A novel control system architecture for quantum computing

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Abstract

Sinara is an open-source, open-hardware control system specifically created for quantum applications that is currently operational in numerous global laboratories. Its design is based on ribbon cable connections linking a controller with peripheral modules. This seemingly uncomplicated and economical method, however, has raised concerns about system reliability, thermal management, and effective monitoring. As quantum technologies evolve beyond their exclusively experimental phase, it becomes imperative for control systems to offer a higher level of dependability in their hardware platforms. In this poster, we introduce an innovative system architecture named DI/OT, based on the Compact PCI-Serial standard, a product of collaborative development with CERN. Our objective with this new architecture is to facilitate smoother system maintenance, enhance reliability, and broaden its applicability beyond quantum physics applications.

ARTIQ

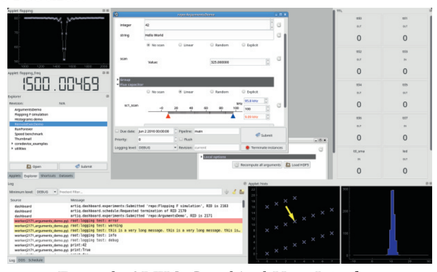
Advanced Real Time Infrastructure for Quantum physics (ARTIQ) is an integrated software/gateware system designed for control of atomic physics experiments.

```
start = now_mu()                # capture current time
for i in range(4):              # for all DDS channels...
  delay(5*us)                   # ...with 5 ns delay...
  dds[i].set_frequency(350*MHz) # ...set frequency to 350 MHz.
  dds[i].pulse(2*us)            # ...emit 2 us long RF pulse
offset_mu = \
  self.core.time_to_mu(3*ms)    # convert 3 ms to machine unit
at_mu(start + offset_mu)        # 3 ms after start...
dac.set_dac(5, 4.5)             # ...set DAC channel 5 to 4.5
```

Example ARTIQ DSL code

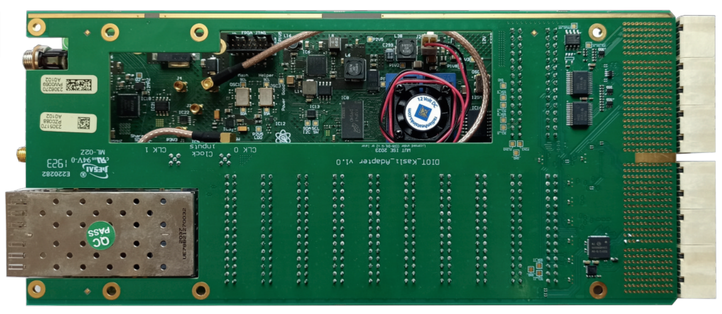
Most important features of ARTIQ

- Precise timing control with 1 ns timing resolution.
- Support for Sinara modules.
- Uses Python-based Domain Specific Language for easy experiment description.
- Flexibility - one can build a system comprised of any combination of modules.
- Synchronized, scalable control over many controllers using multi-gigabit transceivers (between crates) and over LVDS lines (in-crate connections).
- Easily integrates with other devices such as laser controllers and opto mechanical devices.
- GUI, scheduler and native database support for archiving experiment results.



Example ARTIQ Graphical User Interface

A



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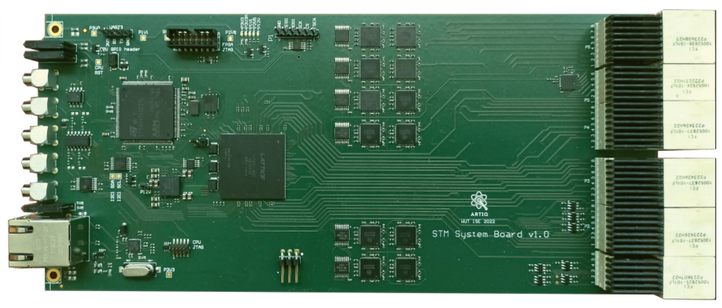

