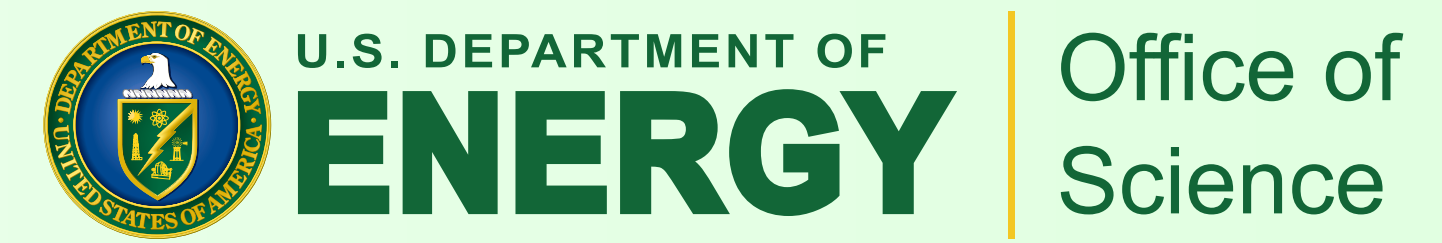


Obsidian: a compact platform for scalable and intelligent acoustic-band active stabilization control

Qiang Du, Larry Doolittle, Michal Gaska, Michael Betz, Alessio Amodio, Stijn Wielandt, Shreeharshini Murthy, Lucas Russo, Vamsi Vytla, Tong Zhou, Alessandro Ratti

Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

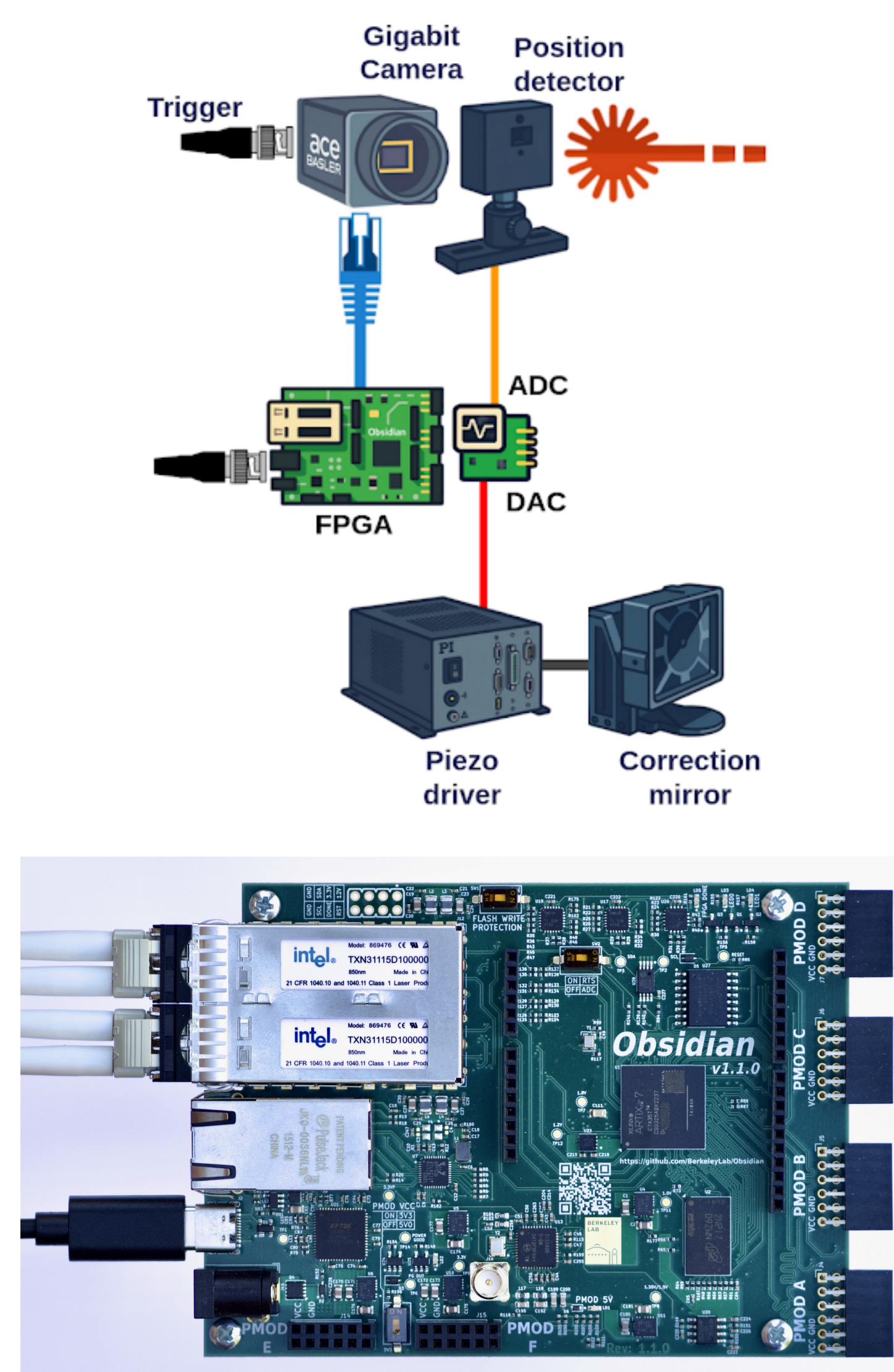


Abstract

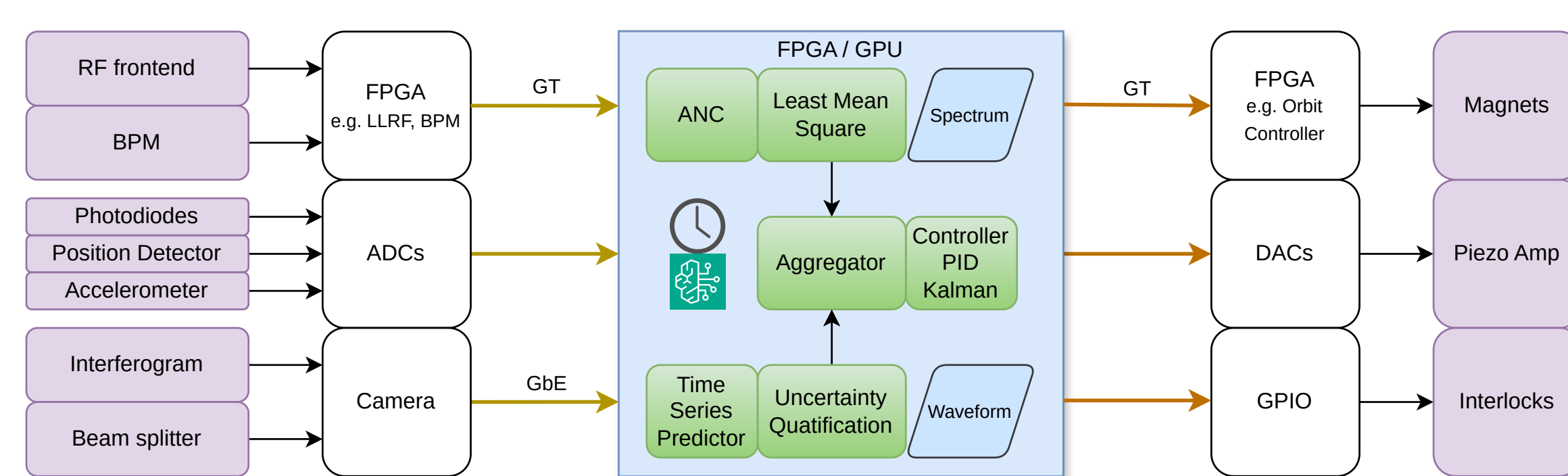
Optimal beam parameters in high-power lasers and accelerators require active stabilization against environmental perturbations. Typically residing in the acoustic frequency band, these perturbations are corrected via piezo actuators or magnets. Common applications include coherent laser combining, laser pointing stabilization, resonance control in superconducting radio-frequency (SRF) cavities, and beam orbit regulation in storage rings. Recent experimental demonstrations of machine-learning-based stabilization in laser pointing and coherent laser combining have validated the concept of AI-enhanced active noise control. We present the Obsidian board, a general-purpose, open-source hardware platform and FPGA carrier designed for real-time control implementation. Supporting both Micro-Research Finland (MRF) timing and White Rabbit protocols, the Obsidian board interfaces with Low-Level Radio Frequency (LLRF) controllers or Beam Position Monitors (BPMs) through dedicated timing and Gigabit transceiver links. It executes hard real-time control algorithms while bridging MHz-to-kHz sampling rates for acoustic-band I/O. Key application demonstrations include MRF Event Generator (EVG) / Event Receiver (EVR) timing nodes, synchronous Machine Vision via a GeniCam camera interface, and laser pointing and coherence stabilization via FPGA-based ML pattern recognition.

