Development of a data acquisition system for kinetic inductance detectors

wide dynamic range and high sampling rate for astronomical observation

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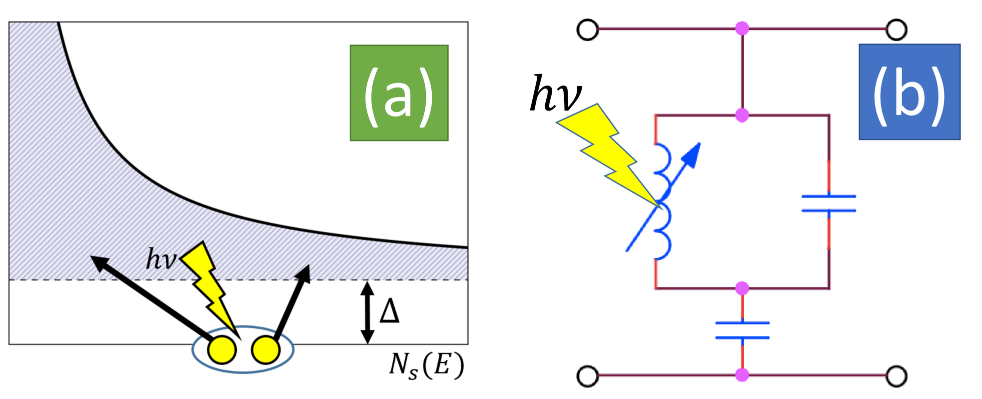
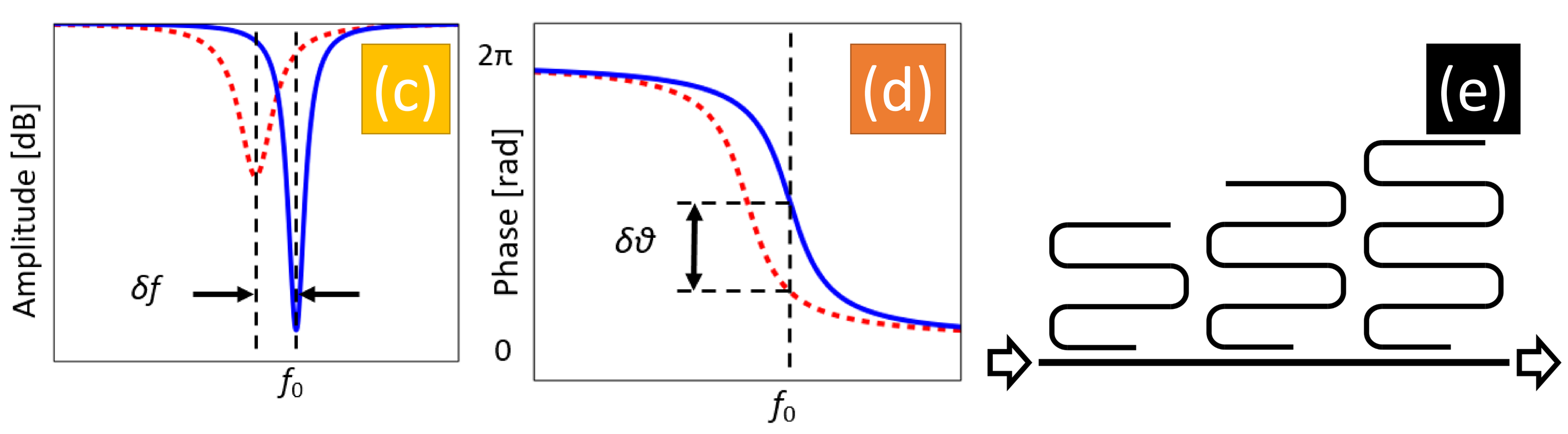
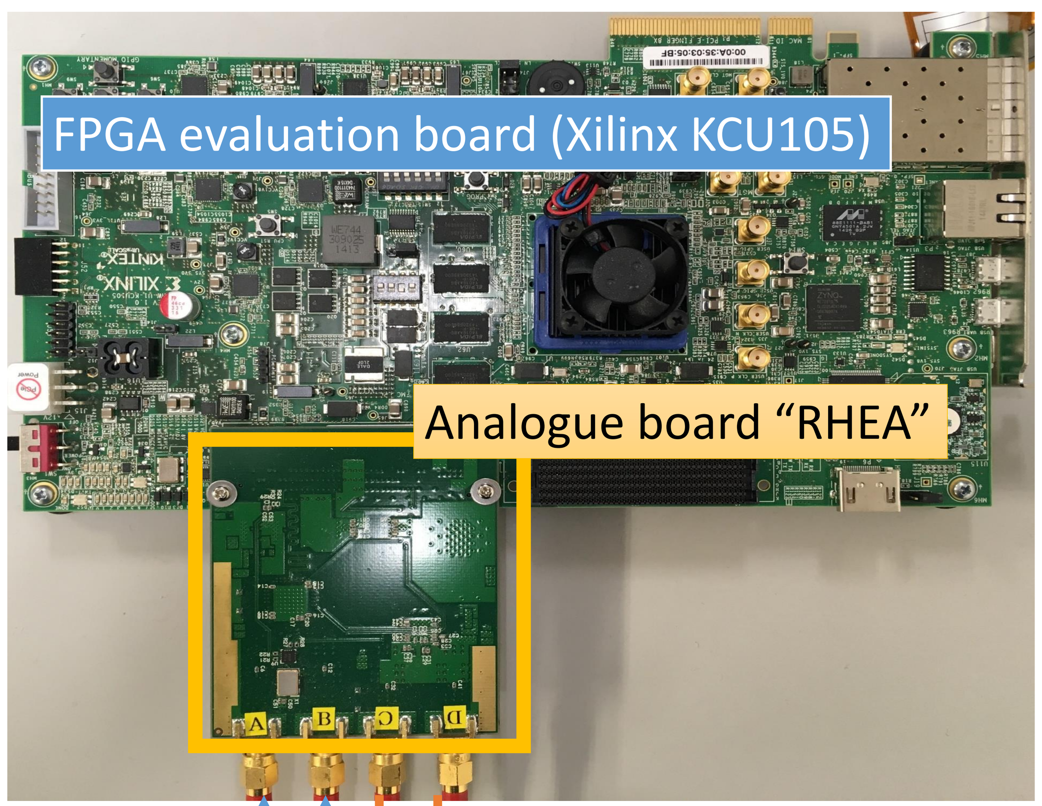
1. MKID

