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LLRF SYSTEM FOR THE ESS PROTON ACCELERATOR

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Abstract

The European Spallation Source is driven by a proton linear accelerator that will have an average beam power of 5 MW. The accelerator is pulsed at 14 Hz with a pulse length of 2.86 ms, and consists of both normal conduction and superconducting accelerating structures. The long pulse and the high goals of energy efficiency and availability create special challenges for the LLRF system.

LLR SYSTEM OVERVIEW

The low level RF (LLRF) system controls the phase and amplitude of the electrical field in the cavity by measuring the field and comparing the measurements against a set of desired values. The control system will use a PI-controller with the addition of adaptive feed-forward compensation. Two different frequencies will be used in the accelerator, 352.21 MHz and 704.42 MHz.

Figure 1 shows a conceptual overview of the LLRF system for one cavity. The LLRF control system output (2) is connected to the pre- and power amplifier. The phase of the output is set relative to the phase reference signal (8), which is distributed in the accelerator tunnel with one tap per cavity. The output from the power amplifier (4) is isolated from the cavity by a circulator. The output is also monitored, in order to be able to linearize the amplifier chain by a pre-distortion block in the LLRF system. The field in the cavity is picked up by a probe antenna, and is fed back to the LLRF system. This cable is routed from the tunnel in parallel with the phase reference signal to compensate for temperature drifts. The additional signals indicated are used for monitoring the system.

The LLRF system is also responsible for monitoring and storing the signals it receives. The monitoring is done in order to find abnormalities and shut down the RF cell before any long term damage occurs, and is implemented by threshold detectors. The LLRF system is only responsible of delivering warnings and errors signals, not the actual shut down decision, which is taken by the local protection system. This in turn is connected to the machine protection system (MPS) of the accelerator. Storing of signals is done to be able to analyse why the accelerator was shut down, this functionality is part of the post mortem system. Stored signals can also be used for monitoring of systems while the accelerator is running.

The LLRF system also handles the physical tuning of the cavities. This is done by motion controllers. The high power of the field and the proton beam will physically defect the superconducting cavities through Lorenz forces. To compensate for these effects the cavities needs to be stretched or squeezed. Two systems are used for this, one slow coarse-grain system using a stepper motor and one fast fine grain system using Piezo-crystals, where the former mostly compensate for the deformation of the cavity when cooled down or heated, and the latter for Lorenz force Compensation.

HARDWARE

The parts will be housed in enclosures suitable for mounting in a 19" rack cabinet. The aim of component

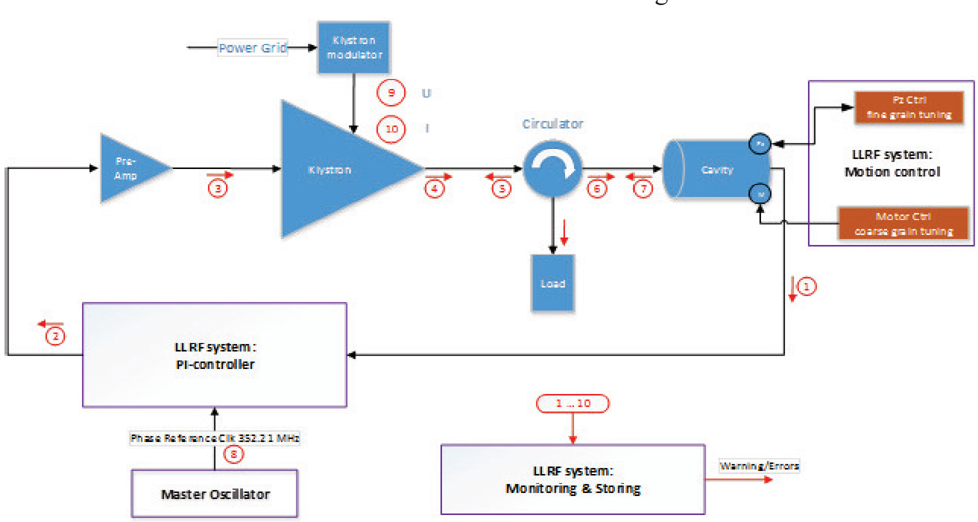

Figure 1: The LLRF system for one superconducting cavity.

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selection has been to build a modular system that is based on industry standards, in order to increase the possibilities of finding second sources in the procurement process. A modular system is also easier to keep running over long time, as only individual sub-components will reach their end of life at a certain time, and thus make the identification and development of the necessary replacements a smaller task. It will also make it feasible to quickly exchange broken modules.

There is an ongoing effort at ESS to harmonize the hardware used across the facility. The development of the LLRF system has been an integral part of this work, and it has influenced the choice of individual sub-components.

The main part of the electronics will be housed in a MTCA.4 chassis. This standard has evolved from standards used in telecommunication towards applications that have higher demands. The MTCA.4 standard is especially targeted towards the accelerator industry. One big benefit of the standard is the inclusion of remote diagnostics functionality and the possibilities of a redundant design.

The motion control of stepper motors for slow tuning will be handled by off-the shelf motion controllers. The control of the fast tuners will be integrated into the MTCA.4 crate, as these must be tightly synchronized to the beam pulse arrival time.

