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USAGE OF THE MicroTCA.4 ELECTRONICS PLATFORM FOR FEMTO-SECOND SYNCHRONIZATION SYSTEMS

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Abstract

At the European XFEL and FLASH at DESY optical synchronization systems are installed providing sub-10 femtosecond electron bunch arrival time stability and laser oscillator synchronization to carry out time-resolved pump-probe experiments with high precision. The synchronization system supplies critical RF stations with short- and long-term phase-stable reference signals for precise RF field detection and control while bunch arrival times are processed in beam-based feedbacks to further time-stabilize the FEL pulses. Experimental lasers are tightly locked to the optical reference using balanced optical cross-correlation. In this paper, we describe the electronic hardware for supervision and real-time control of the optical synchronization system. It comprises various MicroTCA.4 modules including fast digitizers, FPGA processor boards, and drivers for piezos and stepper-motors. Advantages of the system are the high-level of integration, state-of-the-art performance, flexibility, and remote maintainability.

INTRODUCING MicroTCA.4

MicroTCA is an electronic framework for signal processing derived from the Advanced Telecommunication Computing Architecture (ATCA). MicroTCA.4 was released as an official standard by the PCI Industrial Manufacturers Group (PICMG) in 2011 and is supported by the xTCA for physics group, a network of physics research institutes and electronics manufacturers. Opposed to other xTCA standards it is also designed for analog processing of low-noise signals. Its main improvements are enhanced rear I/O connectivity and provisions for precision timing. MicroTCA.4 has inherited many of the advantages of ATCA including capabilities for remote monitoring, remote maintenance, hot-swap of components, and the option to duplicate critical components, making the standard highly modular, reliable and flexible. It also made the outstanding digital signal processing performance of ATCA systems more affordable and less demanding in terms of space requirements and energy consumption.

MicroTCA.4 System Architecture

Fundamental components are the chassis which is available in different form factors and sizes, the optionally redundant power supply, an optionally redundant crate management controller (MCH), and CPU with hard drive [1].

For user applications specific analog and digital processing cards are used. From the front, Advanced Mezzanine Cards (AMC) which can also be used on ATCA carrier cards are inserted to the crate. There are various connections on the backplane which provide e.g. Gigabit Ethernet and PCI Express links between the slots and the MCH, dedicated clock and trigger distribution lines, and point to point links between the slots for fast real time communication between the cards. Additionally, there is the possibility to insert cards from the rear of the crate, so-called Rear Transition Modules (RTM) which connect to the according AMC board via the Zone 3 connector. This connection provides 60 differential pairs for analog or digital signals, which are defined in the standard [1]. Some cards incorporate connectors for additional industrial standard piggy back boards like FPGA Mezzanine Cards (FMC) or IndustryPack (IP) modules.

MicroTCA.4 AT DESY

Meanwhile, for basically all accelerators at DESY the technical groups decided to use the MicroTCA.4 standard. For example at the European XFEL and FLASH this involves the LLRF field control [2], the timing and machine protection systems, standard diagnostics like beam position monitors [3] and camera readouts, and the optical synchronization system [4]. In the course of the developments required for fulfilling the demanding tasks, the standard was further adapted and improved.

In order to facilitate the development of new boards for extending the portfolio of applications and to ensure the availability of spare parts, DESY took the initiative for a better establishment of the MicroTCA.4 standard in industry. With financial support from the Helmholtz Association and industry partners the Helmholtz Validation Fund (HVF) was established in 2012.

Therefore, most board designs are licensed to various industry partners who offer those components as 'commercial of the shelf' products. This way it is easy for other institutes and companies to make use of the sophisticated designs (e.g. high speed digital or low noise analog cards) without the need for own developments or additional agreements.

As successor of the HVF the MicroTCA Technology Lab [1] was founded at DESY to help external partners with their MicroTCA related projects. A competent team of engineers offers support for all aspects like hardware and firmware development, or the implementation and commissioning of MicroTCA systems at the facility.

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OVERVIEW OF MicroTCA.4 MODULES USED IN THE SYNCHRONIZATION SYSTEM

The hardware modules required for the different tasks in the optical synchronization systems like signal detection, sampling, processing, and actuating are mostly generic and applicable in different setups and configurations. Only for a few very specific tasks individual boards were designed.

In this chapter most of the used modules are introduced with a short description.

SIS8300L2 Versatile FPGA (Virtex 6) AMC board with 10 channel 125 MSPS 16 bit digitizers and 2 fast DACs, available at Struck Innovative Systeme GmbH [5].

FMC25 Versatile FPGA (Virtex 5) AMC board for data processing and FMC carrier with two high pin count FMC slots. The board was developed at DESY and licensed to the company CAEN ELS [6].

