Microwave SQUID multiplexer read-out of large MMC detector arrays

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Metallic magnetic calorimeters (MMCs) are calorimetric low-temperature particle detectors that are the devices of choice for many applications due to their outstanding energy resolution, their very fast signal rise time, their quantum efficiency close to 100% as well as their large energy bandwidth. Presently, large MMC detector arrays are under development to enable, for example, experiments with imaging capabilities or significantly increased count rates. In particular, large-scale MMC detector arrays are currently developed for the direct neutrino mass experiment ECHo which aims to investigate the electron neutrino mass by means of a high-resolution and high-statistics calorimetric measurement of the electron capture spectrum of 163Ho. In order to achieve a neutrino mass sensitivity in the sub-eV/c2 range the ECHo experiment requires a very high statistics spectrum with up to 1014 counts. This can only be acquired in a reasonable measurement time by means of large MMC detector arrays with 104 - 106 detector pixels in total. However, such a huge number of detectors makes a single channel detector read-out hardly possible due to system complexity, costs as well as parasitic heat load to the cold-stage of the cryostat. Hence, a multiplexing technique is certainly required. A very promising frequency domain multiplexing approach, the microwave SQUID multiplexer, was suggested by K. Irwin et al (Appl. Phys. Lett. 85, 2107 (2004)). Here, each detector is read out by a non-hysteretic rf-SQUID which is inductively coupled to a superconducting quarter-wave resonator. A signal in the detector changes the parametric SQUID inductance resulting in a resonance frequency shift of the related resonator. Since each resonator has a unique resonance frequency and is capacitively coupled to a common feedline, it is possible to simultaneously monitor the resonance frequency changes of all resonators by using a software defined radio technique.

Very recently, we have developed an MMC detector array with 64 pixels that is read out by an on-chip microwave SQUID multiplexer. This array is supposed to be used as a first prototype for the ECHo experiment. Each rf-SQUID is a second-order parallel gradiometer employing a slotted washer design to reduce parasitic capacitive coupling effects between the SQUID and the input coil. A common flux modulation coil which is coupled to all SQUIDs allows for flux biasing or flux modulation of all SQUIDs. For frequency encoding, coplanar microwave resonators with unique resonance frequencies in the frequency range 4 GHz up to 8 GHz are used. They are capacitively coupled to a common transmission line. The loaded quality factor can be precisely controlled by the coupling capacitance between the resonator and the feedline and is adjusted to give a loaded Ql of about 5000. The resulting bandwidth per pixel hence allows to resolve detector signal rise times below 500 ns and to arrange a few hundreds of channels per multiplexer without suffering from cross-talk between neighboring resonators. The estimated energy resolution of this array is about 5 eV. We present details of the design of our detector array with integrated microwave SQUID multiplexer. Furthermore, we discuss the results of its characterization and compare with our design values. Finally, we demonstrate for the very first time the successful read-out of MMC detectors by means of an on-chip microwave SQUID multiplexer.