Fast Intra Bunch Train Charge Feedback for FELs based on Photo Injector Laser Pulse Modulation

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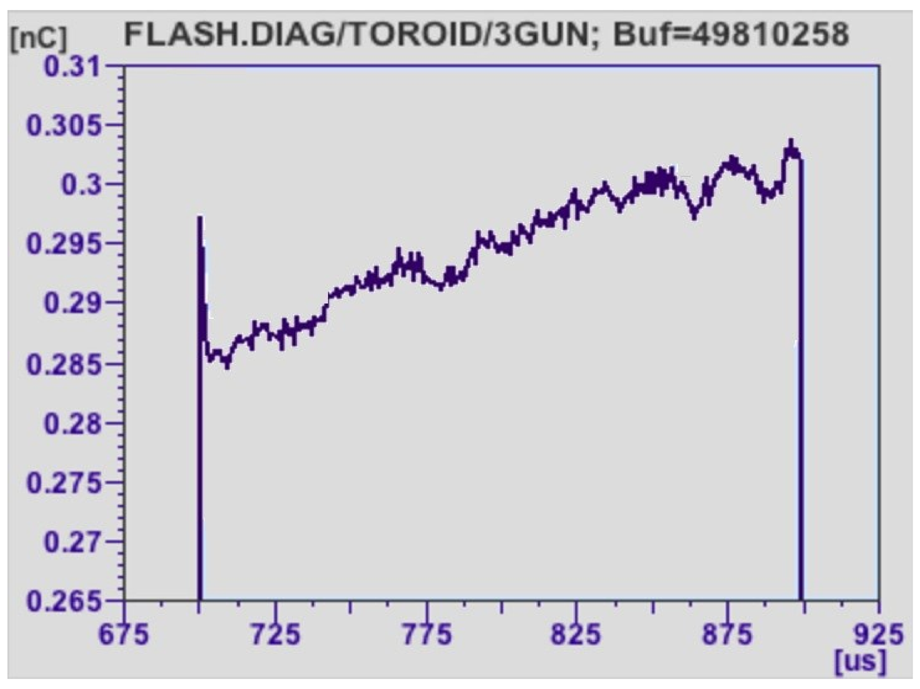
Motivation

Modern high repetition rate Free Electron Lasers (FELs) are driven by a high energy electron beam generated by a superconducting accelerator operated in pulsed mode. Electron bunches are produced by a complex photo-injector system which can generate long electron bunch trains.

Intra bunch train charge instabilities disturb the longitudinal phase space of the electron bunches introducing instabilities in bunch peak current, pulse duration and shape.

Noticeable charge oscillations and a charge slope along the bunch trains in the range from 0.5 % to 3 % are observed. They are caused mainly by the photo-injector laser, but also by instabilities in the RF-gun accelerating field and time dependent effects in the photo emission process.



Intra train charge variation over a train with 200 bunches observed in FLASH (charge slope artificially amplified).

