ULTRA-HIGH PRECISION TIMING SYSTEM FOR THE CEA-LASER MEGAJOULE

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Abstract

High power laser such as the Laser MegaJoule (LMJ) or National Ignition Facility (NIF) requires different types of trigger precision to synchronize all the laser beams, plasma diagnostics and generate fiducials. Greenfield Technology, which designs and produces picosecond delay generators and timing systems for about 20 years, has been hired by CEA to develop new products to meet the LMJ requirements. More than 2000 triggers are about to be set to control and synchronize all of the 176 laser beams on the target with a precision better than 40ps RMS. Among these triggers, Greenfield Technology's GFT1012 is a 2 or 4-channels delay generator challenging ultra-high performances: an ultra-low jitter between 2 slaves of 4ps RMS and a peak-to-peak thermal drift over 1 week lower than 6 ps due to a thermal control of the most sensitive parts (thermal drift is below 1ps/°C) and specific developments for clock management and restitution. Ongoing investigation should bring the jitter close to 2 ps RMS between 2 slaves.

INTRODUCTION

The Laser MegaJoule (or LMJ), is a high-power laser facility based in France dedicated to study high energy density physics and more particularly inertial confinement fusion [1]. To control and set up all of the 176 laser beams and laser and plasma diagnostics, the LMJ timing system must meet harsh requirements [2]. Recent evolution of the trigger requirements has split the timing system specification into 2 performance categories: standard and high precision timing (SPT/HPT). Requirements are sum up on Table 1 below.

Table 1: LMJ Timing System Requirements

	Range	**Jitter** (RMS)	**Thermal drift** (peak-to-peak, over 1 week)	**Qty.**
SPT Triggers	±1s	><100ps	<2ns	~2000
HPT Triggers	± 50µs	<5ps	<10ps	~500

Greenfield Technology (GFTy) is a company specialized in timing systems for 20 years and has been mandated to give a global solution. To achieve this task with cost control, GFTy has designed a specific timing system for the LMJ from the command-control software to the optical splitters in addition of the master-slave architecture (see Figure 1 for details).

ULTRA-HIGH PRECISION SLAVE GFT1012

To achieve ultra-high precision triggers, GFTy has designed the GFT1012 which is a 2 or 4-channels slave. GFT1012 conception has been focused on two major axes:

- Minimize noise to minimize temporal jitter
- Thermal control to maximize stability over time

Noise Control

To be compatible with the rest of the timing system architecture, GFT1012 is linked to the optical network made of a master clock and two stages of optical splitters. GFT1012 is able to decode the same optical signal made of a 1B/2B message at 155,52MHz. However, to minimize instability due to the optical reception sensibility, GFT1012 incoming optical power has been maximized by choosing 1-to-4 optical splitter as second stage of the optical network (instead of 1-to-16 optical splitter for GFT1018, standard slaves also used on LMJ).

Clock management is essential in timing system, that is why a clock and data recovery (CDR) function is implemented after optical reception. This function can be achieved by a PLL (phase-locked loop) such as ADN2817 and ADN2814 from Analog Devices but these components are designed for higher frequency systems (up to 2.7Gb/s for ADN2817 and 675 Mb/s for ADN2814) and are no more dedicated for 155,52MHz timing system frequency. Table 2 shows In/Out clock jitter for different frequencies: at 155 MHz, the jitter is way above 5ps RMS.

Table 2: In/out RMS Jitter for ADN2814 and ADN2817

Frequency	**ADN2817**	**ADN2814**
155 MHz	15 ps	8.2 ps
311 MHz	11.5 ps	3.2 ps
622 MHz	5.7 ps	2.7 ps
1.2GHz	3.3 ps	-

Furthermore, GFTy tests on ADN2814 shows that this PLL was not as stable as expected over time and 8ps variation in few minutes have been measured (see Figure 2).

