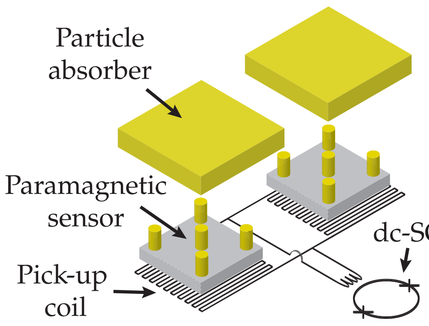
Microwave SQUID Multiplexing for Metallic Magnetic Calorimeters

Mathias Wegner, Kirchhoff-Institut für Physik, Heidelberg University

Metallic magnetic calorimeters

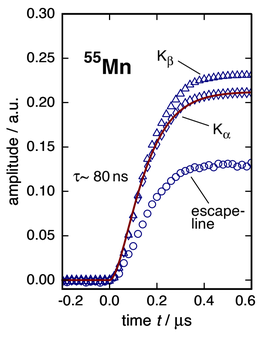


Energy deposition	Temperature rise	Decrease of magnetization	Change of magnetic flux
δE	$\rightarrow \delta T = \frac{\delta E}{C_{\mathrm{tot}}}$	$\rightarrow \delta M = \frac{\partial M}{\partial T}\frac{\delta E}{C_{\mathrm{tot}}}$	$\rightarrow \delta\Phi \propto \delta M \propto \delta E$

Impedance matching for optimal detector readout:

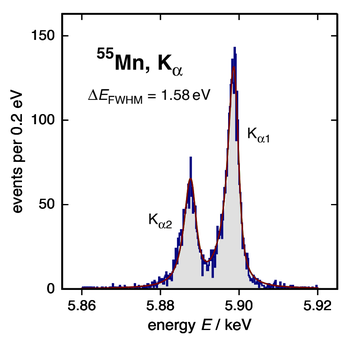
$$L_{\mathrm{in}} = L_{\mathrm{det}}/2 + L_{\mathrm{par}}$$

Very fast signal rise time



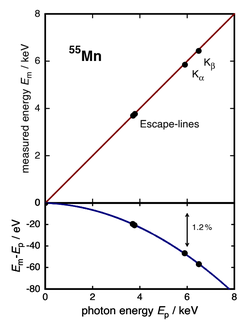
→ Large readout bandwidth

Very good energy resolution



→ Low readout noise

Excellent linearity

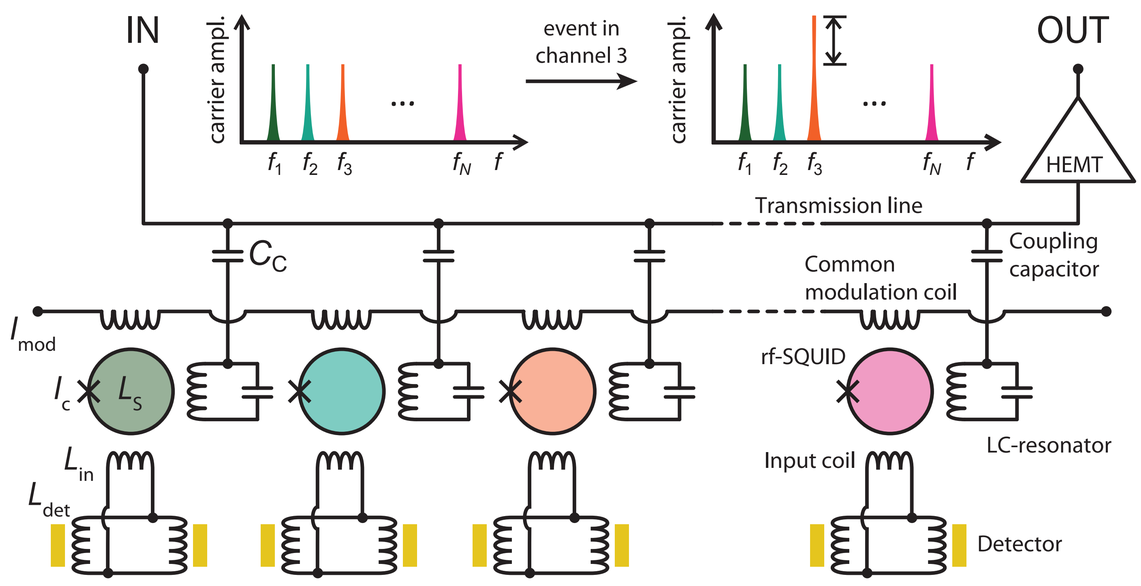


→ Linear signal readout

Single channel readout not suited for large detector arrays → Microwave SQUID Multiplexing

