Toward a millimeter imaging spectrometer using magnetic field tunable kinetic inductance detectors (KIDs)

L.Soriano[1], E.Prêle[1], M.Calvo[1], A.Monfardini[1] and F.Levy-Bertrand[1]

[1]*Univ. Grenoble Alpes,CNRS,Grenoble INP, Institut Néel, 38000, France*

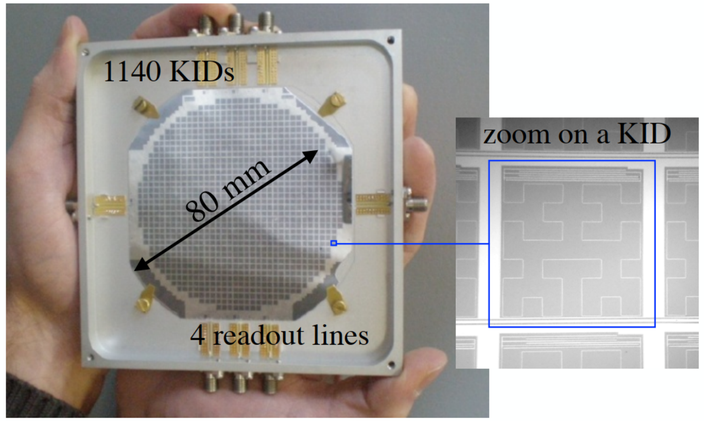
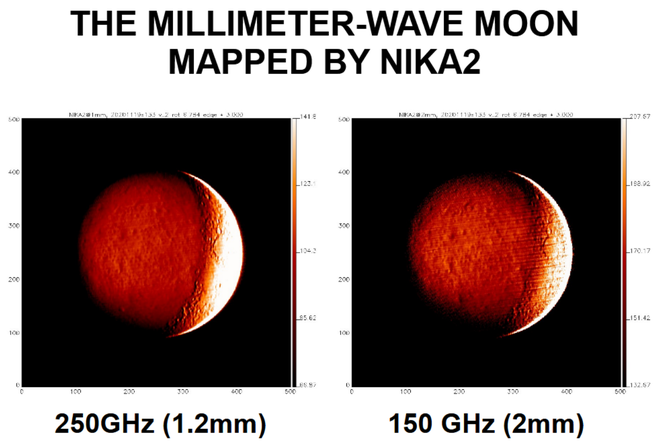


Photo of a KID array installed in the NIKA2 mm-camera

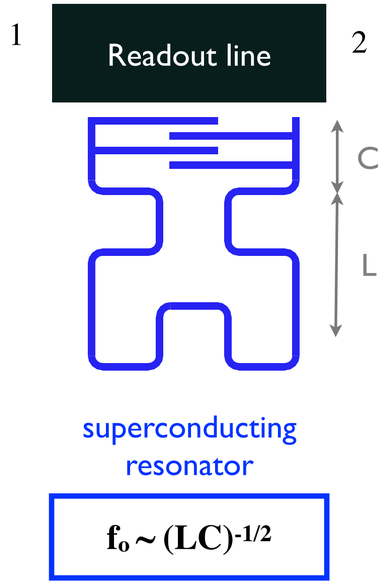


© K.Zacher, IRAM 30 M telescope located on the Pico Veleta, Spain

Working principle of KIDs

Planar superconducting LC resonator on an insulating substrate

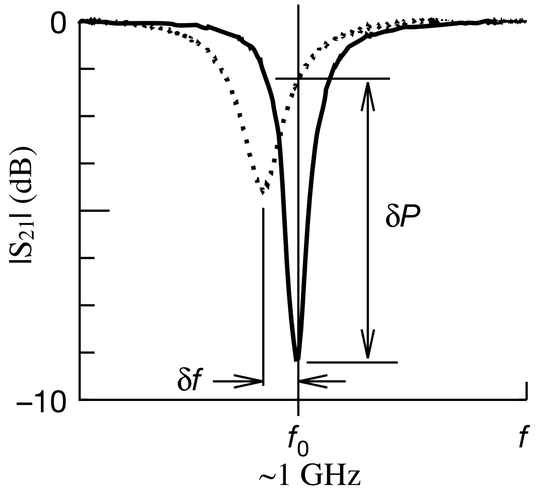
Design



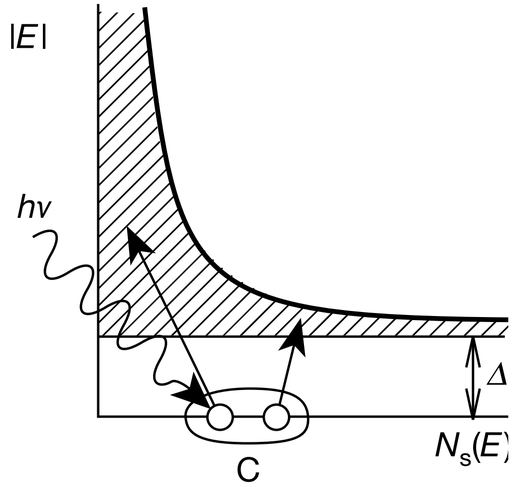
$f_o \sim (LC)^{-1/2}$

$L \sim 1/N_s$ kinetic inductance

RF-electrical measurement



Superfluid density N_s



2Δ Superconducting gap (depend on material)

Day et al, Nature 425, 817 (2003)

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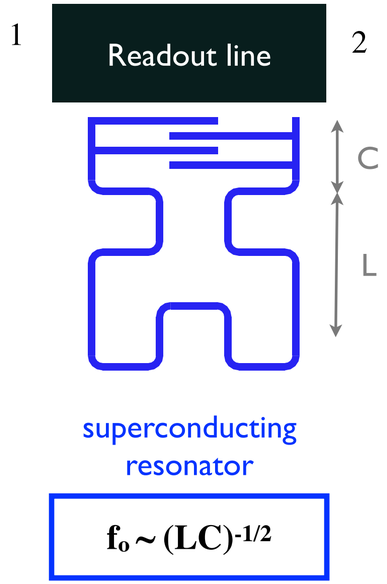

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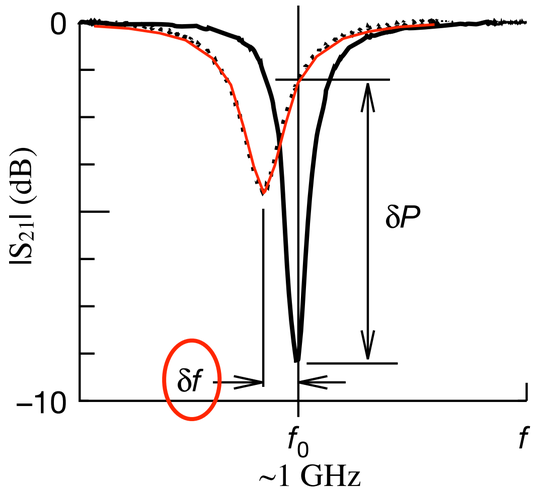
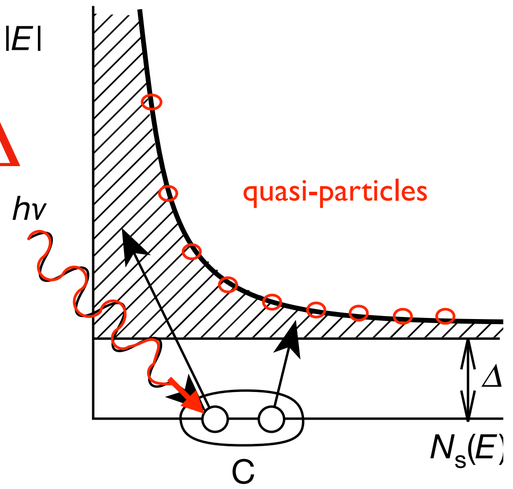


δf due to change in N_s

Q-factor ↘ due to dissipation

Superfluid density N_s

$h\nu > 2\Delta$



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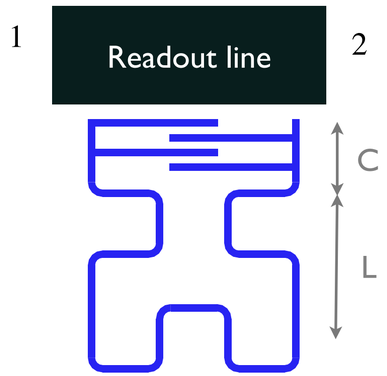

superconducting resonator

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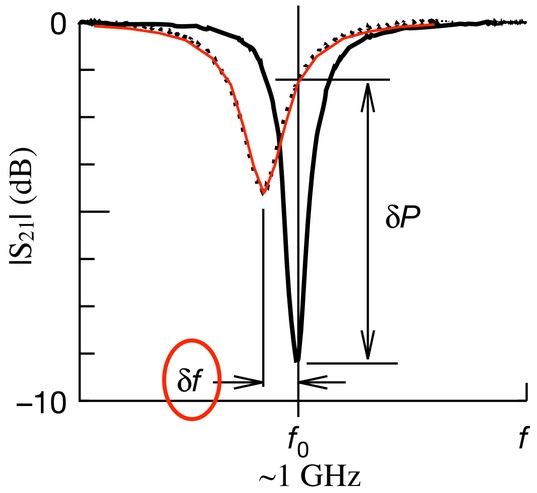

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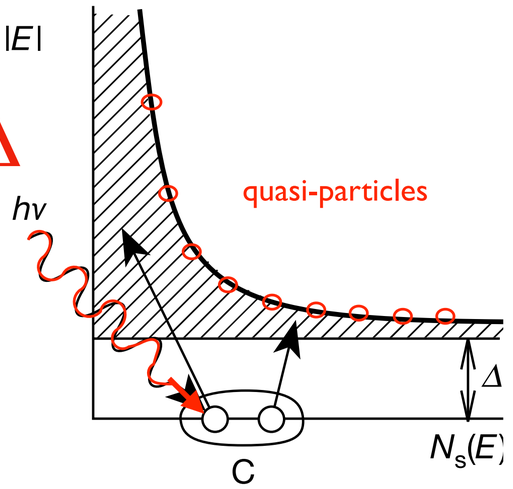
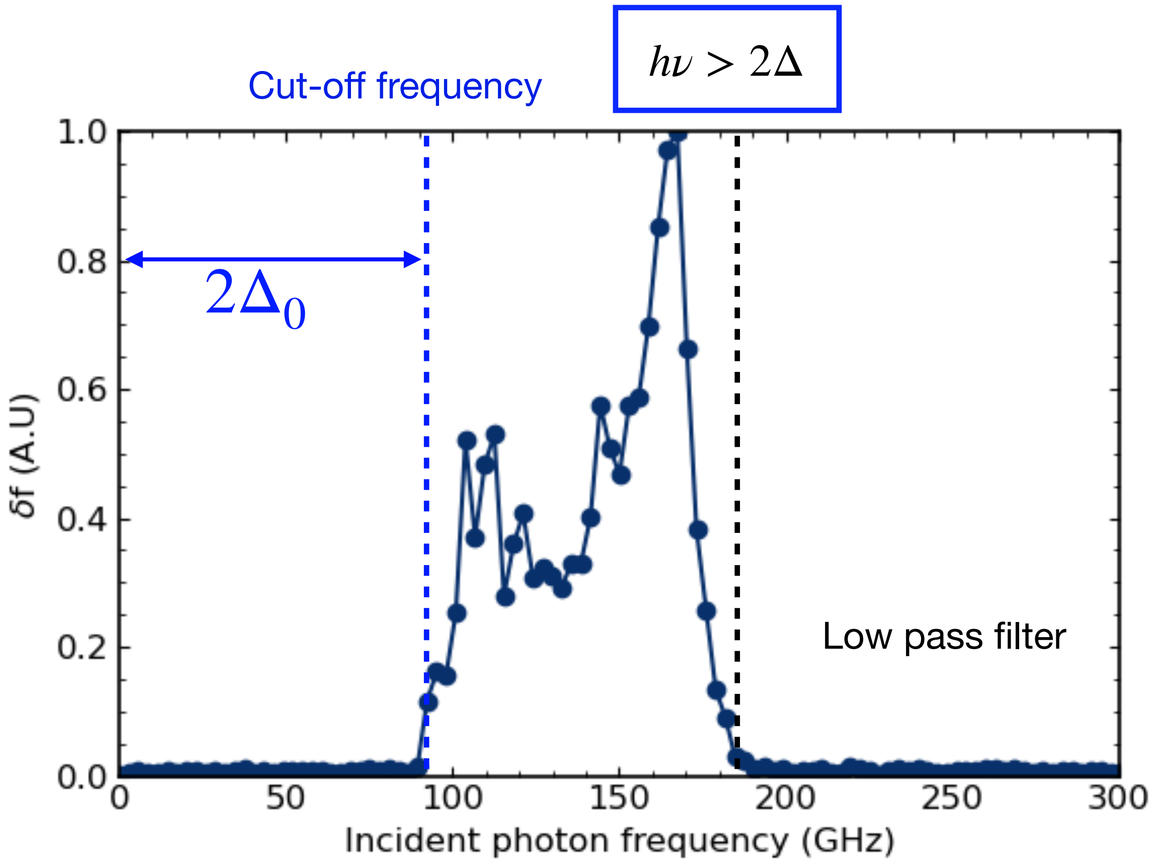


2Δ Superconducting gap (depend on material)

Photon detection of $h\nu > 2\Delta$ through frequency shift $\delta f \propto P(h\nu)$

Day et al, Nature 425, 817 (2003)

HKID project



Applied Physics Letters 126, 042602 (2025).

