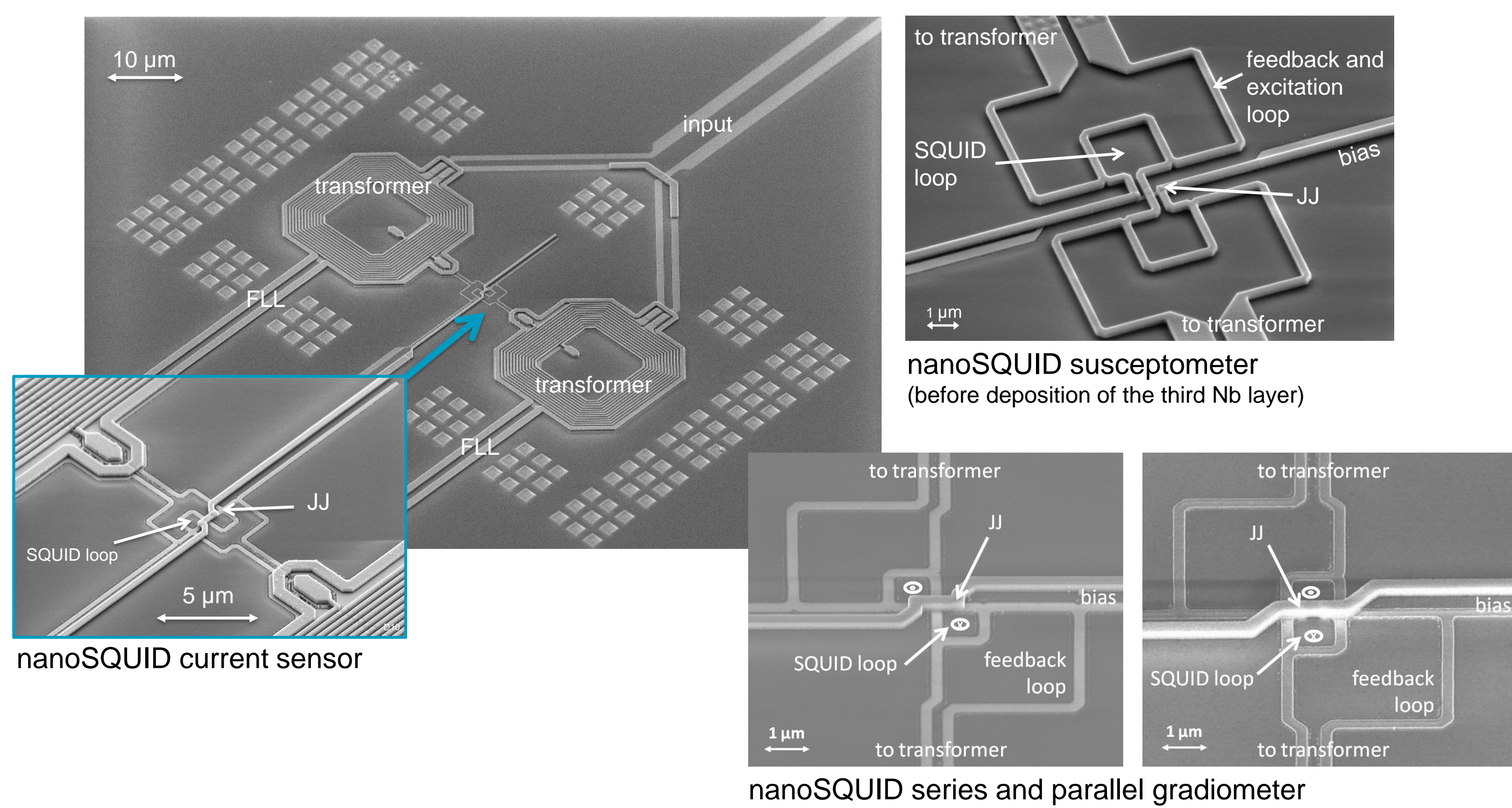# Towards practical HfTi-nanoSQUID sensors

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For practical nanoSQUID applications, sensor designs are desirable which include sophisticated electronic functionalities for optimum performance. A feedback circuitry including transformers is used for linearization of the periodic flux-to-voltage characteristic. Excitation coils might be integrated enabling the investigation of magnetic properties of nano-sized samples, and rf-filters improve the robustness of the devices.

