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UPGRADE OF THE ELBE TIMING SYSTEM

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Abstract

The ELBE center for high power radiation sources is operating an electron linear accelerator to generate various secondary radiation like neutrons, positrons, intense THz and IR pulses and Bremsstrahlung. The legacy timing system has been modified and extend over the past two decades to enable new experiments. Part of this system is using obsolete parts which makes the maintenance more complex and the heterogenous structure requires a major revision of the timing signal generation and distribution at ELBE.

A new timing system based on the Micro Research Finland hardware platform is being adapted to be used at ELBE. It will enable parallel operation of two electron sources and subsequent kickers to serve multiple end stations at a time. The hardware enables low jitter emission of timing patterns and a long term drift compensation of the distribution network. In spring 2023 the development of the software has been accomplished, which included the mapping of operation modes and different complex beam patterns onto the capabilities of the commercial MRF platform. The system generates complex beam patterns from single pulse, to macro pulse and 26 MHz continuous wave (CW) operation, including special triggers for diagnostics and machine subsystems.

REQUIREMENTS

The requirements for the new timing system have been derived mainly from the features of the old timing system and feature requests from the ELBE user community. Timing signal receivers as well as operators expect a particular composition of different signals, that have to be delivered by the new timing system.

Even though ELBE is a CW machine, a macro pulser is used to generate pulsed, low current beams. This mode is mainly used for beam tuning in order to allow a safe operation of destructive diagnostics like view screens. The macro pulser setting defines in turn also the timing for diagnostic triggers for the low level radio frequency (LLRF) controllers, cameras and loss monitors. If in operation, the macro pulser chops the beam into short bursts using magnetic steerer coils. The inductance of the coils combined with the capabilities of the driver unit define the rising and falling slope of the macro pulse train. At ELBE slew rates are on the 10 µs scale and define the shortest opening time of 100 µs. The minimal period is derived from the maximum camera sampling time of 10 ms. So, the period can be set to multiples of 10 ms up to many minutes period.

Biological experiments at ELBE require a very complex trigger pattern in order to adjust the applied dose and its structure to a sample with high accuracy. At the same time the background radiation needs to be reduced which means to suppress dark current from the injector section.

For this application a dedicated single pulser system needs to be in place, which allows for patterns with single bunch resolution, periods up to minutes and a possibility to combine the gun pulse emission with a macro pulse gate to suppress dark current. These features are required for both thermionic injector and superconducting radiofrequency (SRF) gun that are available at ELBE.

Table 1 summarizes the main pulser modes of the timing system and their parameter range. In detail, the requirements are much more complex, the edge cases and error handling makes the implementation a complex development. The complete specification has been written into a design documents which serves as a reference for the implementation process.

Table 1: Main Pulser Modes and Their Parameter Ranges

	Unit	Min	Max
Electron Bunch Rate	Hz	0.03	26e6
Macro Pulser Period	s	10e-3	33864
Macro Pulser Duty Cycle	s	100e-6	33864
Single Pulser Period	s	115.5e-9	33864
Single Pulser Duration	s	38.5e-9	33864

SYSTEM DESCRIPTION

Hardware

For the implementation at ELBE different systems have been evaluated and after a comprehensive feasibility study a European Tender has been awarded to COSYLAB to set up the new ELBE timing system. As hardware platform the Micro Research Finland Oy (MRF) timing modules have been selected [1].

The latest revision of the MRF hardware is available for MicroTCA standard, which is becoming more and more popular in accelerator community and found its application for new beam diagnostic systems and LLRF systems at ELBE.

The system consists of event master modules (EVM) that are generating and send a continuous stream of events which are received by event receiver modules (EVR). EVRs are located in different sections around the accelerator and generate physical trigger signals based on the event stream. EVMs and EVRs are connected over optical fibers, forming a hierarchic structure which allows for a high flexibility and the possibility to extend the system with ease.

Each EVR has four fixed TTL outputs on the front panel and provides two slots for universal IO modules, each housing two physical outputs. There are universal IO modules for different logic levels, electrical and optical outputs and special outputs that allow for a fine delay with picosecond precision. Standard modules can delay output signals with the precision of an event clock cycle. In addition a dedicated rear transition module can be attached to the EVR, providing five additional slots for universal IO modules. A fully equipped EVR can in turn deliver 18 output signals to connected timing clients. Timing clients in the same MicroTCA crate can be triggered through the differential backplane trigger bus.

The interconnections between EVMs and EVRs are subject to timing drifts due to changing environmental conditions. The system offers an active drift stabilization, minimizing the residual instability to < 10 ps peak-peak.