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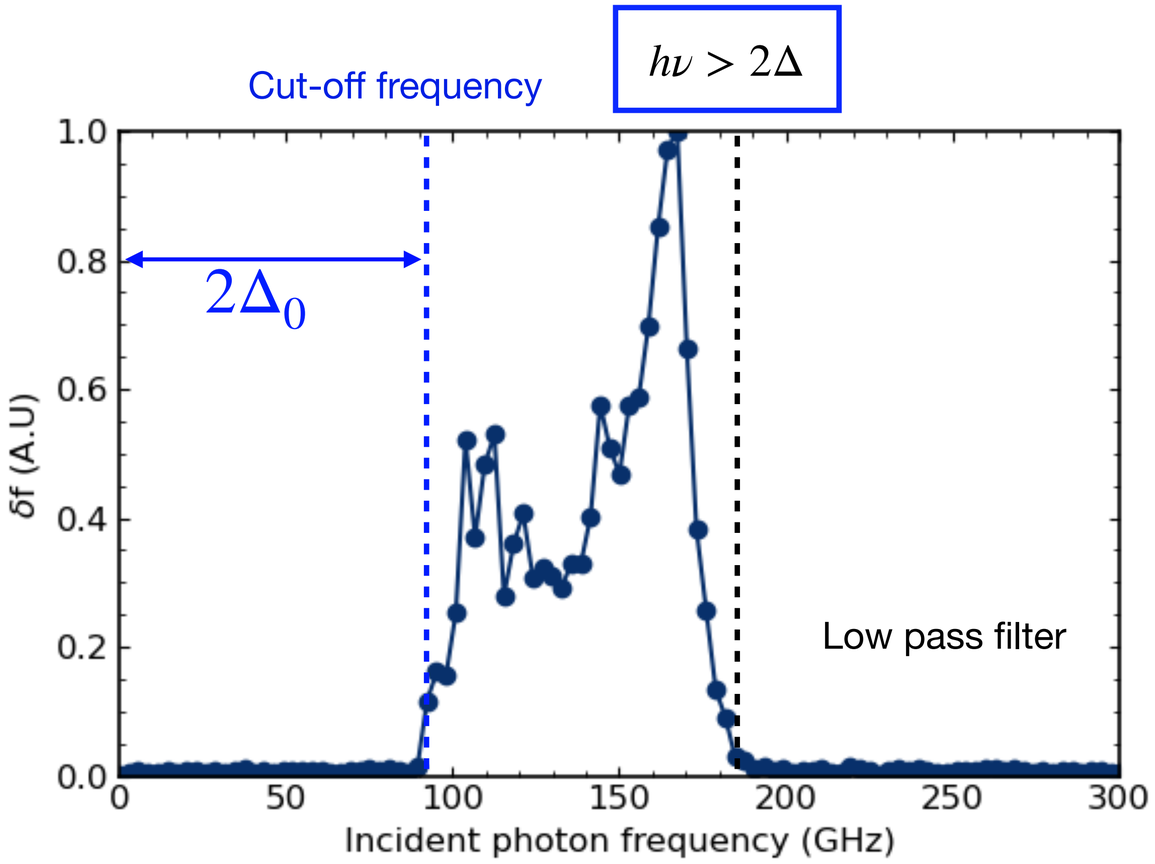

$$\Delta(H) = \Delta_0\sqrt{1 - (\frac{H}{H_c})^2}$$

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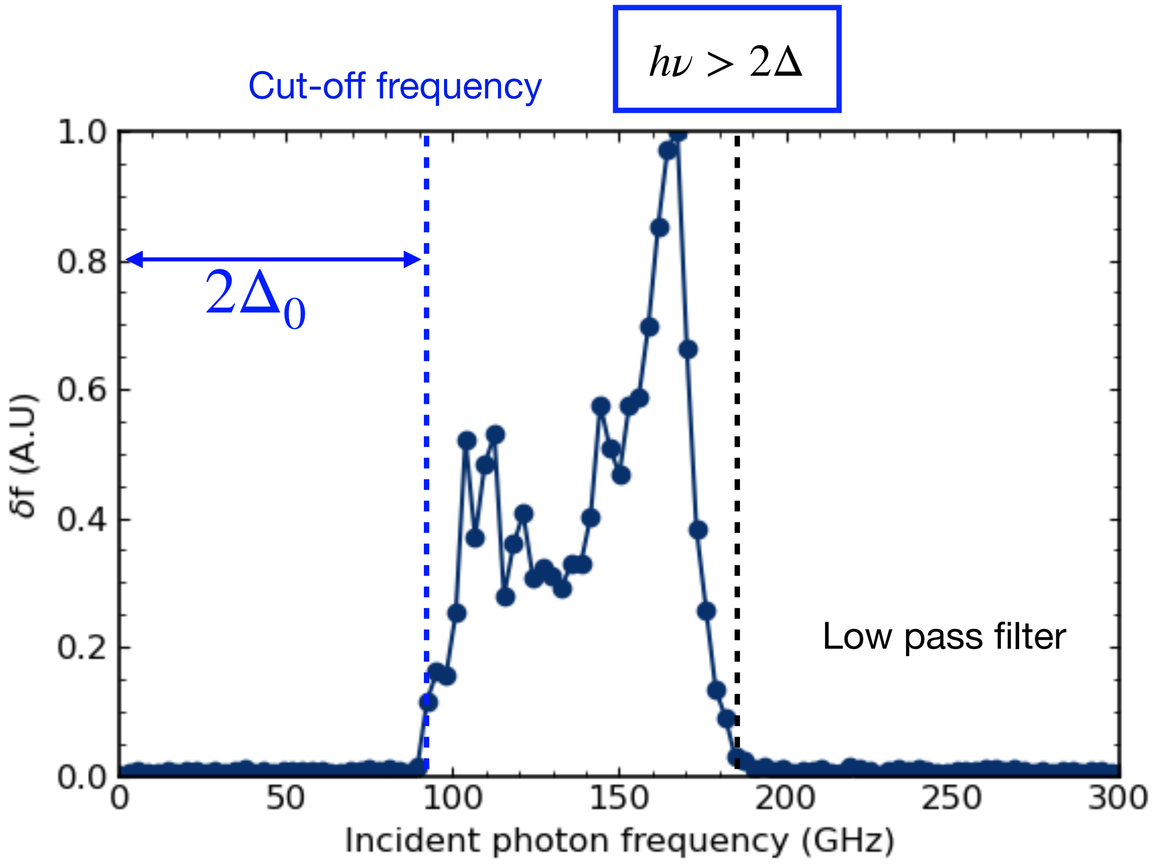

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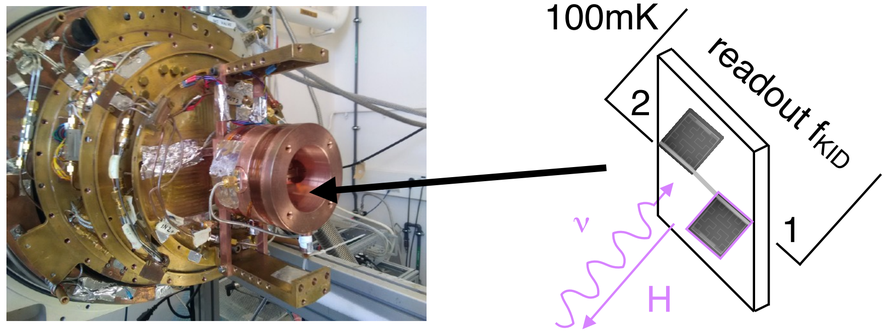

NbTi superconducting coil

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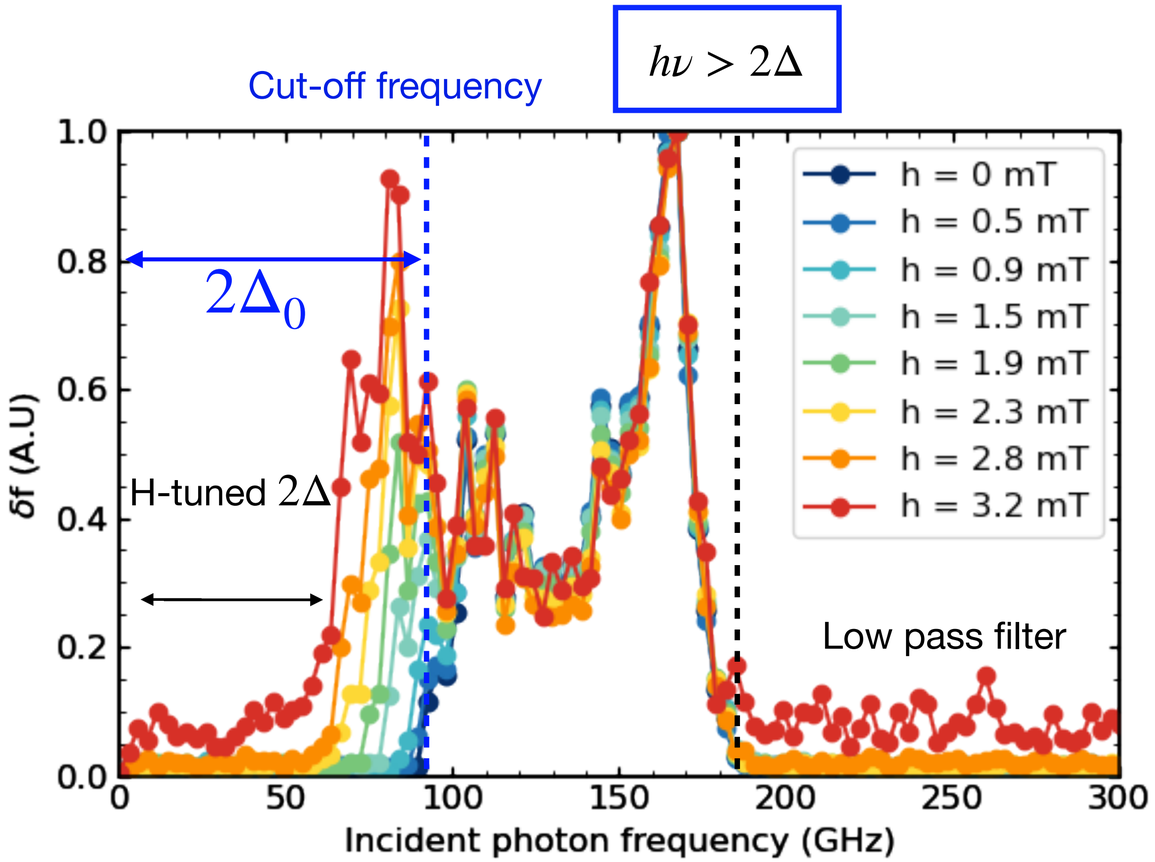
HKID project



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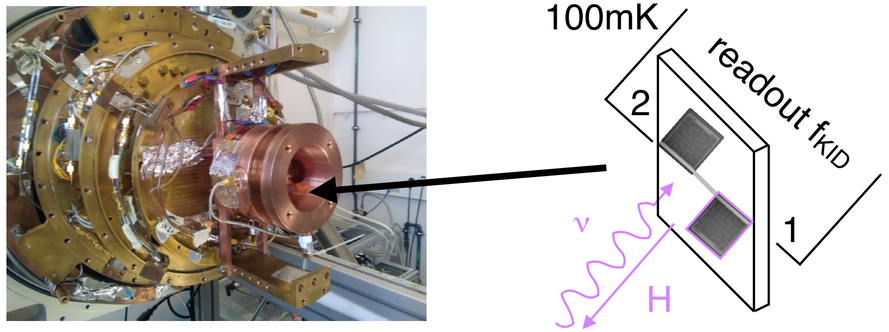

