

Upgrade and Characterization of the U.S. Naval Research

Laboratory Nd:YAG SLR Laser

H. R. Burris¹, A. E. Reed, M. Davis², A. Peltzer, M. Vilcheck, M. Ferraro¹

U. S. Naval Research Laboratory, Code 8123

4555 Overlook Ave., SW

Washington, DC. 20375

1) Research Support Instruments, Inc., Lanham, MD.

2) Honeywell Technology Solutions, Inc., Lanham, MD.

Abstract

The U.S. Naval Research Laboratory (NRL) is constructing a new satellite laser ranging facility at a field site in the Washington, DC area. The laser system for the facility will be a modified and upgraded Continuum Nd:YAG. This paper discusses the upgrades and improvements made to the laser system, including the addition of a new CW, passively mode-locked (SESAM) oscillator with a Faraday rotator isolator, the upgrade of the synchronization and timing electronics, and the conversion of the original oscillator to a regenerative amplifier. We also report on the characterization of the laser system after the upgrade, including average pulse width, timing stability, pulse profile and quality.

Introduction

The Continuum Nd:YAG laser system that will be used in the new NRL SLR facility was previously deployed at the Starfire Optical Range, 3.5m telescope facility. The laser output was frequency doubled ($\lambda = 532\text{nm}$) so that there was approximately a 50% energy loss due to the doubling process, as well as a significant atmospheric attenuation loss. The oscillator at that time was actively mode-locked, Q-switched, and cavity dumped. The oscillator output amplitude and pulsewidth were very unstable and the system required excessive operator maintenance. Synchronization to external sources was difficult since the oscillator cavity dumping was triggered by light leakage from the cavity and thus jittered with the cavity build up time.

To improve the overall stability of the laser system, several modifications and additions were made: 1) a very stable, CW mode-locked Nd:YVO₄ oscillator from Time-Bandwidth products was added along with a Faraday isolator from Electro Optics Technology (EOT), 2) the previous Nd:YAG oscillator was converted to a regenerative amplifier, and 3) timing divider, delay, and synchronization electronics from Quantum Technology were integrated (see figure 1 below).

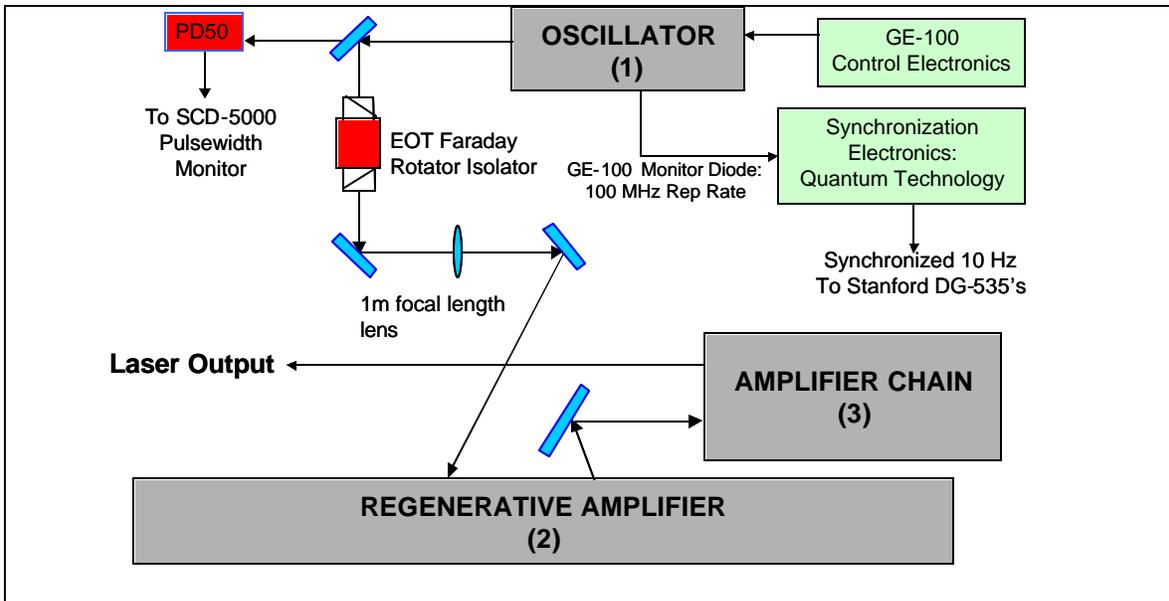


FIGURE 1: Upgraded Laser System Block Diagram

In addition to these improvements, the primary operating wavelength will be the Nd:YAG fundamental of 1064nm. Even though recent advances in avalanche photodiode (APD) technology have made detectors much more efficient at 1064nm, they are still less efficient than they are at the frequency-doubled wavelength of 532nm. However, the improved 1064nm efficiency coupled with the 2x energy increase gained from not doubling and the improved atmospheric transmission at 1064nm (see figure 2 below) should result in an overall gain in ranging efficiency.

