064 nm (pending suitable sensors)
  - Total energy: 1.8 J per second (green + IR)!
Protection of the receiver

- Monostatic system
- Protect receiver (SPAD / PMT) from backscatter
- 10 Hz: Rotating shutter
- 100 Hz:
  - Liquid crystal shutter
    - Response time ca. 100 µs
    - Max. transmission 30 %
  - LC optical gate with polarizer (Degnan)
    - Response time ca. 10 µs
    - Max. transmission 90%
    - Rather bulky for our system
  - Boost up rotating shutter (600 → 3000 or 6000 rpm)
    - Max. transmission 100%
Upgrade History

- Laser ordered end of March 2007 (Delivery: Oct. 2007)
- Additional components:
  - Rotating shutter: Inhouse design and fabrication
  - New optical components for 532/1064 nm: Mid 2007 till early 2008
  - PC card with FPGA by Graz Observatory: Fall 2007
  - Pulse distribution comparators (FH Deggendorf): Early 2008
- Implementation of FPGA card and rotating shutter
- Observation with old system until Feb 2008
- Installation new Laser: March/April 2008 (!)
- First echos: April 7 / Routine operation: April 24
Upgrade Costs

- Laser: EUR 270,000.–
- System modifications: 70,000.–
  - New coatings
  - Optical components
  - Electronic components
- Total: 340,000.–
Laser: Main Specifications (1)

- Technology: Diode pumped solid state laser (DPSSL)
- Pulse generation: SESAM technology oscillator (SEmiconductor Saturable Absorber Mirror)
- Wavelengths: 1064 + 532 nm (Nd:YAG)
- Pulse rate: 90–110 Hz, adjustable with external trigger. Additional decimation with pockels cell
- Configuration: Oscillator, regenerative amplifier, multipass amplifier (actual: double pass)
- Pulse energy: >20 mJ @ 1064 nm (actual: 18 mJ)
  10 mJ @ 532 nm (actual: 8.3 mJ)
- Pulse width: < 40 ps (FWHM) (actual: 58 ps)
Far-field distribution @ 532 nm

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Mean</th>
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<tr>
<td>13.5% Width Horiz (μm)</td>
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<tr>
<td>13.5% Width Vert (μm)</td>
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Laser: Main Specifications (2)

- Pulse contrast: $< 1/200$
- Beam diameter: 6 mm
- Stability of energy: $< 1\%$
- Pointing stability: $< 5$ arc sec
Laser: Main Components

- Oscillator (100 MHz)
- Regen
- Doublepass Amplifier
- Attenuator
- SHG (KTP)
- Beam splitter 0–100 %

Max. 18 mJ
Max. 8.3 mJ
2–98 % transm.
18 mJ
Transmit/Receive Switch Mirror

- Laser side: AR coating
- Telescope side: Rmax coating plus elliptic AR coating
Rotating Shutter (1)

- **Task: mechanical range gate / window**
  - Protects the receiver from backscatter during satellite ranging
  - Opens receiving path only for expected returns

- **Disk with two holes right after the field stop (pinhole)**
  - → Rotating frequency: 50 Hz (=3000 rpm)
  - → Speed (r=70mm): 22 mm/ms (=79 km/h)
  - → Hole Diameter: 6 mm (open for 280 μs)
  - Driven by DC Servo motor with integrated controller operated in stepper mode

- **Tests in closed-loop control showed:**
  - Epoch of shutter wrt to return +−50 μs (1% of 10ms)
Rotating Shutter (2)

- **Shutter control (by Control PC via FPGA card)**
  - Phase and frequency depending on current ranging parameters

- **Shutter safety monitor (hardware implemented)**
  - Assures that shutter is unintendedly opened at firing time
  - Checks speed and position 2 ms before firing time.
  - Blocks laser if conflict to be expected
    - 1) by disabling pockels cell (Regen)
    - 2) by fast mechanical shutter
Rotating Shutter (3)

- Photo sensor 3 „OPEN“
- Photo sensor 1+2 for prelim. speed and position check
- 2 holes
- 16 cm
PC Interface Card with FPGA

- Built/programmed by TU Graz (F. Koidl)
- Main functions:
  - Laser firing rate (Period: 9 to 11 ms, Res: 10 $\mu$s)
  - Digital range gate/window (2 ch.) (Res: 5 ns)
  - Clock for current epoch (Res: 1 $\mu$s)
  - Rotating shutter open pos. epoch (Res: 1 $\mu$s)
  - Var. frequency generator for rotating shutter control
  - Laser firing pre-pulses (rot. shutter safety monitoring)
  - Control register to enable
    - Laser pump diodes / Pockels cell / Safety shutter etc.
  - Several auxiliary I/O channels
FPGA PC card (ISA–Bus)

1 PPS  10 MHz

4x8 Out

3x8 Inp

FPGA

3 cm

ISA–Bus

20 cm
Laser Control

● Provided by Thales Laser:
  ▪ FPGA based control unit with clock generator
  ▪ Special notebook with LabView user interface for
    • Individual (manual) control of laser components
      - Oscillator, Amplifiers, Masterclock, Control unit
    • TCP/IP server component