Principle of microwave SQUID multiplexing

Energy deposition	Change of magnetic flux	Change of SQUID inductance	Shift of resonance frequency	Increase of HF amplitude
δE	$\rightarrow \delta\Phi$	$\rightarrow \delta L$	$\rightarrow \delta f_{\mathrm{r}}$	$\rightarrow \delta A$



Two coaxes + one HEMT amplifier → 1000 channels

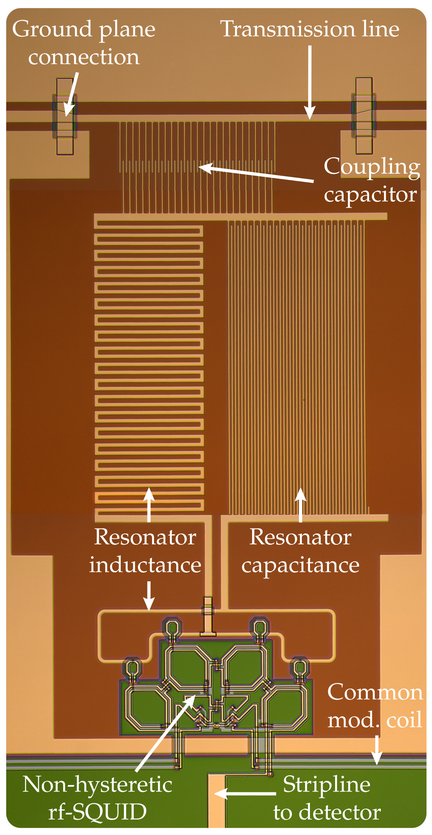
Multiplexer design "ECHo_LEMUX"

Lumped element resonators made of niobium

- Bandwidth $\Delta f = 1\,\mathrm{MHz}$ to resolve signal rise time τ_0
- Intrinsic quality factor $Q_{\mathrm{i}} > 1.000.000$

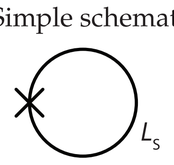
  Power consumption $P_{\mathrm{diss}} < 10\,\mathrm{pW/channel}$

