Miniature velocity probe for Superfluid Turbulence

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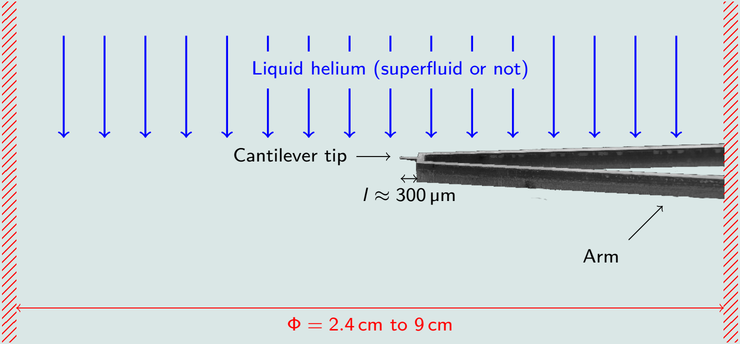
Experimental setup



Measurement principle

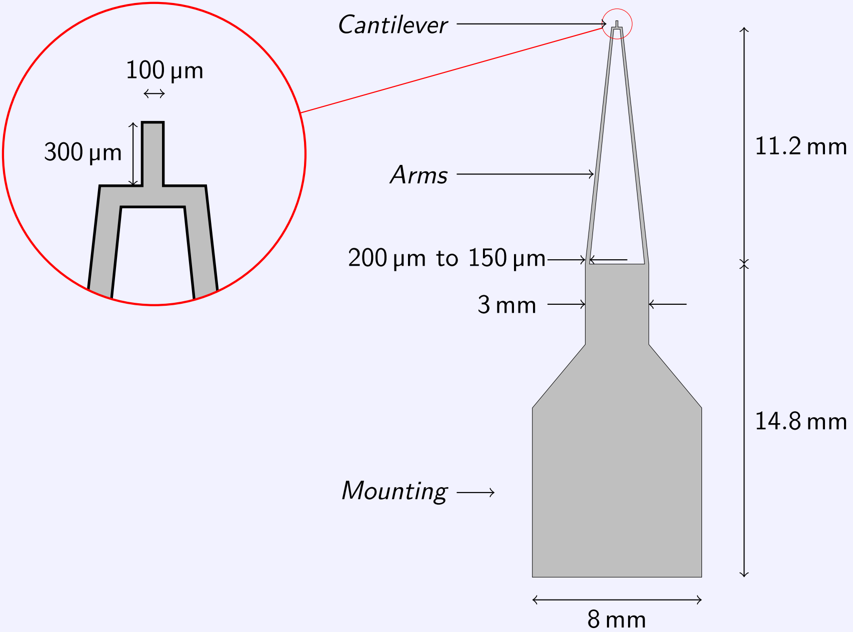
- The cantilever tip is deflected by the flow
- Known to be effective in air and water (Barth *et al.*, 2005)

Probe Geometry

Specifications for the probe geometry

- The cantilever tip must be inserted in the bulk of the flow
- The arms have to be as transparent as possible for the incoming flow especially near the measured volume
- The mountings have to fit in the room available outside the flow inside the cryostat

Probe Geometry



Measurement techniques

Desired specifications for the deflection measurements

- Large frequency range, typ. DC to 50 kHz
- High signal dynamics
  In turbulence, the power of the fluctuating signal scales like $f^{-5/3}$, ie. if power P_0 at f_0, then $P_0/50$ at $10f_0$
- Working temperature range : 1.1 K to 4.2 K

Possible solutions

Optical detection, Strain gauges, LC resonator, ...