● Client program on Linux station computer
  ▪ Connection by TCP/IP over LAN
  ▪ Control commands and status requests
  ▪ Laser ON, OFF, Status, Error resets

● Firing order and pockels cell control by electrical signals from FPGA card on request by Control PC
Range Gate Control (Control PC<-->FPGA)

- FPGA: generates firing order (defined by Control PC)

- PC: For each laser pulse (100 Hz cycle time):
  - Waits for start pulse flag from FPGA card
  - Immediately reads start epoch
  - Computes expected stop pulse epoch from actual start epoch and range prediction
  - Sends stop pulse epoch to FPGA
  - Keeps start and expected stop pulse epochs in ring buffer for later use

- FPGA generates range gate (SPAD) and window (PMT)
Overlap Avoidance

- **100 Hz:** Whenever flight time is multiple of 10 ms:
  - Stop pulse arrives at same time as a start pulse is generated
  - Receiver will see backscatter of start pulse
  - Receiver could be damaged or at least measurement made impossible

- Avoid overlaps:
  - Cut out parts of the passes (about 5 percent loss)
  - Adjust firing epochs by inserting short delays (Graz)
  - Change firing rate once shortly before overlap would occur (by Control PC via FPGA card)
Calibrations (old – new system)

Old
423 nm

New
532 nm

RMS = 80ps

RMS = 35ps
Range Precision: Good Target

Satellite: Champ

Single-shot RMS
34 ps = 5.1 mm
Single photon regime
Range Precision: Good Target

Satellite: Champ, single-photon mode

SPAD-generated asymmetry

Single-shot RMS
34 ps = 5.1 mm
Range Precision: Lageos

- Asymmetry from target structure
- SPAD-generated asymmetry
- Single-shot RMS
  77 ps = 11.5 mm

Target signature (retroreflectors at different target depths) plus SPAD asymmetric behaviour
### Performance on GNSS Satellites (Glonass)

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<th>Bin Number</th>
<th>Number of Obs per Bin</th>
<th>Residual (ns)</th>
<th>RMS (mm)</th>
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**Maximum 13 % return rate**

**Up to 4000 returns per normal point**
### Performance on GNSS Satellites (Giove-A)

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<th>Number of Obs per Bin</th>
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18 normal points stored. Bin width: 300 sec

Maximum 8% return rate
Performance on GNSS Satellites (GPS–36)

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<td>Maximum 9% return rate</td>
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Summary

- 100 Hz Nd:YAG solid state laser system
  - Stable energy and pointing

- 8.3 mJ / pulse @ 532 nm with excellent far field profile
  - Suitable for one-way ranging and transponder experiments

- Single shot RMS: 35 ps / 5 mm @ 532 nm for good targets

- Up to 13% RR on high satellites
  - Observation also possible through haze or thin cirrostratus

- Backscatter protection with 100% modulation (rot. Shutter)
  - PMT are also possible detectors

- Prepared for two-colour ranging
  - if a suitable detector is available in future
End

Thank you!
Timing system

- **Time Base**
  - 5MHz Quartz + Freq. Doubler (Oscilloquartz SA, Neuenburg) free running, compensated only once per day for aging (New: 10 MHz Quartz implemented shortly)
  - 10MHz distribution (FH Deggendorf)
  - Divider chain and distribution for clock pulses
    - 1 PPS
    - 100 PPS
    - Other rates
  - GPS timing receiver (Truetime) for synchronization by time comparison

- **Event timer for start and stop epochs (Riga)**
Rotating Shutter
Status End of 2007

- **Two-color 10 Hz system (Ti:Saph–Laser)**

- **Accuracy**
  - Single-shot 10 mm blue (423nm), 20–25 mm IR (846nm)
  - Range biases: Blue < 1 cm, IR < 2 cm
  - Bias between blue and IR 10–15 mm: Origin probably internal IR calibration

- **Maintenance and operation**
  - Relatively high maintenance costs of laser
  - Aging of components, difficulty with spare parts
  - Frequent readjustments (every day or every few days)

- **Availability**
  - Ca. 11 months per year
Pulse contrast at 532 nm

4 nm 1:650  14 nm 1:195

Measure | P1: pkp(kC2)  | value | 5.13 V  |
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C2 DC1M

- 2.00 mV/div
- 6.000 mV

- 0.00 mV
- 7.70 mV

C2 DC1M

- 5.00 mV/div
- 15.00 mV

- 0.00 mV
- 26.05 mV
Measurement of the pulse width

<table>
<thead>
<tr>
<th>Diode current (A)</th>
<th>Pulse width (ps)</th>
</tr>
</thead>
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<tr>
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<tr>
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<td>52.6</td>
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<td>1.3</td>
<td>54.9</td>
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<td>1.4</td>
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</tr>
<tr>
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<td>1.9</td>
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<td>2.0</td>
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