OThH4.pdf

Electro-Optical Synchronization System with Femtosecond Precision

Jurij Tratnik, Leon Pavlovic, Bostjan Batagelj, Luka Naglic, Tomaz Korosec and Matjaz Vidmar
University of Ljubljana, Faculty of Electrical Engineering, Trzaska 25, 1000 Ljubljana, Slovenia
jure.tratnik@fe.uni-lj.si

Abstract: A novel system for the RF synchronization is presented. It makes use of standard, commercially-available telecommunication optical components. The added timing jitter of 5 fs_{RMS} has been measured on the first experimental tests.
OCIS codes: (230.2035) Dispersion compensation devices; (320.2250) Femtosecond phenomena

1. Introduction

State of the art timing and synchronization systems [1,2] are needed to operate the fourth generation light sources based on linear accelerators driven Free Electron Lasers (FELs). Some evolving solutions for the timing distribution and the RF synchronization use interferometric schemes [3-5] for the stabilization of fiber links that transport the clock signal or/and use mode-locked pulsed lasers [6]. The weaknesses of these solutions are in stabilizing the group velocity, the phase stability at the beginning of the operation and the timing stability.

Previously proposed electro-optical scheme in 2001 [7] used single optical fiber and directly modulated Fabry-Perot laser. Due to low RF frequency (below 1 GHz) used, that solution did not gain better jitter results than coaxial-distributed infrastructure.

Our proposed electro-optical synchronization system consists of the transmitter (Tx), located at the place of the low-jitter master oscillator and the receiver (Rx), located at the remote location. Both units are connected with a singe-mode optical fiber pair in a loop-back to achieve phase-noise and phase-drift compensation.

2. Synchronization system design and operating principle

The block diagram of the Tx and the Rx unit is shown in Fig. 1. The Tx unit is composed of two main compensation blocks and a laser source, while the Rx unit consists of a receiver block and filtering electronics.

The external synchronization RF-reference signal at 2998.01 MHz modulates the optical carrier at 1550 nm with an electro-optical modulator (EOM). The modulated signal is then propagated to the Rx unit (red line in Fig. 1) where a fraction of a signal is decoupled and demodulated on the photodiode D3. Since the signal to noise ratio (SNR) at the output of the photodiode is not suitable for further distribution, the output signal is cleaned in the phase-locked loop (PLL) using a temperature-controlled 500 kHz wide cavity filter as a flywheel.

To compensate clock-phase drifts in a link, most of the incoming optical signal is fed further to the return line (blue line in Fig. 1), where the signal is demodulated on the photodiode D1. The demodulated signal is then compared with the reference signal at the phase comparator 1. Phase-error signal is used for the laser-wavelength tuning. Exploiting the fiber's inherent chromatic dispersion, link-length (RF-signal group delay) variations are compensated and therefore the RF-signal phase at the Rx is stabilized. For an internal compensation of the EOM some portion of the modulated optical signal is also fed to the photodiode D2 (green line in Fig. 1).

The source of an optical signal is a commercially-available 10 Gbps DFB laser with an integrated EOM and thermo-electric cooler/heater (TEC). The wavelength tuning used for the fiber phase-drift corrections is achieved by regulating the temperature of the laser chip with a PI regulator. Such type of laser is also used because of a good price/performance ratio due to relatively high production quantities and tough requirements in the telecom environments.

All RF components except the laser source, which is independently heated or cooled, are kept in a precisely temperature controlled blocks at the same temperature with a 0.01 degree C precision. Thus equal components (RF amplifiers, PIN photodiodes, phase comparators) behave in the same way at different locations in both, the Tx and the Rx unit. Temperature-stabilized chambers minimize thermal drifts that enable long-term stability.

