A distributed trigger system for picosecond LASER facilities

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***Abstract*—The Commissariat à l'Energie Atomique (CEA) is developing a unique picosecond timing system for the Laser MegaJoule (LMJ) project which includes an original concept to trigger picosecond laser sources with ultra-low jitter. We present the concept and how it can be used to implement the LMJ optical fiducial system or to synchronize a picosecond X laser source. We expose achieved performances.**

I. Introduction

The *Laser MégaJoule* (or LMJ) is a huge laser facility currently under construction in France. It will be dedicated to inertial confinement fusion (I.C.F.) and will be operating in 2010. It requires a unique timing system with unprecedented performances. One of its features is the ability to trigger picosecond laser sources with sub-picosecond jitter.

We describe the principle of this timing system that must achieve picosecond range accuracy. We explain the principle of its distributed architecture and present achieved performances.

II. The Laser MégaJoule project

The *Laser MégaJoule* will focus 1.8 MJ of U.V. light on a small target ball, filled with deuterium and tritium hydrogen isotopes, that will be compressed and heated up to the ignition point (fig. 1, 2 and 3). The optical power will be provided by 240 laser beams that must be precisely focused, power-balanced and synchronized. Each laser pulse will have a particular temporal response to generate specific effects such as mechanical compression, plasma heating, and ignition. To control the proper operation of the facility, several kinds of measurement and control systems have to be developed.

Figure 1. The LMJ buiding (300 m × 150 m)

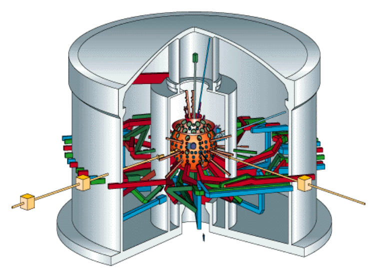

Figure 2. The 10 m target chamber (at center)

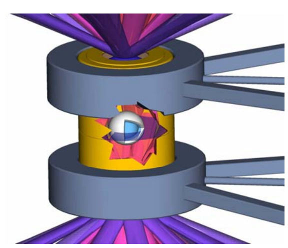

Figure 3. The target (a 2 mm ball filled with deuterium and tritium)

III. THE LMJ TIMING SYSTEM REQUIREMENTS

The LMJ needs a timing system capable of delivering 4,000 trigger signals in single shot mode over an area exceeding 30,000 m^2, with a dynamic range of up to 2 s, an accuracy ranging from 1 µs down to 10 ps and a jitter ranging from 100 ns down to 5 ps (rms). Its purpose is to trigger all subsystems of the facility including laser subsystems (oscillators, amplifiers, Pockels cells, pulse shaping devices, …) and all ultra-fast diagnostics of the facility (real time digitizers, ultra-fast cameras, streak cameras, …). The timing system must also deliver many optical fiducial signals to accurately time-stamp some critical diagnostics.

IV. A DISTRIBUTED ARCHITECTURE USING A BI-DIRECTIONAL FIBER OPTIC TIME NETWORK

To meet all the requirements, we have conceived a system based on very accurate slave delay generators connected to a master clock through a bi-directional fiber optic time distribution network (see figure 4).

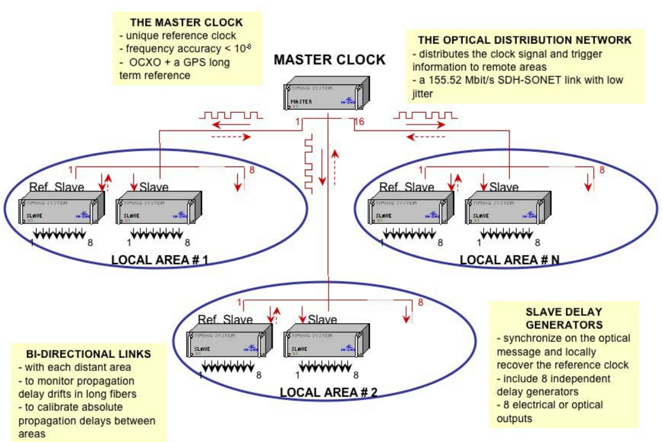

Figure 4. The LMJ timing system architecture

Principle :

- *The master clock* is the unique time reference for the facility. It runs a very stable OCXO which can be permanently locked to the GPS to avoid long term drift. It generates an optical numerical 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 through the entire building. It uses 155.52 MHz SDH-SONET components. The length of main fibers between the master clock and a local area in the building can reach up to 1 km.

