dc-SQUIDs and SQUID based multiplexers for the readout of metallic magnetic calorimeters

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Superconducting quantum interference devices (SQUIDs) are presently the most sensitive wideband devices for measuring various quantities that can be naturally converted into magnetic flux. Due to their intrinsic compatibility with low operation temperatures, they are very well suited for the readout of calorimetric low-temperature particle detectors such as metallic magnetic calorimeters (MMCs). However, MMCs are relatively sensitive to the input circuitry as well as the noise performance of the readout SQUID. In particular, it is very well known that parasitic inductances in the input circuit are leading to a reduction of the signal size of the detectors and SQUID noise sets a limit to their energy resolution.

Driven by the need for devices that are specifically optimized for the readout of small- and large-scale MMC detector arrays, we are currently developing low-Tc current-sensing SQUIDs that are fabricated using a Nb/Al-AlOx/Nb trilayer technology and selective niobium etching. More precisely, we are developing microwave SQUID multiplexers that are based on non-hysteretic, unshunted rf-SQUIDs for the readout of large-scale MMC detector arrays consisting of hundreds or even thousands of detectors as well as lumped-element and integrated two-stage dc-SQUID setups for the readout of single-channel detectors with lowest possible noise.

We start with a general discussion of the influence of the energy sensitivity of the readout device on the energy resolution of MMCs. Here, we particularly focus on the influence of low-frequency excess noise which is caused, for example, by atomic two-level systems or electron spins at the surface of the SQUID wiring and discuss possibilities to overcome the resulting limits on the energy resolution. We continue with a discussion of our SQUID designs and show that our dc-SQUIDs show an exceptional small low-frequency excess flux noise contribution, reaching intrinsic energy sensitivities down to 30 h at 1 Hz at millikelvin temperatures. Due to this very good low-frequency noise performance, our dc-SQUIDs basically allow for the readout of MMCs with an energy resolution below 1.5 eV. By a further optimization of our SQUID designs reducing the white noise level and enhancing the magnetic coupling factor we even expect to read out MMCs with sub-eV energy resolution. Furthermore, we discuss the performance of a 64 pixels detector array that is read out by means of an integrated on-chip microwave SQUID multiplexer (µMUX). Within this context, we demonstrate for the very first time a µMUX based MMC readout and discuss the µMUX performance such as the energy resolution on the basis of acquired spectra of an 55Fe source. Finally, we outline possible routes to further increase the energy resolving power of both single channel detectors and large detector arrays.