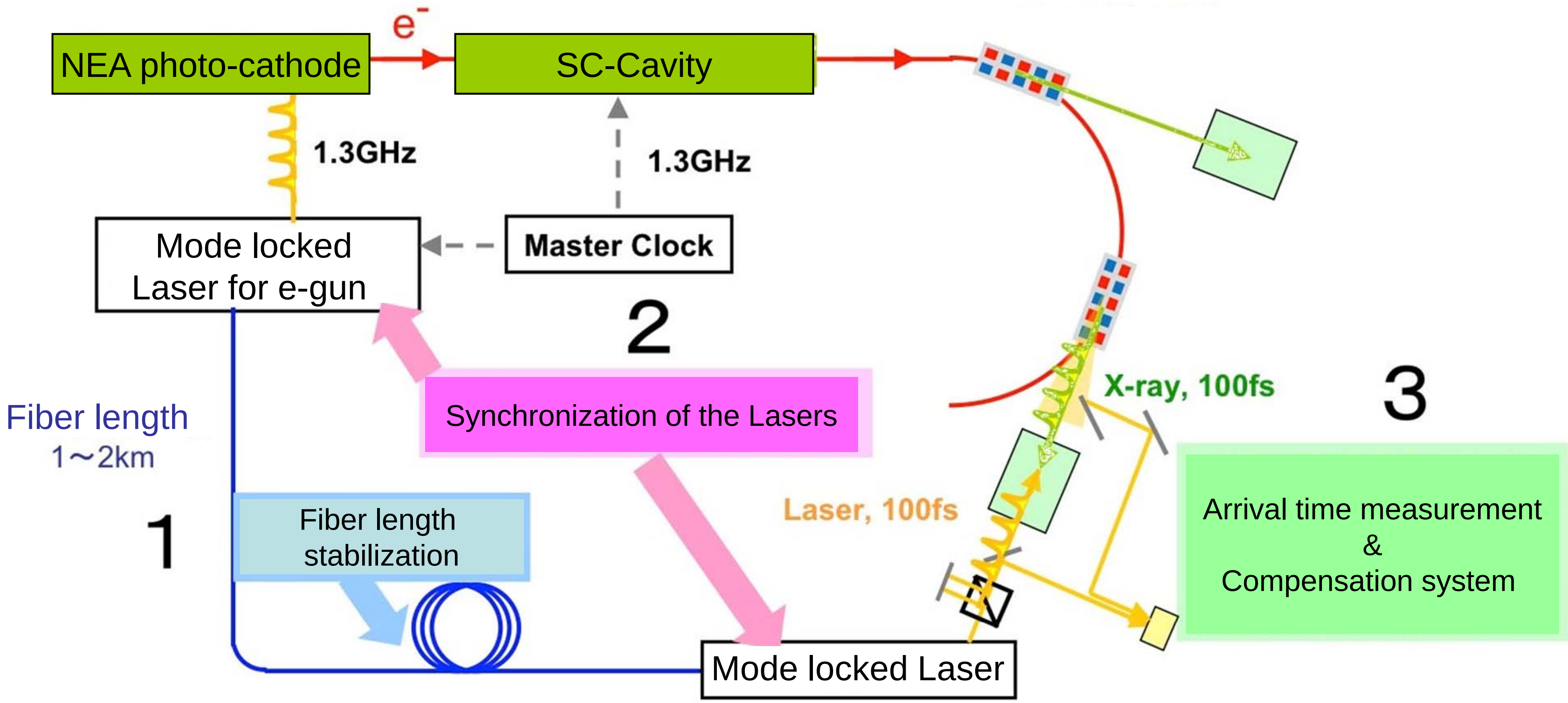
Development of femto-second Timing Distribution System

@ERL2011 WG4 2011/10/19
Takashi Naito (KEK)

ERLexp timing system requirement



Total jitter <20fs

Development issue

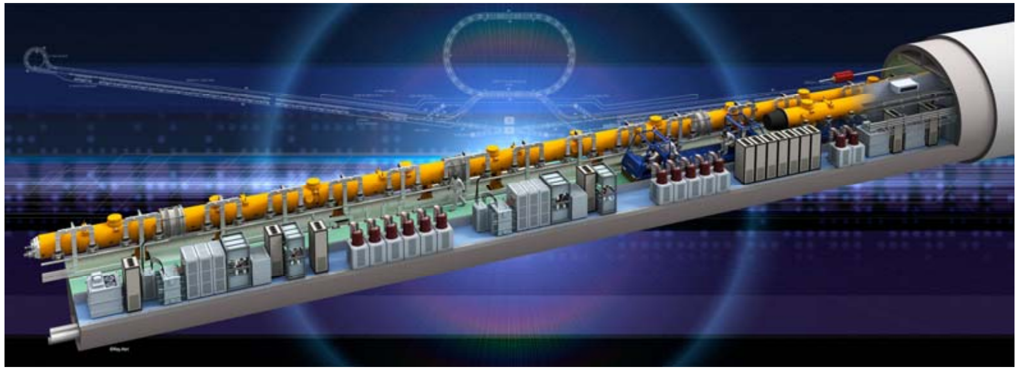
1. Timing distribution system
2. synchronization of the lasers(e-gun laser & pumping laser)
3. Arrival time measurement & compensation

Precise timing for current and future accelerators

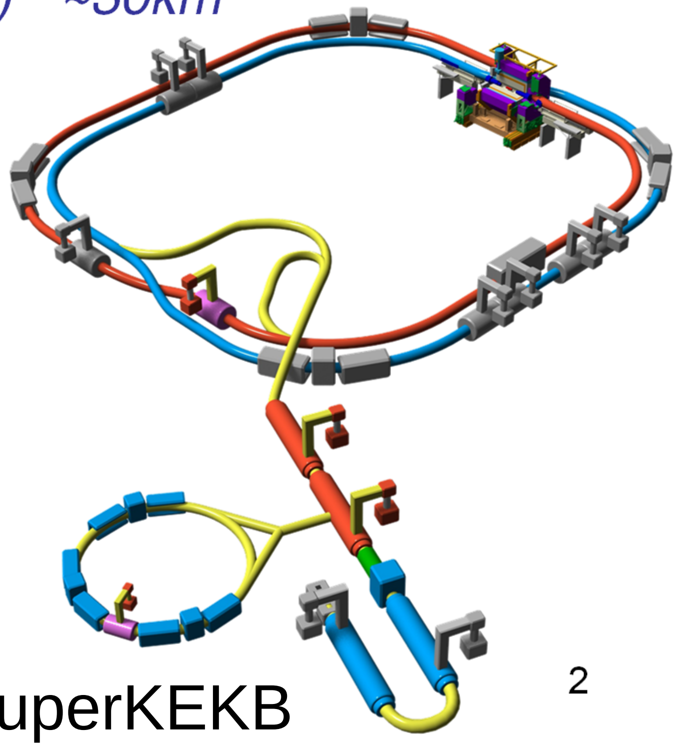
precise reference clock distribution is required not only for ERL, but current and future accelerators Super KEKB and ILC in KEK.

The reference clock for the acceleration devices needs to keep the accuracy for all locations.

•SuperKEKB (509MHz)	0.1°	(0.54ps)	~3km
•SuperKEKB (2.856GHz)	0.5°	(0.5ps)	~0.4km
•ILC (1.3GHz)	0.1°	(0.21ps)	~30km



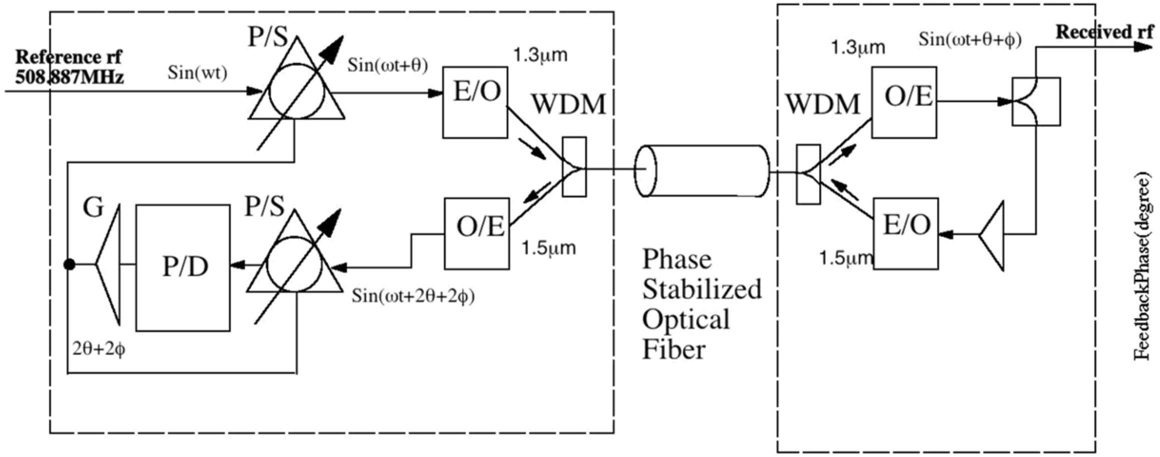
International Linear Collider

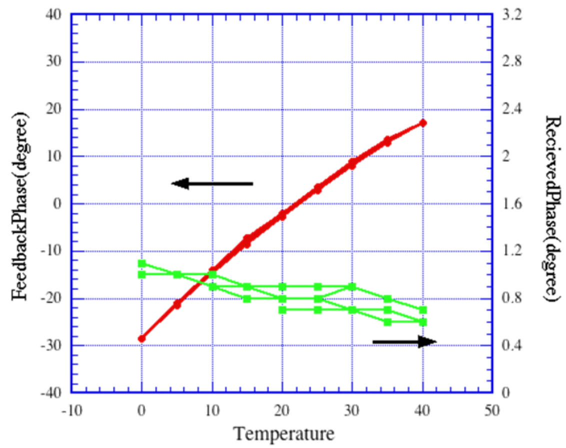


SuperKEKB

Timing Stabilization effort(previous development)