Measurement techniques

Chosen technology : RF superconducting resonator

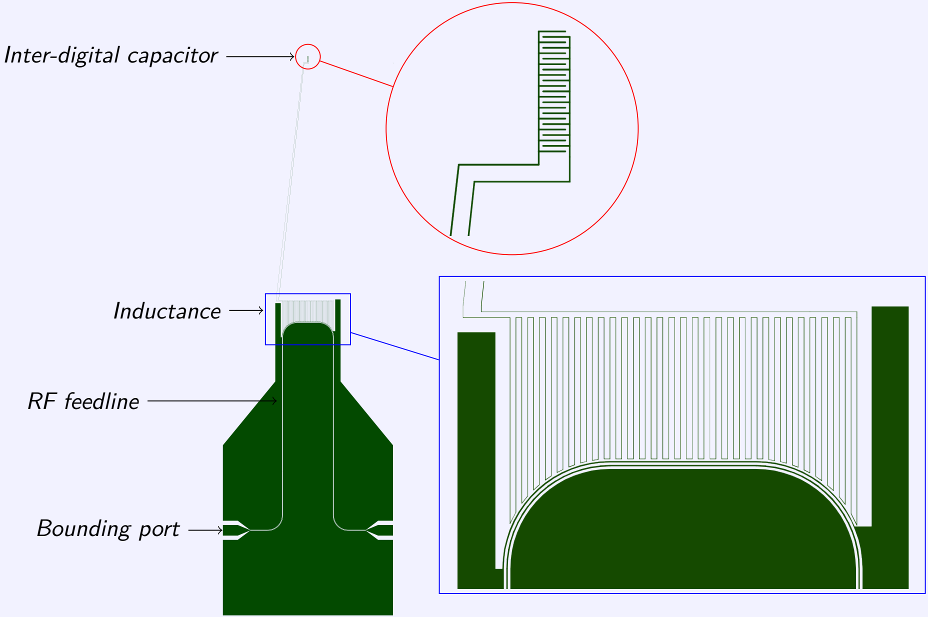
Pros :

- Well known technology for fine measurements (eg. NIKA project)
- Fast dynamics
- Multiplexing perspectives
- Easy to micro-machine

Cons :

- Oxides introduce phase noise $\Rightarrow$ proscribe SOI solutions
- RF circuitry and electronics

Superconducting LC Resonator



Inter-digital capacitor

Inductance

RF feedline

Bounding port

At first order, we expect :

$$f_0 = \frac{1}{2\pi\sqrt{LC_0}}\left(1 - \frac{\Delta\ell}{2\ell}\right)$$

Mechanics says :

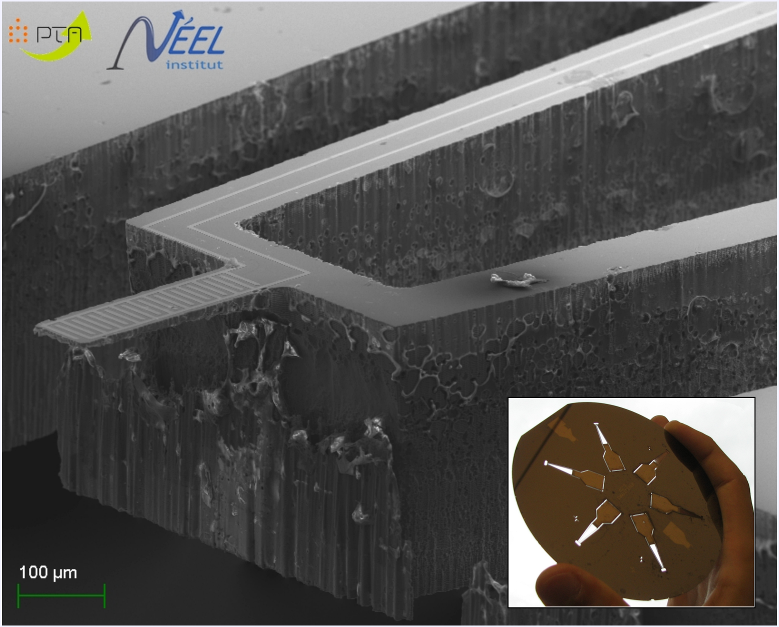
$$\frac{\Delta\ell}{\ell} \sim \frac{P}{E}\frac{\ell^2}{e^2}$$