General structure and fabrication of the nanoSQUIDs

Planar nano-structures fabricated using e-beam lithography and chemical-mechanical polishing process steps, allow complex nanoSQUID layouts with up to 3 niobium layers.

- lateral dimensions of SNS JJs — 150 nm x 150 nm to 260 nm x 260 nm
- thickness of HfTi barrier — about 20 nm
- line width (SQUID loop) — 200 nm
- SQUID loop inner diameter — 840 nm to 2.2 µm

nanoSQUID current sensor

nanoSQUID susceptometer
(before deposition of the third Nb layer)

nanoSQUID series and parallel gradiometer

Measurement setup

Magnetic flux noise, linearity and field tolerance are measured in flux-locked-loop mode (FLL) and 2-stage configuration with a SQUID series array (SSA) as cryogenic preamplifier.

Double-walled probe stick with
- nanoSQUID
- SQUID series array
- superconducting coil system consisting of a large solenoid and two identical inner coils nearly approaching Helmholtz coil geometry
- leads of coil system in He-gas
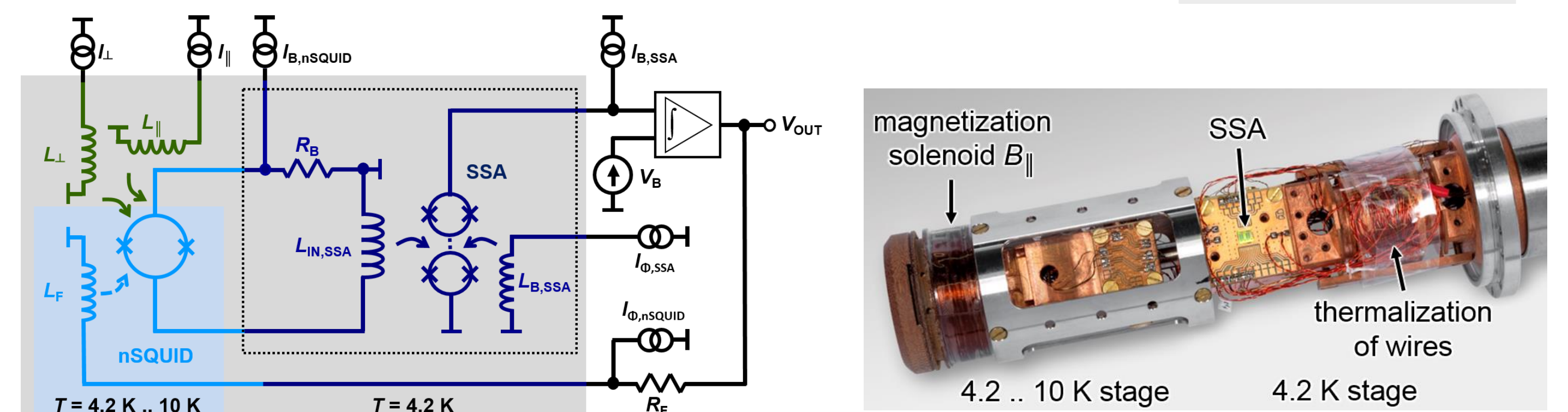
The SSA operates in magnetic fields of 100 µT in maximum and is therefore mounted approximately 6 cm away from the coil system.
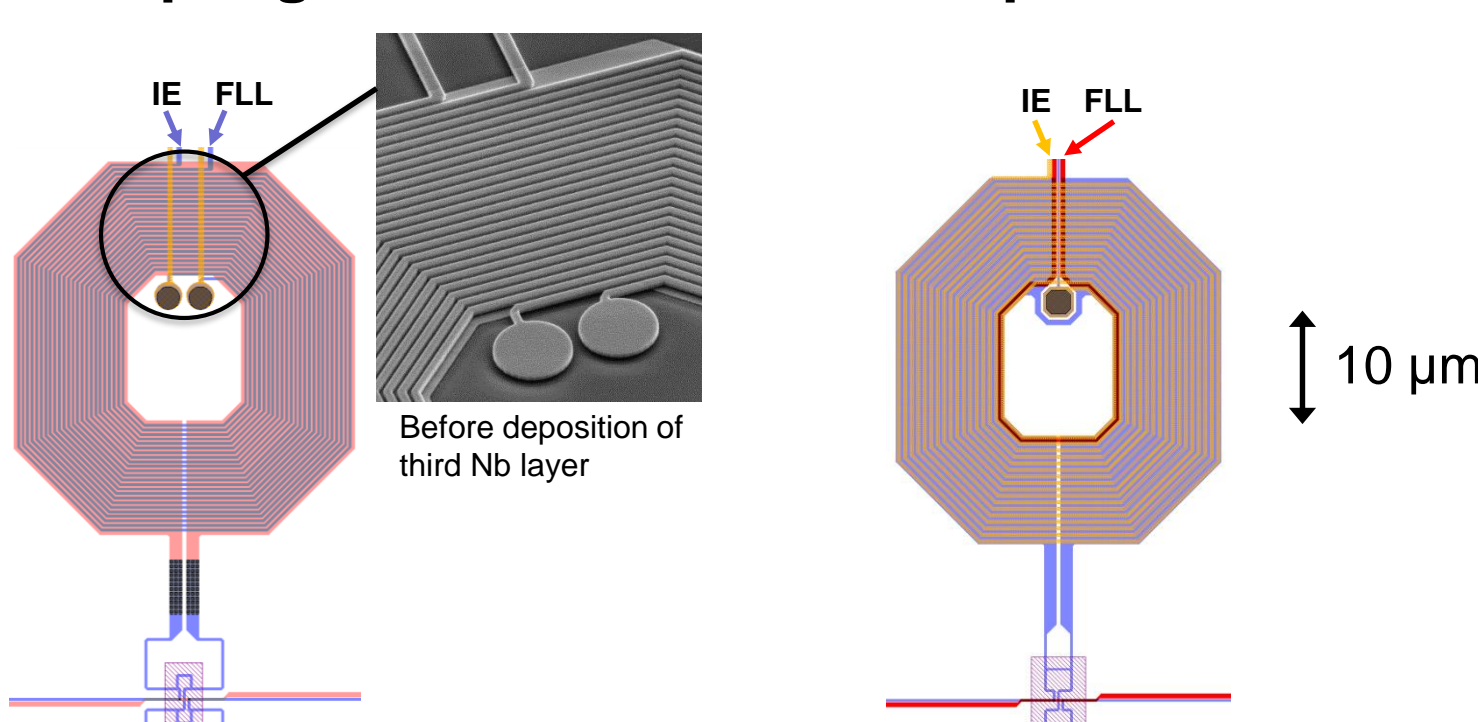
Coupling transformers