T.Naito et. al., Linac2000

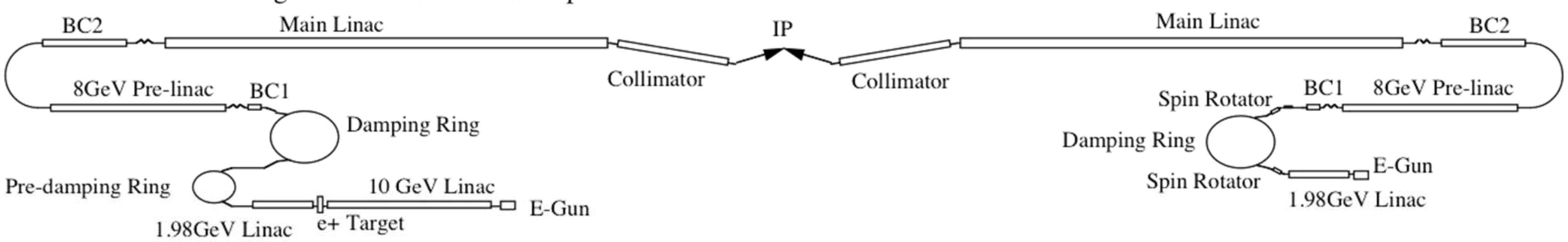


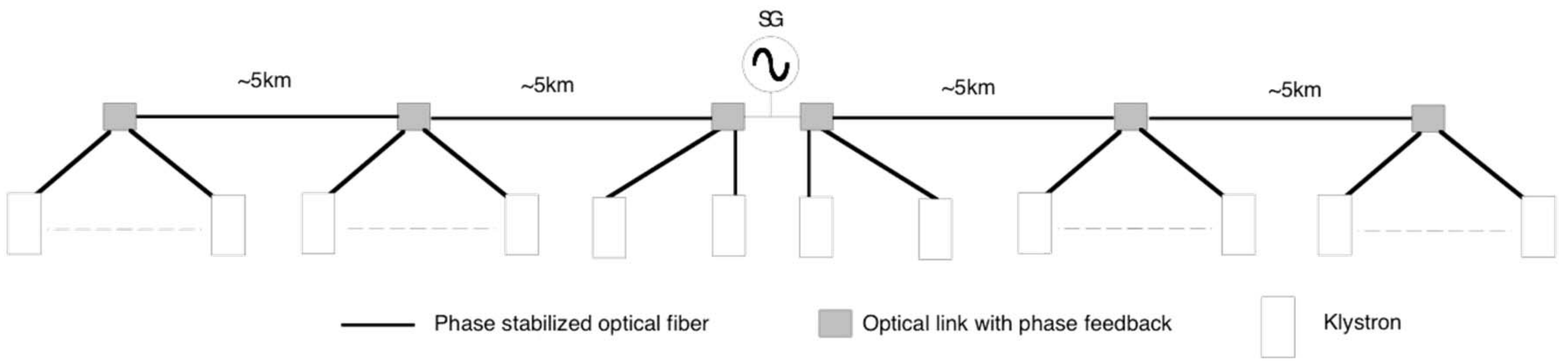


P/S: phase shifter
P/D: phase detector
WDM:wave-length division multi/demultiplexer

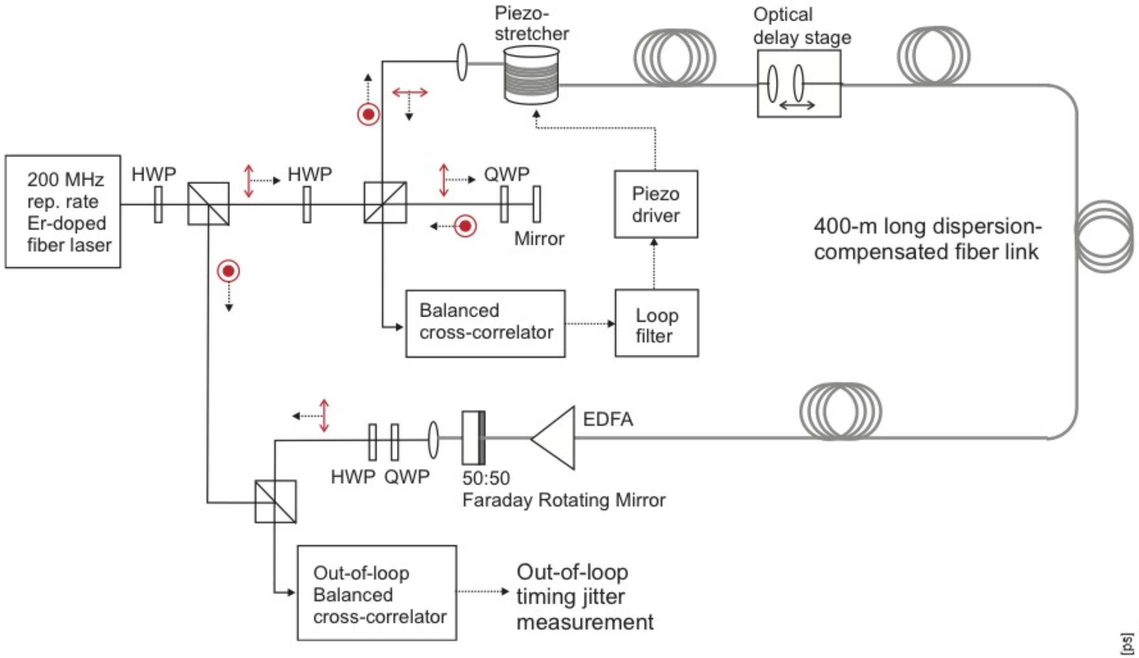
E/O: optical transmitter
O/E: optical receiver

250ps ->2.5ps





DESY Timing Stabilization system



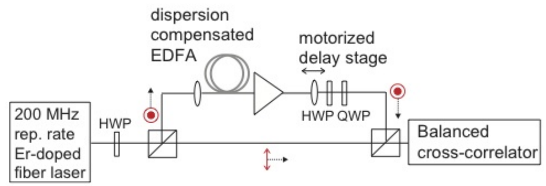


Figure 1: Experimental setup for the noise characterization of EDFAs.

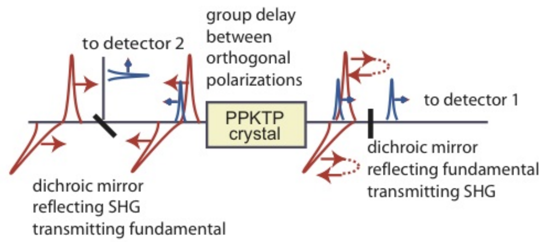
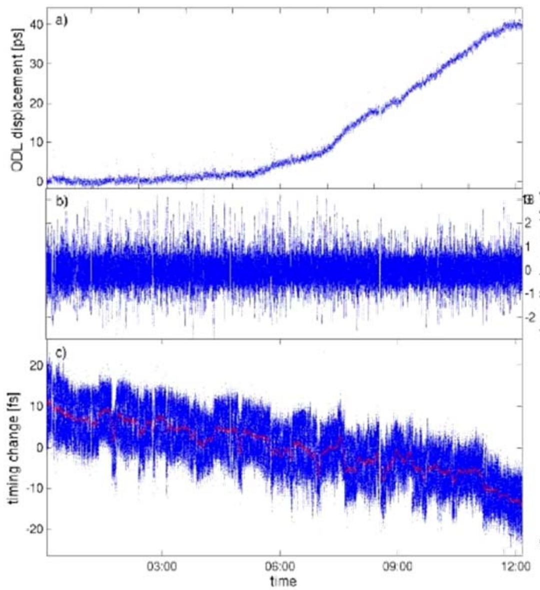


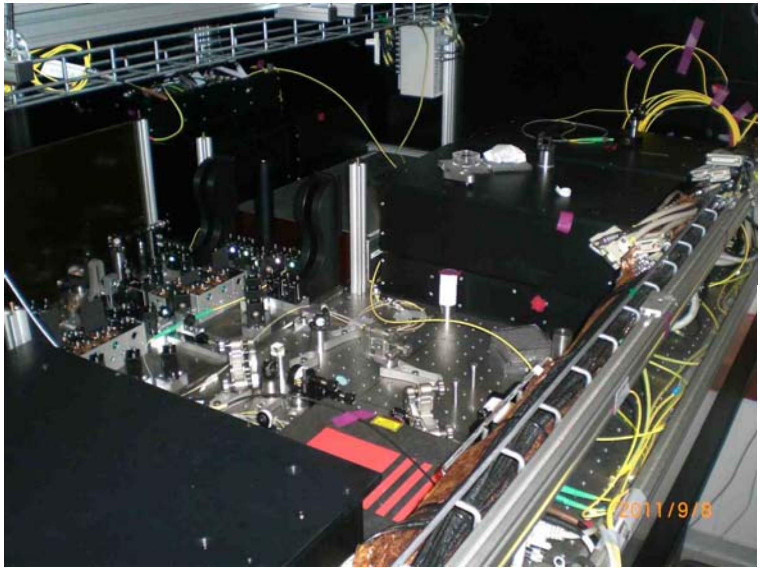
Figure 2: Principle of the balanced optical cross-correlator.

