High precision long-term stable fiber–based optical synchronization system

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ABSTRACT

A fiber-based , high precision long-term stable time synchronization system for multi-channel laser pulses is presented , using fiber pulse stacker combined with high-speed optical-electrical conversion and electronics processing technology. This scheme is used to synchronize two individual lasers including a mode-lock laser and a time shaping pulse laser system. The relative timing jitter between two laser pulses achieved with this system is 970 fs (rms) in five minutes and 3.5 ps (rms) in five hours. The synchronization system is low cost and can work at over several tens of MHz repetition rate.

Keywords: ICF; OPCPA; time synchronization; long-term stable

1. INTRODUCTION

In high power ultrafast laser systems, accurate and stable time control of multi-channel laser pulses is a significant technology, which has a great influence on the system reliability and accuracy. Timing jitter on the order of 10 ps (rms) is required in many physical experiments and subsystems of the laser systems.

Inertial confinement fusion (ICF) is a process of thermonuclear reaction depending on inertia thermonuclear compression and heating the material, then releasing energy[1]. Several nanoseconds laser pulses irradiate the target made of thermonuclear material at the same time to realize thermonuclear fusion. Those laser pulses are actually generated from several low power laser pulses amplified by Nd:glass amplifiers. Due to the obvious gain saturation in the amplifier[2], the front end should outputs a time shaping pulse to pre-compensate the pulse distortion cause by gain non-uniformity. Generally, for ensuring the accuracy of physics experiment, a high precision long-term time synchronization between the time shaped nanosecond pulse and a laser probe pulse is required[3]. In addition, synchronization system is also significant

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for optical parametric chirped pulse amplification (OPCPA), which requires a precise temporal overlap of the interacting pulses in the nonlinear crystal to achieve stable performance[4].

To achieve precision optical pulses synchronization, various techniques have been proposed and demonstrated, including homologous laser pulses stacker[5], homologous triggering signals[6], producing triggering signal with Si-photoconductive switch[7] and high precision scheme of generating triggering signal[8]. In the methods mentioned above, a high speed step generator is necessary to drive the electric-optical modulator. However, the process of trigging a step generator will introduce extra time jitter (>1 ps) and the step generator cannot work in the case of the repetition frequency over 10 kHz, which greatly limits the working condition of the whole system. In this paper, we proposed a new scheme with high synchronization precision without a step generator. The relative timing jitter between two optical pulses achieved with this system is 970 fs (rms) in five munities and 3.5 ps (rms) in five hours, which is the highest synchronization to our knowledge. And the synchronization system can work at several tens of MHz repetition rate. The synchronization scheme has worked for several months with high precision on the NLF (National Laser Facility).

2. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 1. A part of the mode-locked laser pulse is conditioned by the synchronization system into a shaped electric signal as the driving signal of electrical-optical modulator to realize the synchronization between the two pulses.

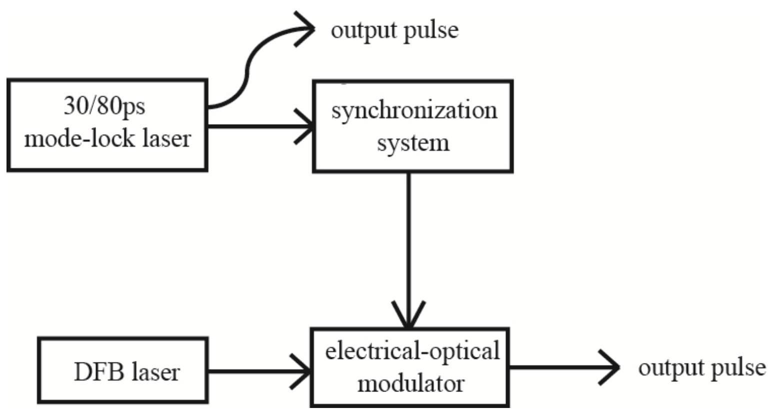


Fig. 1. Synchronization between the short pulses and the nanoseconds pulses

The laser synchronization system mainly consists of a fiber pulse stacker, an optical-electrical converter, a high speed comparator, two broadband high speed electric amplifiers and aperture-coupling stripline (ACSL), as shown in Fig. 2. The hundred-picosecond short pulse from mode-locked laser is stacked into a nanoseconds pulse with fast rise time through a pulse stacker that is composed of a series of fiber couplers connected by optical fibers in different lengths. Then the optical pulse with disorderly top is converted to an electric signal that has a rapidly rising edge the by high speed optical-electrical converter. In the synchronization system, the bandwidth of the optical-electrical converter is chosen to be 7.5 GHz to make sure that the rise and fall edge of electric signal is fast enough. After that, a high speed comparator is used for shaping the electric signal to get a high quality square wave. In addition, a broadband high speed electric amplifier is used to amplify the electric signal to several volts as the signal source of ACSL. The ACSL is able to shape the square wave into arbitrary waveform[9]. Ultimately, another broadband high speed electric amplifier is used to amplify the square wave to several volts, which is the half-wave voltage of the electrical-optical modulator. Then, a high quality electric signal with enough time width, fast rise edge and sufficient amplitude is obtained, which is qualified for driving the electrical-optical modulator used for chopping laser pulse from DFB laser. By using this system, the ultrafast laser pulse has a stable time relationship with the nanoseconds chopping laser pulses and the synchronization process between the two laser pulses is realized.

