ULTRA PRECISION TIMING SYSTEM FOR THE LASER MEGAJOULE

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Abstract

This article presents a specific timing system designed for the Laser Megajoule project. This accuracy timing system has to deliver 64 electrical trigger signals with a very low jitter (< 5 ps rms) in order to synchronize the 240 laser pulses on the same target, in single shot mode and over 100 meter distances.

After a dimensioning phase leading to the architecture of the system and the selection of components, a prototype was developed providing 8 electrical trigger signals.

We expose the architecture and the excellent results achieved on this prototype regarding jitter, thermal drift and delay linearity.

INTRODUCTION

The Laser MegaJoule (LMJ) is a high power laser facility designed 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 240 laser beams is crucial to compress symmetrically the millimetre-size target in order to warm 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 the quadruplet laser sources are separated within the building by several hundred meters. This kind of performance is also required for fiducial pulses used to temporally mark laser and plasma diagnostics.

The performances of the standard / precise synchronization system are however not totally sufficient in order to reach the 40 ps rms specification in some cases [2]. To reach the specifications, another kind of timing system, called ultra-precision timing system (UPTS) has therefore been designed to improve jitter and drift performances. It will be used to trigger each quadruplet laser pulse and to generate fiducial signals for diagnostics whereas standard / precise LMJ timing system will trigger all other subsystems.

This article deals with this UPTS: its principle[1] is exposed on section 3, whereas its metrological characterization and the first results obtained on a prototype will be described in section 4.

REQUIREMENTS OF THE LMJ TIMING SYSTEM

The LMJ needs a timing system to deliver 8,000 trigger signals in single shot mode over an area exceeding 30,000 m², with a dynamic range up to 2 s, an accuracy ranging from 1 s down to 5 ps and a jitter ranging from 100 ns down to 5 ps rms. Its purposes is to trigger all subsystems of the facility including laser subsystems (oscillators, Pockell cells, pulse shaping devices, …) and all ultra fast diagnostics of the facility such as real time digitizers, ultra fast cameras, streak cameras which requires several hundreds of trigger signals and fiducial signals.

To guarantee the requirements compliance and to reduce the cost of delay generators, the 8,000 channels of the LMJ timing system are divided in three classes, each of them having a different accuracy and delay range (see table 1). They include from two up to eight independent delay generators able to drive electrical trigger outputs.

Table 1: Requirements of the LMJ Timing System

Class	Delay Range	Jitter	Resolution
Standard	1s	< 100 ps rms	< 5 ps
Precise	100 us	< 15 ps rms	< 2 ps
Ultra Precise	100 ns	< 5 ps rms	< 10 ps

ULTRA PRECISION TIMING SYSTEM (UPTS)

The LMJ needs for UPTS are: a jitter lower than 5 ps rms, a thermal drift lower than 5 ps/°C and a wander over 1 month lower than 15 ps.

Architecture of the UTPS

We have designed a high accuracy, low jitter timing system [3] based on a single trigger signal distributed by passive devices. A high voltage pulse generator, triggered by standard and precise master system passively distributes 44 trigger signals for the 44 Arbitrary Waveform Generators (AWG) using inductive power splitters. The electrical signals are transmitted with large bandwidth coaxial cables. The delay of each signal is tuned with a specific electro-mechanical delay line allowing a 100 ns range delay. The end of the transmission cable is connected to an electronic voltage limiter circuit. This circuit limits the amplitude of the transmitted signal, shapes the trigger signal and reduces the signal rise time. Each component of the UPTS was selected for its particular characteristics such as excellent jitter, thermal stability and lower signal degradation. We particularly paid attention to the rise time and the voltage amplitude.

Prototype of the UPTS

A prototype offering 8 independent triggering signals with 20 ns delay range over 100 meter distance was

[1] French Patent # FR2893464 and European Patent #EP1786104
[2] With collaboration of Greenfield Technology (French company) and contribution of Conseil General de l'Essonne

developed and tested in our laboratory[2]. The figure1 shows this prototype architecture and the trigger signal propagation trough each step. At the end of the UPTS, slaves deliver 1 ns rise time and10 V amplitude trigger signals.