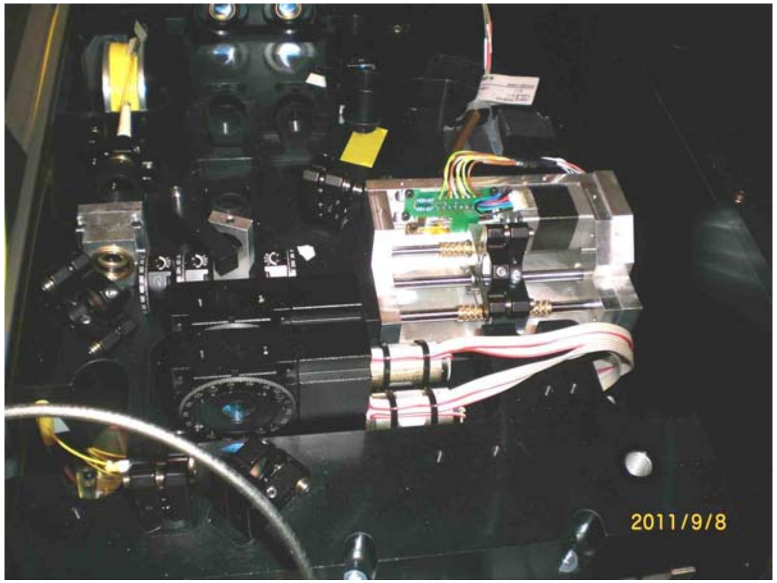


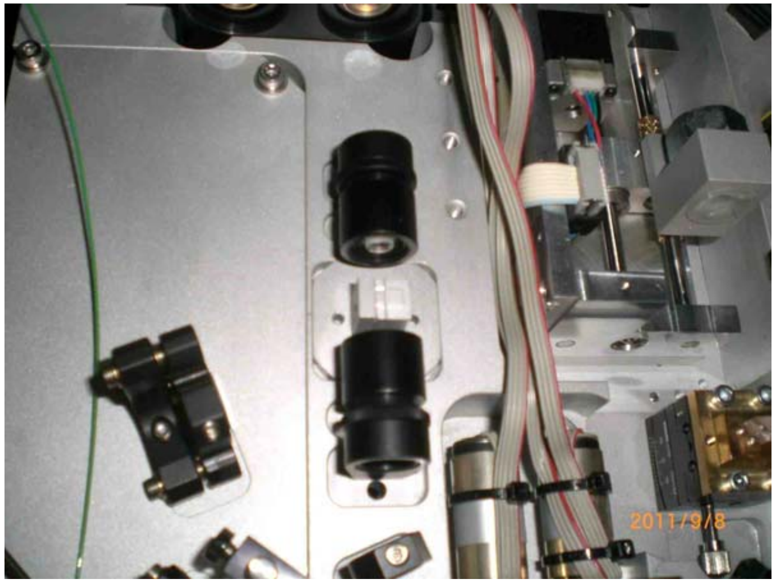
F.Loehl, et.al. PAC07

Figure 6: Drift measurement of a 400 m long fiberlink. a) Displacement of the optical delay line (ODL). b) piezo stretcher displacement. c) timing change at the end of the fiber-link. The red line indicates slow timing changes. The timing jitter is (4.4 ± 1.1) fs.

DESY Timing Stabilization system(2)







SLAC(LCLS) Timing Stabilization system

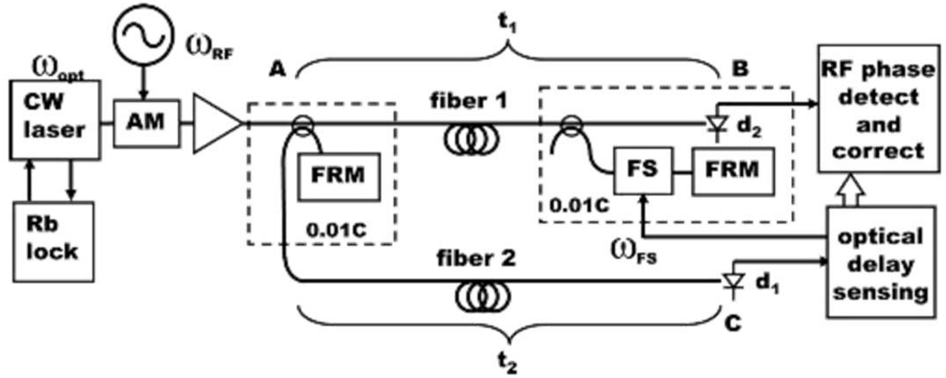


Fig. 1. Schematic layout of a single-channel rf transmission over an optical link. The rf frequency is 2850 MHz. AM, amplitude modulator; FRM, Faraday rotator mirror; FS, optical frequency shifter. Dotted rectangles indicate components temperature controlled to ±0.01°C.

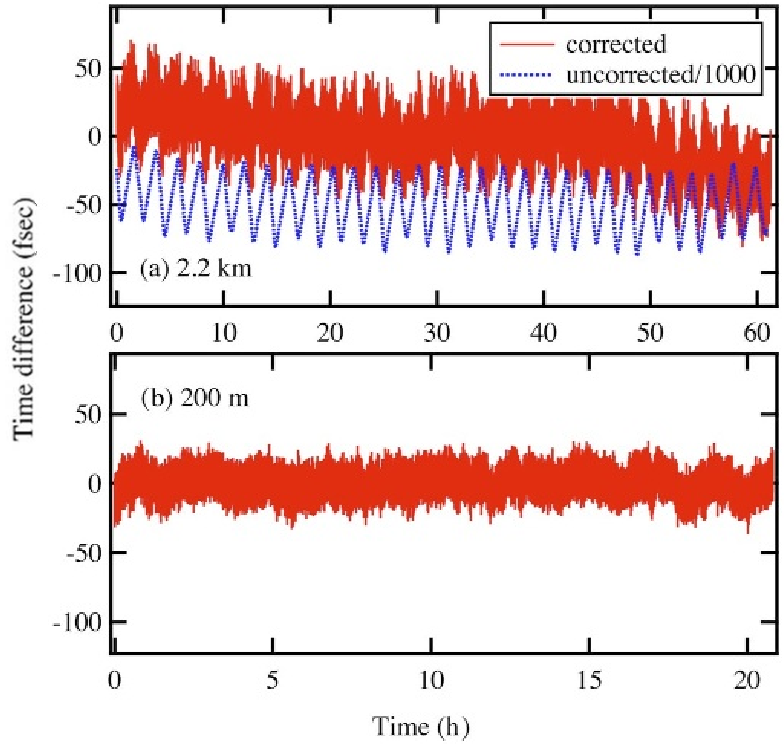
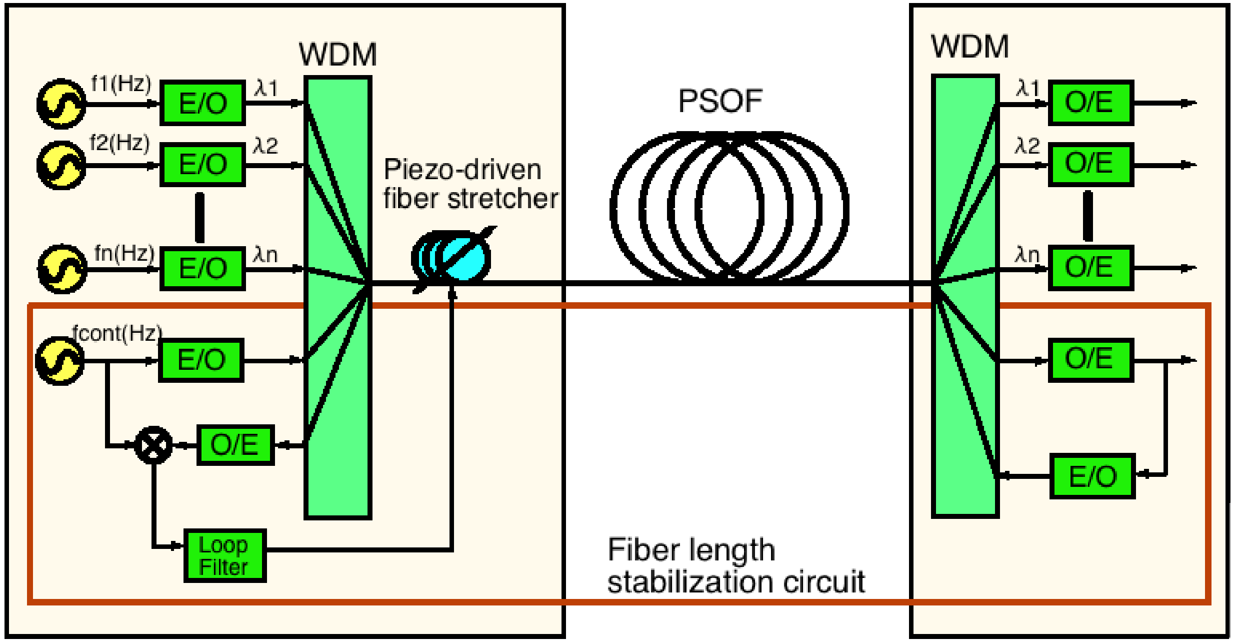


Fig. 3. (Color online) Relative drift of a 2850 MHz signal transmitted over a long and short (2 m) fiber. (a) 2.2-km-long fiber. The relative time difference has an rms deviation of 19.4 fsec over 60 h. The relative time difference (/1000) without the correction is also shown. (b) A 200 m fiber has an 8.4 fsec rms deviation over 20 h.