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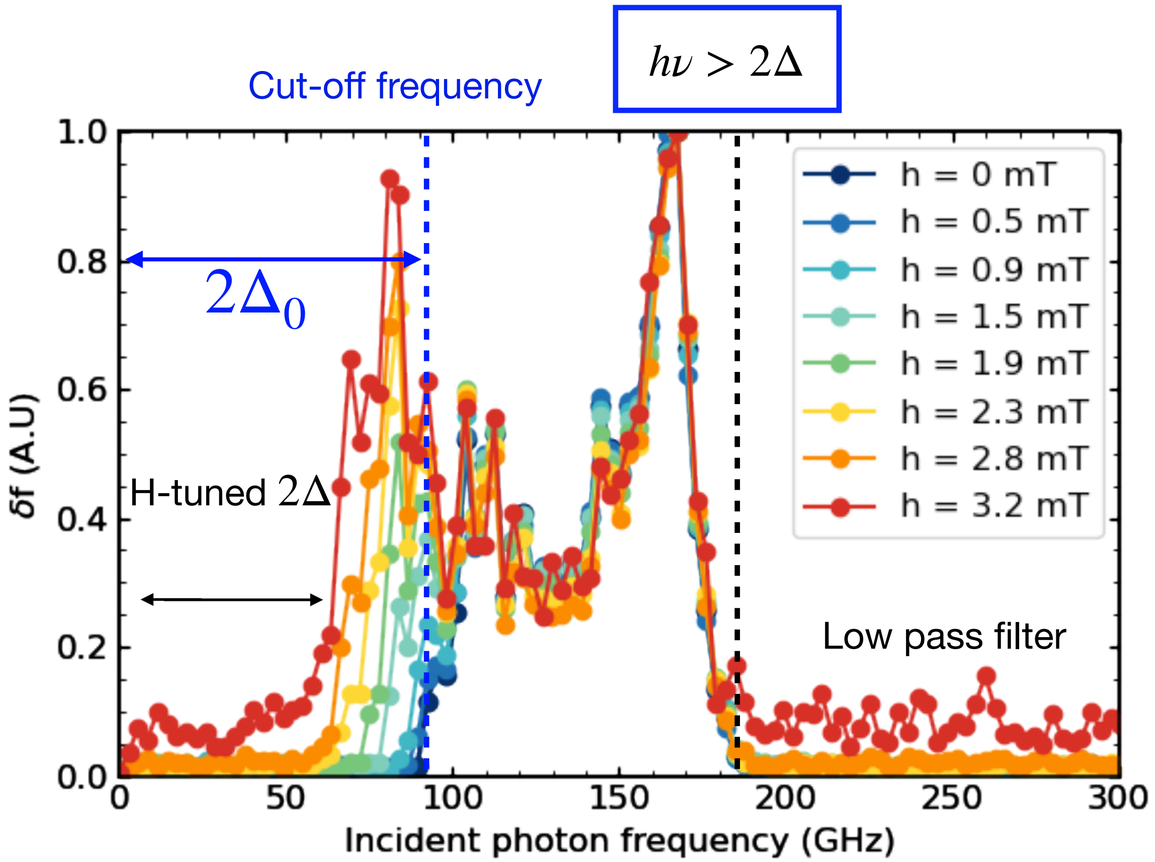

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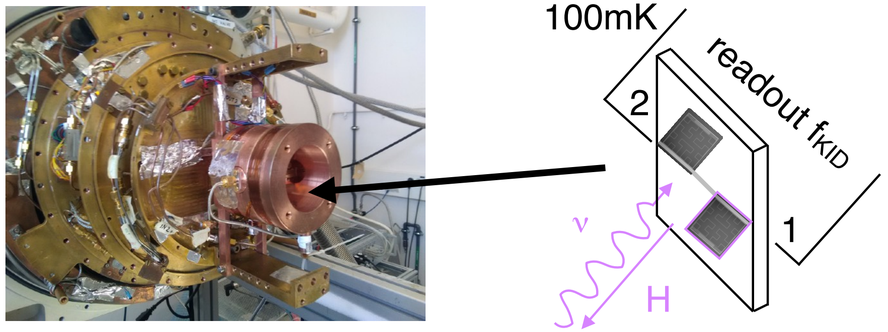

NbTi superconducting coil

Photon detection is tunable

Possibility of spectroscopy at different frequency bands

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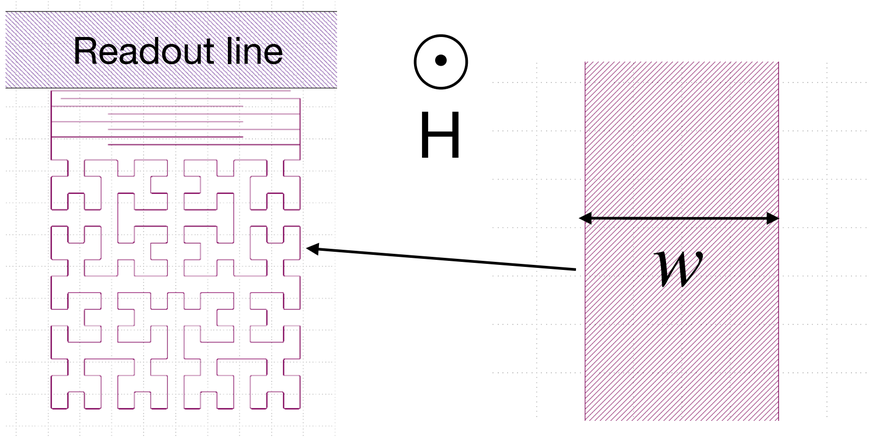
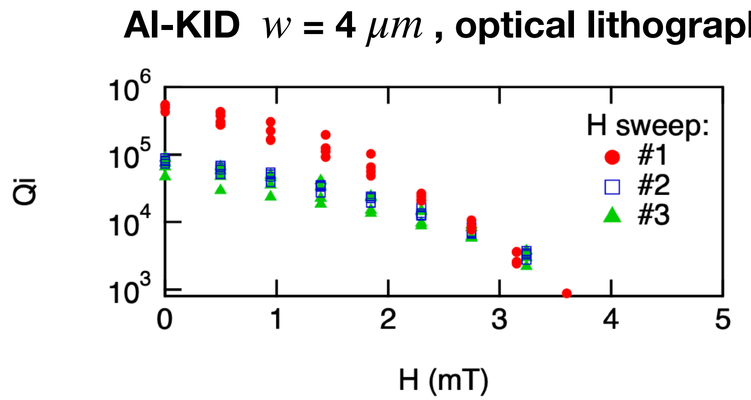
Magnetic field effect on KIDs : reproducibility





KIDs electrical response depends on H-history

Vortex motion creates dissipation and affects Q_i

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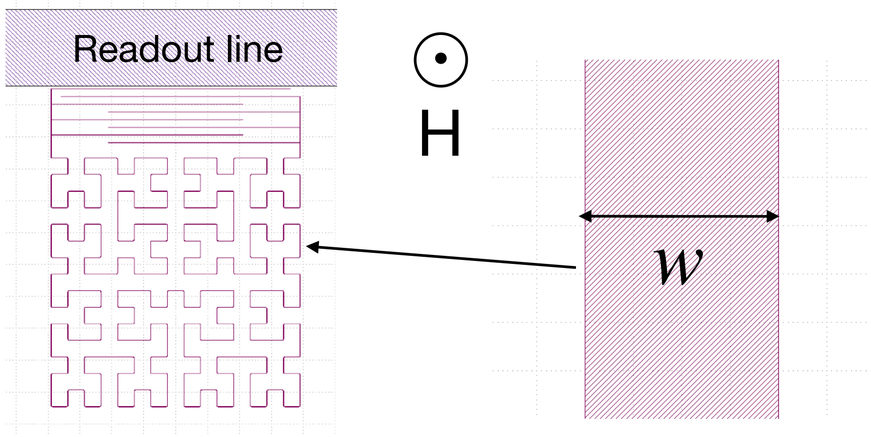
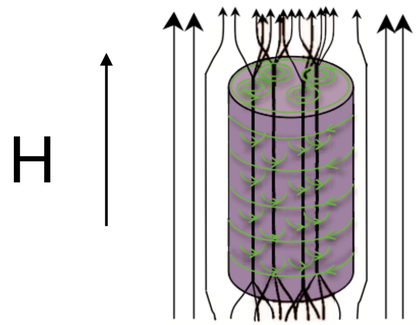




Supercurrent circulating around a normal core

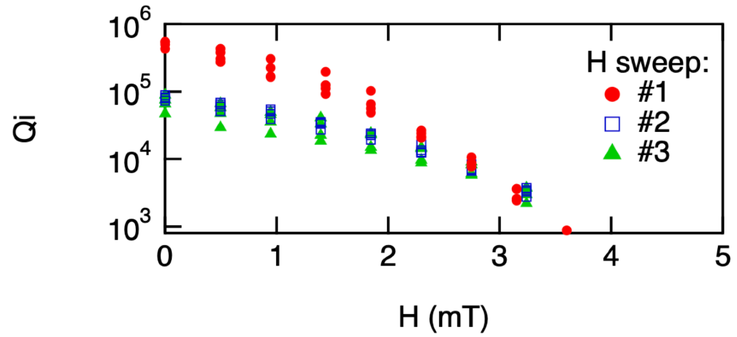
Magnetic flux quantum ϕ_0

Prevent vortex formation

$$H > \frac{\pi\phi_0}{4w^2}$$

For H = 40 mT : w < 200 nm

Al-KID w = 4 μm , optical lithography



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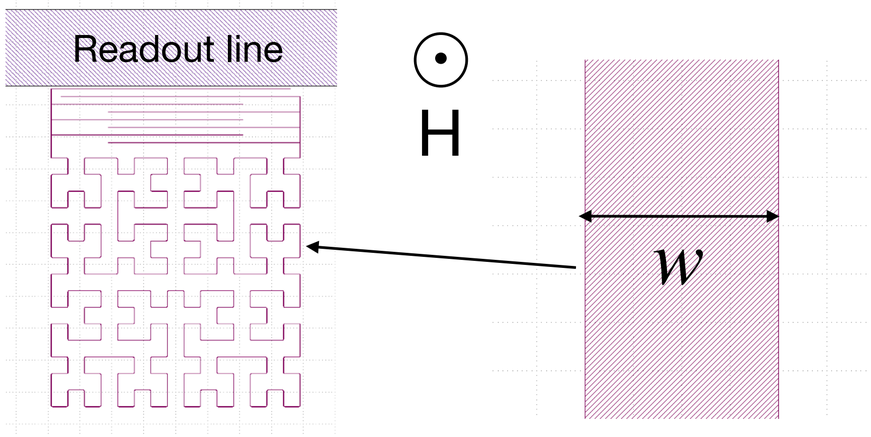

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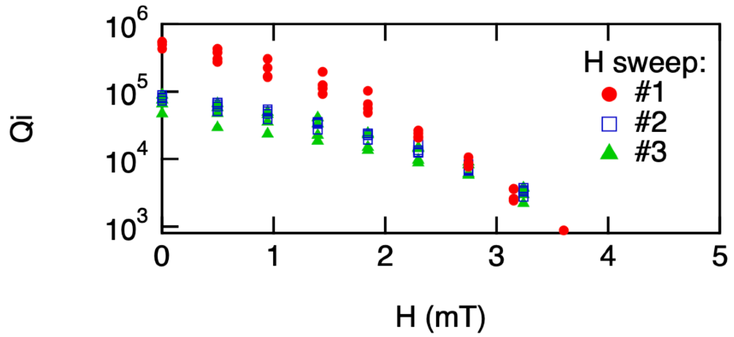

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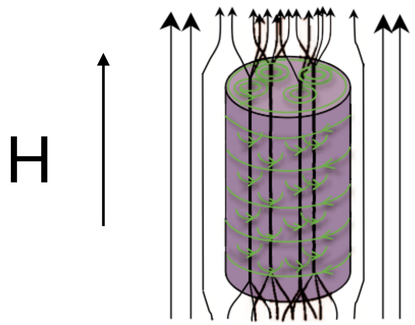

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w = 200 nm
Possible with electronic lithography !

