Development of an amplified variable shaped long pulse system for Vulcan

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Introduction

We have previously reported [1] on the development of fiber based modulator systems for the generation of temporally shaped pulses with variable widths for Vulcan. This report details the improvement on this project – the development of software to control the pulse shape and most importantly the building and testing of a diode pumped regenerative amplifier to boost the energy up to the millijoule level. Finally, the construction of a triggering scheme to enable the synchronization and amplification of the regenerative amplifier output of the shaped pulses by Vulcan with initial tests suggesting amplification up to the 50mJ level.

Fiber based modulator control

The prototype Arbitrary Waveform Generator, AWG, has now been replaced with one that has greater software control. The original AWG generated 300 pulses that have 200ps widths and are separated by 100ps with separate control of the amplitudes of the different pulses. However the gains of the electronic amplifiers within the AWG were not equal and this resulted in pulse shapes that were difficult to control. The software function of the updated AWG takes into account the overlap as well as the variable gain of the samples to calculate a set of waveform data to produce the desired output. To improve the user interface, a Visual Basic 6 programme has been develop to generate a text file which can then be edited if required before being downloaded into the AWG. The specified halfwave voltage of the fiber modulator determines the maximum required voltage. Figure 1 shows the interface that gives the option of generating a range of pulses of various lengths and shapes. For the tests on the regenerative amplifier, a 2 ns pulse generated from this software, consisting of 20 points was edited to produce the 'M' shaped optical output on the oscilloscope shown in figure 2 – monitoring of the pulse used a 5% fiber tap [1] before being re-collimated using a lens based fiber collimator for free space injection into the regenerative amplifier.

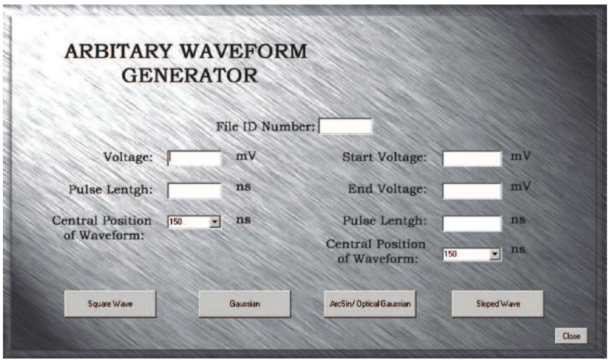
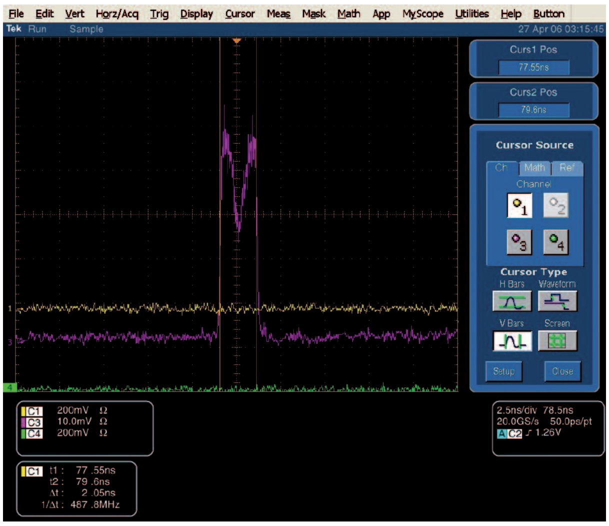


Figure 1. User interface for the control of the AWG and fiber modulator.



Curs1 Pos 77.55ns
Curs2 Pos 79.6ns

C1 200mV Ω
C3 10.0mV Ω
C4 200mV Ω

2.5ns/div 78.5ns
20.0GS/s 50.0ps/pt
A C2 ⨍ 1.26V

C1 t1 : 77 .55ns
t2 : 79 .6ns
Δt : 2 .05ns
1/Δt : 487 .8MHz

Figure 2. Shaped pulse from modulator – the data file has been modified to produce the 'M'.

