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STATUS OF CONTROL AND SYNCHRONIZATION SYSTEMS DEVELOPMENT AT INSTITUTE OF ELECTRONIC SYSTEMS*

M. Grzegrzółka†,A. Abramowicz, A. Ciszewska, K. Czuba, B. Gąsowski, P. Jatczak, M. Kalisiak, T. Leśniak, M. Lipiński, T. Owczarek, R. Papis, I. Rutkowski, M. Sawicka, K. Sąpór, D. Sikora, M. Urbański, Ł. Zembala, M. Żukociński, ISE, Warsaw University of Technology, Poland

Abstract

Institute of Electronic Systems (ISE) at Warsaw University of Technology designs, builds and installs control and synchronization systems for several accelerator facilities. In recent years ISE together with the Deutsches Elektronen-Synchrotron (DESY) team created the RF synchronization system for the European XFEL in Hamburg. ISE is a key partner in several other projects for DESY flagship facilities. The group participated in development of the MTCA.4 standard and designed a family of components for the MTCA.4-based LLRF control system. Currently ISE contributes to the development of the Master Oscillators for XFEL and FLASH, and phase reference distribution system for SINBAD. Since 2016 ISE is an in-kind partner for the European Spallation Source (ESS), working on the phase reference line for the ESS linac, components for 704.42 MHz LLRF control system, including a MTCA.4-based LO signal generation module and the Cavity Simulator. In 2019 ISE became one of the co-founders of the Polish Free-Electron Laser (PolFel) located in the National Centre for Nuclear Research in Świerk. The overview of the recent projects for large physics experiments ongoing at ISE is presented.

INTRODUCTION

Institute of Electronic Systems (ISE) is part of Warsaw University of Technology - one of the leading technical universities in Poland. ISE develops state of the art electronic systems. Among others, ISE collaborates with Deutsches Electronen Synchrotron (DESY) and European Spallation Source (ESS), working on control and synchronization systems for linear accelerators. This contribution presents the overview and status of the most significant on-going projects under development at ISE.

XFEL MASTER OSCILLATOR

In collaboration with DESY, ISE was developing Master Oscillator for European Xray Free Electron Laser (E-XFEL) [1]. ISE was responsible for the component selection, prototyping, design of system modules, installation, and commissioning of the frequency synthesis system. The system currently provides ultra-low-noise 1.3 GHz reference signal at the E-XFEL facility, offering following parameters: < 16 fs rms jitter (10 Hz to 1 MHz bandwidth), < 10^{-12} long-term frequency stability, and +41dBm of output power.

Currently, ISE works on a novel real-time redundancy subsystem [2] (Fig. 1) whose aim is to further improve overall reliability of the Master Oscillator. This solution will provide continuous reference signal even in case of almost any potential failures in the system. It is accomplished through continuous monitoring of signal's parameters, low-latency detection and switching, and energy storage in a high-Q filter.

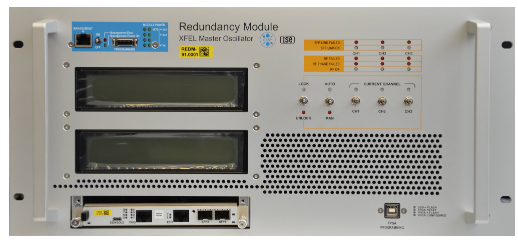

Figure 1: Photo of the XFEL Master Oscillator Redundancy Controller.

UPGRADE OF MASTER OSCILLATOR FOR FLASH

ISE is also involved in development of a new Master Oscillator system for FLASH facility. Contribution of ISE is similar to E-XFEL's case and include preparation of system concept, design and assembly of system modules, as well as participation in installation and commissioning activities.

Main motivation for the efforts is to refresh the dated system and improve the performance. Architecture of the new system will follow the previously developed E-XFEL's Master Oscillator and surpass its performance (expected rms jitter below 10 fs rms). Current activities are concentrated on working out the detailed concept and selection of the most critical components.

SINBAD SYNCHRONIZATION SYSTEM

SINBAD (Short Innovative Bunches and Accelerators at DESY) is an accelerator research facility at DESY. It will be a host for many experiments, related to ultra-short electron bunches and high gradient acceleration techniques.

