A Second Generation Digital Readout for Large Photon Counting UVOIR MKID Arrays

Neelay Fruitwala[1], Paschal Strader[3], Alex B. Walter[1], Nicholas Zobrist[1], Gustavo I. Cancelo[2], Ted J. Zmuda[2], Ken Treptow[2], Neal Wilcer[2], and Benjamin A. Mazin[1]

[1]Department of Physics, University of California at Santa Barbara, Santa Barbara, CA; [2]Fermi National Accelerator Laboratory, Batavia, IL; [3]Dominican School of Philosophy and Theology, Berkeley, CA

We present the development of a second generation digital readout system for photon counting MKID (Microwave Kinetic Inductance Detector) arrays, operating in the UVOIR (UV, optical, infrared) regime. A single complete set of readout electronics is capable of reading out 1024 pixels (with a target spacing of 2 MHz) in a 2 GHz band between 4 and 8 GHz. Ten such units are combined to read out our 10,000 pixel DARKNESS array; this setup, combined with a 80 TB storage server, can record every photon's arrival time, energy, and absorption location for over 10^7 photon/second. At a cost of roughly $7/pixel, this system could conceivably be scaled up to read out much larger arrays.

System Overview

CASPER ROACH 2:

- Hardware and toolflow developed by the Collaboration for Astronomy Signal Processing and Electronics Research at UC Berkeley
- Virtex 6 FPGA and PowerPC control CPU
- Implements channelization, optimal filtering, and triggering algorithms

ADC/DAC board

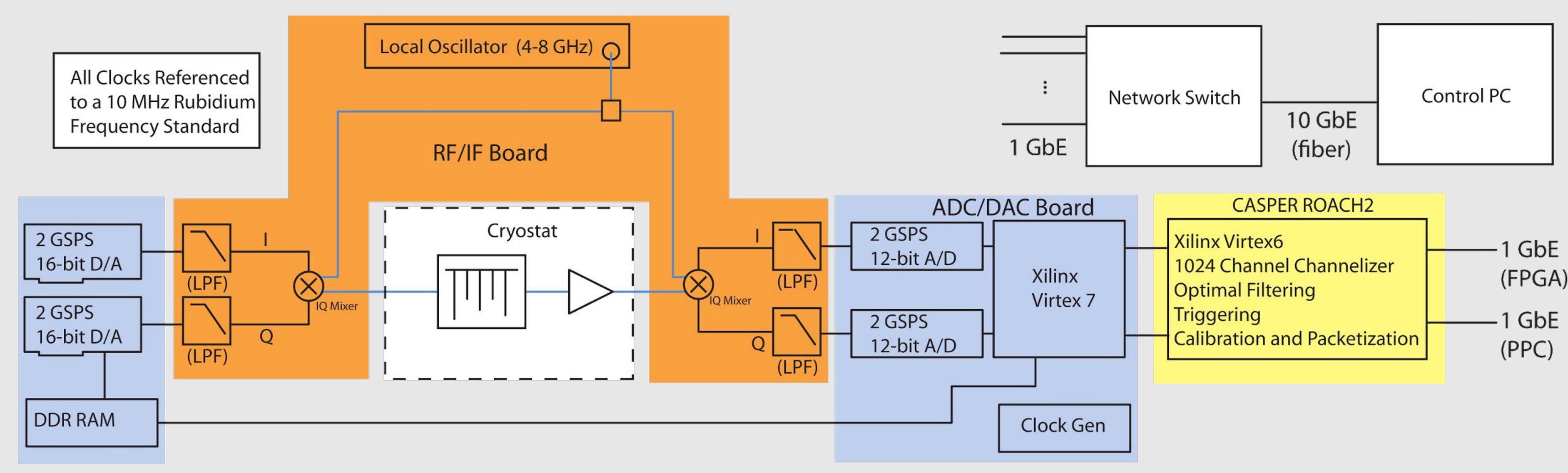
- Utilizes two 2 GS/s 12-bit ADC/DAC pairs to span 2 GHz of bandwidth using an IQ modulation scheme
- Virtex 7 FPGA
- Custom designed at Fermilab