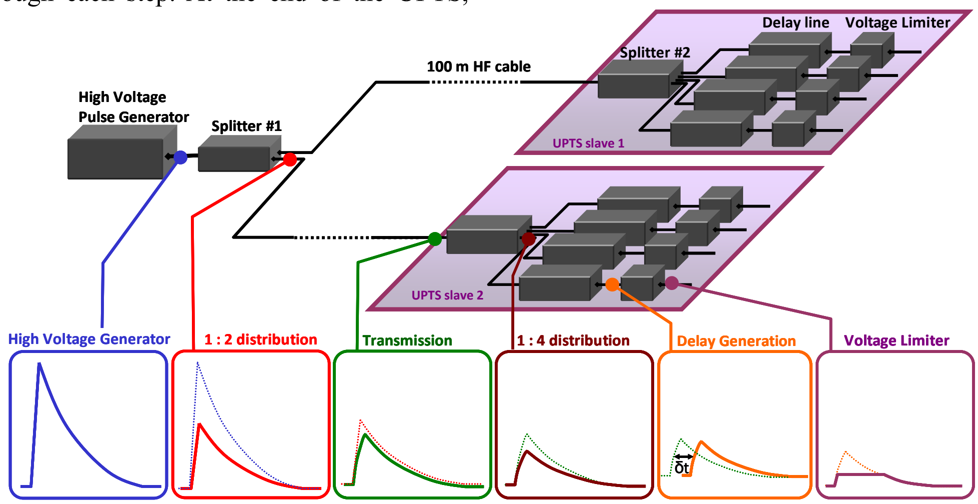

Figure 1: Architecture of the Ultra Precision Timing System prototype.

UPT Prototype Qualification

A complete metrological characterization was realized in our laboratory to know the performances of our UPTS prototype and optimize it. The followings parts present metrological results obtained regarding jitter, thermal drift and delay generator accuracy with and without correction.

Jitter Measurements

We measured three different jitters:

- The “Intra slave jitter” is the jitter between two output channels of an UPTS slave. The result is as low as 3.2 ps rms,
- The “Inter slave jitter” is the jitter is between two output channels from two different UPTS slaves. The two jitter values are the same (3.2 ps rms), that means the two 100 meters cables do not induce additional jitter,
- The “Global Jitter” represents the total jitter of the whole UPTS prototype. It notably includes trigger jitter of the master. We obtained 3.7 ps rms that is consistent with the 2 ps jitter estimation of the master.

These results show that our UPTS prototype meets the 5 ps rms requirements for inter slave jitter.

Thermal Drift

Major contributors of the thermal drift are the 100 meter long cables, the delay lines and voltage limiters. To test the sensitivity of the UPTS to temperature changes, an UPTS slave associated with 100 meters length HF cable was placed in a temperature-controlled oven. The thermal coefficient of delay was measured equals to 3.6 ps / °C. This value meets the 5 ps / °C requirements.

Delay Generator Linearity

We selected an electro-mechanical delay generator which is totally passive to minimize jitter and wander. The resolution of this delay line is 10 ps. We had to correct its non-linearity over the total range delay (20 ns) by creating a correction table from a picosecond time metrology realized on the delay line using very accurate equipments such as sampling oscilloscopes or picosecond time interval counter. We significantly improve the accuracy of the delay line from 450 ps to ± 10 ps by applying this correction as it is shown on the figure 2.

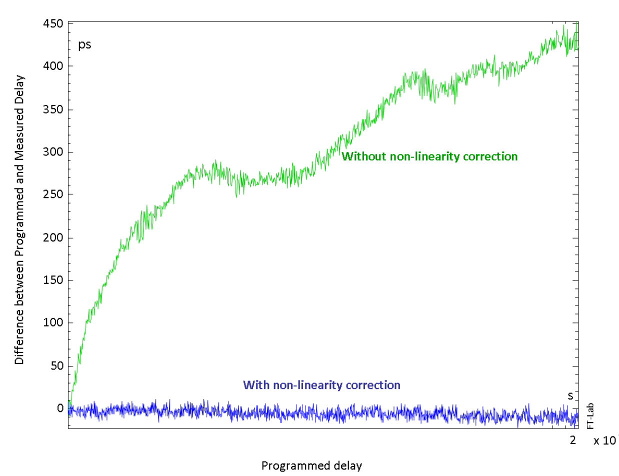

Figure 2: Delay line accuracy with and without correction.