Machine Vision based Control

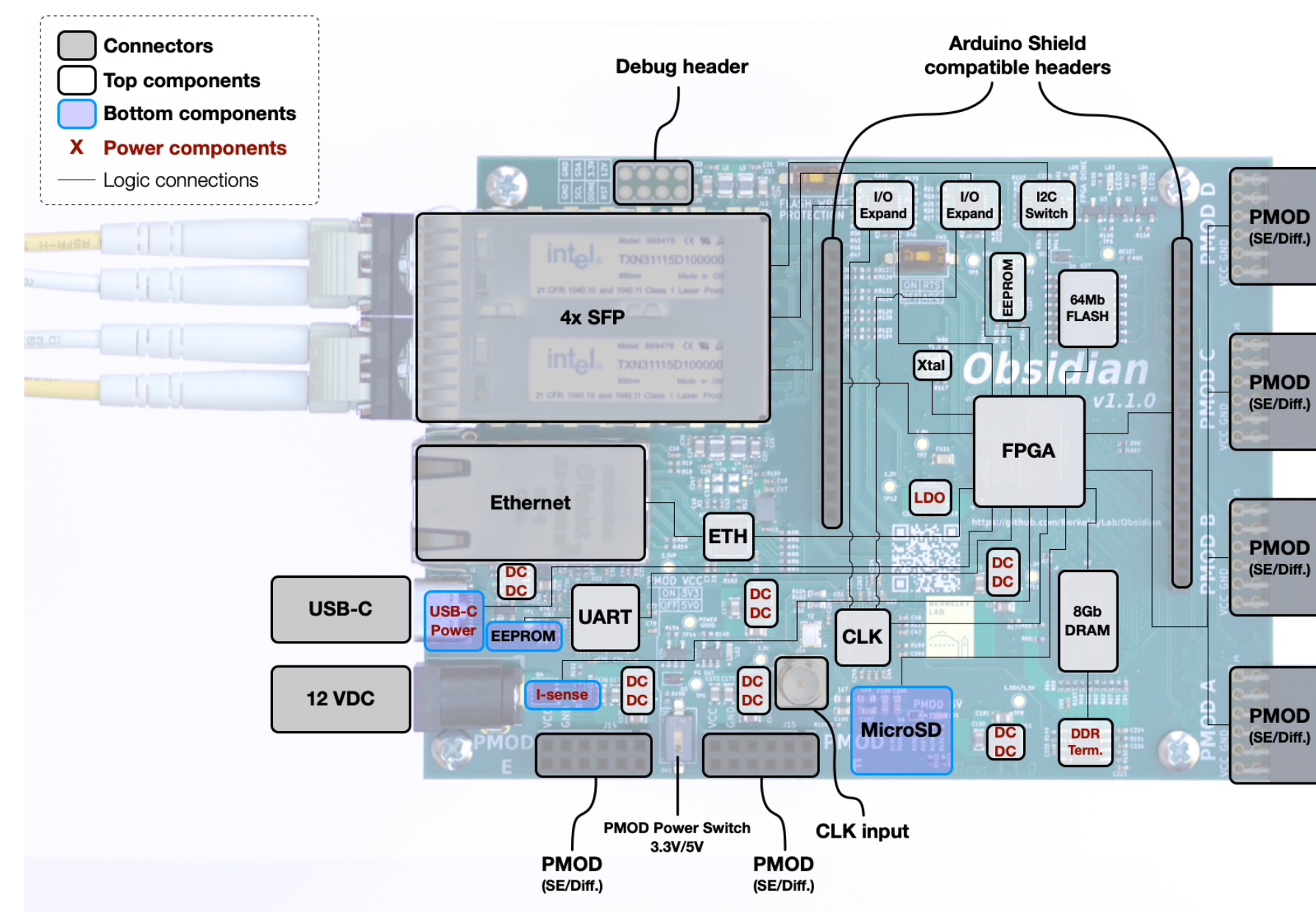
kFPS MV+ML Beam Stabilization



Architecture and Interfaces



Obsidian bridges sensors and actuators with real-time, synchronous AI based control