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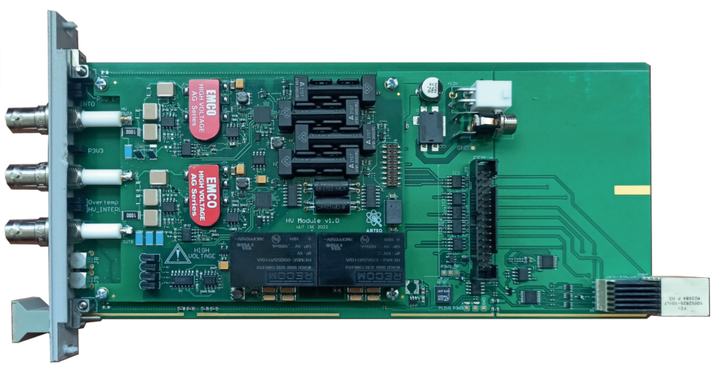

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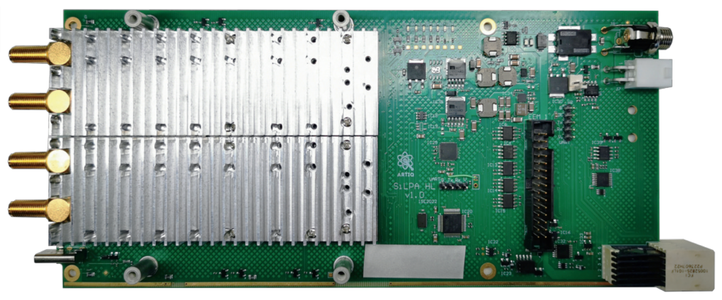


Collaboration with CERN kick starts the project with a manufacturing scale already reached by EEM. By basing future Sinara modules on DI/OT we gain an opportunity to benefit from continued support of the standard by CERN, including **standardization of crate format [F,G]**, management interface, power supplies and thermal management. Adoption of DI/OT will allow us to expand the ecosystem with existing DI/OT modules, including System Board Controller with Zynq Ultrascale+ MPSoC and FMC HPC Carrier with Kintex Ultrascale FPGA.
DI/OT also can extend Sinara modules with additional specialized connectivity such as multi-gigabit signals. Each module connects to a backplane, which enables quick reconfiguration of the system and improves power distribution increasing power limit per module.

We envision the process of adapting Sinara to the DI/OT standard to start with using adapters. They allow use of **existing modules [I, 9 out of 50+ modules]** with a new standard at minimum development cost, as well as use of already manufactured devices. **DI/OT Kasli Adapter [A]** offers support for up to 8 modules (6 in full connector mode), management and debugging (JTAG) interfaces as well as clock distribution. **DI/OT EEM Adapter [H]** allows use of Sinara EEM module with up to 2 EEM connectors by exposing communication, clock and management interfaces. New modules are designed with Sinara EEM system backward compatibility as well as native support for DI/OT.

During the transition phase, DI/OT native versions of EEM modules and Kasli/Kasli SoC controllers will be developed. There also is a project of porting ARTIQ control system to Zynq Ultrascale+ SoC, which will allow to use DI/OT System Board as the crate controller in Sinara.

EEM FMC Carrier [D] is a FMC controller equipped with Artix 7 FPGA with 256MB DDR3 memory (same as Kasli). Thanks to the newly implemented DRTIO over EEM, the EFC board can be used as an ARTIQ satellite subsystem. Supports full HPC FMC with 4 MGT links and can use both external and internal clock source (front panel SMA connector).

