Development and Integration of a New Low Level RF System for Medaustron

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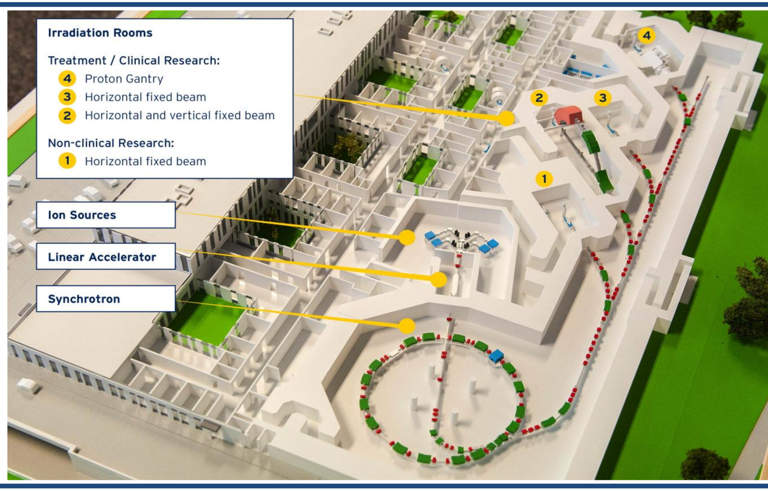
The MedAustron Ion Therapy Center

The MedAustron Particle Therapy Accelerator (MAPTA) is a synchrotron-based machine optimized for ion therapy. The design, based on the PIMMS (Proton Ion Medical Machine Study), provides proton and carbon ions for treatment and non-clinical research. The facility features 4 irradiation rooms, three of which for clinical operation while one room is dedicated to non-clinical research. Proton patient treatment started in December 2016. Since then, carbon ion beams and further treatment rooms have been commissioned, reaching full facility operation in 2022 with the activation of the proton Gantry while continuously ramping up treatment capacities.



The MAPTA RF Systems

The MedAustron injector [1] features four RF cavities: a four-rod Radio Frequency Quadrupole, a Buncher Cavity, an Interdigital H-Mode drift tube Linac and a Debuncher cavity. All Injector cavities are operated at 216.8MHz powered by dedicated high level RF amplifiers, driven by a common commercial low level RF system to ensure proper and controlled phase relations.

In the synchrotron a 12 cell Finemet® loaded RF cavity accelerates the beam up to 800MeV or 400MeV/u for proton and carbon ions respectively. Each cell provides a wideband, low Q behavior with 12 independent RF amplifiers driven by a centralized VME based LLRF developed by CERN [2].

Synchronized Beam Instrumentation

The MedAustron accelerator complex profits from a set of non-invasive beam instrumentation devices [3] to enable online beam monitoring. Within the injector this includes phase probes distributed along the Linac and medium energy beam transfer line, for time-of-flight measurements, and a four-button probe at the upstream end of the IH tank for beam position verification at drift tube entry.

In the synchrotron ring 20 shoe-box pick-ups provide horizontal and vertical beam position measurements, as well as base-line tune via a coupled BBQ system and two dedicated Schottky monitors for each transverse plane.

