Elettra Sincrotrone Trieste

THE BUNCH ARRIVAL MONITOR AT FERMI FEL FACILITY

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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 Bunch Arrival Monitor (BAM) longitudinal diagnostic provides a measurement of the temporal stability of the electron beam relative to the timing reference distribution system with a sub-10-fs RMS resolution. Each BAM station is divided in a front-end, where the electron beam time-jitter is converted in amplitude modulation, and a back-end for the acquisition of the signals and communication to the control system. A beam-based optimization tool is implemented to improve the long term performances of the FEL facility.

INTRODUCTION

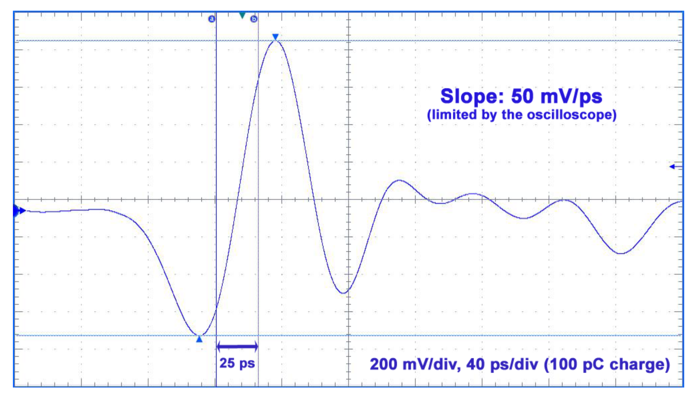
The Bunch Arrival Monitor (BAM) is based on the original idea developed at DESY [2] which uses an electro-optical scheme to measure, in a non-destructive way, the arrival time of the electrons with high resolution (≤ 10 fs RMS). The time reference for the diagnostic is provided by ultra-stable optical pulses distributed along the facility by the femtosecond timing system.

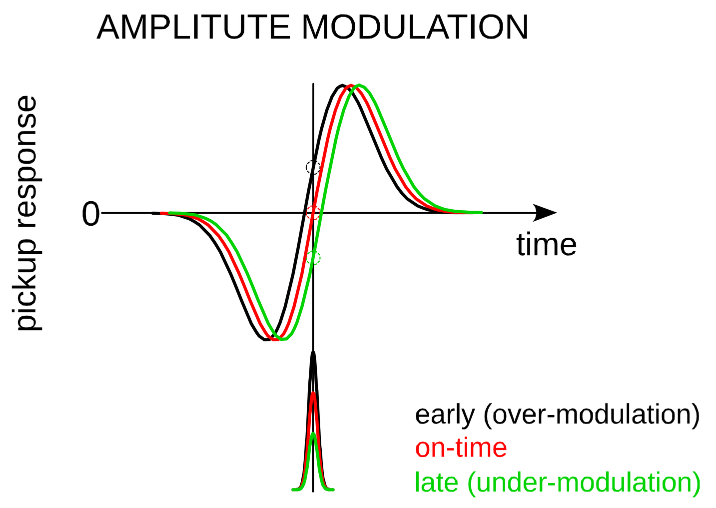
Each BAM station consists of two main parts:

- **front-end** module installed in the machine tunnel. It encodes the arrival time variations of the e-beam into the amplitude of one pulse of the timing reference system. It includes the hardware used for the calibration of the measurement;
- **back-end** module installed in the service area. It converts the optical signals in the electrical domain, extracts the clock signal used for the analog-to-digital conversion and transmits the data to the control system.

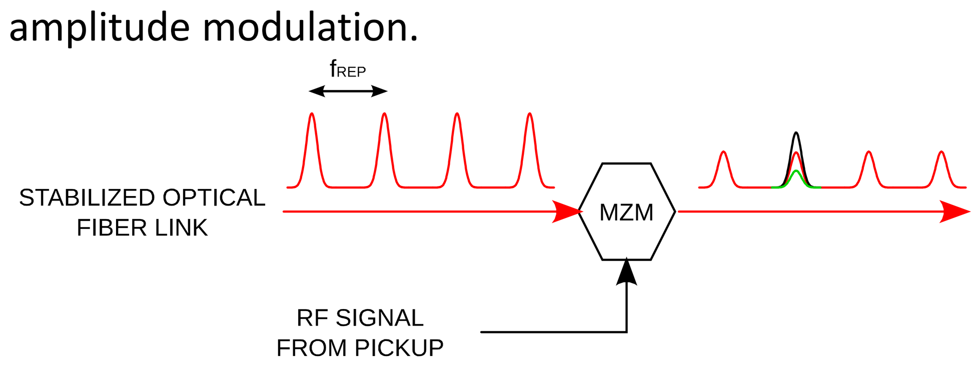
PRINCIPLE OF OPERATION

The beam pick-up has four open-coax-line electrodes with a bandwidth of several tens of GHz. The response from the pick-up, acquired directly in the machine tunnel by using a real-time oscilloscope with a 12.5 GHz bandwidth, shows a first steep slope of few tens of mV/ps.

