Single versus multi-photon SLR using SPAD detectors

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Key questions #1 – Session 3

- What are the factors that are currently limiting performance: data quantity and quality?
- Return signal strengths and satellite return rates, single x multiple photons approach ……
- “never ending story…” in SLR
SLR systems performance comparison

- Based on *Quarterly Global Report Cards* published by ILRS www pages.
- Simple averages over 4Q 2016... 2Q2017 all 5 data centers
- Selected 6 SLR sites among the most productive:
  1. Yaragadee multi photon
  2. Changchun single – multi photon
  3. Mt.Stromlo 2 single – multi photon
  4. Herstmonceux single photon only
  5. Graz single – multi photon
  6. Matera multi photon

<table>
<thead>
<tr>
<th>Site Information</th>
<th>DFGI Orbital Analysis</th>
<th>Hitotsubashi Univ. Orbital Analysis</th>
<th>JCET Orbital Analysis</th>
<th>MCC Orbital Analysis</th>
<th>SHAO Orbital Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Location</td>
<td>Site Number</td>
<td>LAG Rms (mm)</td>
<td>% Good LAG, NP</td>
<td>LAG Rms (mm)</td>
<td>% Good LAG, NP</td>
</tr>
<tr>
<td>Baseline</td>
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<td>20.0</td>
<td>10.0</td>
<td>95.0</td>
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<tr>
<td>Yaragadee</td>
<td>7080</td>
<td>3.3</td>
<td>149</td>
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<tr>
<td>Changchun</td>
<td>7082</td>
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<td>2.1</td>
<td>5.6</td>
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<td>Mt.Stromlo_2</td>
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<td>173</td>
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<td>Herstmonceux</td>
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<td>9.1</td>
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</tr>
</tbody>
</table>

~ identical HW
SLR systems performance comparison # 1

Lageos Precision

- Stations 2, 3, 4, 5 are using C-SPAD detector by F.Koidl, Graz
SLR systems performance comparison # 2
Bias long term stability

1 Yaragadee
2 Changchun
3 Mt. Stromlo
4 Herstmonceux
5 Graz
6 Matera

Bias stability [mm]

Station

Prochazka, Kodet, Blazej, 21th Workshop, Riga, October 2017
Workshop goals #2

Prochazka et al, 19th ILRS Workshop, Matera, 2015

- “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 problem
Key questions #2 – Session 3

- For single photon “..The current philosophy is to reduce return rate to about 10% to try to capture primarily singles”.

- “What would we lose if we expanded the capture rate to 20%, 30% or more? “

- Two key issues
  - Echo signal detector response
  - Target response
GOOD NEWS
Using 10 ps laser pulse @ 532 nm
SPAD detector can operate up to 50% rate
with negligible (< 1mm) time walk when
applying 2.2*sigma data editing
(J.Kodet, J.Eckl, Wettzell, 2014)

BUT
This feature can be utilized for ideal targets only,
laser time transfer or one way ranging.

Echo signal spread by target depth will cause a
significant time walk for rates > ~ 15 %
New single photon only SPAD detector for SLR

- SLR and laser time transfer ground segment
- 200um TE3 cooled SPAD
- New control circuit (8 GHz bw)
- Output pulses fall times ~ 40 ps
- Low noise for kHz reprates

- Jitter (single shot) \(1.5 \text{ mm rms}\)
- Low temperature drift \(< 70 \text{ fs/ K}\)
- Timing stability TDEV \(< 80 \text{ fs @ hours}\)

- Field version is under construction now.
- More details on the Poster
CONCLUSION

- Answers to several key questions:
  - Single photon only approach is providing the best bias stability and the lowest NP spread while maintaining high station Lageos productivity (Herstmonceux).
  - Echo rates up to 50% can maintain sub-mm biases using < 10ps lasers and zero depth target.
  - New SPAD detector provides 1.5 mm single shot jitter and extremely high timing stability and low drift.
  - My dream – zero target signature geodetic satellite (uncoated Luneburg sphere on ~ Lageos orbit)