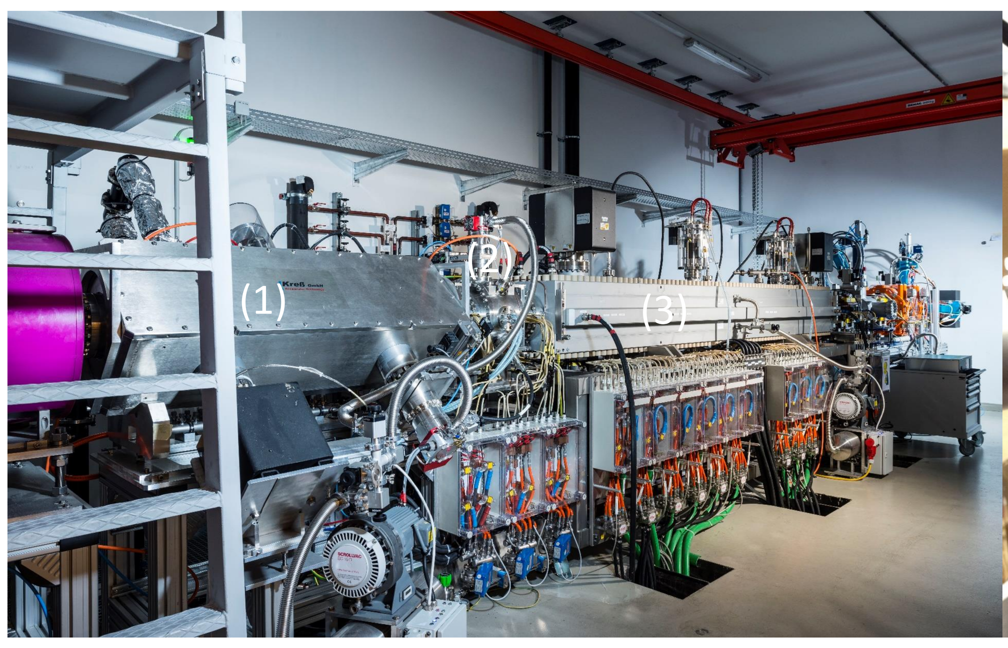
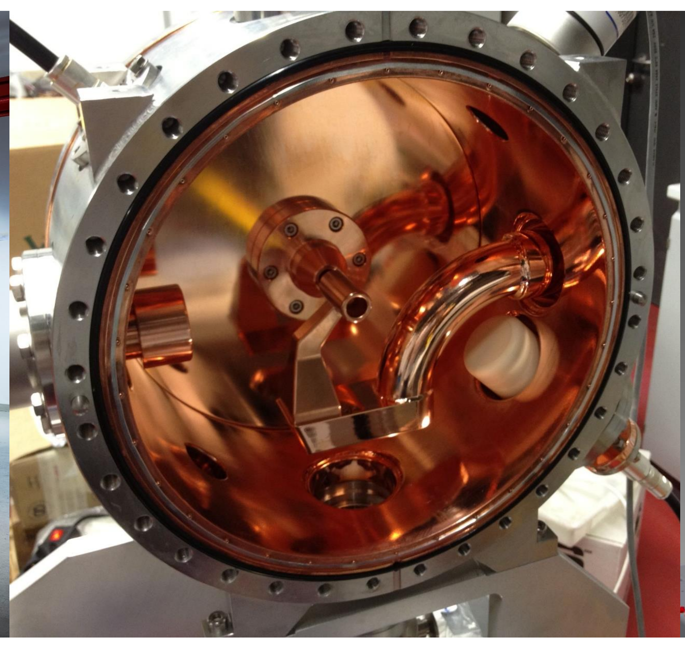


Fig.1: MedAustron Linac bunker: A 8 keV/u beam is injected into an RFQ (1) accelerating it to 400 keV/u, followed by a buncher cavity (2) and an IH-type LINAC (3) where the beam reaches 7 MeV/u before injection into the synchrotron.



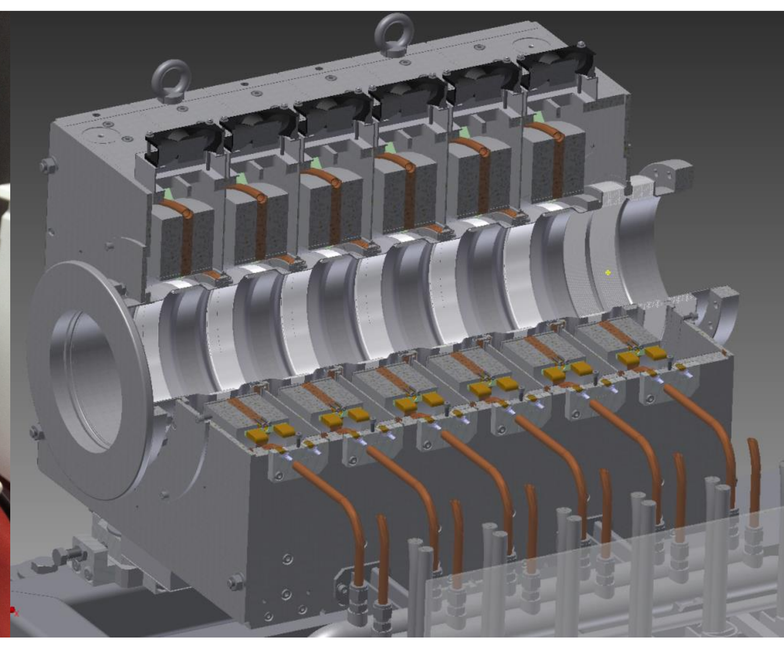


Fig.2: The MedAustron Buncher/Debuncher cavity (left) used to rebunch the 4.6ns microbunches before IH-Tank injection and to minimize the momentum spread for multi turn injection. One of the two synchrotron cavity blocks (right) featuring 6 Finemet® loaded cells for operation at 0.47-3.2MHz and voltages up to 5kV.