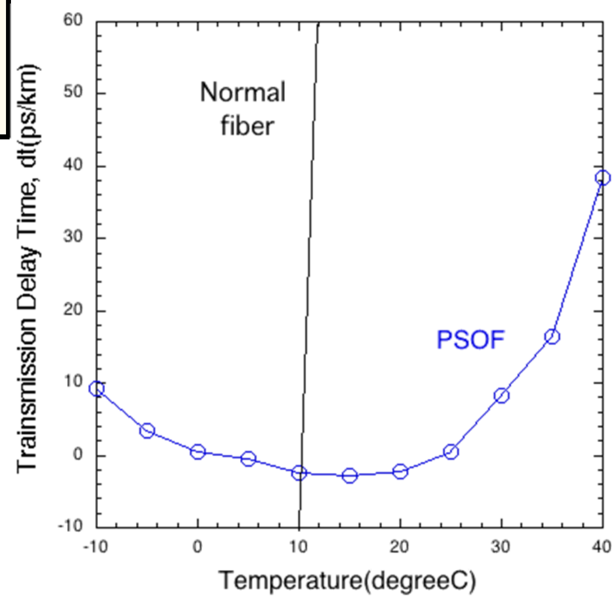
R.Wilcox, et.al. OPTICS LETTERS

System Layout



WDM: wavelength-division multiplexing

Phase stabilized optical fiber (PSOF)
5ps/km/degC



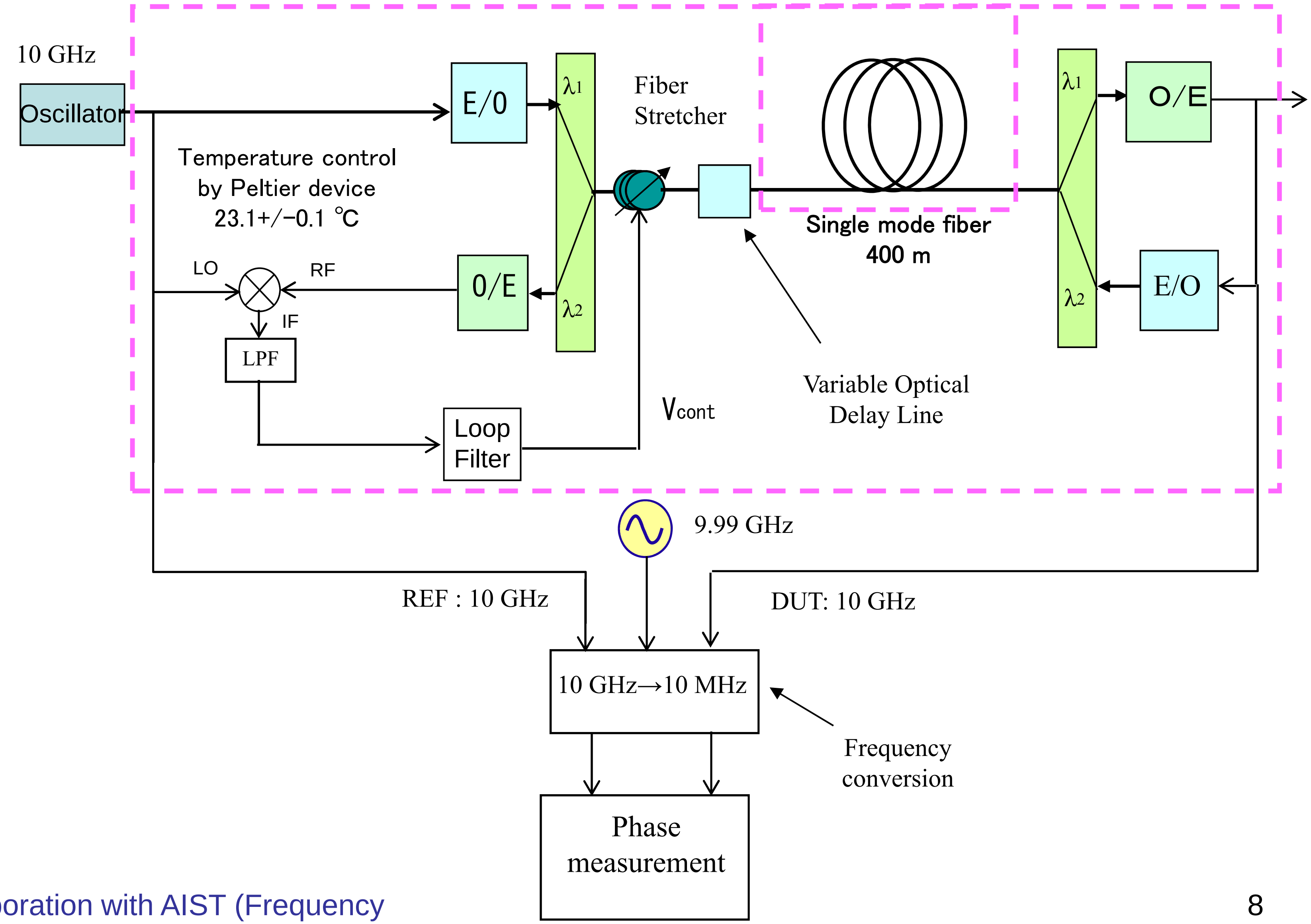
Feature of this system

•PSOF for small thermal expansion

•FB with fiber stretcher, simple and reliable

