Upgrade of the LLRF Control System at LNL

D.Bortolato[1], S.Pavinato[1,3], D. Pedretti[1,3], D. Marcato[1], F. Gelain[1], E. Munaron[1],
M. Bellato[2], R. Isocrate[2] and M. Bertocco[3]
[1]Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, 35020 Legnaro, Italy
[2]Istituto Nazionale di Fisica Nucleare, Sezione di Padova, 35031 Padova, Italy
[3]Department of Information Engineering, University of Padova, 35031 Padova, Italy

Abstract

For the SPES project at Legnaro National Laboratories (LNL), a Low-Level Radio Frequency (LLRF) controller has been designed to have flexibility, reusability and an high precision. It is an FPGA-based digital feedback control system using RF ADCs for the direct undersampling and it can control at the same time eight different cavities. The LLRF system was tested on the field with an accelerated beam. In the last year some improvements on the firmware, software and hardware of the control system have been done. In this paper the results carried out in the more recent tests, the future works and the upgrades of the system will be detailed.

RF system

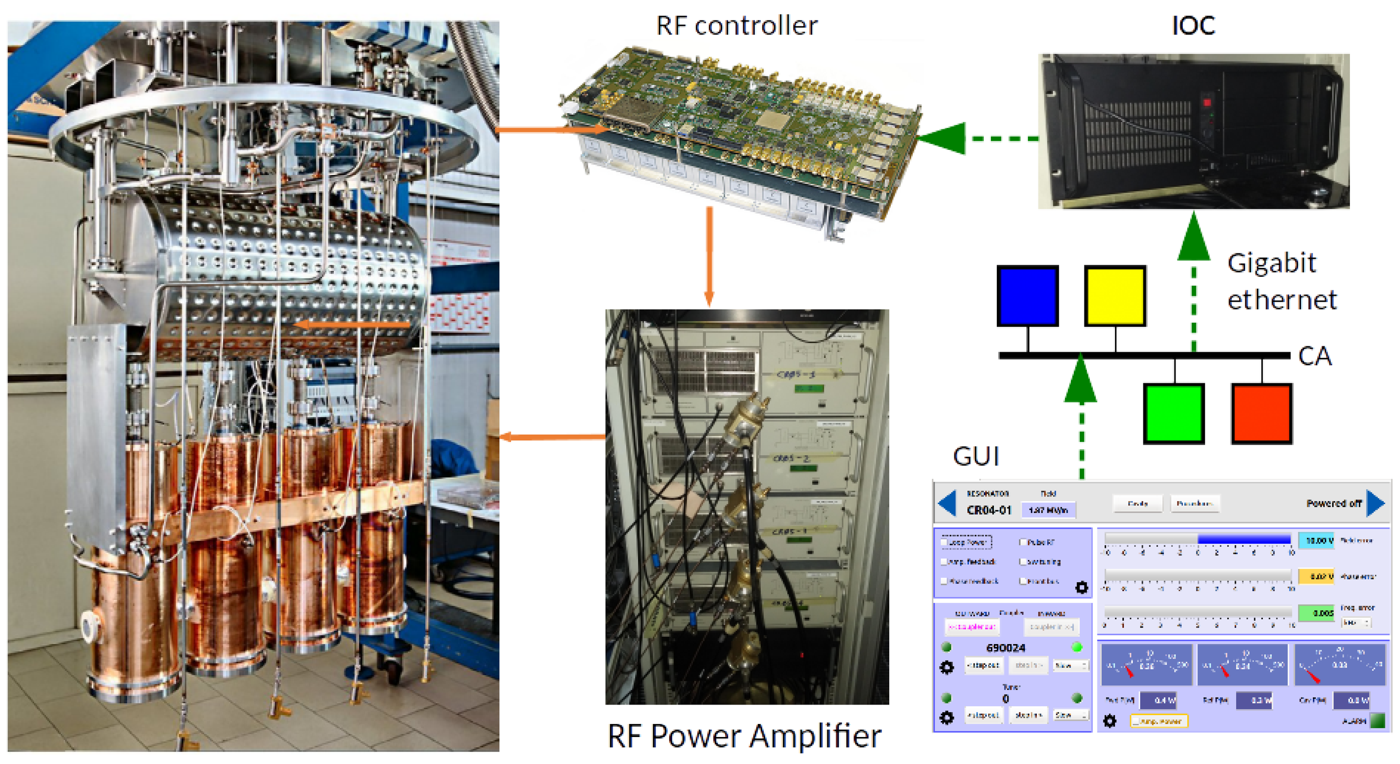

Figure 1: Measurement setup during the RF control system validation

The RF controller interacts directly with the cavities and it works in a real-time closed loop. It is a set of analogue and digital electronics which provides phase, amplitude and frequency corrections to stabilize the RF field in presence of disturbances and vibrations due to other subsystems of the accelerator. The control algorithm is implemented via a programmable device as a FPGA. This increases dramatically the flexibility and the programmability of the controller. The digital board of the RF controller can work in a wide range into the RF spectrum. It is a versatile tool, easy to adapt to 40/80/160/352 MHz resonators, thus spanning all types of cavities of the final SPES configuration. The controlling and the monitoring of the RF controller is done by the particle accelerator control system based on EPICS.

RF IOC

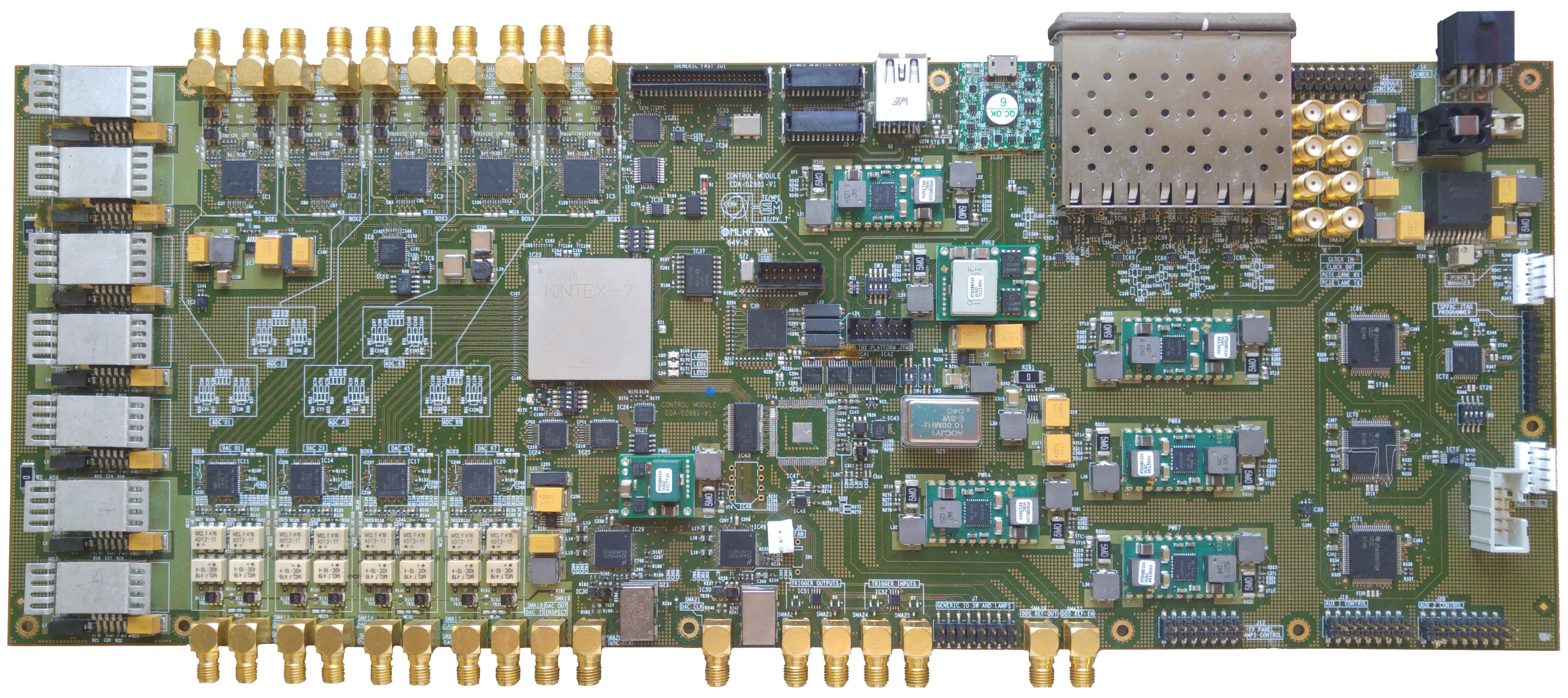

Figure 2: RF IOC board.