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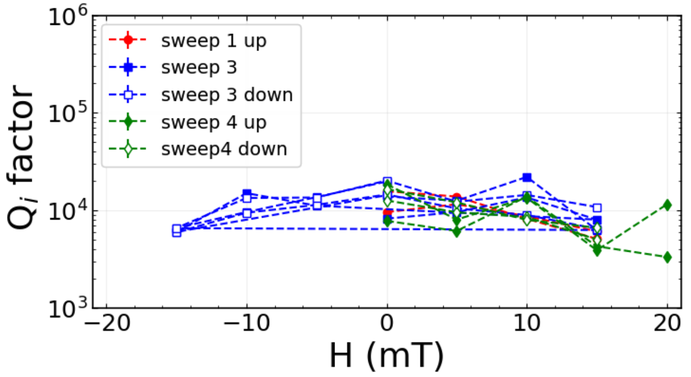
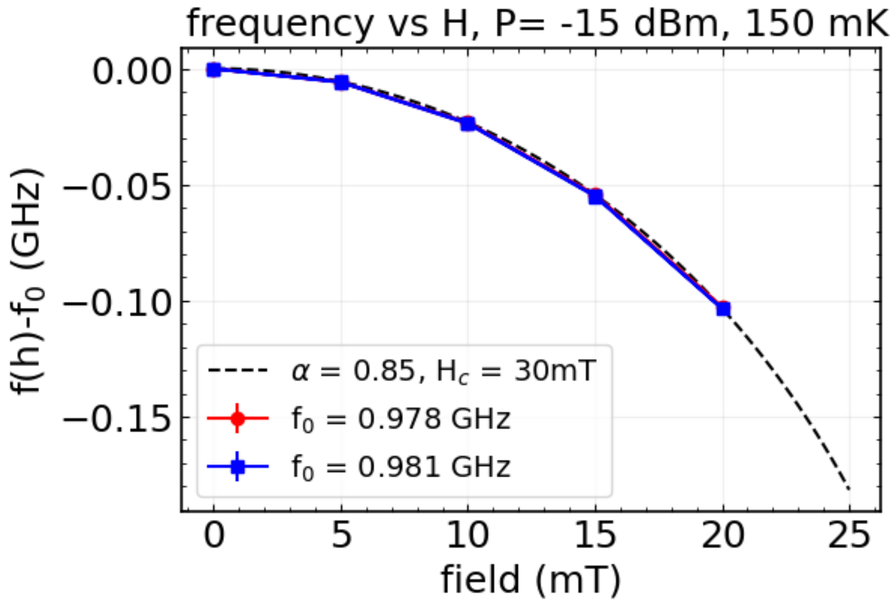


Reproducible while sweeping up and down

Vortex-free KIDs for w= 200 nm

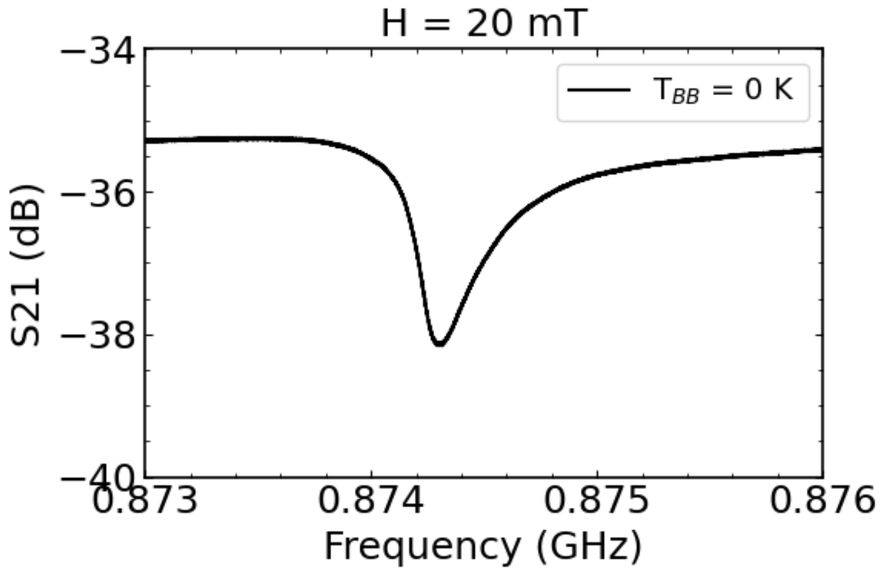
Magnetic field effect on KIDs : $\delta f(H) >> \delta f(h\nu)$

Field contribution $\delta f(H)$



$$\delta f(H) = (1 - \frac{\alpha}{2}(1 - \sqrt{1 - \frac{H^2}{H_c^2}}))f_0$$

VNA response



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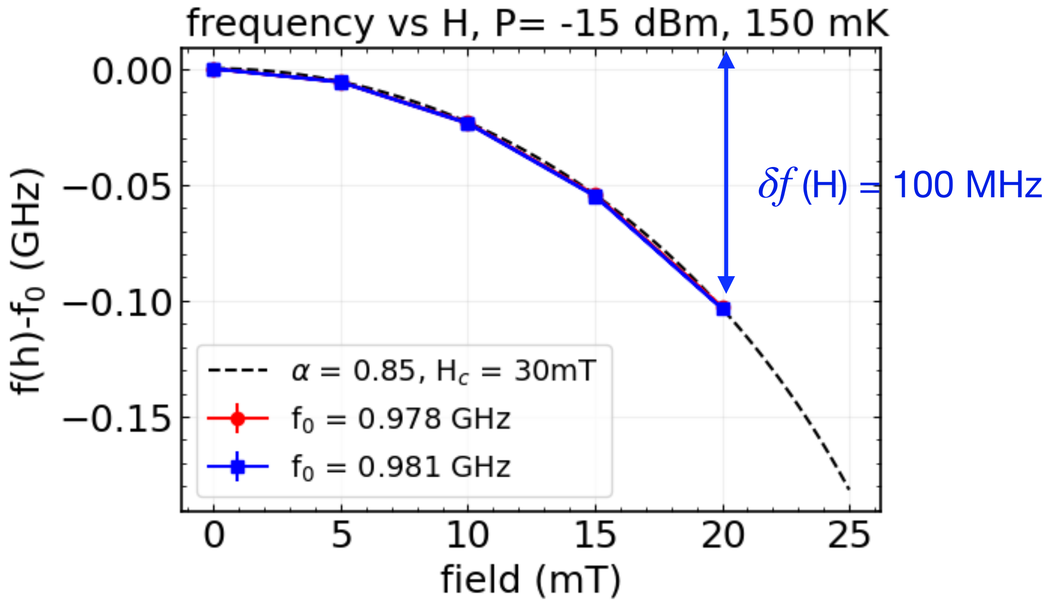

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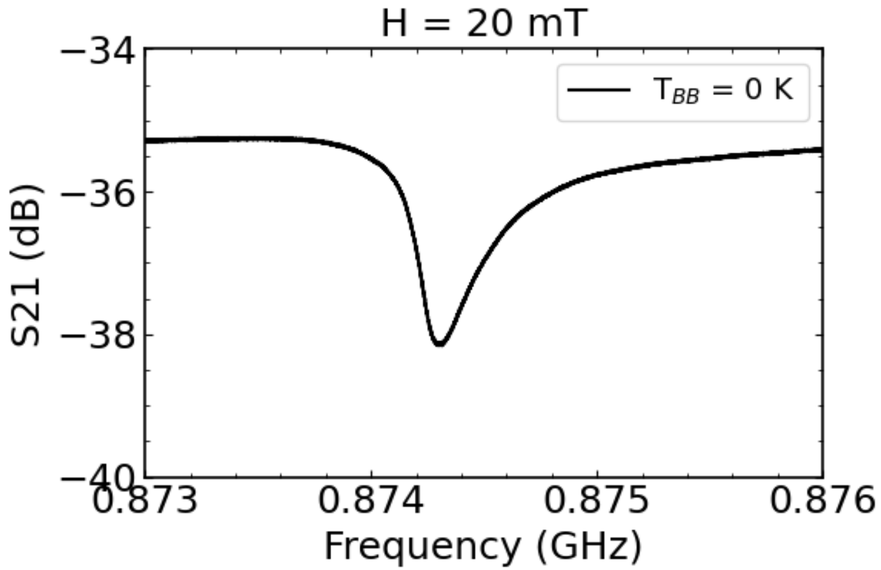

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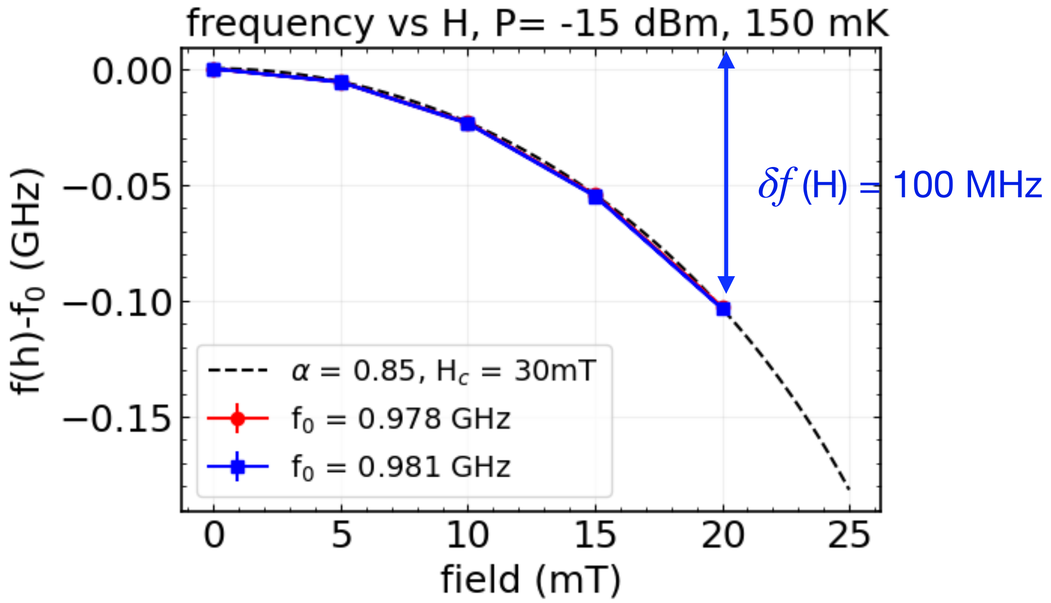

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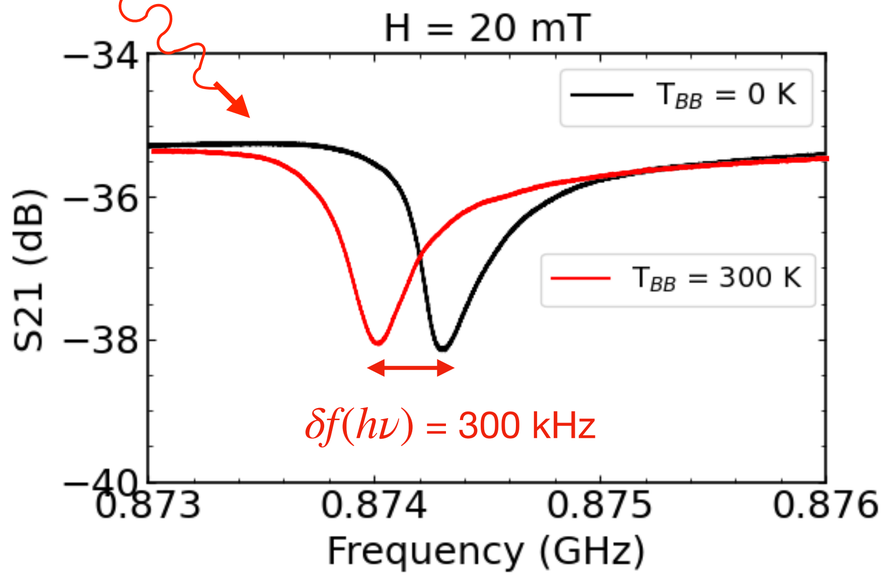
$h\nu > 2\Delta$