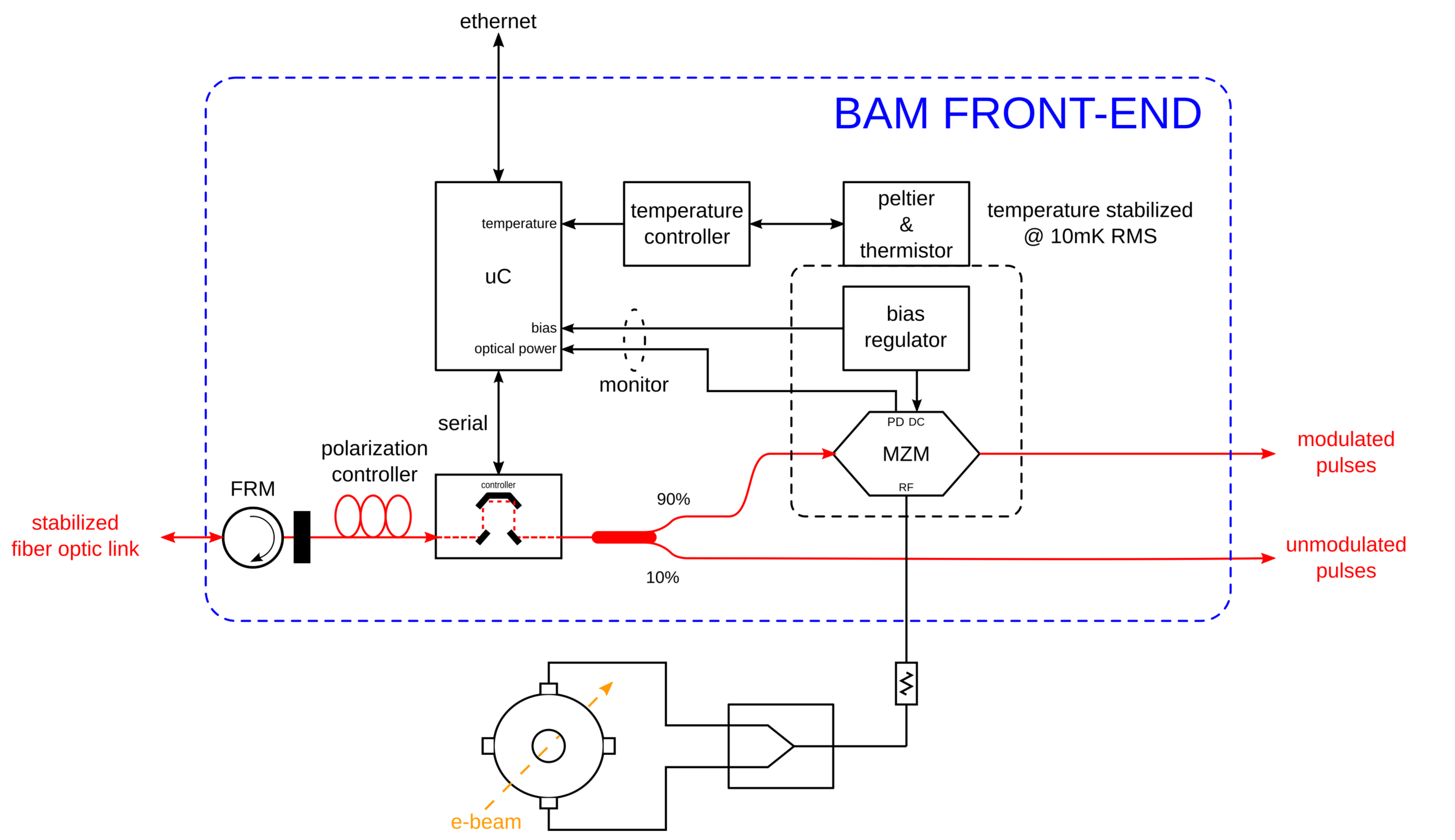




An optical pulse samples the pick-up response in the zero-crossing, electron arrival time fluctuations are then converted into amplitude modulation.