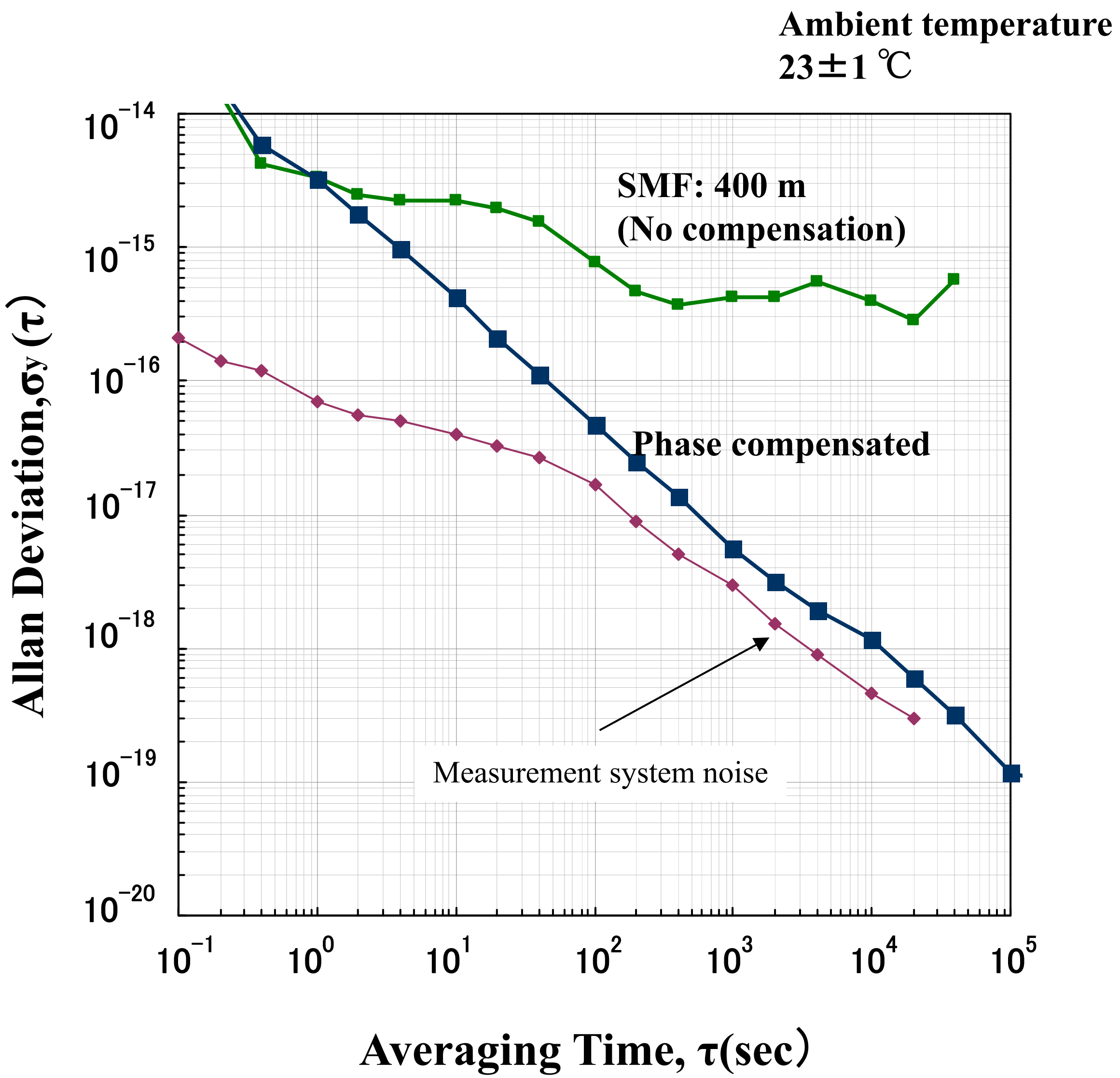
•WDM for multi-signal transmission

Fiber length stabilization circuit（Freq:10 GHz）

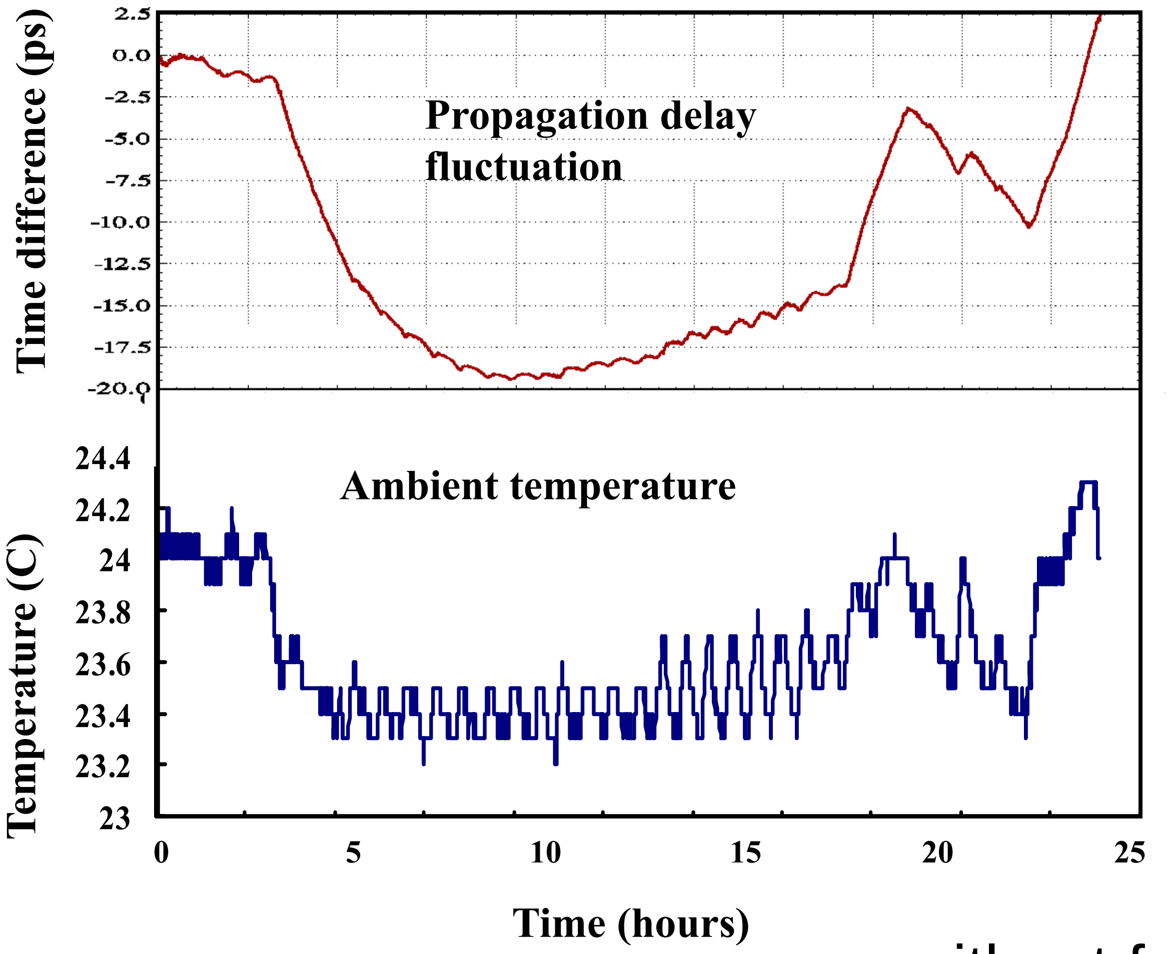


Collaboration with AIST (Frequency measurement system section, NMJ)

Allan Deviation of the phase FB

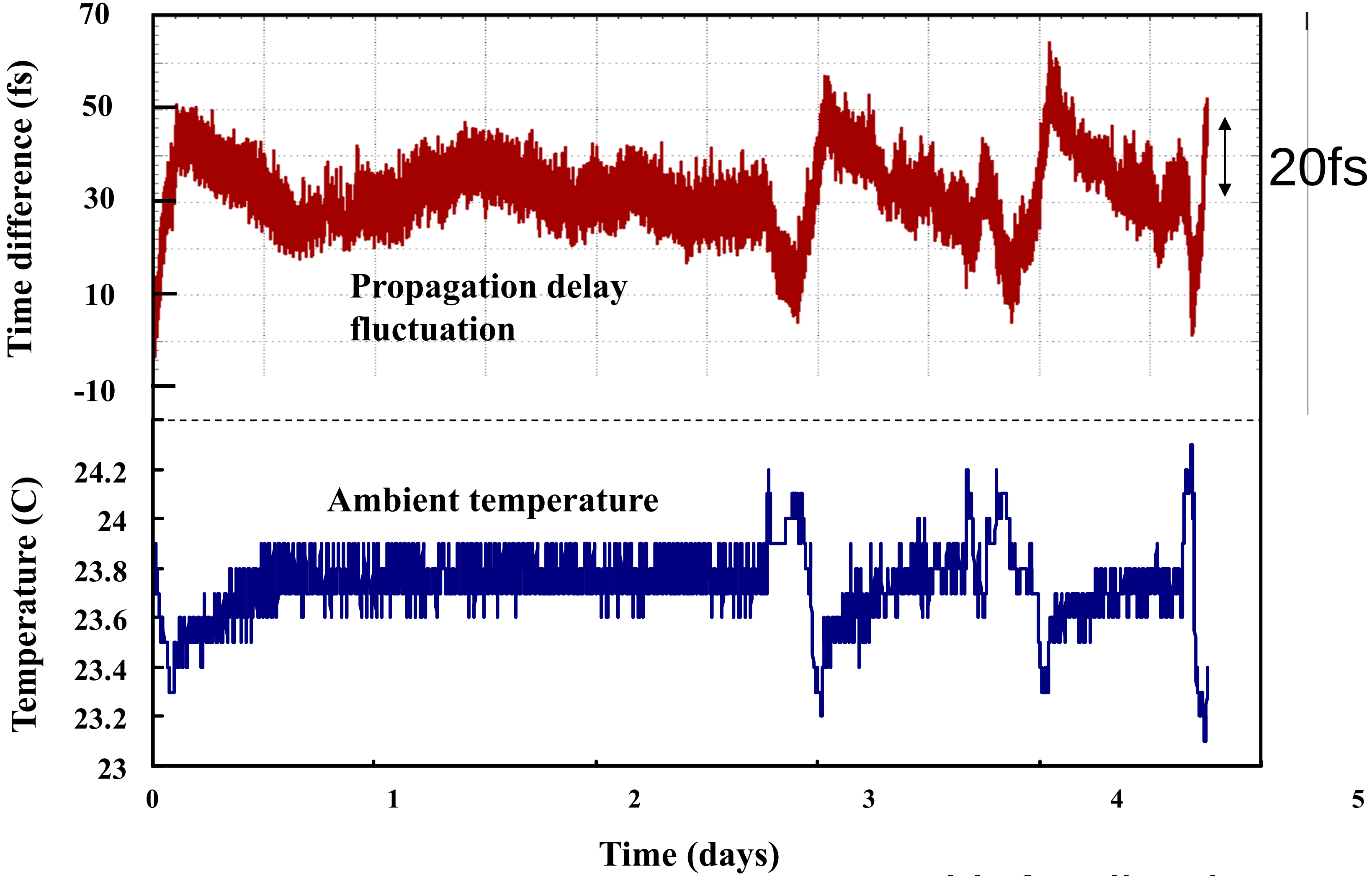


One day measurement (w/o FB)