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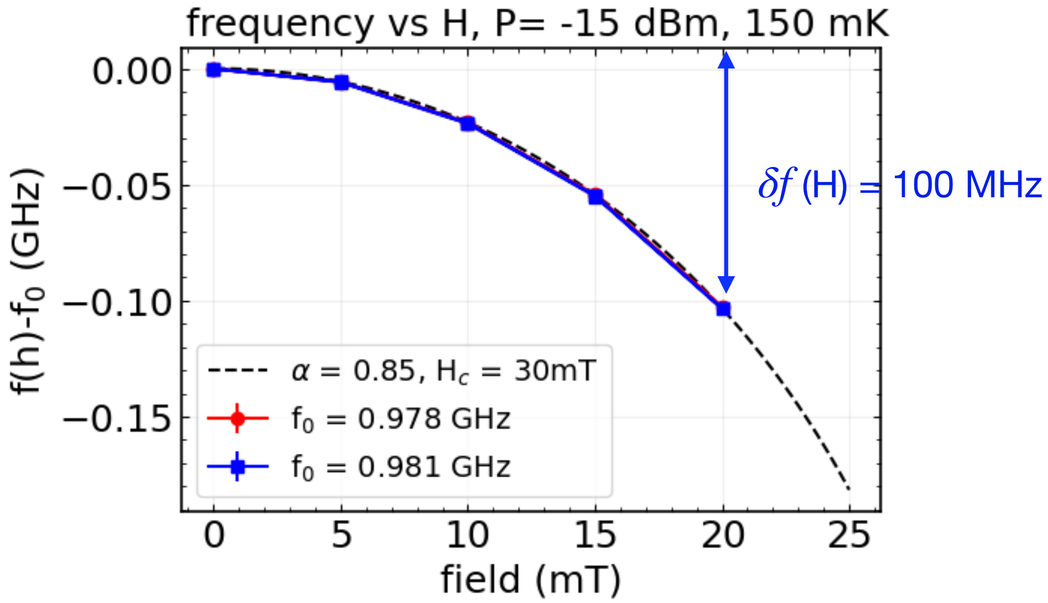

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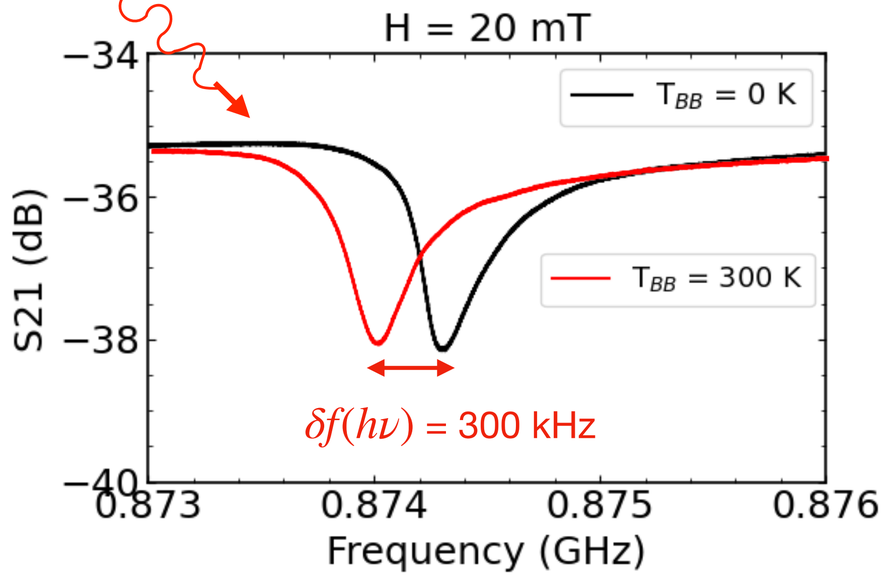

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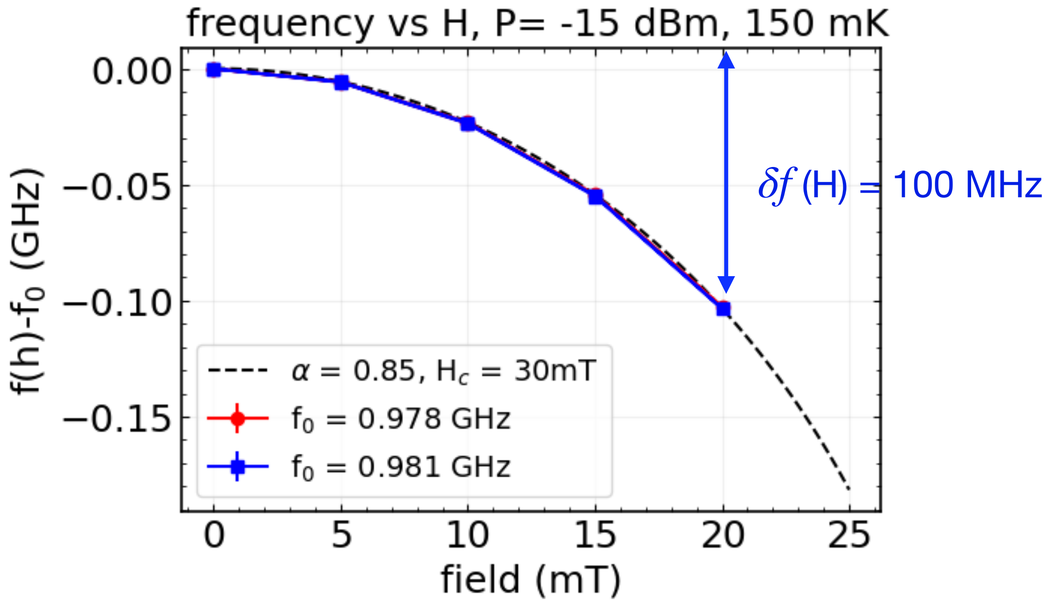

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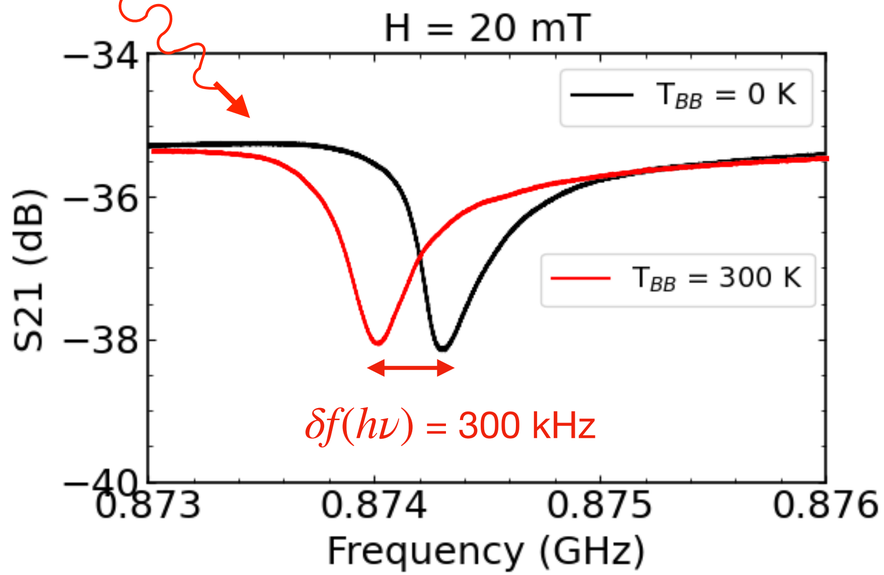
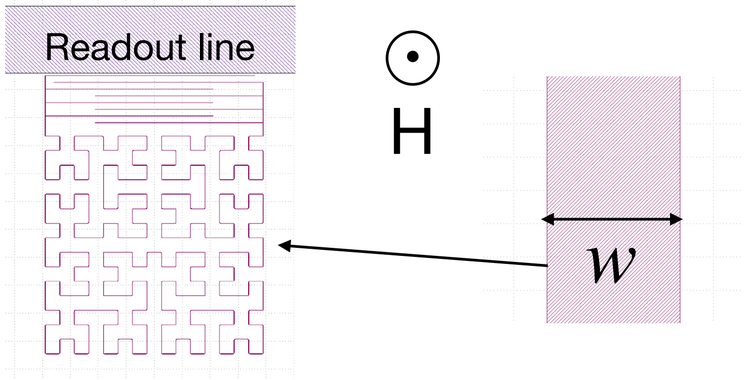


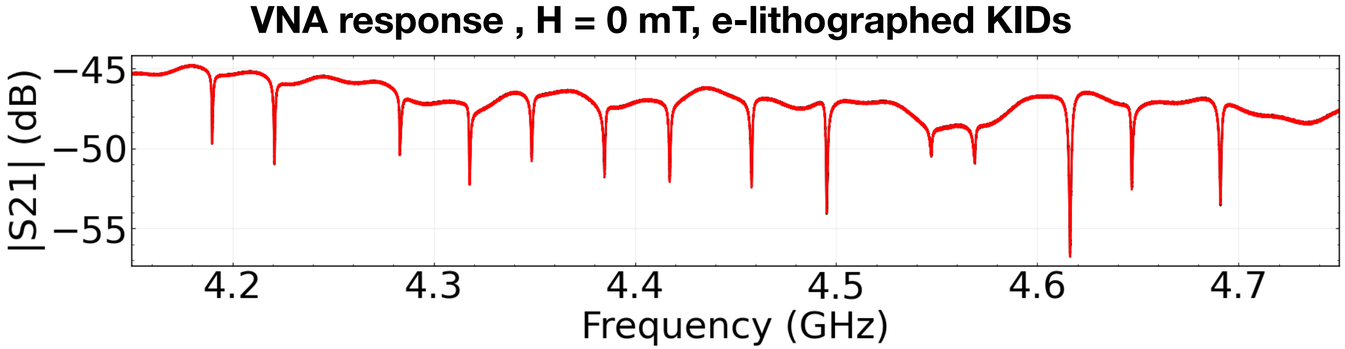
$$\boxed{\delta f(H) >> \delta f(h\nu)}$$

Calibration + a new readout electronics (J. Minet and M.Abdkrimi)

= disentangle $\delta f(h\nu)$ from $\delta f(H)$

Tuning w = 200 nm KIDs





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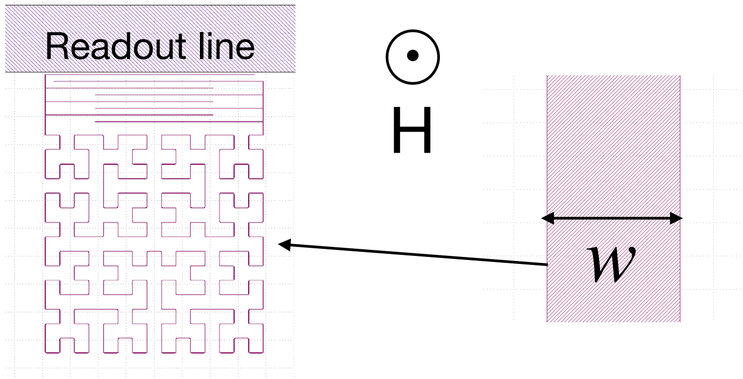