The event clock rate can be selected from 50 MHz to 166.6 MHz, and has been defined to 130 MHz at ELBE. This is a ten times the nominal ELBE bunch repetition rate of 13 MHz and one tenth of the accelerator cavity frequency of 1.3 GHz. This event clock rate defines the minimum spacing between to events to 7.7 ns.

At ELBE one EVM is set up per injector, allowing for independent operation in separate beamlines and combined emission into the ELBE accelerator. For machine timing receivers like beam diagnostics LLRF MicroTCA EVRs are applied. For users that do not use MicroTCA hardware we provide PCIe based receiver modules, which is more cost effective.

Software

While the hardware could be used from stock, the Software needed to be tailored to the requirements of ELBE. The base implementation is done using EPICS and EPICS mrfioc2 module [2]. This offers access to all features of the timing system, diagnostic functionality and basic graphical user interfaces (GUI).

The logical mapping of the ELBE machine structure to software is a complex process. It reflects the operation of two injectors in parallel, different beamline sections and beam modes. The above-mentioned beam modes, macro pulse, single pulse and CW are realized as sequences of events, combined with prescalers in order to generate bunch triggers, triggers for LLRF, macro pulser, kicker and diagnostics. The sequences are being built by a algorithm, that translates the user defined parameters into the correct EVM and EVR settings. This complex algorithm, the handling of edge cases and error handling is the major effort needed for the system integration.

The graphical user interfaces are designed using Phoebus [3]. In the course of the design process it has been extended and offers now a simple way to control the operation modes of the timing system, parameter checks, error handling and status information of all hardware components (Fig. 1).

The Phoebus Interface is mainly used for system test and commissioning. Currently a interface for the ELBE SCADA system WinCC is developed which will make the timing system a part of the operator panels used for the machine control.

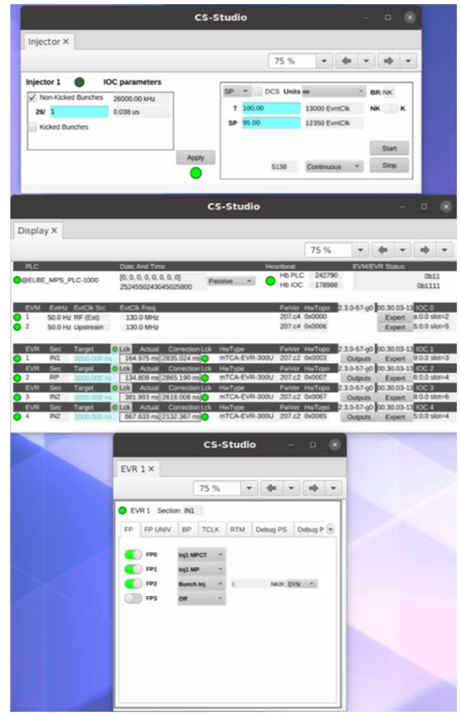

Figure 1: ELBE Timing System Phoebus GUIs to control injectors, EVR outputs and a status panel of all EVMs and EVRs

All machine parameters are checked by a master programmable logic controller (PLC) which acts as the main instance for machine protection. User commands and status signals from the timing system are processed and interlock signals are generated accordingly.

WORK IN PROGRESS

In spring 2023 the development of the software has been accomplished, which included the mapping of operation mode and different complex beam patterns onto the capabilities of the commercial platform. Figure 2 shows the setup used for the intensive on-site software tests.

In parallel, machine development shifts have been used to test all components at the ELBE accelerator. Especially the machine protection system functionality and parameter transfer between timing hardware and MPS PLC has been tested thoroughly to ensure safe operation of the system.

In a next step the complete transition from the legacy system to the new timing system will be made. While all old timing system generators will be replaced by MRF hardware in one step, the old timing distribution system can be replaced stepwise. The whole process means a major change to the operation of the ELBE accelerator and needs to be planned in great detail in order to ensure a seamless transition und not to lose time devoted to user operation.

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Figure 2: Timing System Test Setup.

CONCLUSION

A new flexible timing system has been developed for the ELBE accelerator. The system will replace many hardware components which are generating timing signals for ELBE and unify the timing pattern generation as well as the distribution in one modular system.

The software development has been finalized in spring 2023, dedicated machine development shifts have been used to implement and test the interface to the machine protection.

In a final step the legacy hardware will be replaced by MRF components and the new timing system will be the only source of clock signals for the ELBE operation.

REFERENCES

[1] Micro Research Finlad Oy, `http://www.mrf.fi`

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

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