LASER MEGAJOULE TIMING SYSTEM

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Abstract

This paper describes the Timing System under development on the Laser Mégajoule (LMJ) which purpose is to synchronize the laser beams on the target to better than 40ps rms and to trigger laser and plasma diagnostics. Our architecture is based on a Standard and High Precision Timing System which delivers trigger signals with jitter down to 15 ps rms coupled with an Ultra Precision Timing System and a Fiducial System with 5 ps rms jitter.

INTRODUCTION

The Laser MégaJoule (or LMJ), is a high power laser facility dedicated to study high energy density physics and more particularly inertial confinement fusion [1]. It is currently under construction at the CEA Cesta site near Bordeaux (France). Synchronization of LMJ's 176 laser beams is crucial to compress symmetrically the millimeter-size target in order to ignite the deuterium and tritium filled capsule. The most demanding experiences need to synchronize the quadruplets (4 beams group) to better than 40 ps rms despite the fact that the quadruplet laser sources are separated within the building by several hundred of meters. This kind of performance is also required for fiducial pulses used to temporally mark laser and plasma diagnostics. Laser operation requires furthermore real-time triggering of front end devices, Pockels cells, flash lamps, laser diagnostics and alignment sensors. However these devices require larger trigger accuracies ranging from 1 □s to 1 ns.

The Timing System developed for the Ligne d'Intégration Laser (LIL), the four beams LMJ prototype, is very similar to the NIF one [2,3,4]. Their designs are both based on very accurate electrical delay generators connected to a master clock through a fiber-optic time distribution network. These systems have demonstrated their capability to fulfil their original specifications in term of jitter and wander over 7 days. This performance is however not totally sufficient in order to reach the LMJ 40 ps rms specification. An Ultra Precision Timing System (UPTS) and a Fiducial System have therefore been designed to improve jitter and long-term drift performance [6,7]. They will be used to trigger each quadruplet laser pulse and to generate fiducials for diagnostics.

LASER BEAM COMPONENTS

LMJ building consists of 4 laser bays distributed from either side of the experience bay. As shown in Figure 1, each laser bay includes:

- A 1053nm (1ω) nanojoule laser that constitutes the unique Master OScillator (MOS) for all the beams of a laser bay.
- An Arbitrary Waveform Generator (AWG) for each quadruplet that generates the desired temporal pulse shape.
- Two preamplifier modules (PAM) per quadruplet raising the energy from 1 nJ to 1 J and including an Optical Delay Line (ODL) to synchronize the two PAM of a same quadruplet.
- A main amplifier injection system which splits the PAM beam in two and injects each beam in a main amplifier. One of two lanes of the injection system is equipped with an ODL used to compensate the propagation time difference between the two beams of the same quadruplet.
- A four pass main amplifier which increases beam energy up to 20 kJ at 1ω.
- An amplifying sensor (AS) able to measure for each beam: energy, power, near field, spectrum and wavefront.

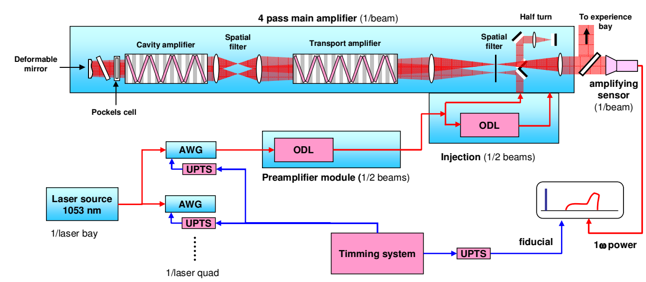

Figure 1: Laser bay main components.

Once the beams have reached the experience bay they are reflected by a series of 6 mirrors to reach the right position around the experience chamber. The Final Optic Assembly (FOA) converts the laser pulse to its third harmonic (3ω) and focuses the beams on the target (cf. Figure 2). A 3□ sensor called Conversion Sensor (CS) measures the beam energy and power after 3□ conversion, and a specific sensor (NAT) consisting of two PIN fast Photodiodes placed on the target positioner allows to measure precisely beams synchronization using 1 J shots delivered by PAMs.

