Cryogenic Current Comparators for 150 mm Beamline Diameter

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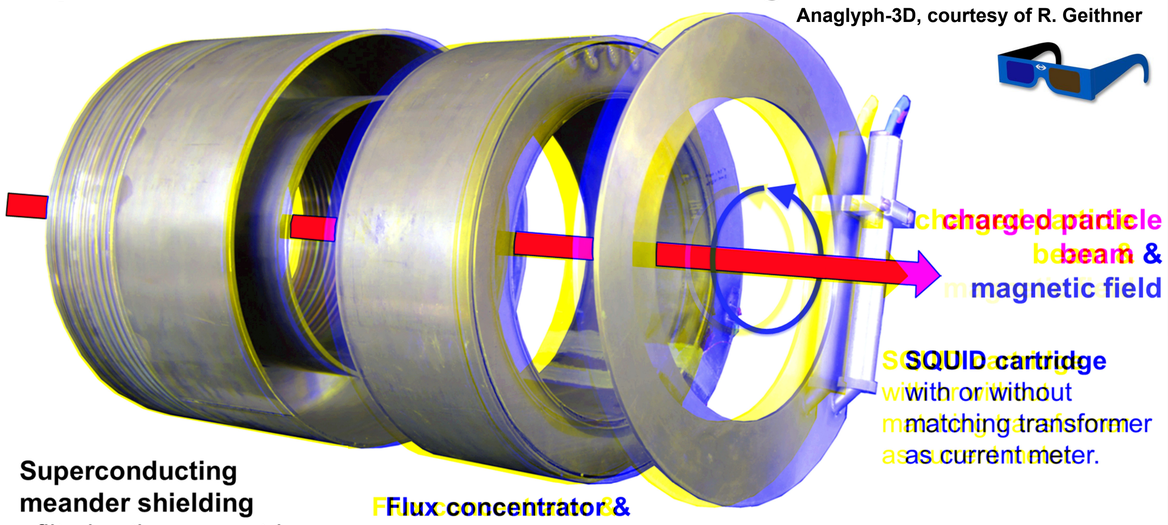
Abstract

New versions of Cryogenic Current Comparator (CCC) sensors with eXtended Dimensions (CCC-XD) for beamline diameters up to 150 mm – necessary for the planned Facility for Antiproton and Ion Research (FAIR) at GSI (Gesellschaft für Schwerionenforschung) – have been realized. These non-destructive charged particle beam monitoring systems are able to measure intensities in the nA-range with a white noise level below 5 pA/√(Hz). The systems are sensitive from DC to several hundred kHz and can be linked-up in a traceable way with national and international ampere-standards.
In its present design, the base body consists of a highly-permeable, nano-crystalline core optimized for low-temperatures (ready for superfluid He-II applications) [1] and a niobium shielding/pickup-coil unit. The flexible SQUID (Superconducting Quantum Interference Device) - cartridge allows for application tuning. Three cartridge versions (direct, balanced and enhanced) are presented, discussed and results of electrical laboratory measurements of the noise behavior and the frequency response are given.

Operation principle

Exploded view of classical meander design CCC (running @ CERN)

Anaglyph-3D, courtesy of R. Geithner



Superconducting meander shielding
- filtering the concentric magn. field component
- complex meander structure
- acts as two long coaxial tubes
- no electrical connection between both tubes
- a frequency-independent parasitic capacity C_m in the nF-range

