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HIGH SPEED DIGITIAL LLRF FEEDBACKS FOR NORMAL CONDUCTING CAVITY OPERATION

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Abstract

In the first half of the year 2014, the MTCA.4 based LLRF control system will be installed at several facilities (FLASH RF Gun, REGAE, PITZ, FLUTE/KIT). First tests during the last year show promising results in optimizing the system for high speed digital LLRF feedbacks (reducing system latency, increase internal controller processing speed). In this contribution we will present further improvements in latency and performance optimization of the system, results and gained experience from the commissioning of the system at the mentioned facilities.

INTRODUCTION

The new MTCA.4 based LLRF system for FLASH and XFEL [1–3] is designed for controlling up to 32 superconducting cavities by one common klystron. The structure of the LLRF system is optimized for multi channel processing. It is designed to measure and process up to 96 RF signals (forward, relfected and probe of 32 cavities) with up to six 10-channel analog down-converters (DRTM-DWC10) and ADC-boards (SIS8300L) (Fig. 1). All the data is send via the low latency link (LLL) to the main controller board (DAMC-TCK7) where the main control algorithms are implemented and all the data is processed. The computed control signal is send via the LLL to the vector modulator board (DRTM-VM2) to drive the klystron.

SINGLE CAVITY LLRF SYSTEM

For the single cavity LLRF and normal conducting facilities, the multi cavity system structure is optimized in terms of cost and performance. First, for the single cavity LLRF system in general less signals for the RF regulation have to be detected. Second, the higher bandwidth of normal conducting systems necessitate lower system latency for the fast digital feedback operation in terms of achievable feedback gain and RF field stability. Therefore a new analog front-end board is designed (DRTM-DWC8VM1), which is a combination of the DRTM-DWC10 and DRTM-VM2. It combines an 8 channel down-converter and a single channel vector modulator on one rear transition module (RTM) (Fig. 2). All the required data preprocessing and control algorithms can be implemented on the advanced mezzanine carrier (AMC) ADC-board (SIS8300L). By removing the two LLLs between ADC and controller, and controller and

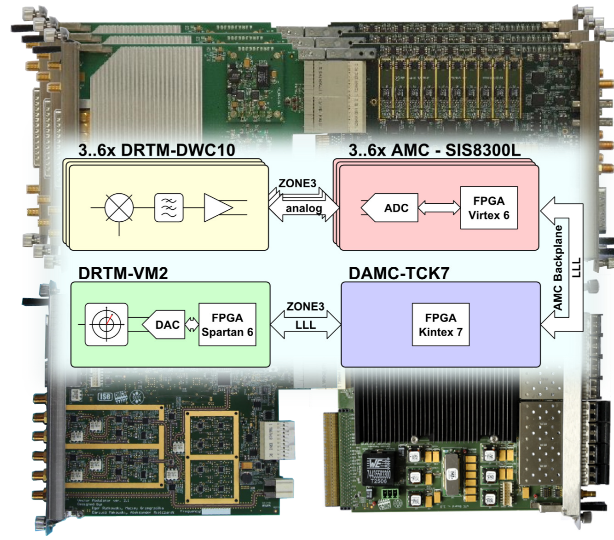

Figure 1: Basic hardware structure of the MTCA.4 based multi cavity LLRF system designed for processing of up to 96 RF signals.

vector modulator, the system latency is reduced. Additionally, less hardware is needed, which means lower cost and lower probability of failure. For the single cavity controller firmware the preprocessing part (field detection) and the main controller algortihms are combined and integrated in the FPGA on the AMC ADC-board.

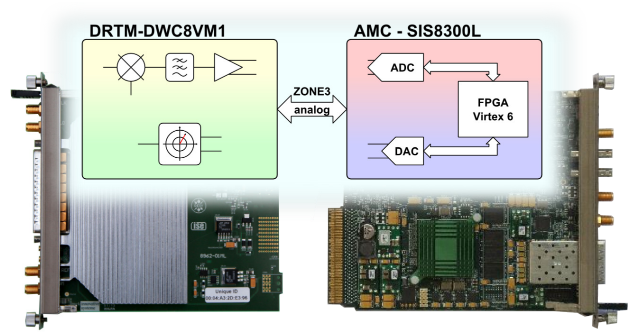

Figure 2: Basic hardware structure of the MTCA.4 based single cavity LLRF system.