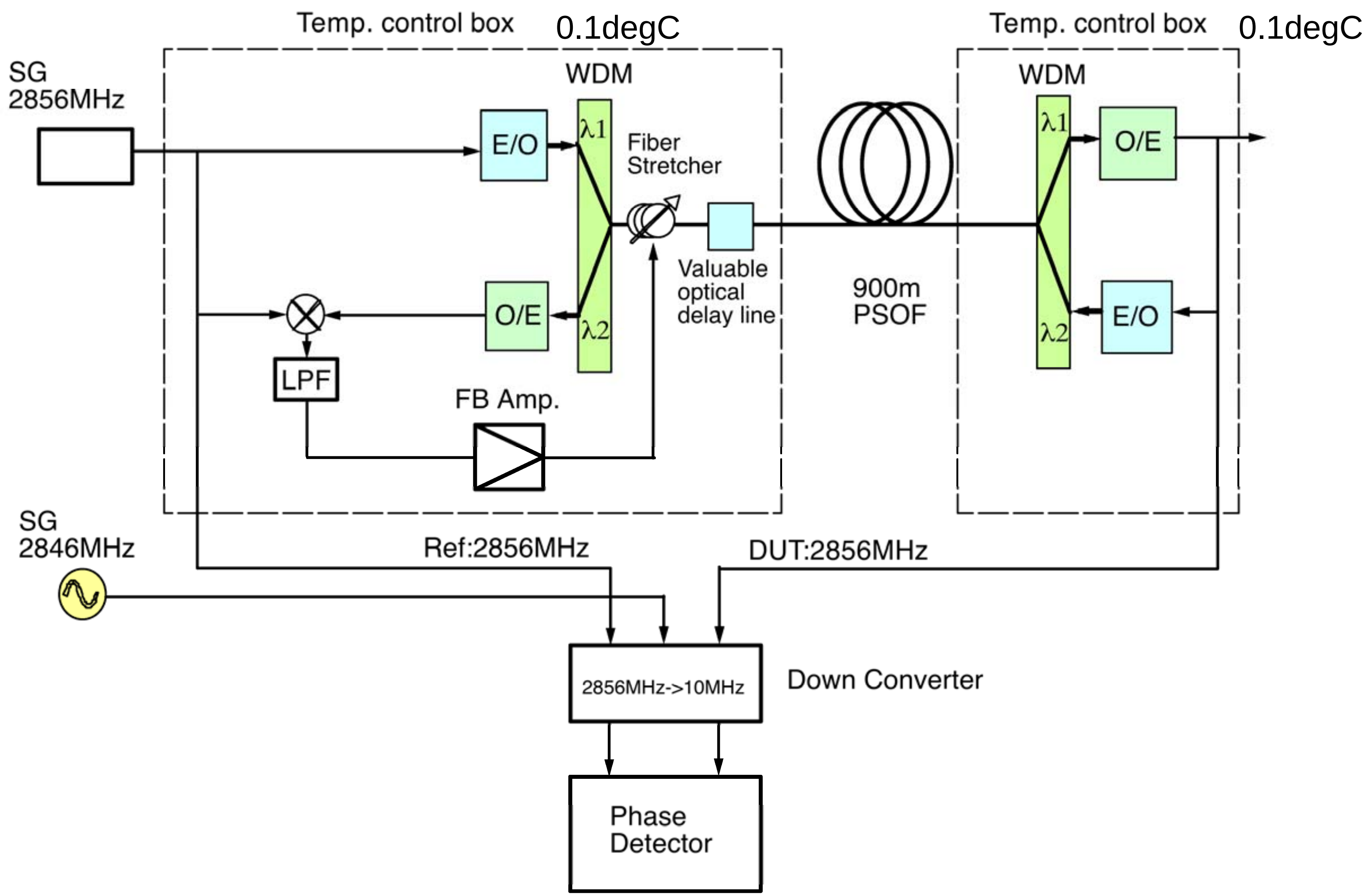
without feedback

One day measurement (with FB)



with feedback

Experimental setup(Frequency:2856 MHz)



Experimental setup(Optical Link and WDM)

Externally Modulated Transmitter and Receiver SITU3000-TS & SIRU3000-TS

0.05 – 18 GHz, Thermally Stable 1550nm Externally Modulated Self-Contained Transmitter and Receiver

The Emcore Small Integrated Transmitter Unit (SITU) is a high performance externally modulated transmitter for applications from 50 MHz to 18 GHz. The SITU3000-TS is a fully integrated unit that contains both the optics and the control electronics. The units provide thermal phase stability through the use of minimum lengths of internal fiber. Only DC input voltages and the RF signal are required for operation.

The units can be used to construct transparent links for antenna remoting. The broad bandwidth is intended for applications such as electronic warfare and Ku band systems. Other applications include delay lines and signal processing systems.

The system operates at a nominal wavelength of 1550 nm. Wavelength selected lasers on the ITU grid are also available for WDM applications.

Applications

- **Microwave antenna signal distribution**
- **Broadband delay-line and signal processing systems**
- **Frequency distribution systems**
- **Radar system calibration**
- **Phased array antenna systems, interferometric antenna arrays**

Performance Highlights

100 GHz WDM

DiCon's 100 GHz WDM is designed to multiplex and demultiplex signals in multi-wavelength systems based on the ITU 100 GHz grid. The component uses a thin film filter mounted between a pair of GRIN lens collimators. The 100 GHz WDM is housed in a compact, environmentally stable package that offers superior resistance to humidity and temperature and is suitable for mounting on a printed circuit board or within a module.

Features

- Wide 0.22 nm passband
- Low insertion loss
- High isolation for demultiplexing applications
- Rugged, environmentally stable package
- Tested to Telcordia GR-1221

Applications

100 GHz WDMs multiplex and demultiplex signals in dense WDM systems. Featuring 0.2 nm channel passbands and 100 GHz channel spacing, the 100 GHz WDM is well suited to long haul transport networks. The 100 GHz WDM provides high isolation without the need for active temperature control.