Regenerative amplifier design and construction

The shaped output fiber modulator systems are energy limited to ~nJ because of their limited power handling capabilities. As is common on other such long pulse systems [2,3], a key aspect of this project required the design and construction of a diode pumped regenerative amplifier (Figure 3) to amplify the mJ level.

A telescope was used to match the beam radius of the shaped input pulses to that of the cavity of the amplifier. They pass through a faraday isolator that is used to generate the output of the amplifier by rejecting the returning pulses. The cavity is formed by two concave mirrors separated by 1.5m enabling amplification of pulses up to 10ns in duration. This type of cavity has large beam radii at either end of the cavity. Consequently, the active components are placed at either end simplifying the alignment. To reduce the footprint of the cavity and enable easy pumping, the cavity has been folded, some of the mirrors being highly reflecting at 1053nm and anti-reflecting at 805nm, the pump wavelength. This enables us to use an end-pumped geometry for the amplifier, resulting in high small signal gains and a good spatial overlap between the pump and cavity modes within the gain crystal aiding energy extraction. The pump power is provided by 2 fiber coupled 25W CW diodes operating at 805nm. This wavelength has been chosen to minimize the difference between the absorption coefficients for the two polarizations because the pump light from the delivery fiber will be essentially unpolarised. We have found that the average absorption coefficient for the two polarisations at 805nm in 1% doped Nd:YLF is 1.5cm^{-1} so in a 1.5cm long crystal we absorb approximately 85% of the pump light. We now have 2cm long crystals and expect to absorb 95% of the pump light using them. The delivery

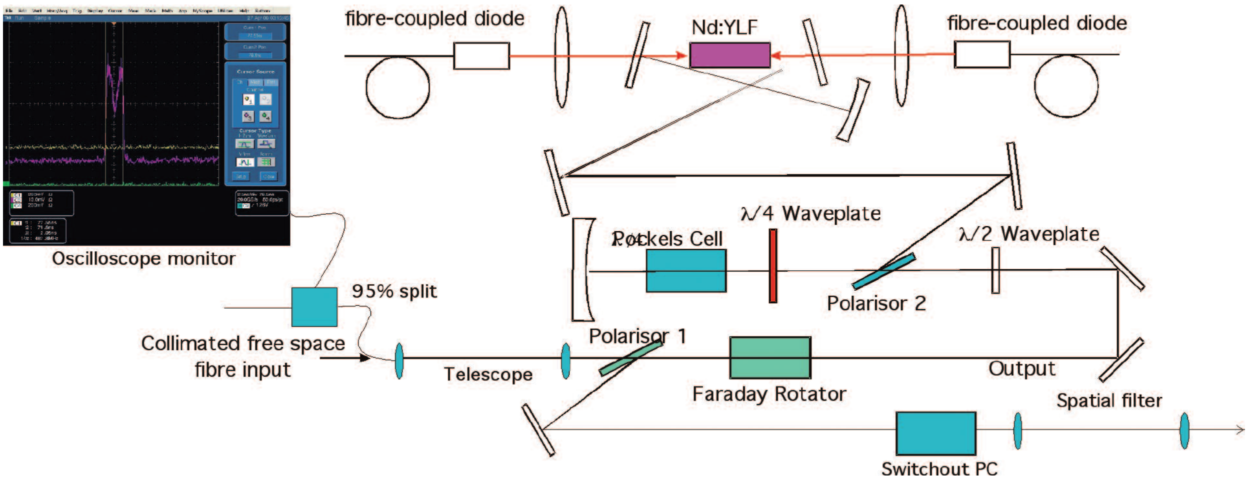


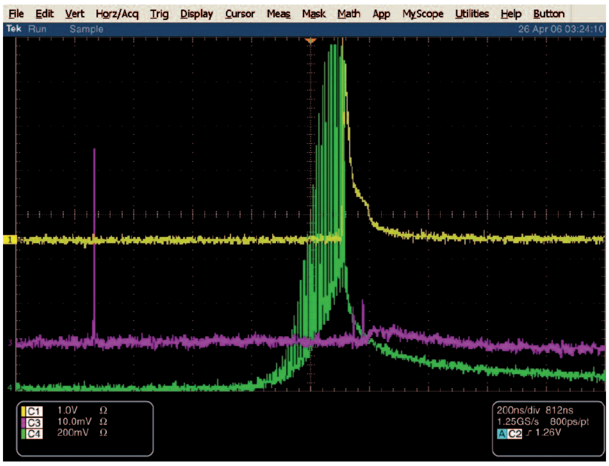
Figure 3. Schematic of the regenerative amplifier.