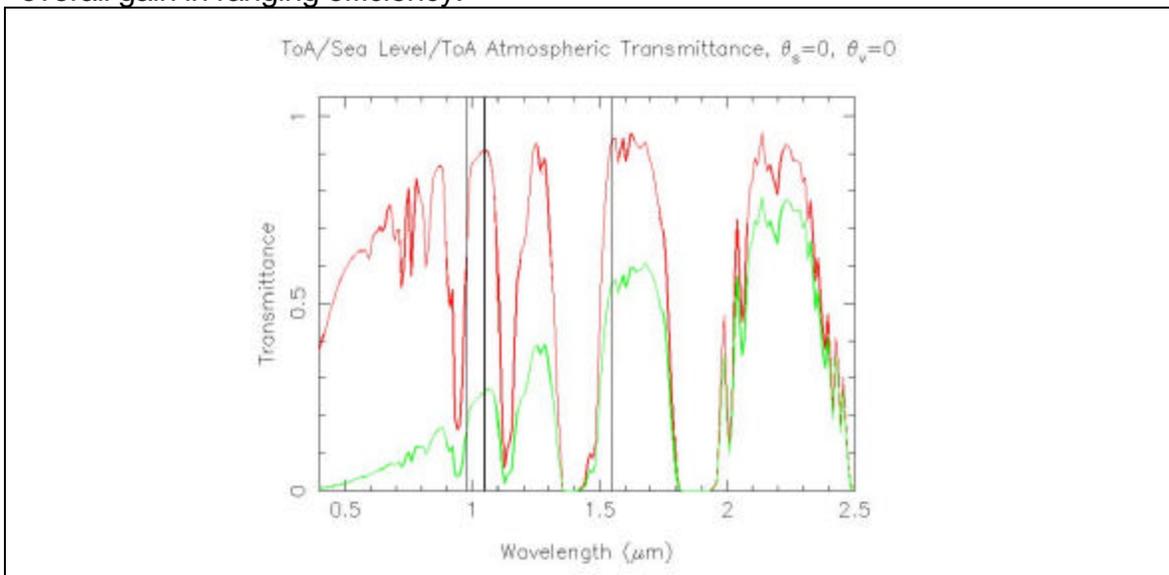


FIGURE 2: This graph shows transmittance through atmosphere for a clear day (red trace) and for a misty day (green trace). The transmittance is two-way, vertical, and includes absorption, Rayleigh scattering, & Mie scattering (aerosol).

Oscillator

The new oscillator is a CW, mode-locked, Nd:YVO4 laser from Time-Bandwidth Products. It is diode-pumped and passively mode-locked with a semiconductor saturable absorber mirror (SESAM). The output is a CW mode-locked pulse train at 1064nm with a pulse repetition frequency of 100MHz. The laser is air-cooled, requires only 150 watts of input power, and has a very small footprint (63cm by 31cm). The typical output pulse width of this laser (model GE-100) is 8 picoseconds. However, our typical requirements are for a much longer pulse width to prevent self-focusing damage in the rod amplifiers when operating at high pulse energies. Therefore, our oscillator has been modified from the standard model by the addition of two etalons in the oscillator cavity. This allows three possible output pulse widths: 8 psec (no etalon), 30 psec (1 etalon), 190 psec (2 etalons). The relevant specifications of the laser are listed in table 1 below. The general oscillator schematic is shown in figure 3 below.

Table 1:

Time-Bandwidth GE-100 Oscillator Specifications

Wavelength	1064nm
Pulse rep rate	100MHz
Pulse width	8, 30, or 190 psec
Average power	850mW (with etalons); 1100mW (no etalons)
Polarization	Linear, horizontal, 100:1
Spatial mode	TEM00 (Elliptical for this cavity)
Time-bandwidth product	< 0.6
Amplitude noise	< 1% rms

