The Optical Timing System of FERMI light source

Elettra Sincrotrone Trieste

F. Rossi#, M. Ferianis, M. Predonzani

The FERMI seeded FEL is a user facility that has been designed for producing high-quality photon pulses in the EUV and soft-X-ray spectral range. The most demanding requirements in terms of temporal stability are the synchronization in pump and probe experiments and the time overlap between the seed laser and the electrons. The FERMI Optical Timing System is used to generate and distribute, over stabilized fiber optic links, an ultra stable phase reference (i.e. the “clock”) to be used for the synchronization of all the accelerator components requiring a femtosecond time stability like the radio-frequency plants, the laser systems and the longitudinal diagnostics.

Introduction

The Optical Timing System of FERMI light source exploits optical techniques to achieve the demanding performances required by a seeded free-electron laser facility.

The specifications for the timing system are expressed in terms of short-term stability (jitter in the bandwidth 100 Hz - 10 MHz) and long-term stability (drift over at least 8 hours). In the original conceptual design, the requirements for the reference distribution were less than 50 fs RMS on both time scales.

The performances must be satisfied over large-scale installations transferring the intrinsic stability of the master oscillator to remote locations (in our case up to about 350 meters) by suppressing the excess phase noise introduced by a fiber optic link.

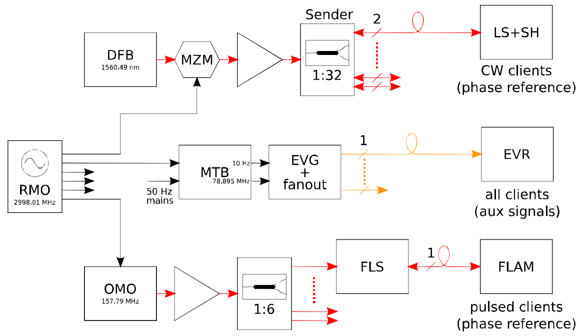
Architecture

The main blocks are:

- Reference Master Oscillator (RMO, crystal-based oscillator locked to a rubidium reference)
- pulsed phase reference distribution
- CW phase reference distribution
- Master Time Base (MTB)
- Event System (trigger distribution) composed of an event generator (EVG) and many receivers (EVR)

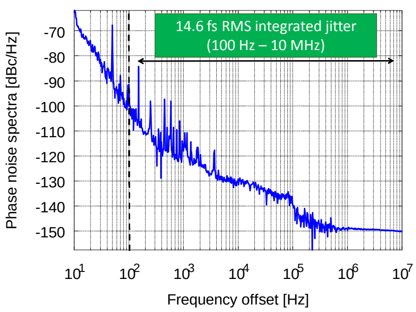
We have implemented a hybrid solution exploiting state-of-art architectures for the distribution of the phase reference:

- pulsed subsystem – lasers and longitudinal diagnostics like the Bunch Arrival Monitor and the Electro-Optical Sampling
- continuous-wave subsystem – radio-frequency plants

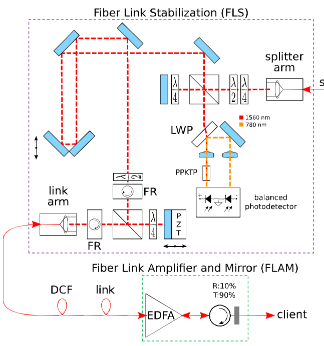


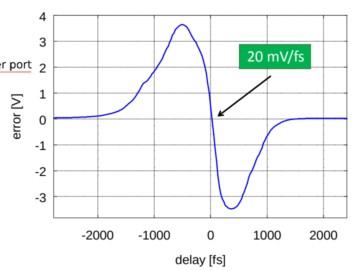
The pulsed subsystem

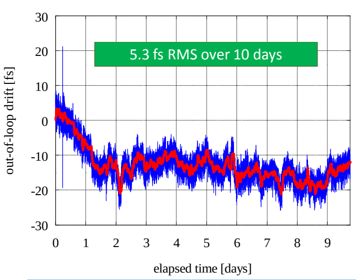
The core element is the Optical Master Oscillator (OMO) which is a passively mode-locked pulsed laser with a very good short-term timing stability (less than 25 fs RMS integrated in the bandwidth 1 kHz – 10 MHz). The laser is locked to the RMO to encode the reference frequency on its repetition rate and inherit the long-term stability of the RF source.