where

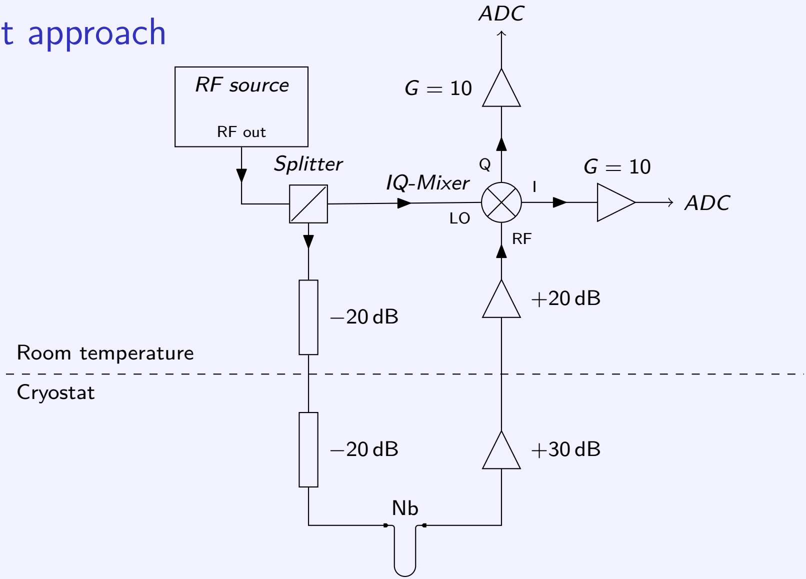
$$P \sim \rho v^2$$

We expect :

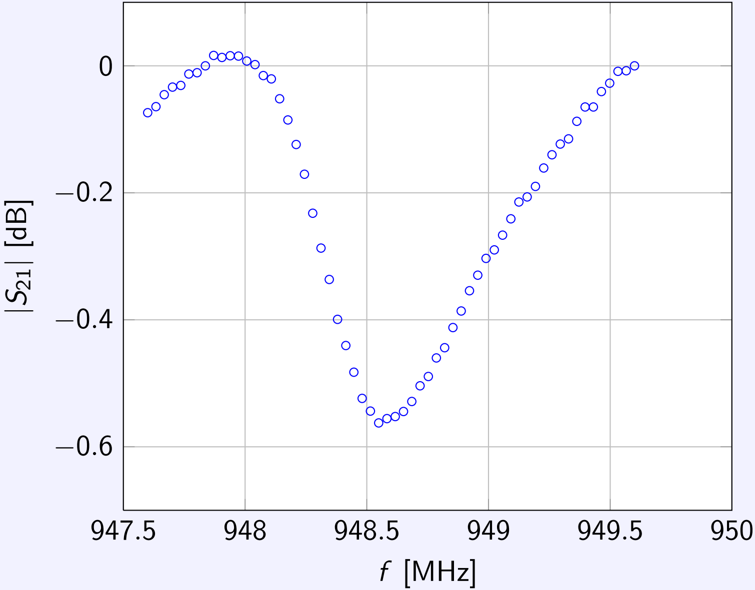
$$\frac{\Delta\ell}{\ell} \sim 5 \times 10^{-5}$$


