

TIMING SYSTEM FOR THE HALPS/L3 ELI PROJECT

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Abstract

The High Repetition-Rate Advanced Petawatt Laser System (HAPLS) forms part of the European Union's Extreme Light Infrastructure Beamlines project (ELI-Beamlines) which will be the first international laser research infrastructure of its kind. HAPLS will generate peak powers greater than one petawatt at a repetition rate of 10 Hz with 30fs wide pulses. ELI will enable unprecedented techniques for many diverse areas of research. HAPLS requires a high-precision timing system that operates either independently or synchronized with ELI's system. Greenfield Technology, a producer of mature picosecond timing systems for several years, has been hired by LLNL to provide just such a timing system. It consists of a central Master Timing Generator (MTG) that generates and transmits serial data streams over an optical network that synchronizes local multi-channel delay generators which generate trigger pulses to a resolution of 1ps. The MTG is phase-locked to an external 80 MHz reference that ensures a jitter of less than 10ps rms. The various qualities and functions of this timing system are presented including the LabVIEW interface and precision phase locking to the 80MHz reference.

INTRODUCTION

HALPS is planned to become PW workhouse of the ELI-beamlines facility composed of 3 other laser systems. ELI-beamlines located in Czech Republic is designed to explore fundamental physics under extreme conditions. It will contain the world's most powerful lasers for use by the international scientific community. ELI-beamlines is one of three laser facilities currently under construction as part of the ELI project (European Union's Extreme Light Infrastructure): ELI Attosecond located in Hungary to investigate natural phenomena on ultra-short timescales and ELI Nuclear Physics located in Romania dedicated to the new field of photonuclear physics are the two remaining facilities.

HALPS's short-pulse laser will use titanium-doped sapphire as its amplification medium. This laser is designed to convert the energy from the pump laser to 30-joule, 30-femtosecond pulses for a peak power exceeding 1 petawatt. HALPS is key to firing at 10Hz for hours at a time. The aim of such a laser is to generate secondary sources of electromagnetic radiation and accelerate charged particles. It will contribute to the development of laser-driven fusion power plants as well [1].

The HALPS block diagram is depicted on Figure 1. The main parts are: a pump laser + frequency converter and a short pulse laser + compressor.

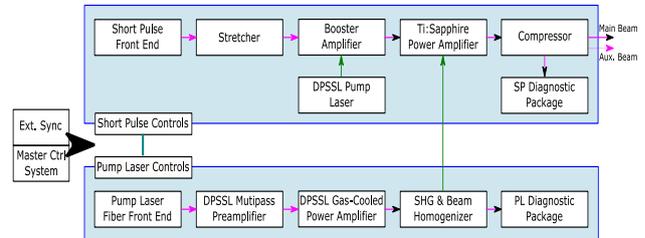


Figure 1 : HALPS block diagram

We discuss the timing system required for such a laser.

PURPOSE

Synchronization of the pump laser beam and the short pulse laser beam requires generation of numerous precisely timed triggers. In addition the output of the laser needs to be synchronized in time with the balance of the ELI-Beamlines facility.

The purpose of the facility timing system is to generate and distribute over optical fibres a serially encoded, time critical data pattern to multiple zones. These zones contain multichannel delay generators that comprise the Local Timing System. The delay generators decode the data pattern contents and generate the electrical and optical triggers required by HALPS.

The low-jitter high precision timing system from Greenfield Technology has been selected by LLNL.

LOW JITTER – 1PS ELECTRICAL TIMING SYSTEM

Greenfield Technology has developed high precision timing systems for 10 years [2]. Its timing systems are already in use in several big physic instrument systems such as SOLEIL [3], LMJ, APOLLON [4], LULI (France) or Jupiter, NIF (LLNL, USA).

The one presented here has been customized to fulfill LLNL/HALPS requirements (output standard, clock frequency and content of the serial data stream). One of the major system specifications is the MTG phase locked specification to the 80MHz external clock with an rms jitter from clock to optical data stream less than 10ps. The different parts of the designed timing system are described in the following sections.

Master Timing Generator

The primary function of the MTG is the generation and distribution of timing data. It is composed of the Master Timing Transmitter and a Control Interface.

The Control Interface function serves the dual purpose of providing internal computation and control within the MTG and as interface to an external computer: Ethernet protocol communication using TCP/IP.

