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Status of SLR upgrades at the U.S. Naval Research Laboratory's Optical Test Facility

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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 an upgrade of the entire system was necessary 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.

Component	Impact
Focus Controller replacement	New zero backlash design, absolute encoder design improves reliability and performance.
Axis Amplifier replacement	New PWM design uses COTS components for easy repair and upgrade. Switch from linear to PWM amplifiers introduces noise, see jitter testing results below.
Real Time Computer replacement	Increases availability through decreased system faults, allows for latest QNX OS and performance margin for future upgrades. Modern COTS peripheral cards allows NRL to upgrade its interfaces.
Sun Avoidance	Improved automation and reduced S/W development on NRL side.
Cleaning of M1, M2 and M3	M1 reflectance is nearly identical to that at initial installation, M2 and M3 have some degradation but are still in good condition. This process allowed for a thorough inspection if surfaces.

Completed Upgrades

- Telescope hardware and software upgrade
  - See details below.

In-Progress Upgrades

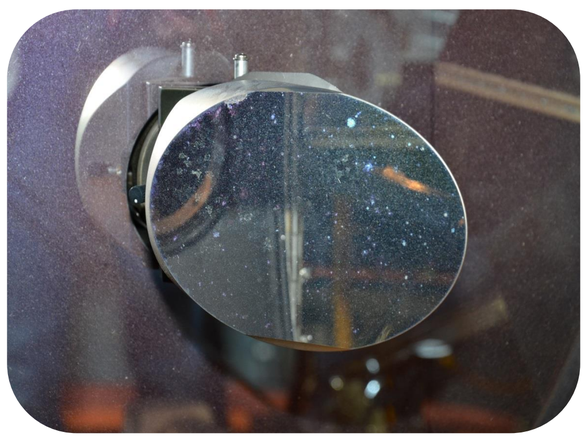
- Software upgrades
  - Integrating new calibration piers
  - Updating NRL software to align with new telescope ICDs.
  - Improving automation of ephemeris management and ground calibrations.
  - Configuration management of all software.
- NGS survey
  - The IERS Site Survey Team at the National Geodetic 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 Clearing House support.
  - Increase automation of data processing.
- Integration of 1 kHz 1064 nm laser ranging system
  - 100 ps pulse-width
  - 1.4 mJ / pulse @ 1kHz, 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 raman cell
  - 200 mJ / pulse @ 1560 nm, 450 mJ / pulse @ 1064 nm
  - 3 nsec pulse width
  - Adjustable divergence, nominally ~100 µrad

Site Acceptance Test Results

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



Dirty Tertiary and Primary

Azimuth Jitter Test Results

LOS Vel. Deg/sec	Freq Band .1 – 10 Hz (Spec)	Pre-Upgrade	Post-Upgrade	Freq Band 10 – 20 Hz (Spec)	Pre-Upgrade	Post-Upgrade
0.0	0.75 µrad	0.023 µrad	0.176 µrad	200 nrad	19.9 nrad	173 nrad *
0.1	2.0 µrad	0.009 µrad	0.059 µrad	200 nrad	19.8 nrad	111 nrad *
1.0	10.0 µrad	1.157 µrad	0.884 µrad	400 nrad	23.0 nrad	158 nrad *

LOS Vel. Deg/sec	Freq Band 20 – 100 Hz (Spec)	Pre-Upgrade	Post-Upgrade	Freq Band 100 – 1000 Hz (Spec)	Pre-Upgrade	Post-Upgrade
0.0	100 nrad	26.7 nrad	48 nrad	50 nrad	3.4 nrad	< 10.3 nrad **
0.1	100 nrad	8.2 nrad	41 nrad	50 nrad	3.2 nrad	< 10.3 nrad **
1.0	200 nrad	4.5 nrad	40 nrad	100 nrad	6.3 nrad	< 10.3 nrad **

Elevation Jitter Test Results

LOS Vel. Deg/sec	Freq Band .1 – 10 Hz (Spec)	Pre-Upgrade	Post-Upgrade	Freq Band 10 – 20 Hz (Spec)	Pre-Upgrade	Post-Upgrade
0.0	0.75 µrad	0.043 µrad	0.203 µrad	200 nrad	50.9 nrad	176 nrad *
0.1	2.0 µrad	0.043 µrad	0.128 µrad	200 nrad	50.9 nrad	179 nrad *
1.0	10.0 µrad	0.553 µrad	0.847 µrad	400 nrad	67.4 nrad	166 nrad *

LOS Vel. Deg/sec	Freq Band 20 – 100 Hz (Spec)	Pre-Upgrade	Post-Upgrade	Freq Band 100 – 1000 Hz (Spec)	Pre-Upgrade	Post-Upgrade
0.0	100 nrad	6.9 nrad	9 nrad	50 nrad	2.2 nrad	< 10.3 nrad **
0.1	100 nrad	9.5 nrad	11 nrad	50 nrad	2.3 nrad	< 10.3 nrad **
1.0	200 nrad	6.5 nrad	17 nrad	100 nrad	3.2 nrad	< 10.3 nrad **

* A significant increase in jitter over pre-upgrade performance.
** L3 IOS was unable to successfully collect performance data. Once noise floor was removed there was no signal left.

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 one of the highest risk tasks but turned out to be one of the smoothest portions 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 effected 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.