1-MHz Line Detector for Intra-bunch-train Multichannel Feedback

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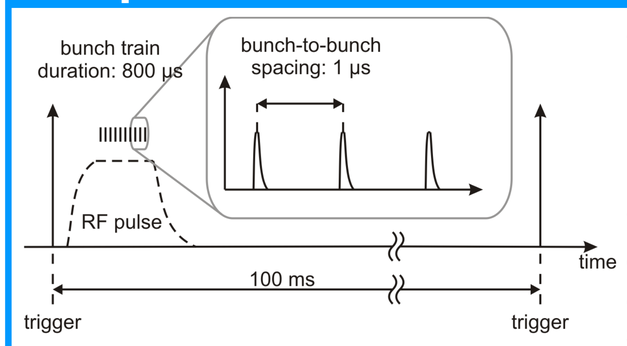
Introduction

The measurement and control of the electron bunch length is one of the key diagnostics in linac-based free-electron lasers to reach the required peak current in the electron bunches. In order to use the multi-channel signals from longitudinal bunch shape measurements for intra train feedback for the European XFEL, line readout rates in the MHz range and low latencies are required. These tight constraints cannot be fulfilled with commercial multichannel radiation detectors (line cameras). The paper presents a 256 channel detector that allows analyzing optical or infrared radiation with 1 MHz rate and a few microseconds latency using photodiode arrays, as needed for synchrotron light monitors, electro-optical bunch length measurements, or other laser based diagnostics. The proposed architecture aims at high frequency readout with low latency by using a multichannel electronic front-end designed for HEP, combined with Si or InGaAs detector arrays with very fast response time, and a low-latency data acquisition system. Currently, the device is at the conceptual design stage.

Requirements



Pulse mode timing scheme for FLASH operation.

The detector must follow the FLASH pulsed mode operation:

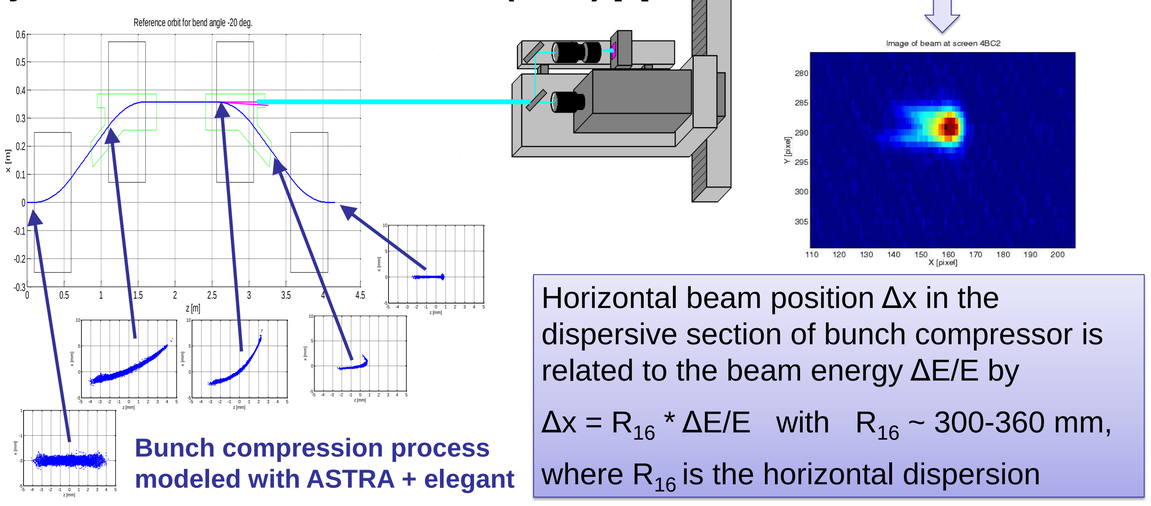
- repetition rate: 10 Hz
- minimum bunch-to-bunch spacing: 1 µs

The detector is planned to be used in control feedback loops which act on phase and amplitude of the accelerating structures:

