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DESIGN OF THE LASER-TO-RF SYNCHRONIZATION AT 1.3 GHz FOR SHINE*

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Abstract

Next generation photo-science facility like Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is aim to generate femtosecond X-ray pulses with unprecedented brightness to film chemical and physical reactions with sub-atomic level spatio-temporal resolution. To fulfill this scientific goal, a high-precision timing synchronization is essential. The pulsed optical synchronization has become an indispensable scheme for femtosecond precision synchronization of X-ray free-electron lasers. One of the critical tasks of the pulsed optical synchronization is to synchronize various microwave sources. For the future SHINE, ultralow-noise pulses generated by a mode-locked laser are distributed over large distances via stabilized fiber links to all critical facility end-stations. In order to achieve low timing jitter and long-term stability of 1.3 GHz RF reference signal for the accuracy Low-Level RF(RF) field control, an Electro-optical intensity Modulator (EOM) based scheme is being developed at SHINE. In this paper, we present the progress on the design of the optical part and the integrated electronics of the laser-to-RF synchronization.

INTRODUCTION

For the large-scale X-ray free-electron laser facilities, it is a critical task to synchronize and distribute femtosecond stable radio frequency (RF) reference signals along the accelerator. The RF field stabilization is controlled by low-level radio frequency (LLRF) system and its RF reference signals have a significant impact on the energy stability and therefore then on the electron bunch arrival time stability.

Conventional RF cable distribution scheme easily exceed the required femtosecond stability due to changes in environmental factors, such as temperature and humidity. Microwave phase-locked techniques based on direct photodetection cannot overcome timing drift in photodetection and it is sensitive operating conditions of zero AM-to-PM conversion. To circumvent these issues, a balanced optical-microwave phase detector (BOMPD) based on a differentially-biased Sagnac-loop interferometers were developed and successfully demonstrated at a rather high RF of 10.225 GHz [1]. However, under the 1.3 GHz accelerating frequency, BOMPD-based scheme encounters some problems. It can be observed that the phase detection sensitivity depends on the microwave signal steepness at the zero-crossing point. Besides, at the 1.3 GHz frequency, the asymmetrically-biased Sagnac-loop becomes more difficult due to strict path length control.

An EOM-based scheme proposed by DESY group has demonstrated that it is well suited for the 1.3 GHz accelerating frequency [2]. The phase error output of the laser-to-RF phase detector is fed to an optoelectronic phase-locked loop for either locking an ultra-low noise DRO (1.3 GHz) to the pulsed optical reference, or vice versa, to lock optical master oscillator (OMO) to a RF master oscillator (RMO).

LASER-TO-RF PHASE DETECTOR

The pulsed optical reference is delivered by Menhir Photonics Inc, operating at a wavelength of 1555 nm and at a repetition rate of 216.67 MHz, delivering ~ 140 fs pulses to the stabilized fiber links. It is expected that the added timing jitter of the stabilized fiber link is below 5 fs rms integrated from 10 Hz to 10 MHz. The pulsed optical references are distributed by the stabilized fiber links to various end stations along the accelerator. The stabilized fiber links based on balanced optical cross-correlator (BOC) [3] are actively stabilized in order to compensate timing drift induced by length changes of the laid fiber links and to propagate the femtosecond stable reference pulses to the end stations, such as the laser-to-RF synchronization.

A commercially available 1X2 dual-output electro-optical intensity modulator (EOM) is the central component of the laser-to-RF phase detector. Before the pulsed optical reference of the stabilized fiber link output enters the 1X2 dual-output EOM, it is split by a polarizing beamsplitter cube (PBC), and one part is delayed by 1/4 period relative to the other part. Then the two optical pulses are recombined and enter the EOM, where their amplitude is modulated. Those two output signals show an inverted modulation. Following the EOM, one of those two outputs is delayed by 1/2 period relative to the other output. Both outputs are recombined again and detected by photodetector. Finally, two error voltages are obtained. The phase voltage error is used to lock to the pulsed optical pulses. For the proper operation of the EOM needs to be biased into the working point with the steepest voltage response. Therefore, the bias voltage error has to be continuously fed back to stabilized the output power to the 50% transmission point, which is the most sensitive point.

Optical Part

The optical part for the monitor, polarizing beam split, first delay, first recombination, electro-optical modulation, second delay, second recombination and local reference output is shown in Fig. 1.