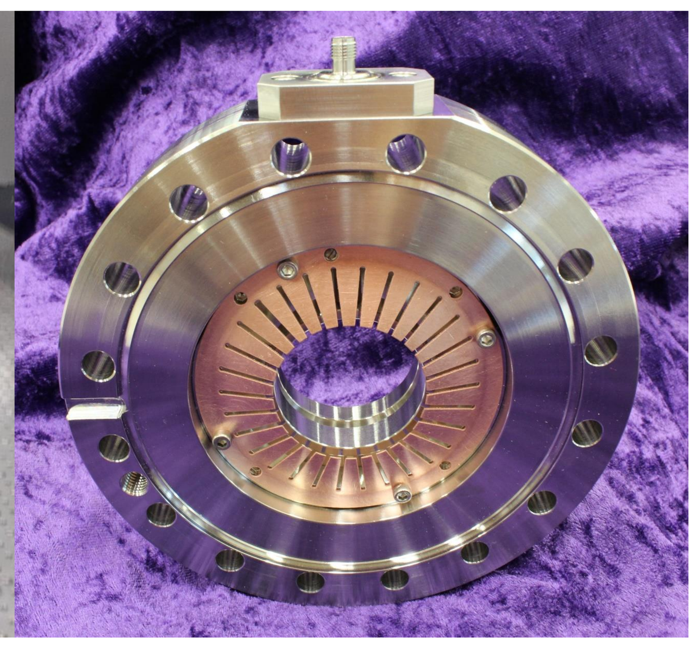


Fig.3: Synchrotron shoe-box pick up (left) as used by the synchrotron LLRF for radial position and phase regulation. A commercially available phase probe from NTG [4] (right) as installed in the MedAustron Linac for time-of-flight measurements.

New Low Level RF Platform

The currently used and commercially procured injector LLRF was reported end of life in 2017. MedAustron secured sufficient hardware components to maintain operation for a longer period of time. In the course of further developments a new LLRF system is being developed in collaboration with Instrumentation Technologies, based on commercial off-the-shelf components of a µTCA.4 platform. The COTS hardware is capable of the full frequency range needed for any RF application in Medical centers.

The new system shall operate in a **0.4-400MHz** range for Linac and Synchrotron compatibility. Required **voltage** signal stability is **0.2% RMS** for amplitude and **0.1° RMS** for **phase** control. Real time **RF-pulse control** shall be available as well as regulated **cavity tuning** for all injector cavities. As for the synchrotron application the system will provide frequency ramping, a B-train interface, **multiple harmonics** regulation on cavity voltage/phase, radial **beam position** and beam **phase regulation** as well as **RF knock-out** capability.

The Gateware and Firmware is developed in **reusable blocks** which can be reconfigured to provide the requested application (e.g. RF-Pulse generation, Beam Diagnostic,...). Additionally, there are multiple instances of most blocks available to easily expand the LLRF to multi-cavity regulation or to digitize and analyze multiple diagnostic devices in parallel (e.g. Beam Pickups, Schottky monitor,..). The main building blocks are multi harmonic numerically controlled oscillators (NCO) with real time frequency tuning capabilities and LLRF controller blocks which combine the baseband demodulation, baseband regulation and RF modulation for complete regulation chains from any hardware input to any output.

Any of the NCOs or the LLRF controller blocks can be fed with low jitter "setpoint sequences" to generate any **RF-Pulse shape** including any **frequency-**, **amplitude-** or **phase-modulation schemes**. Additional blocks are implemented for synchrotron phase regulation or phase locking to external master oscillators as well as beam position calculation and regulation. **VSWR checks**, for machine interlock functionality to turn off any RF output, and Plunger **Tuners**, which regulate **high Q cavities** to resonance, are available too.