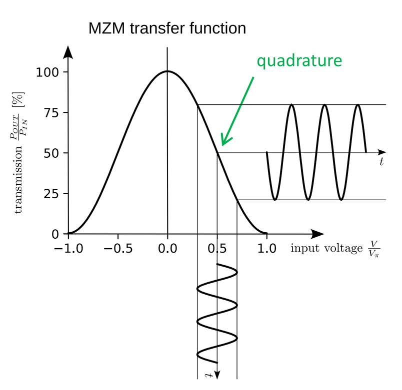


THE FRONT-END

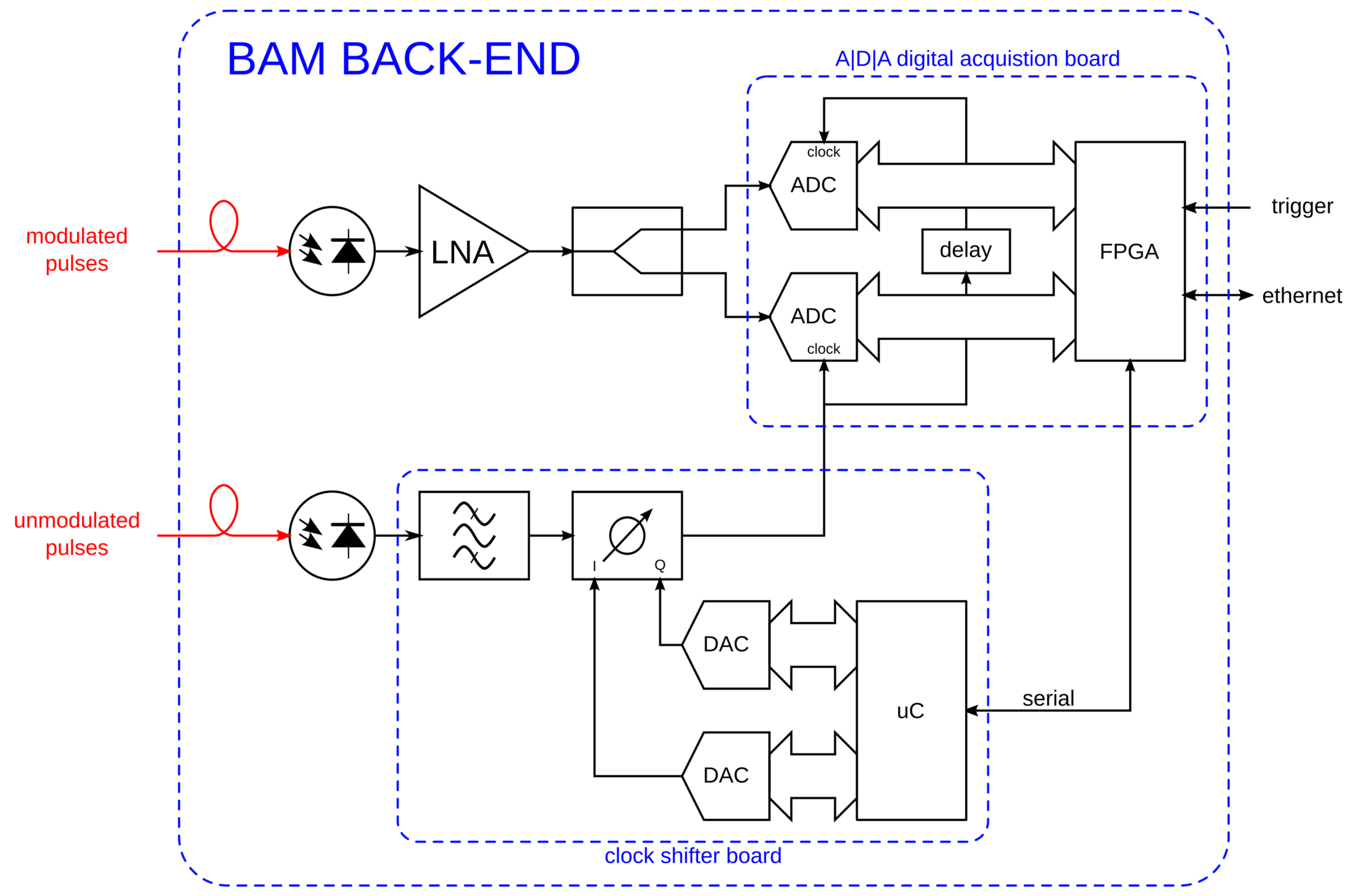


The core element of the front-end is a Mach-Zehnder intensity Modulator (MZM), with 12.5 GHz RF bandwidth, fed by the signal coming from the beam pick-up. Two opposite electrodes are combined to reduce the dependence of the signal to the transversal position of the e-beam. An attenuator is used to avoid overloading the RF port of the modulator.

