Specific Timing System for the *LASER MEGAJOULE* Pulse Shaping Function

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***Abstract*—This article presents a specific timing system for one function of the LASER MEGAJOULE project. The architecture of the timing system is shown and the dimensioning of the different components is discussed. The results of the metrology and the calibration of an electro-mechanical delay line are presented.**

I. Introduction

The *LASER MEGAJOULE* (LMJ) project which is being managed by the CEA is to build a 240 beams laser for inertial confinement fusion experiments, i.e. to study high energy and density plasma produced by imploding deuterium-tritium targets with high energy laser beams. In addition to pulse energy or spatial focusing resolution requirements, a very precise beam-to-beam power balance and timing are also required to guarantee a highly homogeneous target compression. Thus, the different systems of each beam must be time-controlled precisely (15 ps single-shot RMS jitter) to obtain 240 synchronised laser pulses on the same target. Furthermore, the laser is built on 30,000 m² ground area. Consequently, a specific timing system must be designed to generate many trigger pulses to control the laser and diagnostics (around 4000 signals) with a high time precision (from some microseconds to some picoseconds, for a dynamic range of up to 2 s) everywhere inside the LMJ building.

The timing system which we will use for the main parts of the LMJ synchronized functions, is based on an optical fibers network. This network includes a master clock from which the time is transferred to different zones of the building by an optical numerical bit sequence and slave generators where highly accurate delay generators are coupled with the regenerated clock [1].

However, a new timing system is necessary for the pulse shaping function. This function allows generating the 240 laser pulses with a specific shape. The triggers of pulse shaping devices must be very precise (jitter lower than 10 ps rms) to synchronize the 240 pulses. Consequently, we have designed a high accuracy timing system with low jitter.

II. Architecture of the Specific Timing System

The specific timing system is based on passive devices without jitter : a high voltage pulse generator will distribute 60 trigger signals for 60 pulse shapers (one shaper for 8 laser beams). The signals are transmitted with large bandwidth coaxial cables. The delay of each signal is adjusted with a specific electro-mechanical delay line. After the cable transmission, we used a voltage limiter circuit to limit the amplitude of the trigger signals (typically 10 V of transmitted signals amplitude) and consequently to reduce signals rise time (see Fig. 1).

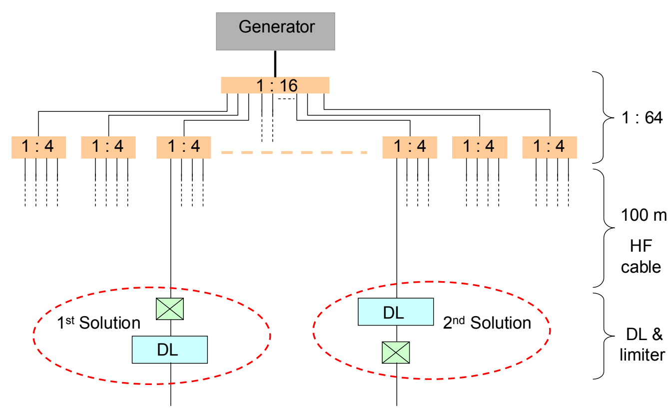

Figure 1. Architecture of the specific timing system (DL = Delay Line)

III. Choice of the Power Dividers and the Pulse Generator

This article illustrates the technical process of the dimensioning of the specific timing system. First we designed the power divider network, and then we defined the appropriate pulse generator.

For the power dividers, we looked into two main categories: resistive and inductive power dividers. The

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followings are some calculations showing the respective results for each category.

A. Power dividers

1) Resistive solution

This is the classical kind of power dividers, which the output voltage is equal to the input voltage divided by the number of output ways :

$$V_{out} = \frac{V_{in}}{N} \quad (1)$$

where V_{out} is the output voltage, V_{in} is the input voltage and N is the number of ways.

2) Inductive solution

Contrary to the resistive power dividers, the output voltage does not depend on the number of output ways, but on a ratio, which is fixed and defined by the composition of the power divider. This can be compared to a transformer, based on inductive properties. By comparison to the relation (1), the output voltage is defined by :

$$V_{out} = \frac{V_{in}}{R} \quad (2)$$

where V_{out} is the output voltage, V_{in} is the input voltage and R is the ratio of the inductive power divider.