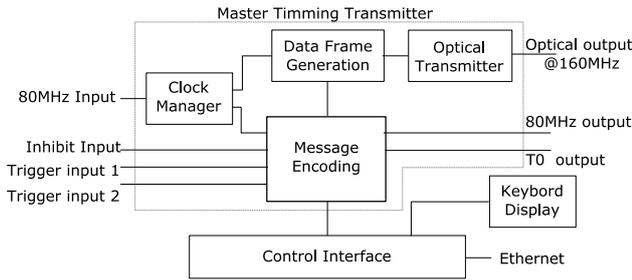


Figure 2 : MTG block diagram

The Master Timing Transmitter is composed of 4 blocks (see Figure 2):

- Clock Manager, ensuring the phase lock to the external 80MHz reference or operation in the absence of this reference,
- Message Encoding, in charge of the assembly of a data frame containing synchronization data based on both internally generated and externally provided data,
- Data Frame Generation, in charge of serialization and 1B/2B encoding of the data frame contents @160MS/s,
- Optical Transmitter, converting the serial electrical data signal into a serial optical data, 6dBm – 1550nm.

The 20 kHz rate data frame is composed of a synch pattern, dynamic data and a 2 byte CRC. The dynamic part carries periodic events – epochs, single shot events and inhibit control bit – keys.

6 epochs are encoded in the data stream (see Table 1). Epochs occur for a single frame at both fixed rates and user specified periodic rates, each epoch phased to the shortest one and coincident to the 80MHz reference clock.

Table 1 : Epochs rates

Name	Allowable Frequencies (Hz)
FE1	1000
FE2	100
FE3	10
F1	1000, 500, 200, 100, 50, 20, 10, 5, 3.333, 2
F2	200, 100, 50, 20, 10, 5, 3.333, 2, 1, 0.5
F3	50, 20, 10, 5, 3.333, 2, 1, 0.5, 0.2, 0.1

The 4 single shot keys encoded in the data stream can be initiated in one of three ways: front panel, external trigger inputs and software command. These 4 keys are two pairs of independent synchronous keys, each pair consisting of a primary key and a secondary key synchronous with the F3 epoch. A burst function is available enabling the generation of N sequenced primary and secondary keys (see Figure 3 – SS1/SS2 generation, N=2).

The inhibit key reflects the state of the inhibit control that can be controlled by either the external input or a

software command. When active, it inhibits the data frame generation.

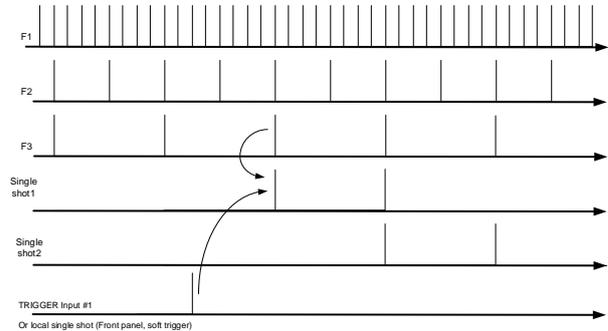


Figure 3 : Key sequence (burst mode N=2)

Multichannel Delay Generators (8 channels)

The primary function of the Delay Generators is the generation of precision trigger pulses based on user settable delays and data control keys received from the MTG via an optically transmitted serial data stream.

The control keys include epochs and single shot events that control timing of the laser system. The 8 channel Delay Generators are using an Ethernet protocol communication via a TCP/IP interface.

Channel delays are achieved by combining digital delay – coarse delay – and analog delay – fine delay. Each channel has independent delay setting. The resolution of the digital delay part is determined by the recovered clock from the optical data stream, that is to say 6.25ns. The 1ps resolution of the analog delay part is achieved by using electrical verniers. By combining both parts, the system can deliver delays in a range 0 to 10s with a resolution < 1ps, rms jitter < 15ps between two delay generators and accuracy < $250ps + delay * t_c$, with t_c related to the reference clock (e.g. Rubidium clock: $t_c \sim 10^{-12}$).

Each output delivers square pulses that can be independently set in amplitude, delay, trigger and width.

Time Interval Meter (TIM)

Its aim is to measure the elapsed time between two trigger events with 1ps resolution. This measure is reported back to the timing control computer. The timing control computer will then adjust the delay settings of the system Delay Generators such that the time difference between the two measured triggers is less than 10ps.

The purpose is to enable two independent high precision timing systems to operate as a single time coordinated timing system. The TIM is using an Ethernet protocol communication via a TCP/IP interface.

The Greenfield Technology time interval meter is 1ps resolution device that can be optically linked to the MTG (to ensure clock coherence). It is composed of 4 inputs: one start, one stop, one gate and one optical input. One interesting feature of the device is its arming mode selection: a measure can be initiated by one of the 4 inputs.