The MZM has to be DC-biased to operate in quadrature such that all the optical laser pulses are initially modulated to the half amplitude. By doing so, shot-to-shot electron arrival time fluctuations, with respect to the optical timing reference, produce over- or under- amplitude modulation of the sampling pulse. The MZM and the bias regulator are temperature controlled to minimize drifts of the working point.



THE BACK-END

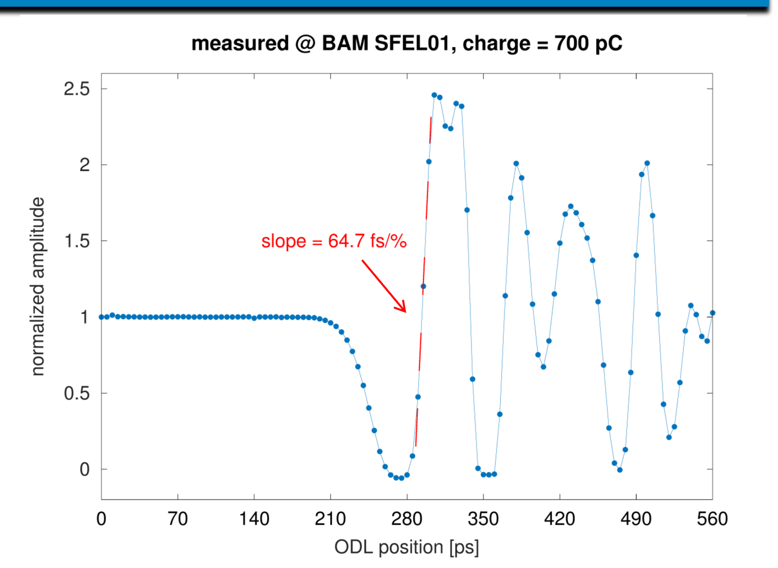


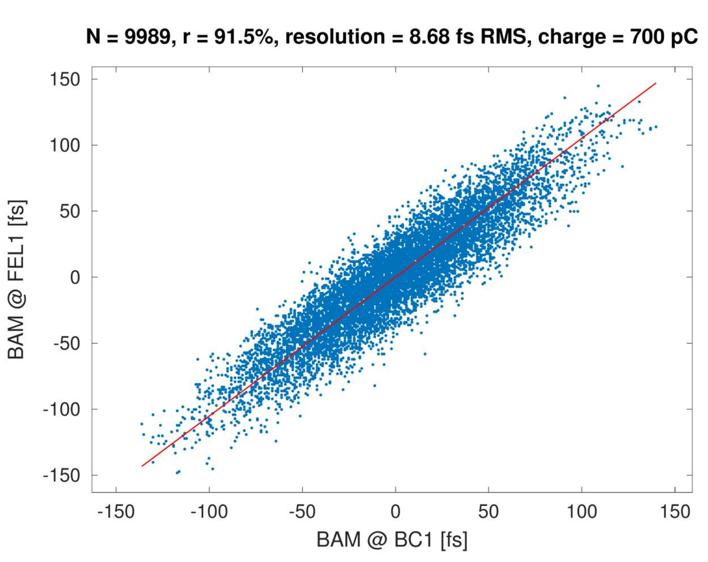
The back-end digitizes the modulated pulses using a dedicated analog–digital–analog (ADA) board, the input signal is split in two and acquired by two 16-bit ADCs working at a clock rate of 157.79 MHz. The delay between the sampling times of the ADCs is fixed (equal to a few hundreds of picoseconds) to acquire simultaneously both peak (P_k) and baseline (B_k) of each laser pulse and calculate its amplitude ($A_k=P_k-B_k$) in the acquisition window (k=1-512). To avoid influence of amplitude drifts the modulated pulse amplitude is normalized to the average amplitude of a group of previous unmodulated pulses.

The acquisition clock is extracted from the unmodulated pulses in a dedicated board that features an automatic gain control for the incoming signal and provides a low-phase noise electrically adjustable phase shifter based on a passive IQ modulator.

