

MODERNISATION OF THE 108 MHz RF SYSTEMS AT THE GSI UNILAC

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Abstract

A substantial modernisation of the RF systems at the 108 MHz Alvarez type post-stripper section of the GSI heavy ion linac UNILAC was launched in 2014 to prepare the existing facility for future FAIR operation. A new 1.8 MW RF cavity amplifier prototype for low duty-cycle operation (2 ms RF pulse length at 10 Hz repetition rate) based on the widely-used tetrode TH 558 SC was built by THALES. The procurement of a 150 kW solid state driver amplifier is in preparation. An RF test bench for the amplifier prototypes is built at GSI including new control racks, commercial grid power supplies, and a modern PLC system for amplifier control. The existing powerful 1 MVA anode power supplies will be re-used and are also equipped with new PLC systems. The development of a digital low-level RF system based on the MTCA.4 standard and commercial vector modulator and FPGA boards was started. Status and details of the modernisation as well as first commissioning results of the new high power amplifier prototype are reported.

INTRODUCTION

The 40 years old UNiversal Linear ACcelerator UNILAC at GSI and the synchrotron SIS18 will provide high current high brilliance heavy ion beams for the new Facility for Antiproton and Ion Research FAIR. To assure reliable operation as well as the required beam quality, a replacement of the existing Alvarez type post-stripper linac is planned [1] and a substantial modernisation of the corresponding 108 MHz RF systems was launched in 2014 [2, 3].

MODERNISATION OF THE EXISTING POST-STRIPPER RF SYSTEMS

In a first step, the existing Alvarez RF systems are modernised and modularised in a way that the old 1.6 MW high power amplifiers (HPA) and the 160 kW drivers can be replaced by new amplifiers later [2]. Separate control racks are being installed comprising modern PLC systems, new fast interlock and monitoring units, and commercial grid power supplies. These control racks will be used with the existing amplifiers first and with new ones later. For the time being, the HPA stage of the Alvarez tank 3 (A3) was modernised in that way as a prototype. A PLC test system based on Siemens S7-1500 was built and programmed including a human machine interface [4]. The system handles monitoring and interlocks of all cooling circuits and power supplies including turn-on and turn-off sequences of the supply voltages, system access interlocks, control of the motorized tuning circuits of the HPA, basic switch-on and switch-off commands of the driver amplifier and LLRF, etc. The CPU,

HMI, and the major part of the PLC system will be installed in the control rack, whereas a subunit will be located in a separate crate in the HPA comprising the I/O modules for all signals provided there. The subunit and the complete PLC system are designed for use with both amplifiers – the existing HPA as well as the new 1.8 MW Thales amplifier. Integration and full tests of the new PLC system in the rebuilt A3 HPA is planned until the end of this year.

The powerful 1 MVA, 24 kV anode power supplies will be re-used in future. The old relay based local control of the A3 supply was substituted by a second Siemens S7-1500 PLC system [3]. First tests of the complete A3 system comprising the upgraded anode power supply and the rebuilt HPA stage (using a manual test control unit instead of the HPA PLC) were successfully performed. The same modernisation is planned for the remaining four Alvarez RF systems within 2016 – 2017.

For long-term substitution of the old driver amplifiers, the procurement of a 150 kW solid state RF amplifier prototype is in preparation.

NEW 1.8 MW AMPLIFIER PROTOTYPE

A new 1.8 MW cavity amplifier prototype for short pulse operation (2 ms pulse length at 10 Hz repetition rate) based on the widely-used tetrode TH 558 SC was developed and built by Thales [5] (Fig. 1) and was delivered to GSI recently.



Figure 1: New 1.8 MW cavity amplifier prototype after factory acceptance tests at THALES.