3) Power calculations

In order to design the pulse generator and the power divider network, we computed the maximum and mean power, using the relations as follows:

$$P_{\max} = \frac{U^2}{r} \quad \text{maximum power} \quad (3)$$

$$P_{average} = \frac{U^2}{r} \cdot \frac{T_{pulse}}{T_{rec}} \quad \text{mean power} \quad (4)$$

where U is the voltage, r is the resistance, T_{pulse} is the duration of the pulse at 50% of the amplitude signal, and T_{rec} is the recurrence period.

4) Results - Choice of the power dividers

To reach a compromise between our technical specifications and 'realistic' solutions, power was decreased as much as possible.

Our aim was to obtain 100 V on each of the 64 outputs ways, with a 50 Ω adapted system.

The input and the output of the power divider network, except the different intermediate step of the network, where considered. First, we determined the input voltage for both cases :

- Resistive power dividers :

$$V_{in} = V_{out} \cdot N = 100 \cdot 64 = 6400V \quad (5)$$

- Inductive power dividers : to achieve our 64 ways system, we used a configuration as bellow,
    - a power divider with 1 input and 2 outputs with a ratio $R_1 = 2$,
    - a power divider with 1 input and 8 outputs with a ratio $R_2 = 3$,
    - a power divider with 1 input and 4 outputs with a ratio $R_3 = 3$.

And finally we found :

$$V_{in} = V_{out} \cdot R_1 \cdot R_2 \cdot R_3 = 100 \cdot 2 \cdot 3 \cdot 3 = 1800\ V \quad (6)$$

The table I shows peak-to-peak and mean powers for both solutions.

TABLE I. COMPARISON BETWEEN RESISTIVE AND INDUCTIVE SOLUTIONS

	Resistive solution		**Inductive solution**	
	$P_{\max}$ (kW)	P_{mean} (mW)	$P_{\max}$ (kW)	P_{mean} (mW)
Input	819	8192	64.8	648
Output	0.2	2	0.2	2

Obviously these results lead us to choose the inductive solution.

B. Pulse generator

Consequently, we designed a pulse generator respecting the technical points described earlier. This dimensioning includes the determination of parameters such as the amplitude, the duration, the rise time and the frequency rate of the pulse delivered by the generator. These points were determined at the time of the definition of synchronization signals.

Once again the pulse generator was adapted with the entire system, that is to say 50 Ω.

- *Amplitude* : using the previous computation, we have determined that the designed pulse generator should deliver an electric signal up to 2 kV.
- *Rise time :* we determined by simulation (cf. §¤IV.A) the rise time of the electric signal: considering the 10-90% rise time, it must be less than 500 ps. This is the upper limit determined during the simulation. The lower limit is strongly-

related by the bandwidth of the other devices on the timing system. It has no use to send a 50 ps rise time signal if the bandwidth of power dividers is only 500 MHz.

- *Duration :* the duration used is the duration given at fifty percent of the amplitude. To reach reasonable powers, we limited the duration to 10 ns with an exponential decrease.
- *Frequency rate :* this parameter is also limited by power, as shown on § III.A.3. It has been fixed to the lower limit which allows us to make the metrology of the timing system, which is 1 kHz.

IV. POSITION OF THE VOLTAGE LIMITER

The signals are transmitted from the pulse generator and the power divider network to the voltage limiter and the delay line through HF cables. The length of the cables can be up to 200 meters, causes temperature instability and deformation of the transmitted signals. Therefore a specific cable was selected to reduce these phenomena by using a large bandwidth and a very low thermal drift.

For the simulation presented further on, we considered the use of this specific kind of cable.

A. Calculation

We could only simulate the part located after the power dividers network and we used an electric signal meeting technical points already presented to start the simulation:

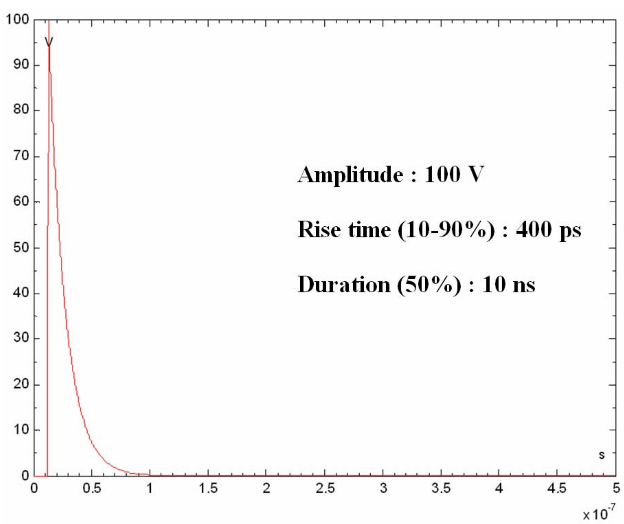

Figure 2. Electric signal before HF cable

Using the pulse response of the cable, the simulation provides for a 100 meters HF cable a damaged signal:

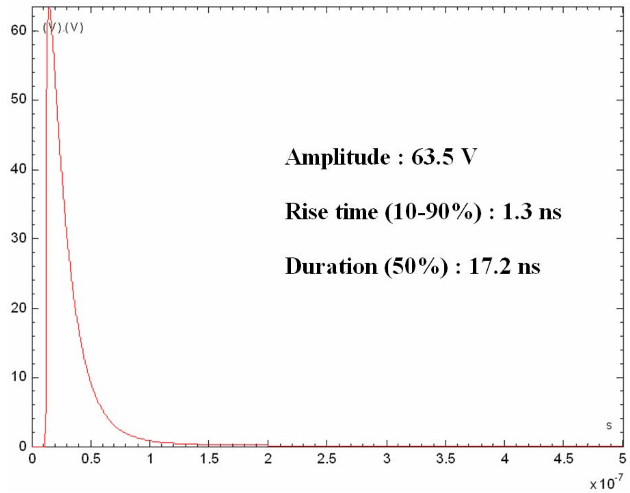

Figure 3. Electric signal after 100 meters HF cable

The digital simulation starts from this signal and is based on convolution between it and the pulse responses of the delay line and the voltage limiter.

B. Simulation results

The main goal of this simulation is to select the best architecture among the possible two which are :

- Case A: the voltage limiter is placed before the delay line
- Case B: the voltage limiter is placed after the delay line.

1) Case A

At the end of the cable, the signal passes trough the voltage limiter, and immediately after the delay line. The simulation presents the final synchronization signal for this configuration:

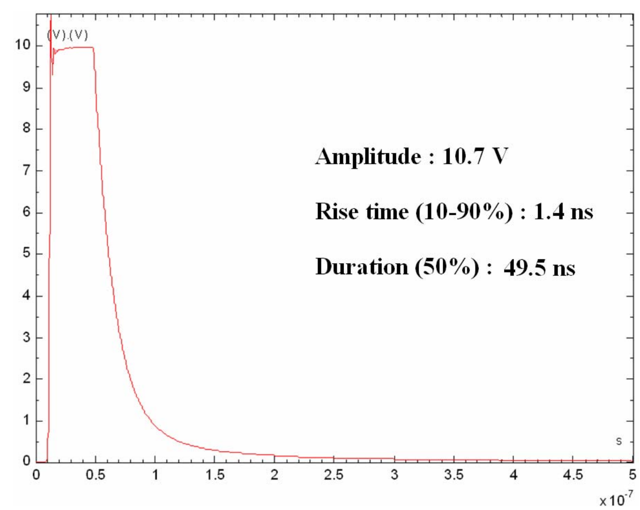

Figure 4. Case A - Electric signal after voltage limiter and delay line

2) *Case B*

In this configuration, the delay line is placed before the voltage limiter. By executing the same simulation, the results are significantly different :

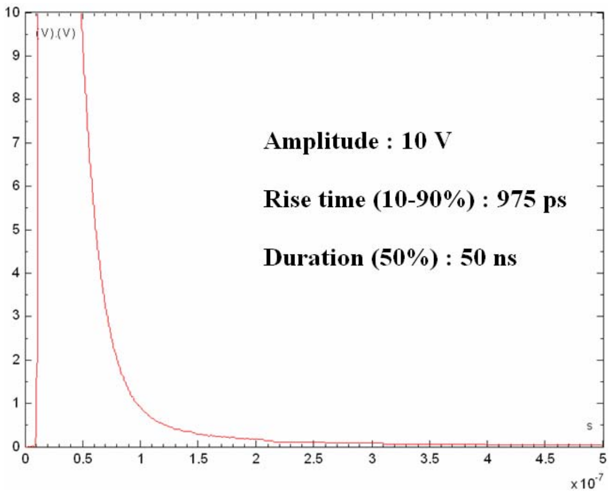

Figure 5. Case B - Electric signal after delay line and voltage limiter

3) *Discussion*

The second case seems to yield better results than the first one. However the voltage limiter used during this simulation was considered without default. Thus it is difficult to affirm this result is definitive.