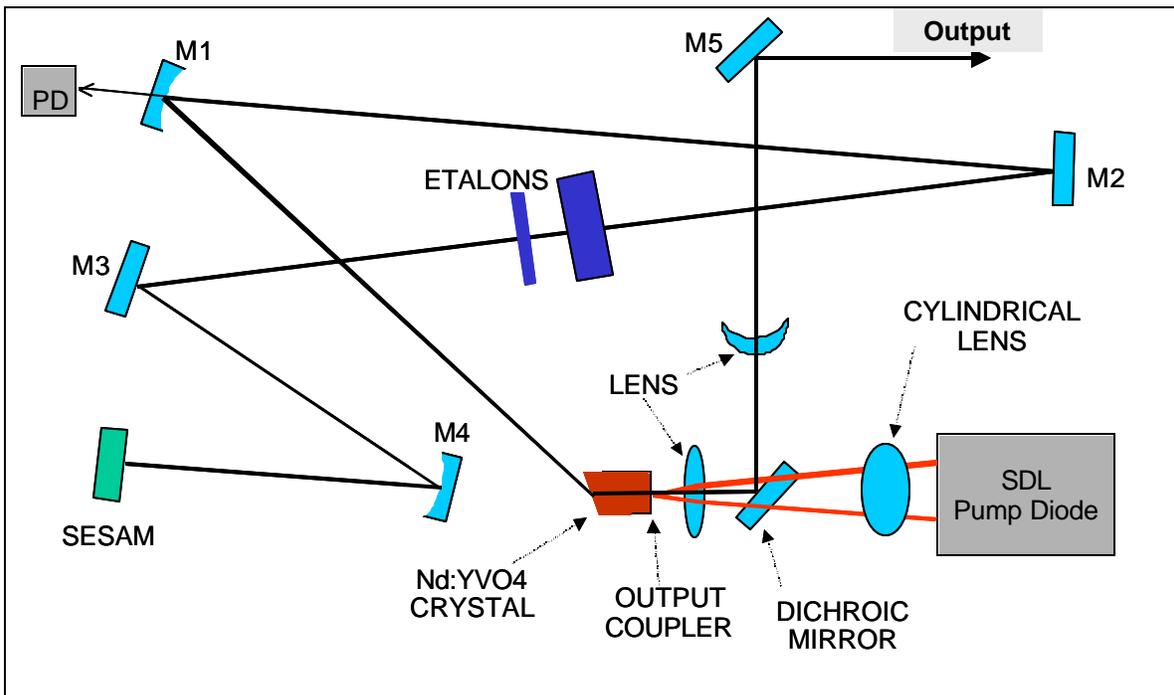


FIGURE 3: Oscillator Schematic

The oscillator output pulse characteristics were measured and characterized. Examples of the transverse profile measurement and the pulswidth measurement are shown below in figures 4 and 5. The fact that the oscillator transverse profile is elliptical is of no consequence since we are using a regenerative amplifier. The temporal and spectral properties of the seed pulse into the regenerative amplifier cavity are the important parameters. The transverse profile and quality of the laser beam will be determined by the regen.