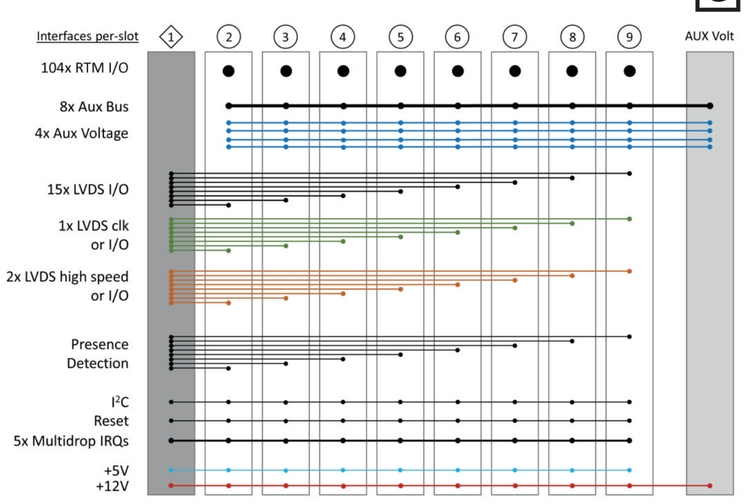
HVSUP_ISOL [C] is a high voltage floating supply dedicated to Gas Electron Multiplier detectors and blade ion traps. It has two channels with every POS and NEG configurations possible. Both channels have a common terminal for easy cascading. Output range is ±100 V / 15 mA up to ±6 kV / 0.25 mA per channel depending on the assembly. It has interlock input and interlock output for external control, triggering and forced sequencing. Currently, software is developed to control HVSUP_ISOL with ARTIQ or with MQTT via new STM System Board.

SiLPA [E] is a Simple Low distortion Power Amplifier. It was designed as a simpler version of a Booster device that can be used inside a common crate with other peripherals. It consists of two channels with RF gain of 40 dB and bandwidth of 800 MHz. The board can be controlled by Kasli with ARTIQ, STM Sys Board and MQTT protocol or run as a standalone device with its own firmware thanks to the possibility of mounting optional STM32 chip.

STM System Board [B] is a new low cost DI/OT controller for non-realtime tasks. It uses STM32 microcontroller and ECP5 FPGA for computing and controlling up to 8 peripheral boards.

F

G



H

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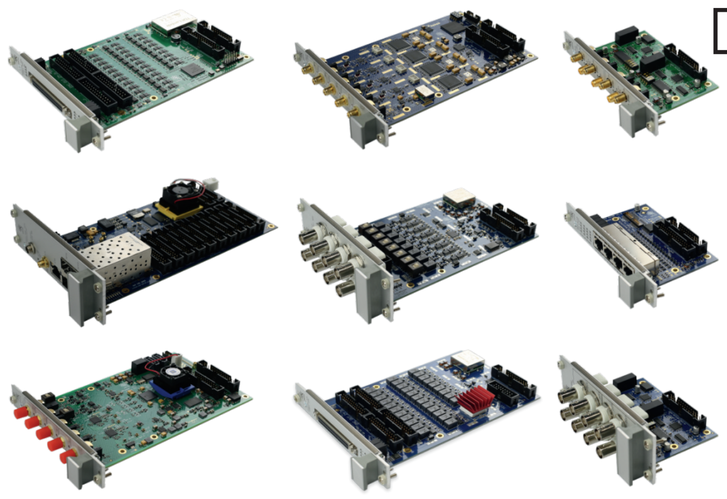

More on Sinara

Purchasing Guide

More on DI/OT

Open source

Both ARTIQ and Sinara are open source and are open for contribution and suggestions.

How do I find out more about the hardware?

Visit sinara hw.github.io

Why open source?

- Gives ability to review and learn from the design.
- It is easier to repair and customize the design.
- It ensures continued availability, irrespective of potential changes in the production landscape.

Where do I obtain hardware?

Sinara modules are commercially available, see purchasing guide (QR).

Can I contribute?

- Yes! Use production boards, submit bug reports, and make suggestions based on your lab experience.
- Much of the documentation is user contributed.
- Fund new gateware/software development to add new features and help bring prototype boards to production.

I have a use case not covered by current or planned hardware.

Open a new issue at: **github.com/sinara-hw/meta** and we'll work with you!

Acknowledgments

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