FMC20 Low-cost FPGA (Spartan6) AMC board for interfacing with actuator modules and FMC carrier with two FMC slots. The board was developed at DESY and licensed to the company CAEN ELS [6].

AD84 Generic analog IO RTM board with 8 channel 10 MSPS 16 bit digitizers and 4 channel DACs. The board was developed at DESY, not yet licensed to an industry partner [1].

DWC8300 10 channel low-noise down converter RTM board (0.7 GHz – 4 GHz). The board was developed at DESY and licensed to the company Struck GmbH [6].

PZT4 Generic 4 channel piezo driver and piezo sensor RTM board with switchable output range (up to ±80 V), internal DAC or external input, and internal or external power supply [7]. The board was developed at DESY and licensed to the company Piezotechnics GmbH [8].

MD22 2 channel stepper motor driver FMC board with end-switch and encoder readout. The board is capable of driving up to 1.8 A coil current and supports 256 micro steps. It was developed at DESY and is licensed to the company CAEN ELS [6].

AD16 Generic ADC FMC board with 16 channels up to 200 kSPS and 18 bits resolution. The board was developed at DESY and is not yet licensed to an industry partner [1].

UNIO Versatile, general purpose, low-cost IO FMC board with 48 IO pins. Each pin can be assigned to digital IO, gnd or alternate function like ADC, DAC, power supply, or UART (12 V) via a CPLD. The board was developed at DESY, not yet licensed to an industry partner [1].

SFP4 Generic 2 or 4 channel SFP+ GbE or fiber transmission FMC board. Board was developed at DESY and licensed to the company CAEN ELS [6].

LASY RTM board under development at DESY especially for laser synchronization purposes. Besides down-converter channels with two-tone calibration capabilities it incorporates many laser specific inputs and features.

TOPOLOGY OF THE SYSTEMS

Laser Oscillator Synchronization Electronics

An RF signal (1.3 GHz + laser oscillator repetition rate) generated from the laser pulse train is down-converted on a DWC8300 (later on a LASY board) to an intermediate frequency which is digitized on an SIS8300L2 board [9]. Additionally, the baseband signals from a balanced optical cross-correlator (OXC) [10] or electro-optical detection method (MZM Setup) [11] are fed to other ADC channels on that digitizer AMC. The digital signals contain the phase or timing jitter information with femtosecond precision. The feedback controller output is digitally transferred to the next slot in the crate where it is received by an FMC20 board. From here a PZT4 is addressed to drive the piezo(s) in the laser oscillator cavity. If the required tuning drive exceeds the piezo range a coarse tuning step has to be performed. Depending on the laser oscillator architecture, this is either a temperature step initiated via an UNIO board or a delay stage step driven either by a stepper motor via a MD22 or a piezo motor via another PZT4 channel.

Additional inputs of the down converter and later the LASY are used for bucket detection to set the correct absolute timing and for some other required monitoring and control signals.

As the PZT4 is capable of driving more than one piezo also laser oscillators with two piezos and/or two lasers oscillators can be synchronized with no additional hardware.

Fiber Link Stabilization Electronics

For the stabilization of the numerous up to few km long synchronization fiber links e.g. in the European XFEL [4] MicroTCA.4 offers a very compact and efficient solution because four links can be stabilized using only two slots in the crate. The heart of the link stabilization unit (LSU) is an OXC whose signal is digitized on an AD84 board (2 ADC channels per link). The processing is done on an FMC25 board which computes the feedback controller output and, similar to the laser application, transmits the required actuator stroke to an FMC20 board. Again, this board addresses the piezo driver in the rear which drives a piezo-based fiber stretcher to compensate for the detected timing change in the link fiber by stretching a piece of it. Also here a delay stage is required for coarse tuning when the piezo stretcher reaches its limit. Therefore, also here, a MD22 is used. For a complete set of four LSUs all eight ADC inputs from the AD84, all four piezo driver outputs from the PZT4, and all four motor drivers of two MD22 FMCs mounted on the FMC20 are used.

