ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPA070

ADVANCEMENTS OF ELBE TIMING SYSTEM UPGRADE

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Abstract

Modern Big physics experiments call for optimizations of machines in various aspects. Integration of an advanced control system is one of them, and timing system as controls' backbone is most often required to be upgraded significantly or even designed and implemented anew. The complexity of experiments at HZDR ELBE and the range of varieties of its instruments and subsystems is combined with top-notch performance requirements. These, coupled with hardware obsolescence, dictate an implementation of a new timing system. It must generate trigger patterns in a range from a single shot on demand up to 26 MHz CW which requires a universal and complex implementation of the pattern composition and validity checks. The system must be compatible with all existing timing triggering patterns and must provide configuration options for new features. The design of such timing solution drives further adaptation and modification of the event-based timing system built on MRF HW. As a result, we realized the new Control Software with an extended range of functionalities. While maintaining the common functionality we made it suitable for the most demanding experiments today.

SYSTEM DESCRIPTION

The upgrade to the ELBE timing system is comprised of upgrades to timing hardware, timing software and MPS PLC.

Timing Hardware

New timing hardware was selected from the commercial vendor of timing systems Micro Research Finland (MRF) [1]. With selection of the event based MRF timing hardware the new system becomes more flexible and as it is designed as a modular system with event masters (EVMs) and event receivers (EVRs) as its main components.

EVMs are responsible not only for generation and distribution of system-wide timing clock, which is synchronized to externally provided RF reference and main driver of the event distribution network, but also for event generation.

Responsibility of the EVR is to react on events received through the event distribution network and to set physical outputs based on the conditions specified by the operator.

Another feature of both EVMs and EVRs is that they can generate and emit a preconfigured sequence of events. This allows for generating a desired sequence of events in advance and loading it at the time of need.

As the MRF provides their hardware in various form factors, the one most suitable for the HZDR system was a MicroTCA (mTCA) based solution for all EVMs and majority of EVRs with an option to use PCIe form factor EVRs for certain experimental station setups.

The radiation source ELBE (Electron Linac for beams with high Brilliance and low Emittance) uses two injectors and delivers multiple secondary beams. To cover all event generation use-cases of the two ELBE injectors, the system has two EVMs (mTCA-EVM-300) that are responsible for generating timing patterns. These patterns can be independent of each other (independent injector operations) or they can depend on one another and this allows for generation of timing patterns coordinating both injectors in feeding electron bunches into the ELBE accelerator.

Additional EVMs are also planned for use in a role of a fanout to extend the number of EVRs installed in the system.

Majority of EVRs will be of the mTCA form factor (mTCA-EVM-300U). This is due to other devices used for beam diagnostics and low-level frequency control (LLRF), which are of the same form factor, and this allows for coordinated triggering over the mTCA backplane. In addition to the backplane triggers the mTCA EVR provides 8 outputs on the front panel (4 TTL level trigger signals, 4 outputs provided by the 2 Universal IO modules) and 10 outputs with the use of the rear transition module (mTCA-EVRTM-300) and 5 Universal IO modules.

Additional EVRs of the PCIe form factor (PCIe-EVR-300DCS) are planned for setups where special backplane triggers are not required. With this card an additional interface distribution box is needed (IFB-300SAM) that provides mounting point for up to 8 Universal IO modules (16 outputs).

All the above mentioned MRF hardware is from the 300 series that provides an integrated solution for a continuous measurement and compensation of propagation delays throughout the whole event distribution network. This allows for the individual adjustment of EVR specific target delay and as such it provides precise delivery of output triggers at desired time.

Timing Software

As MRF hardware offers a variety of features and different setpoints, the timing software is an essential component that connects all the options and features into a cohesive, consistent, yet an easy-to-use tool, which supports operators in their day-to-day work and scientists in their pursuit of new discoveries and improving mankind.

EPICS controls software framework [2] is used for the implementation of the new timing software. Besides the EPICS base implementation, several additional EPICS modules are used: mrfioc2 [3], s7plc [4], autosave [5] and sequencer [6].

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Timing software is designed in such a way that operators, through selections of a few parameters on the Graphical User Interface (GUI), control the whole generation of the event sequences, its loading onto the MRF hardware, and starting of the next experiments.

Operators are guided through the selection of parameters regarding the generation of bunches in different groups (kicked or non-kicked) and then through the selection of the operation mode (macro pulsed or single pulsed beam), followed by operation mode specific parameters assignments (pulse period, pulse duration, …).

In the background the software verifies that the parameters as selected by the operator are in line with general limitations of the timing system (various resolutions, checks regarding overlapping events, …) and with the parameter range allowed by the Machine Protection System (MPS), imposed and verified on the MPS programmable logic controller (PLC). This is done through continuous communication between the EPICS software and Siemens PLC using s7plc EPICS module.