- feedback, input or excitation lines are gradiometric and galvanically separated from the SQUID loop by a coupling transformer
- different types of transformers available:

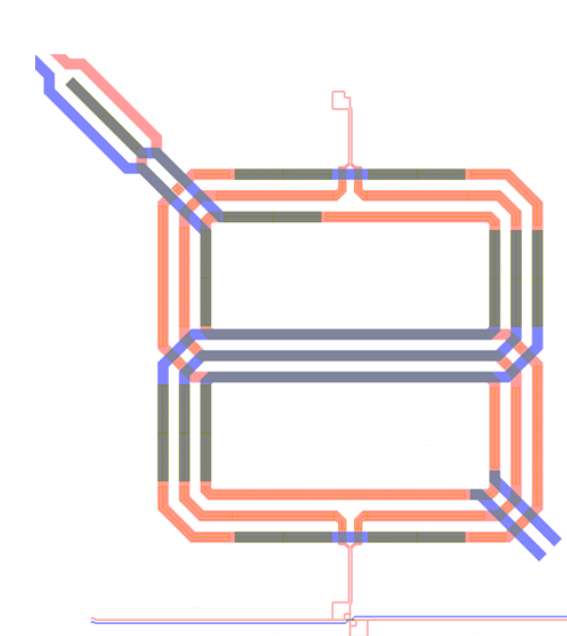**Coupling transformer of current sensor (CTC)**
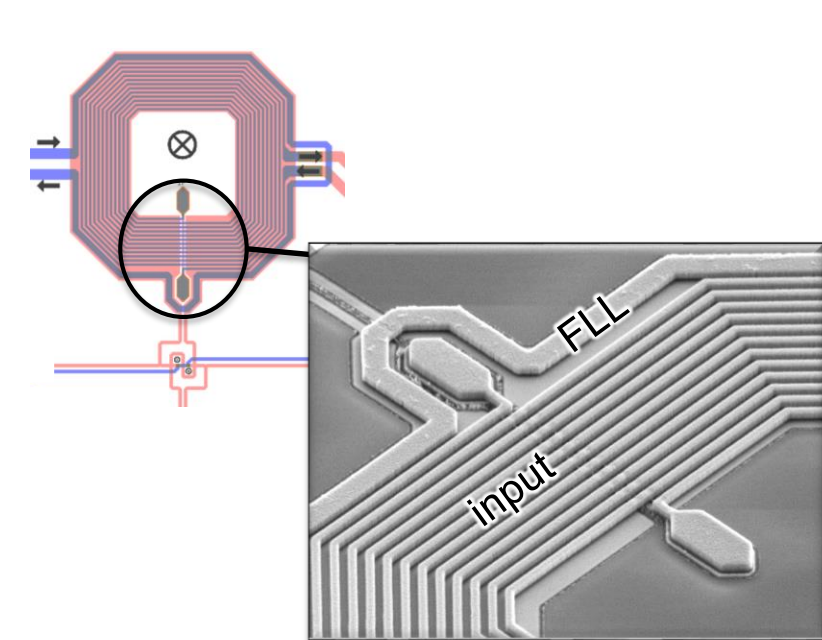
width of lines (input/FLL)	200 nm / 600 nm
number of turns	12 / 1
width of washer	5.8 µm
current sensitivity	0.05 mA/Φ_0 / 0.5 mA/Φ_0

Coupling transformers of susceptometers

Before deposition of third Nb layer

width of lines	200 nm
number of turns	12 each
width of washer	10 µm

width of lines	200 nm
number of turns (excitation/FLL)	17 / 1
width of washer	10 µm

Gradiometric coupling transformer (GCT)

width of lines	2 µm
current sensitivity*	2.9 mA/Φ_0

Bias reversal transformer (BRT)
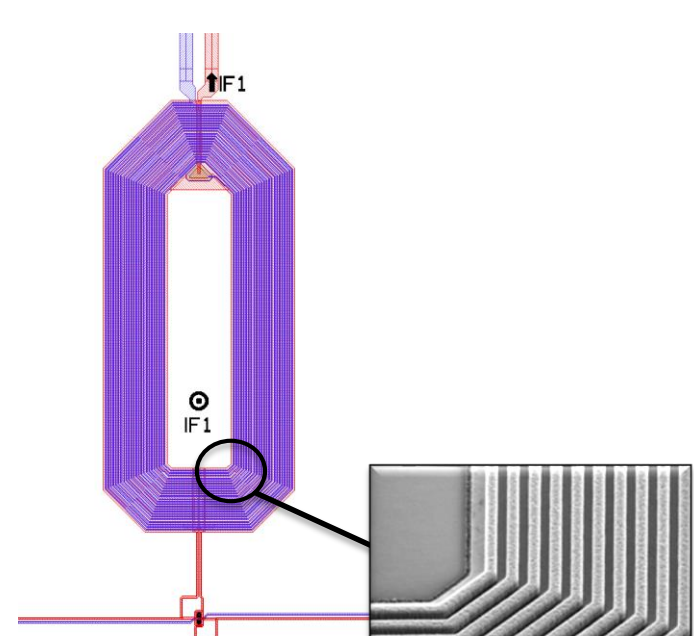
width of lines	200 nm
number of turns	24
width of washer	10 µm
current sensitivity*	0.15 mA/Φ_0