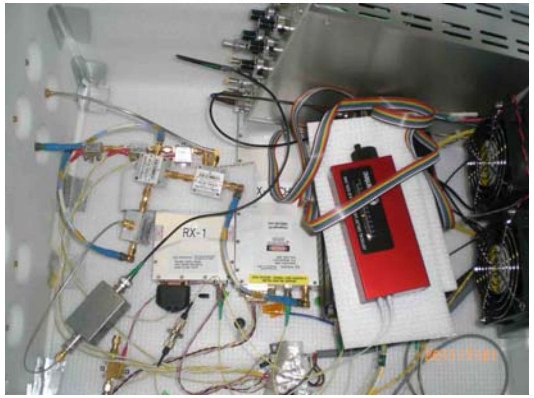
DiCon FIBEROPTICS, INC

Measurement setup

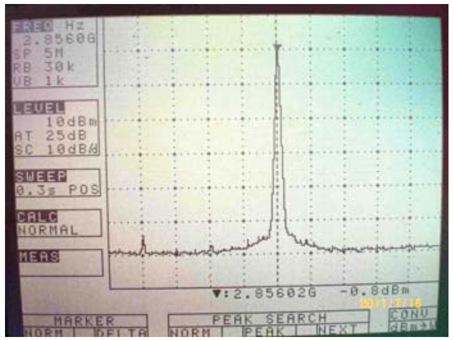
Phase detector

Receiver

Transmitter

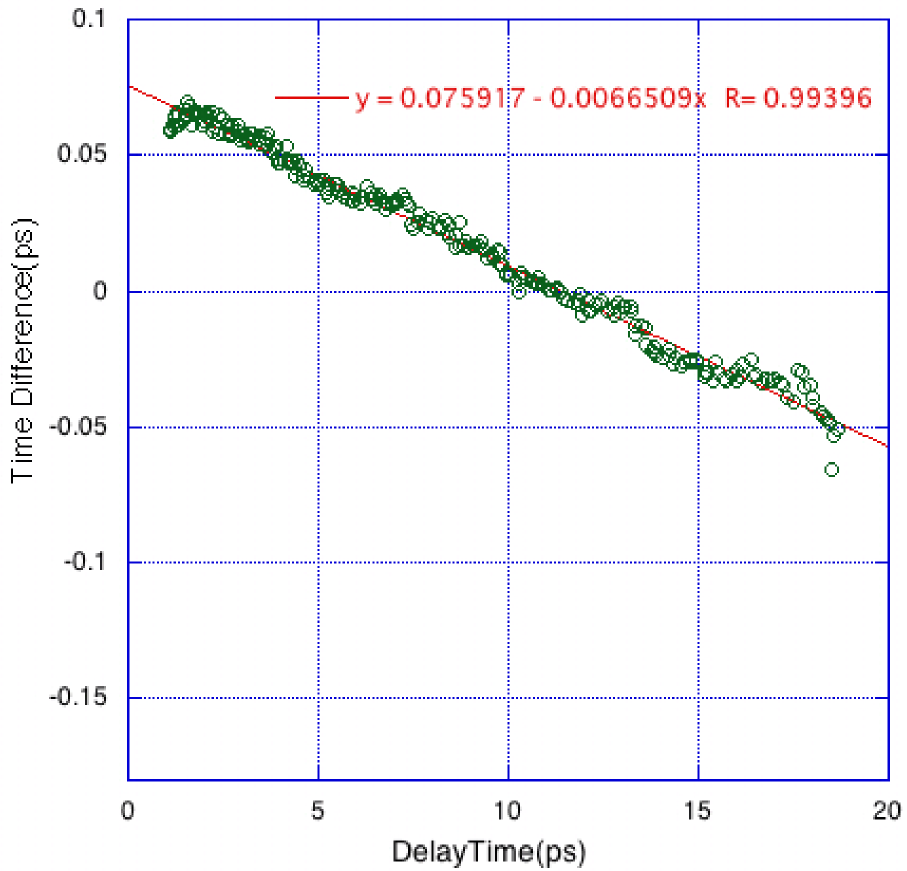


Inside of the TX



Spectrum of the FB signal

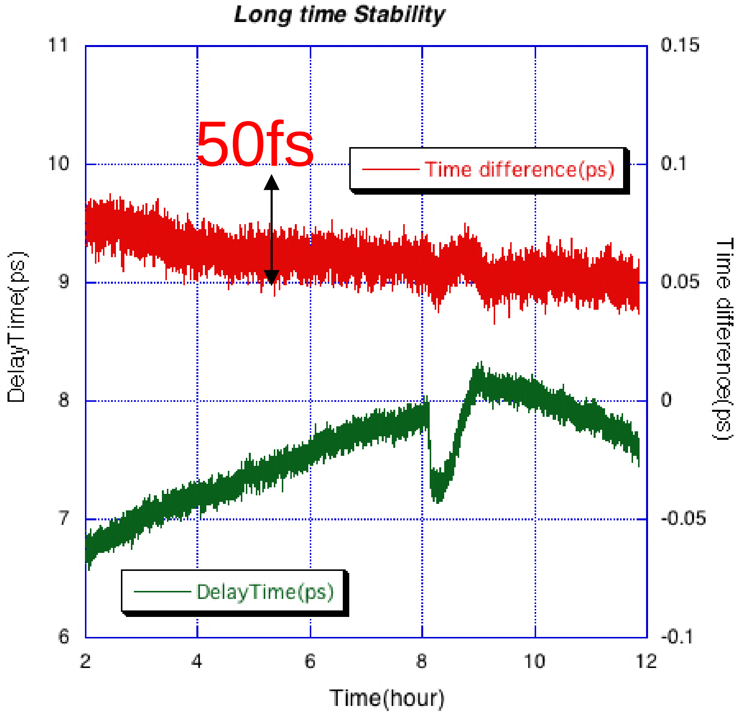
Feedback gain

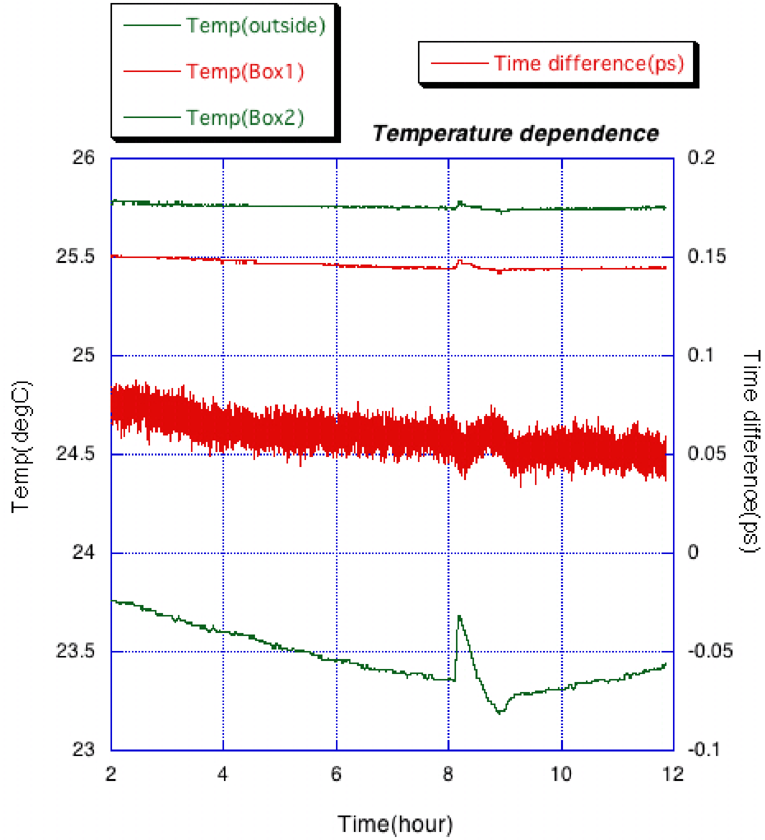


The feedback gain is decided by the loop filter gain. The maximum gain is adjusted under the condition of the low noise and without oscillation.

The measurement is done by measuring the feedback phase when changing the fiber length. The feedback gain was 44dB in our case. It means that 16 degree of the phase change is compressed to less than 0.1 degree.

Long time stability(1)



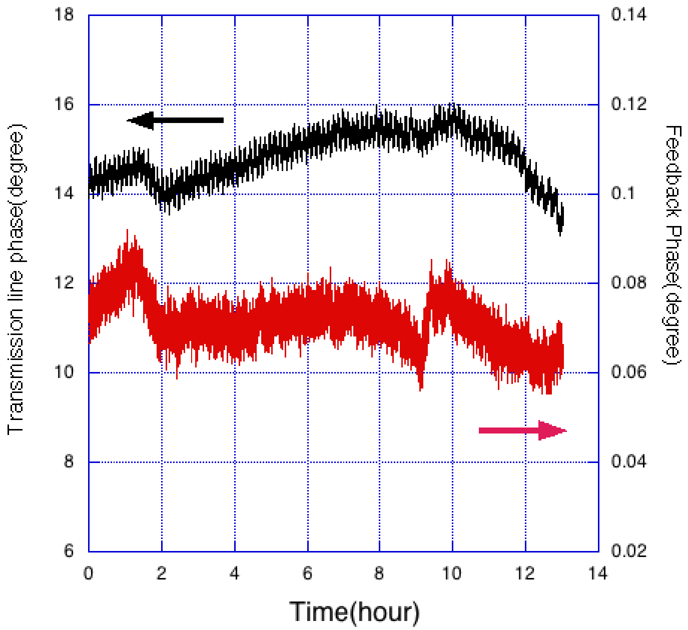


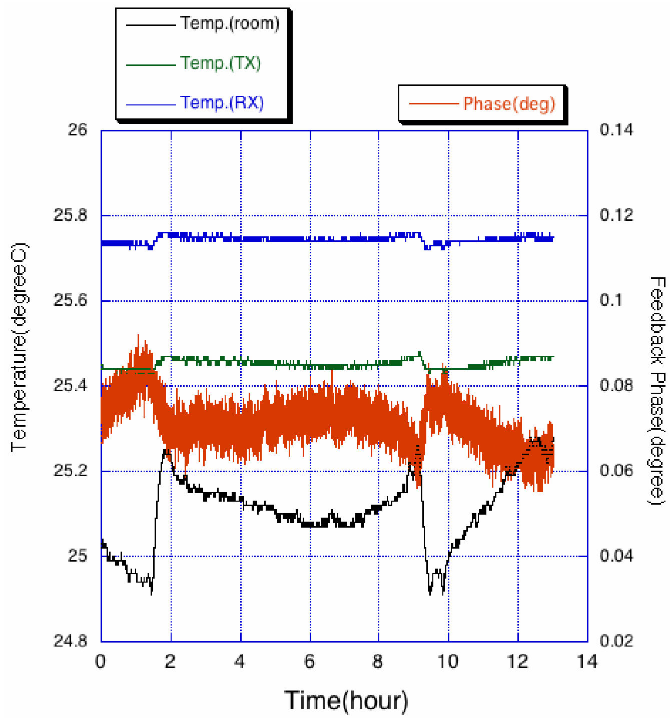
10hour trend ~50fsp-p

Comparison with the temperature

Long time stability(2)