A 3D drawing of the cavity amplifier as well as a short description can be found in Ref. [2]. The amplifier is built in grounded cathode configuration. All RF parts of the cavity are silver plated. The three main tuning circuits (input matching, input and output tuning) are equipped with DC motors for tuning during operation. A 3-1/8 inch coaxial transmission line is used for the input RF signal whereas a 6-1/8 inch coaxial line is applied at the output.

The cavity amplifier circuits are installed in a steel support structure and housed in a closed cabinet (Fig. 1). The cabinet comprises also the RF filters for the tube supply voltages as well as air and water cooling installations including flow meters and valves for filling and draining of the cooling water. At GSI, the cooling media will be provided by the existing central forced-air and deionised water cooling systems serving all amplifiers and power supplies at the UNILAC RF gallery.

An additional smaller cabinet is connected directly to the main amplifier cabinet (Fig. 1, left part), providing a service platform, a grounding box for the tube supply voltages, and a 19 inch chassis accessible from the front. The service platform facilitates tube exchange and easy access to the HV box on top of the amplifier covering the power tube, the anode decoupling capacitor, and the waveguides for higher order mode (HOM) damping.

The 19 inch chassis comprises a commercial water-cooled switch-mode DC power supply for the tube filament (25 V, 600 A), 24 V power supplies for the tuning circuit motorisation and for local control components, circuit breakers, terminal blocks for signal distribution, and space for a local control unit. For test operation, a manual control unit developed by GSI is used which controls all interlocks (safety contacts, cooling media) and the motorised tuners. For routine operation the manual control unit will be replaced by the PLC subunit described in the previous section.

During factory tests, the amplifier was operated with continuously supplied anode and grid voltages. RF pulses were created by shaping the low-level input RF signal to the driver amplifiers. Parasitic oscillations which occurred around 900 MHz could be damped successfully by placing ECCOSORB MF-124 bars at the bottom of the output circuit of the cavity [5].

Special tests were performed to ensure good suppression of parasitic oscillations during pulsed operation [5]. These tests were done without RF input signal, i.e. the amplifier RF input as well as the output were terminated with 50 Ω . Normal operating voltages were applied to the anode (24 kV) and to the screen grid (1.5 kV). The control grid voltage was switched from zero anode current (at -600 V G1 voltage) to high anode current levels at short-pulse operation ($\leq 500 \mu\text{s}$ pulse length). Initially, HOM around 1.96 GHz were excited by these DC pulses. After installation of additional ECCOSORB pieces in the output cavity and reduction of the filament voltage from 23 V to 21 V, these oscillations could be suppressed successfully and DC anode pulse currents up to 78 A corresponding to an anode dissipation power of 1870 kW during pulses were achieved without any disturbances.

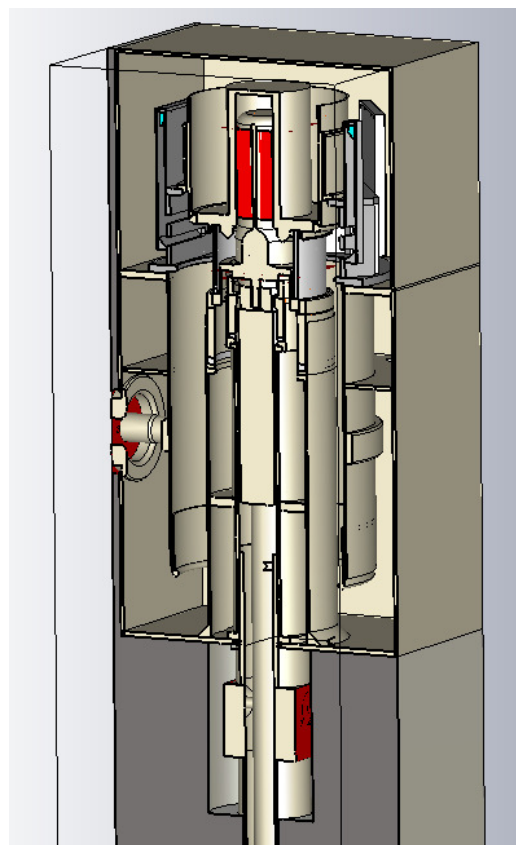


Figure 2: CST Microwave Studio model of the Thales 1.8 MW cavity amplifier [6].