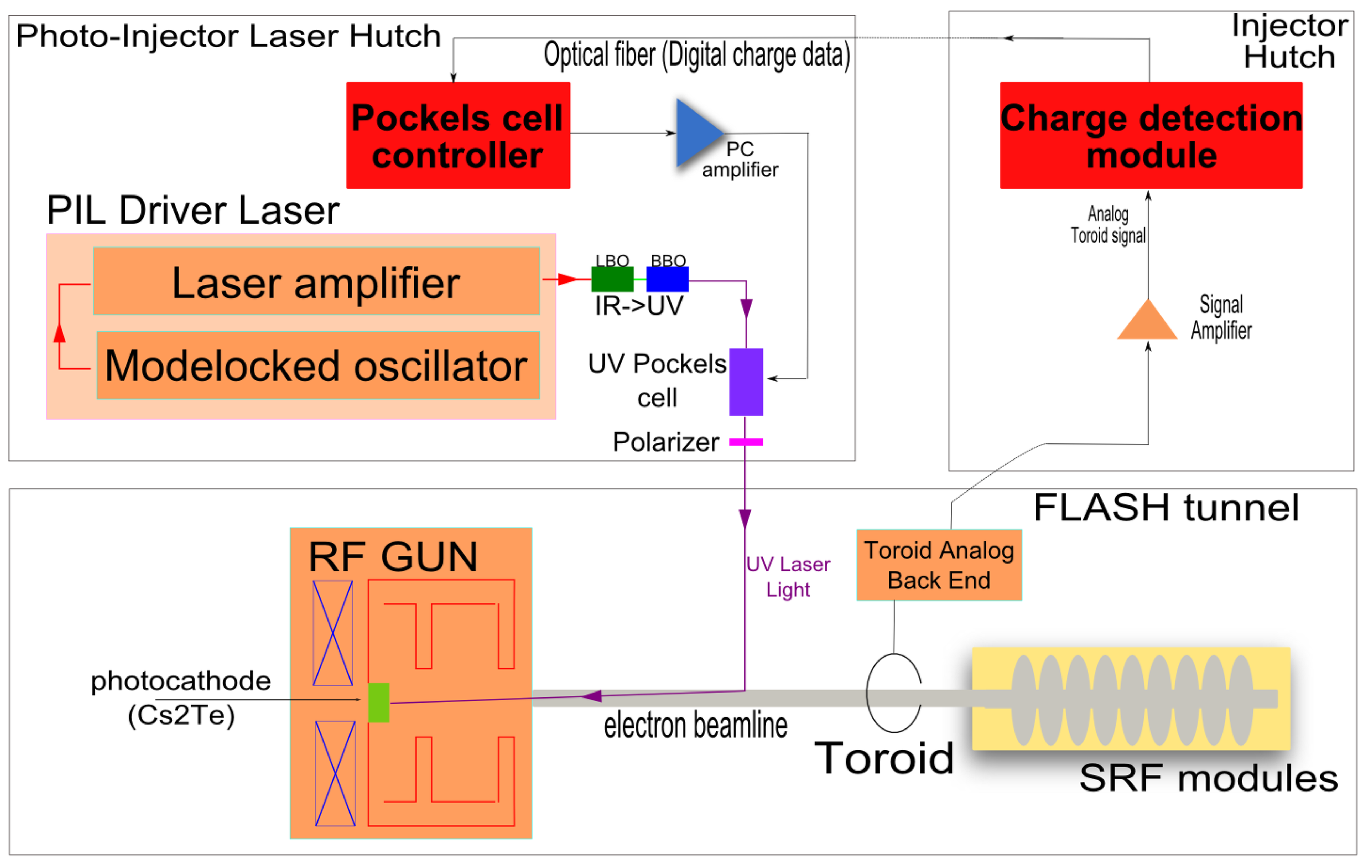
Intra Bunch Train Charge Stabilization System

In order to stabilize charge in the bunch trains generated by Photo-Injector Laser System dedicated system has been designed. Operation principle: the electron bunch charge is read by a toroid, the feedback system acts on a Pockels cell modulating the laser polarization and thus, with a subsequent polarizer the laser energy.

The feedback loop delay must be smaller than 1 μs, the distance between bunches in the train.

Main components of the system are:
- Real time charge detection module
- Fast Pockels cell controller module
- BBO Pockels cell and amplifier

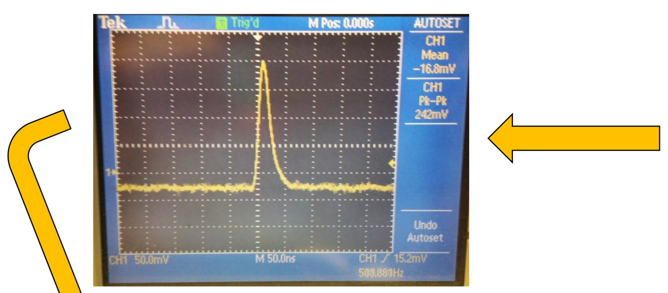
Modern electronic components built according to Micro Telecommunication Computing Architecture (MTCA.4) standard has been employed in the system.



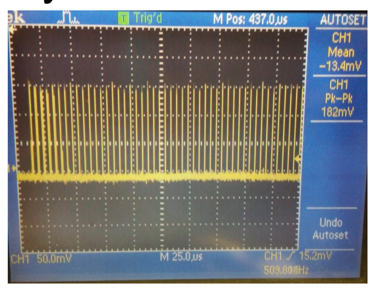
Block diagram of the FLASH Photoinjector and the intra bunch train charge stabilization system.