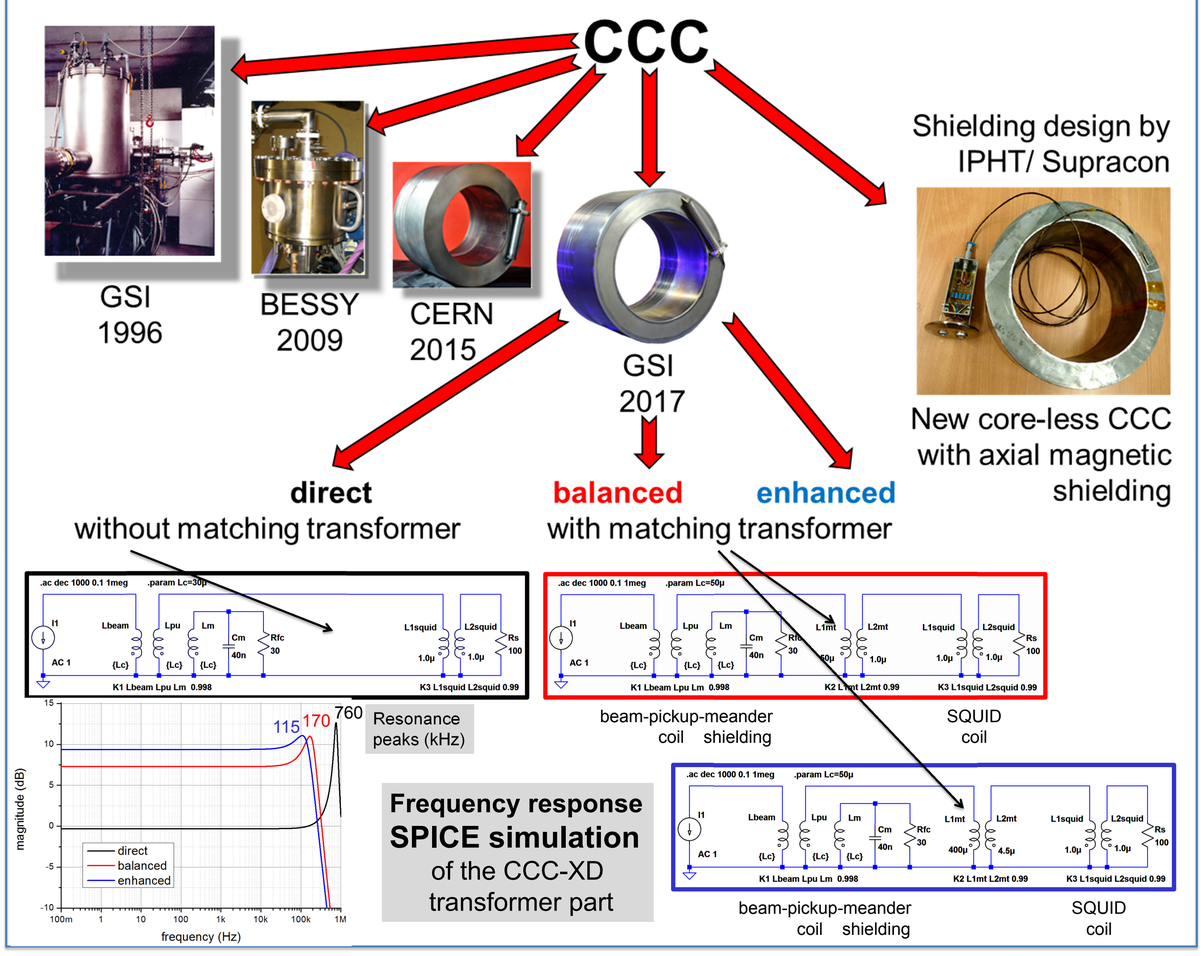
Flux concentrator & Superconducting pickup coil
- special highly-permeable, nano-crystalline core
- optimized for low-temperature applications
- magnetic field concentration at the tube ends
- full faced one-turn pickup coil
- frequency-dependent inductance L_{pu} in the range (10..100) µH

Top cover
- connects both parts of the meander shielding tubes
- creates a one-turn full faced frequency-dependent coupling coil
- inductance L_m (like the pickup coil)
- creates a L_mC_m-resonator
- resonance frequency above 100 kHz.