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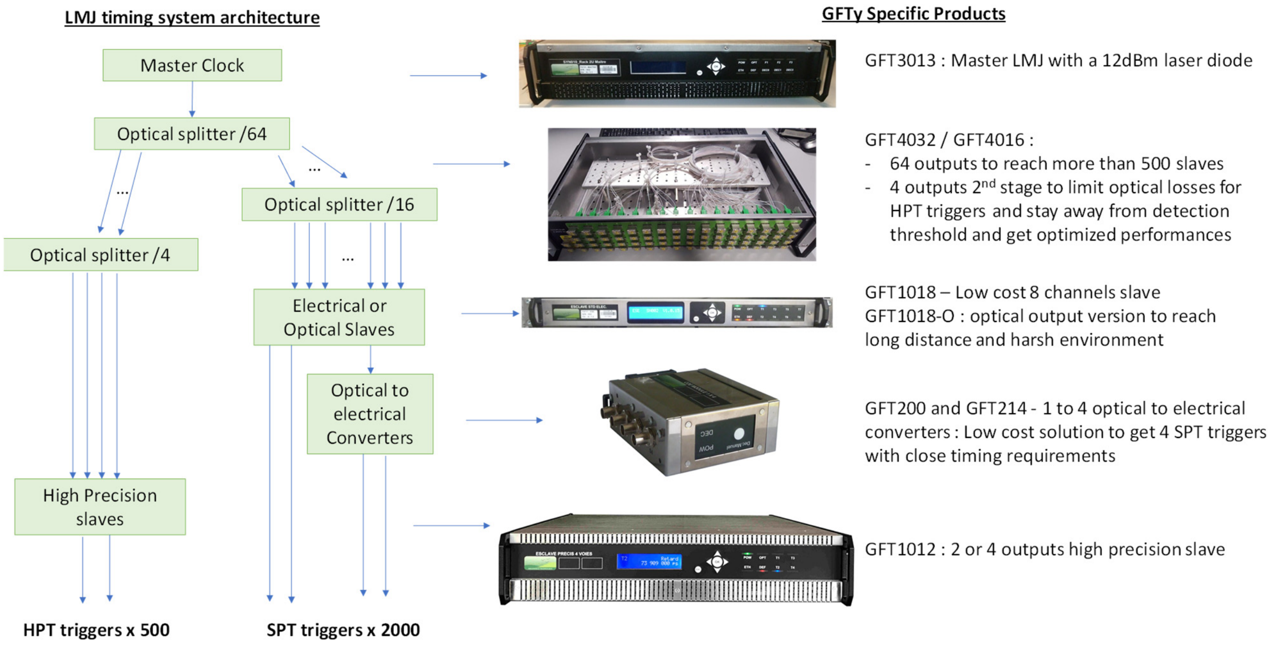


GFT3013 : Master LMJ with a 12dBm laser diode

GFT4032 / GFT4016 :
- 64 outputs to reach more than 500 slaves
- 4 outputs 2nd stage to limit optical losses for HPT triggers and stay away from detection threshold and get optimized performances

GFT1018 – Low cost 8 channels slave
GFT1018-O : optical output version to reach long distance and harsh environment

GFT200 and GFT214 - 1 to 4 optical to electrical converters : Low cost solution to get 4 SPT triggers with close timing requirements

GFT1012 : 2 or 4 outputs high precision slave

Figure 1: LMJ timing system architecture associated with specific GFTy products.

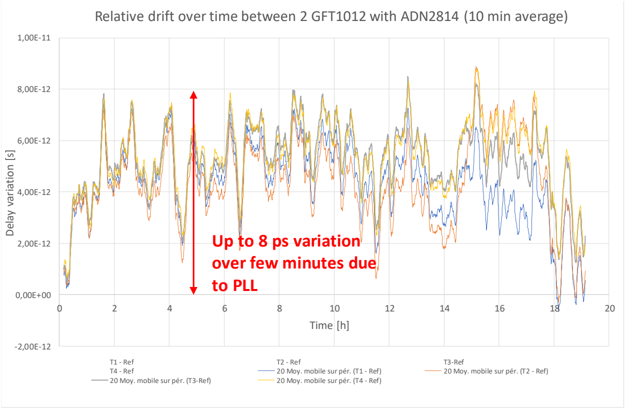


Figure 2: Stability of 2 GFT1012 thermally stabilized with a CDR function made with an ADN2814 PLL.

Changing frequency was not a possibility for LMJ (but could be a next generation solution). Then, GFTy decided to design its own CDR function to limit noise and be more stable. RMS jitter below 3ps has been measured before output drivers.

To minimize noise sources, metal shielding has been developed: GFTy split the electronic devices into 2 isolated parts, power management and system part on one side and stabilized performance on the other side (Figure 3). See as "a box in a box" this second part is also thermally controlled with 2 80mm ventilators (see thermal control part below).

Thermal Control

Thermal variation impacts directly on delay stability. It is a well-known issue in GFTy products and thermal management implies different cost solutions:

- GF1018, low-cost solution has 50ps/°C thermal drift
- GFT1004, standard solution has 15ps/°C thermal drift
- GFT1012, precise solution target has 1ps/°C thermal drift ambition

Thermal control has been achieved thanks to Peltier cells. To minimize current on Peltier cells, dimensions have been limited and the global slave architecture has been split into isolated function (each block seen on Figure 3).

