Helmholtz Institute Jena

# A Cryogenic Current Comparator for FAIR with Improved Resolution


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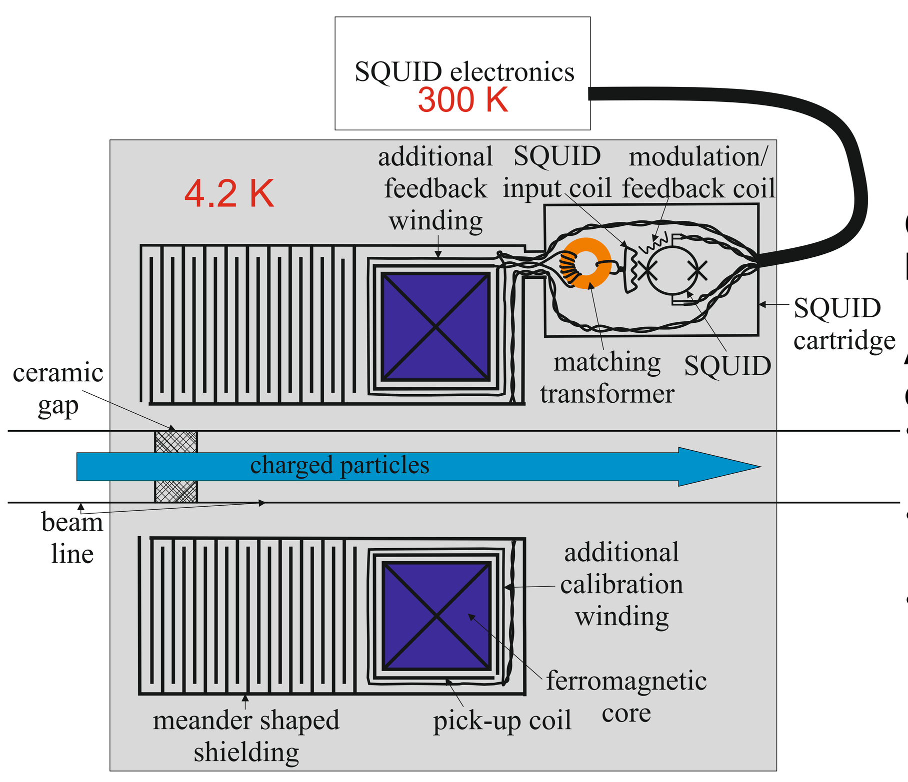
## Introduction

A Cryogenic Current Comparator is a highly sensitive tool for the non-destructive online monitoring of continuous as well as bunched beams of very low intensities. The noise-limited current resolution of such a device depends on the ferromagnetic material embedded in the pickup coil of the CCC. Therefore; the main focus of research was on the low temperature properties of ferromagnetic core materials. In this contribution we present first results of the completed Cryogenic Current Comparator for FAIR working in a laboratory environment, regarding the improvements in resolution due to the use of suitable ferromagnetic core materials.

## Design Concept




**Cryogenic Current Comparator Principle**

A CCC consists of the following main components:

