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Control system for ion Penning traps at the AEgIS experiment at CERN

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Abstract. The AEgIS experiment located at the Antiproton Decelerator at CERN aims to measure the gravitational fall of a cold antihydrogen pulsed beam. The precise observation of the antiatoms in the Earth gravitational field requires a controlled production and manipulation of antihydrogen. The neutral antimatter is obtained via a charge exchange reaction between a cold plasma of antiprotons from ELENA decelerator and a pulse of Rydberg positronium atoms. The current custom electronics designed to operate the 5 and 1 T Penning traps are going to be replaced by a control system based on the ARTIQ & Sinara open hardware and software ecosystem. This solution is present in many atomic, molecular and optical physics experiments and devices such as quantum computers. We report the status of the implementation as well as the main features of the new control system.

1. Introduction

The primary scientific goal of the Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy (AEgIS) [1], located at the antimatter accelerator (AD) facility at CERN in Geneva, is to test the Weak Equivalence Principle with antihydrogen atoms by the direct measurement of the Earth's gravitational acceleration, g, on antihydrogen. The pulsed source is generated by the charge-exchange reaction between Rydberg positronium atoms and antiprotons, trapped, cooled and manipulated in electromagnetic traps. This reaction is described by the equation:

$$\bar{p} + Ps^{*} \rightarrow \bar{H}^{*} + e^{-}$$

The visualization of experimental setup is shown in figure 1 [2].

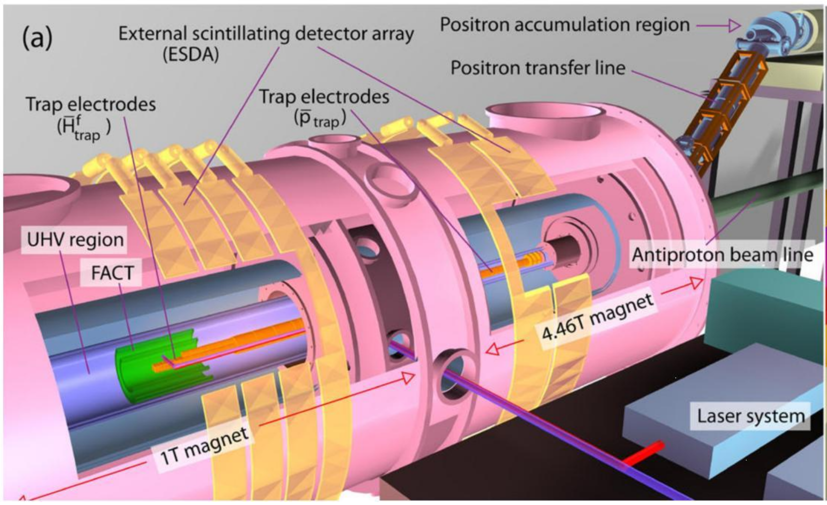

Figure 1: Sketch of the AEgIS apparatus.

Two Penning traps are used in the experiment. The first one with 5 T magnet is a unique trap to hold the antiprotons and the positrons. In the 1 T trap region antihydrogen atoms are formed and accelerated towards the gravity module [3]. The pulsed production scheme can also be used for other physics topics as symmetry tests using positronium or experiments with antiprotonic atoms.

2. ARTIQ & Sinara

Sinara is an open-source hardware ecosystem designed by physicists for use in quantum science laboratories largely focused on work with trapped atomic ion qubits [4]. It offers modular, well tested, based on FPGA technology solutions for AMO experiments with sub-ns time resolution. It aims to meet lab-specific requirements maintain the high quality of architectural design, reproducibility and support. Sinara uses two main form factors for hardware requiring real-time control: microTCA (uTCA) and Eurocard Extension Modules (EEM). The example of Sinara setup in adapter create is shown in figure 2.