- *Slave delay generators* locally recover the reference clock and trigger information from the data stream. They include 8 independent delay generators that drive electrical or optical trigger outputs. They can generate arbitrary delays within a range of 2 s with a sub-picosecond resolution.

- *Bi-directional links* use two slightly different wavelengths which are separated with WDMs. One wavelength is used by the master to broadcast time messages to slaves. An emitter using another wavelength has been included to one slave system per local area, and the master unit includes an optical converter plus a time interval meter, to measure and monitor propagation delay in long fiber optics.

V. TRIGGERING ULTRA-SHORT LASER PULSES

A. *Principle*

The LMJ timing system must trigger ultra-short pulsed lasers with a sub-picosecond jitter for fiducial and metrology requirements.

This is achieved by locking a mode-locked laser to a reference frequency delivered by the timing system and triggering all sub-functions of the laser with trigger outputs of the timing system (see figure 5). The reference frequency can be the reference clock itself, or one of its sub-harmonics. It is recovered from the master clock with no phase uncertainty by processing both the data modulation and the time information issued by the master clock. The laser cavity is phase-locked to this frequency, therefore, with no phase uncertainty with the master clock frequency. Different types of mode-locking have been successfully tested, depending on the laser type: passive mode-locking, active mode-locking or Kerr lens mode-locking.

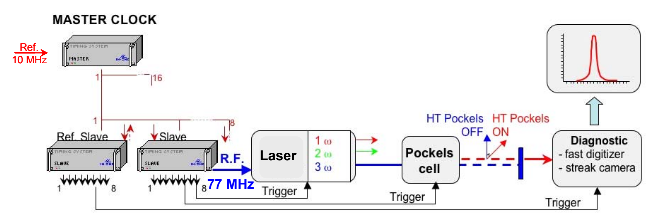

Figure 5. Principle of triggering an ultra-short pulsed laser with the timing system

This architecture has been validated and is already successfully implemented on several lasers used by the CEA.

B. *The LMJ optical fiducial system*

The purpose of the LMJ optical fiducial system is to provide optical time stamps (single pulses or train of pulses) to accurately time-correlate the incident LMJ laser pulse and the temporal evolution of plasma.

The laser pulse is recorted on a streak camera during the main shot and/or during pre-shots or post-shots (fig. 6).

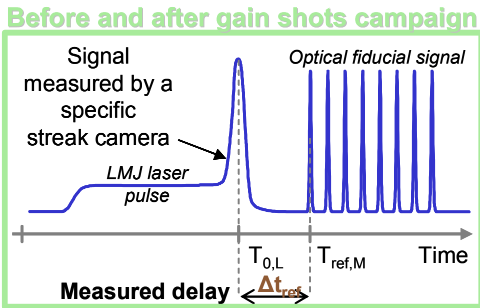

Figure 6. Time stamping the laser pulses

Recordings of physics phenomena (such as X ray emission) are time stamped during the main shot (fig. 7).

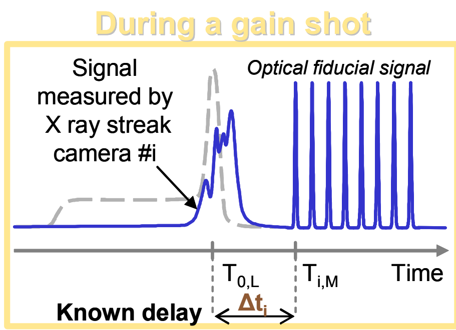

Figure 7. Time stamping an X-ray streak camera

The optical time stamps must be generated at 526 nm and 351 nm ("2 ω" and "3 ω"). Therefore the optical fiducial system can be based on a single 1,053 nm laser source, locked to the timing system according to the principle previously described. This source is amplified, frequency doubled and tripled and split in a number of channels (as illustrated in figure 8).