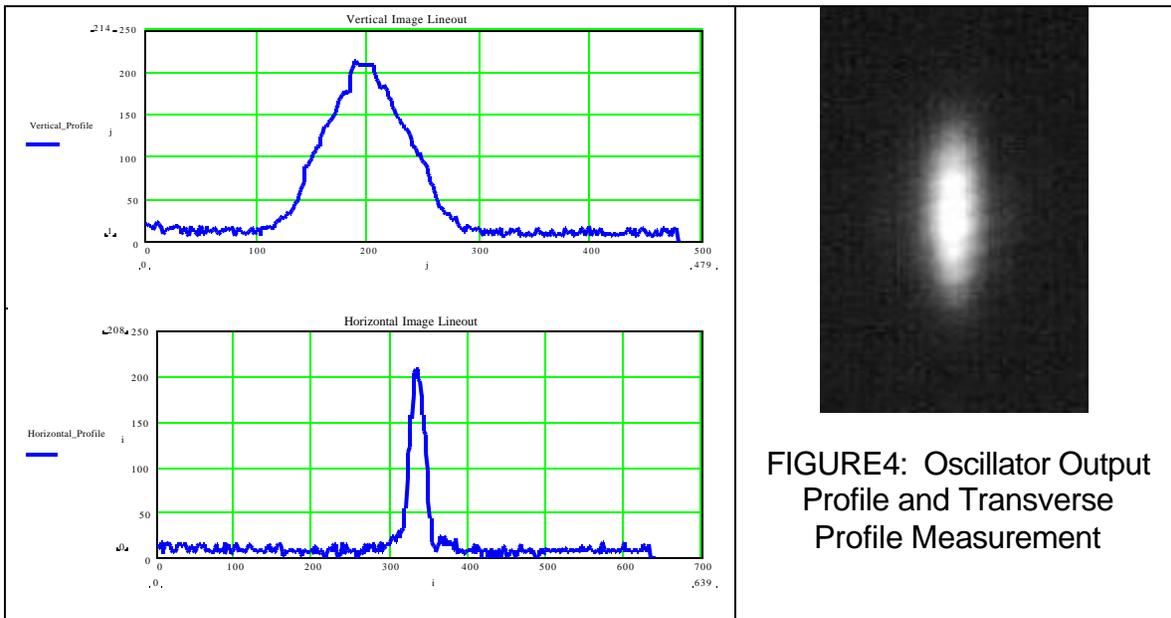


FIGURE4: Oscillator Output Profile and Transverse Profile Measurement

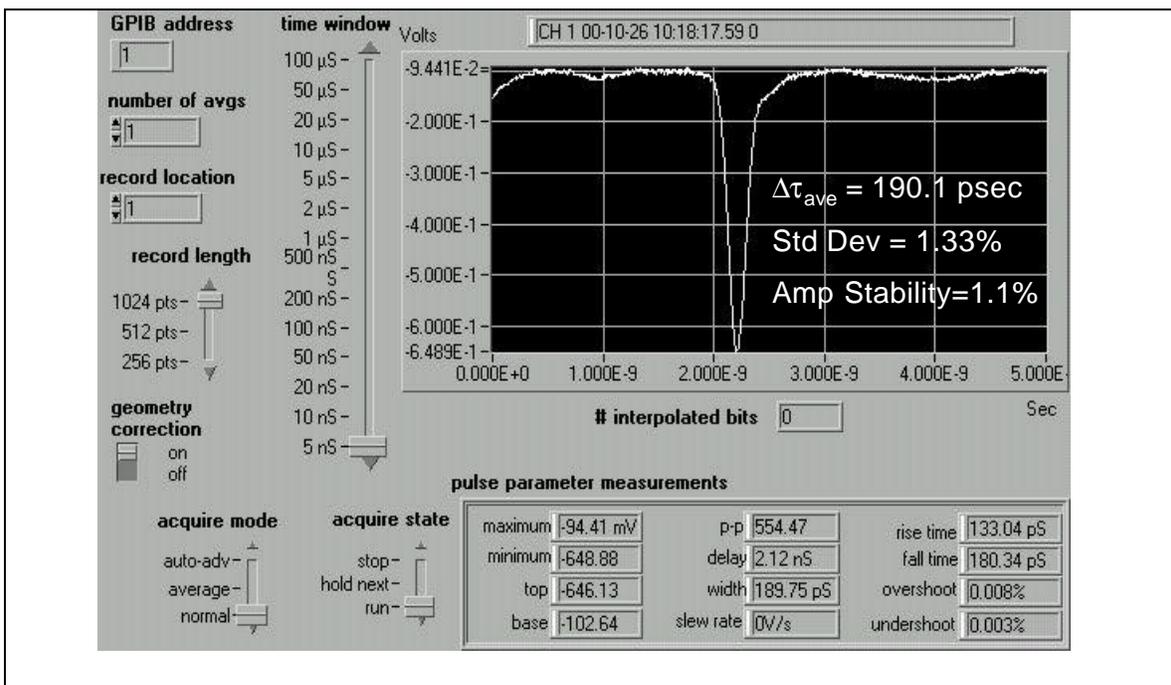
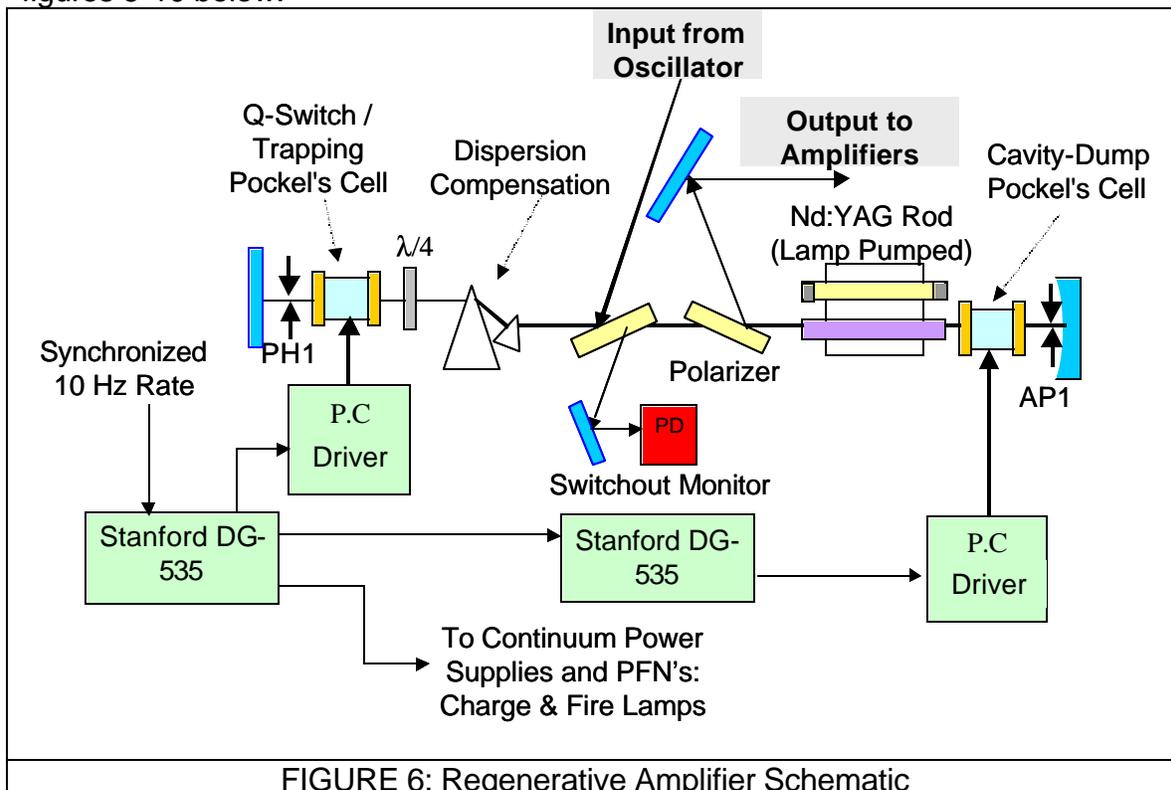


FIGURE 5: Pulsewidth measured with Opto-Electronics model PD-50, 8 GHz, InGaAs Photodiode and Tektronix SCD-5000, 4 GHz Transient Digitizer.

Regenerative Amplifier

Seed pulses from the oscillator are injected into the regenerative amplifier continuously. The majority of these pulses are rejected from the regen cavity after one round-trip and are removed from the optical train at the permanent magnet Faraday rotator isolator that provides isolation between the oscillator and regen. The Quantum Technology model DD1 divider and delay unit receives a 100MHz synch signal from the oscillator monitor photodiode. The DD1 can be operated as a stand-alone divider, or it can be windowed with an external 10Hz signal to provide a 10Hz rep rate that is synchronized to the oscillator pulse train. This synchronized 10Hz is used to trigger two Stanford DG-535 delay generators that provide the necessary delays for all of the regenerative amplifier timing and triggering requirements as well as the flashlamp triggering for the rod amplifiers. Seed pulses from the oscillator are trapped in the regen at a 10Hz rate by triggering the pulse trapping Pockel's cell at the appropriate time, and after several tens of round trips (and sufficient amplification) are removed by triggering the cavity-dump Pockel's cell. The regen can also be operated as a stand alone Q-switched, cavity-dumped oscillator by blocking the seed beam from the Time-Bandwidth oscillator and using the pulse-trapping Pockel's cell as the Q-switch. In this mode, the output pulse width is typically ~ 6.5nsec. A schematic of the regenerative amplifier and typical characterization measurements are shown in figures 6-10 below.



