Vulcan Laser Timing System Upgrade

Contact *dave.pepler@stfc.ac.uk*

D.A. Pepler, P.B.M. Oliveira and I.O. Musgrave
Central Laser Facility
STFC Rutherford Appleton Laboratory
Harwell Campus
OXON. OX11 0QX

Introduction

The Vulcan Laser Timing & Synchronization System is a large conglomerate of analogue and digital electronics that all together has provided a range of repetitive (1Hz, 2Hz and 10Hz) signals and single-shot triggers. Above the needs of supplying the fundamental repetitive signals to the Front-End Oscillator Controls, switching and synchronizing the main laser electronics and amplifiers to one of several different oscillator frequencies (~80MHz), these signals are then widely distributed and repeated throughout the Facility (including the Capacitor Bank, Laser Bays 1 – 4, Operational and User Control Rooms and multiple Target Areas) to trigger digital delay generators, high-speed pulsed fan-out units, high-voltage pulsed Pockels Cell drivers, electro-optic devices as well as a suite of imaging, spectral and temporal diagnostics.

As the Laser System itself has expanded and been enhanced in various ways the timing system has had to be modified to manage the growing complexity of requirements. The result of having a cascade of varied time delay generators, electronic gating devices, fan-out units and long electrical cable runs is that +/- 250ps optical jitter can be observed between short-pulse (ps) and the electrically driven long-pulse (ns) oscillators and this has become a limiting factor for running certain user experiments or high-speed diagnostics such as streak cameras.

Upgrade Requirement

In order to both simplify and increase the performance of the trigger system some key changes have had to be applied to the way that the Front-End operates. Previously, the Laser Facility was served by up to 4 different laser oscillators each of which operated at distinctly different frequencies around 80MHz. This necessitated having programmatically controlled Radio Frequency (RF) multiplexed switches and resynchronization electronics which even at the very start of the trigger system introduced some +/- 100ps of timing jitter between the electrical and optical pulses.

Reducing to a single RF was a key constituent for the specification and purchasing of a commercial laser trigger system and following a competitive tender exercise a trigger system was purchased from Greenfield Technology (France) [1]. In parallel with this purchase, developments in the Vulcan Front-End allowed the number of short-pulse oscillator dependencies to be reduced to two and with the application of a commercial 'Lok-to-Clock®' option installed on a Spectra-Physics Tsunami Titanium Sapphire oscillator [2] and optically phase-locking this to a Spectra-Physics InSight DS+ [3] oscillator, a single operational RF was able to be achieved - thus avoiding the need for the RF multiplexing electronics and the jittery RF resynchronization units.

Figure 1 Installation of the Greenfield Master Oscillator and Slave Unit in the Front-End Oscillator Room.

The Greenfield system is based around the concept of a single Master Oscillator and multiple Slave units each individually fiber-optically coupled to the Master (see Figure 1). The Master operates from either an internal or external RF clock and subsequently provides the initial source of all the repetitive signals (1Hz, 2Hz and 10Hz and with options up to 1kHz) distributing these and other timing markers to the Slaves each of which have an early T0 trigger output plus ten other programmable delay electrical pulse outputs.

Initial Installation and Testing

Because of the differences between the old and new system an extensive period of testing was conducted offline and then a staged implementation was planned. There however was some delay in this as the initial testing and control developments showed that following the servicing of the InSight DS and the implementation of the Lok-to-Clock® a change of oscillator frequency had occurred which took the fundamental frequency out of the 80MHz +/- 10kHz acceptance range of the Greenfield Master's external RF input. This unfortunately required all units to be sent back to the factory for a modification of internal settings and re-calibrations to 79.926MHz.

Once the updated units were received, the Master and one Slave were installed alongside the existing timing system so as to allow further testing in the more exacting operational environment of the Vulcan laser system. The parallel operation was relatively easy to implement as the old timing system was initiated by an external electronic 10Hz and 1Hz module in the Vulcan Main Control Room (MCR) and the Greenfield system was configured to simply mimic these fundamental signals using 2 of the 11 outputs of the Slave.

The initial installation was able to be conducted during a scheduled maintenance period and the only complication in this was that, rather than being located in the MCR, the Greenfield Master and Slave were chosen to be located in the Front-End Oscillator Room adjacent to the Tsunami and InSight oscillators - so as to minimize the electrical cable lengths from the optical to electrical converter and the RF input of the Master. This meant that the 10Hz distribution was effectively reversed, though now more logically placed, with timing signals emanating from the Oscillator Room out to the MCR for the ongoing distribution to the Target Areas.

Commissioning (Phase 1)

The parallel operation of the two timing systems freely allowed direct comparisons between them to be made with minimal disruption of normal Facility Operations.