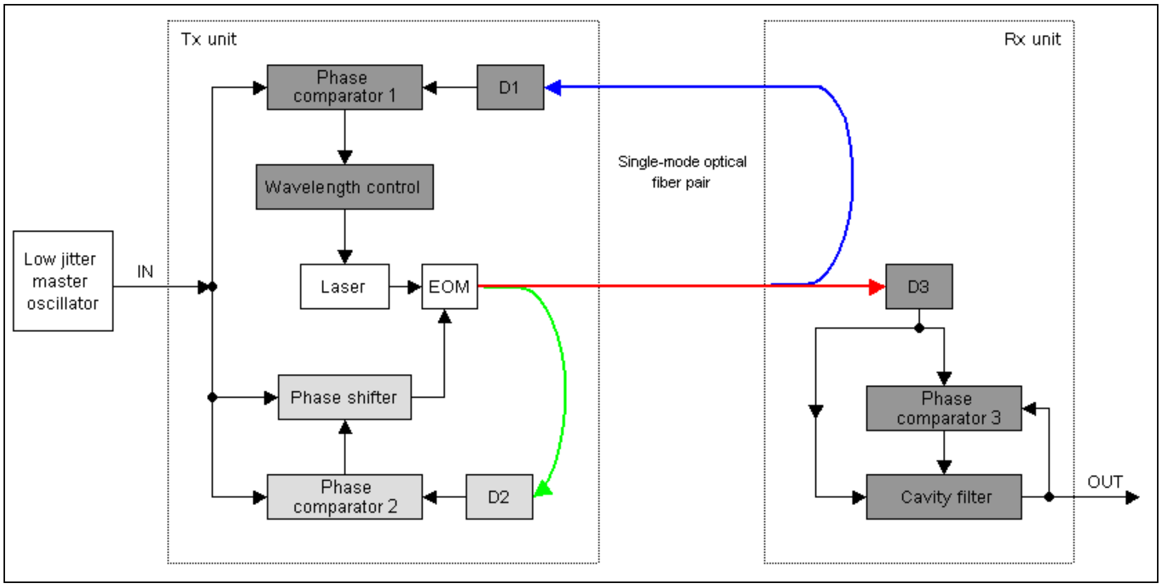

Fig. 1. Block diagram of the Electro-optical synchronization system

With a 5 nm laser-wavelength tuning range, 48 ps of time delay compensation can be achieved (52° RF phase at 2998.01 MHz, 600 m fiber-loop length, chromatic dispersion coefficient D=16 ps/nm.km) [8]. Affordable temperature changes in the optical path can be calculated as $\Delta T=(c\cdot D\cdot \Delta\lambda)/(k_n+n\cdot k_t)$, where ΔT is a temperature change, c speed of light, D chromatic distortion coefficient, $\Delta\lambda$ tuning wavelength, n refractive index of the fiber, k_n= 5·10^-6/K temperature coefficient of the refractive index and k_t= 7.5·10^-7/K a temperature expansion coefficient of the fiber. For both optical lines (transmission and return) it is assumed and measured that the polarization mode dispersion (PMD) is lower than 10 fs and can be neglected in the 300 m long fiber. To achieve such a low total PMD, a G.652 category optical fiber with a PMD of 0.02 ps/√km was selected.

3. Measurement results

Several measurements were made on the proposed synchronization system with different optical fiber lengths. One of important measurements is the RMS added jitter. A low-jitter master VCXO oscillator, developed at University of Ljubljana, was used as a reference signal and the output of the system was connected to the Agilent E5052A signal source analyser (SSA). RMS added jitter $jitt_{add}$ is calculated as $jitt_{add}=sqrt(jitt^2_{meas} - jitt^2_{gen})$, where $jitt_{meas}$ is a measured RMS jitter of complete transfer chain and $jitt_{gen}$ is a master-oscillator jitter.

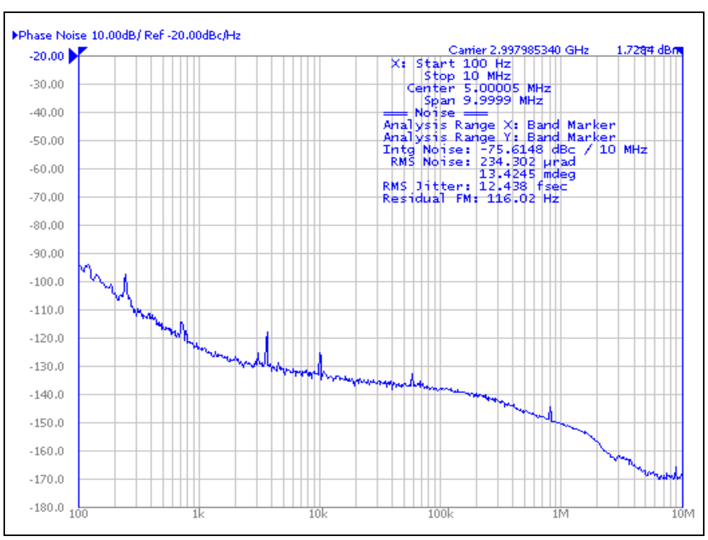

Fig. 2. Measured RMS jitter of the reference signal is 12.4 fs, integrated from 100 Hz to 10 MHz