CALIBRATION AND RESOLUTION

An optical delay line is used for the calibration by performing a sweep of the modulated optical pulse around the zero-crossing of the first slope of the pick up signal.

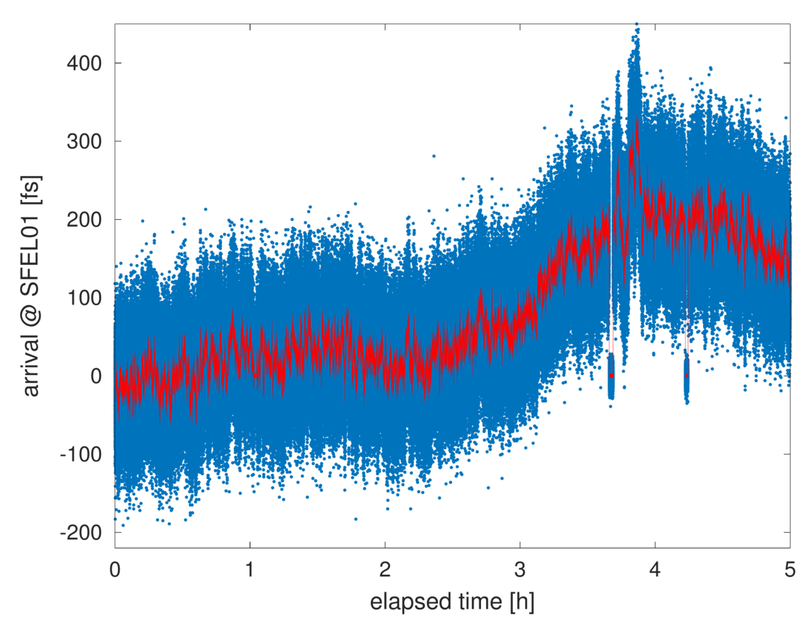




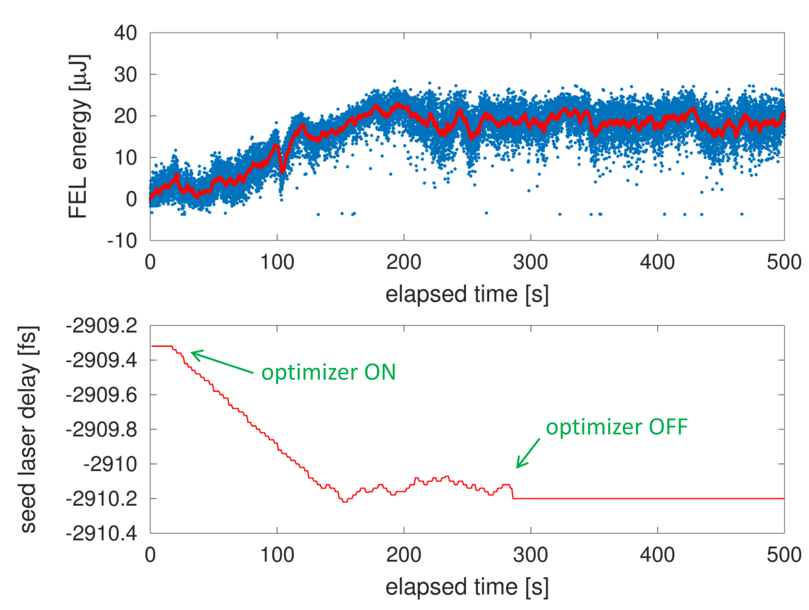
The resolution of the BAM has been validated by analyzing the shot-to-shot correlation between two BAM stations. It depends on the slope of the RF transient and the amplitude noise of the full acquisition chain (from the optical pulses to the back-end electronics, typical values are in the range 0.13-0.18%).

USING THE BAM FOR MACHINE OPTIMIZATION

On a short-time scale, the time-jitter of the electrons is around 40 fs RMS. A slow drift is clearly visible on a longer time scale.



We use the BAM diagnostic measurements to implement a beam-based optimization [3]. In this way the compensation of slow timing drifts improves the long term performances of the machine.



REFERENCES

[1] L. Pavlovic et all, "Bunch arrival monitor at FERMI@elettra", BIW 2010

[2] F. Loehl et all, "A sub 100 fs electron bunch arrival-time monitor system for FLASH", EPAC 2006

[3] G. Gaio et all, "Advances in automatic performance optimization at FERMI", ICALEPS 2017

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