fiber for the Limo diodes has a core radius of 200µm with a NA of 0.22 so that the M^2 at 805nm will be ~170. This ensured that the pump beam radius did not vary significantly within the crystal. The pumping is achieved by imaging the output of the fibers to the centre of the crystal using a telescope comprising 35 and 100mm and 200mm lenses. This combination of focusing lenses has prevented the occurrence of thermal fracture of the Nd:YLF crystal. The Nd:YLF crystal is mounted in a copper heatsink which has been designed to optimize thermal contact along the whole crystal length. This is aided by using a layer of indium foil between the crystal and the copper. Overlap of the pump beams and oscillator input is ensured by imaging the fluorescence from the surface of the crystal using a ×4 magnification zoom Macro leans with a working distance of 10cm onto a standard CCD chip.

Regenerative amplifier tests and results

A mini-cavity formed by one curved mirror and a 60% transmitter enabled checking of correct YLF crystal orientation/wavelength – this was then used to align the regenerative cavity using apertures to define the optical path either side of the intracavity pockel cell with the polarizer 2 set at the appropriate angle. The regenerative amplifier was run at 10Hz using an appropriate Vulcan trigger source. After appropriate timing of the intracavity pockel cell enabling trapping of the seed pulse after one round trip, the intracavity energy was monitored on diodes aligned to look at ‘leakage’ from the regenerative amplifier cavity. Figure 4 and 5 shows both the input pulse as well as the buildup of the intracavity pulse – the output pulse being amplified to the ~0.5mJ level. The saturated trace of Figure 5 (yellow trace) also shows that the output pulse has some substructure – this was ‘cleaned’ up as shown in the pink trace of Figure 6 using the switchout PC shown in Figure 3.

Both temporal stability and beam quality of any seed source are important issues for injection into a low repetition rate large glass laser like Vulcan. The shot to shot stability of the regenerative amplifier was observed to be better than 5% over long periods of time – a key benefit of diode pumping. The output beam quality and divergence control needed to be improved to enable injection onto the outer track of Vulcan – this was accomplished using the spatial filter shown in figure 3. The result was an exceptionally stable good quality beam suitable for injection into Vulcan.

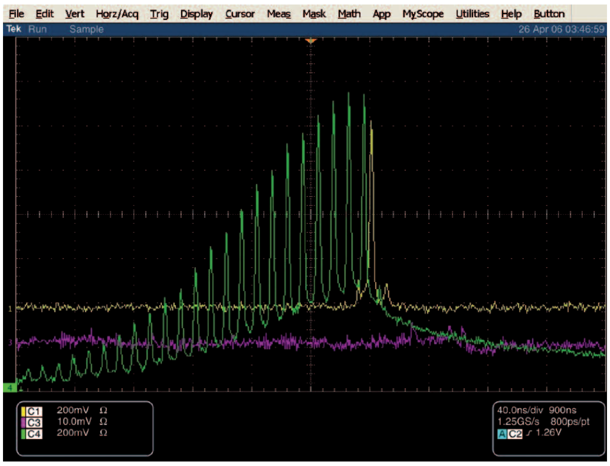


Tek Run Sample 26 Apr 06 03:24:10

C1 1.0V Ω
C3 10.0mV Ω
C4 200mV Ω

200ns/div 812ns
1.25GS/s 800ps/pt
A C2 ƒ 1.26V

Figure 4. The injected pulse from the modulator (pink) as well as the intracavity pulse (green) and output pulse (yellow saturated signal).