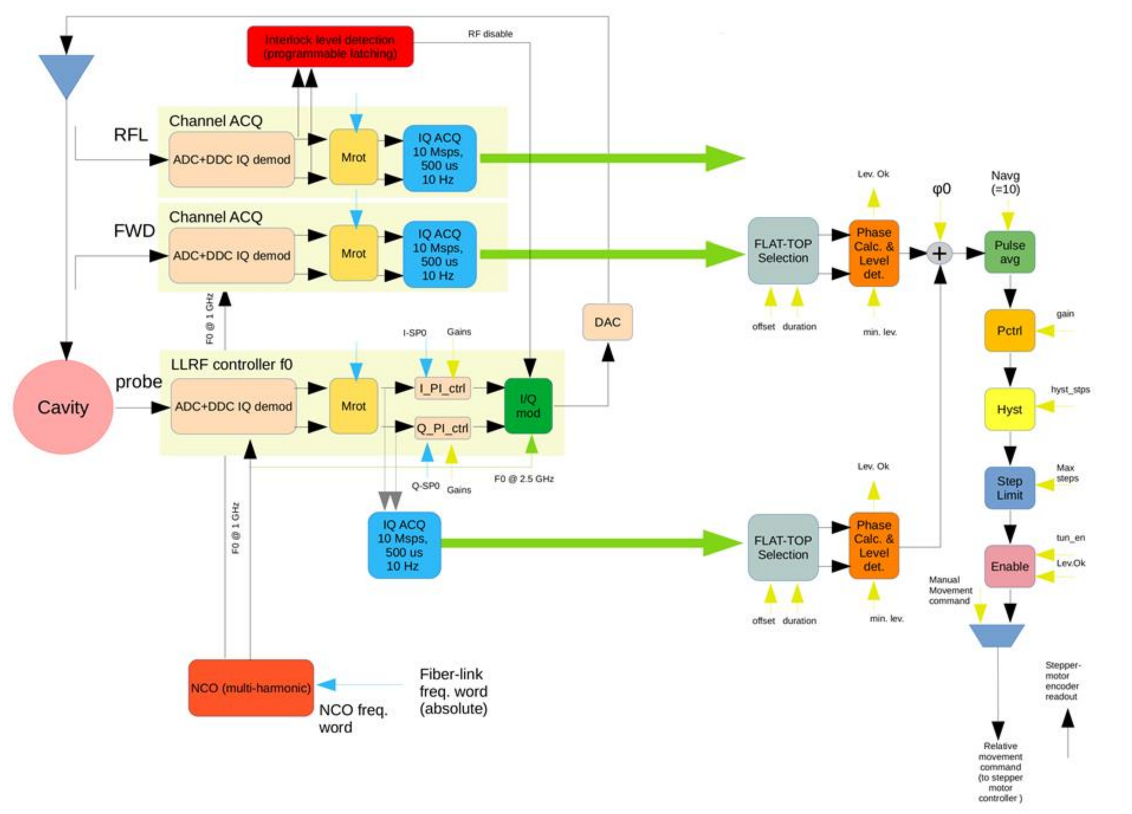


Fig.4: Block diagram focusing on the Injector LLRF emphasizing cavity control, interlocks at too high reflected powers and cavity tuner regulation.