Finally, the specified 1.8 MW RF peak output power was reached on dummy load at the factory with 92 kW RF input power (13 dB gain). Harmonics levels up to $h=6$ were measured at the output line at ≤ -41 dBc. A 3×8 hour test run at full RF output power was completed successfully without any trip.

At GSI, integration of the new amplifier into the existing equipment (anode power supply, driver amplifier, RF transmission lines, etc.) is in progress, as well as control racks similar to those built for the A3 amplifier. A coaxial transmission line switch will be used to switch between a water dummy load and the Alvarez tank 4 of the UNILAC. Commissioning and tests at GSI are planned from Q4/2016 on. Finally, routine operation of the new amplifier on Alvarez tank 4 is planned during regular beam time from 2018 on.

Microwave Studio Simulations

Eigenmode and electromagnetic field simulations of the complete amplifier cavity system were performed at GSI using CST Microwave Studio, in particular, to investigate HOM effects [6]. A detailed model of the amplifier was created (Fig. 2). The model was parameterised for all built-in tuning elements, allowing for range sweeps during simulation. For the electron tube, a conductive material was added to emulate the anode current flow. By comparing simulations with and without HOM absorbers it could be shown that major HOM are efficiently suppressed by the five built-in waveguide HOM dampers.

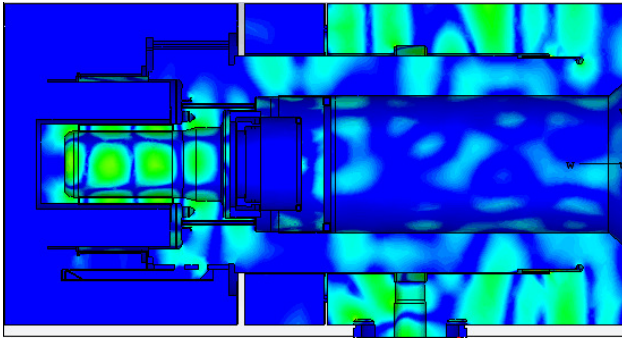


Figure 3: Electric field pattern for an eigenmode at 1.96 GHz as simulated with CST Microwave Studio.

Simulation of modes around 1.96 GHz as observed during the factory tests confirmed that these modes are very probably excited internally in the tube (Fig. 3).

D-LLRF SYSTEM DEVELOPMENT

A digital low-level RF (d-LLRF) system for the control of the field amplitude and phase in the accelerating cavities, RF pulse shaping, and a fast interlock mechanism is being developed. Special challenges at the UNILAC are the huge dynamic amplitude range corresponding to ion mass-to-charge ratios between 1.0 for protons and 8.5 for U28+, non-linear RF amplifier characteristics, and beam loading. For an U28+ ion beam with a beam current of 15 mA the beam loading is about 300 kW compared to ≤ 1100 kW for cavity losses in each Alvarez tank.

Former tests of a commercially available system [2] revealed the need to develop a precise, flexible system with state-of-the-art technology. MTCA.4 is an open hardware standard originating from the telecom market. The development of a MTCA.4 based LLRF system for XFEL by DESY offers synergy effects and long-term availability of components. A new test system was setup at GSI [7] (Fig. 4) comprising primarily the SIS8300-L2 digitizer (10 x 16 bit, 125 MS/s ADC, 2 x 16 bit, 250 MS/s DAC, Xilinx Virtex 6 FPGA) and the DS8VM1 vector modulator board.