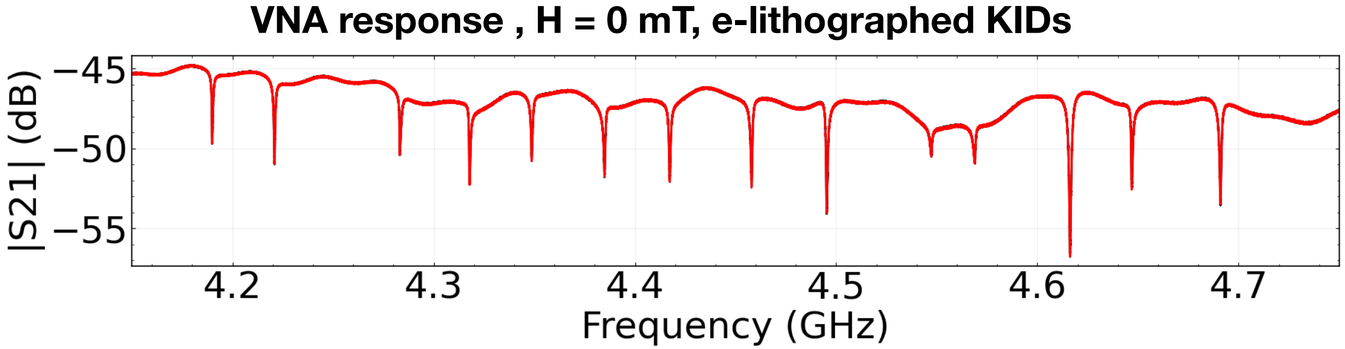

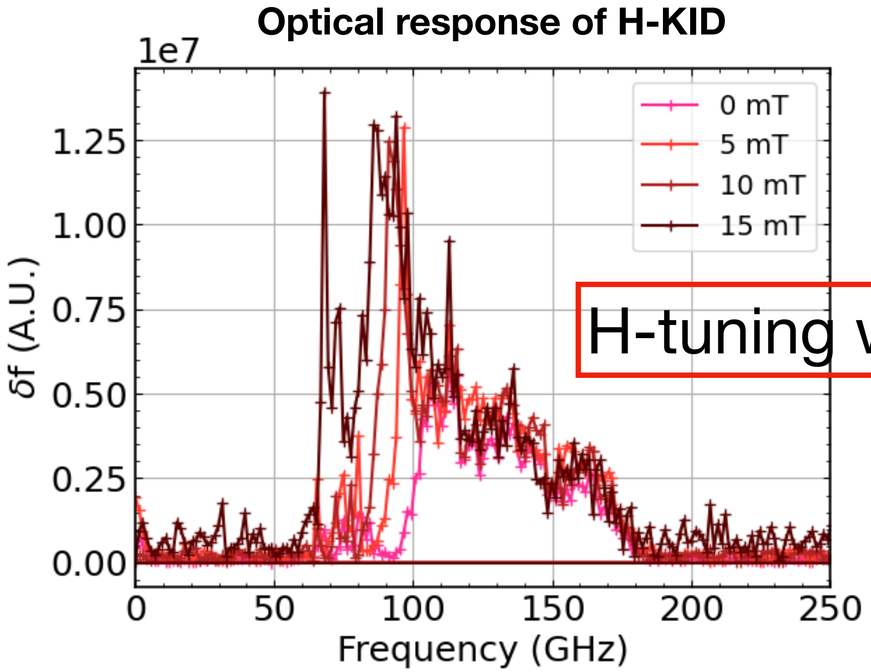

H-tuning works

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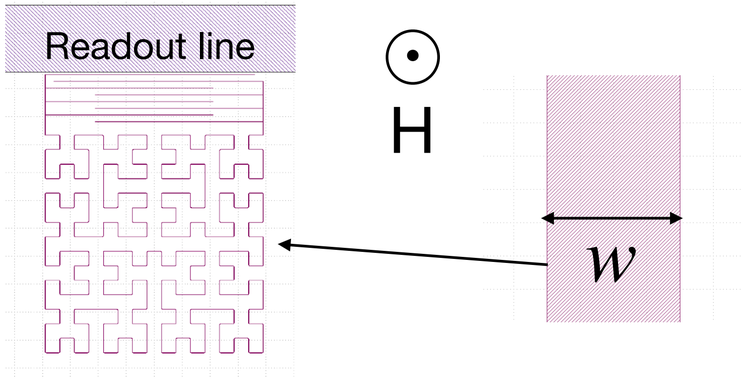

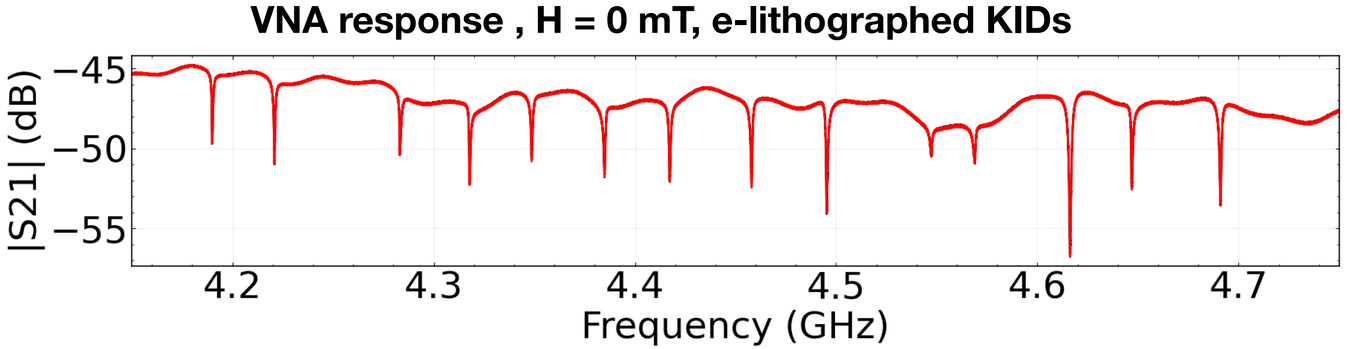

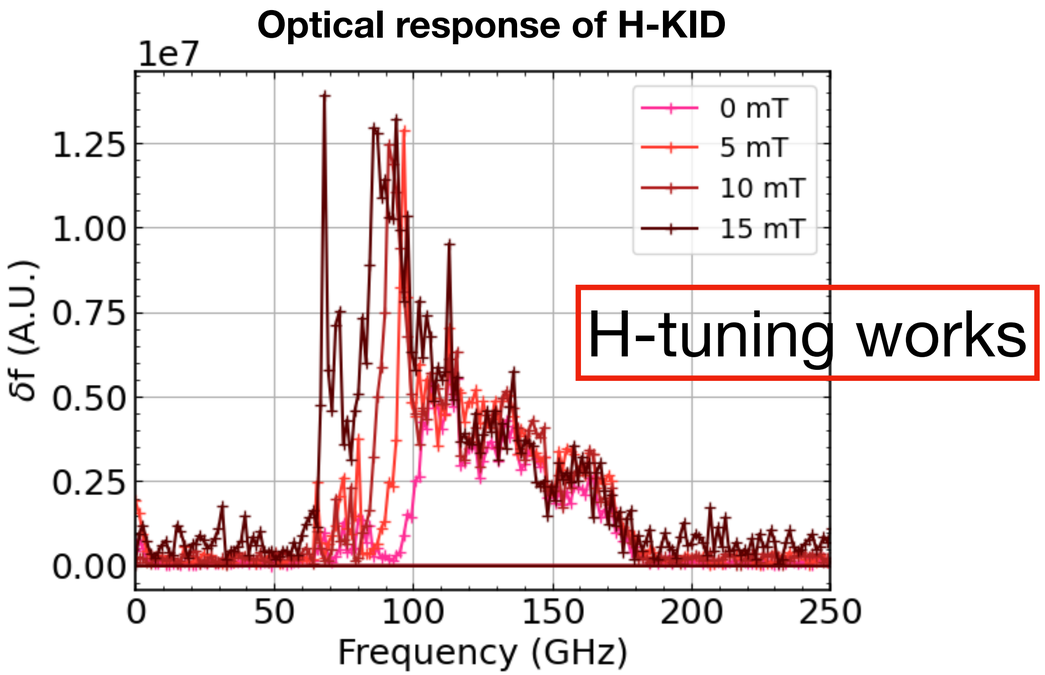

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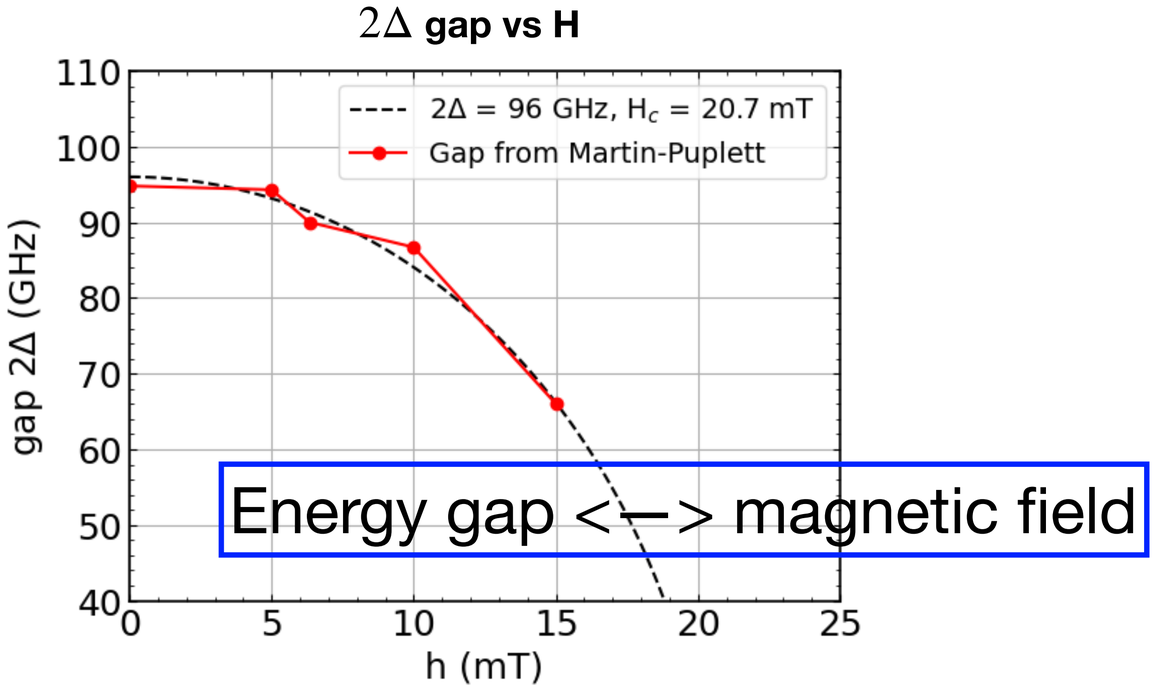


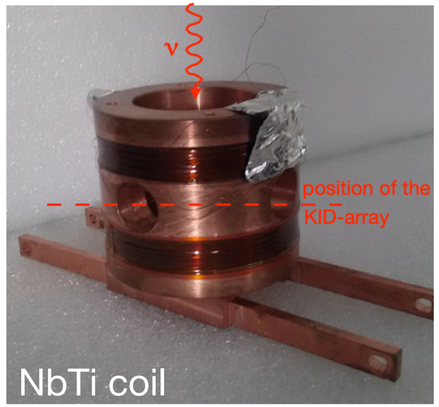
Energy gap <—> magnetic field

Conclusion and outlook

Mm-wave Imaging

+

H-spectrometry



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H-KID
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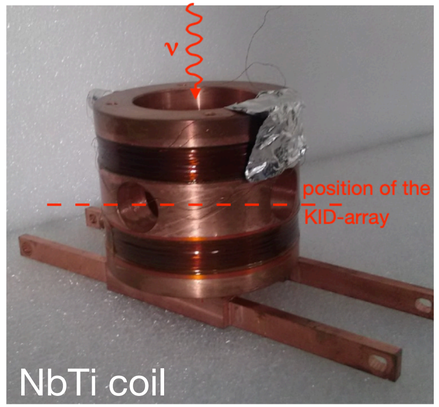
+

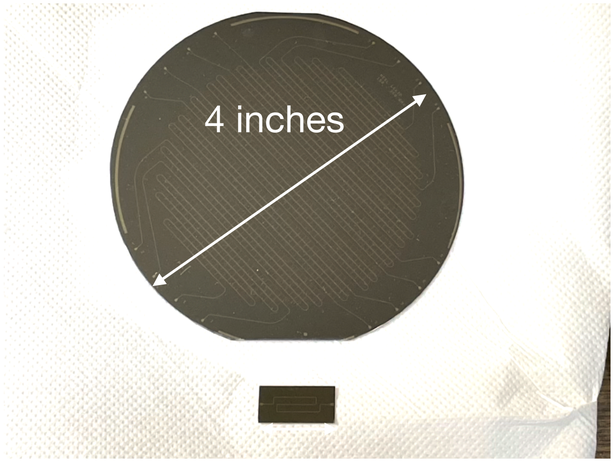
H-spectrometry



=

H-KID Spectrometer

Scaling up



4 inches (10.16 cm) wafer 1000 KIDs

15 KIDs : 2cm x1 cm

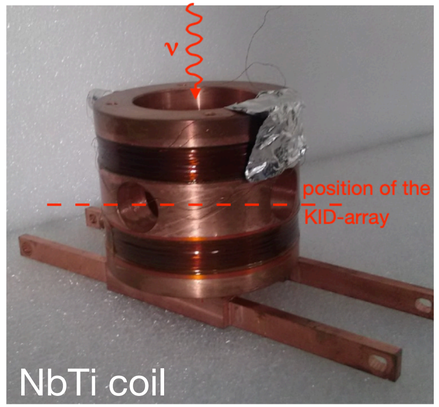
Fabrication process + new coil (T. Gandit and G.Donnier-Valentin)