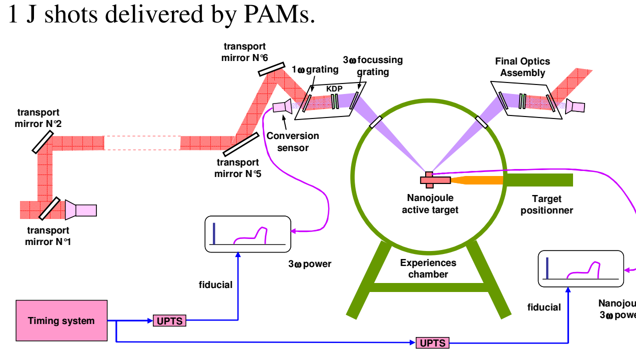

Figure 2: Experience bay main components.

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SYNCHRONIZATION NEEDS

Synchronization needs on the LMJ facility include:

- Beams synchronization using quadruplets ODL and AWG,
- Triggering of power conditioning capacitor banks that feed the flash lamps of the laser amplifiers,
- Triggering of Pockels Cells that protect the amplifiers from spontaneous emission,
- Triggering of laser and target diagnostics and alignment sensors,
- Generation of fiducials used to temporally mark laser and plasma diagnostics.

As shown in Figure 3, three levels of timing performance are required for triggers:

- Standard Precision Timing (SPT) for triggers having 150 ps rms jitter and ranging from -1s to +1s from the shot (i.e. “Target T0”),
- High Precision Timing (HPT) for triggers having 15 ps rms jitter and ranging from -50µs to +50µs from the shot (i.e. “Target T0”),
- Ultra-high Precision Timing (UPT) for triggers having 5 ps rms jitter and ranging from -50ns to +50ns from “MOS T0”.

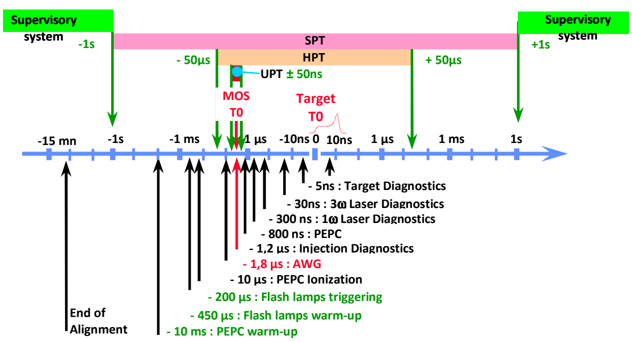

Figure 3: Synchronization timings needed during a shot.

Table 1 below summarizes performance and quantities needed for the LMJ Timing System.

Table 1: Performance and Quantities Needed

	Range	**Jitter** (rms)	**Wander** (peak-to-peak, over 1 week)	**Quantity**
SPT triggers	±1s	150ps	<2ns	~2000
HPT triggers	±50µs	15ps	<20ps	~80
UPT triggers	±50ns	5ps	<10ps	~100
Fiducials	±50ns	5ps	<10ps	~200

STANDARD AND HIGH PRECISION TIMING SYSTEM

The Standard and High Precision Timing System (SHPTS) is responsible for the SPT and HPT triggers, as defined above. It is based on very accurate slave delay generators connected to a master clock through an optical distribution network (see Figure 4). Time is distributed to remote areas within the facility by sending an optical bit sequence through single mode fibers. The master clock is the unique time reference for the facility. It runs a very stable quartz oscillator which can be permanently locked to the GPS to avoid long term drift. It generates an optical digital message whose modulation frequency is the image of its internal oscillator, while the data stream is used to send trigger information to delay generators. The optical distribution network distributes the reference clock and trigger information over the whole facility (i.e. over distances of up to 1 km), using the 155.52 MHz SDH-SONET standard communication protocol. Slave delay generators locally recover the reference clock and trigger information from the data stream. They include eight independent delay generators able to drive electrical or optical trigger outputs. They can generate arbitrary delays within a range of ±1 second with a sub-picosecond resolution.