C7 transformer (C7T)

width of lines of washer	1.5 µm width 8 µm
current sensitivity*	3.4 mA/Φ_0

* coupled to nSQUID series gradiometer

nanoSQUID series array (nSSA)

- lateral dimensions of JJs — 150 nm x 150 nm
- width of lines — 300 nm
- number of turns — 4 (2 in Nb layers 1 and 3, each)
- width of washer — 900 nm
- number of single SQUIDs — 64, 128, 256
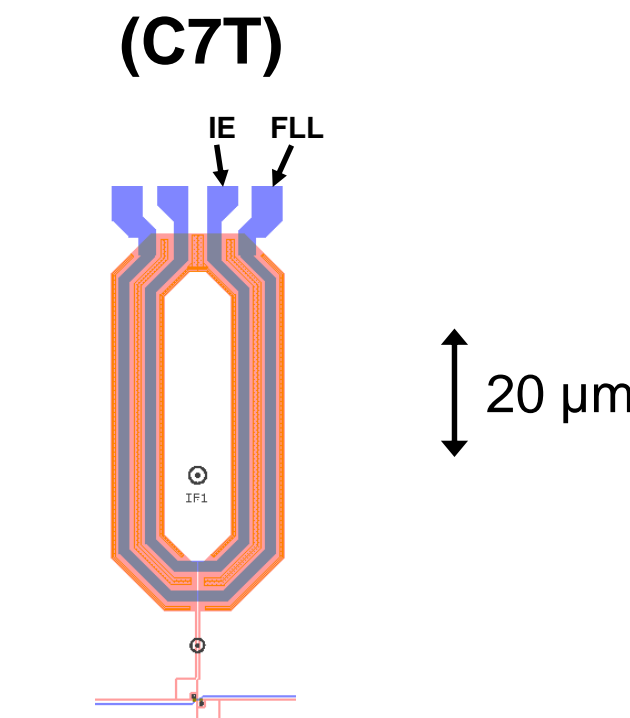
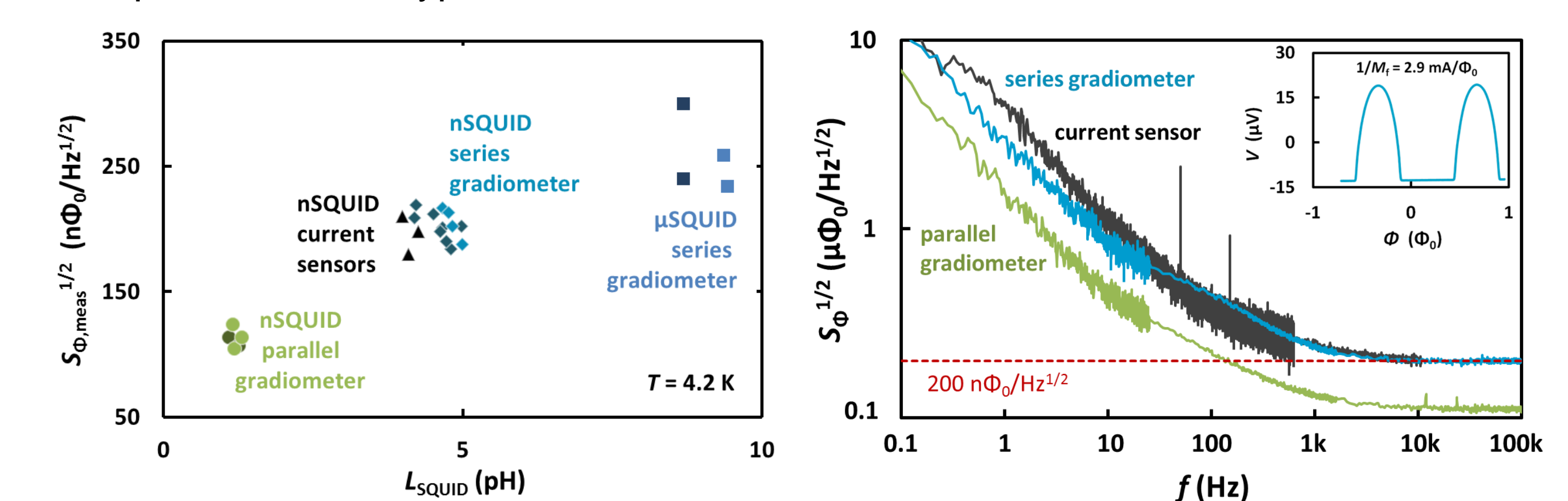## Operation in dc magnetic fields