To ensure proper and stable work of ARES - Accelerator Research Experiment at SINBAD - a high frequency phase reference distribution system had to be designed, manufactured, installed, and tested [3]. This includes temporary distribution system that will be later upgraded to its final form, utilizing active interferometric phase stabilization [4, 5], optionally supported by thermal stabilization.

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† M.Grzegrzolka@elka.pw.edu.pl

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The ISE team is responsible for developing phase reference distribution system architecture, designing all the sub-modules, coordinating manufacturing, pending tests and installation of the system, as well as conducting research on new approaches to the reference signal phase stabilization problem at SINBAD. First modules of the interferometric phase stabilization links were manufactured and are currently being tested.

ESS' PHASE REFERENCE LINE

The European Spallation Source (ESS) in Lund (Sweden) is a next-generation neutron source. The particles are emitted from a rotating tungsten target bombarded by a high energy proton beam produced in a linear accelerator (linac). It consists of more than 200 different accelerating RF cavities and diagnostics instruments along the 6̃00 m tunnel, each requiring precise phase synchronization for Low-Level Radio Frequency (LLRF) and Beam Diagnostics systems which operate at two frequencies: 352.21 MHz and 704.42 MHz. The required phase stability at both frequencies is 0.1° for short term (during 3.5 ms pulse) and 2.0° for long term (hours to days) between any two points in the 600 m long accelerator tunnel.

A precise Phase Reference Distribution System (PRDS) will provide low phase noise and low drifts reference signals for components along the linac. Active drift compensation techniques cannot be used due to high level of radiation inside the tunnel. ISE/WUT develops PRDS basing on a passive synchronization scheme, where pick-up cables from RF cavities and beam diagnostic instruments are paired and length-matched to corresponding reference distribution cables [6, 7]. Since both connections are exposed to the same environment conditions (temperature, pressure, humidity) phase drift errors between them are minimized. This allows to make the PRDS system passive and to place it in the accelerator tunnel.

The main part of the PRDS is a Phase Reference Line (PRL). It is based on a single 1-5/8" coaxial (air) rigid line (Fig. 2) placed under the ceiling of the accelerator tunnel. The line distributes the reference signals close to the linac, providing them to 58 points (Tap Points), corresponding with the linac subsystems. Each Tap Point consists of the directional coupler [8, 9], which picks up the signals from the rigid line and delivers them to the endpoint distribution module called PRL Split Box (Fig. 3). Each unit has several frequency-selective (filtered) signal outputs which provide reference signals (352.21 MHz or 704.42 MHz) locally in the tunnel.

The 352.21 MHz and 704.42 MHz reference signals are generated by the Master Oscillator which is an ultra-low-noise signal generator. These have to be distributed to nearly 300 endpoints, requiring in total 300 W of input power. To amplify the reference signals low phase noise power amplifiers were developed together with Institute of Radioelectronics and Multimedia Technology at WUT. The PRL is

Figure 2: Photo of assembled element of the rigid line.

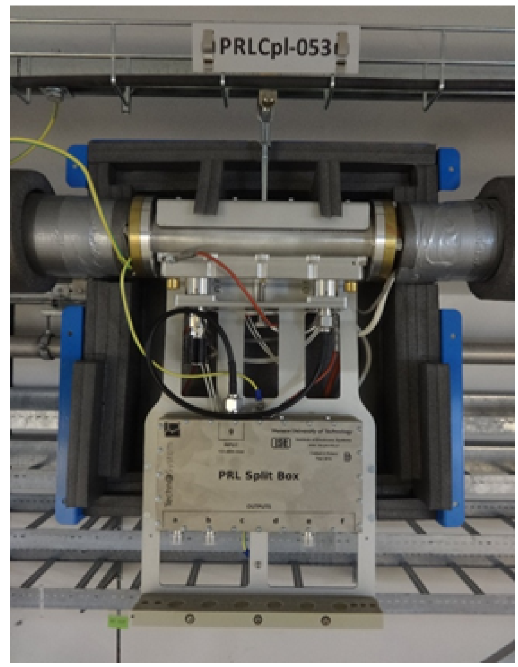

Figure 3: Tap Point interior (half of thermal insulation removed).

supplied with both reference signals at a single point located in the middle of the line. A dedicated high power 3 dB hybrid coupler is used to provide RF power to both branches of the PRL.

