Status Update on MicroTCA based Fast Orbit Feedback System for PETRA IV

Progress in the digital signal chain

Sven Pfeiffer on behalf of the PETRA IV - WP2.08

Hamburg, 11.12.2024





FOFB system topology

Latency optimized topology

- 1 global orbit control unit (GOC)
 - Close to RF system / timing system
 - Short path from GOC to LOC in experimental halls
- 16 (15) distributed local controllers (LOC)
 - Collection of BPM information
 - Transmission of updated magnet current to power supplies
- Optical fiber communication links
 - Global to all local systems \rightarrow classical regulation (star topology)
 - Local to local system
 - For local control scheme integrating experiments
 - Redundant system mode (decentralized) as future upgrade





Ring:2.3km, 789 BPMs, 560 fast correctors,FOFB:10% (5%, 3%) beam stability, DC to 1kHz





DESY. | Status Update FOFB System for PETRA IV | MTCA WS 2024 | S. Pfeiffer |

FOFB - a cross-directional problem

A two dimensional control problem

The goal is to maintain the beam position

- Throughout the ring \rightarrow spatial domain
- **Over time** \rightarrow temporal domain

$$G(s) = \begin{pmatrix} r_{11}G_{11}(s) & \cdots & r_{1n}G_{1n}(s) \\ \vdots & \ddots & \vdots \\ r_{m1}G_{m1}(s) & \cdots & r_{mn}G_{mn}(s) \end{pmatrix}$$

with $r_{mn} = \frac{\sqrt{\beta_m(z)\beta_n(z)}}{2\pi Q} \cos(\pi Q - |\phi_m(z) - \phi_n(z)|)$

• All corrector channels with identical temporal response

$$\mathbf{G(s)} = G(s)\mathbf{R} \longrightarrow \mathbf{C(s)} = C(s)\mathbf{R}^+$$

2 step simulation

- SISO dynamical system (1 location with all TFs)
 - Worst case scenario → best case for MIMO
- MIMO system (spatially distributed) with main dynamics





FOFB sub-systems



- Subsystems based on PETRA IV design
- Disturbance spectra approximated with measurement at PIII
- PI controller optimized
 for disturbance rejection
 - Goal: 1kHz
- PI controller optimized for reference tracking
 - Integration of experiments (photon diagnostics)



Digital signal chain

Baseline concept

Standard support modules/boards per crate

- 2x PS (redundant)
- MCH, CPU, x3timer

2 versions of AMC boards only (no options)

DAMC-UNIZUP as BPM data collector

			JMENTATION OLOGIES
	BPM _{i,1} crate		
			CPU
			X3TIMER
5 x 2 BPM (n = 20) 			
	→	RTM-BPM	UNIZUP
	→	RTM-BPM	UNIZUP
	->	RTM-BPM	UNIZUP
	->	RTM-BPM	UNIZUP
	-	RTM-BPM	UNIZUP

Talk: Aleš Bardorfer



Courtesy: M.Fenner, S.Chystiakov

Channel tuning



DRTM-8SFP+

 Fanning out the MGT channels from DAMC-UNIZUP

SELECTOR SETTINGS

New product

 Brings 1 to 8 MGTs to RTM @ 12.5 Gbps

DESY. | Status Update FOFB System for PETRA IV | MTCA WS 2024 | S. Pfeiffer |

Digital signal chain

Baseline concept

Standard support modules/boards per crate

- 2x PS (redundant)
- MCH, CPU, x3timer

2 versions of AMC boards only (no options)

- DAMC-UNIZUP as BPM data collector
- DAMC-FMC2ZUP for
 - BPM data concentration, main processing
 - Communication with frequency shaping filter to magnet PS
- DFMC-6QSFP+ (24LC fiber links)

Monitor GOC crate as observer



Magnet PS Communication •

Latency budget

BPM electronics

Long delays/latencies (>1µs)

FB computation by large

scale matrix multiplications

Baseline concept

•

•

٠

Short delays/latencies (<1µs)

- Data serialization for 1 lane • link (el. or opt.) transfer
- Data alignment •
- Data filtering to equalize • dynamical transfer function



\rightarrow 78µs as expected loop latency



LOC, crate

LOC

BPM_{12.8}

BPM_{i1} crate

20)

2

≥

മ

BPM

UNIZUP

23µs

Board

Optical

Cable

Backplane

Max length



GOC rack

PS

1µs

200m

Digital signal and processing chain

Requirements for the MicroTCA components

- **Software** with ChimeraTK framework
- Open source FPGA firmware framework
- Hardware
 - Operability (Low latency and parallel processing in FW)
 - Maintainability
 - Modularity / flexibility (FPGA IP libraries)
 - High data rates & long communication paths
 - QSFP+ and optical single-mode links
 - Scalability
 - Larger to smaller FOFB schemes
 - BPM LOC GOC
 - BPM GOC
 - BPM only







gitlab.desy.de/fpgafw/fwk

Talk: Dietrich Rothe

Talk: Cagil Guemues



Digital signal and processing chain

Requirements for the MicroTCA components

- Software with ChimeraTK framework
- Open source FPGA firmware framework
- Hardware
 - Operability (Low latency and parallel processing in FW)
 - Maintainability
 - Modularity / flexibility (FPGA IP libraries)
 - High data rates & long communication paths
 - QSFP+ and optical single-mode links
 - Scalability
 - Larger to smaller FOFB schemes
 - BPM LOC GOC
 - BPM GOC
 - BPM only



Digital signal and processing chain

Requirements for the MicroTCA components

- Software with ChimeraTK framework
- Open source FPGA firmware framework
- Hardware
 - Operability (Low latency and parallel processing in FW)
 - Maintainability
 - Modularity / flexibility (FPGA IP libraries)
 - High data rates & long communication paths
 - QSFP+ and optical single-mode links
 - Scalability
 - Larger to smaller FOFB schemes

DESY. | Status Update FOFB System for PETRA IV | MTCA WS 2024 | S. Pfeiffer |

- BPM LOC GOC
- BPM GOC
- BPM only







Talk: Cagil Guemues

FOFB system



Outlook

Fast orbit feedback developments

- Large scale GOC processing
 - Twice *large scale matrix multiplication* with 1580 x 560 elements
 - *Fast fault detection* of non-functioning correctors and their exclusion from ORM
 - \rightarrow Local effect otherwise global error

Versal chip

- Programmable logic for finegrained parallel processing, sensor fusion, ...
- Low latency DSPs, Als, ...
- Terabit network-on-chip



https://www.xilinx.com/publications/events/developerforum/2018-frankfurt/introducing-the-versal-architecture.pdf

Multi-bunch feedback developments

• DRTM-MBFB-FE

Courtesy: S.Jablonski





DESY. | Status Update FOFB System for PETRA IV | MTCA WS 2024 | S. Pfeiffer |

Thank you.

PETRA IV

For the materials provided:

- Adeel Amjad
- Behzad Boghrati
- Stanislav Chystiakov
- Burak Dursun
- Michael Fenner
- Szymon Jablonski
- Sajjad Hussain Mirza

& those who were forgotten here...

Contact

DESY. Deutsches Elektronen-Synchrotron Sven Pfeiffer DESY - MSK <u>sven.pfeiffer@desy.de</u> (+49) 040 8998 2744

www.desy.de