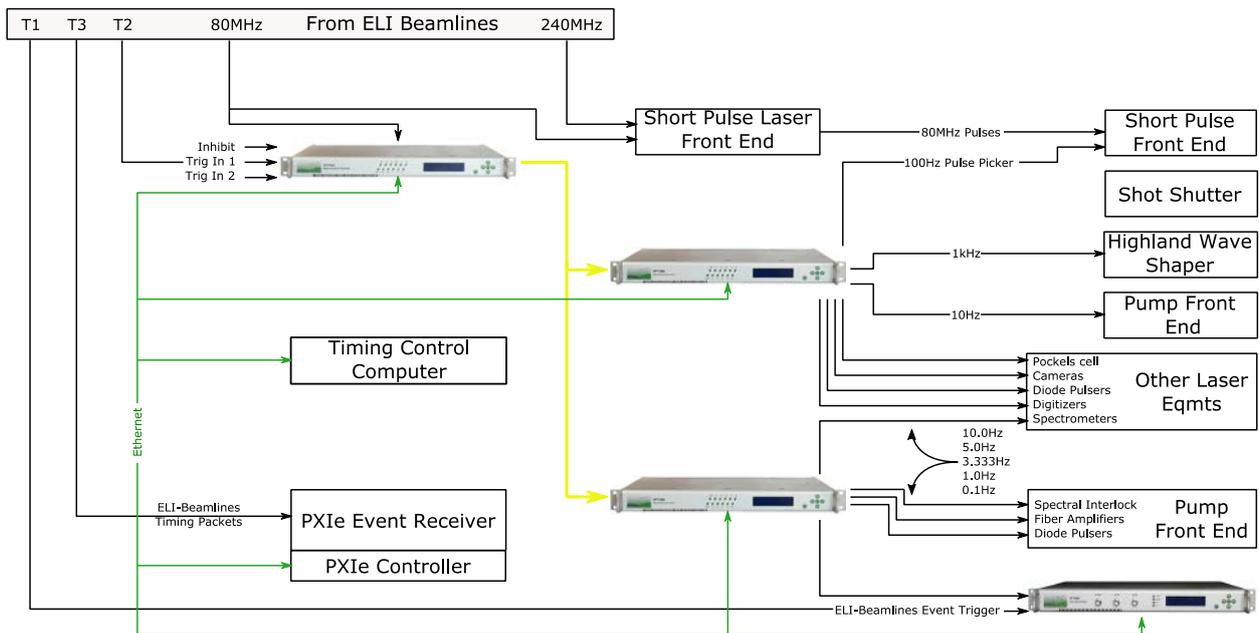


Figure 4 : HALPS timing system

PRECISION CLOCK – RATE STABILITY

The main goal of the MTG design was to achieve a jitter from reference clock to optical data stream less than 10ps rms with a phase lock relationship. The ELI Beamline system is using a 80MHz Ti:sapphire master oscillator distributed over the 4 laser rooms. This clock ensures a high stability reference to the overall system, including the timing system.

The MTG converts that 80MHz reference into a 160MHz clock used to generate 1B/2B encoded message. A “0-delay” PLL is in charge of the conversion and of the fixed phase relationship. It ensures a deterministic phase, reproducible on every device reset. Its architecture is based on a two-stage cascaded PLL: the first stage provides a low-noise jitter cleaner function while the second stage performs the clock generation locked on the internal high-performance VCO. It enables a sub-200fs rms jitter even coupled with a low cost external crystal.

The reference clock to optical data stream jitter that is achieved by the MTG is presented on Figure 5: 7.8ps rms.

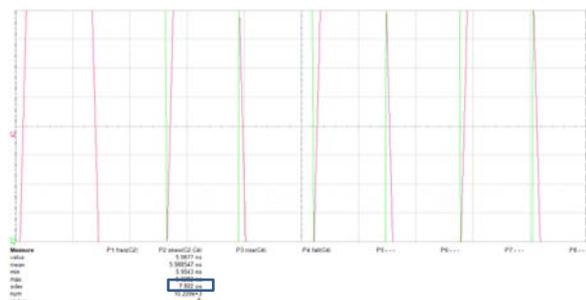


Figure 5 : Reference clock to optical data stream jitter

L3 CONTROL SYSTEM

The overall L3 timing system architecture is presented on Figure 4.

All the Greenfield Technology devices are controlled via an Ethernet link by using simple syntax commands compliant with LXI standard. An embedded control application allows any web browser to check and modify the device parameters as well. Each device is composed of a front panel allowing users to instantly check/modify device parameters locally.

Greenfield Technology provides with every devices low level Labview VIs to build its own control interface.

People from ELI have developed a complete Labview interface based on these low level VIs to control each device.

CONCLUSION

HALPS timing system is currently under test at the LLNL facility. This system will provide functionalities needed for the L3 part of ELI-beamlines with the benefit of the Greenfield Technology device flexibility.

Such a system can be extended to manage up to 256 trigger events and control more experimentation rooms.

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