DEVELOPMENT OF TIMING DISTRIBUTION SYSTEM WITH FEMTO-SECOND STABILITY

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Abstract

A timing distribution system with femto-second stability has been developed for the RF synchronization of accelerator and the laser synchronization of the pump-probe experiments. The system uses a phase stabilized optical fiber(PSOF) and an active fiber length stabilization. The PSOF has 5ps/km/degC of the temperature coefficient. The active fiber length stabilization uses the phase detection of the round-trip sinusoidal wave and the deviation is compensated with the fiber stretcher.

In this paper, we present the test results of the signal transmission using a 900m long PSOF for 2.856GHz and 1.3GHz RF signals. The stabilities of 2.856GHz and 1.3GHz signal transmission were 0.04degree(40fs) and 0.06degree(130fs), respectively.

INTRODUCTION

Future accelerators require the high accuracy reference signal for each acceleration component and the synchronization with the experimental devices over the long distance. In the case of International Linear collider(ILC), the reference signal of the acceleration frequency(1.3GHz) needs to have 0.1 degree(0.2ps) of the stability over 30km long. The high accuracy reference is required for not only ILC, but also for other projects in progress at KEK. Especially, the synchronization between the beam and the laser system of the pump probe experiment at energy recovery linac (ERL) requires less than 50fs stability. The required accuracy and the distance for each project are listed in Table 1. Such a high accuracy reference signal cannot be achieved by conventional coaxial RF distribution system. We developed a system using an optical fiber and the active fiber length stabilization. Some of the reference signal transfer system using optical fiber link are already investigated and tested [1-7]. We designed multi-signal transfer in a single fiber. Wavelength Division multiplexing (WDM) is used for the signal multiplexing and the round trip signal transfer. The high accuracy signal transfer is also required not only the acceleration frequency but the other frequency and the trigger signal of the accelerator. One of the frequencies is used for the feedback of the fiber length stabilization. This frequency itself can be used for the high accuracy reference. Phase stabilized optical fiber (PSOF)[8], which has a low thermal expansion coefficient, is used for the fiber to reduce the control range of the fiber length stabilization. We tested two frequencies (2.856GHz and 1.3GHz) for the feedback frequency of the fiber length stabilization.

Table 1: Frequency, Distance and the Requirement

Accelerator	Frequency	Distance	Requirement
ILC	1.3GHz	30km	*0.1° (0.21ps)*
SuperKEKB (ring)	509MHz	3km	*0.1°(0.54ps)*
SuperKEKB (Linac)	2.856GHz	400m	*1°(1ps)*
ERL (experiment)	1.3GHz	1km	*< 50fs*

SYSTEM LAYOUT

Figure 1 shows the layout of the distribution system. The lowest two pairs of optical links consist the fiber length stabilization circuit. The RF signal is converted to optical signal using a wavelength. The transmitted optical signal is converted to the RF signal and the RF signal is converted to optical signal again using a different wavelength then send back using same fiber. The phase of the round tripped RF signal is compared to the sending phase by an RF mixer. The detected phase deviation is feed backed to the fiber stretcher. The piezo-driven fiber stretcher keeps the length to constant from the sending end to the receiving end. Generally, higher frequency has high sensitivity for detecting the phase difference. A pair of WDM is used for the signal multiplexing. The advantage to use WDM is easy to add the other signal not only the RF signal but also the pulse signal. The high accuracy bean trigger is also required for the experimental detector in ILC.

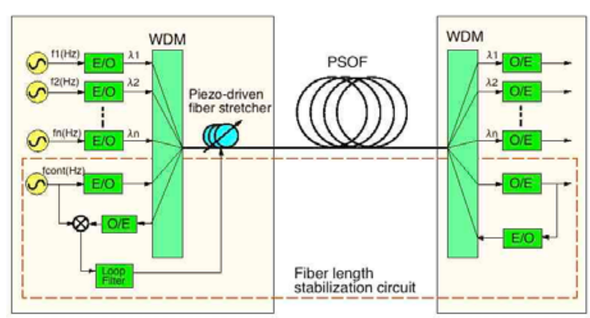

Figure 1: Overall Layout of the distribution system.
E/O: electrical/optical converter, O/E: optical/electrical converter, WDM: wavelength division multiplexing, PSOF: phase stabilized optical fiber.