Conclusion and outlook

Mm-wave Imaging

+

H-spectrometry



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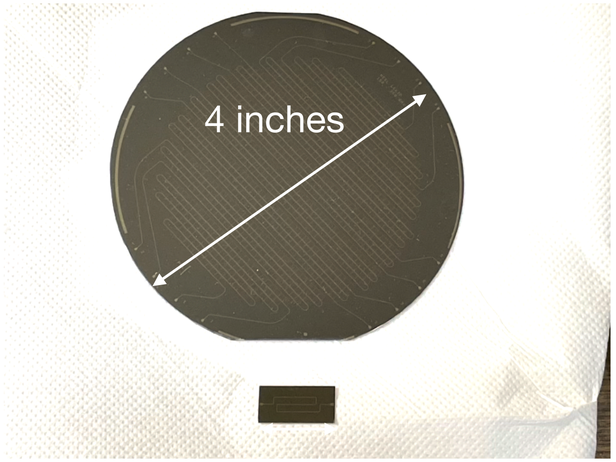
H-KID Spectrometer

Scaling up



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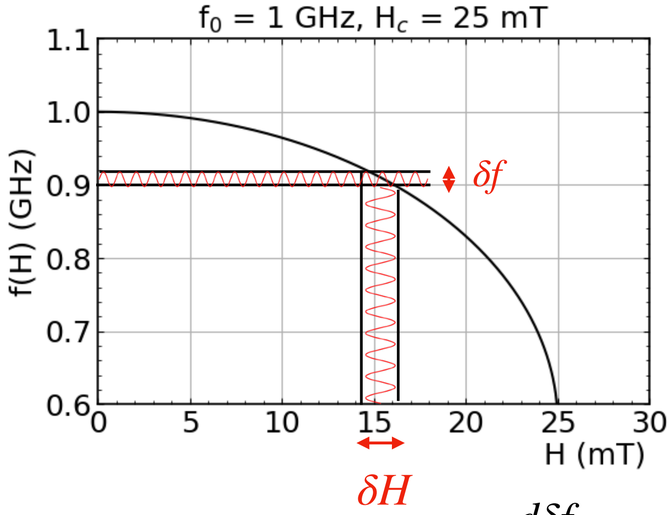
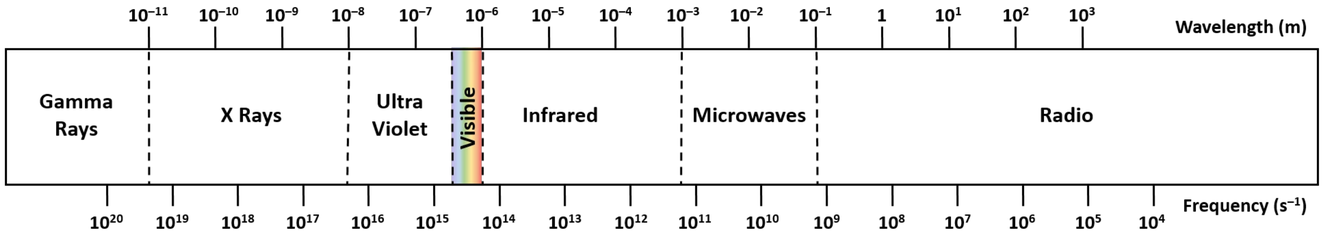
Spectroscopy

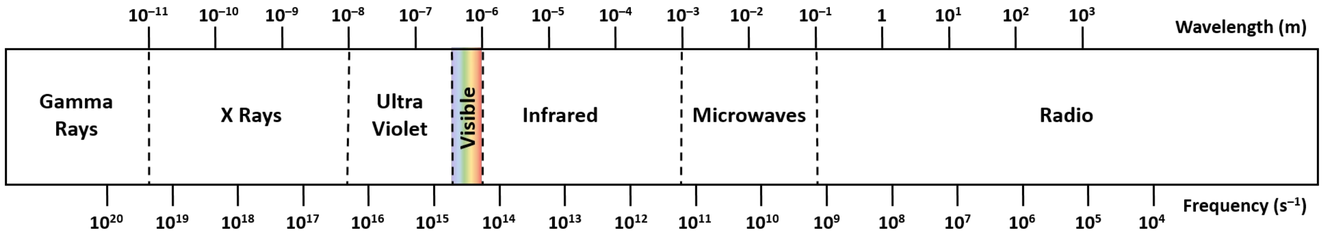


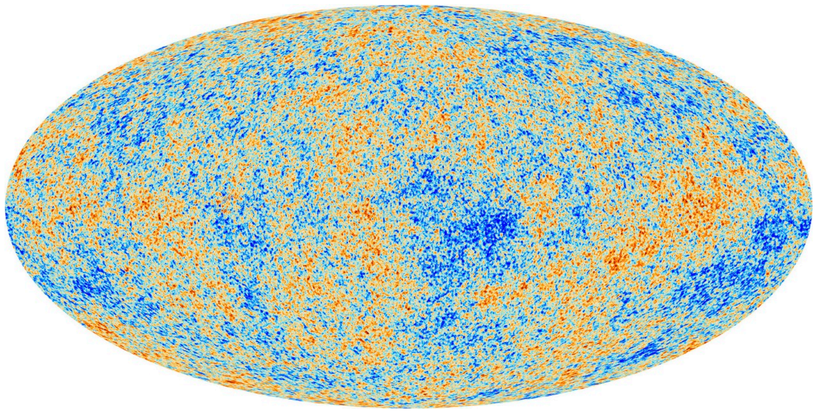
Lock-in detection → $\frac{d\delta f}{dH}$

Millimeter wave observations



Millimeter wave observations

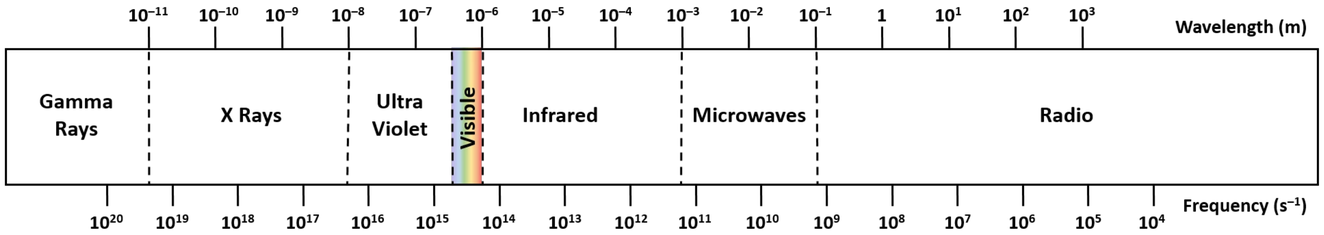


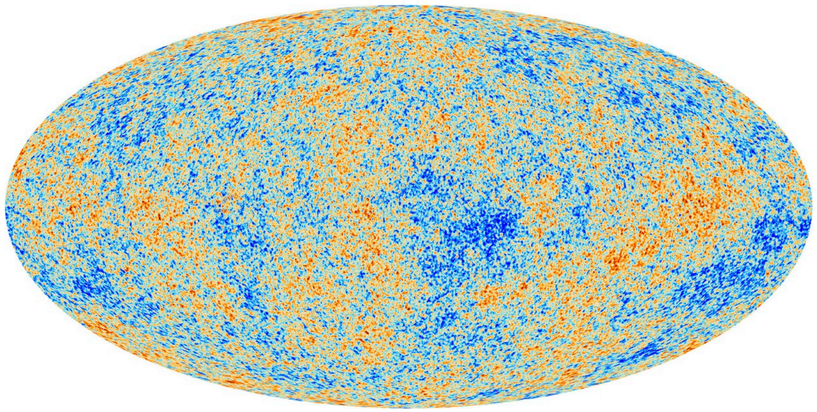


Cosmic Microwave Background observed by Planck

The Oldest light of the Universe, 380 000 years old

Millimeter wave observations





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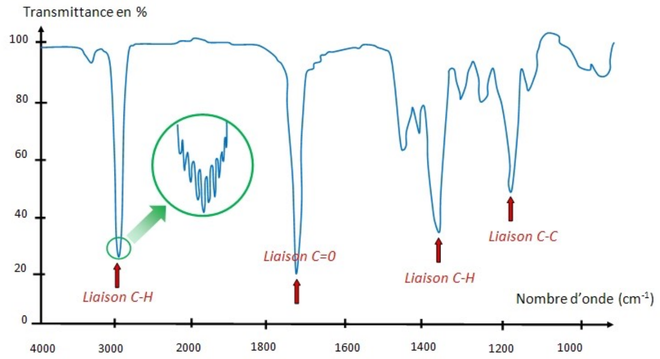
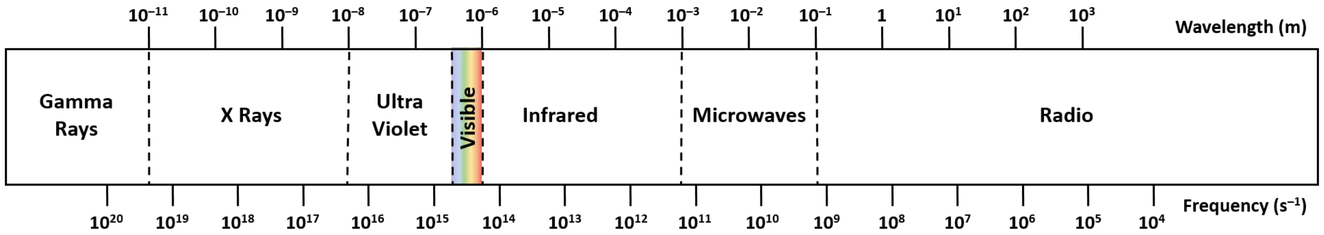
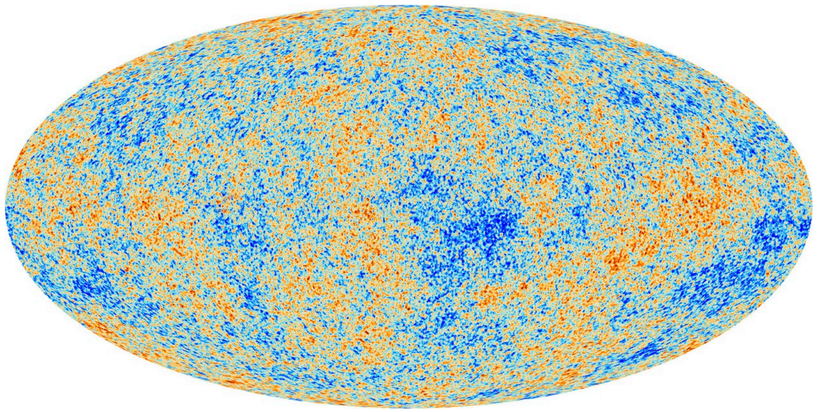


Detection of C[II] lines at different redshifts

Millimeter wave observations





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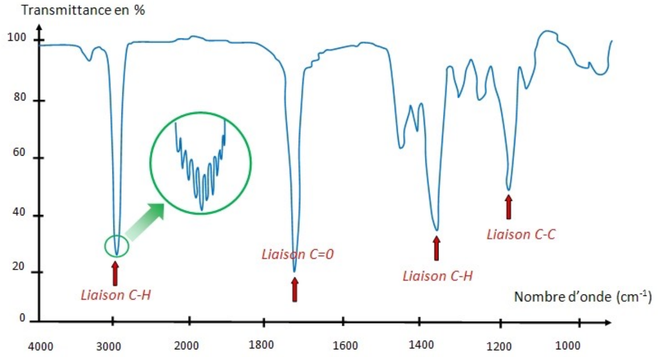