The general crate layout for the single cavity LLRF system is shown in Fig. 3. Here the planned system for the PITZ RF Gun is shown exemplary. It is installed in a two rack-unit MTCA.4 crate with six AMC and four RTM slots. The main crate infrastructure consists of a power module (Telkoor

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1kW), a management controller hub (MCH), a CPU, and a timing module (x2timer). The three AMC/RTM pairs are foreseen for the main LLRF controller (SIS8300L/DRTM-DWC8VM1), for signal monitoring (SIS8300L/DWC10), and machine protection (DAMC02/RTM-MPS).

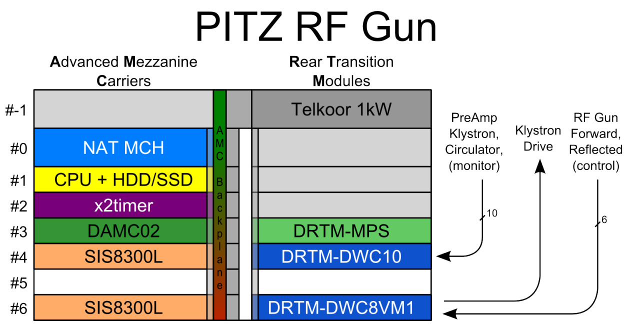

Figure 3: General crate layout for a single cavity LLRF system. The layout of the planned system for the PITZ RF gun is shown exemplary.

RUNNING FACILITIES/SYSTEMS

In this section, a short summary of the facilities and their installation and commissioning status is given.

XFEL/FLASH/PITZ RF Gun

From LLRF system point of view the RF Gun at FLASH, XFEL, and PITZ is almost the same. It is an L-band 1.5-cell normal conducting cavity operating at 1.3 GHz with a loaded quality factor of approx. 20e3, an RF pulse length of up to 800 us, a pulse repetition rate of 10 Hz, and a target RF peak power of up to 6.5 MW. The waveguide distribution differs a little. At the XFEL RF Gun the power from the klystron is split up into four waveguide arms and send down to the RF gun, where it is recombined, while at FLASH and PITZ it is just split into two arms (Fig. 4). The specialty for the LLRF on all of these RF Guns is the missing probe pickup. Therefor, a virtual probe out of the forward and reflected signal of the last directional coupler at the RF Gun is calculated and used for regulation.

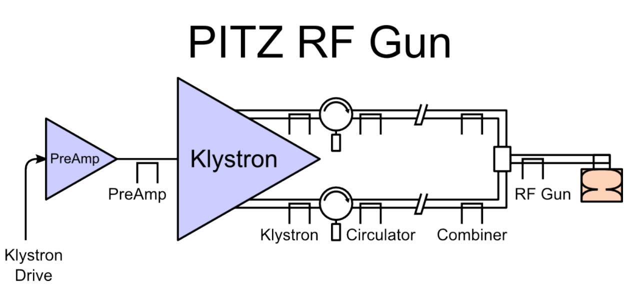

Figure 4: PITZ RF Gun waveguide distribution system and locations of the directional couplers. Each coupler signal (forward and reflected) is measured by the LLRF system for regulation and/or monitoring purpose.

XFEL In November 2013 the XFEL RF Gun and the LLRF system was installed and successfully commissioned in December 2013. The results are presented in [4] at this conference. Next tests with RF and beam operation are scheduled for July 2014.

FLASH Beginning of 2014, the new single cavity LLRF system was installed at the FLASH RF Gun and running in parallel to the old VME system for signal monitoring and commissioning of the new system in the same time (basic server and firmware functionality). For this purpose all RF signals were split. First tests of driving were performed in March 2014 and at that time nominal power of 5.5 MW and pulse length of 450 us were achieved in feed forward mode only. Since the RF Gun at FLASH is quite sensitive to too high RF power, the feedback operation was just performed at a power level of 2 MW and a pulse length of 200 us. To protect the RF Gun and increase its life time, a fast protection and exception handling system is developed, which reacts during the RF pulse and turns off the drive signal within less than 1 us. Tests were scheduled in May, but problems prevented successful tests. Since FLASH is a user facility, no further study shifts were available during the first halve of this year. Nevertheless, the errors are fixed and next tests are scheduled for the second half of this year. The focus than will be on the fast protection and exception handling, and a permanent operation of the RF Gun at FLASH with the new single cavity LLRF system.

PITZ At PITZ the new system was installed in March 2014 and is running in parallel to the old VME system like at FLASH (RF signals were split, too). After some issues with the timing system, first tests of driving with the new system were successfully performed in May 2014 (Fig. 5). A pulse length of 650 us and gradient of 30 MV/m (matches a forward power of approx. 4.7 MW) were achieved in feed forward mode. Because of the missing protection and exception handling system no feedback tests were performed. Due to a longer shutdown period at PITZ (amongst other installation of a new RF Gun) no further tests could be performed. Next tests are scheduled for the second half of this year. Latest end of this year a permanent operation of PITZ with the single cavity LLRF system is considered.