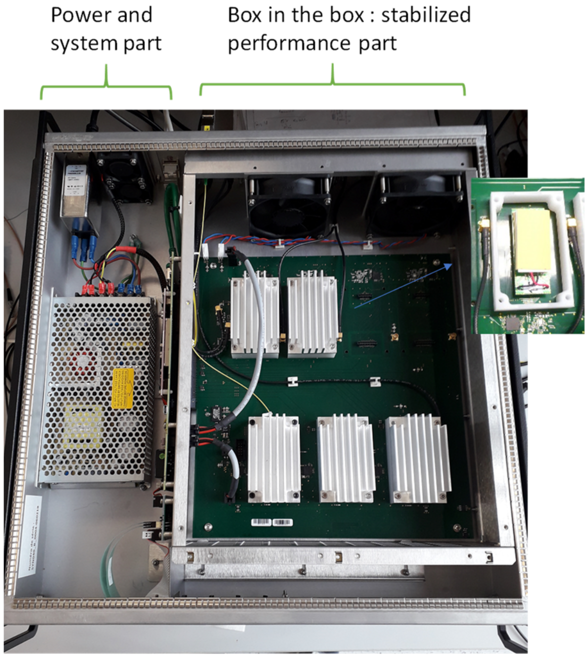


Figure 3: GFT1012 Top view – Insert: Peltier cell view below metallic part.

Compromise between thermal control and noise management was challenging:

- Metal shielding of every function was best for noise but added too much thermal transfers: plastic box was

preferred for mechanical consolidation and air gap for thermal isolation
- Peltier cells are driven with PWM (pulse width modulation) which can bring noise: performance part and thermal control part have isolated grounds to limit noise

GFT1012 PERFORMANCES

RMS Jitter

RMS jitter is measured thanks to a Lecroy oscilloscope that has been characterized with a 0.9ps RMS internal jitter. Jitter has been measured between two different GFT1012 as shown in Figure 4.

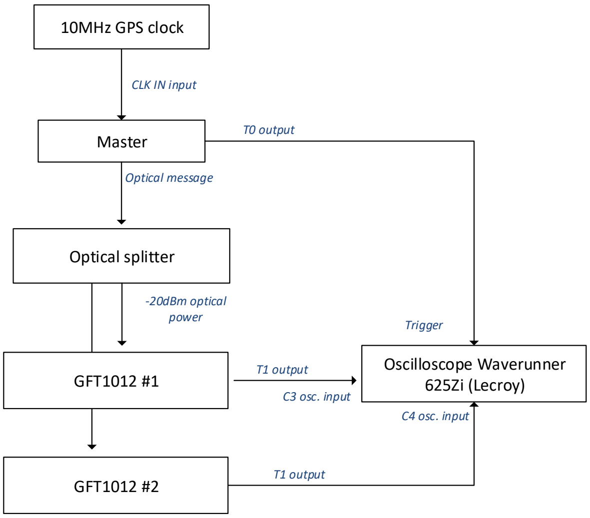
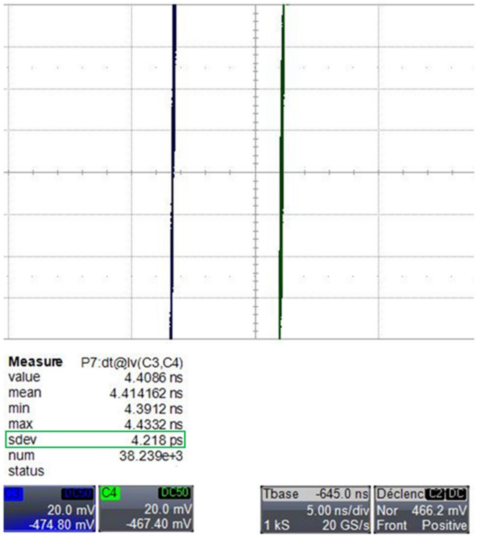


Figure 4: Jitter measurement setup.

RMS jitter below or about 4ps has been measured and confirmed by CEA measurement [2]. GFTy measurement is shown on Figure 5. LMJ requirement of 5ps is then guarantee.



Measure	P7:dt@lv(C3,C4)
value	4.4086 ns
mean	4.414162 ns
min	4.3912 ns
max	4.4332 ns
sdev	4.218 ps
num	38.239e+3
status	

Figure 5: Jitter measured between 2 GFT1012: 4ps RMS.

Performance limitation is due to the use of PWM to control temperature: turning PWM off brings back RMS jitter below 3ps. GFTy supposes that ground shielding could be better and a new conception could even bring RMS jitter to a lowest level never reached: 2ps rms jitter could be expected.

Thermal Drift

Before testing the stability over time, GFTy tested the stability over temperature. Use of a climatic chamber stabilized at 0,1°C allows to decorrelate thermal contribution of GFT1012 to the thermal contribution of fibers, master clock and time interval meter as shown on Figure 6.

