# Electro-optic bunch profile monitor at FLASH

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## Application Note

### Introduction

FLASH, the Free-electron LASer in Hamburg, is a fourth generation light source producing intense and short laser pulses in the VUV and soft x-ray regime. To establish a high peak brilliance, the SASE process is used, transferring the energy from a short, relativistic electron bunch to a light pulse. As the stimulation and amplification of the light emission happens in a single pass, FLASH is called a high-gain SASE-FEL.

For the SASE process, short electron bunches are needed. These cannot be produced by a photoinjector gun but must be established in a two-step system of acceleration and compression. Therefore, FLASH is equipped with two magnetic chicanes, the bunch compressors. Here, the bunches coming from the photoinjector cathode having a length of several picoseconds (ps) are compressed by a factor of 5 to 10 reaching a length of about one ps after the first bunch compressor. Further compression takes place in the second bunch compressor, leading to electron bunches with a typical length of few hundred femtoseconds.

Sophisticated diagnostics are needed to characterise the electron bunch and to survey the bunch compression. Different systems are in operation by now, all of them having their own advantages and drawbacks. Typically, a tool with a good temporal resolution needs a lot of infrastructure and works destructive, that means, the electron bunch cannot be used for SASE afterwards.

### Setup

During the last months, a new longitudinal bunch diagnostics device has been established downstream the first bunch compressor, where the expected length of the electron bunches is about one picosecond (ps). It utilises the electro-optic (EO) or Pockels effect that describes the fact that some materials change their birefringence when an electric field is applied to them. Here, an electro-optic crystal is placed beneath the electron bunch inside the beam pipe. When the electron bunch passes, the electric field of the relativistic electron bunch traverses the crystal leading to a change of the birefringence. This change can be probed with a laser pulse that is sent through the crystal at the very same time.

Unlike other EO experiments done at FLASH during the last years, this new EO monitor is meant to be permanent installation and shall be further developed to a standard diagnostic tool. It is optimised to be robust and reliable.

The setup (see fig. 1) consists of the monitor front-end installed at the beam pipe and a lead shielded box next to it containing all the needed infrastructure. A commercially available ytterbium doped fibre laser is locked to the accelerators RF master oscillator using a digital control loop.

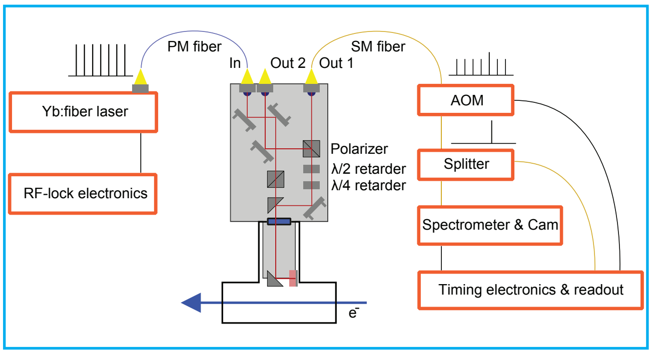


Figure 1: Setup of the new electro-optic monitor at FLASH

This laser produces pulses with a central wavelength of 1030 nm, a length of about 7 ps after stretching (linear chirp), a pulse energy of 1.5 nJ and a spectral bandwidth of 55 nm FWHM at a repetition rate of 108 MHz. Through a waveguide optical fibre, these pulses are delivered to the front end. Here, the light is linearly polarised and sent through a vacuum window into the beam pipe. The light is directed to the crystal via a mirror. Having crossed the crystal, it is reflected by a coating under a small angle, thus hitting an outcoupling mirror on its way back. The charge pro le of the electron bunch is now imprinted in the laser pulse as a polarisation modulation. As the laser is stretched to a length exceeding the length of the electron bunch a bit, the first part of the charge pro le is imprinted in the first part of the laser pulse, and so on. And due to the linear chirp, the leading part of the laser pulse consists of redshifted spectral components and the followed by the bluer parts. Thus, a relation between the spectral components and the polarisation modulation is established.

Passing through a quarter- and a half wave retarder in the analyser section sets the polarisation of the laser pulse in a way that in the following polariser all the non-modulated parts of the laser pulse are reflected. Thus, the polarisation modulation has been turned in an amplitude modulation, with different parts of the electric field encoded in different spectral components (electro-optic spectral decoding, EOSD). Now the propagation through further dispersive media does not in influence the information carried by the modulated laser pulse. The pulse train is then guided via optical fibre to an acusto-optical modulator for gating only one pulse out of the pulse train, and reaches the spectrometer and camera.

### Spectrometer

The Andor Shamrock SR-163 spectrograph is a small and dust resistant device, so that the camera and the spectrograph fit in the lead shielded box together with the other devices. The camera, an Andor iDus InGaAs photodiode array DU490A-1.7, has mainly been chosen for three reasons, that are sensitivity, robustness and integration in the control system. First, only an InGaAs detector is sensitive enough in the wavelength range of the laser. It should be mentioned that the experiment requires a single pulse with a pulse energy in the range of some tens of picojoules, spectrally resolved, to be detected. Second, a robust system was needed as the camera is installed inside the accelerator tunnel. This is an area with restricted access, so maintenance can only be carried out occasionally. A reliable system is required that can withstand the harsh environment inside the accelerator tunnel (dust, radiation). And third, this type of camera has already been integrated into the FLASH control system DOOCS (distributed object oriented control system), making it easy to control the camera remotely (see fig. 2). A special server has been written to include all the features of the Andor software in the FLASH standard control system, such as the setting of the exposure time or the control of the CCD cooling. The integration in DOOCS also enables the use of the data acquisition system (DAQ) and is important for the development of the EO monitor towards a standard diagnostic tool used by the machine operators.

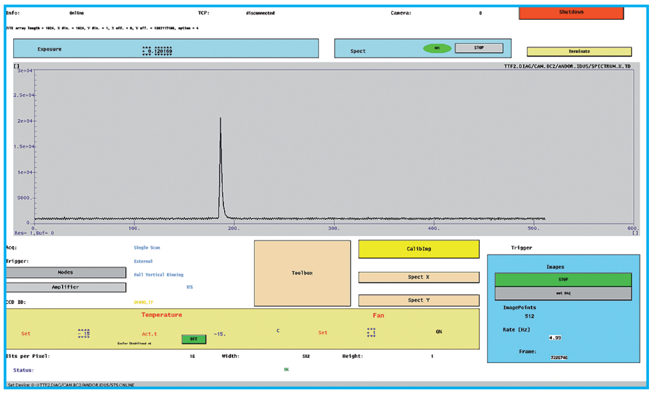

**Figure 2: Control panel used in the FLASH control system for the Andor iDus InGaAs detector. The camera has been fully integrated in the accelerators control system, allowing for easy data acquisition and complete remote control.**

### Reference

Breunlin, Jonas - "Commissioning of an Electro-Optic Electron Bunch Monitor at FLASH", Diploma thesis, DESY, Hamburg, 2011

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