DEVELOPMENT OF TRIGGER AND CLOCK DELAY MODULE WITH ULTRA-WIDE RANGE AND HIGH PRECISION *

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Abstract

Pump and probe experiments using short pulse lasers and synchrotron radiations require precise timing relation between the laser pulse and the RF reference signal of the accelerator. The pulse laser needs clock signal for a mode-locked laser and trigger signal for a regenerative amplifier. The delay time of these two signals were usually adjusted by using a mechanical phase shifter or a cable delay. They have disadvantages of short tuning range or discontinuity in the clock signal. We developed a new delay system, which can continuously change the delay time with the range over 200 ns and the precision better than 3 ps. The key point of the system is combination of an IQ modulator and a synchronous counter. The IQ modulator can change the phase of the RF signal with infinite amount with high precision in ether positive or negative direction. The phase-modulated RF signal is fed to a frequency divider and its output is used for the clock signal of the mode-locked laser. The signal is also fed to the synchronous counter and its output is used for the trigger of the regenerative amplifier. The effectiveness of this system was confirmed by an experiment carried out at the SPring-8. Composition of the delay system, performance and its applications are described in the paper.

INTRODUCTION

The SPring-8 is one of the 3rd generation X-ray source facilities. One of outstanding features of the SPring-8 is its flexible time structure. The FWHM of the X-ray pulse width is about 40 ps. The interval of the pulses can be changed from 2 ns to 600 ns by using a various filling patterns. The interval can be increased of the order of millisecond by using a high-speed mechanical shutter (X-ray Pulse Selector: XPS). Using this feature, time resolved experiments, such as nuclear magnetic resonance, pump and probe experiments are carried out at the SPring-8. In the pump and probe experiments a time evolution of the excited state of material pumped by a laser light (or X-ray) is measured by probing X-ray (or laser light) by changing the irradiation timing of pumping light. In the experiments we need following signals:

a) Clock signal for a mode-locked laser whose frequency is 84.76 MHz, which is one-sixth of the RF reference frequency of 508.58MHz.

b) Trigger signal for a regenerative amplifier with, for example, 949Hz repetition rate.

c) Trigger signal for a XPS with same repetition rate as b).

All these signals should be precisely synchronized to the timing of the X-ray. And the clock signal of a) should be continuous to avoid frequency jump of the mode-locked laser. Because the X-rays are generated from the electron bunches stored in the ring, and the timing of the electron bunches are determined by the acceleration RF system, the signals for the laser can be generated from the RF reference signal. Usually mechanical delay modules such as trombones or cable delays are used to change the clock timing. But they have disadvantages: the trombone has a short tuning range, and the cable delay has a discontinuity when the delay length is changed using RF switches.

To achieve the large delay range with high precision without discontinuity, we developed a new timing system. It consists from a phase delay with infinite tuning range and a synchronous counter. Detail of the composition of the system and its performance are shown below.

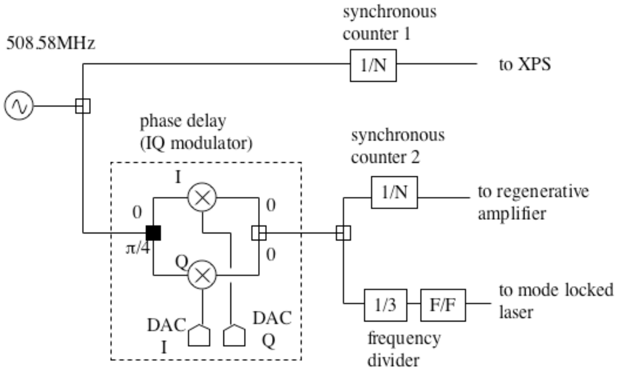

Fig. 1. Schematic diagram of the trigger and clock delay system.

COMPOSITION OF TRIGGER AND CLOCK DELAY SYSTEM

The trigger and clock delay system is composed by a phase delay and a synchronous counter. Fig. 1 shows the schematic view of the trigger and clock delay system. The 508.58MHz-RF reference signal is divided into two. One is fed to a synchronous counter No. 1 to generate a trigger signal for the XPS. The timing of the signal is adjusted to synchronize that of X-ray pulse. The other reference signal is fed to a phase shifter to make a delayed reference signal. The delayed signal is divided into two. One is fed

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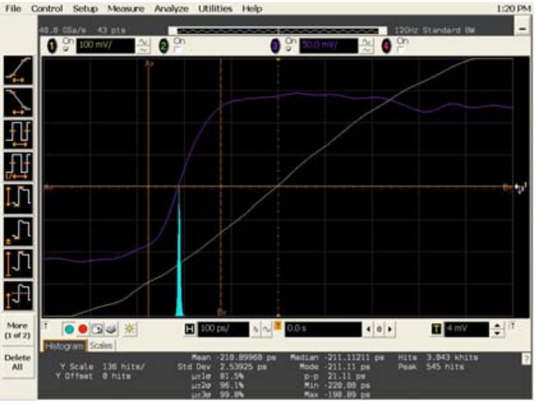
to a frequency divider to generate a clock signal for the mode-locked laser. The other delayed signal is fed to a synchronous counter No. 2 whose output is used for triggering the regenerative amplifier.