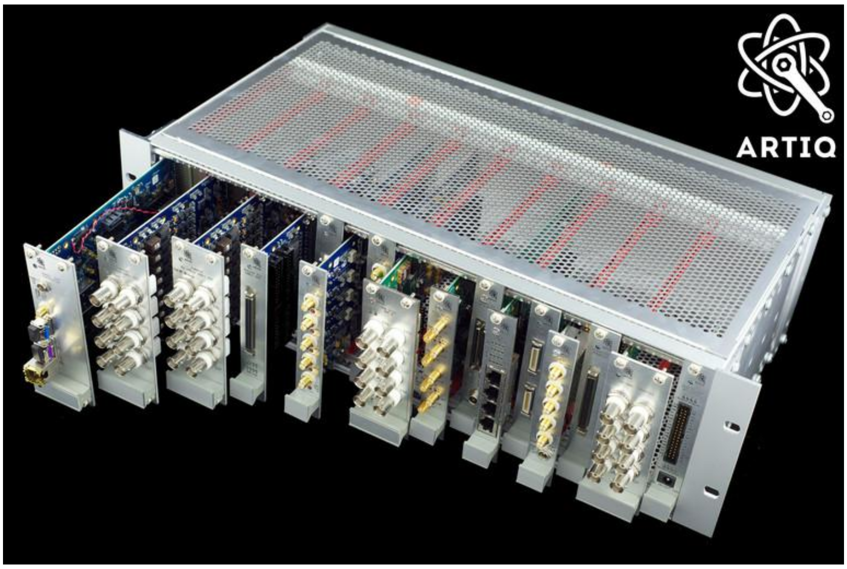

Figure 2: The modules of Sinara & ARTIQ ecosystem

Sinara is designed to work closely with the ARTIQ control software (Advanced Real-Time Infrastructure for Quantum physics). ARTIQ features a high-level, Python-based programming language that allows describing the entire experiment environment. It is compiled and executed on FPGA hardware. It provides deterministic nanosecond timing resolution and sub-microsecond latency while maintaining ease of use and clear code appearance. The Sinara & ARTIQ system allows one to operate and control the entire data acquisition and electronics system.

3. AEgIS Trap Control System

The current custom electronics designed to operate the antiproton catching and antihydrogen production traps of the AEgIS apparatus are going to be replaced by a control system based on the Sinara and ARTIQ ecosystem. Due to the new functionalities brought by it, the new system is more scalable, maintainable and gives the possibility to have an abstract and object□oriented approach to trap control. Our aim is to design an automated system capable of running long-time experiments with effective error handling. The optimal values of potential on the electrodes will be found automatically with self-maximizing methods. The orders of magnitude for the temporal precision on the triggering command we managed to obtain are presented in Table 1.

Table 1: Obtained timing orders

	Timing (order)
Triggering DAC	ms
Trigger response	µs
Triggering synchronicity	ns

4. New Amplifier

To meet the requirements of the antihydrogen production trap's control, a dedicated 8-channel high voltage amplifier, shown in figure 3, was designed [5]. It is created as a part of the Sinara hardware family and has its modular EEM card form. It provides output range +/-200 V, 1 MHz bandwidth and 50 output impedance, able to drive a few meters of cable. This amplifier has quick output disconnect controlled via EEM using OptoMos to limit the noise, over temperature protection and high voltage

HV capacitors rapid discharge circuit. Complete project documentation, including the source schematics, PCB layout, as well as production files is available in the Github repository[6].

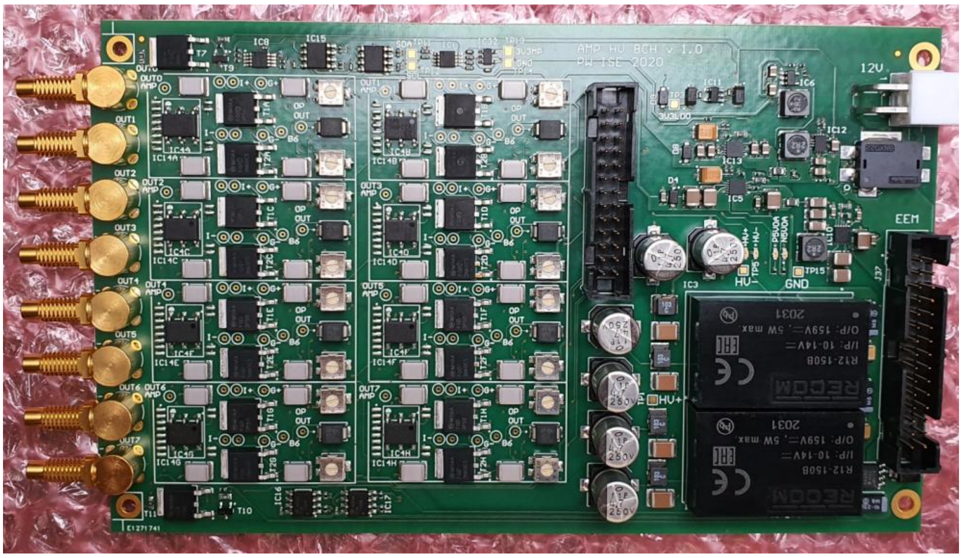

Figure 3: The high-voltage amplifier dedicated to control antihydrogen production trap.

5. Conclusion

A high-precision control system with millisecond triggering DAC timing and nanosecond order synchronicity timing to catch antiprotons, positrons and form antihydrogen atoms and manipulate them is under design. It will enable the automatic running of the experiment around the clock through a well documented, maintainable system, which can also be conveniently used in future experiments.

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