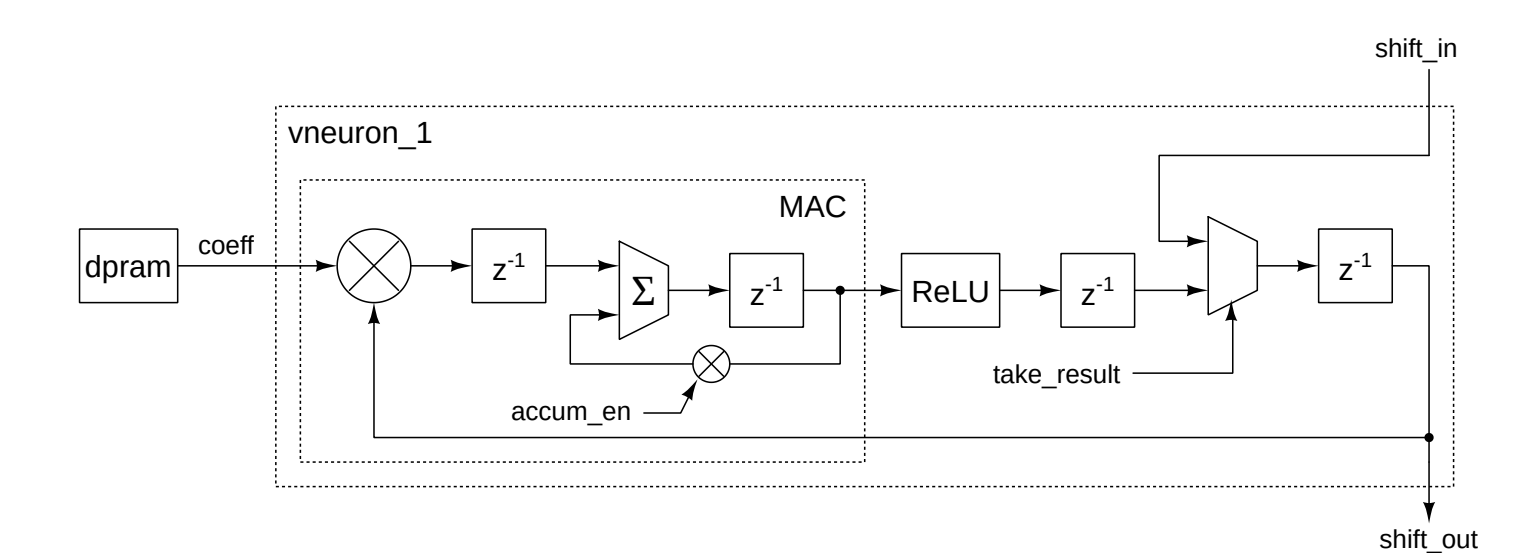


Example Use cases:

- MRF EVG
- MRF EVR
- LLRF companion FPGA
- LLRF Resonance controller

Multi-Layer Perceptron on FPGA

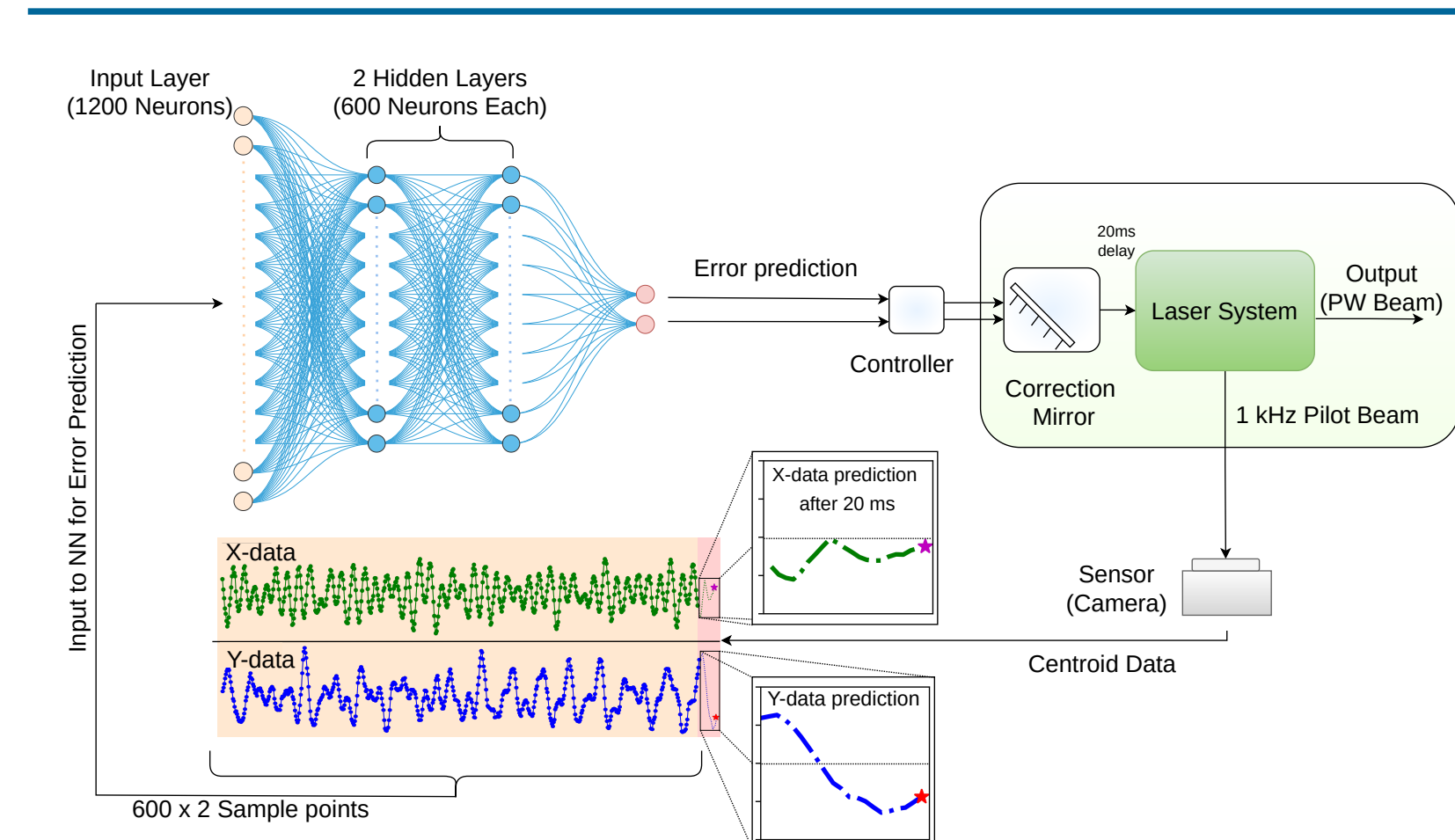
Vneuron: hand-crafted, synthesizable Verilog RTL of a ReLU MLP (132 lines), not machine-generated, built from cascable layers (below).