OThH4.pdf

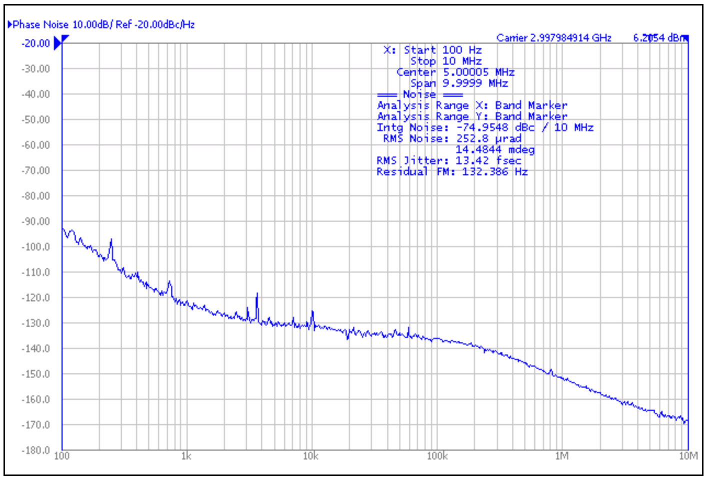

Fig. 3. Measured RMS jitter of the Rx-output signal is 13.4 fs, integrated from 100 Hz to 10 MHz

Single-mode optical fibers adopted for the distribution of the phase reference on FERMI@Elettra, Italy have been used during the field tests. The length of such optical links has been measured to be up to 360 m long. RMS added jitter of the synchronization system is 38 fs, integrated from 10 Hz to 10 MHz and 5 fs integrated from 100 Hz to 10 MHz, respectively. The last added-jitter value is calculated from measurement results shown in Fig. 2 and Fig. 3.

4. Conclusion

We have shown that a CW-clock transfer is possible over several-hundred-meters long link using affordable and commercially-available optical and RF components with an extremely-low added phase-noise and timing jitter. Group delay of the RF signal in the shown clock-distribution system is stabilized by the laser-wavelength tuning and the chromatic dispersion of the optical fibers in the forward and backward direction. Instead of a pair of optical fibers, a single optical fiber can be used with an additional Faraday mirror in the receiver unit.

5. Acknowledgments

This work was supported by Instrumentation Technologies d.d., Slovenia, Synchrotrone Trieste S.C.p.A., Italy and Ministry of Higher Education, Science and Technology of the Republic of Slovenia under research program P2-0246.

6. References

[1] E. Allaria et al., "FERMI@Elettra: A Seeded FEL Facility for EUV and Soft X-rays", FEL 2006. (Berlin, 2006).
[2] M. Ferianis, "State of the Art in High-Stability Timing, Phase Reference Distribution and Synchronization Systems", PAC09. (Vancouver, BC CA, WE3GRI02, 2009).
[3] J. M. Byrd, L. Doolittle, A. Ratti, R. Wilcox, “Timing Distribution in Accelerators via Stabilized Optical Fiber Links”, LINAC 2006, THP007, 577-579. (Knoxville, Tennessee USA, 2006).
[4] J. W. Staples, R. Wilcox, J. M. Byrd, “Demonstration of Femtosecond-Phase Stabilization in 2 km Optical Fiber”, PAC07, MOPAS028, 494-496. (Albuquerque, New Mexico USA, 2007).
[5] J. W. Staples, J. Byrd, L. Doolittle, G. Huang, R. Wilcox, “A Femtosecond-Level Fiber-Optics Timing Distribution System Using Frequency-Offset Interferometry”, LINAC08, THP118, 1063-1065. (Victoria, BC Canada, 2008).
[6] A. Winter, J. Becker, F. Loehl, K. Rehlich, S. Simrock, P. Tege, “An Integrated Optical Timing and RF Reference Distribution System for Large-Scale Linear Accelerators” LINAC 2006, THP003, 565-567. (Knoxville, Tennessee USA, 2006).
[7] J. Frisch, D. Bernstein, D. Brown, E. Cisneros, “A High Stability, Low Noise RF Distribution System” Particle Accelerator Conference 2001, 816-818. (Chicago, 2001).
[8] E. Udd et al., “Fiber Optic Sensors”, John Wiley & Sons, Inc., 134. (Canada, 2006).