The timing of the laser pulse can be changed by changing the amount of the phase delay. If the phase delay is increased by π/4 using this phase shifter, the phase of the clock for the mode locked laser and the pulse timing from the counter No. 2 is delayed in 0.5 ns. If the phase delay is decreased, the timing is made earlier. In case of phase rotation of θ that is over 2π, there is no difference between θ and θ - 2π in the RF property of the 508.58MHz signal. But they make big difference by combining the phase shifter with the counters. The delay time of the counter can be changed much longer than the clock period of 2 ns if the phase angle is rotated in multi-turn. For example, the phase rotation of 100 turns corresponds to the delay time of 200 ns.

We use an IQ modulator as the phase shifter. The reference signal is divided to an in-phase signal (I) and quadrature signal (Q), which has π/4 phase delay relative to the I signal. Both signals are fed to the mixers. The control voltages of the mixers are set to give an aimed phase angle using DACs. The outputs of the mixers are combined in-phase and delayed reference signal is obtained. This phase can be increased or decreased smoothly, and infinitely. The phase angle is determined by the amplitudes of the control voltages from the DACs and its precision is not affected by the amount of the phase rotation. This means the precision is kept constant even if the phase rotation is very large.

We use a HMC495 made by Hittite Microwave Corporation as an IQ phase modulator. The working frequency is 0.25GHz to 3.8GHz. The control signals to the modulator are fed from a SR245 made by Stanford Research Systems that has 13-bits DACs. We use a 17K32 made by Digitex Lab. Co., Ltd as the synchronous counter, which can count up to 30bits with 508MHz clock. Two parameters N and M are set to this counter. N determines the number of the frequency division. M determines the delay time in a step of the clock period.



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 Y Scale  136 hits/        Mean  -210.89968 ps   Median  -211.11211 ps   Hits  3.843 khits
 Y Offset  0 hits       Std Dev  2.53925 ps        Mode  -211.11 ps      Peak  545 hits
                           μ±1σ  81.5%              p-p  21.11 ps
                           μ±2σ  96.1%              Min  -220.00 ps
                           μ±3σ  99.8%              Max  -198.89 ps
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Fig. 2. The screen of the oscilloscope that measured the jitter for the 508.58MHz reference clock (red line) and the output from the IQ modulator (blue line).

PERFORMANCE TEST

We measured the jitter of the output from the IQ modulator relative to the zero cross timing of the 508.58MHz reference clock using an oscilloscope DSO81204B (Agilent). Fig. 2 shows the copy of the screen of the oscilloscope. The root mean square of the jitter was 2.5 ps. Then we fed the delayed reference signal to the synchronous counter. The measured r. m. s. jitter was 2.8ps. The increase of the jitter came from the counter and not from the IQ modulator, because the jitter was not change even if the reference signal was directly fed to the counter. These values include the jitter of the oscilloscope. So the actual jitter of the delay system is less than these values.

In order to determine the precision of synchronization of the timing system in an actual experiment with synchrotron radiation, we carried out pump-probe measurements at the BL40 in the SPring-8 [1]. A lattice constant of a high-purity GaAs crystal was changed when it was irradiated with a strong laser pulse. The slight shift of Bragg angle of the crystal was measured using the diffracted X-ray intensity monitored by an avalanche photo diode (APD). Fig. 3 shows the experimental setup. The strength of the output signal from the APD was measured as a function of the interval between the laser pulse and the X-ray pulse. The interval was changed from -5 ns to 200 ns with a step of 10 ps. The speed of the phase rotation of the IQ modulator was enough lower than the response frequency of the phase lock loop in the mode-locked laser to avoid the frequency jump. Fig. 4 shows the measured intensity of the APD. The precision of synchronization between the laser pulse and the X-ray pulse was determined to be 8.40 ps from this data using deconvolution analysis. This high precision implies that the time response of shorter than 40 ps (SR pulse duration) is measurable. It also demonstrates the benefit of the top-up operation that enables the bunch current almost constant.

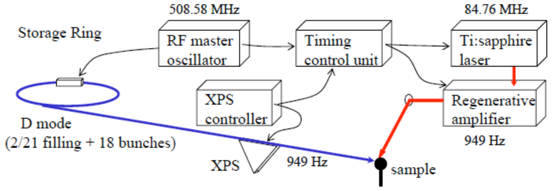

Fig. 3. The setup of the pump and probe experiment.