Tek Run Sample 26 Apr 06 03:46:59

C1 200mV Ω
C3 10.0mV Ω
C4 200mV Ω

40.0ns/div 900ns
1.25GS/s 800ps/pt
A C2 ƒ 1.26V

Figure 5. Expanded view of figure 4 showing the regenerative output pulse (yellow).

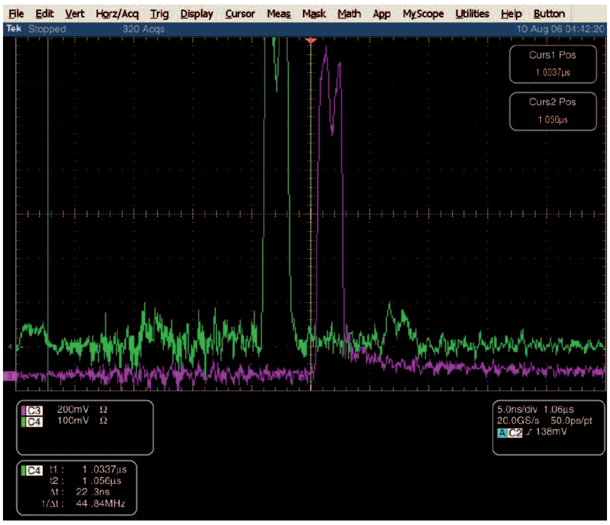


Figure 6. Regenerative amplifier output before and after the switchout PC showing the improvement in contrast.

Synchronisation and timing on Vulcan

Having established a suitable optical beam path injection into Vulcan, appropriate synchronization was required. As is common on Vulcan, this was accomplished using an RF source as an appropriate "clock" as well as a "master" 10Hz source – for convenience, the RF source selected was the Ti-sapphire output thereby synchronising the regenerative amplifier output with TAP.

Timing was obtained using a combination of Stanford Delay generators and trigger re-synchronisers as shown in Figure 7. This would have resulted in minimum jitter of ~50ps of the regenerative amplifier output – determined by the AWG and trigger-resynchroniser and the quality of the RF source. Timing to within the RF cycle of 12ns was obtained using the Delay/Timing Stanford. The AWG/regenerative Stanford was used for fine timing control for the AWG and regenerative amplifier, its fourth output being used to time up the switchout PC.

Alignment on the outer track of Vulcan was obtained – initial tests appeared to be limited by the energy output of the regenerative amplifier – however, Vulcan was successfully fired in this configuration resulting in ~50mJ at the 'corner'.

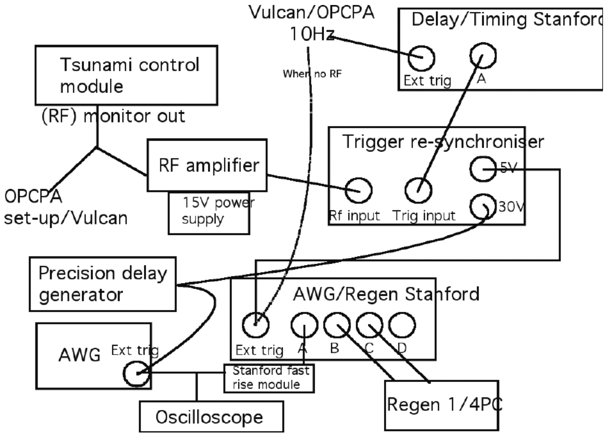


Figure 7. Timing scheme for the AWG and regenerative amplifier for Vulcan synchronization.

Further work

There is clearly a need to increase the energy output before operational delivery to user experiments. Moderate increases of energy to the mJ level should not be difficult – we are in the process of constructing YLF which would be able to generate joule level to function as stand alone OPCPA pumps 3).

References

1. W. Shaikh, *Testing of a fibre based nmodulator system for shaped long pulses on Vulcan* CLF Annual report 2004-2005, RAL TR-2005-025
2. Regenerative Amplifier for the OMEGA Laser System, *LLE Review,* Vol 76
3. L. J. Waxer *et al., High conversion-efficiency optical parametric chirped-pulse amplification system using spatiotemporally shaped pump pulses. Optics letters,* Vol **28**, No.14