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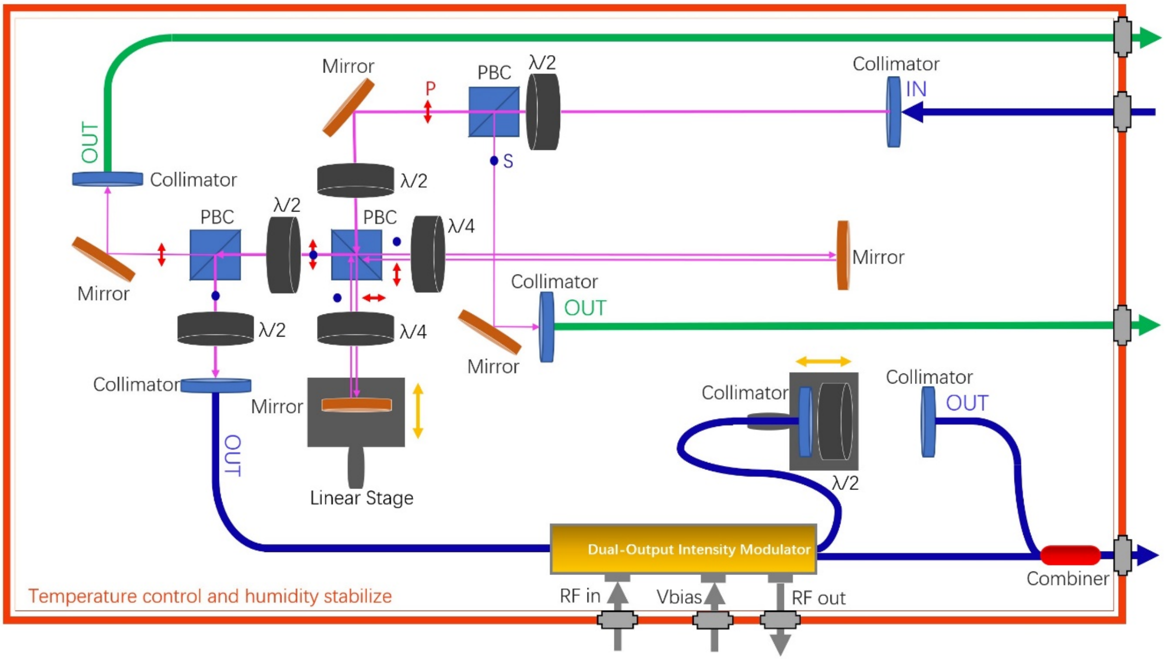

Figure 1: Diagram of the optical part.

Before the pulsed optical references enter the collimator (IN), it is split by Faraday rotator mirror (FRM), with 10% transmission and 90% reflection. After exiting from collimator, the transmitted optical references incident into the free space. Meanwhile, the reflected optical references re-enter the stabilized length link to stabilize the length of the fiber. In free space, a small fraction of the optical power is split by PBC as the local reference output, which is required for the electronics. Then, the optical references are split and precisely adjusted by linear stage. A half-wave plate is used to rotate the polarization coupled into a polarization maintaining pigtailed collimator, which is followed by a 1X2 dual-output EOM. The RF input of the EOM either from the DRO or directly from coaxial cable RF reference distribution system originating from the RF master oscillator and then feed into the EOM. The EOM with RF output not only has higher thermal destruction, but also can be used as a phase-locked RF output, from where the synchronized 1.3 GHz RF reference can be used to connect any end stations that need such a high precision and stable synchronization RF reference. The EOM features two polarization maintaining fiber outputs. One of the outputs will enter the free space for the second delay and be combined with the other one without delay in a fused fiber polarization combiner. The combiner combines the delayed and the non-delayed outputs into a single fiber and then transmits both the two modulated pulses fully to a photodetector and differentiated in the electronics.

For laser-to-RF phase detector, the stability of temperature and humidity are critical. Therefore, carefully engineering is necessary. In the future, a dedicated housing seals the optical part from humidity changes and supports the thermal insulation.

Electronics

The detection of the two error voltages are implemented with RF mixers. The local pulsed references, which is used as the local oscillator (LO) signal to drive those RF mixers, also come from the stabilized length link output, and thus it has a fixed phase relationship with the measured signal. The local pulsed references after photoelectric conversion are divided into two parts by a RF power divider, one of which is for in-loop phase lock, and the other is for out-of-loop long-term drift measurement. The simplified block diagram of the electronics is shown in Fig. 2.

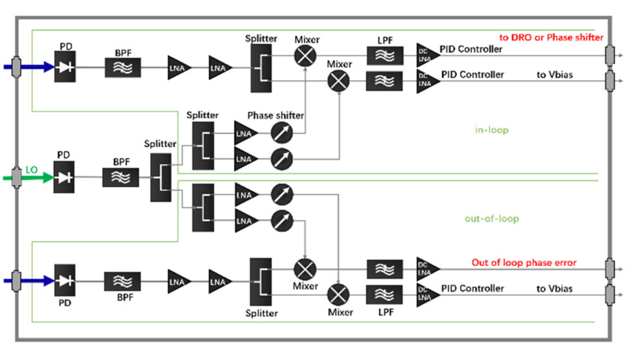

Figure 2: The simplified block diagram of the electronics.

The electronics printed circuit board (PCB) has been designed (see Fig. 3). After the PCB is manufactured, a set of tests will be carried out to prove its proper operation.

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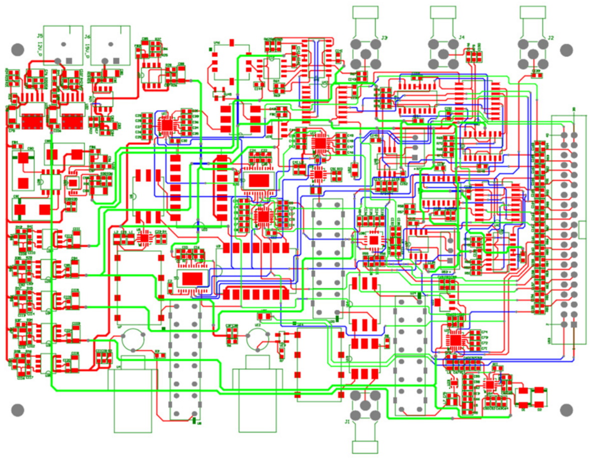

Figure 3: The design of the electronics printed circuit board.

CONCLUSION AND OUTLOOK

In order to achieve low timing jitter and long-term stability of 1.3 GHz RF reference signal, an EOM-based scheme is being developed at SHINE. The first prototype, which is set up out of components, is being assembled and tested. The optical part and the readout electronics are being integrated for a better stability and performance. Finally, all components both the optical part and electronics will be integrated in a 2.5 U housing.

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