SLR Station Biases

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SLR is a space measuring technique which provides UNIQUE feature of DIRECT range / time measurement

Its role is inevitable in ITRF definition and calibration of numerous other techniques (GNSS....)

GGOS requirements 1 mm & 0.1 mm / yr

All the SLR hw chain components must be calibrated for their absolute delays with (sub) mm accuracies
Workshop goals #1

- Which biases should be seen at the stations?
- How do we stabilize calibration?
Accuracy – Biases
“never ending story..”

- GENERAL TECHNIQUE - Comparison to more accurate value
- HOWEVER - for SLR check such a value is not available
- SOLUTION - characterizing all (!) individual hw error budget contributors, their precision and biases
  (M. Pearlman, System characterization parameters, Herstmonceux, 1984)

- PROBLEMS
  - contributors list
  - how to calibrate each contributor ?
  - is our contributors list complete ?
“Ranging machine” error budget contrib.#1
Ground target calibration

- Calibration & target setup: T/R optics configuration, parallax, FoV, ...
- Target distance: range accuracy, target depth, ref. point
- Laser wavefront: near / far field pattern
- Optical arrangement: near field, 1 Photon
- RF interference: for short distances
- Receiver setup: range gating, echo signal strength
- Timing system linearity
The 3 cal. targets /hollow 2D retros/ have been re-surveyed and the calibration procedure tuned until the system internal delay value consistency of 2 mm has been achieved. The 2mm level was a precision limit for the system.

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"Ranging machine" biases identification

RANGING COUNTERS COMPARISON TO P-PET

P. Gibs, Herstmonceux, 2002

- Shown here is a summary plot of all the devices.
SR620 / P-PET Counter Linearity
Potsdam, 2001, LAGEOS pass

50 ps / div

Counter s/n 1014 (in routine use)

non reproducible oscillations

offset - 51 ps

the same measurement, 3 hours later

offset - 45 ps


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"Ranging machine" error budget contrib. #2
Local conditions and atmosphere

- Meteo sensors: calibration, stability
- "Local atmosphere": pollution, in-homogenity,..
- Local ties: relation to coordinates
"Ranging machine" error budget contrib. #3
Epoch timing

- Time scale source, distribution,..
- Clock frequency source, stability relation to “1pps”
- SLR Time reference “1pps”, trig.level, BW,....
- Epoch calibration constant laser fire epoch versus pulse cross. invariant point
Workshop goals #2

- “What changes in procedures and processes would give the stations greater ability to detect biases?”

- ANSWER
  “1 photon only “ approach

- => missing time walk effects
- => reducing target spread problems
- GNSS

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Workshop goals #3

- “What station hardware, equipment, software, etc. would give the stations greater ability to detect biases?”

- In general – greater stability is a prerequisite for smaller biases
New Start detector + discriminator

- fully integrated solution
- Drift $\sim< 350$ fs / K (\(!\))
- Jitter $< 1$ ps
- output NIM fall times $\sim 60$ ps


Graz SLR calibration mean, 120 days each

<table>
<thead>
<tr>
<th>Single shot</th>
<th>TDEV</th>
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<tbody>
<tr>
<td>16.5 ps</td>
<td>$\Rightarrow 13.2$ ps</td>
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October 2015
SPAD detector package
1- photon version
Low temperature drift

- New control electronics,
- Fully passive temperature control
- Outputs rise / fall times ~ 100 ps
- \( \Rightarrow \) jitter < 15 ps
- drift 260 fs / K (!!)

New SPAD + Start + NPET detection delay over 6 days, +/- 2 K

\( +/\!-/\ 900 \text{ fs over 6 days} \)

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Sub-ps Timing System NPET for SLR

- Compact & robust & user friendly
- Jitter $< 0.9$ ps rms
- Non-linearity $< 0.5$ ps
- Temp. epoch drift $< 0.5$ ps / K
- Time int. stab. $\pm/\mp 0.1$ ps /hour

![Histogram](image)

- Cell width = 300 fs
- sigma = 490 fs
- 490 fs rms

![Graph](image)

- Constant fraction of ToA [ps]
- No. of samples
- sigma = 490 fs
- $\pm/\mp 100$ fs

![Graph](image)

- NPET2 time interval (Ch2-Ch1) stability
- +/- 100 fs

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Two Way Time Transfer via single coaxial cable

- Comparison of two independent time scales #1 and #2
- Sub-ps precision & few ps accuracy
- Comparison in parallel to event timing in the same device
- Attractive for accurate epoch ("1pps") reference distribution within the observatory


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Conclusion – (hw) stability

- New Start detector improves the long term SLR system stability to a (sub) ps level

- Single Photon Avalanche Detector was optimized for long term stability of detection delay

- NPET timing system was optimized for SLR provides sub-ps precision and stability

- Two way time transfer option built in NPET provides time synchronization to local time scale with few ps accuracy
Recommendations #1
General

- Operate the SLR on 1 photon level only

- Maintain maximum system delay stability (selection of components, environment, procedures..)

- Permanently try to identify new possible bias sources “.. Suspect everything ..” Herstmonceux, 2015

- Repeatedly check the individual contributors using more accurate references
Recommendations #1
SLR system calibration

- Use optically correct calibration targets
  2D hollow retro recommended for separate T/R

- Use efficient spatial filtering
  small FoV suppresses spurious reflections

- Ensure perfect alignment of the receiver optics
  (star tracking / scanning is a good check)

- Use multiple targets at different az and range
  check the system delay consistency

- Re-survey the targets geometry regularly
  use various scales, techniques,.....