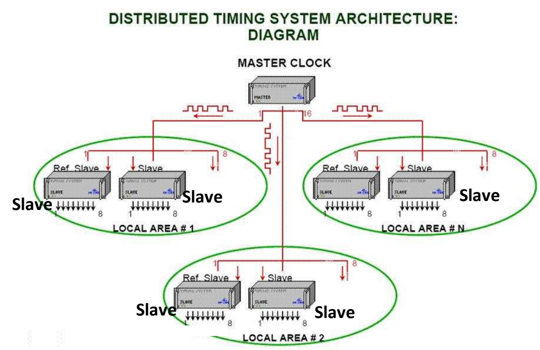

Figure 4: Architecture of the Standard and High Precision Timing System.

Optical fibers are easy to use and well fitted to our need, however their propagation delay varies when temperature changes up to 170 ps/°C/km for the one used on LIL. These variations are not acceptable for our timing system need. Therefore, we designed for the LIL timing system a bi-directional link with two different wavelengths: one to broadcast time messages to slaves and the other to send back to the master a part of the signal received by slaves. With this approach, it was possible to monitor delays in long optical fibers and compensate time variations. Recent studies [5] showed that optical fibers having free space between cladding and coating allow that variation to fall down to 40 ps/°C/km, so the bidirectional link will no longer be needed on the LMJ facility.

The master clock and slaves have internal temperature corrections. Each delay is corrected as a function of the temperatures registered during the calibration process.

ULTRA-HIGH PRECISION TIMING SYSTEM

The SHPTS is not sufficient to reach the 40 ps rms quadruplet synchronization performance. An Ultra-high Precision Timing System (UPTS) is necessary to further

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reduce jitter and wander for triggering AWG and generating fiducials. The LMJ needs for UPTS are: a jitter lower than 5 ps rms, a thermal drift lower than 5 ps/°C and a peak-to-peak wander over 1 week lower than 10 ps.

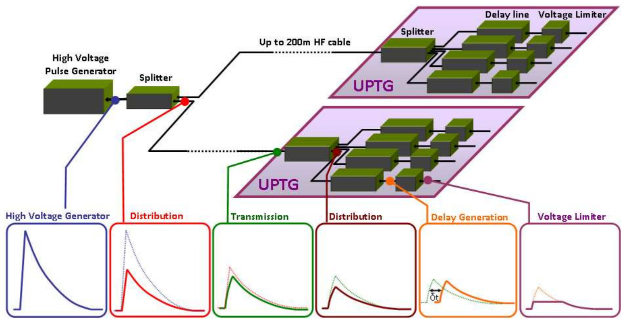

Figure 5: Architecture of the Ultra-high Precision Timing System, from the High Voltage Pulse Generator to the Ultra-high Precision Generators.

The UPTS (see Figure 5) will be based on a single trigger signal distributed by passive devices. A high voltage pulse generator passively distributes 44 trigger signals for the 44 AWG using inductive power splitters. The electrical signal will be split and distributed over large bandwidth coaxial cables to the Ultra-high Precision Timing Generators (UPTG). Those remote equipments include 100-ns-range electro-mechanical delay lines and electronic voltage limiter circuits. Those circuits will limit the amplitude of the incoming signal, shape the trigger signal and reduce the signal rise time.

The UPTS high voltage pulse generator is triggered by the SHPTS master clock, using a specific electrical trigger output showing extremely low jitter with respect to the master clock timing reference.

Two additional units of this system will be used to trigger up to 40 target diagnostics.

FIDUCIAL SYSTEM

For the LMJ, the common main issue between UPTS and fiducial system is a highly stable and extremely low-jitter system. The LMJ Fiducial System will thus be based on a very similar architecture, except that the high pulse voltage generator will be triggered by a specific additional electrical trigger output of the SHPTS master clock showing very low jitter (< 3 ps rms) over a µs-delay range (up to 5 µs) as shown in figure 6.

This µs-delay is required to take into account the laser propagation from the source to the experience target. Furthermore, the high-voltage signal will be delivered to Electrical Fiducial Generators integrating delay lines and pulse shaping circuits.