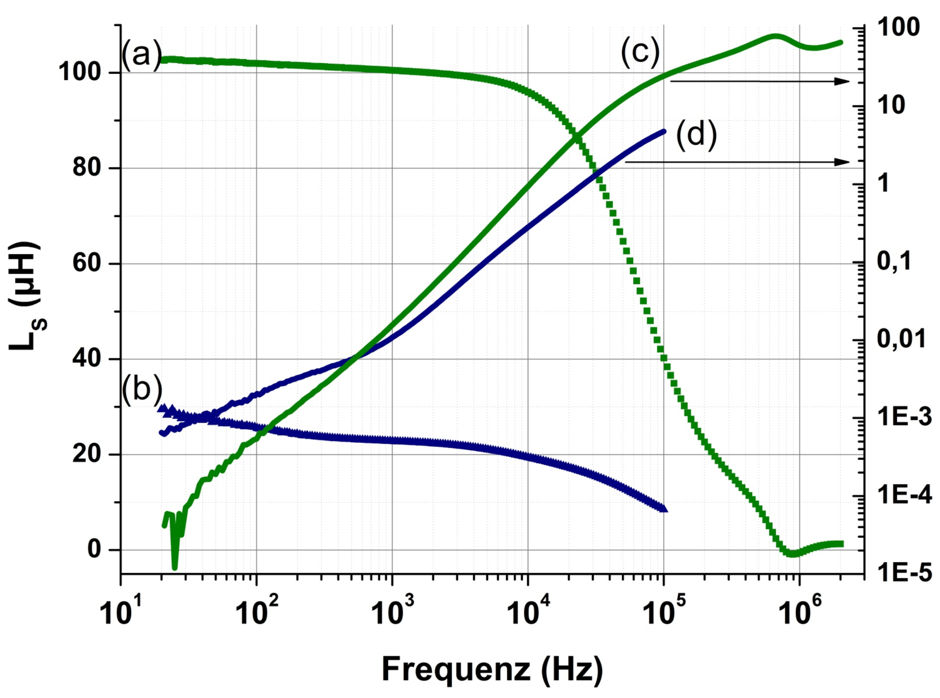
- a superconducting pick-up coil for the passing high energy ion beam
- a highly sensitive LTS DC SQUID system
- an extremely effective meander-shaped superconducting shielding

- The discs of the meander among each other and the pick-up coil are fixed with discs of GFP to minimize mechanical vibrations.
- For the shielding we have chosen a modular configuration to average out manufacturing tolerances and minimize problems due to welding distortion.
- The niobium parts are connected via electron beam welding under UHV conditions.

## Fluctuation-Dissipation-Theorem (FDT)

$$\left\langle I^2 \right\rangle = 4k_B T \int \frac{R_S(\upsilon)}{\left(2\pi\upsilon\left(L_{SQUID} + L_S(\upsilon)\right)\right)^2 + \left(R_S(\upsilon)\right)^2} d\upsilon$$

- Current noise of a coil from measured serial inductance $L_s(\nu)$ and resistance $R_s(\nu)$ [1]
- Noise decreases if $L_s(\nu)$ is increased and $R_s(\nu)$ is low.
- $L_s(\nu)$ seen as an ideal coil whereby $R_s(\nu)$ represents all losses of the core material caused by e.g. eddy currents and parasitic capacitances.
- Resolution of the CCC limited above all by the magnetic properties of the ferromagnetic core material in the pick-up coil.
- Materials with the highest possible permeability at 4.2 K which are constant over a wide frequency range required