- a few microsecond latency

Detector Applications

Synchrotron Radiation Monitor (SRM) [2]



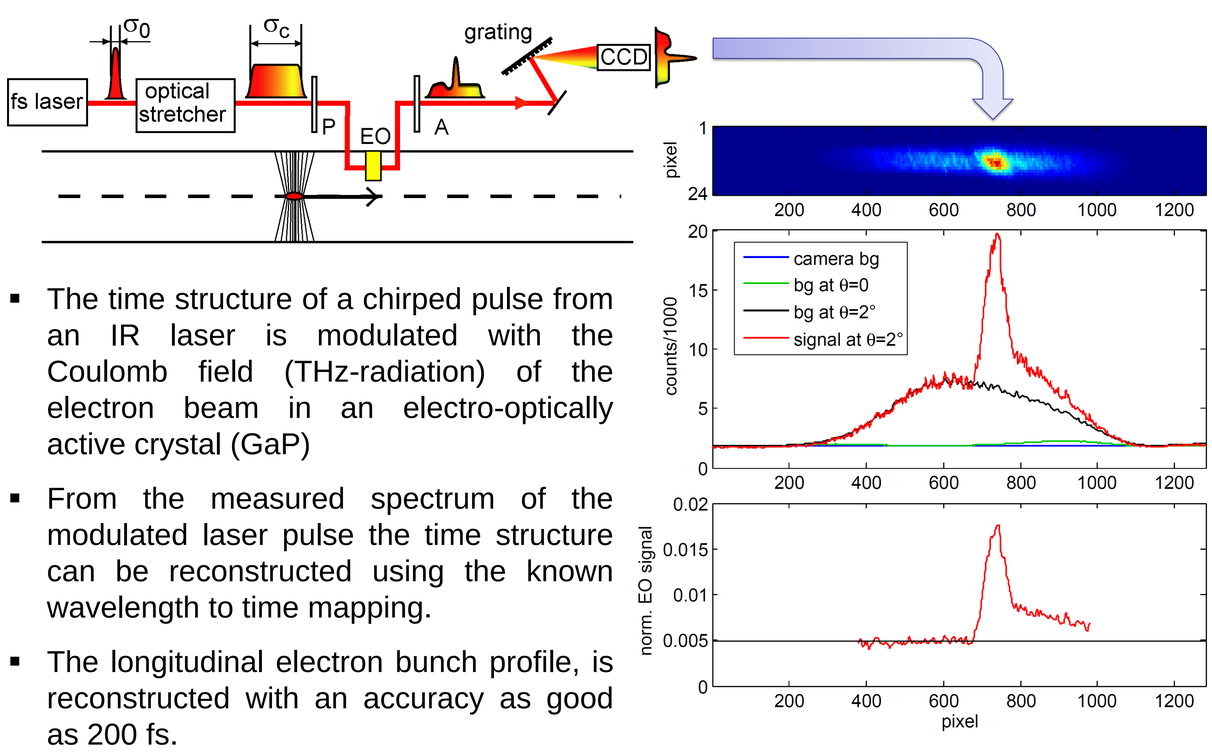
Bunch compression process modeled with ASTRA + elegant

Horizontal beam position Δx in the dispersive section of bunch compressor is related to the beam energy ΔE/E by