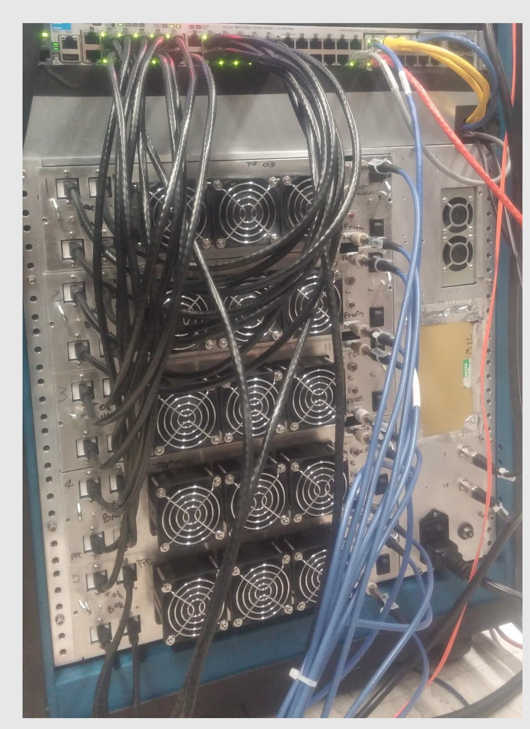
RF/IF board

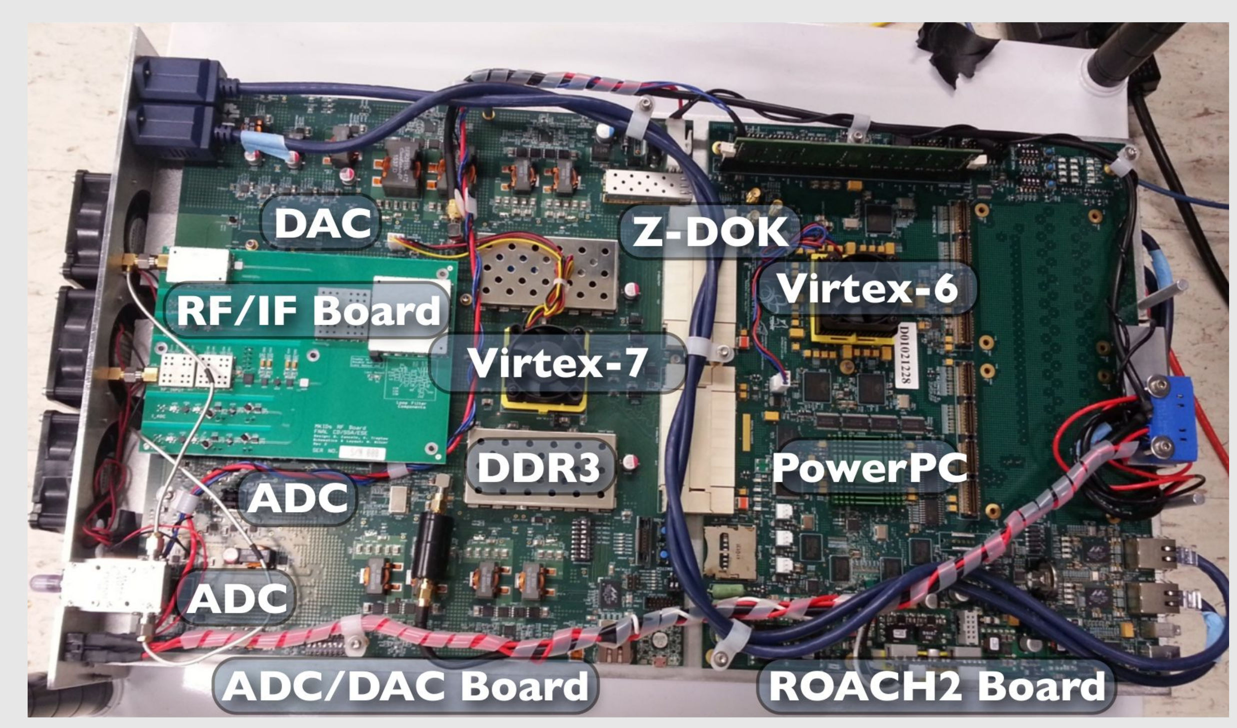
- Performs upconversion and downconversion from IF band (0 Hz) to RF band (4-8 GHz) using an IQ mixer
- Custom designed at Fermilab