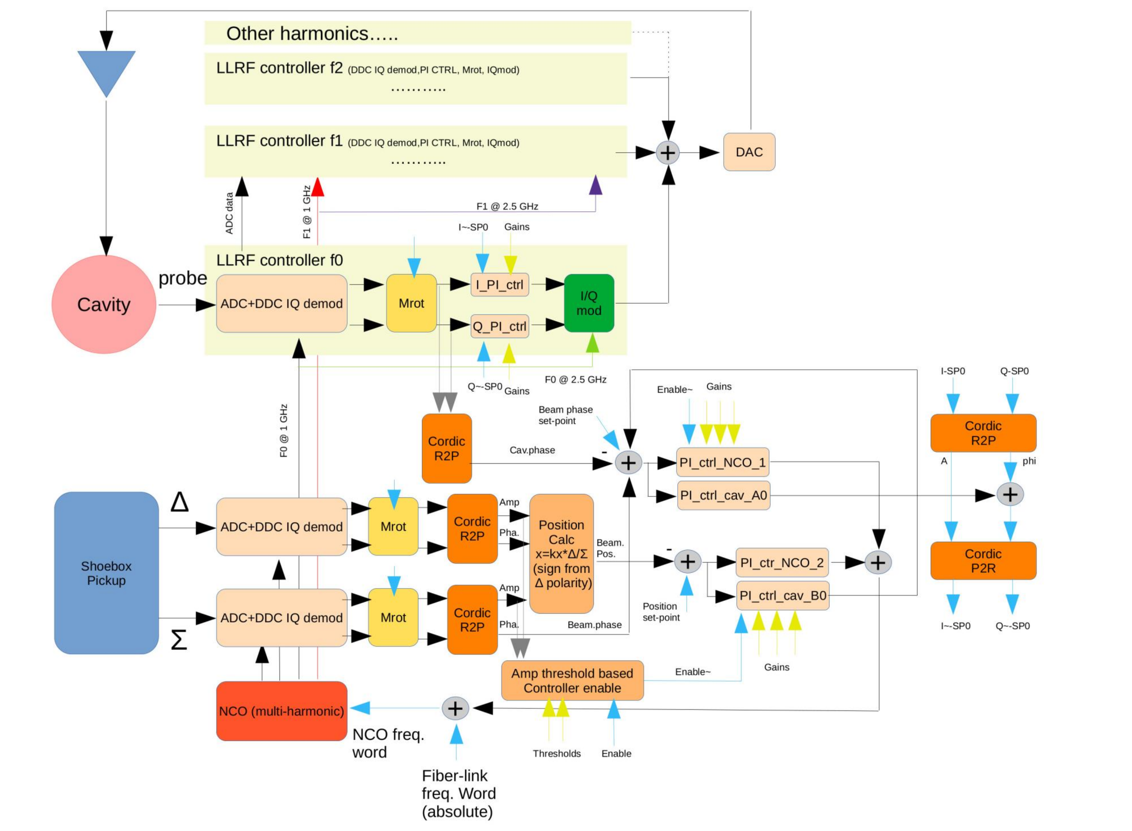


Fig.5: Bock diagram focusing on the synchrotron LLRF emphasizing cavity control and additional readouts for beam-based regulation (phase regulation and radial position regulation) .

Sustainability & Maintainability

Fig.6: MedAustron/I-Tech LLRF platform

A particle treatment center with a projected time of operation of 30+ years has to put special effort into maintenance and development strategy to ensure smooth operation. A key aspect is to minimize technological diversity, the number of necessary spare parts and required training for personnel by limiting the number of specialized devices.

The presented Low Level RF platform follows a **modular approach** in the hardware selection and the firmware implementation. Most of the components can be reused for **different applications**, thus the maintainability is high and diverse training efforts reduced. In the case of MedAustron the new platform will potentially **harmonize 8 different systems** into one hardware setup: Linac LLRF, Synchrotron LLRF, RF knock-out extraction, phase probes & time-of-flight (ToF), four-button probes, beam position pickups, base-band-tune (BBQ) and Schottky monitor.

Cavity tuner

A cavity tuner has been implemented in order to compensate for the temperature related resonance frequency changes. Tuner is regulating on the phase difference of the forward signal and the cavity probe signal. The move commands are sent over Modbus RTU protocol to the stepper motor, that moves the plungers to tune the cavity. There is a possibility of switching to local mode, in which the motor driver can be controlled from the control system. Figure 7 shows the tuner regulation system diagram.

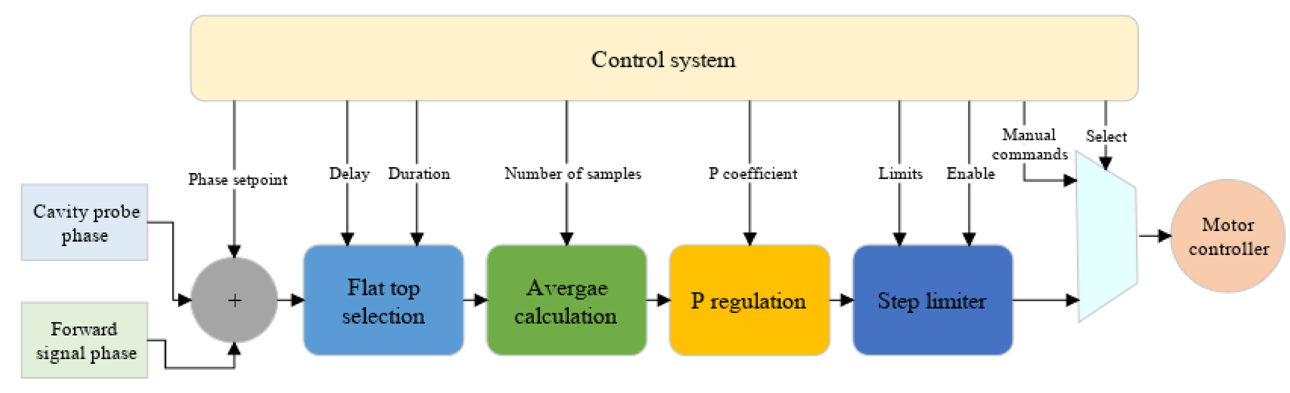


Fig.7: Bock diagram showing the tuner system.

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[4] NTG Neue Technologien GmbH & Co. KG - https://www.ntg.de/produkte/teilchen-beschleuniger/strahldiagnose/kapazitive-sonden/phasen-sonden/

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