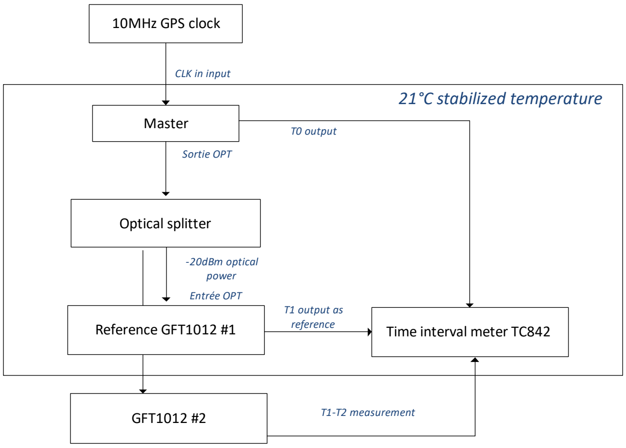


Figure 6: Thermal drift setup.

GFT1012 is almost independent of environment temperature (see Figure 7: delay variation evolution is 0,5 ps/°C (test made between 24,5 and 27,5°C). GFT1012 working temperature is between 20-28°C. Ambition of 1ps/°C thermal drift is achieved.

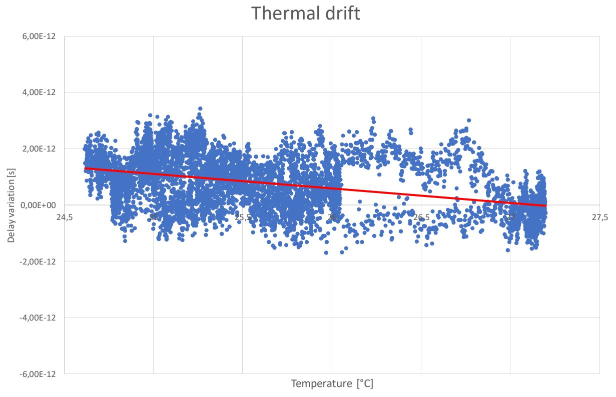


Figure 7: GFT1012 Delay variation function of environment temperature: Slope (in red) of 0.5ps/°C.

Stability Over Time

Stability over time is the main challenge for GFT1012. To test its performance, Figure 8 setup is slightly modified: GFT1012 #2 is now also in the climatic chamber so all of the devices are thermally stabilized at 21 ± 0.1°C. Measurements are made for 1 week: every 30s 10000 measure-

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ments (recurrent frequency of 1kHz) are made and averaged to create one point. Since TC842 time interval meter has high jitter level (about 10 ps RMS), raw measurements are still noisy: since we want to measure long-term drift, a 10min sliding average is added.

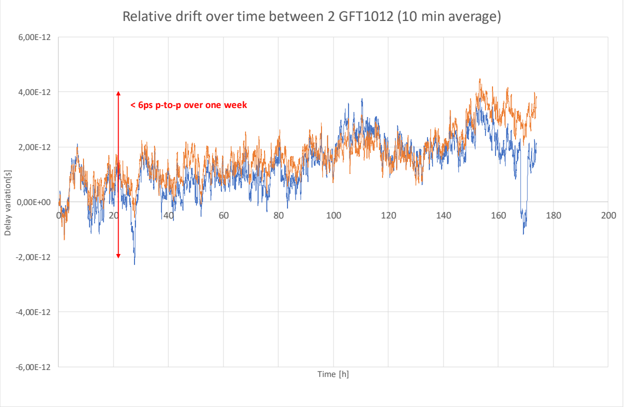

Figure 8: GFT1012 Delay variation function of time over one week.

Results are as expected and contained in 6ps peak-to-peak over one week: daily variation are 2-3ps typ. To confirm that measurement, CEA has set up another experiment with a different climatic chamber and replace the time interval meter by a Lecroy oscilloscope. Single shot measurements have been made to be more representative of LMJ operations: variation of 4ps peak-to-peak have been measured over one month [2].

CONCLUSION

GFTy global solution from command-control to master-slave architecture meets the CEA harsh requirements for the LMJ timing system that will allows to synchronize all of the 176 laser beams within the 40 ps requested based on 2 subsystems able to manage about 2000 triggers ranging from 100ps RMS jitter (GFT1018 low cost solution) to 5ps RMS jitter for ultra-high precision triggers and fiducials thanks to GFT1012. GFT1012 is also very stable over time (6ps over one week and below 10ps expected over months) and over temperature (below 1ps/°C between 21 to 28°C). Verification has been made between 24 and 27°C: variation is 0,5ps/°C. Future development and noise management could bring RMS jitter at about 2ps RMS.

REFERENCES

[1] Laser MegaJoule, `www-lmj.cea.fr`

[2] T. Somerlinck, T. Falgon, N. Bazoge, S. Hocquet, Ph. Hours, and D. Monnier-Bourdin, “Laser Megajoule Timing System”, presented at the ICALEPCS'19, New York, NY, USA, Oct. 2019, paper TUBPR06, this conference.