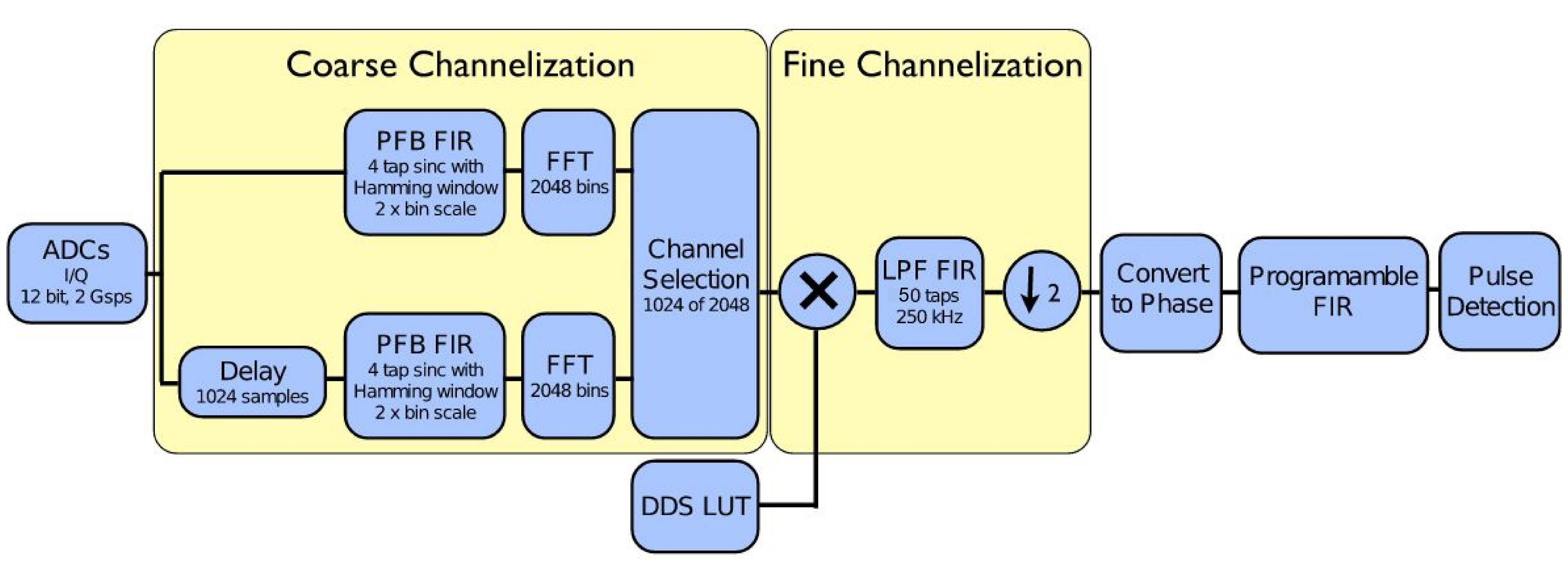
Control Computer

- Open source control software developed in Python using CASPER FPGA control libraries (code: https://github.com/abwalter/MkidDigitalReadout)
- Capable of receiving and recording photon arrival time, energy, and absorption location at a rate of ~10 Gbit/s