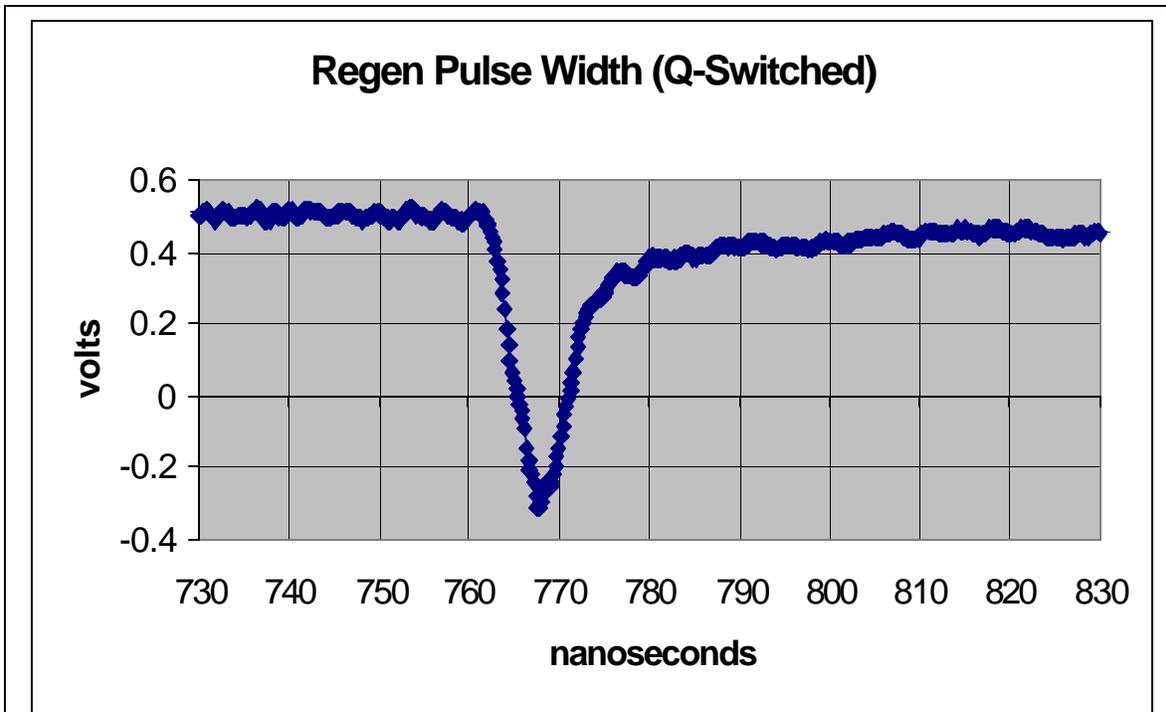


FIGURE 7: Q-Switched, Cavity-Dumped Pulse Measurement
 $\tau_{ave} = 6.5 \text{ nsec}$, 5mJ/pulse @ 10 Hz rep rate

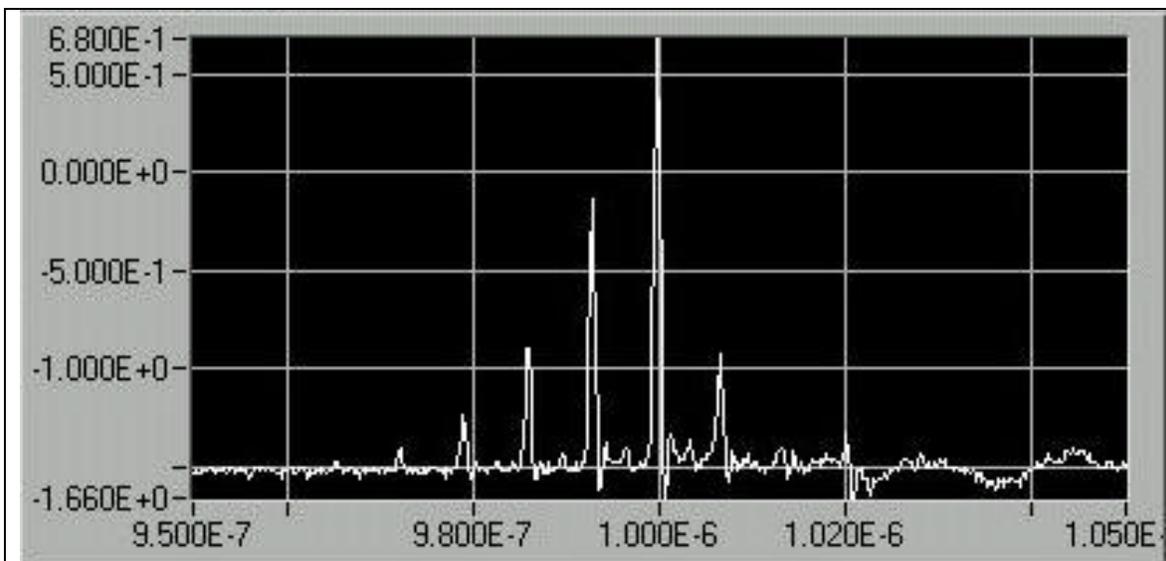


FIGURE 8: Regen monitor diode looks at leakage from cavity thin film polarizer. Last pulse is the remnant of the largest pulse, which has been switched out of the cavity. All pulse trapping and cavity dumping done by timing with Stanford DG-535's, triggered from a Quantum Technology DD1 divider and delay unit.