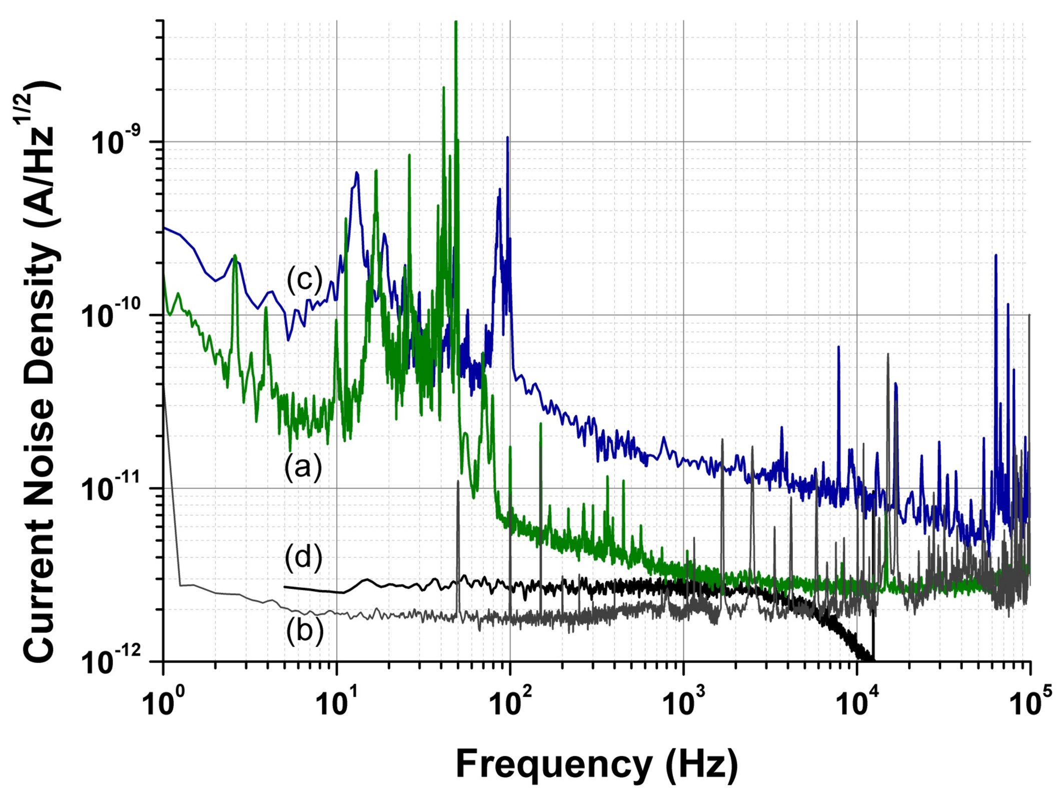



$L_s(\nu)$ at 4.2 K for welded toroidal pick-up coil with Nanoperm M764 core (a), and DESY-CCC pick-up coil with Vitrovac 6025 F core (b) as well as $R_s(\nu)$ at 4.2 K for welded toroidal pick-up coil with Nanoperm M764 core (c), and DESY-CCC pick-up coil with Vitrovac 6025 F core (d).

The serial inductance $L_s(\nu)$ and serial resistance $R_s(\nu)$ of two possible materials were measured using a commercial LCR-Bridge (Agilent E4980A) [2].

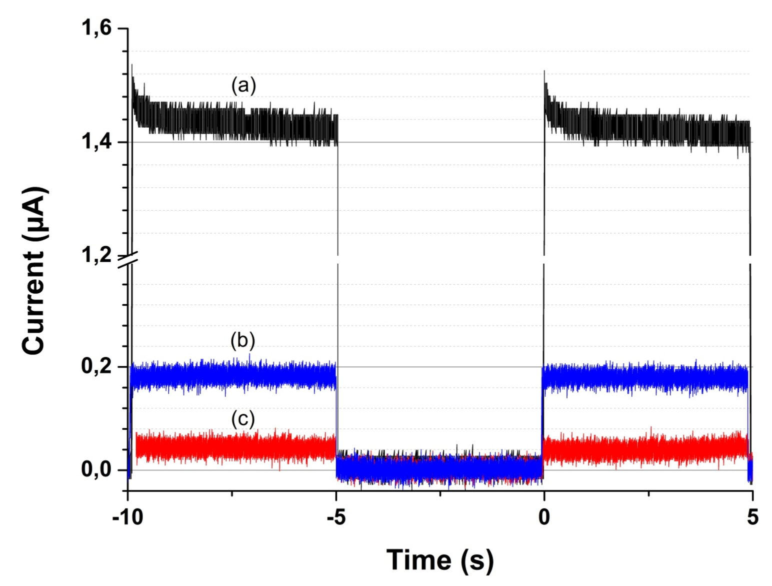
- Vitrovac 6025F [3] well known as core material for low temperature coils. Used as core material of the pickup coil in a former project with DESY Hamburg, operating as a dark current monitor [4]
- Nanoperm M764 [5] selected due to preliminary investigations [2]