After the verification is completed and the operator decides to load the new timing configuration, the parameters entered by the operator are used to generate sequence of events, using sequencer EPICS module, and then transferred to the MRF hardware together with all other relevant settings parameters. In this process the timing software uses mrfioc2 EPICS module to communicate with various timing cards.

While the whole timing system can be controlled through dedicated Graphical User Interfaces (GUIs) created in CS Studio (Phoebus) [7], shown on Fig. 1, a smaller subset of parameters is also exposed for control through the MPS PLC for GUIs created in WinCC.

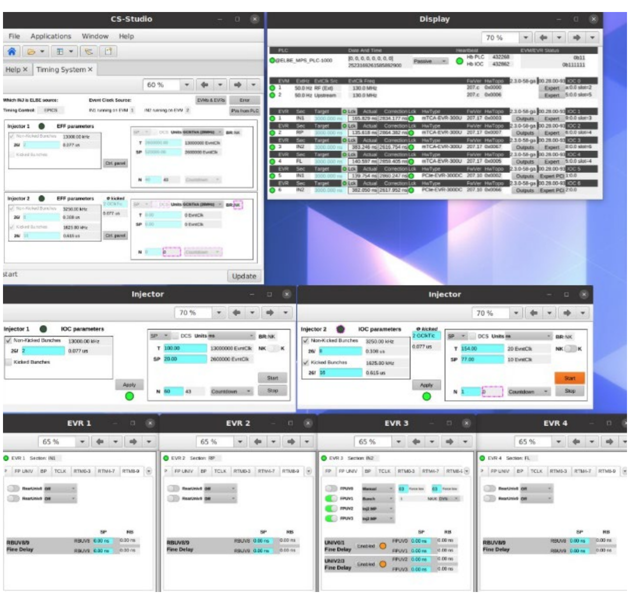

Figure 1: Screenshot of GUIs used for acceptance tests at HZDR.

A lot of time and effort was spent on making the user interfaces as intuitive as possible while providing functionality and hiding complexity. This was a particular challenge for the Single Pulse (SP) operation mode.

Single Pulse mode allows for the generation of a variety of beam patterns. The period of the SP pattern can be set as low as 115 ns on one side and up to 9 hours on the other side. The lowest value for the duration of one single pulse is limited to 38.5 ns.

This allows for a very precise control of the Single Pulse beam (example of a use case [8]) but pushes both hardware and software capabilities of the new timing system.

MPS PLC

A special PLC is used as an interface between the existing control system of ELBE accelerator and the new timing system.

This PLC is connected to computers running timing software and existing PLCs in the ELBE network. It shares timing software configuration parameters (such as RF configuration or which injector is a source for bunches in ELBE accelerator) from PLCs to the timing software, but more importantly, it serves as timing system parameter configuration interface whenever the operators control the whole timing system from WinCC panels.

It also provides MPS related verification of timing parameters (beam current loading, …) and acts as a main protection against loading a potentially harmful timing system configuration or stops the operation when any of the faults occur on the accelerator.

STATUS UPDATE

During the last 2 years several testbenches and test setups were used both at Cosylab, shown on Fig. 2, where most of the development took place, and at HZDR, shown on Fig. 3.

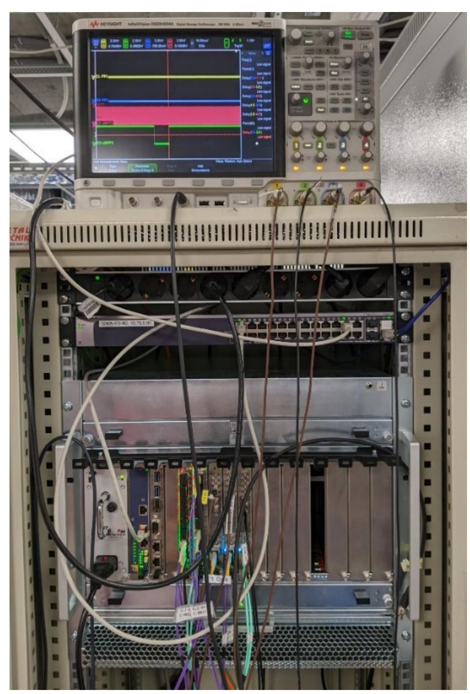

Figure 2: Development testbench at Cosylab.