Microwave Kinetic Inductance Detector (MKID) is a detector which features superconducting quarter-wave resonators. Energy introduced in resonators breaks Cooper pairs (a) and changes surface impedance (b), resulting in lower resonance frequency, broader width (c) and phase shift (d). Multiple KIDs with different resonance frequencies can be read out simultaneously with a single feed line by introducing multi-tone carrier waves (e). This advantage prompts researchers to use MKIDs for observation requiring high statistics.

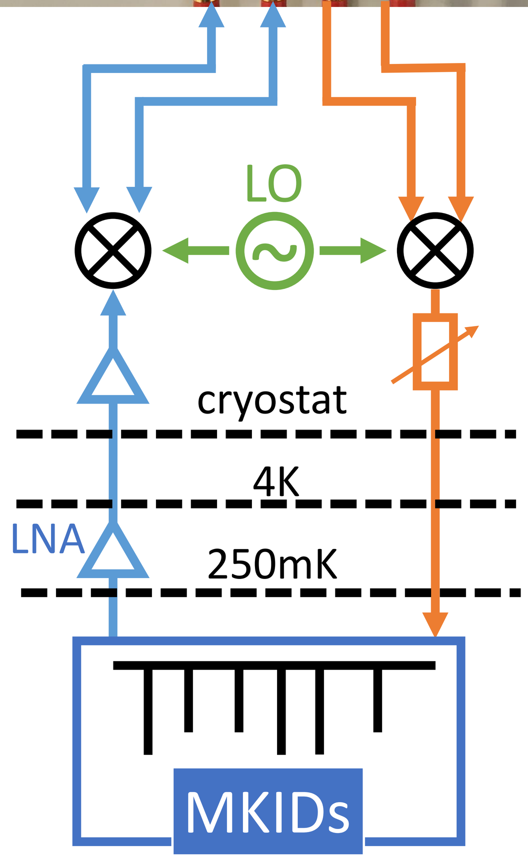




2. Our readout system



Readout electronics for MKIDs consists of: **(i) Carrier wave creation (ii) Return wave interpretation**. We built a readout system for MKIDs by combining a dedicated analog board "RHEA" and an FPGA evaluation board.

