Toward large FOV-high-resolution X-ray imaging spectrometer: microwave multiplexed readout of 32 TES microcalorimeters

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Abstract

We performed a small-scale demonstration at GSFC of high-resolution x-ray TES microcalorimeter arrays output using a microwave SQUID multiplexer. This work is part of our effort to develop detector and readout technologies for future space-based x-ray instruments such as the microcalorimeter spectrometer envisaged for Lynx, a large mission concept under development for the Astro 2020 Decadal Survey. In this paper we describe our experiment, including details of a recently designed, microfabricated and characterized x-ray spectrometer module that is thermally anchored to the 50 mK stage of our laboratory ADI. Using a ROACH2 FPGA at room temperature, we simultaneously read out 32 pixels of a GSFC-built detector array via a NIST-built multiplexer chip with 50 coplanar waveguide resonators coupled to 32 SQUIDs. The resonators are spaced 6 MHz apart (at ~5.9 GHz) and have quality factors of ~35,000. Using flux ramp modulation frequencies of 160 kHz we have achieved spectral resolutions of ~1 eV FWHM on each pixel at 6 K. We present the measured system-level noise and maximum slewing rates, and briefly describe the implications for future detector and readout design.

Microwave SQUID multiplexing

- A few GHz of bandwidth per amplifier channel
- TESs couple to unique microwave resonator
- RF SQUID/bulk microwave resonator
- Resonance matches modulation frequency
- Single microwave feed-line can read-out hundreds of pixels
- Flux ramp much faster than input signal
- Output to be averaged in, e.g., 500 MHz band
- For demodulation

Lynx

A large mission concept under development by NASA for the Astro 2020 Decadal Survey

- Microcalorimeter detector array for Lynx
  - Energy resolution: better than 3 eV FWHM at 0.2 – 10 keV
  - Number of readout channel > 56,000
  - Various angular resolution, energy resolution and count rates
  - Sensor: Transition-edge sensor(TES) or magnetically coupled calorimeter (MCC)
  - Initial approach: Use position-sensitive TES microcalorimeter, “Hydra”. These have multiple absorbers attached to each sensor
  - See also

Promising initial results: microwave multiplexing of 5 TESs

Ongoing work: microwave multiplexing of 32 TES microcalorimeters

- Improved energy resolution – expect non-multiplexed \( \Delta E \) ~1.6 eV based on measurements of similar chip
- 32-channel multiplexing – bond-pad layout compatible with \( \mu \)MUX chip layout

8.8 Tesla TES microcalorimeter, NASA/GSFC

- T_e ~ 89 mK
- 120 mm^2 TES
- 2.5 mm backside Cu
- Absorber: Au/Bi
- 0.5 mm SiN membrane

Low temperature \( \mu \)MUX setup

- ROACH2 with MKID-ADC/DAC board
- ADC/DAC sampling rate: 512 Mbps
- Number of channels: 32
- Bin select: 8 MHz sampling per channel
- Signal bandwidth: 1 MHz

Room temperature electronics

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Response of the \( \mu \)MUX readout

- 33 resonators
- Center frequency ~5.87 GHz, 6 MHz spacing
- Q > 13,500
- Q ~ 14,500 ~ Q ~ 13,500

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Non-uniformity due to gradient in heat sink temperature fixed in subsequent run

Due to the damaged Nyquist inductor and incorrect wiring

Measured system noise and slewing rate

- Noise of readout circuit is the measured noise without TES connection
- Non-coplanar readout circuit on 50 Ohm
- TES noise level ~150 pA/Hz
- \( \mu \)MUX readout noise is a factor of 5 below the TES noise level

Mean slewing rate depends on pulse rise, flux ramp frequency and resonator packaging density
- Approaches for Lynx
  - Slope of the flux ramp
  - Increase the resonator bandwidth

Future work: microwave readout of ‘Hydra’ pixels for Lynx (see Bandier, Smith)