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MICROTCA.4-BASED LLRF FOR CW OPERATION AT ELBE – STATUS AND OUTLOOK

M. Kuntzsch†, R. Steinbrück, R. Schurig, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
M. Hierholzer, M. Killenberg, C. Schmidt, M. Hoffmann, DESY, Hamburg, Germany
C. Iatrou, J. Rahm, Technische Universität Dresden – Chair of Distributed Control Engineering, Dresden, Germany
I. Rutkowski, M. Grzegrzółka, Warsaw University of Technology - Institute of Electronic Systems, Warsaw, Poland

Abstract

The superconducting linear accelerator ELBE at Helmholtz-Zentrum Dresden-Rossendorf is operated in continuous wave (CW) operation [1]. The analogue LLRF (low level radio frequency) system, used since 2001, is going to be replaced by a digital solution based on MicroTCA.4. The new system enables a higher flexibility, better performance and more advanced diagnostics. The contribution shows the performance of the system at ELBE, the hardware and the software structure. Further it will summarize the last steps to bring it into full user operation and give an outlook to the envisioned beam-based feedback system that will take advantage of the capabilities of the digital LLRF system.

SYSTEM STRUCTURE

Hardware

The ELBE injector uses a thermionic gun followed by two normal conducting (NRF) buncher cavities operating at 260 MHz and 1.3 GHz. The main accelerator consists of two cryo-modules, each is equipped with two TESLA-type superconducting cavities (SRF) that are operated routinely in CW mode.

For high bunch charge and high current beams with good beam properties a superconducting photo gun is currently being developed. It contains a 3.5-cell structure operating at 1.3 GHz [2].

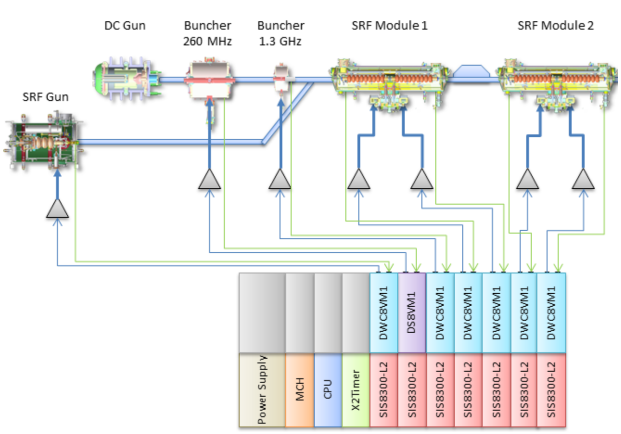

Figure 1: Digital LLRF schematic.

In Figure 1 the main components and the associated hardware are shown. The digital LLRF system at ELBE is based on a modular system using MicroTCA.4 compatible hardware [3]. The standard separates the analogue circuits from the digital data processing. This allows an adaption of the analogue frontend to the desired application, while the digital part remains the same. For all cavities a SIS8300-L2 digitizer board is used which contains fast analogue-to-digital converters (ADCs) and a powerful Virtex 6 field programmable gate array (FPGA).

For the 260 MHz buncher cavity a direct sampling scheme is applied using the DS8VM1 analogue board [4]. For all 1.3 GHz cavities a mixer configuration with DWC8VM1 has been realized [5]. The cavity pickup signals are mixed with a local oscillator (LO) to an intermediate frequency (IF) which is sampled by the ADC sitting on the SIS8300-L2 [6]. The data processing and control loop is done inside the FPGA which allows parallel execution of processes with high data rate.

Software

All digitizer boards are connected to a CPU-board through a PCIe link. Status information and data traces are provided to a server application while this sets all the controller parameters and offers high level features.

For the first test phase a stand-alone DOOCS server application was used to control the system. It could only be accessed by remote login on to the MicroTCA.4-CPU and had no interface to the ELBE control system which is a network of programmable logic controllers (PLCs) and the graphical user interface (GUI) provided by a WinCC server-client system.

In order to overcome these limitations a new server application has been developed using the ChimeraTK framework [7]. This universal toolkit allows development of applications for different control systems like DOOCS and EPICS or the OPC-UA protocol. ChimeraTK enables collaboration and joint software development of institution that are using different control system architectures.

OPC-UA is a powerful protocol for industrial automation and is supported by many commercial suppliers [8]. The features integrated in the ChimeraTK framework are based on the open source implementation open62541 [9] that has been designed to run on different operating systems and hardware platforms.

† m.kuntzsch@hzdr.de

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The interface between WinCC and the digital LLRF server application is based on the OPC-UA protocol.

An expert panel for diagnostics and advanced features is envisioned which will be implemented in LabView. The basic communication scheme is shown in Figure 2.