  Bandwidth Δf adjustable by coupling capacitor C_{C}

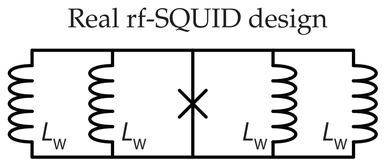


Non-hysteretic, unshunted rf-SQUIDs

Simple schematic



Real rf-SQUID design

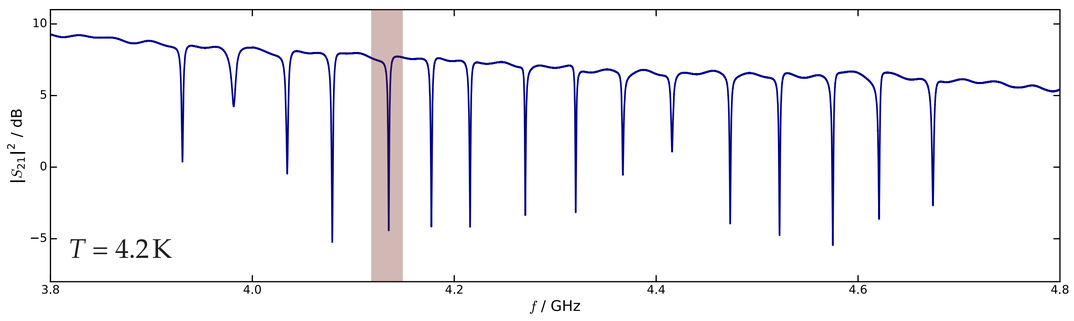


- Parallel gradiometer consisting of four single washers

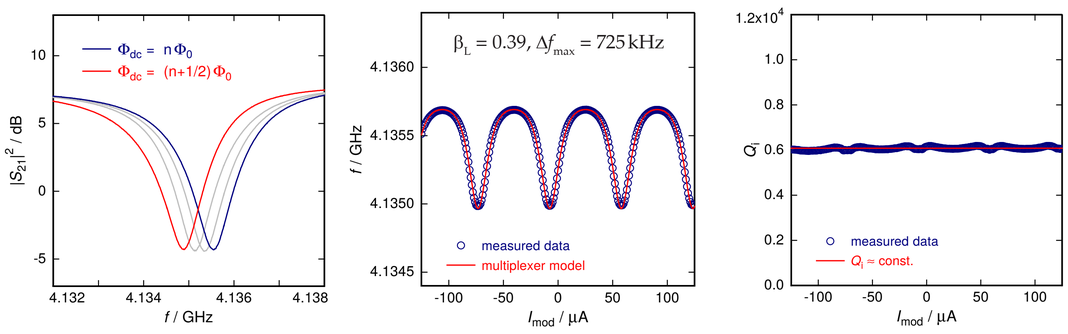
  Suppression of background field changes

  Small rf-SQUID inductance $L_{\mathrm{S}} = 45\,\mathrm{pH}$
- Input coil inductance $L_{\mathrm{in}} = 1.5\,\mathrm{nH}$ matched to detector
- Small parasitic coupling between different SQUID coils

Multiplexer characterization



Detailed characterization of channel 5 (representative for all channels)



Very good agreement with multiplexer model + extracted parameters close to design values

Scaling up for large detector arrays

Problem: Deviation between measured f_{r} and designed f_{r} due to fab accuracy → Post-processing

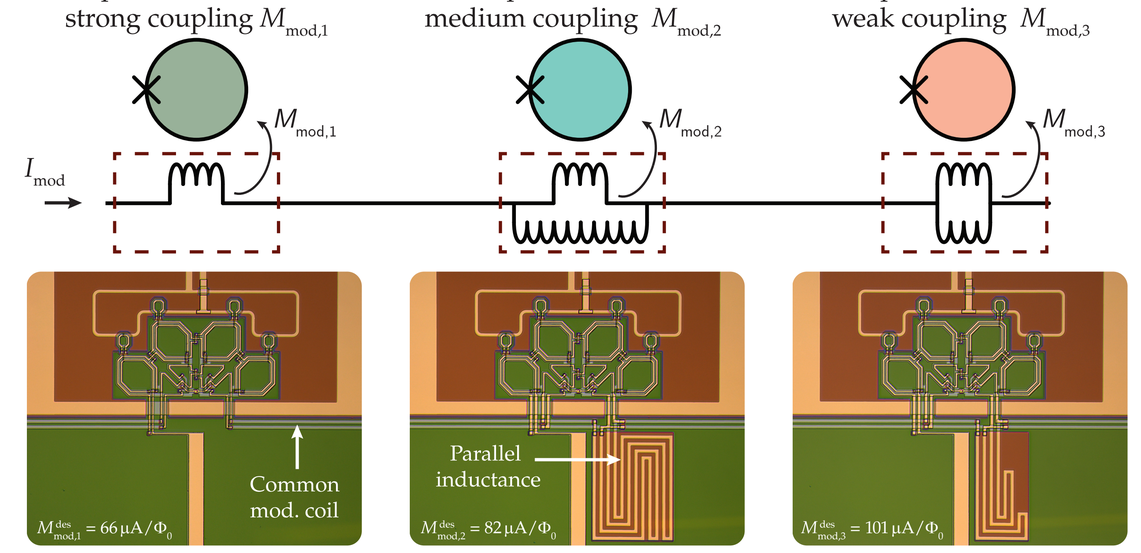
Post-processing: Identification of multiplexer channels

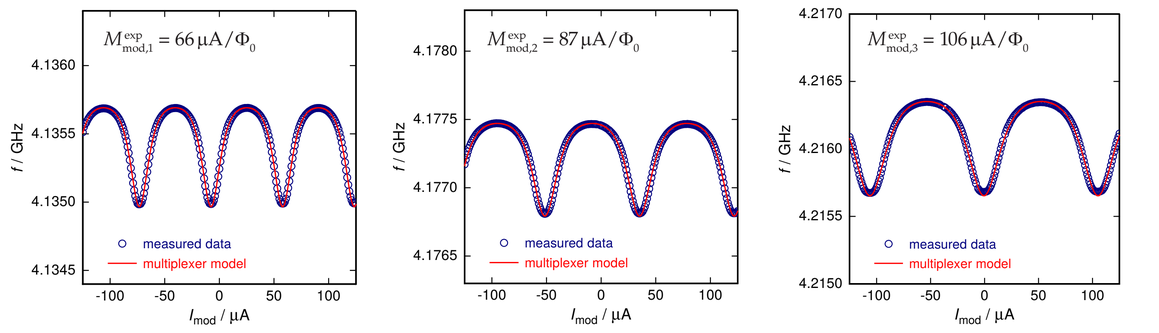
- Channel identification via parallel inductances which lead to reduced couplings $M_{\mathrm{mod,i}}$