- SQUID parameters degrade with applied magnetic field B — depending on the type of transformer

02-02-C1: nSQUID series gradiometer with GCT
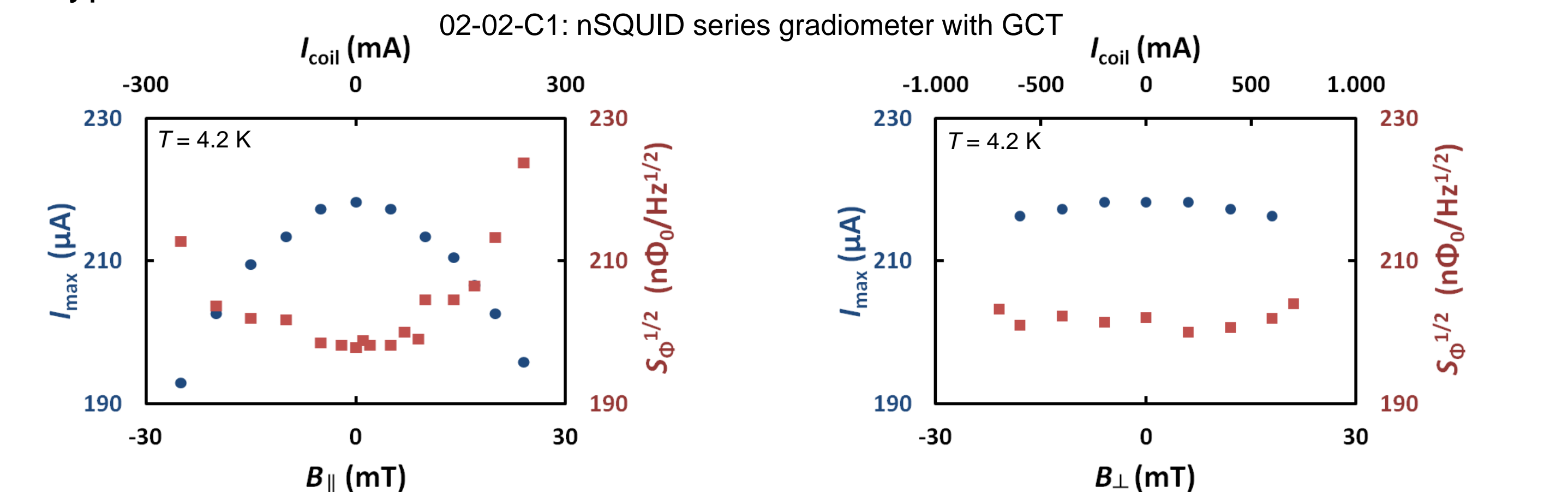
Magnetic flux noise

- increases with SQUID inductance L_{SQUID}
- independent of the type of transformer

Outlook

- Nb/HfTi/Nb nanoSQUIDs with high linearity available for experiments in dc and ac magnetic fields
- new devices under investigation, e.g. combination of susceptometer and nSSA
- at the moment we are testing further improvements:
    - implementing a third Nb layer to increase the coupling
    - avoiding large JJs as vias by using the third Nb layer

[1] S. Bechstein, et. al. ‚HfTi-nanoSQUID gradiometers with high linearity,‘ Applied Physics Letters 106, 072601 (2015).
[2] S. Bechstein, et. al. ‚Investigation of nanoSQUID designs for practical applications,‘ Supercond. Sci. Technol. 30, 034007 (2017).