$\Delta x = R_{16} * \Delta E/E$ with R_{16} ~ 300-360 mm,

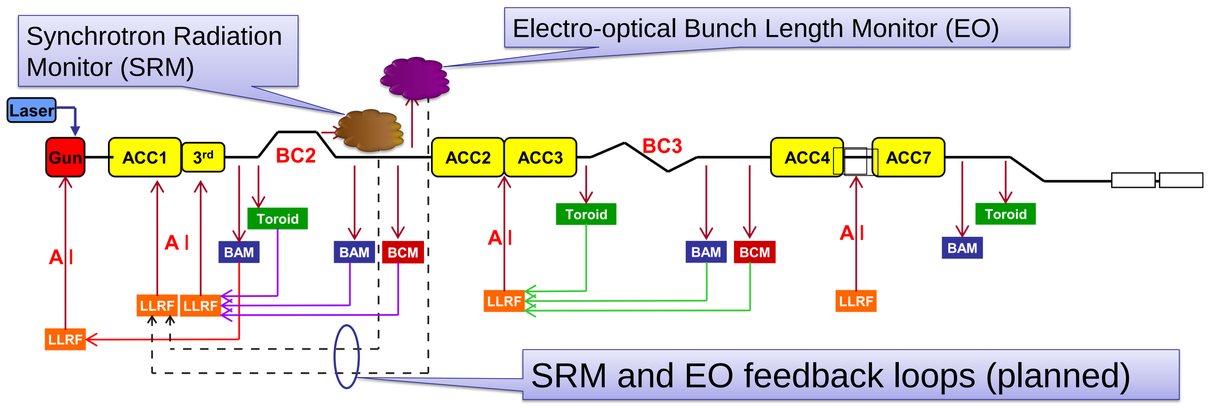
where R_{16} is the horizontal dispersion

Electro-optical Bunch Length Monitor (EO) [3]



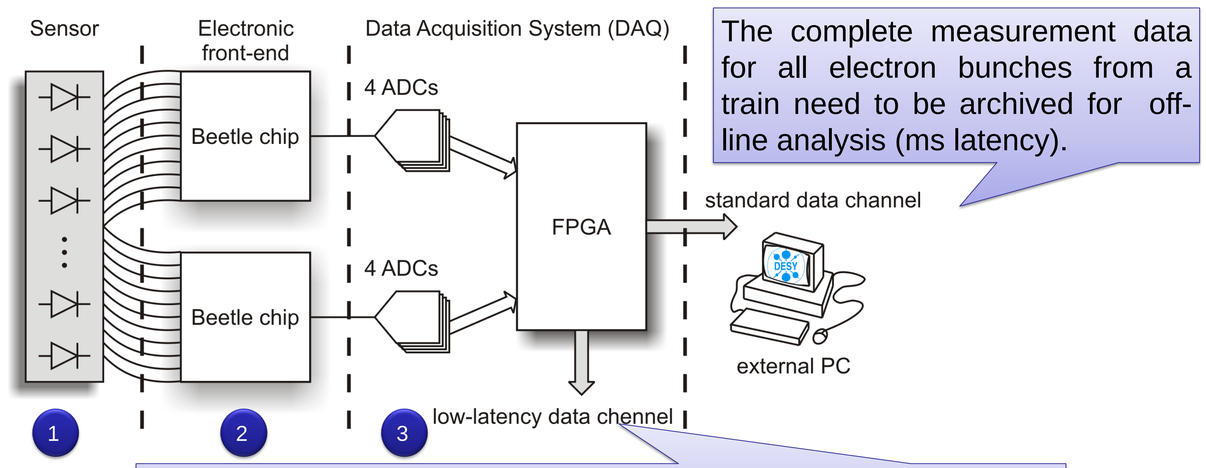
- The time structure of a chirped pulse from an IR laser is modulated with the Coulomb field (THz-radiation) of the electron beam in an electro-optically active crystal (GaP)
- From the measured spectrum of the modulated laser pulse the time structure can be reconstructed using the known wavelength to time mapping.
- The longitudinal electron bunch profile, is reconstructed with an accuracy as good as 200 fs.

Intra-bunch-train feedback [4]



FLASH intra-bunch feedback scheme

Detector Architecture



The complete measurement data for all electron bunches from a train need to be archived for off-line analysis (ms latency).

Only several key parameters characterizing the most important signal distribution features (e.g. peak value, centre of mass, and asymmetry) will be computed and sent further (µs latency).