We used PSOF for the transmission fiber. The specification of the thermal expansion coefficient is 5ps/degC/km. In the case of the normal fiber, the coefficient is 40ps/degC/km. The transmission delay time

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change as the function of the temperature is shown in Figure 2. Especially, the PSOF shows very small thermal expansion from 10 to 20 degree C. The small thermal expansion is essential for the achievement of the high accuracy and has an advantage for the design of the feedback circuit.

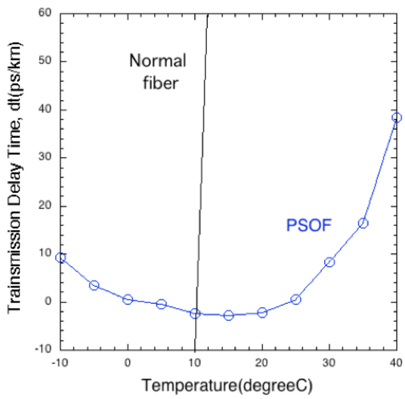

Figure 2: Comparison of the thermal expansion PSOF and normal fiber.

MEASUREMENT SETUP

The experimental setup for the stability measurement is shown in Figure 3. Two RF frequencies are tested in this setup. One is 2.856GHz used for the S-band linac and the other is 1.3GHz used for the ILC/ERL. We used SITU3000 and SIRU3000(EMCORE) for the E/O and O/E. The wavelengths of the E/O are 1552.524nm and1551.721nm, which are selected for the WDM. The WDM has more than 50dB of the signal directivity. Two fiber stretchers(FST-001, General Photonics Co.) are used in series. The maximum optical path difference of two fiber stretchers is 22ps. When a 900m long PSOF is used for the transmission fiber and the environment temperature change is assumed to 2degreeC, the thermal expansion of the PSOF is expected to 10ps.

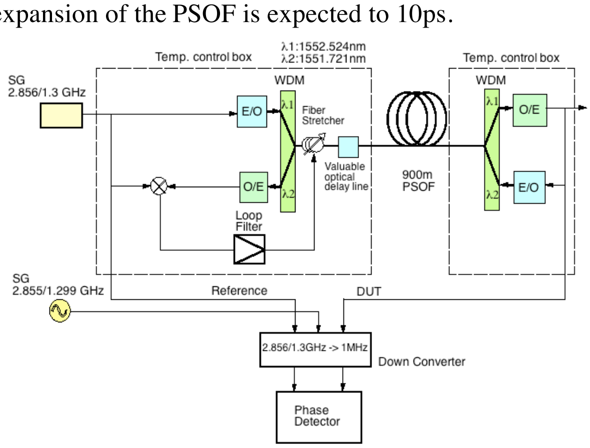

Figure 3: Experimental setup for the stability measurement.

The length of the PSOF is not selected for this experiment. We used the test fiber, which is used for developing JPARC timing system[9]. An optical delay line is installed to adjust the fiber stretcher position. The temperatures of sending/receiving circuits are stabilized to keep the range of 0.1degreeC by peltier cooling unit to avoid the phase drift in the circuit.

MEASUREMENT RESULTS

Feedback gain – We measured the feedback gain of the fiber length stabilization circuit. The feedback gain is decided by the loop filter gain. The maximum is adjusted under the condition of the low noise and without oscillation. The feedback gain is estimated from the ratio of the feedback phase and the timing change of the fiber. The phase is scanned by changing the optical delay line, manually. Figure 4 shows the measurement and the feedback gain is 44dB. It means that 16 degree of the phase change is compressed to less than 0.1 degree.

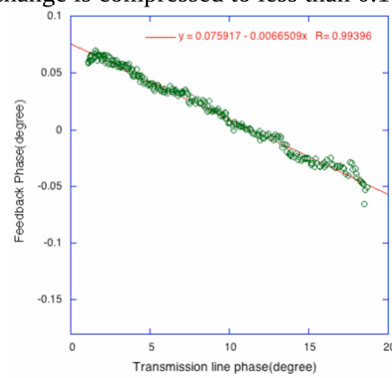

Figure 4: Feedback gain measurement.