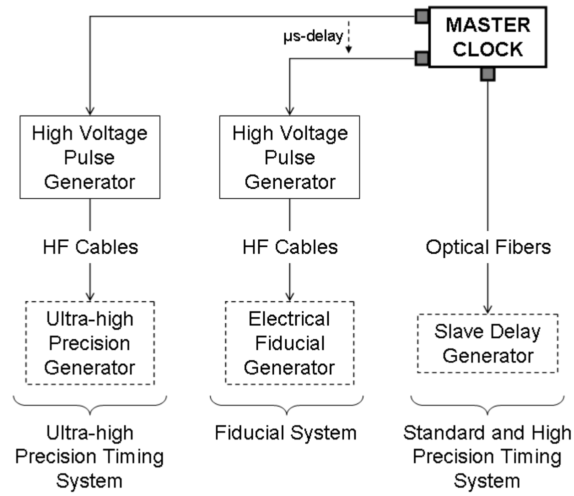

Figure 6: Connection between Standard and High Precision Timing, Ultra-high Precision Timing and Fiducial Systems.

SUPERVISORY COMPONENTS

Supervisory components include (see Figure 7):

- a communication gateway
- a front end.

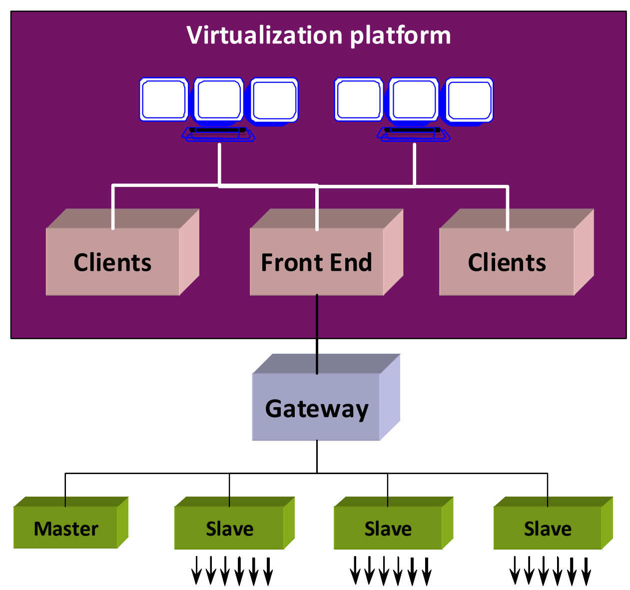

Figure 7: Supervisory components.

Communication Gateway

The communication gateway consists of a PC under Windows 7 allowing the front end to communicate with all synchronization equipments (master, slaves, high voltage pulse generators, ultra-high precision generators and electrical fiducial generators), using a TCP socket protocol that masks equipment complexity and heterogeneity. The front end can load/read gateway configuration files, read results, start/stop equipments,

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configure equipment channels (triggers or fiducials) and read equipment status.

The gateway supports different kinds of equipments: LIL master/slaves, LMJ master/slaves, UPTS equipments, Greenfield GFT series equipments.

Front end

The front end consists of several Virtual Machines (VM) and two multiscreen consoles hosted on the LMJ central virtualization infrastructure.

It executes a PANORAMA application that allows multiple LMJ clients to configure separated groups of channels (triggers or fiducials) triggered synchronously. Clients are typically the front ends of the other LMJ subsystems and shot sequences.

The front end allows the clients to:

- Register groups,
- Add or remove channels to/from a group,
- Configure channels delay and recurrence,
- Activate or deactivate groups, making them available for being triggered or not,
- Trigger groups.

Inside a group, channels can be configured to be triggered on command or repetitively at 0.1 Hz, 1 Hz, 10 Hz, 100 Hz. Repetitive channels start when the group is activated and one-shot channels when the group is triggered. Typically repetitive channels are used by MOS, PAMs and alignment sequences and one-shot channels by shot sequences.

As multiple sequences can use the timing system simultaneously, a reservation mechanism ensures that a client could not trigger channels reserved by another: at group registration, a certificate is granted to the group, and only clients knowing that certificate are allowed to activate and trigger that group.

CONCLUSION

The timing system under development on the LMJ will be able to synchronize laser quadruplets on the target within the requested 40 ps rms. It is based on three subsystems able to manage about 2000 triggers ranging from 150 ps rms jitter to 15 ps rms jitter, and 100 ultra-high precision triggers and 200 fiducials with 5 ps rms jitter. The supervisory system allows multiple clients to register groups, and then simultaneously configure and trigger groups of triggers or fiducials synchronously.

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