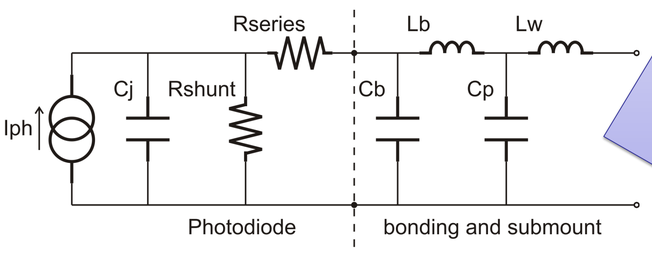
The proposed detector architecture which can be divided into three major functional blocks:

1. sensor– a Photodiode Array (PDA) with 256 independent channels
2. electronic analogue front-end – a multichannel Integrated Circuits (ICs) originally developed for a High Energy Physics (HEP) experiments [1]
3. Data Acquisition System (DAQ) – a block based on Field-Programmable Gate Array (FPGA) responsible for data digitization and processing.

Semiconductor sensor

Considered photodiodes bandwidths:

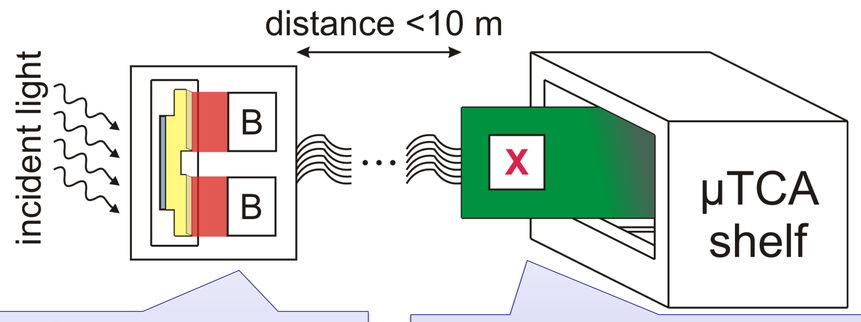
- **InGaAs** – 900 nm to 1700 nm, for infrared (IR) radiation in EO bunch length measurements
- **Si** – 350 nm to 1000 nm, for visible Synchrotron light detection



Photodiode equivalent circuit:

- Iph – photocurrent caused by incident light of appropriate wavelength
- Cj – diode junction capacitance (dependent on reverse bias voltage)
- Rshunt – shunt resistor models dark current of the photodiode
- Rs – Series resistance
- Cb, Cp, Lb, Lw, Rw – parasitic elements connected with bonding and packaging

Hardware Layout



Sensor Board:

Electronic front-end constituted by two Beetle chips which are multichannel readout ICs designed for HEP experiments at CERN [1]:

- 4 pairs of current mode differential outputs which facilitate using long wires
- 40 MHz sampling frequency
- around 1.3 µs latency
- estimated SNR = 36 dB

Data Acquisition System:

Data acquisition (DAQ) module is equipped with

- 8 independent 14-bit analogue-to-digital converters
- Xilinx Virtex-5 FPGA device.
- Serial links

The fast digital processing combined with a low-latency high-speed serial link enables the module to become a part of the real-time LLRF control loop .

Conclusions

The investigations presented in this paper show that with the described detector architecture, 1 MHz line readout rate with few µs latency is feasible. This goal cannot be accomplished using commercially available products. The actual detector behaviour will be tested with a prototype to prove the concept of the bunch-to-bunch diagnostics based on multichannel sensors.

References

[1] S. Loechner, M. Schmelling,; “The Beetle Reference Manual”. LHCb note 2005-105
[2] Ch. Gerth, “Synchrotron Radiation Monitor for Energy Spectrum Measurements in the Bunch Compressors at FLASH”, TUPC03, DIPAC’07, Venice, 2007.
[3] B. Steffen et al., “A Compact Single Shot Electro-Optical Bunch Length Monitor for the SwissFEL”, TUPB42, DIPAC09, Basel, 2009.
[4] W. Koprek et al., “Intra-train Longitudinal Feedback for Beam Stabilization at FLASH”, THOAI2, FEL2010, Malmo, Sweden, 2010

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