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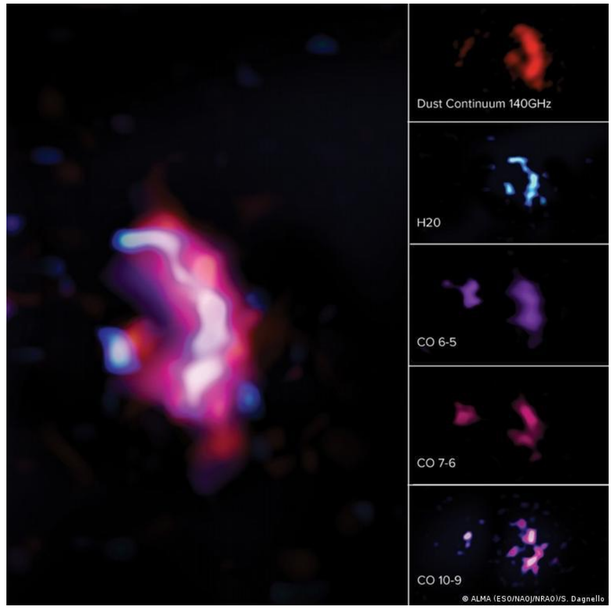


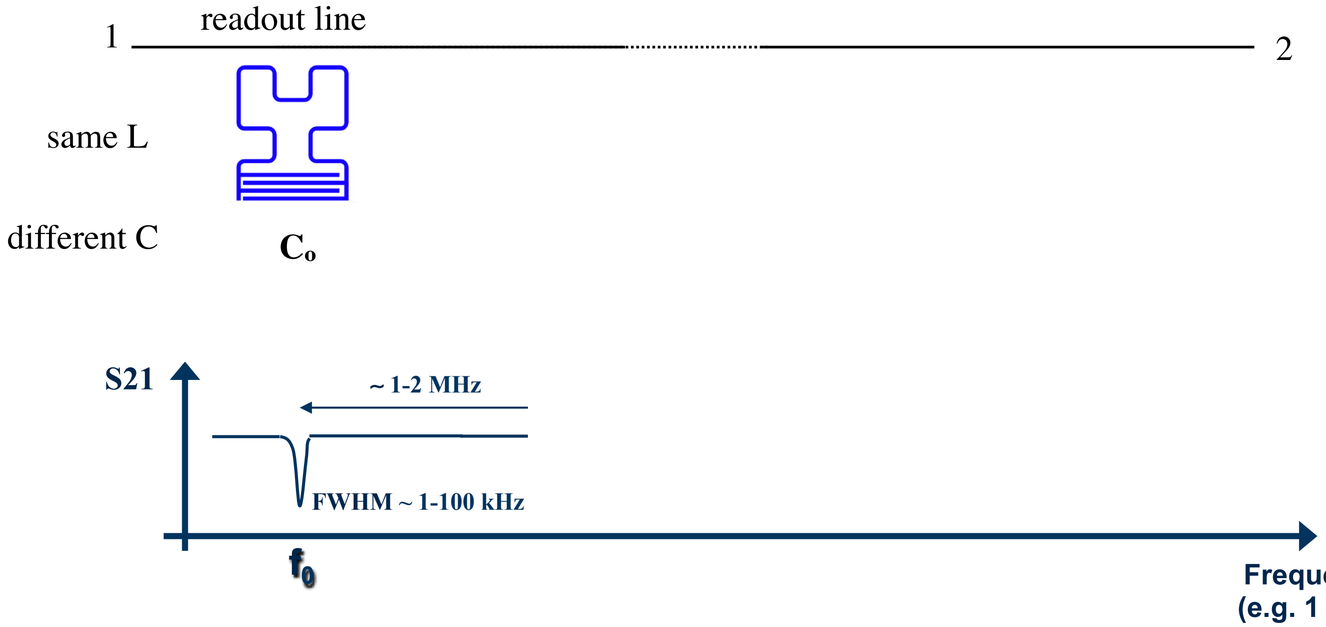
SPT0311-58 Galaxy discovered on ALMA, Redshift Z = 6.9

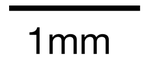
Strandet, M. L. et al. (2017), The Astrophysical Journal Letters, 842, L15

KIDs array

Frequency multiplexing:

$f \sim (LC)^{-1/2}$





one feedline to address hundreds of detectors

Photo of a KID array installed in the NIKA2 mm-camera

L.perotto & al.,Astronomy & Astrophysics 637, A71 (2020)

KIDs array

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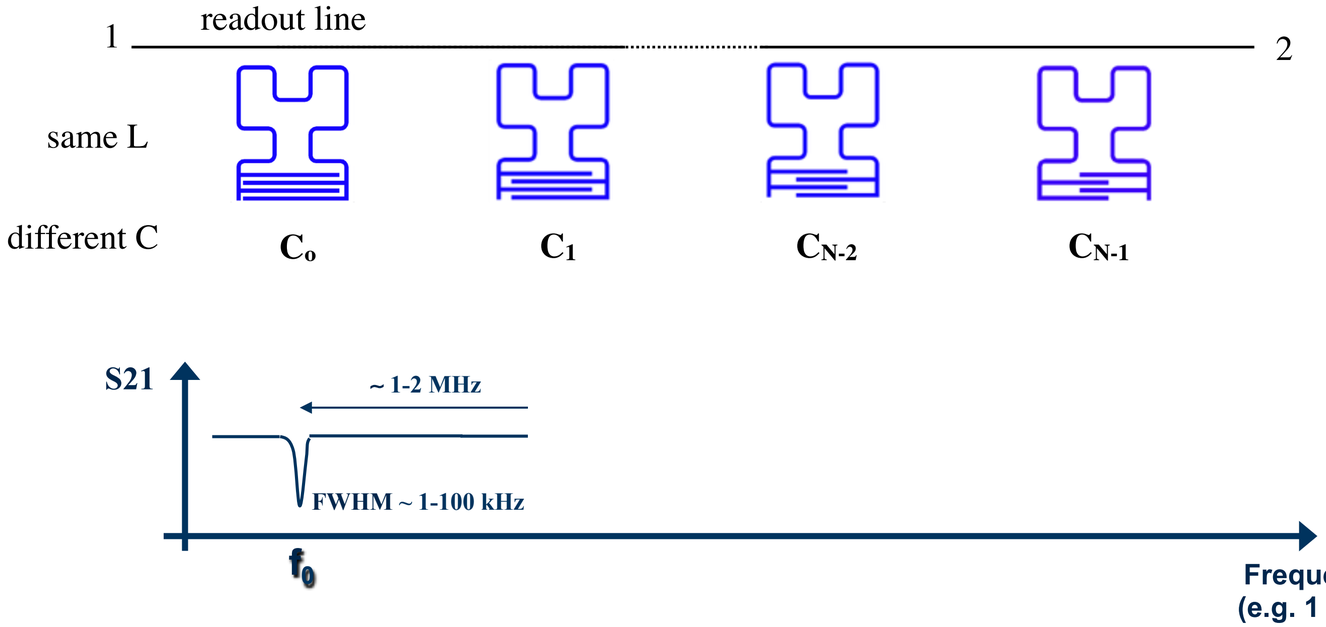

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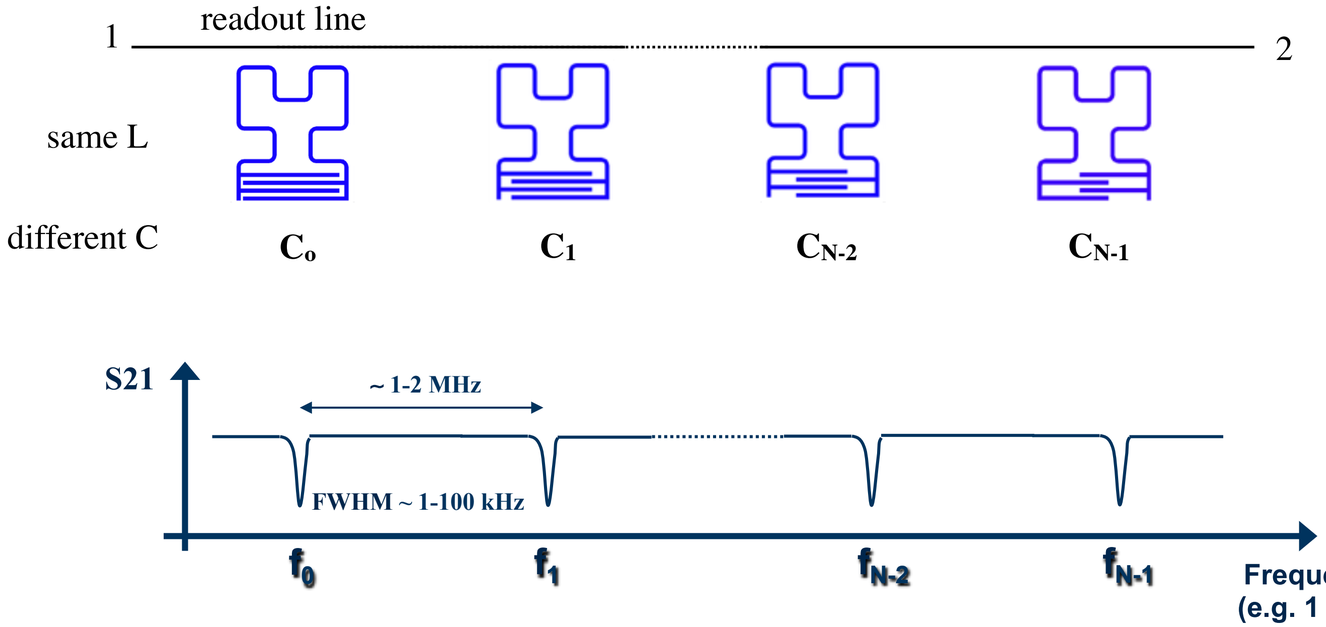

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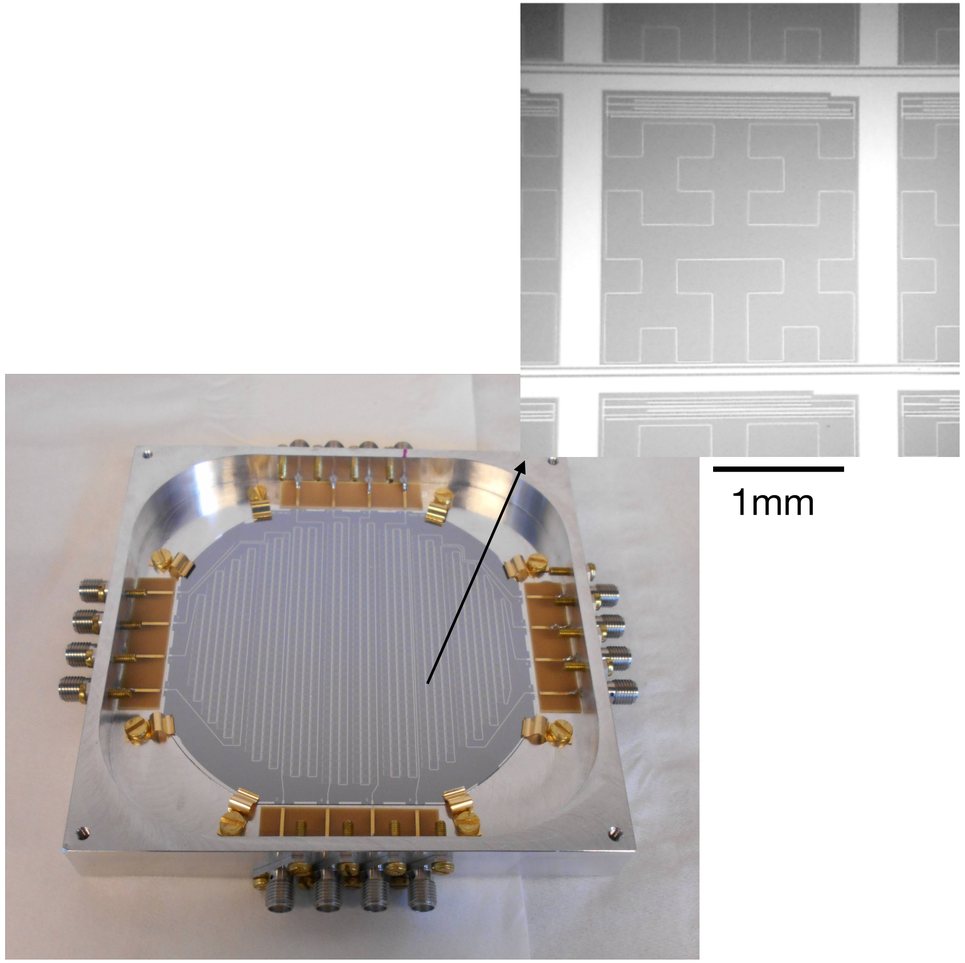

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