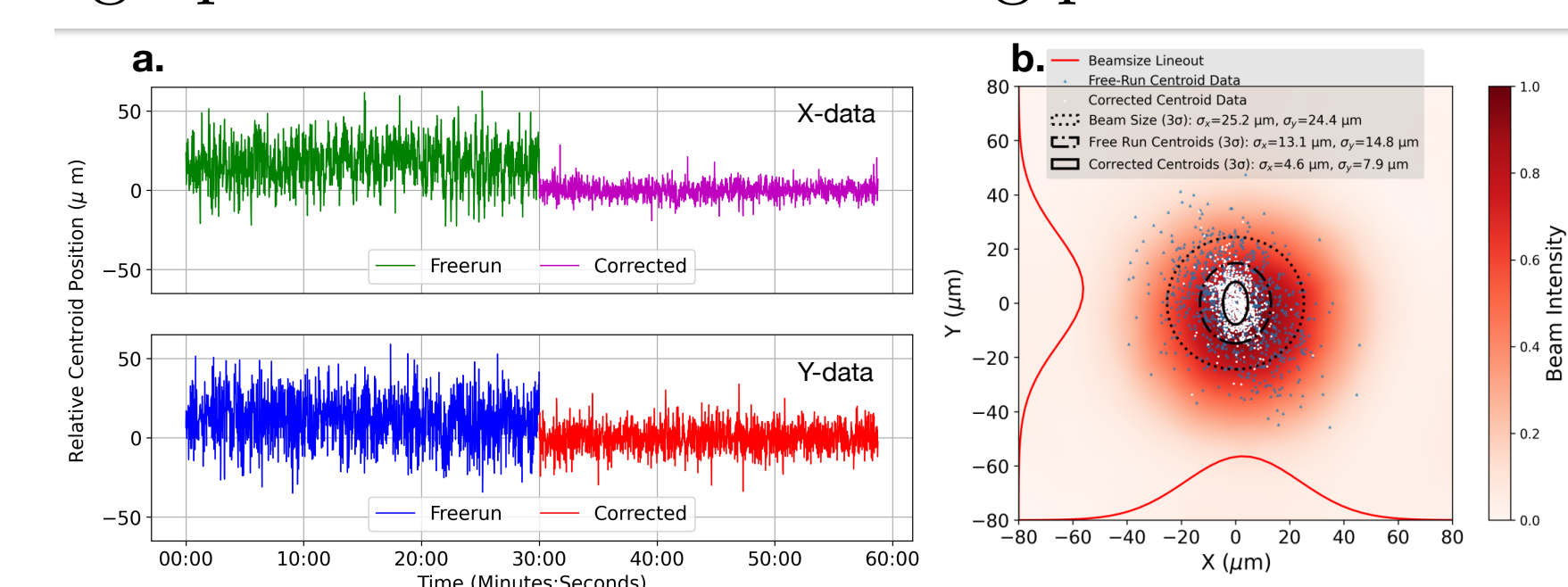
- 3 layers, 16 in, 8 out, 1600 parameters, 18-bit: 131 cycles (1048 ns at 125 MHz)
- 40 neuron blocks use ~16 % of an Artix-7 XC7A100T
- Weights updated at run time without resynthesis or interrupting the loop
- Portable to AMD, Intel and Lattice FPGAs, and to ASIC
- Pattern recognizer for coherent beam combining [Opt. Express 30, 12639 (2022)]

Applications: Intelligent & Real-time Controls for High Power Lasers & Accelerators

