SYNCHRONIZATION SYSTEM FOR TSINGHUA THOMSON SCATTERING X-RAY SOURCE

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Abstract

Tsinghua Thomson scattering X-ray Source (TTX) generates X-ray based on Thomson scattering method. The synchronization system for TTX includes reference distribution, normal conducting cavity Low Level RF control and Laser-RF synchronization. In collaboration with LBNL, we're working on a prototype synchronization system for TTX. Some test result based on Tsinghua Thomson scattering X-ray Source were obtained. In this paper we will show the synchronization system design and preliminary test result.

INTRODUCTION

Synchronization system is a critical system for modern light source which is based on electron accelerator. TTX will generate high quality X-ray pulse from the scattering between Terra watt infrared laser and short electron bunch.

The tasks for TTX synchronization system are: (1) 2856MHz RF reference signal precisely distribution. (2) Low Level RF control system for accelerating field stabilization. (3) Laser-RF synchronization system for both photocathode drive laser and scattering laser phase locking. In collaboration with LBNL, we've got most part of the system done. We're still working on the synchronization system evaluation and final distribution.

The preliminary test result were all obtained from TTX [1] in Tsinghua University.

SYSTEM STRUCTURE

The scheme of the synchronization system is shown in Fig. 2 [2] . The TTX implements the fiber-based CW carrier synchronization technique developed at LBNL for reference distribution [3]. The additive phase jitter budget for reference distribution system is 50 fs RMS. For each client (LLRF, Laser-RF Synchronization, Beam Arrival time Monitor), the final control additive phase noise is aimed at 100 fs RMS.

Compared with the kilometers XFEL facilities, the 100 m TTX facility is relevant small. This will give less stress to the TTX synchronization system.

Reference Distribution

The scheme of reference RF signal distribution system is shown in Fig. 1. CW laser, laser amplitude modulator, reference signal generator and EDFA formed the 'Transmitter' for laser link.

The details about this technique can be found in [3]. The components in the dotted box should be temperature controlled within ±0.01°C. At the receiver end, there is an temperature controlled box, which is not only for temperature stabilization but also for drift compensation.

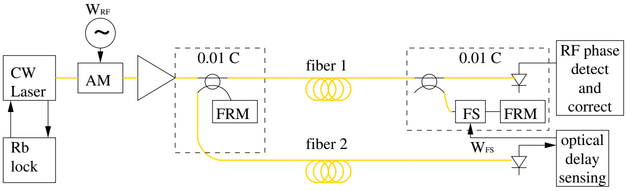

Figure 1: TTX Timing System Scheme.

In our system we haven't added the Rb vapor lock module for cw laser wavelength stabilization yet. During the preliminary test, it shows that the synchronization system of TTX will not be limited by the lack of Rb vapor lock module. In order for long term stabilization, this module will be added to our system later.

There is a receiver chassis for distributed reference signal recovery and link error correction. The receiver chassis also plays another role as Low Level RF (LLRF) controller or Laser-RF synchronization controller. Figure 3 shows the receiver chassis. The chassis is composed of two LLRF46 board, 7 down converters, 2 up converters and a Local Oscillator (LO) generation board.

The important signals in Synchronization system are listed in Table 1.

Table 1: Frequency Configuration In Ref/LO Chassis

Signal	**Frequency**
Laser Fundamental	79.3 MHz
Distributed LO	404.6 MHz
RF Reference	2856.0 MHz
Down Conversion LO	2832.2 MHz
IF	23.8 MHz
FPAG Clock	101.15 MHz

LLRF Control

All the hardware for LLRF control has already be shown in Fig. 3. The hardware for Laser-RF synchronization is the same. The only differences are in the wiring diagram and