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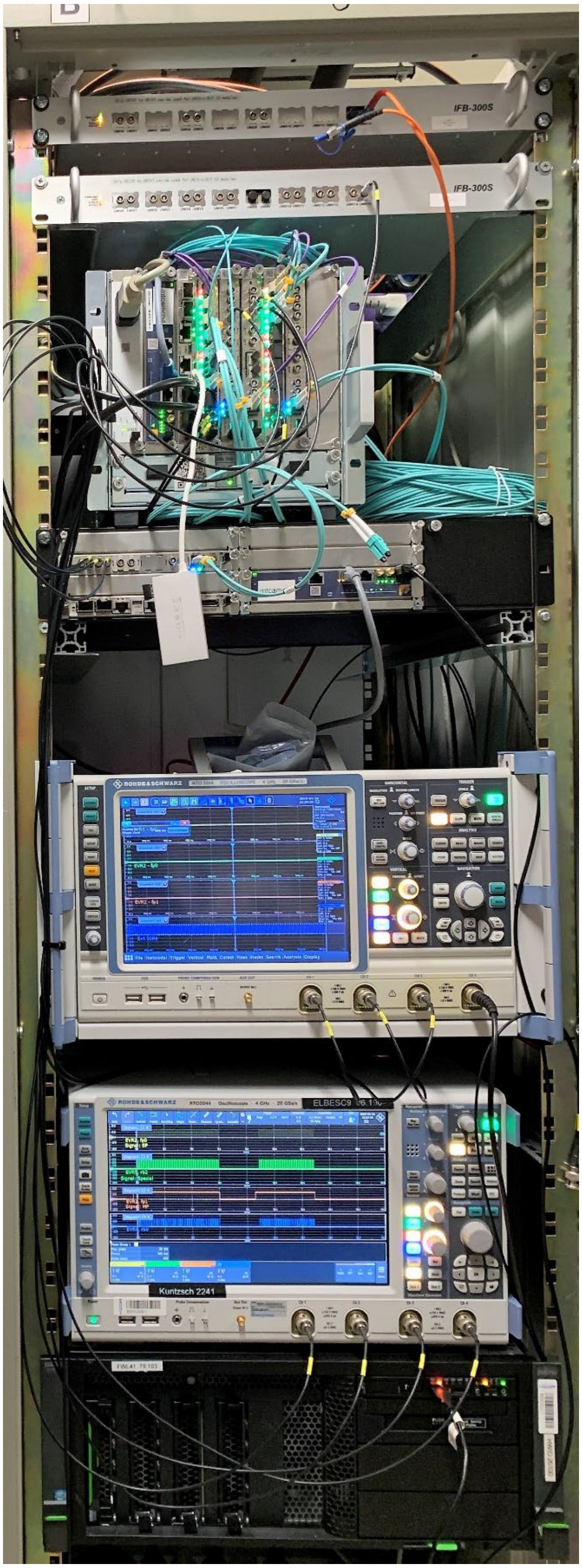

Figure 3: Testbench at HZDR.

These testbenches proved useful for concurrent testing of various aspects of the timing system with focus on different configurations and scaling up the timing system. In addition, compatibility with hardware components and timing clients used at ELBE could be tested and debugged.

With various testbenches at HZDR operators were getting familiar with the new timing system and provided feedback on several different aspects of the timing system design and usability.

During this time Cosylab and HZDR collaborated closely with a quick turnaround time in generation of new releases that included both, bug fixes and new features requested by the end users.

CONCLUSION

Since the last update [9] the development of the timing system has been successfully completed.

With several rounds of commissioning runs already completed, the system has passed the site acceptance testing on one of the testbenches with a simulated environment for MPS PLC.

With continuous support from Cosylab the new timing system will be stepwise integrated into the production environment.

ONLINE SOURCE

[1] Micro Research Finland Oy, `http://www.mfr.fi`

[2] EPICS Experimental Physics and Control System, `https://www.epics-controls.org`

[3] EPICS module mrfioc2, `https://github.com/epics-modules/mrfioc2`

[4] EPICS module s7plc, `https://github.com/paulscherrerinstitute/s7plc`

[5] EPICS module autosave, `https://github.com/epics-modules/autosave`

[6] EPICS module sequencer, `https://www-csr.bessy.de/control/SoftDist/sequencer`

[7] CS Studio (Phoebus), `https://controlssoftware.sns.ornl.gov/css_phoebus/`

[8] E. Beyreuther *et al.*, "Time structure influence on the radiob iological response to MeV electron beams", *Ann. Oncol*, vol. 2, pp. 259-71, 2016. `doi:10.1093/annonc/mdw392.50`

[9] M. Kuntzsch *et al.,* "Upgrade of the ELBE Timing System", in Proc. IPAC'21, Campinas, Brazil, May 2021, pp. 3326-3328. `doi:10.18429/JACoW-IPAC2021-WEPAB287`