In our scheme, all the electric components have bandwidths wide enough to ensure the fast rise time and introducing the smallest time jitter is guaranteed for every step. The synchronization system can be applied to different seeds through designing the interval of fiber pulse stacker and the bandwidth of optical-electrical converter.

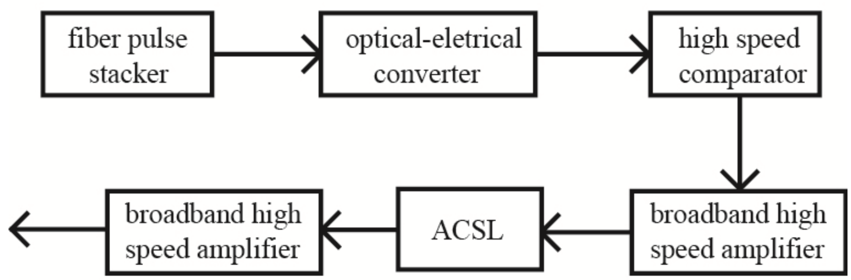
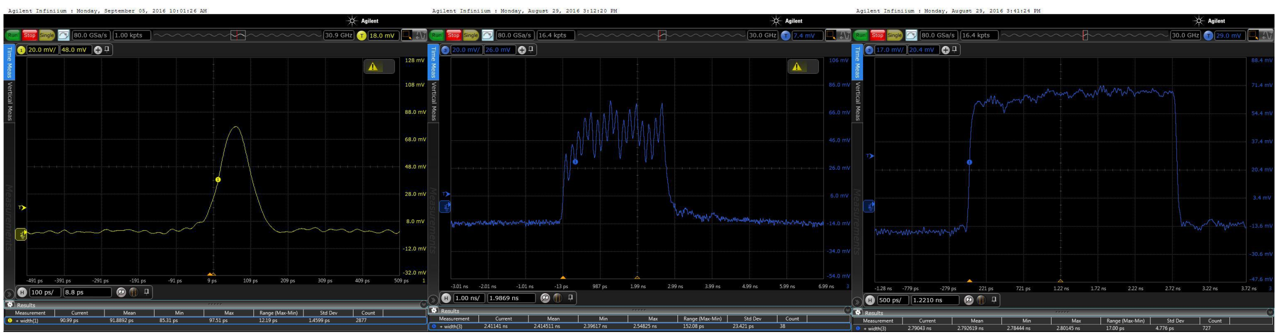


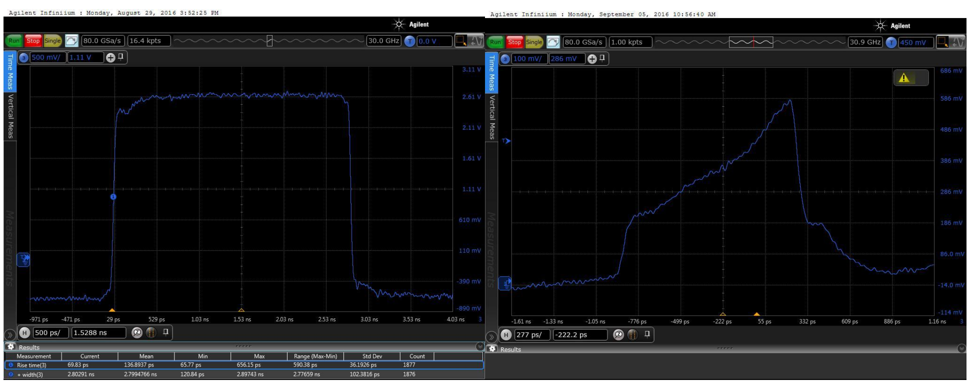
Fig. 2. Schematic diagram of the synchronization system

3. EXPERIMENTAL RESULTS

In our experiments, the experimental results are measured with a fast optical-electrical converter and a 30 GHz oscilloscope (Agilent, DSO93004L). Figure 3 shows the pulse evolution process from the mode-locked pulse to the modulation signal. The mode-locked laser provides pulses of 80 ps. Then the stacked pulse output from the fiber stacker is 2.41 ns with disorderly fluctuation on the top and has 94.2-ps rise time, while the output of comparator is 2.8 ns with fast rise time of 64.7 ps as shown in Fig.3 (a) and (b). Fig.3 (c) is the electric pulse at the end of 10-GHz broadband high speed electric amplifier, which is nearly an ideal square waveform and with the amplitude of 8 V and fast rise time of 55.6 ps. The amplitude of the signal shown in Fig.3 (c) is 2.54 V after 10 dB attenuator, so the actual value is 8 V. At last, the pulse turns into an arbitrary waveform through the shaping of ACSL, as shown in Fig.3 (e). The waveform shown in Fig.3 (e) is an ordinary waveform used in ICF with a lower front edge for gain pre-compensation as the shaping signal of the main laser. And we can get other waveform through changing the shape of stripline in ACSL.