Benefit of superconductivity

1. **Shielding:** Meissner effect
2. **DC-transformer:** Meissner effect / screening current
3. **Current meter:** Superconducting quantum interference device SQUID (Josephson effect + Meissner effect + flux quantization)

Evolution of CCCs (developed and manufactured in **Jena** [2])

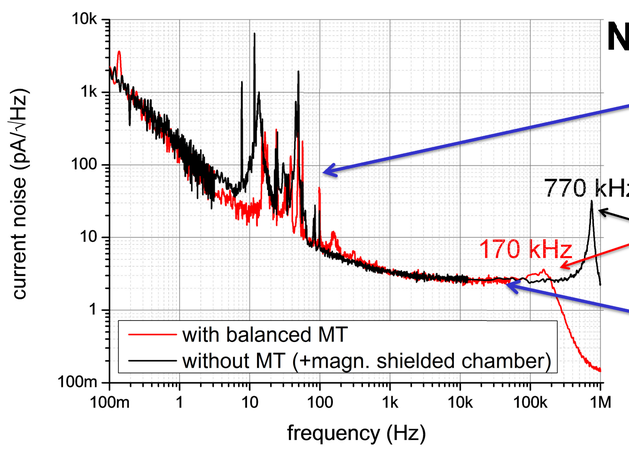


The CCC-XD for GSI/FAIR

Ready for integration into beamline cryostat

Niobium CCC-XD sensor for larger beamline diameters in cryo-measure hall. Free inside diameter: 250 mm, weight: 56 kg.

Noise measurement

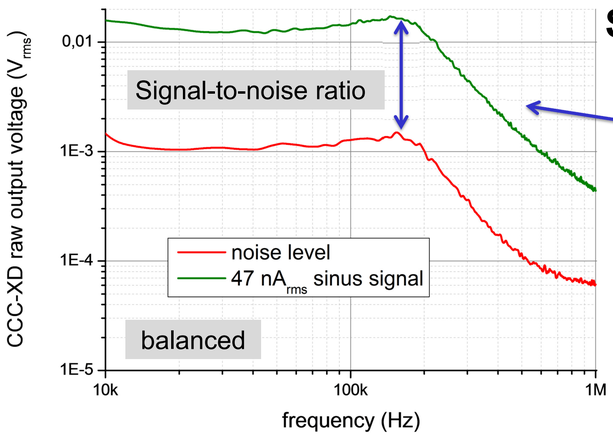


Acoustic noise of two locations
- magn. shielded chamber – noisy
- unshielded cryo-measure hall

Resonance peaks

CCC white input noise below 5 pA/√Hz

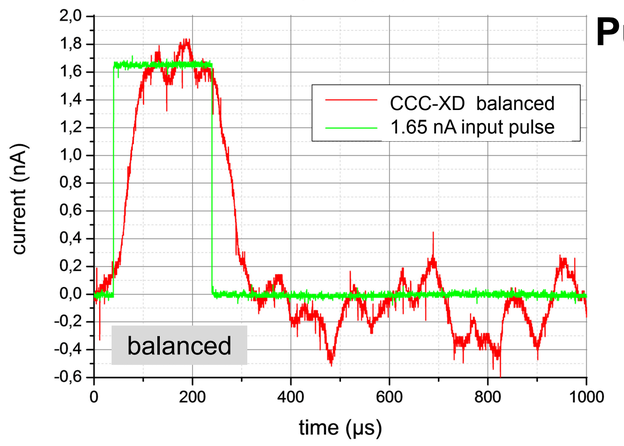
Sinus signal measurement



Small-signal:
Correlation between noise and signal

Large-signal (slew rate @ 200 kHz):
- direct: 0.32 µA/µs
- balanced: 0.16 µA/µs

Pulse signal measurement



200 µs small single pulse
- no mean value
- without any digital signal processing
- SQUID-filter 10 kHz: ON

Conclusion and Outlook

The new CCC-core material GSI328 enables to operate up to several hundreds of kilohertz. Resonance measurements and simulations show that there are still 35 % of the max. inductance at 750 kHz. Using a matching transformer it is possible to create different SQUID-cartridge versions with an additional current magnification of up to 4 times. The system input noise is independent from the matching transformer version because of the dominant core noise. The balanced version is able to measure sinus small-signals with a frequency up to 200 kHz and nA-pulses without any signal correction. Now the CCC-sensor with extended dimensions is ready to be integrated into the beamline cryostat [3].

References

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[2] W. Vodel, R. Geithner and P. Seidel, “SQUID-Based Cryogenic Current Comparators”, in Applied Superconductivity, Handbook on Devices and Applications, Volume 2, P Seidel, Ed. Weinheim, Germany: Wiley-VCH, 2015, pp. 1096-1110.
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