1 Hz PetaWatt Laser Pointing Stabilization

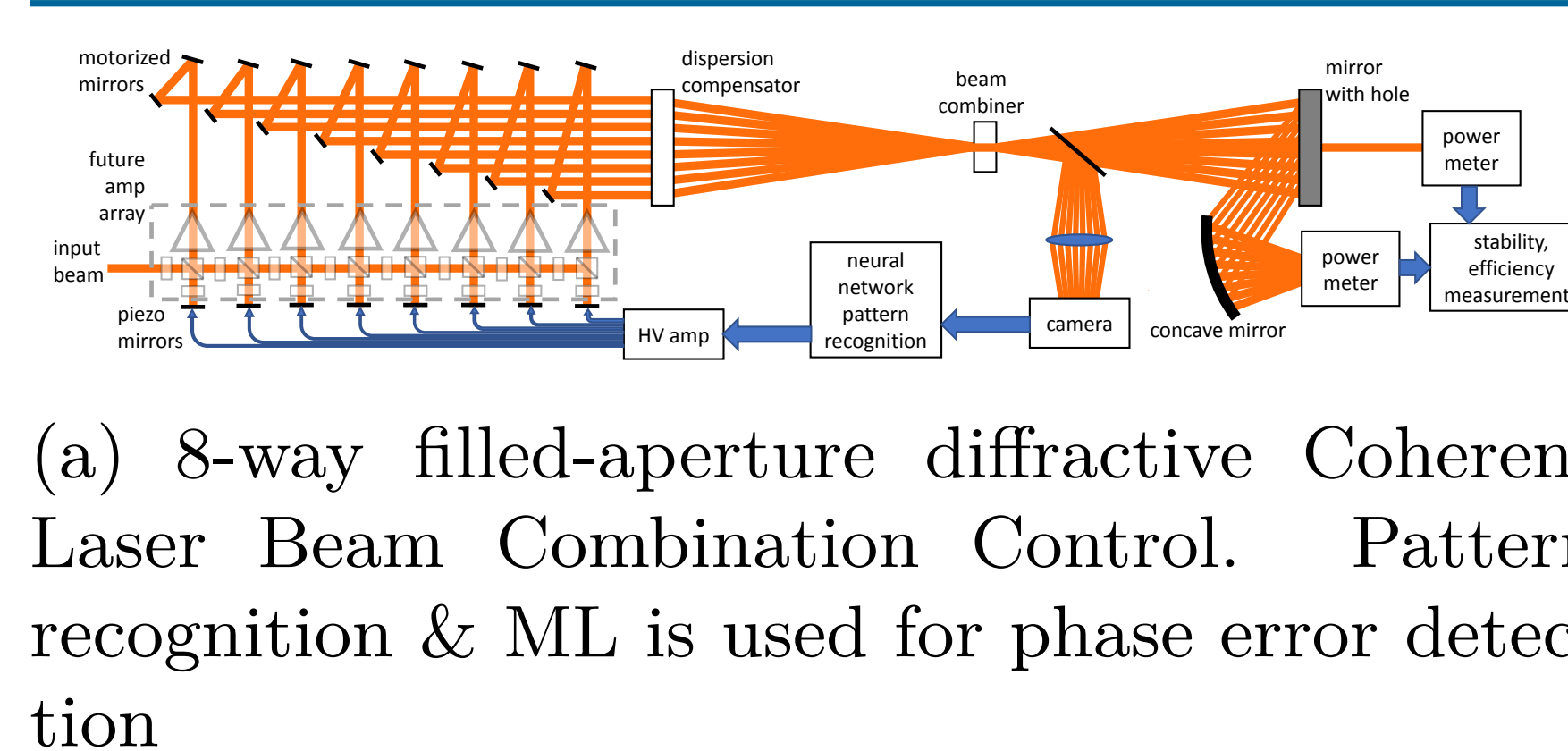


(a) ML time-series predicts correction before high power beam arrives using pilot beams

