Motivation

With next-generation cosmic microwave background (CMB) instruments, such as the Simons Observatory that is developing focal planes with over 50,000 pixels and CMB-S4 requiring an order of magnitude more, there is an ever-growing need for readout systems with both higher multiplexing factors and more streamlined detector packaging. Current systems, such as time-domain (TDM) and frequency-domain multiplexing (FDM), have currently fielded systems with ~70 multiplexed channels. Both these systems use SQUIDS as their first-stage low noise amplifier.

The microwave SQUID multiplexer (µMUX)1,2 is a recently developed technology that has the potential to read out thousands of TES detectors in a single multiplexed channel. In contrast to TDM and FDM which use DC-SQUIDS, µMUX uses rf-SQUIDS. The majority of published work on µMUX has been for spectroscopic applications. Here we discuss the use of µMUX for bolometric applications. We present proof-of-principle results and discuss our plans to enable a 2000 channel multiplexing factor.

Small-scale TES Bolometer Demo

For the measurement results shown below which verify the performance of the µMUXreadout, we mounted 4 detector chips, each containing 6 TES bolometers, into a sample box. The TESs are biased on a common line via two 32-channel 374 μSrf shunt resistor chips in series. We omitted Nyquist inductors that would have limited the TES bandwidth. The TES and shunts are then wired to a pair of 32-channel µMUX chips, which have resonant frequencies, f0, in 25 MHz segments between 5-6 GHz. The bandwidth of each individual resonator is 300 kHz, and their resonant frequencies are spaced apart by 6 MHz (20 times the resonator bandwidth). The 40 readout channels that were not wired to TESs were used to measure the residual readout noise. Finally, a common heater line was wired up to the first of the four TES chips to perform the crosstalk measurements shown below:

\[ \muMUX17a \]

One of the two 32 channel µMUX chips used in the measurements shown below

Operation Principle

Each channel consists of a dissipation-less rf-SQUID coupled to a quarter-wave resonator with its own unique resonant frequency (rf-SQUID acts as variable inductance). All resonators are capacitively coupled to a coplanar waveguide feedline.

Microwave resonator tones are sent down the feedline to interrogate the resonances before being amplified by a 4 K HEMT.

A common flux ramp linearizes the SQUID response.

Density is limited by bandwidth of the warm readout electronics and the resonator spacing.

Flux-Ramp Modulation

- Needed to linearize the SQUID response
- An additional source of flux is coupled to all SQUIDs.
- A sawtooth function is applied that ramps through ~20°C.
- TES signal appears as a phase shift.
- Demodulation of the data produces a readout rate at the sawtooth ramp rate.
- Also modulates the detector signal above the resonator’s 1/f knee.

Measured Noise Performance

Measurements were taken at a bath temperature of 150 mK to simulate a typical radiative load for ground-based CMB observations. The dashed lines are predicted noise levels

- The solid blue line is the measured shunt resistor noise while the solid black line is the average of all dark readout channels
- The solid magenta and cyan lines are the measured detector noise at 50% and 65% Rr, after applying a 3 mode singular value decomposition while the dotted lines show the unsubtracted noise.
- This noise level can be further reduced by increasing the readout bandwidth to 3 kHz.

The above histograms show the measured spacing between nominally 256 resonators from two sets of 5 and 7 GHz resonator band chips. The results show:

- Only 1 set of the 256 resonators are below the 5 mK crosstalk cutoff (~5 MHz).
- The standard deviation of the resonator spacing is 352 kHz, which is one-third of the previous reported 1 MHz.
- This will enable the required resonator yields of ~99% on the full 2000 channel µMUX design.

Future Work

- Fabricate new µMUX resonator design with SQUID and Flux ramp line.
- Verify the frequency placation is not degraded from SQUID introduction.
- Measure readout noise and crosstalk performance.
- Integrate into medium-scale (~500 pixels) TES bolometer demo.
- Design full-scale detector array and readout packaging.

Citations