Each RF controller controls at the same time eight cavities. It is essentially composed of four high linearity dual channel RF ADCs, a Xilinx Kintek 7 FPGA in which the LLRF logic is implemented using VHDL code and four high-speed, high-performance dual channel DACs. Both ADCs and DACs support a JESD204b compatible high-speed serial input data interface. The clock signals are generated by two clock jitter cleaners.

RFFE

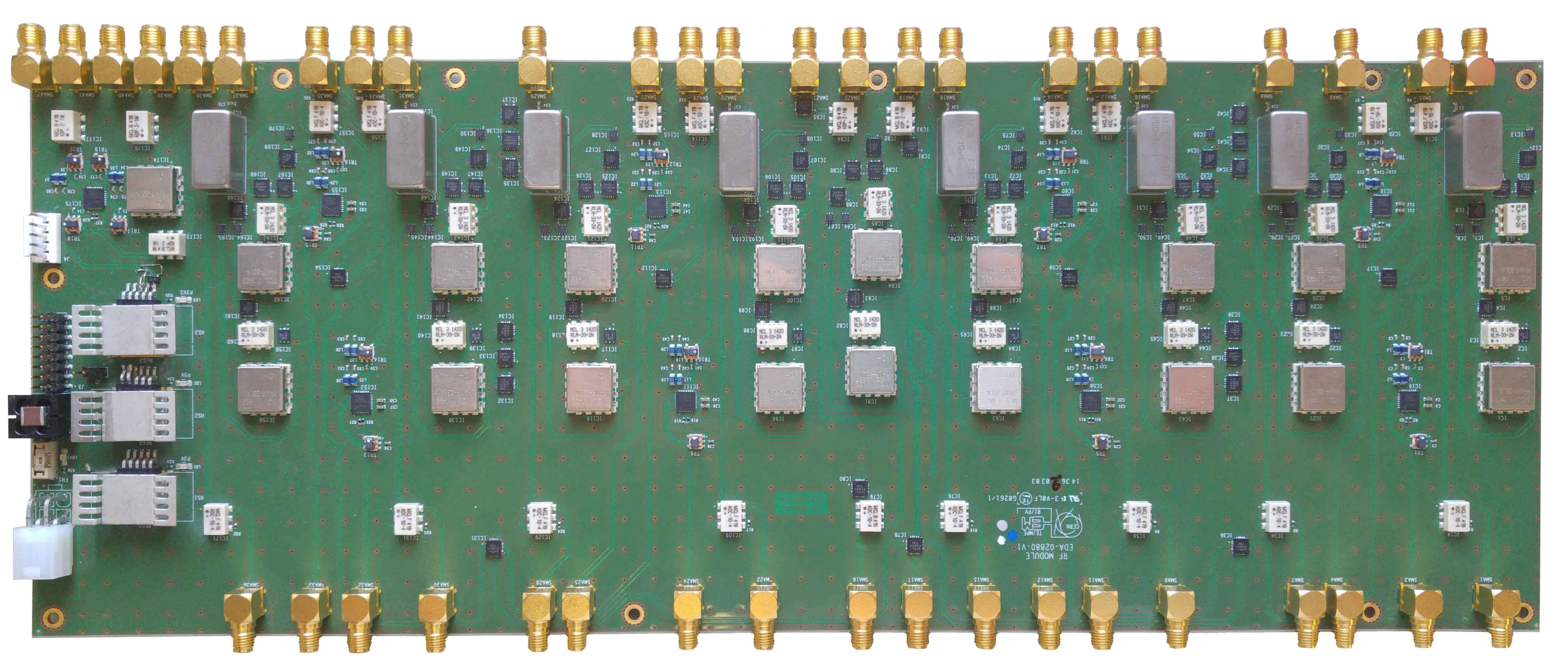

Figure 3: RFFE board.

The RFFE board is in charge of adapt the power level of the signals between the cavities and the ADCs housed in the RF IOC and between the DACs in the RF IOC and the input of the power amplifiers. It is divided in eight sections, one for each cavity controlled. Furthermore for each section there are some test points used to monitor the analog signals through a DRS4 Evaluation Board.