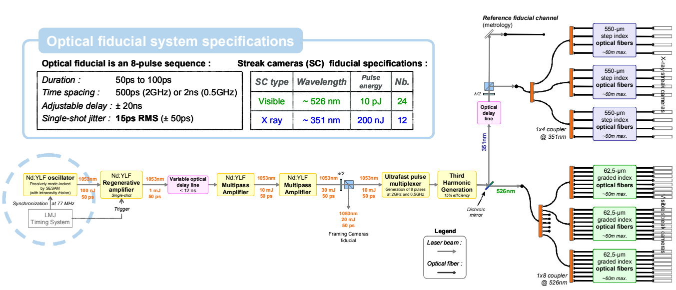

Figure 8. A proposed architecture for the LMJ optical fiducial system

C. *The EQUINOX UV-X laser facility*

EQUINOX is a sub-picosecond pulsed X-ray facility operated for calibration of diagnostics systems of the LIL (Laser Integration Line) and LMJ laser facilities (see figure 9). It is based on a picosecond laser focused on a solid target or into a gas cavity (for harmonics generation).

Figure 9. The femtosecond UV-X laser facility EQUINOX

To have the capability of picosecond time metrology of diagnostics in this facility, we implemented a local timing system similar to those of the LIL and LMJ. The laser is locked to this timing system.

VI. ACHIEVED PERFORMANCES

Detailed architecture and general performances of the timing system have been published in [1] and [2].

An intensive characterization of the picosecond laser trigger functionality was conducted in the EQUINOX facility and with a demonstrator of an optical fiducial system. It demonstrated the following good performances:

- **jitter < 1 ps rms** over 2 hours,

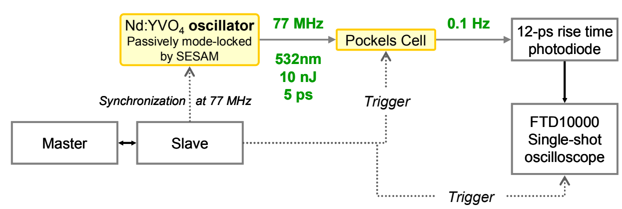

Figure 10. Jitter measurement

<u>Measurement conditions :</u> 720 signals measured at 0.1 Hz, over 120 min using a 7-GHz single-shot oscilloscope with 1-ns time range.

- **long term drift < 11 ps** over 3 days.

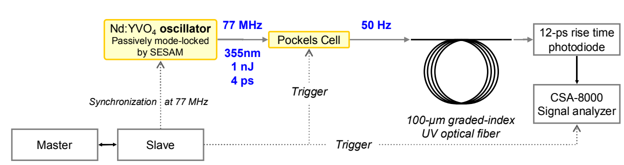

Figure 11. Long term drif measurement

<u>Measurement conditions :</u> average of 90 signals acquired at 50 Hz over 30 min, 5 meas. a day, over 3 days, system turned off during night, 15-min warm-up each morning,

signal analyzer: 50-GHz sampling module, 200-fs resolution, 200-ps window.

VII. Conclusion

The timing system, developed by the *Commissariat à l'Energie Atomique* for I.C.F. and ultra-short pulsed laser facilities, is unique and features unprecedented performances such as a very high accuracy (< 45 ps), very low jitter (< 10 ps, 5 ps typical) and ultra-high stability (< 10 ps).

It also provides a unique functionality to trigger ultra-short pulse lasers with sub-picosecond jitter. This capacity has already been used successfully in EQUINOX, a femtosecond UV-X laser facility and is proposed as a solution for the optical fiducial system of the Laser MégaJoule.

References

[1] P. Leclerc, J.Y. Salmon, J.P. Arnoul, "A picosecond timing system for the Laser MégaJoule", 14th European Frequency and Time Forum, 2000, Proceedings, pp. 73-76.

[2] J.Y. Salmon, P. Leclerc, "Performance of the picosecond timing system for the L.I.L. laser facility", European Frequency and Time Forum'02, 2002, Proceedings, pp. D-002 - D-005.