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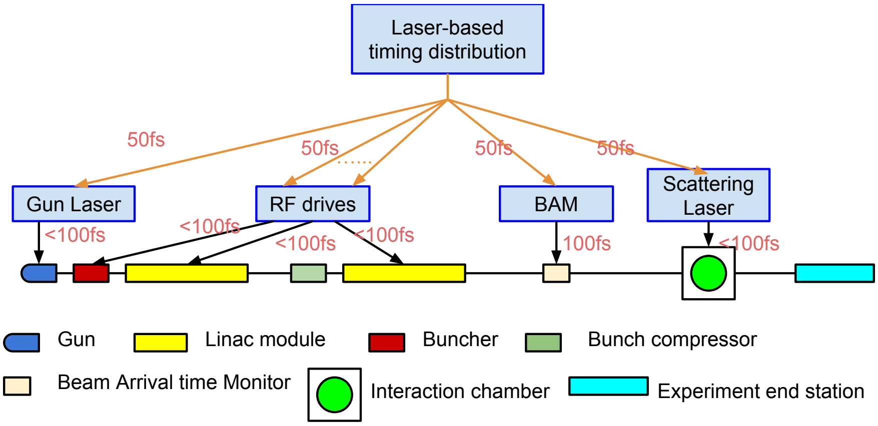

Figure 2: TTX Timing System Scheme.

Figure 3: Receiver Chassis

in the FPGA firmware. The whole synchronization system integrates all the three different systems together based on the core processing circuit ‘LLRF46’ board.

Figure 4 shows the scheme for LLRF control system [2].

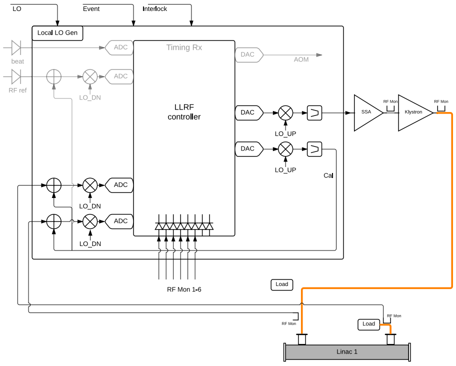

Figure 4: LLRF scheme.

Laser-RF Synchronization

Figure 5 shows the scheme for Laser-RF synchronization control system [2].

The ‘Receiver Chassis’ acts as a controller for Laser-RF synchronization. This chassis is for fundamental/harmonic signal phase detection. The detection of 79.3MHz fundamental signal is for multiple laser oscillator synchronization. And the detection of 2856MHz reference signal is for high precision synchronization.

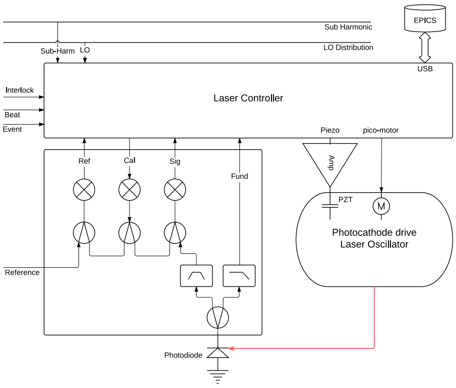

Figure 5: Laser-RF Synchronization Scheme.

SOFTWARE AND FIRMWARE

The firmware for the FPGA implements the critical algorithm of laser link stabilization, LLRF control of cavities field and Laser-RF synchronization.

The FPGA communicate with the rack mount computer through USB port. All the critical functions are working on the FPGAs once it is configured, no host computer is needed for the main function. The host computer is only used to monitor the waveforms and change setting when needed. Softioc will be running on the computer on the rack. The ioc provide full control of all the registers in the firmware.

The algorithm in the FPGA is for amplitude/phase detection and Proportional-Integral feedback. The phase detector is same as the one used in Low Level RF control system. None-IQ was used to to decode the phase/amplitude information. In the decoding procedure, we implemented CORDIC for I/Q to amplitude/phase conversion and Cascaded Integrator-Comb filter for decreasing the fast noise.

PRELIMINARY TEST RESULT

Reference Distribution Test

In Figure 6, the blue line is phase drift calculated from the fiber interferometer loop noted as ‘optical phase’. The green line is measured real phase drift. During the measurement, we twisted the fiber softly. We saw the reference signal through laser link was drifted by 5 ps during the 100s measurement. When we investigated into the difference between interferometer loop correction phase and real phase change, We can use the phase difference in 20s~ 60s for reference distribution additive phase noise estimation (The interferometer loop fellows the slow drift very well in this range). The rms jitter in 20s to 60s is 50fs RMS. Due to the lack of rubidium frequency lock module, the laser wavelength changing will affect the performance. After implementation of the laser frequency lock module, the performance will be improved.