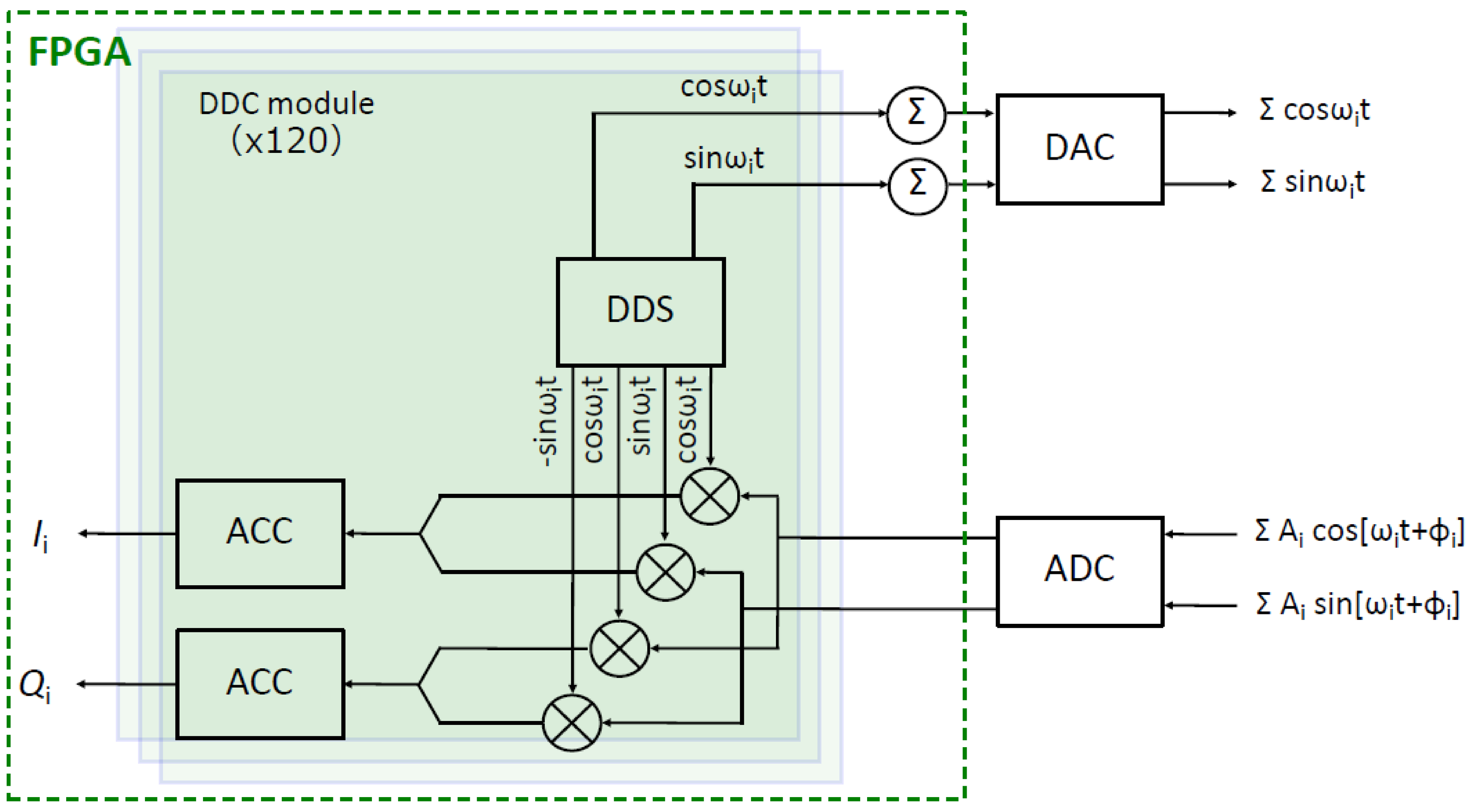


2.1 Analog board "RHEA"

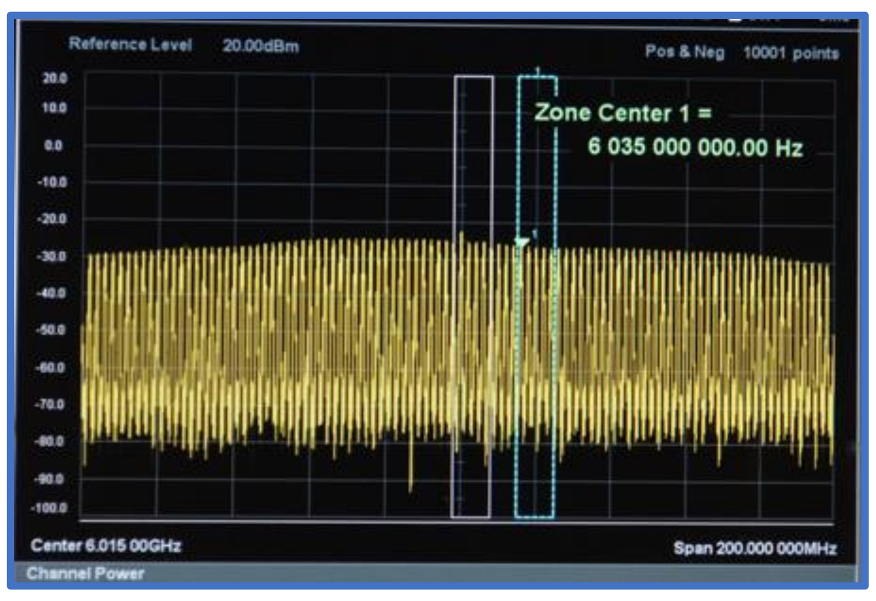
The analog board "RHEA" has two pairs of 14-bit ADC and 16-bit DAC operating at 200 MSPS, whose high bit resolution enables wide dynamic range without losing sensitivity. RHEA also achieves low power consumption and low heat emission in comparison with a commercially available analog board, supporting stable operation.

2.2 Digital processing with FPGA

Schematic of digital processing is as follows. The processor is made up of copies of modules, each with direct digital synthesizer (DDS), multiplexers, and accumulators. Tones are calculated by DDSs and then summed up to make a multi-tone carrier wave. Return signal is mixed with DDS pure waves to separate tones and accumulated to compress data size before transmission. Slow control and data transmission are both carried out through gigabit Ethernet using the SiTCP package available for Xilinx FPGA.