MTCA rack for LLRF

In figure 2 there is a schematic picture of the boards and how they interconnect for a LLRF crate for a superconducting spoke cavity at 352.21 MHz. At this frequency a direct sampling architecture will be used. The CPU is the gateway towards the EPICS network, and is having drivers for all the connected cards.

As the MCH is also connected to the CPU, it is possible to get data from it over the EPICS network. The EPICS connection is routed through the switch fabric in the MCH. The ethernet connection from the MCH is carrying both the EPICS network, and the direct interface to the MCH. Thus it is possible to access the MCH even if the CPU is down, in order to do fault detection and restart the CPU.

The CPU is running all the services necessary for the connected cards. This communication goes over the backplane.

The timing receiver generates triggers based on the timing signals, which are then routed through the backplane to the FPGA board. The FPGA/ADC board with the connected RTM is the main part of the LLRF system, measuring and controlling the amplitude and the phase of the cavity.

The FPGA and Piezo RTM are handling the fast tuners. It is a part of the MTCA crate, as it is dependent on trigger signals from the timing card. The waveform used for compensating the Lorenz force detuning will be adapted to best fit, and this adaption will be handled by the CPU in the crate. The FPGA will only do the lowest level of computations and control.

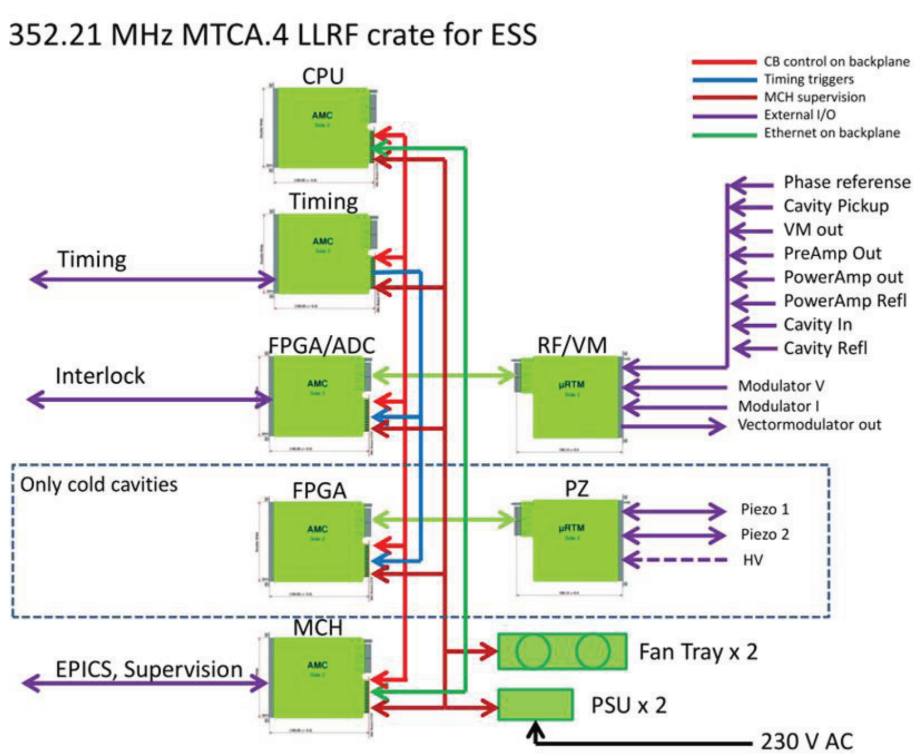

Figure 2: Architecture of a LLRF system.

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Global ESS timing

The interface towards the timing system is by a timing receiver in the LLRF system. This receiver will be housed in the main LLRF crate. The timing system at ESS is at this time based on a system developed by Micro Research Finland. The benefit of the modular system is that if an alternative has to be implemented; such as White Rabbit, only the receiver has to be exchanged in the crate.

The timing system will give four trigger signals to the LLRF system. These triggers are communicated on individual trigger lines on the backplane of the crate.

- A pre-trigger 10 ms before beam pulse start
- A beam pulse start trigger
- A beam pulse end trigger
- Post-mortem trigger

In addition, the timing system will give information on the next pulse length and current. This information goes over the data interface from the timing receiver to the CPU in the crate, and will be used to load the correct parameters for the LLRF system from the memory for that specific pulse type.

Local protection system and MPS

The RF cell is protected by a local protection system. It handles local interlocks in order to protect the RF equipment from damage. It measures a number of parameters in the RF cell, such as RF power meters and arc detectors, and can shut down the RF cell by mainly two methods: by shutting down the modulator (crowbar), and by turning of the output of the LLRF system. The latter is handled by a PIN-diode switch on the LLRF RTM, controlled by a separate control signal directly from the LPS system to the LLRF crate.

The RF cell is an input system to the MPS, but not a mitigation device. The interface towards the MPS system is handled by the LPS.

Summary

The LLRF system for ESS is developed to be highly modular to facilitate upkeep, and to fulfil the high demands on availability and reliability. Large parts of the design is based in industry standards, in order to make it possible to have a competitive bidding during the procurement phase of the project.