Detector module: SIS8300+SIS8900 with LLL connection

- Real-time charge detection module based on MTCA.4 AMC board - SIS8300 (Struck Innovative Systeme GmbH)
- Detection algorithm implemented in Virtex 5 FPGA
- Dedicated high level control software (DOOCS server) for detection parameters setting and system monitoring
- Charge data send to Pockels cell Controller module with fast (3,25 GB/s) fiber low latency link



Single Bunch analog signal



Raw Toroid data of Bunch Train

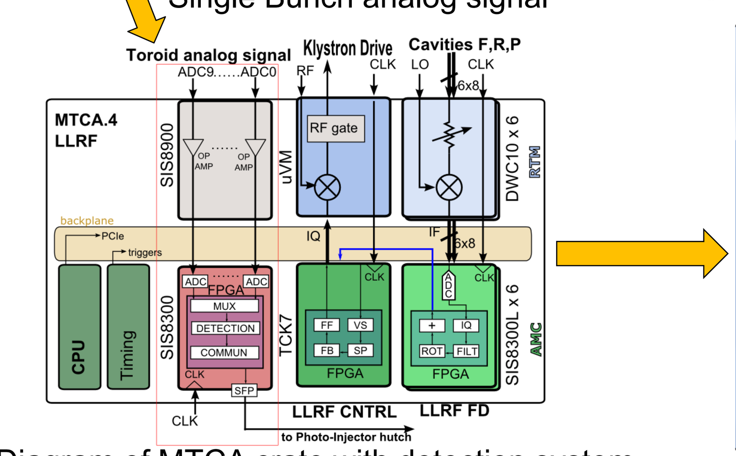
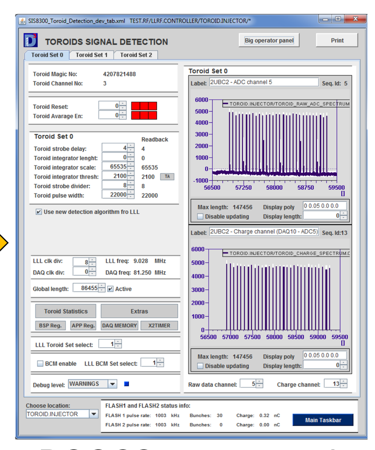


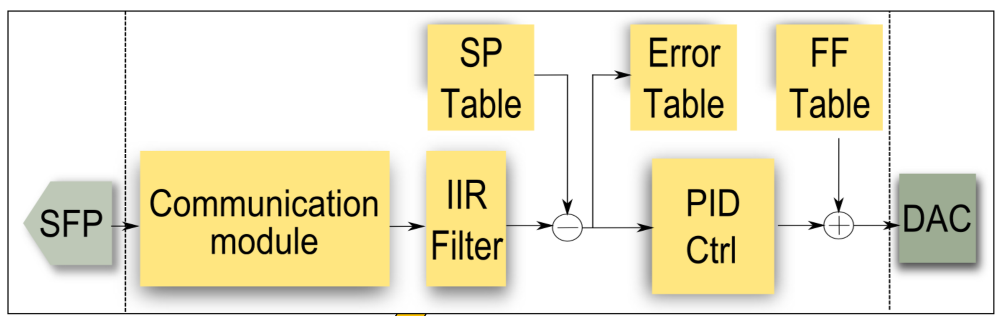
Diagram of MTCA crate with detection system



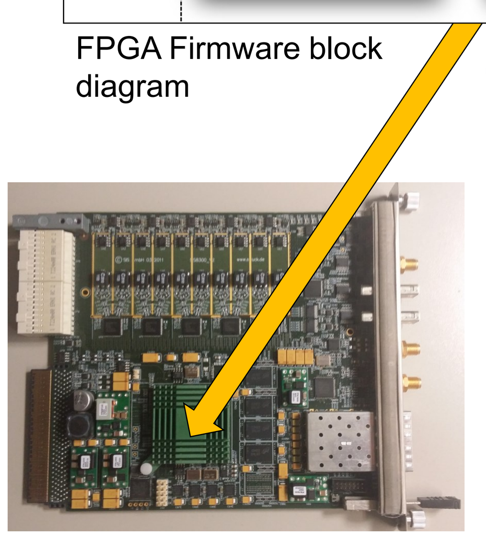
DOOCS server panel

Pockels cell Controller module: SIS8300L with LLL connection

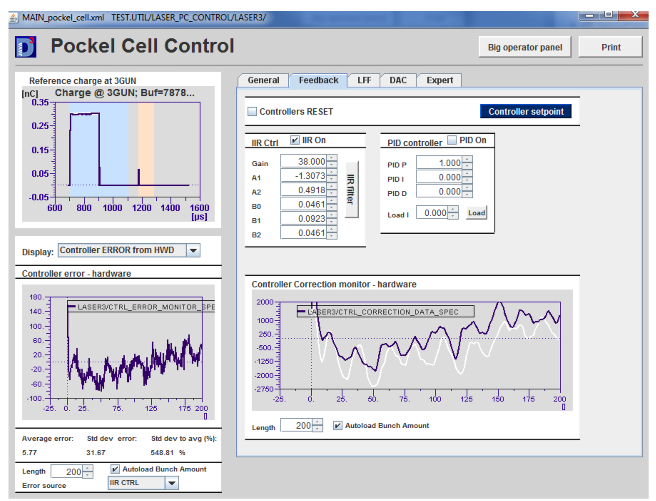
- Pockels cell controller based on MTCA.4 AMC board - SIS8300L (Struck Innovative Systeme GmbH)
- Control algorithm implemented in Virtex 6 FPGA
- Dedicated high level control software (DOOCS server) for data acquisition and monitoring, Learning Feed Forward (LFF) and Setpoint Correction (SC) calculations