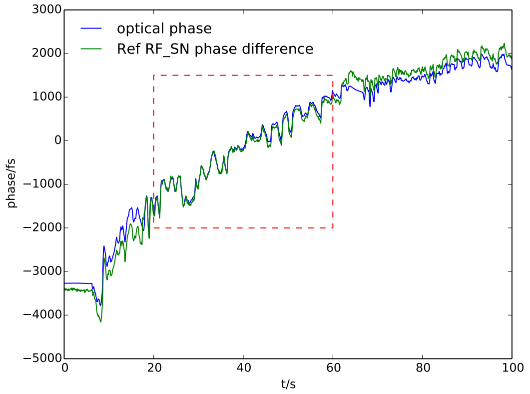

Figure 6: Laser Link Test Result.

LLRF Test

Low Level RF system (LLRF) is to generate milliwatt pulse RF signal, then amplified to high power RF to injected RF cavities. The LLRF system noise is from each component in the RF chain. We evaluated the phase noise added by difference part in the RF chain. In the last high power test, the receiver chassis itself will contribute 80fs RMS jitter (by some modification the receiver chassis will contribute 45fs RMS itself, now). The phase noise added by Solid State Amplifier (SSA) is 126 fs RMS. The phase noise added by klystron and high voltage modulator is 190 fs RMS respectively. For TTX project, high quality SSA and high performance high voltage modulator will be implemented. These preliminary test gave us a better understanding of TTX system.

Laser-RF Synchronization Test

The integral phase noise from 10Hz to 1MHz for 2856 MHz reference signal is 31fs RMS. Much lower than 100 fs RMS. So we used signal source analyzer to measure the absolute phase jitter of laser oscillator.

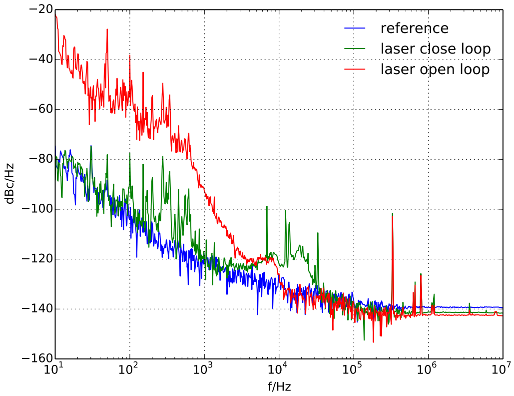

Figure 7: Laser-RF Synchronization Test Result.

Figure 7 shows the phase noise density for close/open loop laser oscillator and reference signal (carrier frequency is 2856 MHz). From this figure we can get the conclusion that our control loop can suppress phase noise lower than 3kHz. The control band width maybe limited by piezo band width. The peaks around 200kHz is the noise from the detection circuits. These peaks affected a lot. we need to upgrade the circuits. The absolute integral phase noise from 10 Hz to 100 kHz for locked laser oscillator is 57.3 fs RMS. By roughly calculation the relevant jitter between laser oscillator and reference signal should be 48.2 fs RMS from 10Hz to 100kHz.

CONCLUSION

The synchronization system prototype for TTX is almost done. We still need to get much more long term test data. In the LLRF test part, we found SSA and modulator are critical part for low noise pulse RF control. Implementation of high quality SSA and modulator is important in TTX project.

REFERENCES

[1] Du Q., Du Y., Yan L., Huang W., Li J., Tang C. Precise control and measurement of Laser–RF synchronization for Thomson-scattering X-ray source Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Elsevier, 2011, **637**

[2] Gang Huang, Q. Du, L. Doolittle, etc. Timing and Synchronization system technical design for TXGLS, 2015.

[3] Wilcox, Russell, J. M. Byrd, Lawrence Doolittle, Gang Huang, and J. W. Staples. Stable transmission of radio frequency signals on fiber links using interferometric delay sensing. Optics Letters, 2009, **34(20)**: 3050-3052.