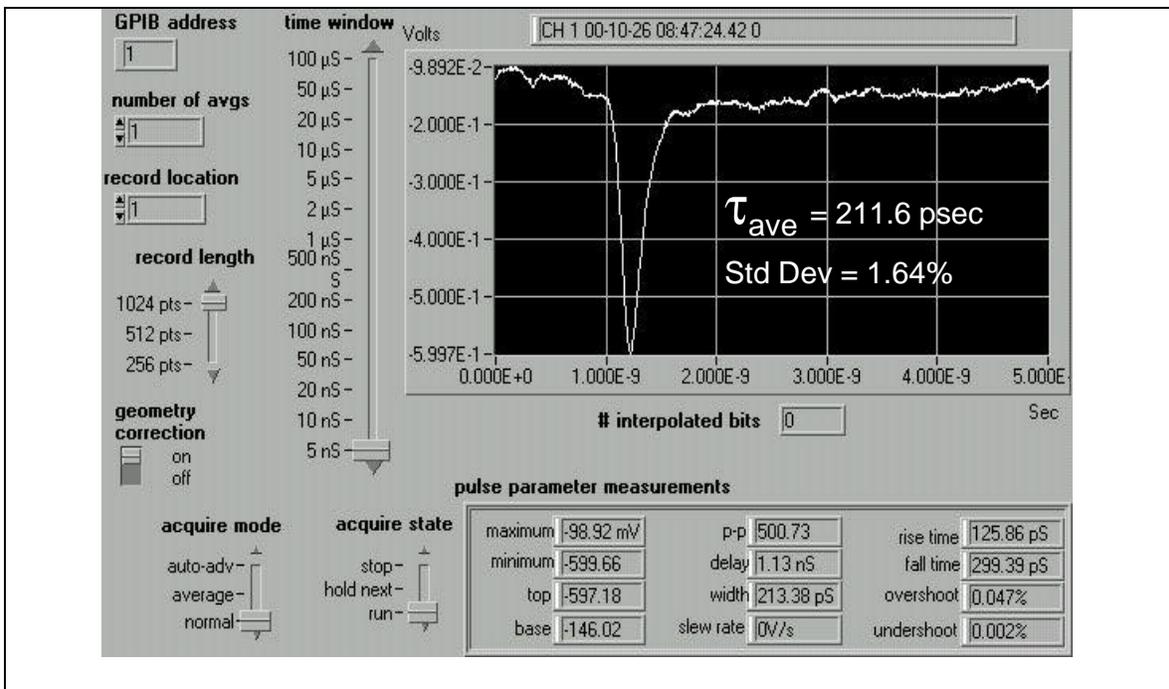
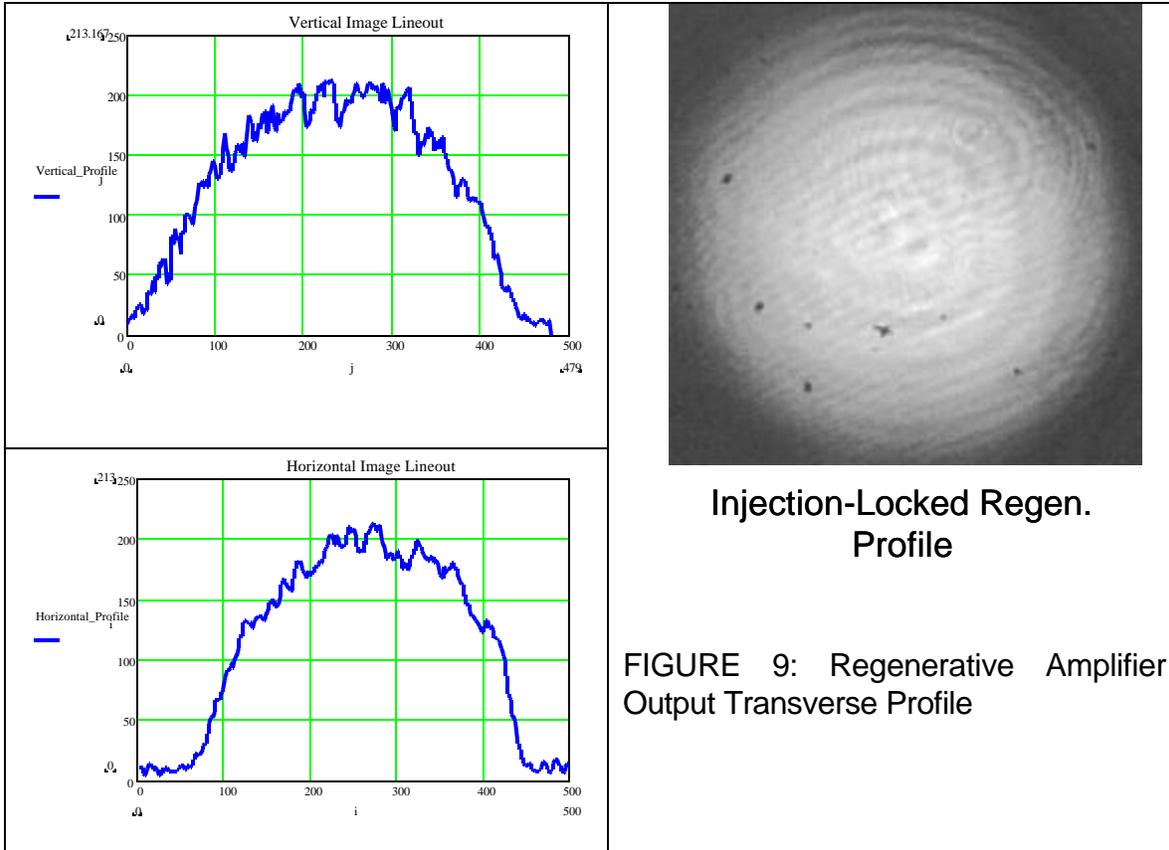
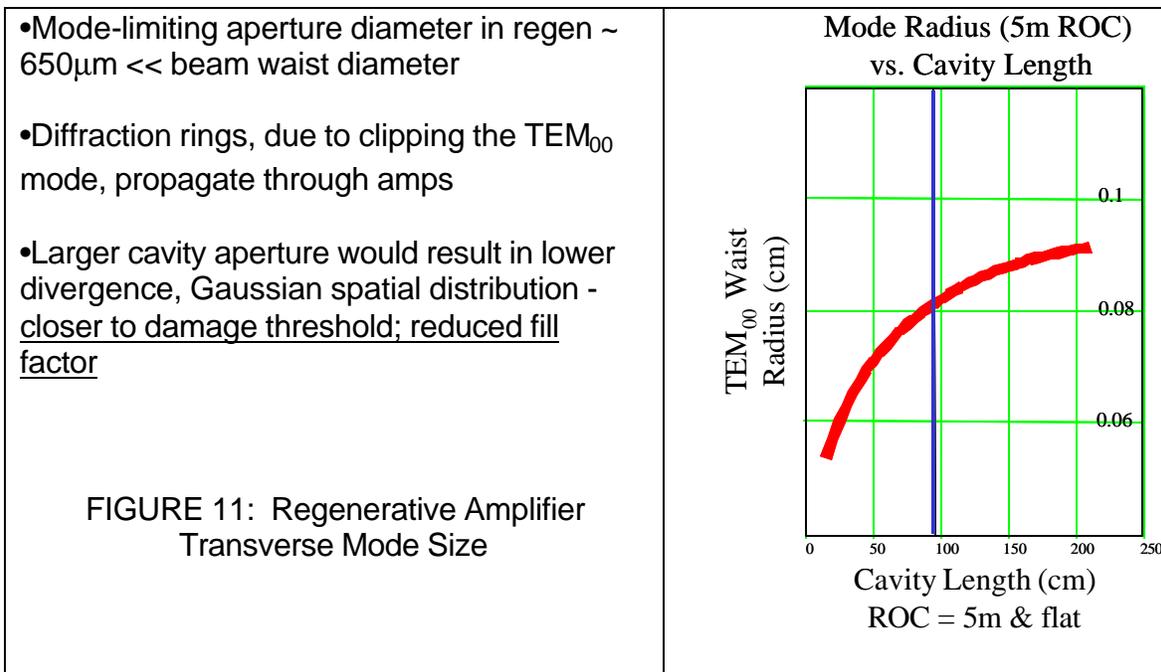