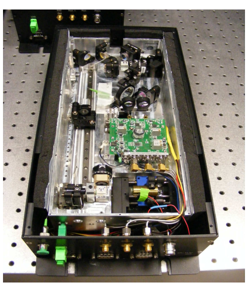


The OMO short pulses are delivered to remote locations through dispersion compensated fiber links. A balanced cross-correlator, based on a non-linear second harmonic generation process produced in a type-II PPKTP crystal, provides high-sensitivity to detect group delay changes along the transmission medium. The fiber length is actively changed with a piezo/motor combo.





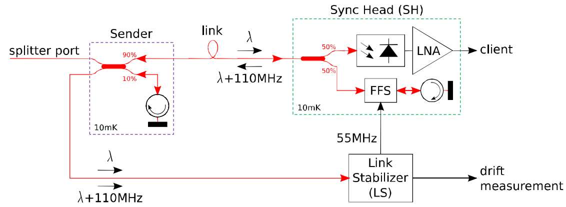




The CW subsystem

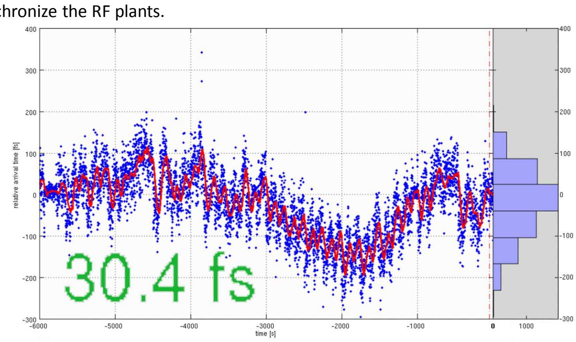
The oscillator of the CW subsystem is implemented with a distributed feedback laser (DFB). The single-frequency laser is used to implement a Michelson interferometer along the timing distribution links and for this reason its wavelength is stabilized against a rubidium gas-cell reference. The radio-frequency of the RMO is transmitted to remote clients by modulating the amplitude of the laser through a Mach-Zehnder modulator (MZM), the working point of which is kept in quadrature with a bias-controller.

Path length changes are measured by exploiting an optical heterodyne technique to detect optical phase drifts. The difference in the thermal coefficient of phase and group velocities is then compensated with a constant correction factor found by measurement of the fiber. The optical path length is then virtually kept constant by shifting the phase of the remote client oscillator.



Measuring performances with the e-beam

The characterization of the timing system stability has been carried out, from the point of view of the electron beam, by means of an indirect measurement through a Bunch Arrival Monitor (BAM) after a dispersive section of the machine. This beam-based measurement provides only an upper limit of the intrinsic performances of the timing system showing the relative stability between the pulsed and the CW references, the former used to synchronize the photo-injector laser and the BAM station, while the latter to synchronize the RF plants.



On a short-time scale, the stability is around 30 fs RMS, while on a longer time scale a slow drift is clearly visible and is currently compensated using a feedback based on the BAM.

Conclusions

FERMI has been the first user facility entirely running, since beginning of commissioning, on a fully-optical timing system implementing state-of-art techniques for the distribution of phase reference signals. The system is running 24 hours / 7 days and it has demonstrated its reliability with only a few failures in many years of operations.

References

[1] M. Ferianis et al., How the optical timing system, the longitudinal diagnostics and the associated feedback systems provide femtosecond stable operation at the FERMI free electron laser, DOI: http://dx.doi.org/10.1017/hpl.2016.6

[2] L. Pavlovic et al., Bunch Arrival Monitor at FERMI@Elettra, Proc. BIW conf. 2010

For additional information please contact:
Fabio Rossi, Elettra-Sincrotrone Trieste
fabio.rossi@elettra.eu