No parallel inductance: strong coupling $M_{\mathrm{mod,1}}$

Midsize parallel inductance: medium coupling $M_{\mathrm{mod,2}}$

Small parallel inductance: weak coupling $M_{\mathrm{mod,3}}$

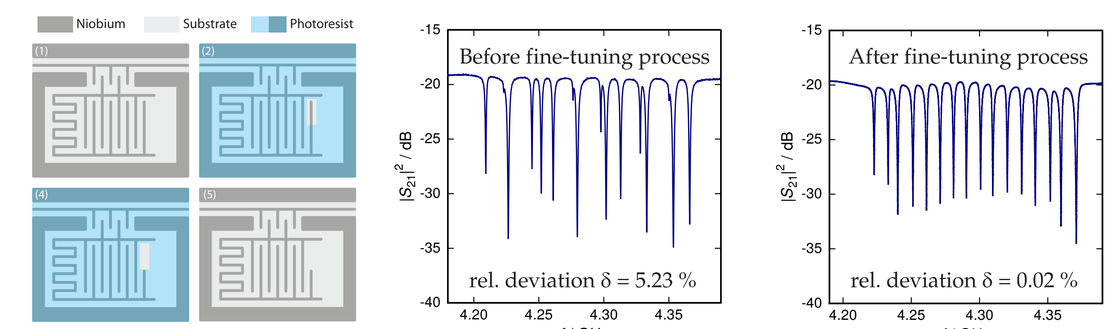




- Removing of parallel inductances during fine-tuning of resonance frequencies

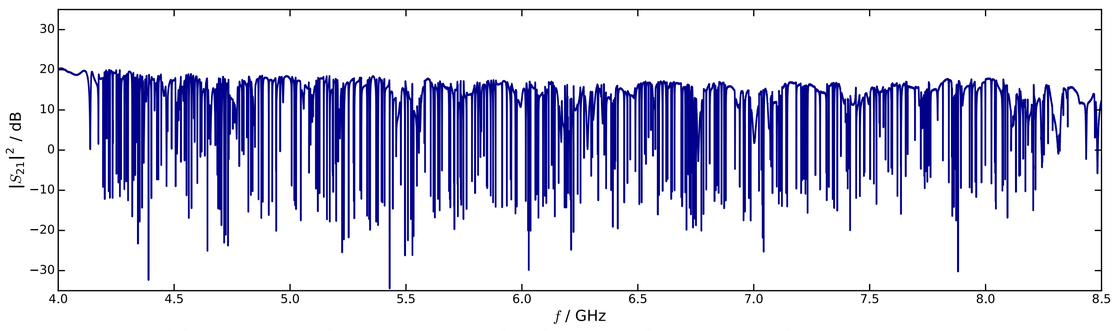
Post-processing: Fine-tuning of resonance frequencies

Measure resonance frequency → Calculate new resonator parameters → Etching process



- Fine-tuning of resonance frequencies f_{r} allows for a resonance frequency spacing $\Delta f_{\mathrm{r}} = 10\,\mathrm{MHz}$

First array based on 400 bare lumped element resonators



- Next step: Fabrication of large array multiplexer with fine-tuned resonance frequencies

References

[1] M. Wegner *et al.*, Microwave SQUID Multiplexing of Metallic Magnetic Calorimeters: Status of Multiplexer Performance and Room-Temperature Readout Electronics Development, *J. Low Temp. Phys.* **193**, 462 (2018)

[2] S. Kempf *et al.*, Design, fabrication and characterization of a 64 pixel metallic magnetic calorimeter array with integrated, on-chip microwave SQUID multiplexer, *Supercond. Sci. Technol.* **30** (2017) 065002

[3] S. Kempf *et al.*, Demonstration of a scalable frequency-domain readout of metallic magnetic calorimeters by means of a microwave SQUID multiplexer, *AIP Advances* **7** (2017) 015007