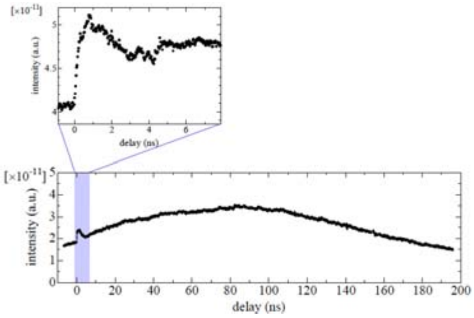

Fig. 4. The output intensity from the APD as a function of the interval between pumping laser and the X-ray pulse.

In the actual experiments, the timing of the X-ray pulse is not constant relative to the RF reference signal and is affected by the gap positions of the insertion devices, the RF acceleration voltages, the filling patterns and so on. So, at the SPring-8, the averaged synchronous phase angle is monitored every one second using a phase detector. It measures the phase difference between the 508.58MHz reference signal and the pickup signal from the button electrode. Fig. 5 shows a trend graph of the averaged synchronous phase angle for 24 hours. The figure also shows the gap positions for some insertion devices. We can see a clear dependence of the synchronous phase on the gap positions. The synchronous phase angles of all buckets are also measured using a high-speed oscilloscope every one minute [2]. Fig. 6 shows an example of the current and the synchronous phase angle of the bunch as a function of the bucket address. The filling pattern is eighteens single bunches with 1.5 mA bunch current and 116 bunch-train that carries the charge corresponding to 73 mA. The RF voltage in the acceleration cavity is reduced as the bunch train passes through because of its high beam loading, and the voltage is recovered gradually during the passage of the single bunches where beam loading is small. Measured synchronous phase angles are stored in a database and by using them the SR users can make compensation to their experimental data.

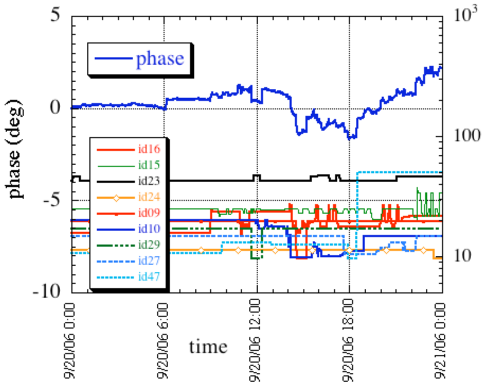

Fig. 5. The averaged synchronous phase angle and the gap positions of insertion devices.

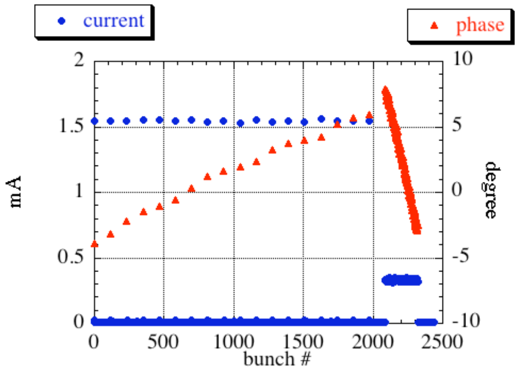

Fig. 6. The current (circle) and the synchronous phase angle (triangle) for the electron bunch as a function of the bucket address.

NEW TIMING MODULE

We are now under fabrication of a module that has all timing function in it by Candox Systems. Inc. The front panel of the module is shown in Fig. 7. The size is 19" wide and 2U height. The input frequency range is from 250 MHz to 800 MHz. The frequency-dividing ratio for laser clock can be selected from even integer of 2 to 512. The synchronous counter for laser amplifier is 32bit. The key components such as IQ modulator, high-speed logic circuits are mounted on a temperature controlled plate. For an application in FEL experiments, this module accepts an external reset signal for counters. The remote control is done with TCP/IP through Ethernet. Its first module will be delivered on March this year and test of the module will be done very soon.

Fig. 7. The front view of the newly developing delay module.

SUMMARY

We developed a trigger and clock delay system used for pump and probe experiments carried out at synchrotron radiation facility. It has a large tuning range of more than 200ns, and high precision of less than 3 ps. It consists of a IQ modulator and synchronous counters. The IQ modulator can be change the signal phase in a wide range over the clock period of 2 ns without degrading its timing precision. The performance was checked by a pump and probe experiment using a GaAs crystal at the SPring-8. The result showed the good time precision of less than 8 ps, which is shorter than the FWHM of the X-ray pulse of 40 ps. This also indicates a high precision and stability of the timing system, and the time structure of the electron bunch is almost constant. The timing system developed here can be used for many applications. The system can be used for laser timing control for SR experiments or FEL experiments, trigger signals for pulse magnets of accelerator and so on. A new delay module is under fabrication, which include all timing functions in 19" width and 2U height.

ACKNOWLEDGEMENTS

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