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Frequency domain multiplexing readout for large arrays of transition-edge sensors

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Future experiments pursuing scientific breakthroughs in the fields of astronomy, cosmology or astro-particle physics will take advantage of the extreme sensitivities of cryogenic detectors, such as transition-edge sensors (TES).

A TES is a thin film of superconducting material weakly coupled to a thermal bath typically at $T < 100$~mK, used as a radiation detector by exploiting its sharp phase transition, providing unprecedented resolving power and imaging capabilities. We have been developing TES micro-calorimeters for X-ray spectroscopy for the Athena X-ray Integral Field Unit (X-IFU), demonstrating under AC bias resolving power capabilities of $E/\Delta E \simeq 3000$.

Performing the readout of thousands of detectors operating at sub-K temperatures represents an instrumental challenge. We have been developing, in the framework of X-IFU, a frequency-domain multiplexing (FDM) technology, where each TES is coupled to a superconducting band-pass LC resonator and AC biased at MHz frequencies through a common readout line. The TES signals are summed at the input of a superconducting quantum interference device (SQUID), performing a first amplification at cryogenic stage. A custom analog front-end electronics further amplifies the signals at room temperature. A custom digital board handles the digitization and modulation/demodulation of the TES signals and bias carriers.

Using Ti/Au TES micro-calorimeters, high-Q LC filters and analog/digital electronics developed at SRON and low-noise two-stage SQUID amplifiers from VTT Finland, we demonstrated using two experimental setups the feasibility of our FDM readout technology, with the simultaneous readout of 31 pixels with an energy resolution of 2.14 eV and 37 pixels with an energy resolution at of 2.23 eV, exploiting 5.9 keV photons from an ^{55}Fe source.

We report the technological challenges of the FDM development and their solutions, already implemented or envisaged to further improve the matureness of this technology, as well as prospects for further scaling up and future possible applications.

Collaboration

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