PSOF located far from cont. box



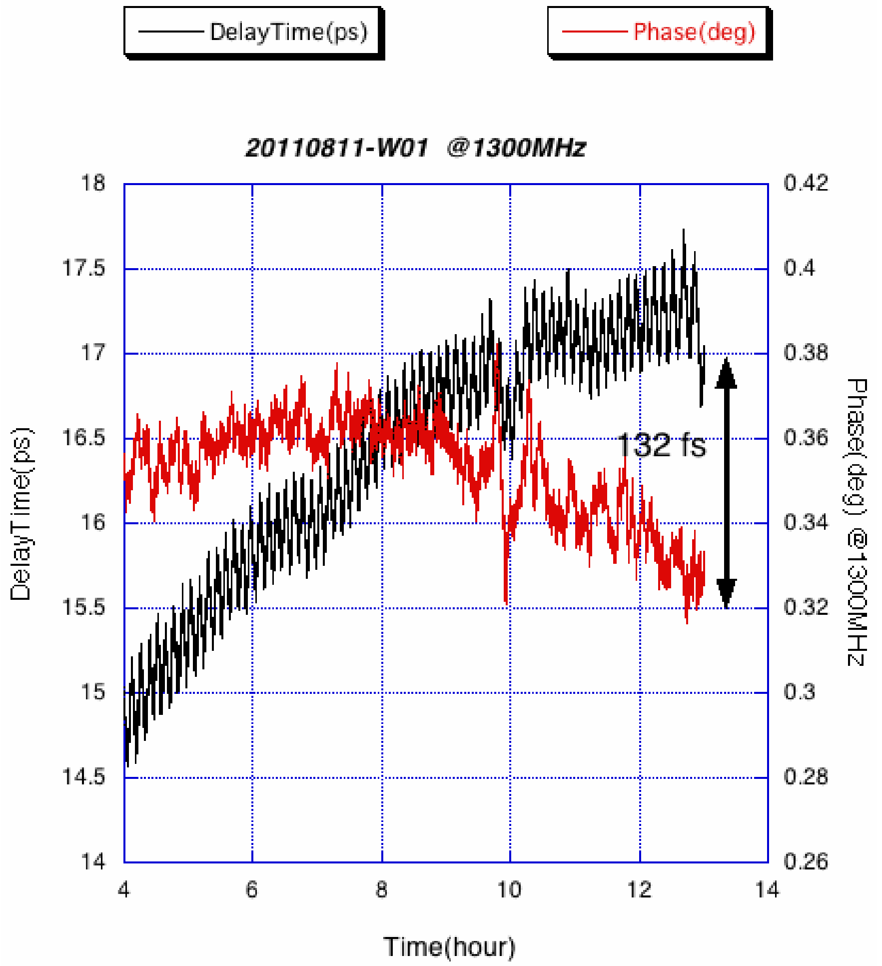


12hour trend ~40fsp-p

Comparison with the temperature

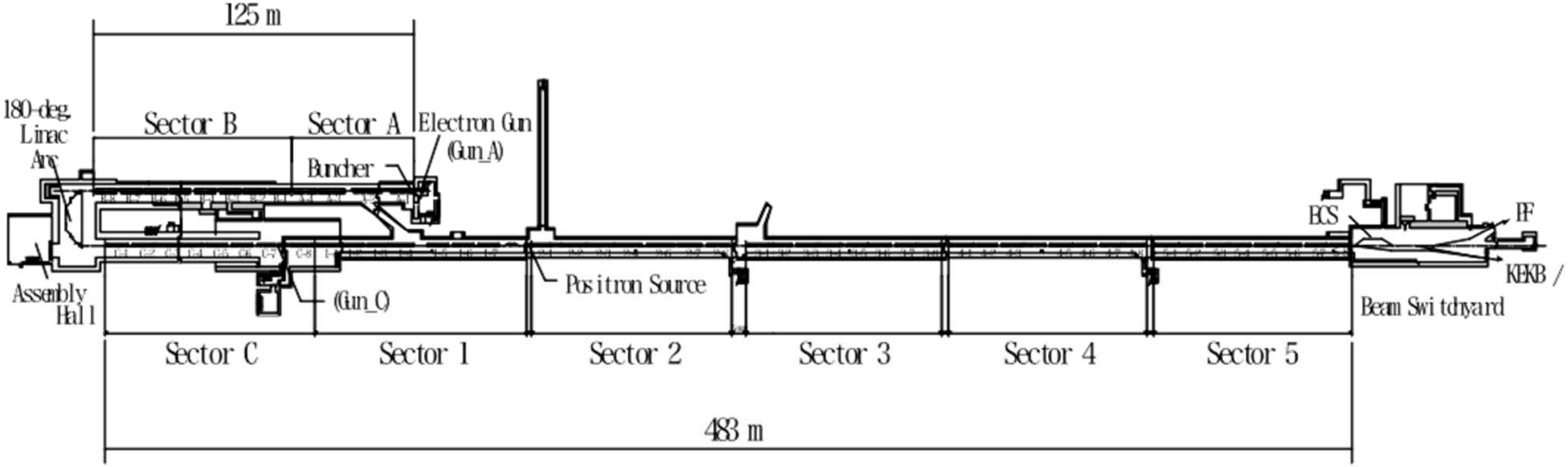
Long time stability(3)

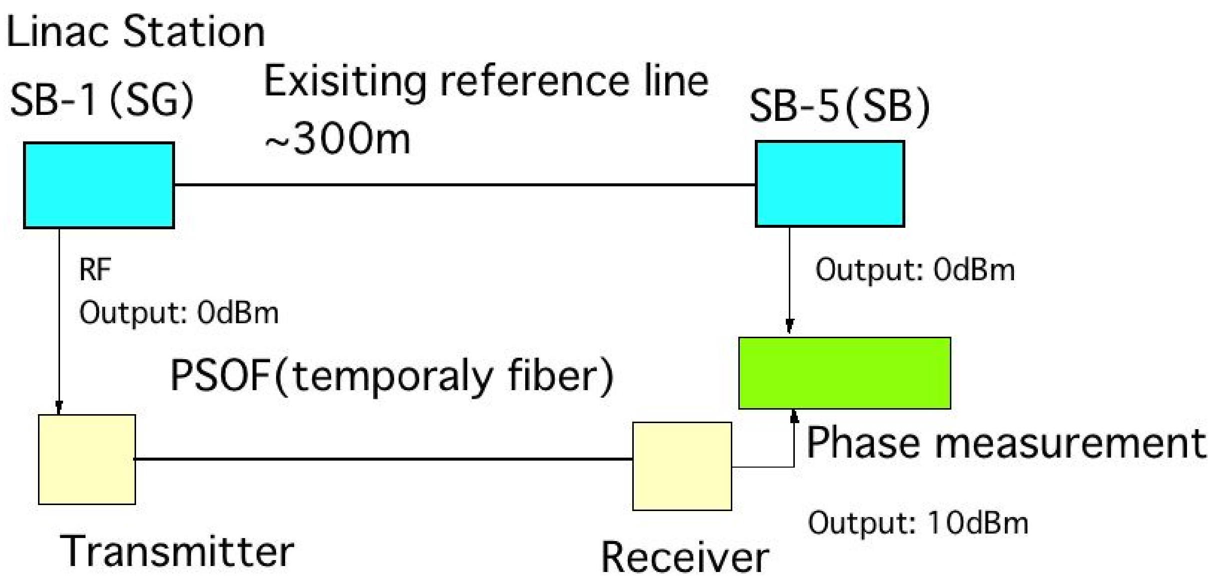
1.3GHz transmission



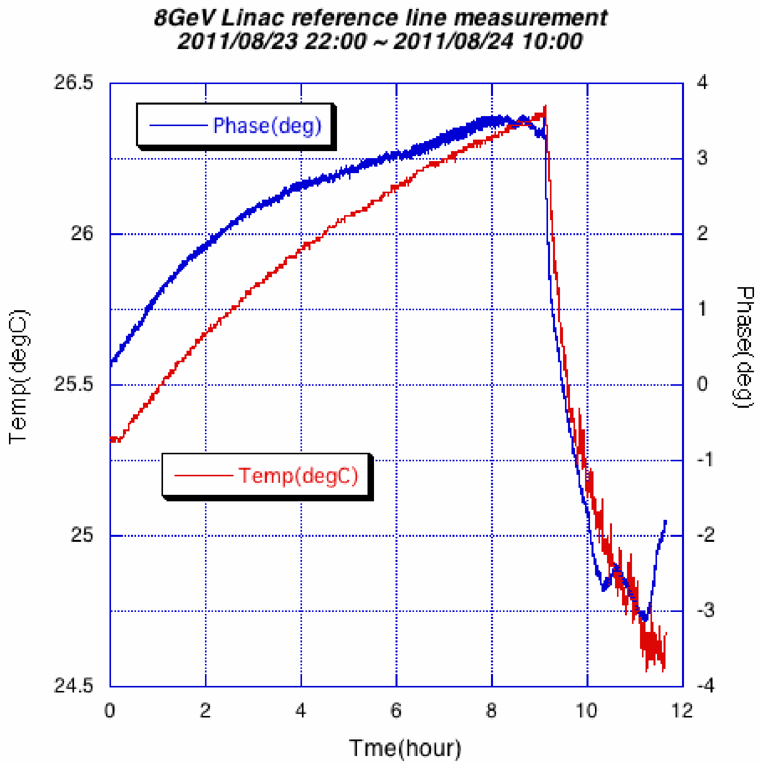
10hour trend ~130fsp-p

8GeV S-band Linac reference line stability measurement

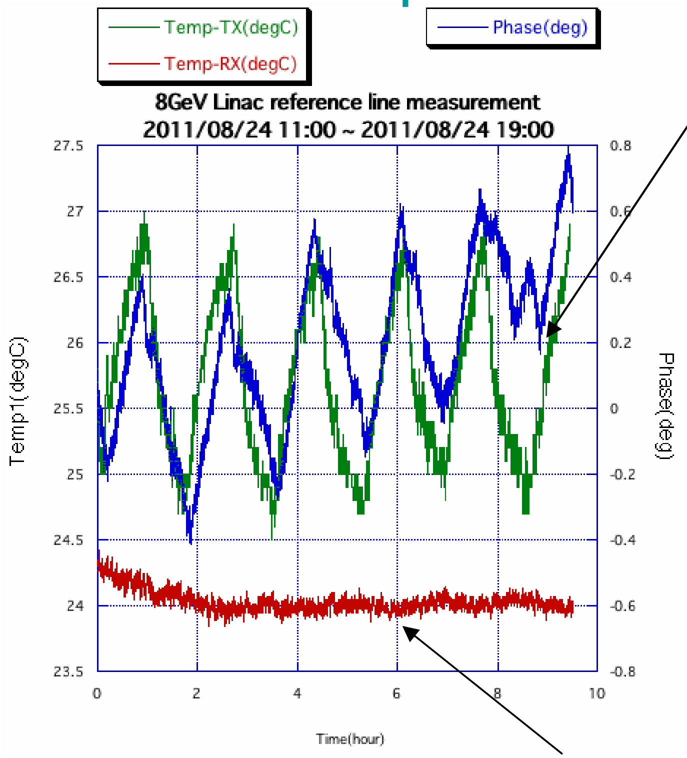




Measurement results



Temp. at transmitter



Temp. at receiver

air conditioner of the klystron gallery turned off -> 6ps

air conditioner of the klystron gallery turned on -> 1.4ps

Summary & Future plan

We have been developed a precise reference clock distribution system using optical links and a feedback circuit. The stability reached to ~50fs for 900m optical fiber and 2856MHz clock transmission.

- *To achieve <20fs stability - temperature stabilize of TX/RX control box up to 0.01degC.*
- *To get higher stability - Higher frequency(11.4GHz) transmission will be tested.*
- *To confirm long distance stability - 10km long PSOF will be tested.*
- *To confirm long term stability - A system will be installed to S-band linac .*