**Telescope Upgrade**

- The 1-meter Brashear tracking telescope used by NRL for SLR operations in Stafford, VA had been slowly degrading. The telescope, originally delivered in 2002, was losing functionality primarily due to age and lack of COTS replacement parts for failed components. It was decided to upgrade the entire system to bring it back inline with current technology and to ensure full functionality into the future. It was estimated that without this upgrade NRL would lose SLR capability by 2015.

- L3 IOS, the manufacturer of NRL's 1-meter tracking telescope, performed a full hardware and software upgrade over the period October 2013 to August 2014. It began with a thorough inspection of the system to identify parts that needed refurbishment or replacement. Presented here is a description of the major upgrades and the results of acceptance testing.

**Completed Upgrades**

- Telescope hardware and software upgrade
- See details below.

**In-Progress Upgrades**

- Software upgrades
  - Integrating new calibration piers
  - Updating NRL software to align with new telescope ICDs.
  - Improving automation of ephemeric management and ground calibrations.
  - Configuration management of all software.

- NGS survey
  - The IERS Site Survey Team at the National Geodetic Survey (NGS) will perform a local survey of the OTF. The team will tie the optical reference point to nearby old and new calibration piers using terrestrial optical methods, and position the OTF with respect to the latest ITRF framework using GPS. Depending on funding, the tie between GGAO and the OTF may also be resurveyed.

**Planned Upgrades**

- Development of new OTF control and processing software
  - New graphical user interface
  - Single mouse click satellite tracking and ranging operations
  - Automate Laser Cleaning House support.
  - Increase automation of data processing.

- Integration of 1 kHz 1064 nm laser ranging system
  - 100 ps pulse-width
  - 1.4 mJ / pulse @ 1 kHz, 2.3 mJ / pulse @ 200 Hz
  - System is aligned on the optical bench but waiting on software integration

- Integration of 50 Hz 1560 nm laser ranging system
  - 1064 nm shifted to 1560 nm using random cell
  - 200 mJ / pulse @ 1560 nm, 450 mJ / pulse @ 1064 nm
  - 3 nsec pulse width
  - Adjustable divergence, nominally ~100 µrad

**Site Acceptance Test Results**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Performance Spec</th>
<th>Pre-Upgrade</th>
<th>Post-Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Track</td>
<td>5 µrad peak LOS / 2 µrad RMS LOS</td>
<td>7.2 µrad peak LOS / 1.25 µrad RMS LOS</td>
<td>7.5 µrad peak LOS / 1.34 µrad RMS LOS</td>
</tr>
<tr>
<td>Star Track</td>
<td>5 µrad peak LOS</td>
<td>1.93 µrad peak LOS</td>
<td>1.97 µrad peak LOS</td>
</tr>
<tr>
<td>Blind Pointing</td>
<td>&lt; 2 arc seconds</td>
<td>1.44 arc seconds RMS</td>
<td>1.55 arc seconds RMS</td>
</tr>
<tr>
<td>Step Test</td>
<td>a. Settle within 2 µrad within 1 second, no motion, sidereal rate, 25 deg/sec</td>
<td>a. Passed with margin</td>
<td>a. Passed with margin</td>
</tr>
<tr>
<td></td>
<td>b. Time optimal move</td>
<td>b. Passed</td>
<td>b. Passed</td>
</tr>
</tbody>
</table>

**Azimuth Jitter Test Results**

<table>
<thead>
<tr>
<th>LOS Vel. Deg/sec</th>
<th>Freq Band 1 – 10 Hz (Spec)</th>
<th>Pre-Upgrade</th>
<th>Post-Upgrade</th>
</tr>
</thead>
</table>
| 0.0 | 0.75 µrad | 0.023 µrad | 0.176 µrad | 200 m/s | 19.9 mrad | 17.3 mrad *
| 0.1 | 2.0 µrad | 0.009 µrad | 0.059 µrad | 200 m/s | 19.8 mrad | 15.1 mrad *
| 1.0 | 10.0 µrad | 1.157 µrad | 0.884 µrad | 400 m/s | 23.0 mrad | 15.8 mrad *

**Elevation Jitter Test Results**

<table>
<thead>
<tr>
<th>LOS Vel. Deg/sec</th>
<th>Freq Band 1 – 10 Hz (Spec)</th>
<th>Pre-Upgrade</th>
<th>Post-Upgrade</th>
</tr>
</thead>
</table>
| 0.0 | 0.75 µrad | 0.043 µrad | 0.023 µrad | 200 m/s | 50.9 mrad | 17.6 mrad *
| 0.1 | 2.0 µrad | 0.043 µrad | 0.128 µrad | 200 m/s | 50.9 mrad | 17.6 mrad *
| 1.0 | 10.0 µrad | 0.553 µrad | 0.847 µrad | 400 m/s | 67.4 mrad | 55.2 mrad *

**Summary**

- L3 IOS's thorough understanding of the mechanical system allowed them to design and build the replacement focus controller offsite then install it with minimal issues within several microns of the original position. This was considered significant as the highest risk to the project had been the smoothing of the install taking only half the expected time.

- The change from a linear amplifier to a pulse width modulated amplifier increased the noise in the system which affected the overall jitter performance. Basic noise reduction techniques such as wrapping the leads through graphite cores, adding capacitors and altering grounding configurations helped reduce noise to acceptable levels. While the jitter results are not as good as the pre-upgrade measurements, or the initial delivery measurements, they remain below the original build specifications where measurements were successful. The increase in jitter is not expected to degrade SLR data quality, or NRL’s ability to perform any of its other missions. The increased time and money necessary to troubleshoot this issue alone was quite significant, accounting for approximately 10% of the total budget and 20% of the total schedule. NRL urges other systems to consider these possible problems when performing their own upgrades and to have schedule and budget margins to allow for an adequate solution to be found if these problems are encountered.

- NRL is preparing to Beta test an initial version of its new OTF Control software. This is a preliminary release that takes advantage of the new telescope control interface and new computer hardware installed by NRL. It will be a significant step towards a more automated SLR system designed to increase data quality and throughput.

- The optics were not considered “dirty” but were cleaned while the manufacturer was onsite so the degradation of the coatings could be measured and as a future cost saving measure. Reflectance measurements indicate the mirror coatings are degrading as expected and still well within specification.