REGAE

REGAE is a small S-band accelerator operating at 3 GHz with an RF pulse length of up to 6 us and a repetition rate of 50 Hz. It is build up of a 1.5-cell RF Gun followed by a 4-cell RF Buncher cavity, both driven by a common klystron. The power is split in the ratio 1:4 (buncher:RF Gun) and a waveguide phase shifter in the RF Gun arm is used to adjust the phase between buncher and RF Gun. Since REGAE started operation in November 2011, it is running with an MTCA.4 LLRF system which is based on the multi cavity scheme [5]. Since May 2014, REGAE is running with the new single cavity LLRF system. One advantage of the new

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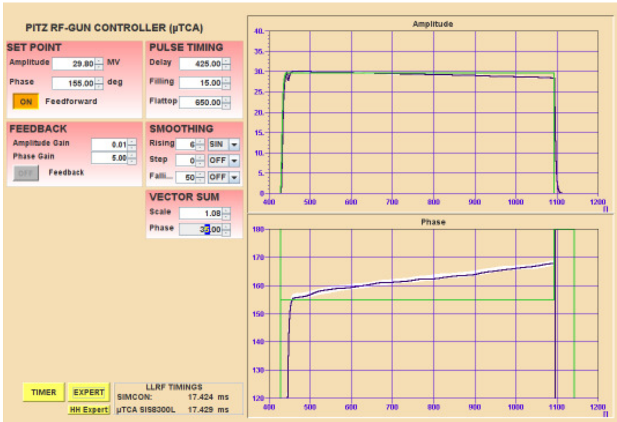

Figure 5: First operation of the PITZ RF Gun with the single cavity LLRF system. On the right side, the calculated virtual probe is shown in amplitude and phase.

single cavity scheme is the reduced latency compared to the old one. Comparative results are shown in Tab. 1.

Table 1: Measured latency budget of the multi and single cavity controller scheme. Each value is determined with respect to the beginning of the feed forward signal, which corresponds to the controller output.

	Multi Cavity	Single Cavity
VM Output	464 ns	360 ns
RF Gun Probe	736 ns	608 ns
Controller Input	1040 ns	664 ns

First tests of feedback operation of the RF Gun at REGAE were carefully performed and show slight stability improvements. Further investigations and optimization of controller parameters are necessary to get reliable results. Especially at REGAE, where one common klystron is driving both structures without isolators in the waveguide distribution, the cross coupling from one cavity to the other and vice versa, disturbs the regulation performance of the LLRF system. Further studies are scheduled. To reduce the latency caused by long cables from the cavity to the LLRF system and to the klystron, a rearrangement of the location of the LLRF system is scheduled within the next two month. The LLRF system will be placed in the REGAE tunnel closer to the cavities. Furthermore it is planned to implement a model based predictive controller to get rid of the remaining system latency.

OUTLOOK

During the second half of this year, further facilities will be equipped with the new single cavity LLRF system. In this section these facilities are shortly presented.

FLUTE

FLUTE is a new test facility currently being built at the Karlsruhe Institute of Technology (KIT) in collaboration with DESY and PSI [6]. It is a normal conducting S-band accelerator operating at 3 GHz with 5 us pulse length and a repetition rate of 100 Hz. It consists of a 2.5-cell CTFII Gun from CERN and a DESY type traveling wave linac structure, both powered by a common 45 MW klystron. The power is split by a 3 dB hybrid and a phase shifter. The LLRF system is provided by DESY and will be a copy of the REGAE single cavity LLRF system. Compared to REGAE, at FLUTE circulators will be installed in front of the RF Gun to reduce crosstalk between the structures.

PITZ Booster

The LLRF system for the PITZ booster will be a copy of the LLRF system for the PITZ RF Gun. Instead of the single directional coupler in front of the RF Gun, the booster has two probe pick-ups, which will be used for the regulation. Installation and commissioning is scheduled for second half of 2014.

PITZ/XFEL TDS

As part of the special longitudinal beam diagnostic for XFEL, several transverse deflecting structures will be installed at XFEL and one at PITZ, too. The first TDS for the XFEL injector and the one for PITZ is a 14-cell normal conducting S-band structure operating at 3 GHz, with a variable pulse length of 0.1-3.1 us and a repetition rate of 10 Hz. The LLRF system will be mainly a copy of the REGAE/FLUTE LLRF system. Installation and commissioning is scheduled for September 2014.

ACKNOWLEDGMENT

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