The design of the new d-LLRF system (Fig. 5) includes

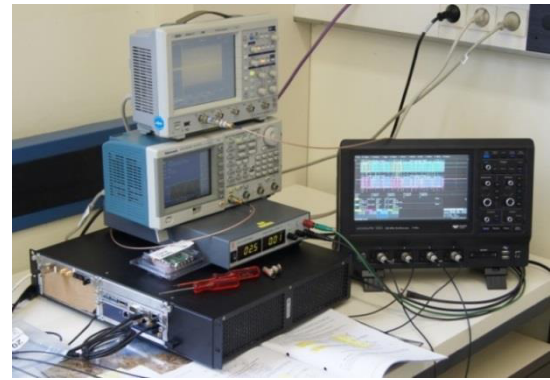


Figure 4: MTCA.4 d-LLRF test system.

direct undersampling of the 108.4 MHz cavity probe signal with a sampling rate of 86.7 MS/s, digital down conversion to base band and translation to amplitude and phase by CORDIC algorithm. The control loops include separate PI feedback and feed forward (FF) controls for amplitude and phase. Simulations showed good results in reducing the impact of beam loading by applying an adaptive feed forward. Additionally a beam current based feed forward is envisaged. A look-up table (LUT) for the amplifier characteristic is implemented. The control signals are transformed to I and Q base band via CORDIC and converted to two analog signals for the vector modulator (VM) generating the RF input signal for the amplifier chain.

As next steps first RF tests with a test cavity and a frequency mixer for beam loading emulation are planned. The integration of the new d-LLRF system will be possible as 1:1 exchange of the existing systems due to the use of an interface adapter board. In the long-run the use of the FAIR standards FESA and White Rabbit are considered.

ACKNOWLEDGEMENT

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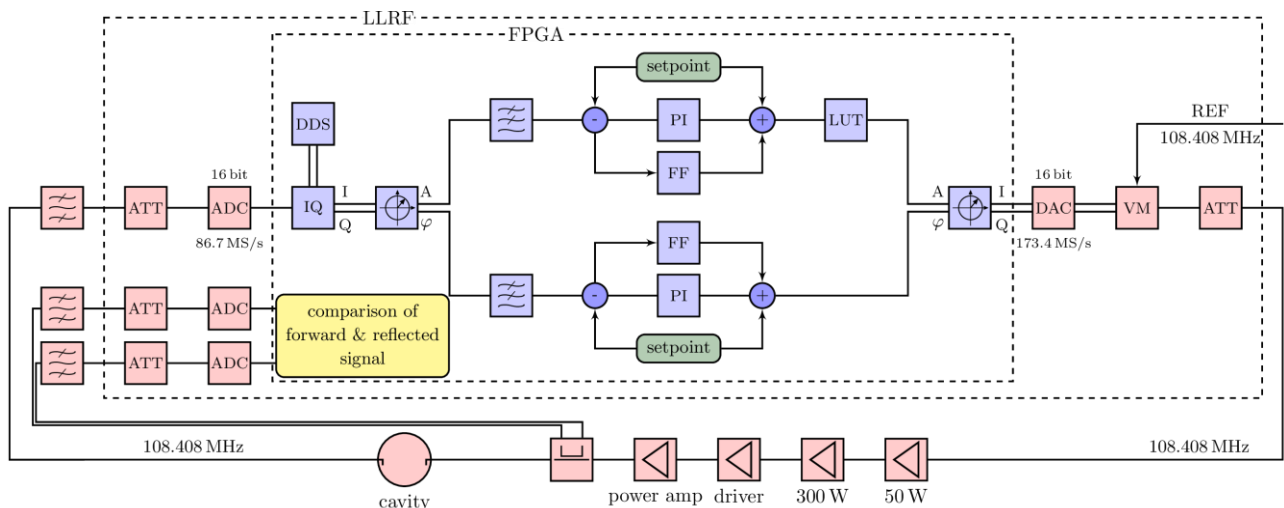


Figure 5: Block diagram of the new d-LLRF prototype (see text).

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