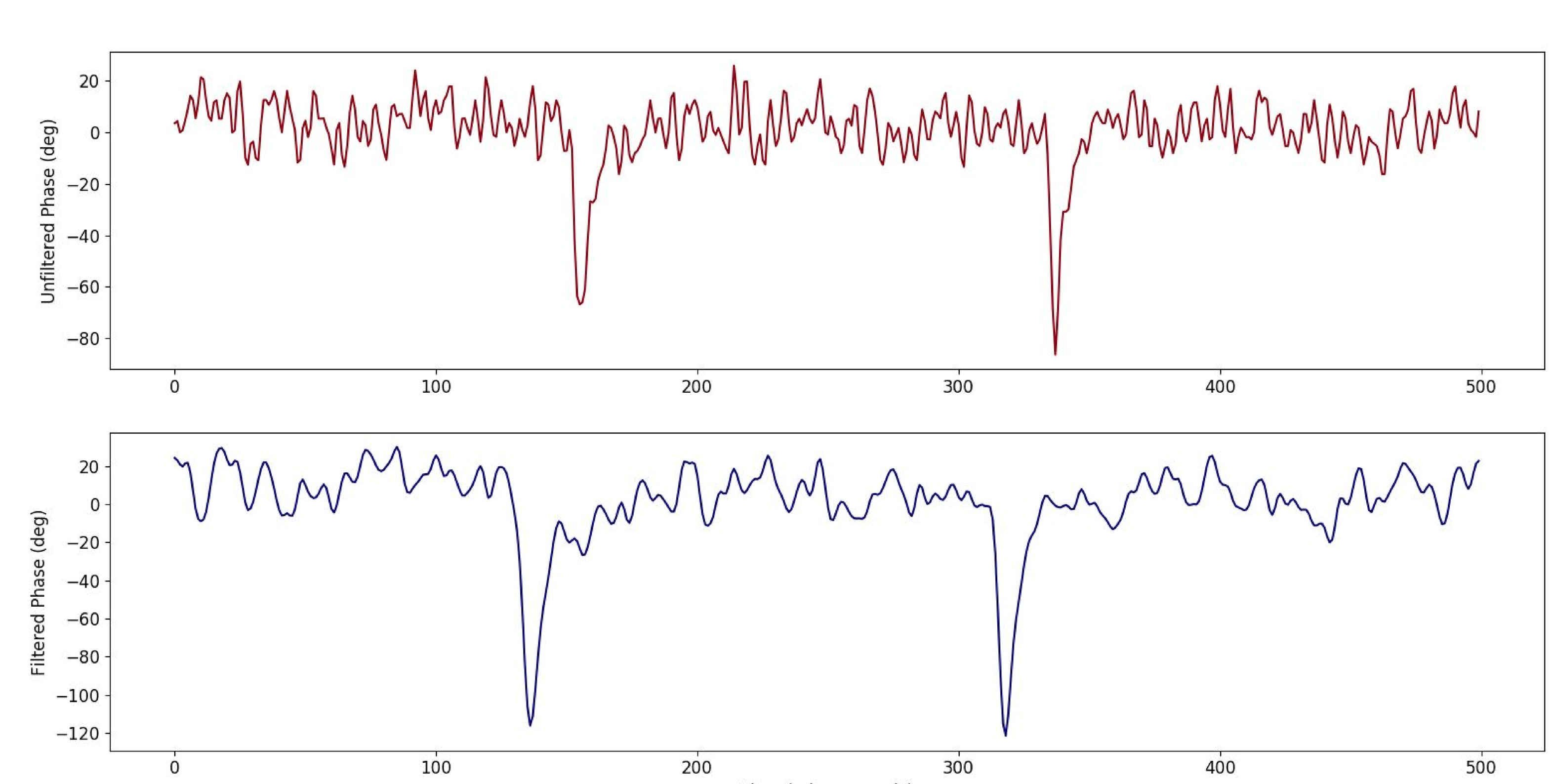


Channelization

- Converts raw ADC Signal into a phase timestream for each pixel (channel)
- Two stage downconversion process
  - Coarse, time multiplexed FFT; 2048 overlapping 2 MHz bins spanning a 2 GHz band
  - Fine channelization using DDS (direct digital synthesis) within each FFT bin to bring each resonator frequency to 0 Hz
- 250 kHz low pass filter to set 500 kHz channel bandwidth
- Obtain phase from arctan(Q/I)

Optimal Filtering and Triggering

- Custom optimal filter generated for each channel to filter phase timestreams
  - Optimizes signal-to-noise of photon pulses
  - Generated using a pulse template and noise spectrum specific to each channel
- Phase timestreams from all channels cannot feasibly be recorded simultaneously, so trigger conditions are needed to identify photon pulses. Two trigger conditions are used:
  - Sigma threshold: pulse must be $n\sigma$ above baseline
  - Derivative conditions to ensure peak is a local minimum
  - Deadtime of 10 microseconds and max count rate of 2500 counts/second are also imposed
- Wavelength calibration (in development):
  - Polynomial coefficients mapping phase pulse height to photon wavelength can be loaded into firmware, allowing for real time determination of photon energy



Plot of phase timestream from a single DARKNESS pixel, showing two photon pulses. The top plot shows the unfiltered phase; the bottom plot has a 50 tap custom optimal filter applied.