Any case, this simulation confirms the theoretical approach of this specific timing system.

V. METROLOGY AND CALIBRATION OF THE DELAY LINE

The delay line used is a passive device with short length of transmission lines which are switched to generate reproducible delays [2].

A. *Metrology of the delay line*

The delay line was characterized by the two main points:

- Time accuracy
- Thermal drift

At the sight of the target precisions, these two parameters are critical and they were measured. After this first step of characterization, a calibration has been applied to improve its performances.

1) *Technical specifications*

The followings are the technical specifications provided by the manufacturer compared to those measured (see table II).

TABLE II. COMPARISON BETWEEN PROVIDED AND MEASURED TECHNICAL SPECIFICATIONS

Technical characteristics	**Provided by the manufacturer**	**Measured**
Operating range	0-20 ns	0-23 ns [1]
Minimum step	25 ps	10 ps [1]
Max. input voltage	1,5 kV	Not measured
Jitter	0 ps	0 ps

2) *Thermal drift*

The thermal drift was estimated to 2 ps / °C. It means a good temperature stability (see Fig. 5).

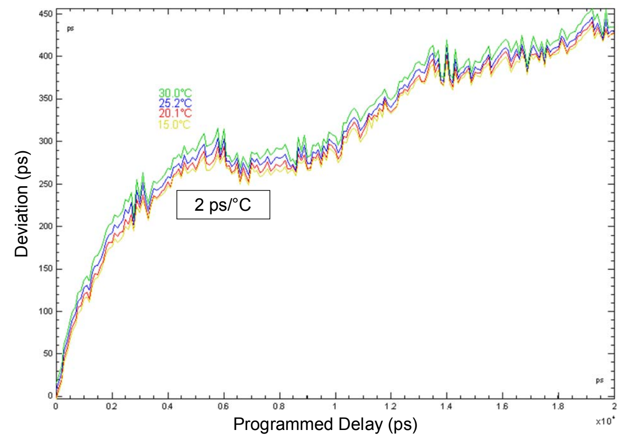

Figure 6. Accuracy and thermal drift of the delay line

B. *Calibration of the delay line*

Before our calibration, the delay line presented a poor accuracy : 450 ps (peak-to-peak value). So we applied a calibration by software to correct the gap.

The correction is based on the measured value of each delay generated by each switched transmission line. This kind of correction gives a very good result : after calibration, the accuracy is improved up to 30 ps (peak-to-peak value), that is to say 5 ps rms.

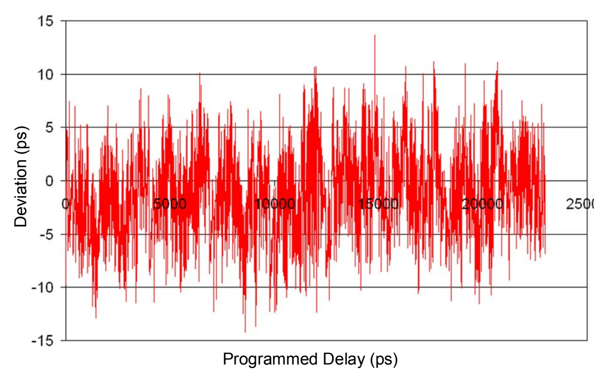

Figure 7. Delay line accuracy after calibration

[1] Values obtained after calibration

VI. CONCLUSION

We designed as specific timing system for the pulse shaping function of the LMJ. With some simulations, we realized the dimensioning of the different components of the system. Furthermore, we measured the accuracy and the thermal drift of the delay line and we calibrated it to get a high accuracy. We are also designing the voltage limiter. The first results we obtained are attractive. To continue this study, we go to develop a prototype with 8 channels during the two next years.

We are registering a patent for the principle of this timing system.

REFERENCES

[1] Timing and optical fiducial systems for the LASER MEGAJOULE, P. Raybaut, M. Prat, V. Allouche, P. Leclerc, J.F. Pastor and J.Y. Salmon, EFTF 2005.

[2] Precision Delay Line, User's Guide, KENTECH