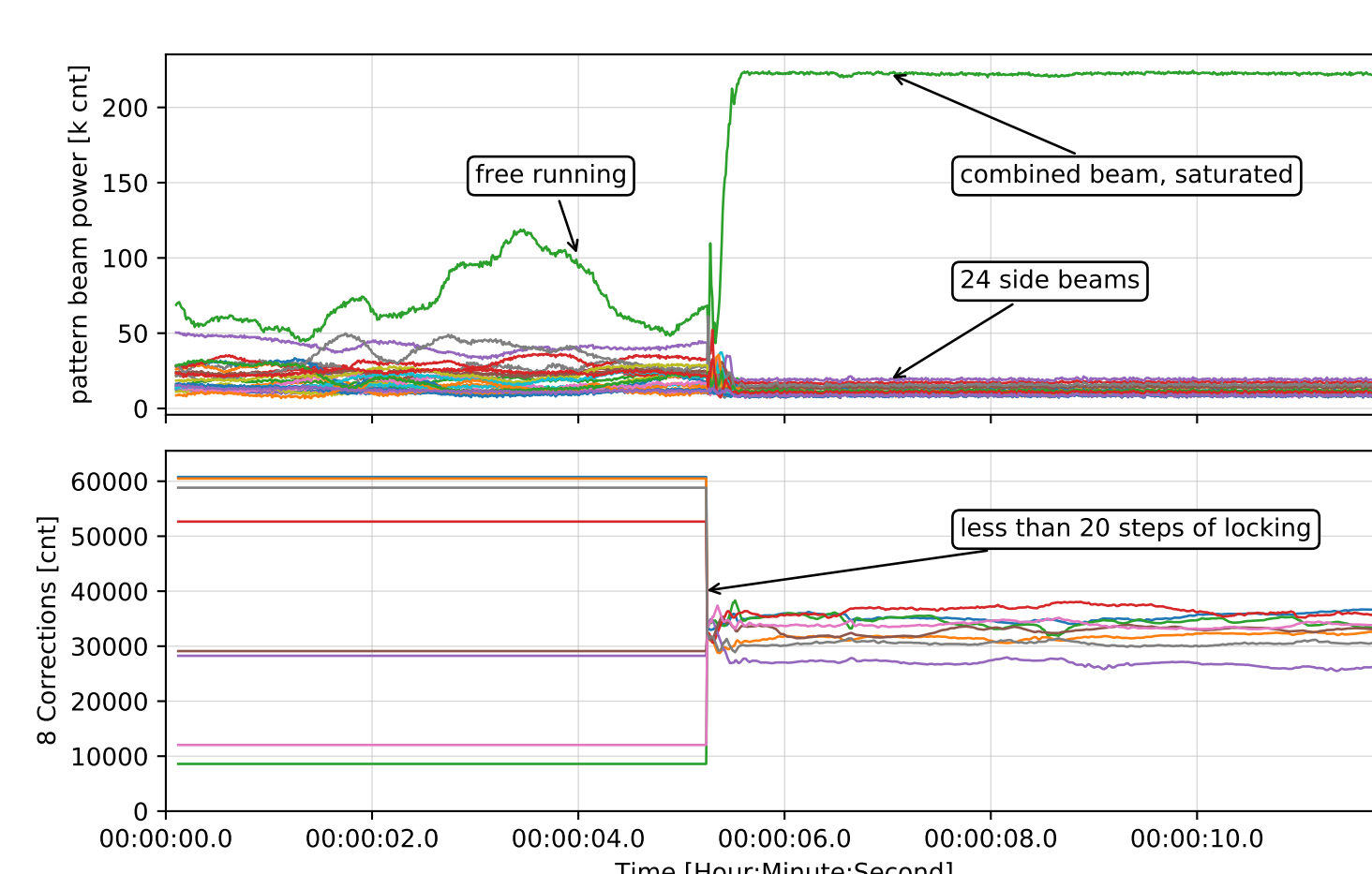


(b) beam pointing instabilities reduced by ~ 65 % in X and ~ 47% in Y

Coherent Beam Combination Control

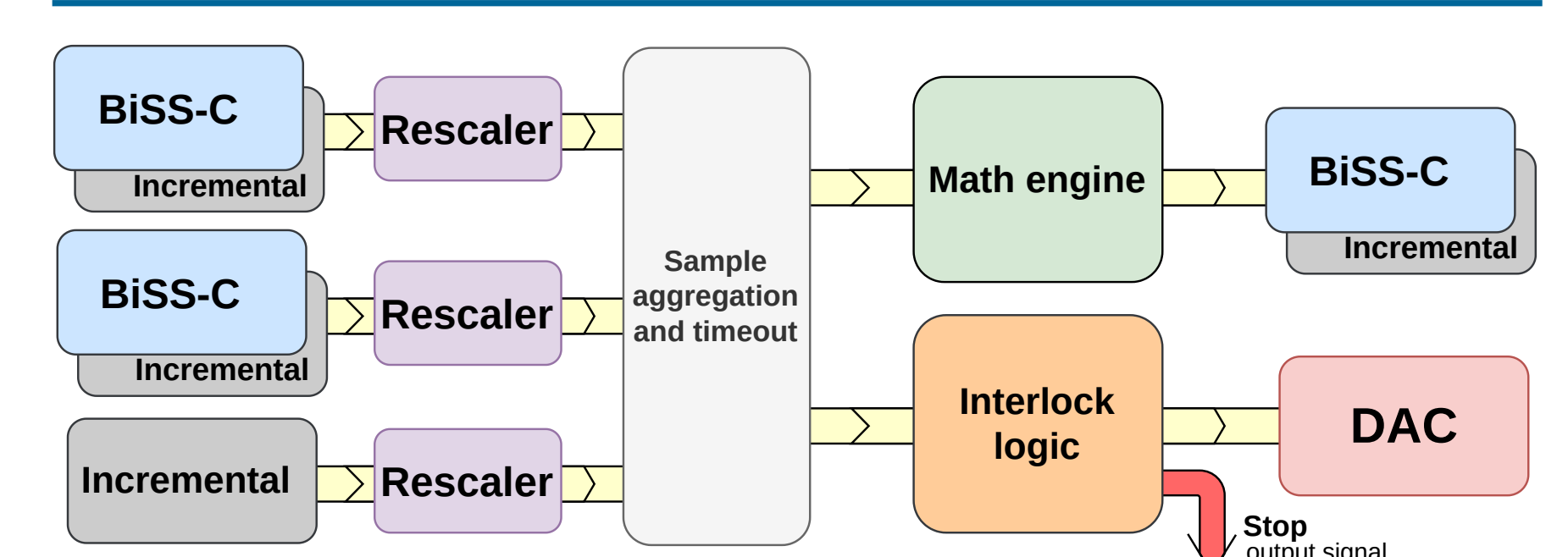


(a) 8-way filled-aperture diffractive Coherent Laser Beam Combination Control. Pattern recognition & ML is used for phase error detection

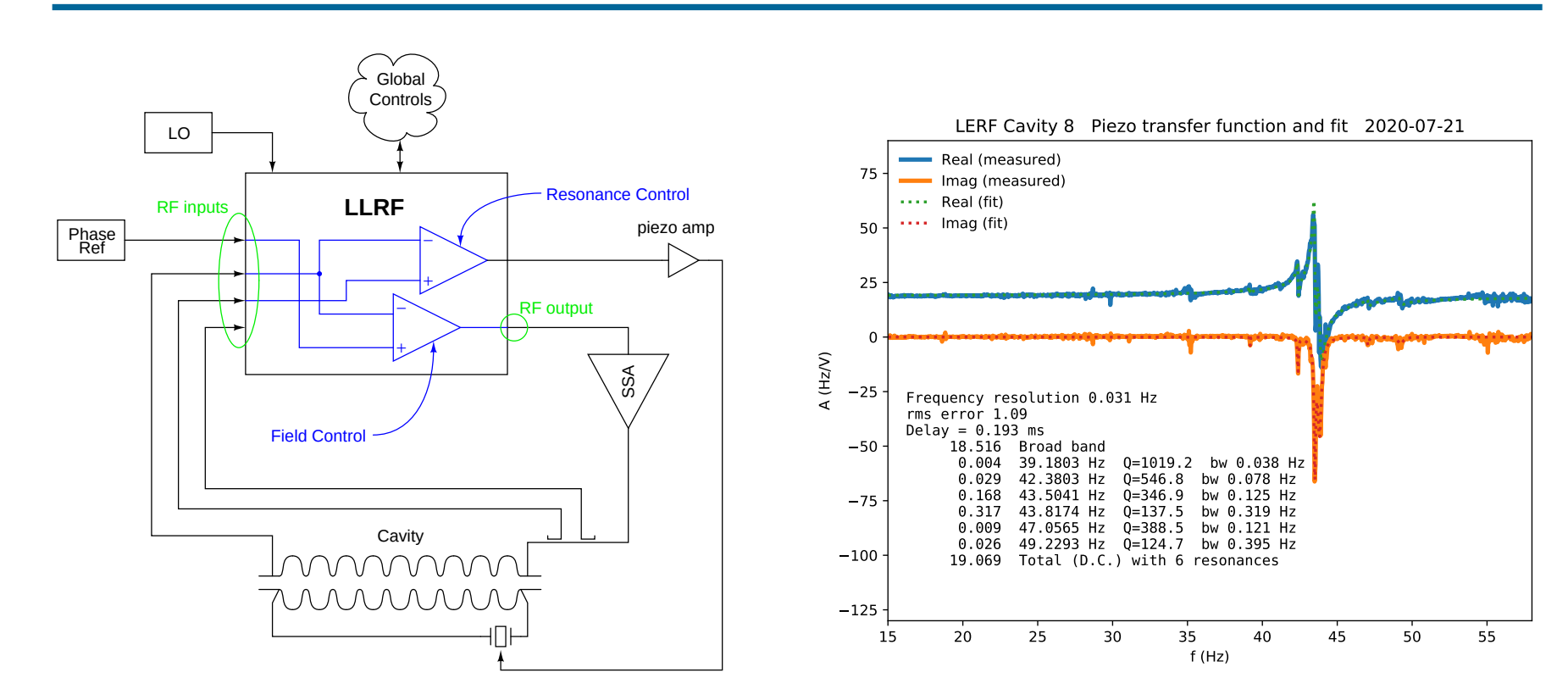


(b) MIMO feedback control achieved 0.4% RMS stability

Motion Control with Motor Encoder



LLRF Resonance Control



Acknowledgement: This work is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.