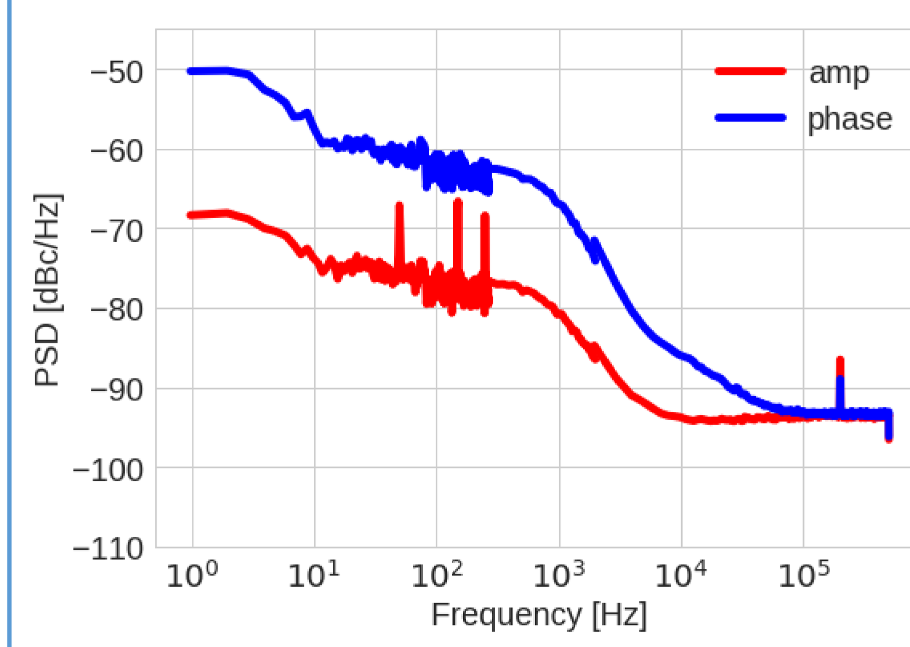


3. Key features



120 multiplexing

Our system achieved 120 MUX with direct conversion method described in Chap. 2. This multiplexing reduces cryogenic cabling, enabling flexible thermal design.

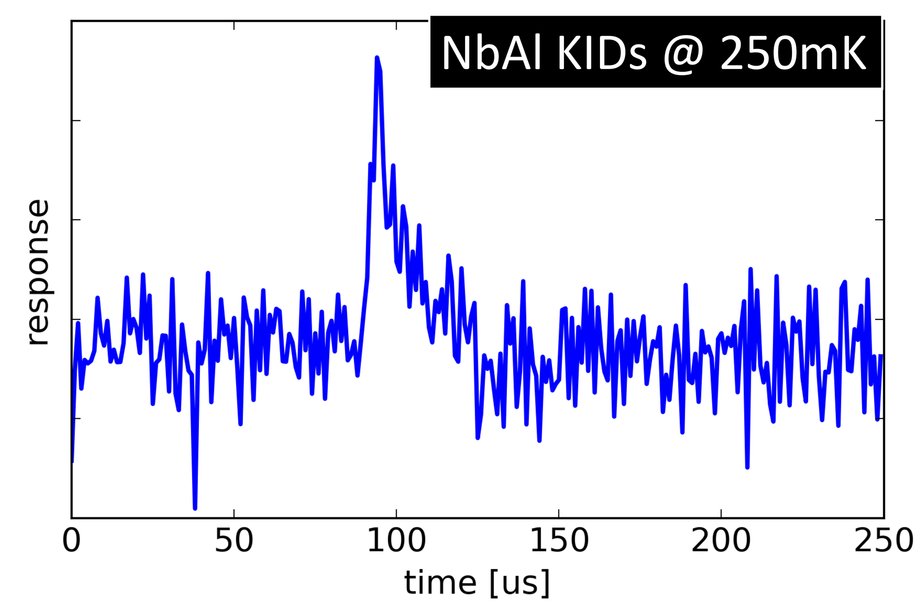


High-speed sampling

Wide dynamic range

Owing to the direct conversion method, over 1MSPS sampling is available without dead time. This enables characterization of MKIDs in detail.

The left figure shows a noise power spectrum density (PSD) of Al MKID cooled down to 150mK in RIKEN cryostat measured by our readout system. This PSD contains information (e.g. roll-off signature around 1kHz) to characterize the device. The frequency of the PSD extends up to 5×10^5 Hz which directly reflects high-speed sampling of our system. Dynamic range of analog board supports measurements free from digitization noise.



Trigger

High sampling rate also enables measurements of events with small time constant such as cosmic muon hits, while large storage and machine power is required for a long run searching for rare events.

Trigger function implemented on the digital board circumvents this problem by online selection detecting jumps in I-Q value before transmission of data to the computer.

4. Application

The system described so far has been developed for GroundBIRD, a CMB telescope with a novel scanning system. In order to achieve high sensitivity for large angular scale, the GroundBIRD telescope utilizes a circular scanning employing rotary joints for gas and electricity. MKIDs well match with this high-speed scan for their prompt time responses. The observation requires high sampling rate (over 1 kSpS), wide dynamic range, and stable operation for the read-out system, which are well fulfilled by our system. Although the data acquisition system was developed for the GroundBIRD experiment, it can be generally used for readout of MKIDs, in particular when the measurement requires high sampling rate and wide dynamic range. Triggering function opens up a possibility for application to particle detection. In addition, the analog board RHEA has a potential for a wide variety of applications beyond MKIDs readout.