## Current Noise Density

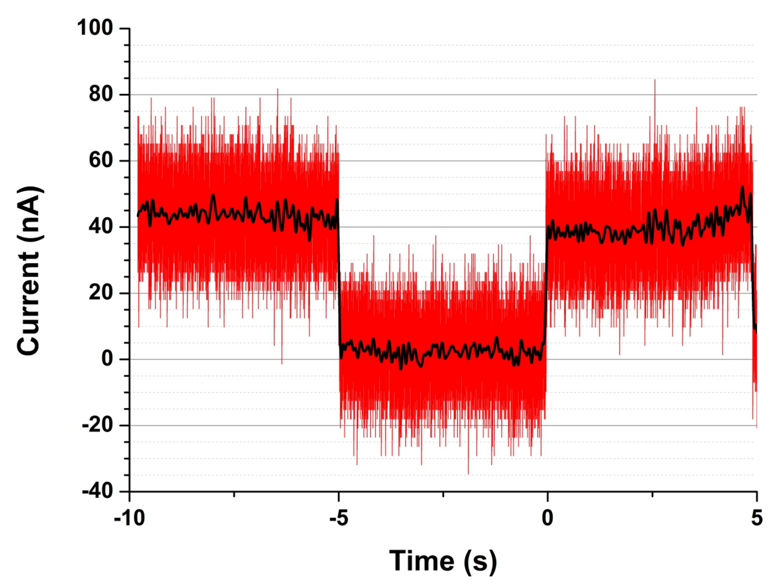



The figure above shows the measured current noise density of the improved FAIR-CCC with Nanoperm M-764-01 core (a) whereas plot (b) represents the intrinsic current noise density of the Supracon SQUID sensor CP2 blue [6]. For comparison the measured current noise density of the DESY-CCC pick-up coil including a Vitrovac 6025 F core is shown (c) whereas plot (d) represents the intrinsic current noise density of the SQUID sensor UJ111 from Jena University [7]. The current noise density was decreased to 21 pA/Hz$^{1/2}$ compared to 110 pA/Hz$^{1/2}$ at 7 Hz and to 2.4 pA/Hz$^{1/2}$ compared to 9.6 pA/Hz$^{1/2}$ at 10 kHz.

## Step Function Response




Full-bandwidth response of the FAIR-CCC to a rectangular current signal of 1.438 µA (black), 185 nA (blue), and 42.5 nA (red) applied to the additional calibrating loop.




Full-bandwidth response of the FAIR-CCC to a rectangular current signal of 42.5 nA (red) applied to the additional calibrating loop and after filtering with a low pass filter (black, 10 Hz cut-off frequency).

## Magnetic Field Attenuation

Magnetic field attenuation is analytically studied in great detail by Grohman et al. [8].
The magnetic field attenuation of the presented FAIR-CCC was directly measured to be:

- **187 dB** for transverse magnetic fields (perpendicular to the beam current) - 0.87 nA/µT
- **199 dB** for axial magnetic fields (parallel to the beam current) - 0.23 nA/µT

## Summary and outlook

The Cryogenic Current Comparator has shown its capability as beam monitor for ions as well as electrons [9, 4]. With the usage of the presented material Nanoperm M-764-01 a linear transfer function up to 10 kHz could be expected. The current noise density of the pick-up coil was reduced by a factor of two to six. With the increased attenuation factor of the meander-shaped shielding a further noise reduction in the low frequency range up to 1 kHz was achieved. This would enable the detection of beam currents below 1 nA which means approximately $10^9$ ions/spill of $^{238}U^{28+}$ respectively $28\times10^9$ protons/ spill for slow extraction with $t_{spill}$ = 5 s. With this resolution the CCC is well suited for the beam diagnostics of FAIR. The next steps are the optimization of the wiring from the SQUID cartridge to the SQUID electronics, the implementation of the matching transformer, and the fabrication of a cryostat for beam line tests.

## References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