FPGA Firmware block diagram



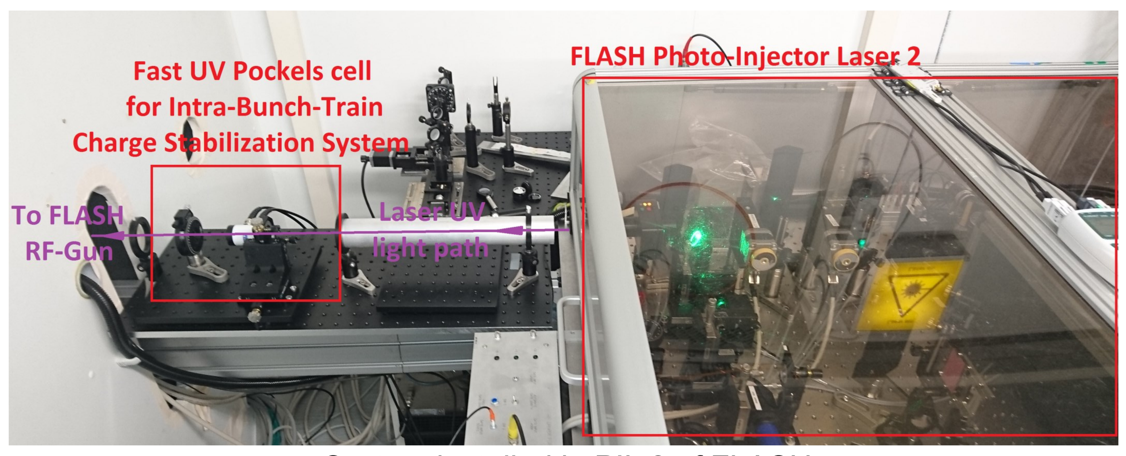
SIS8300L MTCA AMC



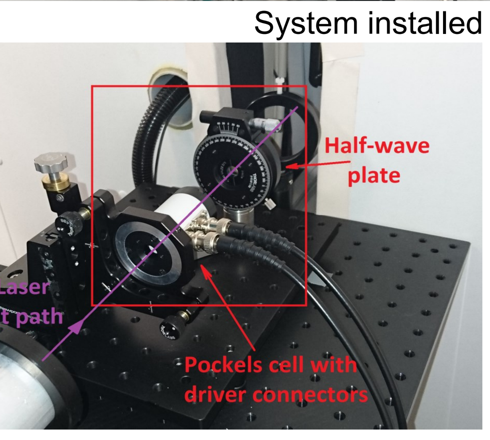
DOOCS server control panel

Actuator module: Pockels cell with the amplifier

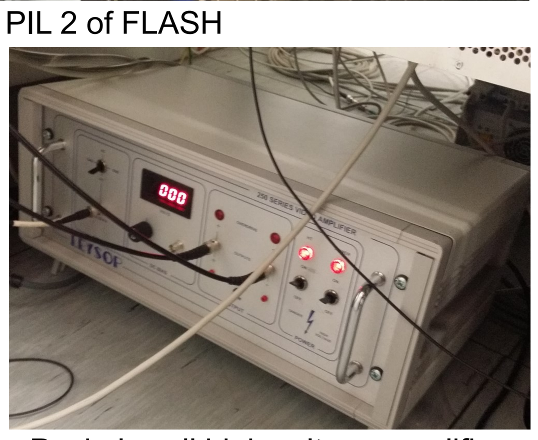
- 5 mm aperture BBO Pockels cell for 262 nm (LEYSOP LTD, England) installed.
- Bandwidth: about 7 MHz.
- High power amplifier (LEYSOP LTD, England) providing correct operation voltages for Pockels cell