This result shows that the UPTS is able to generate a tuned delay with 10 ps resolution.

Feasibility of the UPTS

The metrological characterization results obtained and the efficiency of the linearity correction demonstrated the Ultra Precise Timing System feasibility.

FIDUCIAL AND ULTRA PRECISION TIMING SYSTEM

For the LMJ, the common main issue between UPTS and fiducial system is a highly stable and extremely low-jitter system. Our goal is to upgrade our UPTS to a fiducial system, allowing us to take advantage of all the results obtained in the UPTS development. We plan to use a fiducial system very similar to UPTS except a 3.5 µs delay inserted between the two systems that will be measured very precisely during each experimentation (see Figure 3). This measurement will ensure an event post-dating within an error < 10 ps using appropriate time interval counter or digitizer.

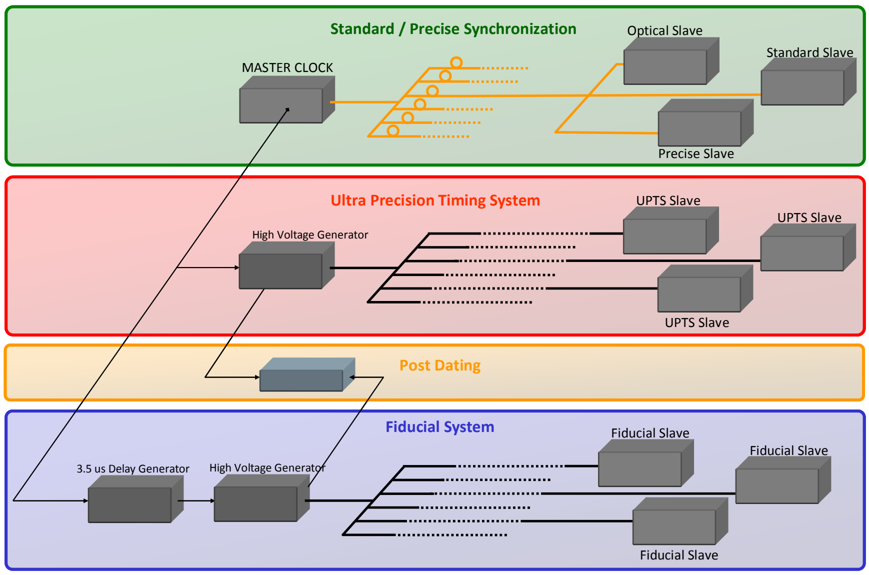

Figure 3: Connection between UPTS, fiducial system and standard / precise synchronization system.

PROSPECTS

The first step is to demonstrate the feasibility of this evolution from the actual prototype. Then we will have to ensure that the 3 systems (UPTS, fiducial system and standard / precise LMJ timing system) can work together.

Then, to improve the performance of the UPTS, we plan to study some improvements as the increase of the transmission distances while maintaining LMJ timing system requirements.

We also need to define the specifications of the fiducial signal such as its shape, its rise time and width to optimize the performances of the fiducial system.

These studies will be realized during the year 2011 in our laboratory.

CONCLUSION

An Ultra precise timing system is under development in our laboratory to provide low jitter and low wander electrical signals. The 8 channels prototype of this system delivers 1 ns rise time -10 V amplitude electrical trigger at 100 m distance with a programmable delay range of 20 ns. The measured jitter of the whole UPTS is 3.7 ps rms and the temperature drift is 3.6 ps/°C. These values meet the Ultra precise timing system requirements of 5 ps rms for jitter and 5 ps/°C for thermal drift.

REFERENCES

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[3] M. Prat and V. Drouet, “Specific Timing system for the Laser Megajoule Pulse Shaping Function”, European Frequency and Time Forum / Time Nav’07, 2007.