LLRF

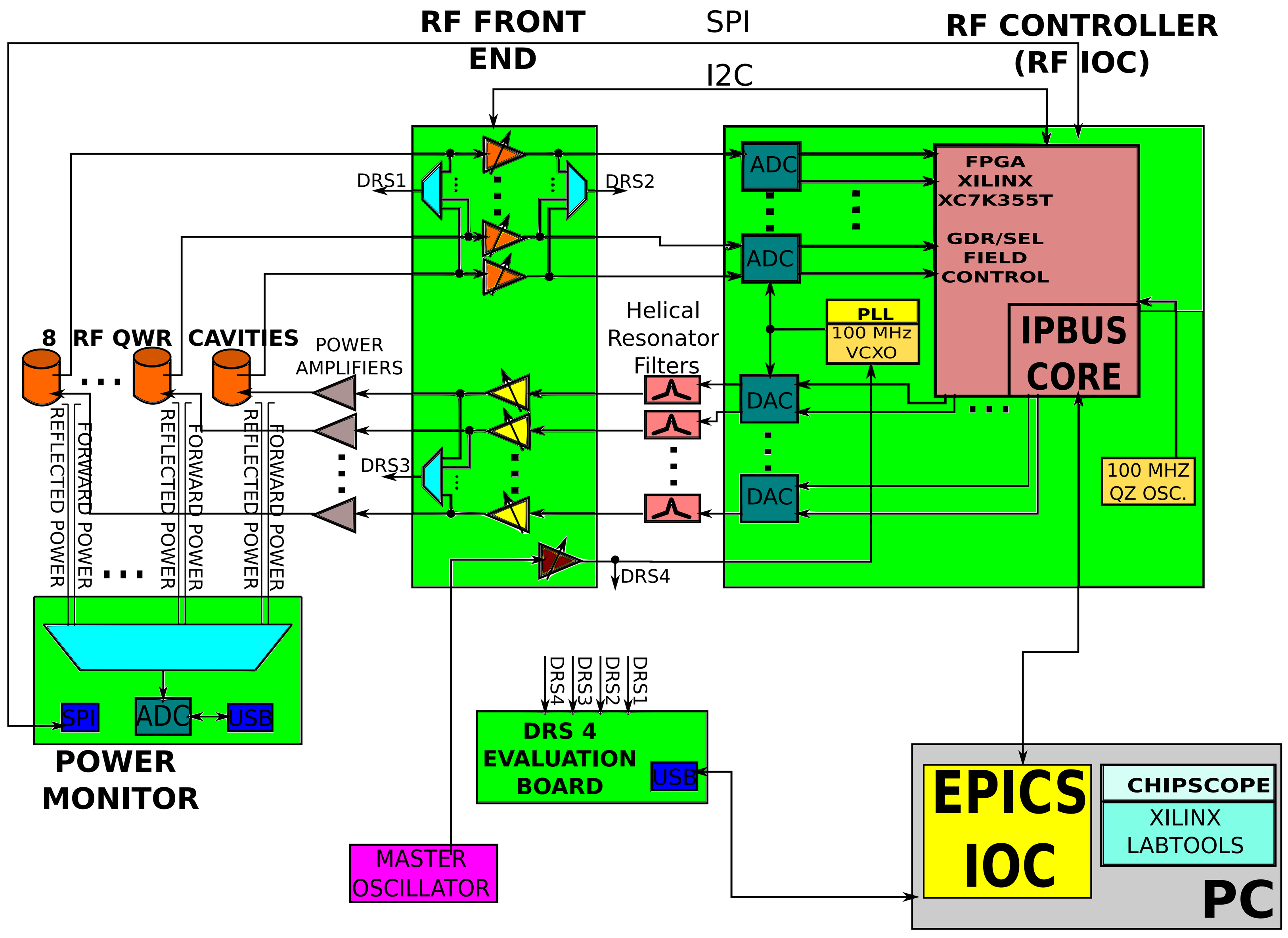

Figure 4: Block schema of a octal resonator controller box.

Each box essentially contains a RF I/O controller card (RF IOC), a RF front end board (RFFE), a Power Monitor board (PM), two DRS evaluation boards and eight Helical Resonator filters.
The EPICS IOC allows input/output operations to the RF controller via Ethernet. It is based on IPbus protocol.

