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LLRF CONTROL UPGRADE AT BESSY-II WITH MTCA.4 PLATFORMS

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Abstract

The synchrotron light source BESSY-II has been in operation for almost 25 years and modernization measures are needed to maintain competitiveness until its successor BESSY-III comes online. One measure is to replace the old analogue LLRF control units with new, state-of-the-art mTCA.4 based digital ones. The so-called "single cavity" firmware developed by DESY is being used together with the ChimeraTK adapter to connect the mTCA to the EPICS control system. A pair of SIS8300KU and a DWC8VM is used, while the tuner is driven by a PhyMotion chassis connected to the EPICS system. We discuss the implementation of the system.

INTRODUCTION

BESSY-II, the third-generation synchrotron light source at Helmholtz Zentrum Berlin, Germany, has been in operation for almost 25 years. During this time, it has played a significant role in advancing research in various fields, including materials science, chemistry, and biology. BESSY-II will remain in operation at least until 2035, overlapping with its successor BESSY-III, which is expected to be ready for user operation in 2036 [1]. During this time, modernization measures are needed to maintain its competitiveness until BESSY-III, comes online.

One of the modernization measures is the replacement of the old analogue LLRF (Low-Level Radio Frequency) control units with new, state-of-the-art mTCA.4 (Micro Telecommunications Computing Architecture) based digital ones. In addition to the benefits of modern digital control systems compared with those of analogue ones (more sophisticated algorithms, easier to remotely control, diagnose, and reconfigure, multi-user operation, etc.), two main reasons are driving the upgrade of the current LLRF controllers:

- Since the RF amplifiers' upgrade, where the old klystrons were replaced by Solid State Amplifiers (SSA) [2], the noise limiting devices have been the analogue LLRF systems.
- In the framework of the BESSY-VSR upgrade, the beam injection from the booster to the storage ring has to be modified in order to inject shorter bunches [3]. For this purpose, a new PETRA-type 5 cell cavity has been installed in the booster ring and a second one is to be installed. These two new cavities have to be driven by new LLRF controllers.

The upgrade is planned in a stepwise manner, with the first stage being the testing of all components of the setup in a test stand with a HOM-damped cavity. Provided the successful operation in the test stand, the system will be used to drive the new booster cavity. Subsequently, the old analogue systems driving the other booster cavity and the storage ring cavities will be replaced.

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MTCA-BASED LLRF CONTROL

The main element of the proposed LLRF control system is based on the components described below.

12-slot Chassis

It is expected that two cavities will be controlled with one chassis, requiring a minimum of 4 slots. However, a 12-slot chassis [4], was chosen to provide room for redundant power supplies, which is an important feature in a user-oriented machine as BESSY-II. The chassis are equipped with two 1kW AC power supplies and a mTCA Carrier Hub [5], which acts as the crate controller, ethernet and PCIe switch.

Processor Board

The first slot of the chassis is equipped with an AMC-CPU [6], with an Intel Xeon processor running a Linux OS. This board is in charge of the communication with the FPGA boards through the PCIe bus of the backplane, sending all parameters needed to properly close the RF loop and receiving the waveforms of the different signals acquired by the FPGA. This board is also in charge of the connection of the chassis to the EPICS control system, as it runs the LLRF control servers based on ChimeraTK [7].

Timing Board

The external trigger signals are received and distributed through the backplane by a NAMC-psTimer [8]. This board might eventually be replaced by Micro Research Finland Event Receiver boards.

Controller Boards

The workhorse of the LLRF system is formed by a SIS8300-KU board [9], and a DWC8VM1 board [10]. The former is digitizer board equipped with a Kintex Ultrascale FPGA where the real time control loop is implemented. Contrary to other facilities, each cavity is driven by an independent RF amplifier, so no Vector Sum control is necessary as, e.g., in the European XFEL. Thus, the so-called "single cavity" firmware developed by DESY is used [11]. Figure 1 shows the block diagram of complete control loop:

- The DWC8VM1 board receives the RF signals from the cavity probe and directional couplers and mixes them with the Local Oscillator signal to get signals in an Intermediate Frequency (IF), which are sent to the SIS8300KU through the mTCA Zone 3 connector. It

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also receives the in-phase and in-quadrature control signals from the SIS8300KU to drive a vector modulator and generate the RF signal that will be amplified by a SSA.

- The SIS8300KU receives the IF signals, it digitizes them, does a non-IQ demodulation and implements the actual control loop. It then sends the control signals back to the DWC8VM1.

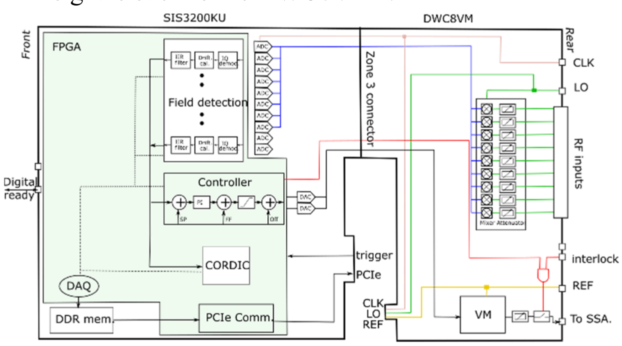

Figure 1: Diagram of the SIS8300KU (left) and DWC8VM (right) boards with single cavity firmware.

TEST STAND SETUP

Before deploying the system to drive the cavity installed in the booster, a test stand has been set up in order to check the proper behavior of each subsystem. A diagram of the complete setup is shown in Fig. 2.