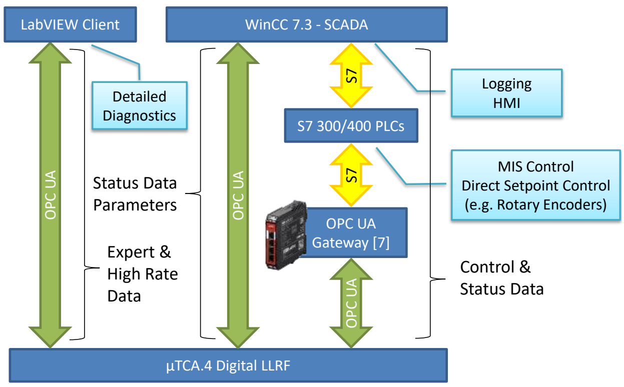

Figure 2: Digital LLRF communication scheme at ELBE

The machine interlock system is tightly connected to the PLCs and receives all relevant data from the LLRF system. It inhibits the drive signal of the vector modulator in the case not all conditions for RF operation are fulfilled.

SYSTEM PERFORMANCE

The phase stability has been measured with a signal source analyzer (SSA) and been compared to the legacy system. Since the controller firmware is still work in progress the results shown here have to be regarded as preliminary.

For the first superconducting cavity a gain sweep has been performed and a jitter of 24 fs rms has been measured (Figure 3). By increasing the gain, the low frequency noise could be reduced while the noise floor above 3 kHz increased.

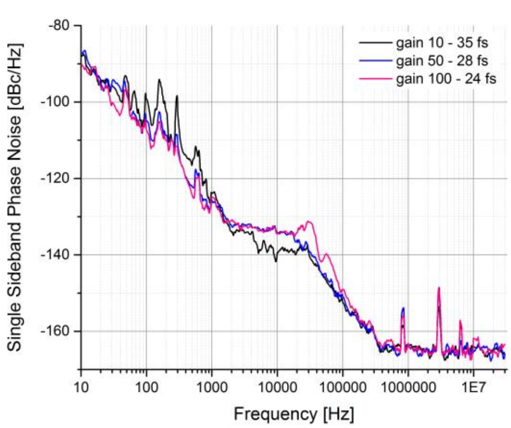

Figure 3: Single-Sideband phase noise from cavity 1 for different gain settings.

The amplitude stability of the system has been evaluated in-loop by measuring the residual amplitude noise and compared to the analogue system. With the digital control a stability level of 0.015 % could be achieved while the analogue control reached 0.053 %.

The digital control benefits from eight downconverter channels for every single cavity that allows to measure forward and reflected power of the cavity with high accuracy and to characterize the high power amplifier chain online.

OUTLOOK

Commissioning

Within the last years the hardware, software and firmware has been developed and tested in dedicated machine development shifts. The upcoming months will be used to bring the digital LLRF into routine operation.

A major step was the rewriting of the LLRF server application with the ChimeraTK framework which allowed the direct communication between the ELBE control system and the digital LLRF for the first time. The first test runs with the new software revealed no major problems but only little long term experience could be gained.

In a first step the NRF buncher cavities will be brought into routine operation since their control is much easier due to the higher bandwidth and lower sensitivity to microphonics.

Beam-Based Feedback

In order to take full advantage of a digital controller, an adaptive beam-based feedback algorithm will be implemented after the basic features and the long-term stability have been validated. The system will acquire measurement data from bunch arrival-time monitors (BAM), compression monitors (BCM) and beam energy sensors (Figure 4). This information will be used to stabilize the electron bunches at the target position or at the secondary source (e.g. free electron laser).

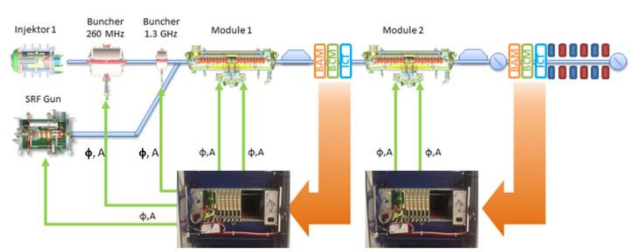

Figure 4: Feedback scheme for ELBE.

The feedback algorithm benefits from the high duty cycle of the CW beam at nominal repetition rate of 13 MHz. Since there is no macro pulse applied the controller can operate in a continuous regime.

CONCLUSION

The ELBE accelerator is in operation since 2001 and provides a CW electron beam for various secondary radiation sources to the users. Future experiments and secondary sources require a higher level of stability. One crucial

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point is the control of the accelerating RF fields. In order to address this new demand a digital LLRF control has been implemented during the last years.

A crucial point was the data interface between the LLRF server application and the ELBE control system. In collaboration with the experts from DESY and Technische Universität Dresden, a robust solution based on the ChimeraTK framework and the OPC-UA protocol could be developed.

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