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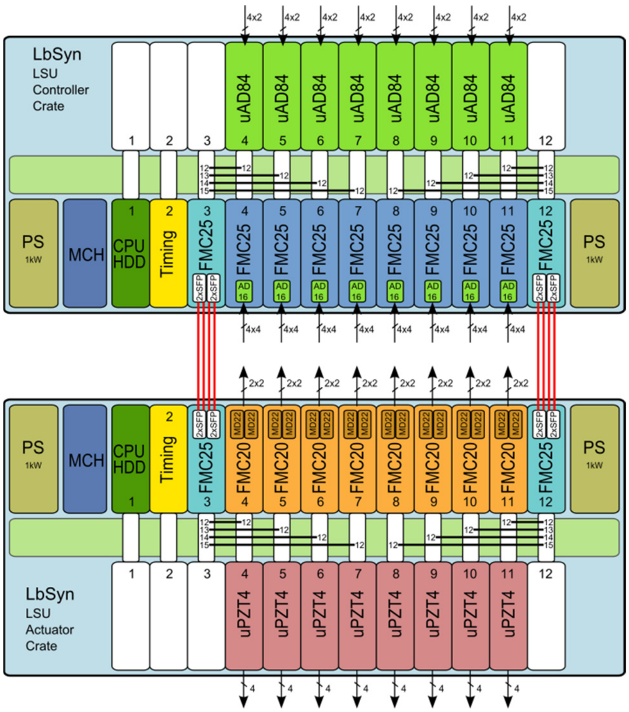

Figure 1: MicroTCA.4 setup for controlling up to 32 Link Stabilization Units.

Additionally, the AD16 FMC mounted on the FMC25 carrier collects slow monitor signals like optical power levels and backup phase detector signals. Four slow ADC channels are available and used for one LSU, again fitting perfectly to the 16 channel ADC when controlling and monitoring four LSUs simultaneously.

In the baseline design of the European XFEL 23 LSUs are foreseen with the possibility for upgrades to more units. Despite the compact design this requires 12 board slots in the crate which are not available since in the 12-slot crate (biggest chassis available) two slots are used by an inevitable timing module and the obligatory CPU board. For this reason and to avoid distortions on the sensitive OXC detector signals by electromagnetic interference from the actuators (piezo = high voltage, stepper motor = sharp current spikes), the detector units comprised of AD84 and FMC25+AD16 are separated from the actuator unit comprised of FMC20+2xMD22 and PZT4 in a different crate. Figure 1 shows a schematic view of the complete setup ready for controlling max. 32 LSUs. The communication between the detector and the actuator crate is done via FMC25 concentrator hubs, collecting the signals from up to four FMC25 controller boards and sending them via SFP4 modules to the corresponding SFP4s on the FMC25 receiver boards. From here the signals are distributed again to the FMC20 boards driving the actuators. To minimize the latency the complete communication happens via low latency point-to-point links on the crate backplane and direct fiber connections between the two SFP4s.

CONCLUSION

The topology of MicroTCA.4 hardware modules used for signal detection, analog/digital processing and actuator driving in the optical synchronization systems was presented.

For example, at the European XFEL, a total number of 25 fiber link stabilization units are in 24/7 operation with this technique, reliably providing femtosecond stable reference signals to the accelerator and experiment lasers.

Up to date, a total number of about 50 different laser oscillators are synchronized at various facilities on the DESY campus and at partner institutes using the described hardware. Still, the demand for further setups is growing as new facilities or sub-systems are continuously being proposed, developed and implemented.

REFERENCES

[1] MicroTCA, `https://techlab.desy.de`

[2] J. Branlard *et al.*, "The European XFEL LLRF System", in *Proc. 3rd Int. Particle Accelerator Conf. (IPAC'12)*, New Orleans, LA, USA, May 2012, paper MOOAC01, pp. 55-57.

[3] F. Schmidt-Foehre, N. Baboi, G. Kuehn, B. Lorbeer, D. Noelle, and K. Wittenburg, "First Tests with the Self-triggered Mode of the New MicroTCA-based Low-charge Electronics for Button and Stripline BPMs at FLASH", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 3509-3511. `doi:10.18429/JACoW-IPAC2014-THPME117`

[4] S. Schulz *et al.*, "Few-Femtosecond Facility-Wide Synchronization of the European XFEL", presented at the FEL'19, Hamburg, Germany, Aug. 2019, paper WEB04, this conference.

[5] Struck Innovative Systeme, `https://www.struck.de`

[6] CAENels, `https://www.caenels.com`

[7] K. Przygoda *et al.*, "MTCA.4 Module for Cavity and Laser Piezo Operation", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 3140-3142. `doi:10.18429/JACoW-IPAC2014-THPRO105`

[8] Piezotechnics, https://www.piezotechnics.com

[9] M. Felber *et al.*, "Compact MTCA.4 Based Laser Synchronization", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 1823-1825. `doi:10.18429/JACoW-IPAC2014-TUPRI107`

[10] J. M. Mueller *et al.*, "All-Optical Synchronization of Pulsed Laser Systems at FLASH and XFEL", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 854-856. `doi:10.18429/JACoW-IPAC2015-MOPHA032`

[11] T. Lamb *et al.*, "Large-Scale Optical Synchronization System of the European XFEL with Femtosecond Precision", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 3835-3838. `doi:10.18429/JACoW-IPAC2019-THPRB018`