(a) (b) (c)



(d) (e)

Fig. 3. Generating process of modulation signal. (a) optical pulse from mode-lock laser; (b) stacker pulse; (c) output of the comparator; (d) output of broadband high speed electric amplifier; (e) modulation signal out from ACSL

The synchronization profile of two laser pulses is shown in Fig. 4. The time jitter is 3.5 ps (rms) in five hours while it is 971 fs (rms) in five minutes. The extremely low time jitter presents the great precision of our system. The time jitter increasing with the time is mainly because of the thermal drift of electric components and the amplitude instability of the seed laser pulse.

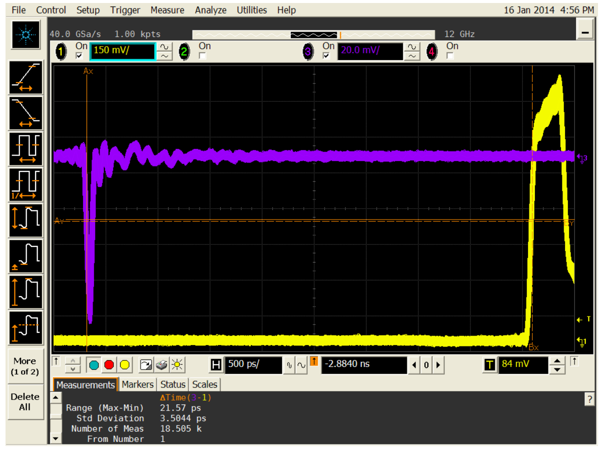


Fig. 4. The synchronization results between two optical pulses measured for five hours

Two homologous optical pulses are used to test the measurement limit of the two channels of oscilloscope. The time jitter between the two homologous pulses is 960 fs (rms) as shown in Fig.5, which can be considered as measurement limit. That means the experiment result of 971 fs in five minutes is close to measurement limit. In addition, there is no special requirement to the repetition rate of the system and it can work at 70 MHz of repetition rate in the experiment as show in Fig.6.

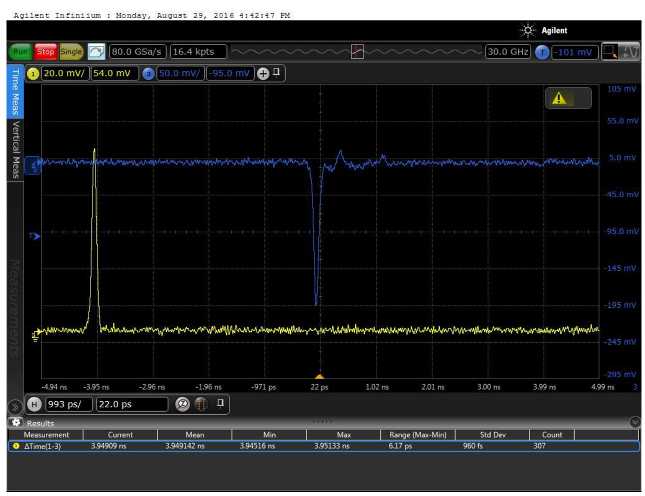


Fig. 5. The time jitter between two homologous pulses

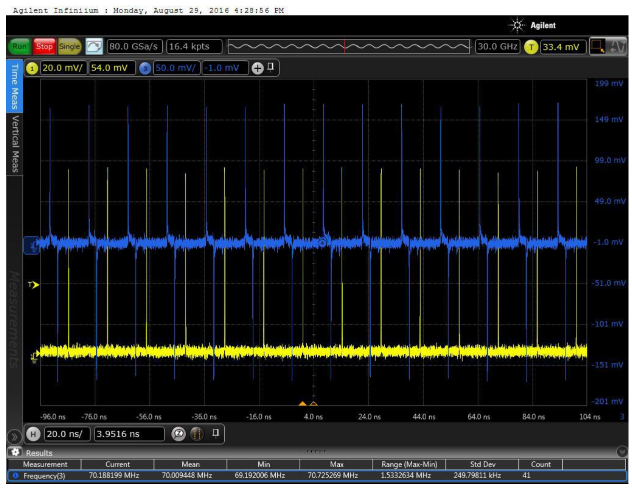


Fig. 6. The impulse sequences out from the mode-lock laser and ACSL

4. CONCLUSION

In conclusion, a high precision long-term stable fiber–based optical synchronization system is presented, which is compact, low cost and can work at over several tens of MHz repetition rate. The result of the experiment shows that the synchronization is reliable and the synchronization precision can greatly meet the demand of physical experiments. The synchronization system is used in NIF laser system to synchronize long and short lasers and has shown excellent properties.

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