Stability measurement (2.856GHz) – Figure 5 shows the timing stability in the case of 2.856GHz signal transmission more than 10 hours. The black line shows the phase change of the transmission line estimated from the control voltage of the fiber stretcher. The red line shows the feedback phase. The phase change of the transmission line is 2.5 degree and the phase change of feedback phase is less than 0.04degree(40fs) during the time. This measurement includes the drift of the phase detector 0.01degree.

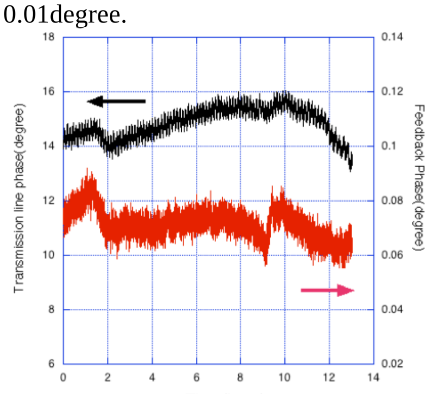

Figure 5: Stability measurement at 2.856GHz signal transmission.

The feedback phase is not proportional to the phase change of the transmission line, completely. Figure 6 shows the comparison of the temperatures and the feedback phase at the same measurement. The blue, green and black lines are the sending/receiving circuit temperatures and the room temperature, respectively. The phase change of the feedback phase is affected by the room temperature. The temperatures of sending/receiving circuits are stabilized less than 0.1degreeC, but the small temperature change is observed. This result shows that the temperature stabilization of the sending/receiving circuits is not enough to achieve the stable feedback phase less than 0.02 degree.

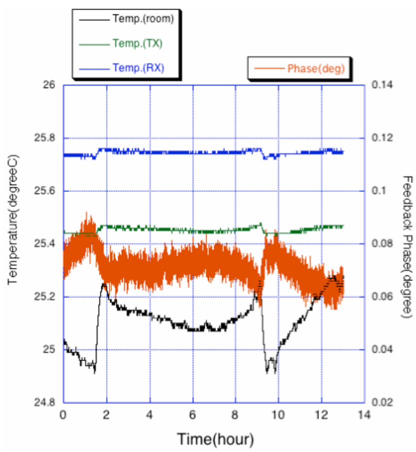

Figure 6: Comparison of the feedback phase and the temperatures

Stability measurement (1.3GHz) – Figure 7 shows the timing stability in the case of 1.3GHz signal transmission more than 10 hours. The phase change of the transmission line is 1.6 degree and the phase change of feedback phase is 0.06degree(130fs) during the time. The phase change of the feedback phase is also affected by the room temperature. The result showed almost same as the 2.856GHz signal transmission measurement. The phase change of the feedback phase does not depend on the feedback frequency, but the time difference of the receiving end is twice for the wavelength of the feedback frequency. It assumed that if higher frequency is used for the feedback frequency, the timing stability will be improved. For example, when 10GHz of the feedback frequency is used, 10fs of the timing stability will be realized.

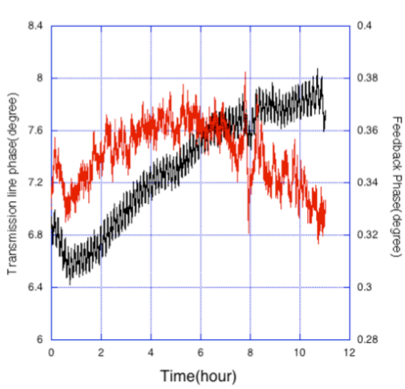

Figure 7: Stability measurement at 1.3GHz signal transmission.

SUMMARY AND FUTURE PLAN

We demonstrated the performance of the high accuracy signal transmission using the PSOF and the fiber length stabilization. The stabilities of 2.856GHz and 1.3GHz signal transmission were 0.04degree(40fs) and 0.06degree(130fs), respectively. For the next step, further stabilization of the temperature of the sending/receiving circuits and higher frequency transmission will be investigated to realize 10fs of the timing stability.

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