FIGURE 10: Pulsewidth of the injection-locked regenerative amplifier, measured with Opto-Electronics model PD-50, 8 GHz, InGaAs Photodiode and Tektronix SCD-5000 4 GHz Transient Digitizer.

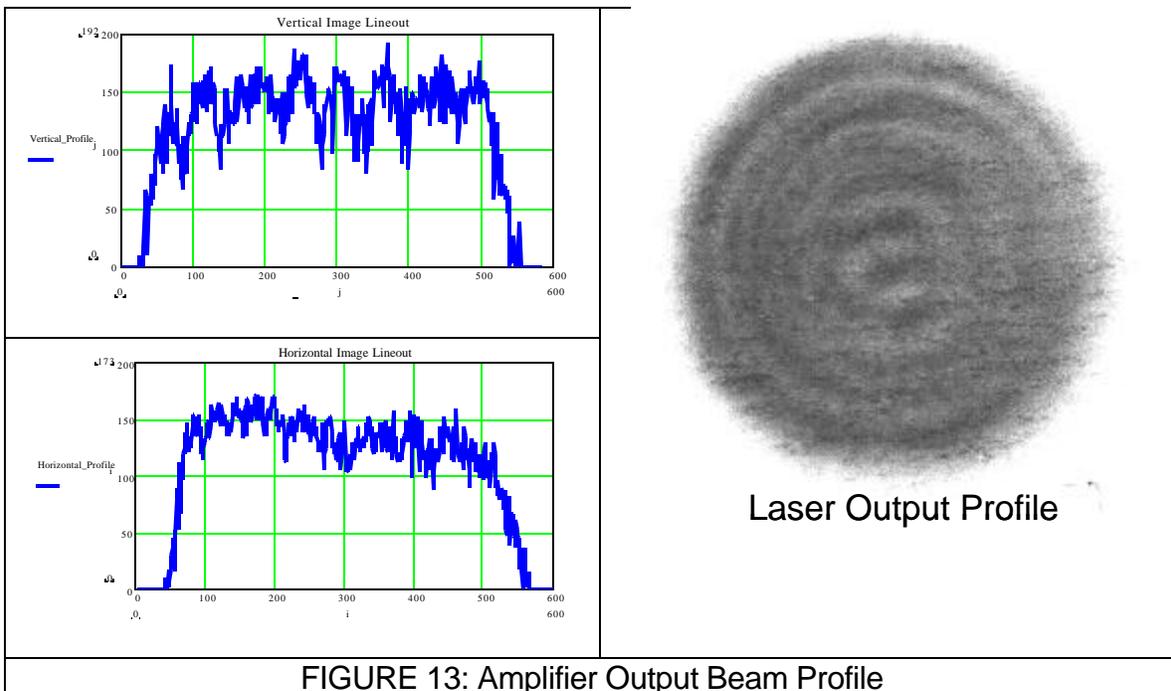
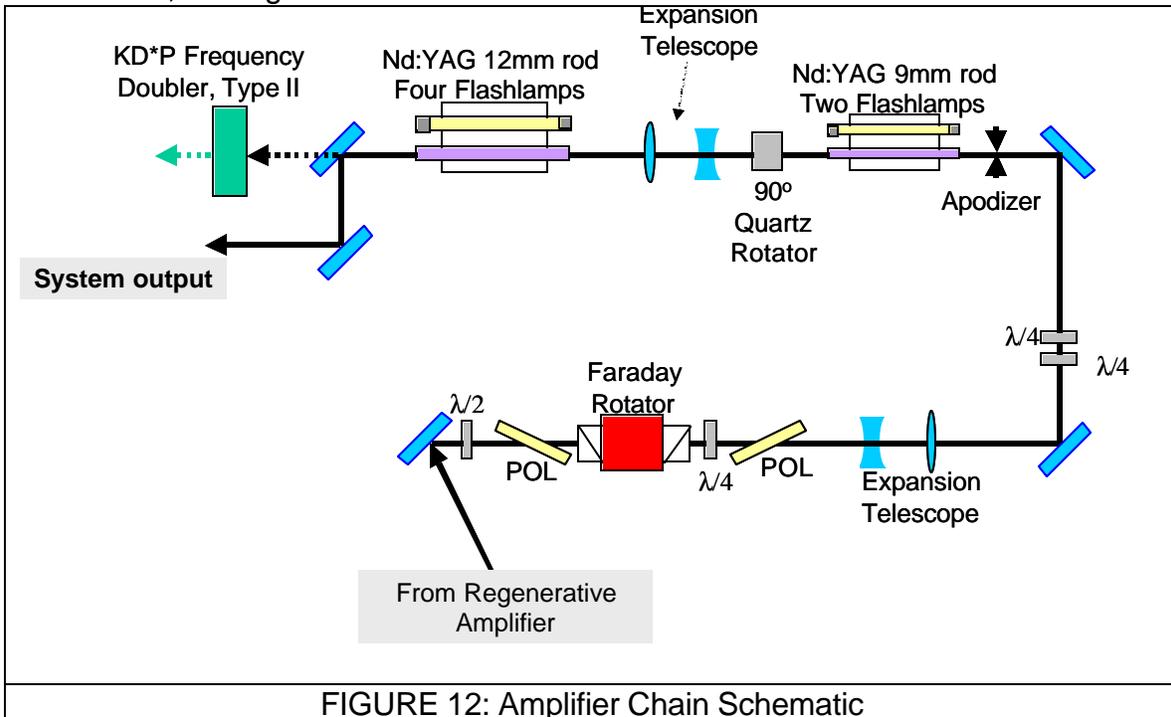
The regenerative amplifier cavity is configured as a diffraction-filtered unstable resonator (DFUR) [1]. The pinhole, PH1, shown above in figure 6 has a diameter of approximately 650 microns. This is smaller than the TEM₀₀ mode diameter for this cavity so that significant diffraction of the cavity mode occurs (see figure 11 below). The aperture, AP1, at the opposite end of the cavity, is an adjustable iris which is closed down to just clip the beam at the first dark ring in the Airy pattern caused by the diffraction from PH1. This results in a much larger transverse mode size ($\phi \sim 4.3\text{mm}$) and greater fill factor in the laser rod. The diffraction pattern clipped at the first dark ring approximates a Gaussian reasonably well, but some diffraction rings do propagate through the amplifiers and can be seen in the output profile from the amplifiers. One possible simple solution to the diffraction rings in the output is to replace the iris, AP1, with a soft aperture of the appropriate size [1]. A better but more expensive solution to the beam quality issue would be the design and installation of apodizers and spatial filters, starting with a serrated-aperture apodizer [2] and filter after the regenerative amplifier to both remove diffraction rings and shape the transverse profile to a “top-hat” to maximize fill-factor and energy extraction in the rod amplifiers.



Amplifier Chain

The amplifier chain following the regenerative amplifier consists of the two original flashlamp pumped, Nd:YAG rod amplifiers of the Continuum laser system. The amplifiers are single pass and have 9mm and 12mm diameter rods respectively. As can be seen below in figure 12, the frequency doubling capability has been retained; however, typically, the laser output will be directed to the SLR transmitter leg without doubling. Figure 13 below has details of the

final output pulse profile. The output beam was measured as $\sim 1.7\times$ diffraction limit (measured by the “energy in the bucket” method; i.e. focused through pinholes with known diameters). The output beam divergence was measured as ~ 3.9 mrad, full angle.



Conclusion

In conclusion, the Naval Research Laboratory's Nd:YAG laser system for Satellite Laser Ranging has been modified and upgraded to produce four possible output pulse widths (8psec, 30psec, 190psec, or 6.5nsec) at either 1064nm or 532nm with increased reliability and far less operator maintenance than the previous commercial system required. At the primary pulse width of 190psec and at the Nd:YAG fundamental wavelength, 1064nm, the laser system is capable of producing ~600mJ per pulse at a 10Hz repetition rate. However, the SLR facility will typically operate with a pulse energy of ~100mJ. As of this writing, the laser system has been installed at the new SLR facility and is in the final stages of characterization.

References

- [1] Paul Pax and Jeremy Weston, "Novel Large Mode Volume Resonator," *IEEE J. Quantum Electron*, Vol. 27, No. 5, pp. 1242-1246, 1991.
- [2] J. M. Auerbach and V. P. Karpenko, "Serrated-aperture apodizers for high-energy laser systems," *Applied Optics – LP*, Vol. 33, No. 15, p. 3179, 1994.