System installed in PIL 2 of FLASH



Pockels cell setup in UV laser beam optical path

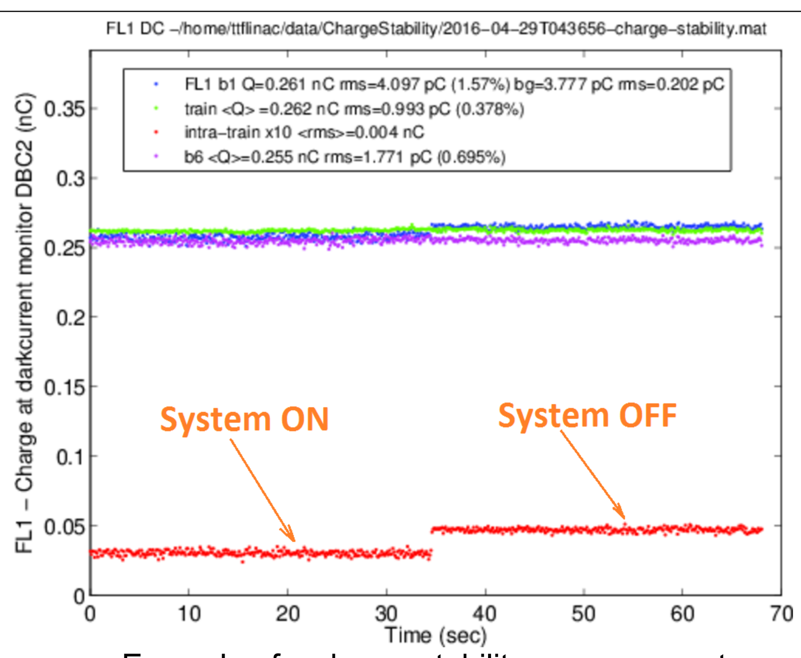


Pockels cell high voltage amplifier

First results and plans

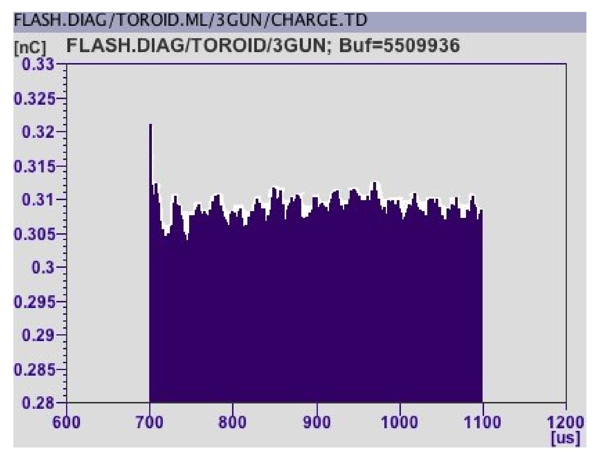
Results

- System has been installed in the FLASH photoinjector laser.
- First system tests have been performed in March and April 2016.
- During tests in March laser system was less stable than during the April tests.
- A charge oscillations of unknown source were observed.
- In both cases, the charge stability and train flatness could be improved by the feedback system.

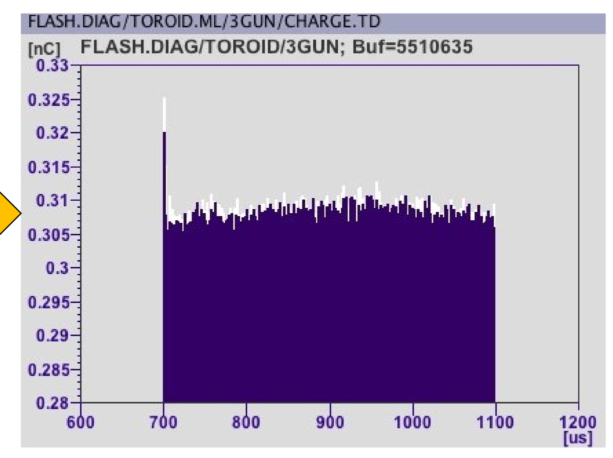


Example of a charge stability measurement.

Charge stability measurements	Units	March 2016 tests			April 2016 tests		
		System OFF	System ON	Improvement	System OFF	System ON	Improvement
Intra-train stability	rms (nC)	0.003 nC	0.002 nC	50 %	0.005 nC	0.003 nC	40 %
Train to train stablity	rms (pC)	3.261 pC	2.505 pC	23 %	1.145 pC	0.817 pC	30 %
	rms (%)	1.23 %	0.947%		0.445 %	0.31 %	



Bunch train (200 pulses) with visible oscillations.



Oscillations minimized by Intra-Bunch-Train Feedback System

Plans

- Currently the main limitation of the system seems to the charge detection: high noise level, detection algorithm.
- In June new toroid electronics with less noise will be installed.
- New detection algorithms are planned to be developed and tested.
- More tests of the system are required.

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20th Real Time Conference (RT2016), 5th-10th June 2016, Padova, Italy

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