IPbus

In this project the slow control is based on IPbus protocol. IPbus allows the communication between the RF controller and the accelerator control system, without placing a computer, where an EPICS IOC can run, close to the controller. The software IOC is executed on a virtual machine. In this way you can exploit the advantages given by a virtual machines, constantly backed-up and easy to maintain, and reduce the wiring required.

Measurements and Results

When the EPICS architecture to control the RF controller was completed rf control system validation started. It consisted in the installation of the new RF controller with its control system EPICS based in the ALPI facility. The cavities were SEL locked and a beam was accelerated. The stability of the LLRF controller was assessed. Suitable indicators for validate the stability performance are the rms value of the residual errors, in phase and magnitude, of the RF IOC board. A good visualization of the different perturbation frequency is achieved calculating the integrated rms detuning spectrum:

$$\Delta d(f_n)_{rms} = \frac{\sqrt{\sum_1^n |\mathcal{F}[\Delta d(t)]_i|^2}}{\sqrt{2}}$$

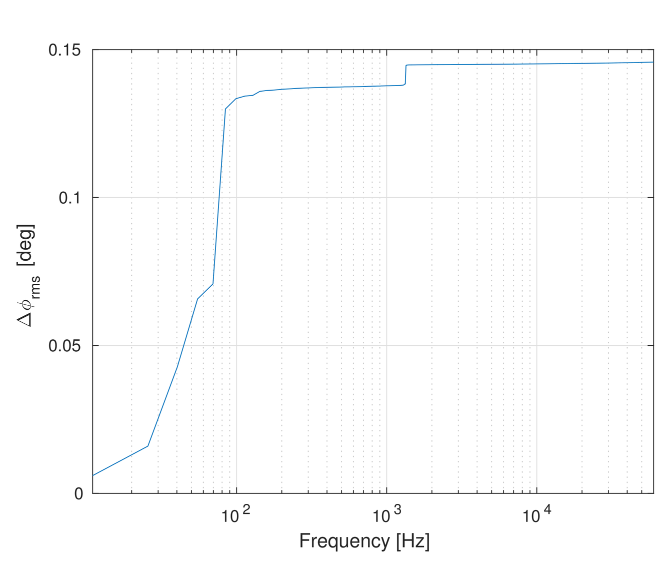

Figure 5: Step response of the field magnitude for a medium beta cavity.

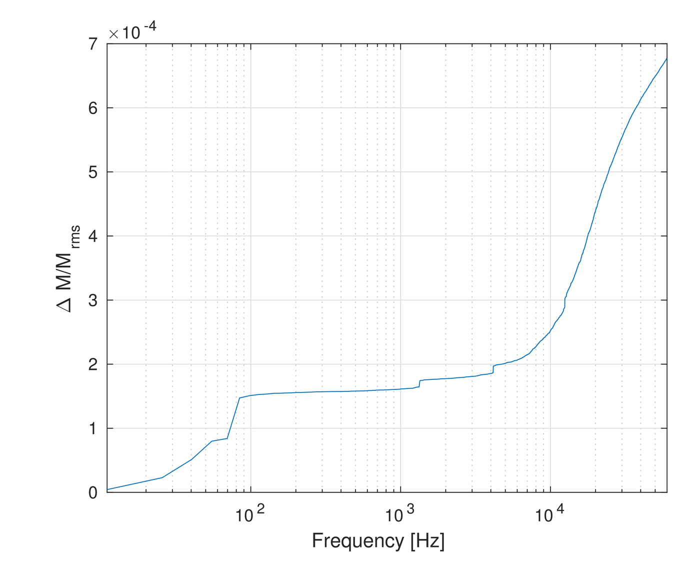

Figure 6: Step response of the phase for a medium beta cavity.

The total value of the phase fluctuation is $0.145°$ rms, while for the field fluctuation is $6.9 \cdot 10^{-4}$.

Conclusions

- The measurements shown that the new RF system guarantees a phase and an amplitude stability margins consistent with those required for a heavy ion linear accelerator as ALPI.
- The measurements done to qualify RF control system have been come to an end. The hardware developed is now ready for the first production in order to substitute the old analog controllers.