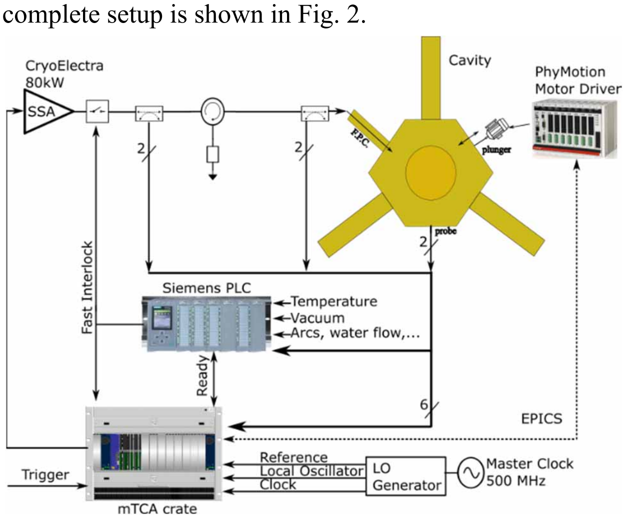

Figure 2: Complete setup composed by a mTCA crate, a Siemens PLC, a Cryoelectra SSA, a PhyMotion motor driver and a Local Oscillator Generator.

A High Order Mode (HOM) damped normal conducting (NC) 500 MHz cavity [12], is installed in a radiation-controlled area.

The fundamental power coupler of the cavity is connected to an 80 KWatt Cryoelectra SSA [13]. Figure 3 shows the 80 KW amplifier. All system parameters (RF power levels, vacuum level, temperatures, cooling water flow, electrical arcs, mTCA system-ready signal, etc.) are monitored by a Siemens PLC [14], which tells the mTCA controller that the system is ready to be driven and is able to fast interlock both an RF switch at the output of the SSA and the DWC8VM1 board when a dangerous value is reached.

Figure 3: CryoElectra 80kWatt CW Solid State Amplifier.

The cavity is tuned by a plunger driven by a stepper motor which is controlled by a PhyMotion driver [15]. This device can be operated in three different modes: locally, remotely through an EPICS connection, and automatically. In the latter, phase of the probe antenna signal and that of the forward power read by the LLRF controller are compared. The difference is a measure of the cavity detuning which must be minimized to decrease the RF power reflection of the system. If the phase difference exceeds a certain threshold, the system will automatically recalibrate by adjusting the plunger until the difference is less than a certain value.

Finally, the LLRF system gets the necessary RF signals (500 MHz reference, 525 MHz local oscillator and 25 MHz clock) from an external Local Oscillator Generator, which uses a set of frequency dividers and mixers to generate them from a Signal coming from the master clock (500 MHz). The external triggers are adapted for the timing board by dedicated board [16].

The complete setup is controlled through EPICS control system. Figure 4 shows two of the LLRF panels: the main control panel where all control parameters can be set and readback and the RF channels' parameters where the system can be calibrated and monitored.

Except for some minor details, the system is ready to start the tests. First of all, the LLRF system needs to be calibrated using several, RF power meters. After that, continuous wave operation will be tested, and finally, the usual ramping-up and ramping-down operation of the booster cavity will be checked.

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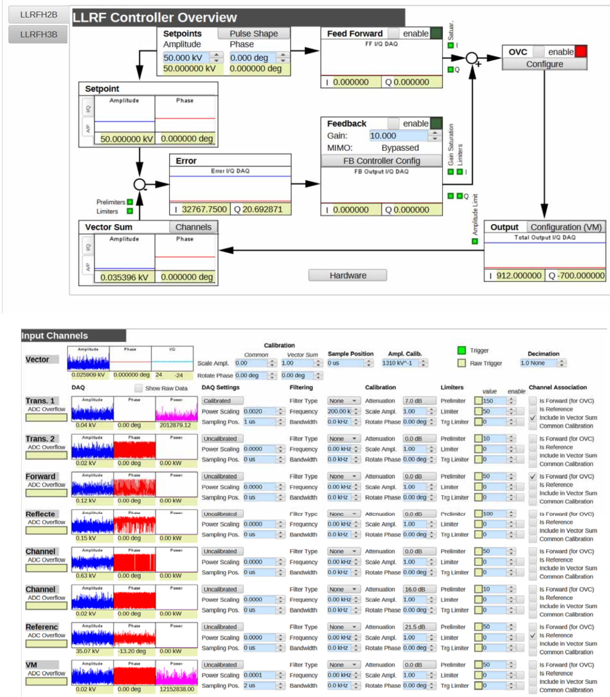

Figure 4: LLRF main control panel (up) and RF channels' panel (down).

CONCLUSION

The current BESSY-II's analogue LLRF control system has been in operation for almost 25 years, and after the RF amplifiers' upgrade has become the limiting factor in terms of noise. Moreover, the installation of new booster cavities and the lack of spare units, make the upgrade of the LLRF control with a modern digital system necessary. mTCA.4 is the chosen architecture for the new digital LLRF control, where a set of SIS8300KU and DWC8VM1 are used to drive the cavity with the so-called single cavity firmware.

In order to test the system, a complete test stand with, among other components, a cavity, an 80KW solid state amplifier, a PLC, and a mTCA.4 chassis has been prepared. Once the system is tested in continuous Wave mode and ramp-up and down mode, it will be deployed to the already installed new booster cavity.

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