To achieve the best possible drift performance and fulfill ESS synchronization requirements, the PRL is equipped with an active temperature stabilization system. For the same reason, the rigid lines are sealed, filled with dry nitrogen, and equipped with a pressure stabilization system.

The temperature control system consists of dedicated thermal insulation which covers the PRL mainline as well as the Tap Points together with heating elements and PT100 temperature sensors. The precise regulation of PRL temperature (+/- 0.1 °C) is controlled by the Temperature Control Box (TCB), based on commercial PLCs.

The PRL project is in its final stage. Around 75% of the equipment is already installed in the ESS facility. The remaining components will be installed and commissioned by mid-2020.

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ESS' LLRF CONTROL SYSTEM

ISE realize the ESS LLRF project as part of the Polish Electronics Group (PEG) Consortium [10], collaborating with ESS and Lund University on development of the LLRF control system used in the medium and high beta section of the ESS' linac [11]. PEG is mainly responsible for the design of several components for the LLRF control system. It will also assemble the system units, test them, and install them in the accelerator.

ISE is responsible for design of four components: LO RTM, PSS Switch, RF Splitbox, and Cavity Simulator. It will also plan the in-rack cabling and supervise the installation of the LLRF control systems in the accelerator.

LO RTM

The LO RTM (Fig. 4) [12] is MTCA.4 compliant module responsible for generating the Local Oscillator (LO) and clock signals and distributing them to four LLRF control system units. The generation circuit is based on direct analog frequency synthesis scheme optimized for a very low additive phase noise.

Total number of 36 boards will be installed in the accelerator and test systems. So far, 15 pieces were manufactured and tested. They are foreseen to be used in cavity test-stands and systems in the medium beta section.

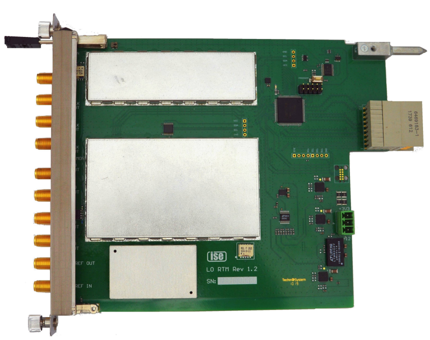

Figure 4: Photo of the LO RTM board.

PSS Switch

In case of personal safety emergency, the PSS Switch (Fig. 5) is responsible for turning off the RF signal that drives the high power amplifier feeding the accelerating cavities. Because the device is part of the Personal Safety System (PSS), it has to be very reliable. It is realized as a 19" module, and it is based on a high isolation mechanical RF relay.

Figure 5: Photo of the PSS Switch.

RF SplitBox

The RF SplitBox (Fig. 6) distributes the RF signals between LLRF control and interlock systems. The device consists of seven 2-way power splitters, two 3-way power splitters, and an RF low-pass filter for the LLRF output signal. The device must ensure low phase drifts (<0.004 °/K) between the RF reference and cavity probe signals. Series of measurements comparing different types of devices were performed and custom-designed Wilkinson RF dividers were selected for the design.

Figure 6: Photo of the RF SplitBox.

Cavity Simulator

The Cavity Simulator (Fig. 7) [13] is not a part of the LLRF control system, but it was designed to verify its proper operation. The device reproduces the signals coming from the accelerating cavity and the amplifier driving it. The simulation model is implemented in a high-performance Xilinx Kintex Ultrascale FPGA. A custom front-end with a set of fast data converters was designed to interface the RF signals.

Four units of the Cavity Simulator were manufactured. The main features of the firmware were implemented, but the development to extend the device functionality is still on-going.

Figure 7: Photo of the Cavity Simulator.

SUMMARY

The overview of the current projects for linear accelerators developed at ISE was presented. ISE continues development of state of the art electronic systems. One of the future projects is the development of the trigger and synchronization system for Polish Free Electron Laser (PolFEL), currently under construction in the National Centre for Nuclear Research in Świerk.

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