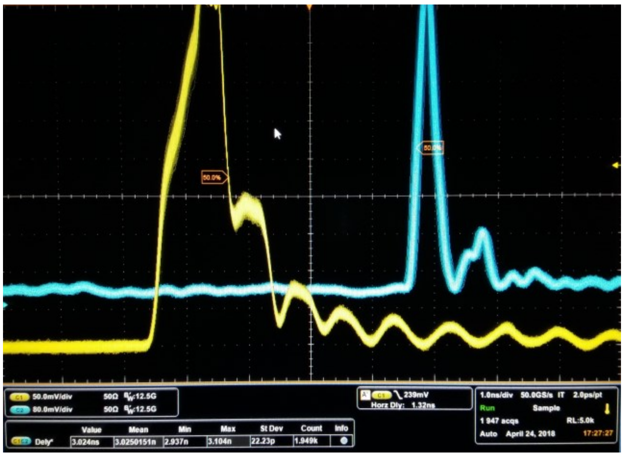

Figure 2 Image of oscilloscope measurements made between the optical outputs of the Shaped Long Pulse and Insight DS+ oscillators showing a relative timing jitter of ~25ps RMS.

One of the common pairing of oscillators for operations into TAW is to have a long-pulse (1ns) oscillator synchronized to a short-pulse (ps) oscillator and Figure 2 shows the result of a recent test with the new Greenfield system of the relative timing jitter between the optical pulse trains of the InSight DS+ and Shaped Long Pulse (SLP) oscillators. This jitter was measured on a Tektronix 71254C digital oscilloscope at about 25ps RMS which is a substantial and significant improvement over the original timing system performance.

Other comparisons of the existing timing system trigger signals gave a good degree of confidence to switch key timing components from the existing system to the Greenfield. Initially, this implementation phase is just in the Vulcan Front-End and replaces input triggers to other digital delay generators - Stanford Research Systems (SRS) DG535s & DG645s.

This Front-End only implementation is partly because the control programming of the Greenfield is also progressing in parallel and is not immediately ready to replace all settings of the SRS delay generators that are required to change to different stored settings according to the laser system configuration selections and more

Firstly then, the two SLP 10Hz triggers to ‘slow’ (ms regime) and ‘fast’ (ns regime) SRS boxes were replaced followed by the 10Hz and 2Hz triggers to another suite of SRS’s that trigger the 10Hz and 2Hz regenerative amplifiers and Optical Parametric Chirped Pulse Amplification (OPCPA) stages. With both the 10Hz and 1Hz signals also going to the MCR for computer control system synchronization and onward transmission to the Target Area Control Rooms.

Single-Shot Testing

As the main laser is a single-shot device with repetition rates for pre-amplifiers and low, medium and high energy shots potentially being once every 10 seconds, 2 minutes, 5 minutes and 20 minutes respectively; the next stage of the system deployment will be to implement Slave units inside the Main Laser Area and both Target Areas that are configured for single-shot operation and to eliminate all the existing on-shot gating electronics and fan-out electronics that are currently required and which inevitably add a degree of jitter at each and every stage.

Four bundles of armored fiber-optic cables with lengths of up to 125 meters have already been installed in readiness for locating two Slave units inside the Laser Area and one in each of Target Area West (TAW) and Target Area Petawatt (TAP).

However, further testing within the Laser Area of the single-shot triggers demonstrated that the sequencing and some of the timings of delayed triggers were not always consistent and following discussion with Greenfield and replication of the Slaves configuration in France, further firmware updates were seen to be required.

Two additional Slave units with the most up-to-date firmware have recently been obtained and tested. One has subsequently been installed in the Front-End (replacing the original Slave) and the other has been located in Laser Area One (LA1) for further comparisons with existing shot triggers. When fully configured they will provide ready access to any of the Master’s repetitive or single-shot triggers with accurately timed pre-triggers of up 2 seconds.

Additional Developments (Phase 2)

It is expected that the firmware in all the other Slave units will soon be updated to bring them all into line and this will then allow deployment into both TAW and TAP. To start off with it is expected to run these Slaves alongside the existing triggers for comparative tests as the on-shot Electro-Magnetic Pulse (EMP) production from targets is often disruptive to electronics. It is expected that these two devices will be located so as to be readily configurable by TA Staff.

The Vulcan Control System software also requires further coding to allow the Greenfield system to provide a full functional and operational replacement of the existing SRS boxes within the Front-End and Laser Areas. These enhancements are ongoing and planned to be completed and tested over the summer of 2018.

Final Commissioning (Phase 3)

In due course it is expected that an additional fiber-optic bundle will be installed into Target Area East (TAE) and several more Slave units will be commissioned (in particular within the Front-End) so as to provide replacements of all the triggers generated by the current use of SRS boxes.

Conclusions

The timing system has had a fundamental overhaul and even in its first phase of change - with the temporal jitter down to ~25ps RMS - is now far superior in terms of jitter performance and electrical noise immunity. It is better configured, simpler, more readily understandable and allows for further expansion. Phase 2 will see an implementation of single-shot operation and deployments into TAW, TAP and the Laser Areas. Phase 3 will complete the replacement of the old trigger system components and in eliminating cascades of delay generators and fan-out modules is expected to provide an additional reduction of the residual jitter.

Acknowledgements

We wish in particular to thank Dominique Monnier Bourdin of Greenfield Technology for all the time and ready support that he has given to solving the firmware issues found during this project.

References

1. Greenfield Technology https://greenfieldtechnology.com
2. Spectra-Physics Tsunami http://www.spectra-physics.com/products/ultrafast-lasers/tsunami
3. Spectra-Physics InSight DeepSee http://www.spectra-physics.com