PTA
NÉEL
institut
100 µm

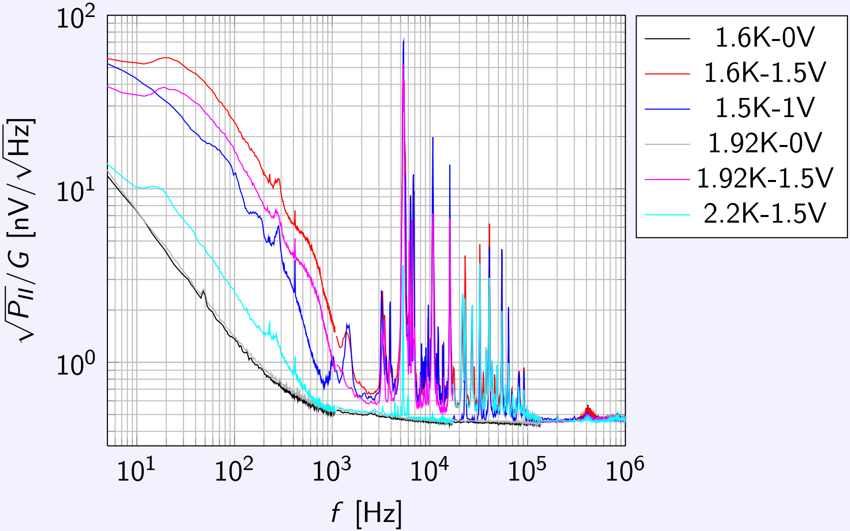
First approach



Source RF: Agilent N93A10A, Splitter: ATM, IQ-Mixer: Miteq
ADC: VXI + cartes Agilent E1437A


0
−0.2
−0.4
−0.6
$|S_{21}|$ [dB]
947.5
948
948.5
949
949.5
950
f [MHz]

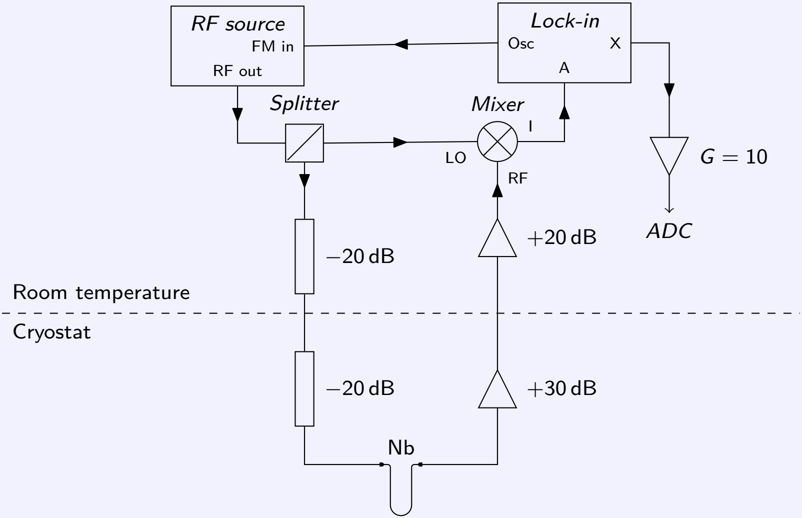
Amplification RF: 38dB+18dB ($G = 10^{(18+38)/20} = 631$)

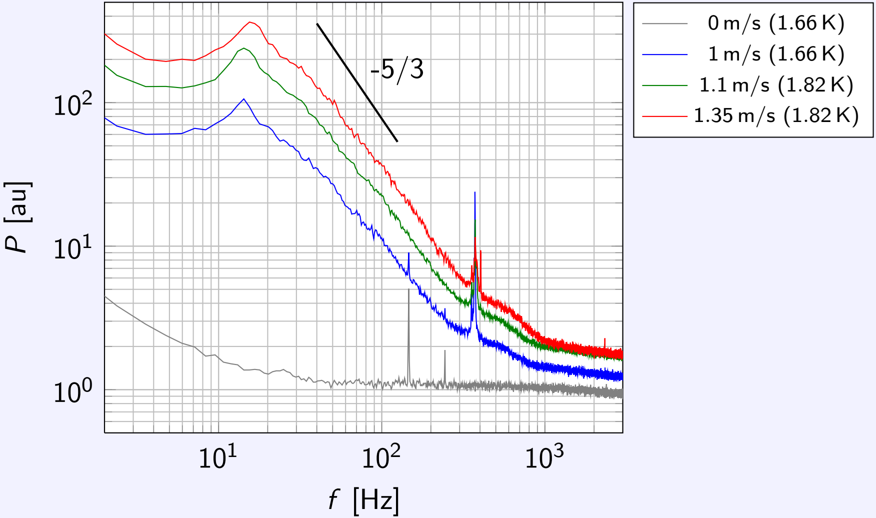


We have a prototype working and its dynamics is comparable to the best anemometers known to work in He II

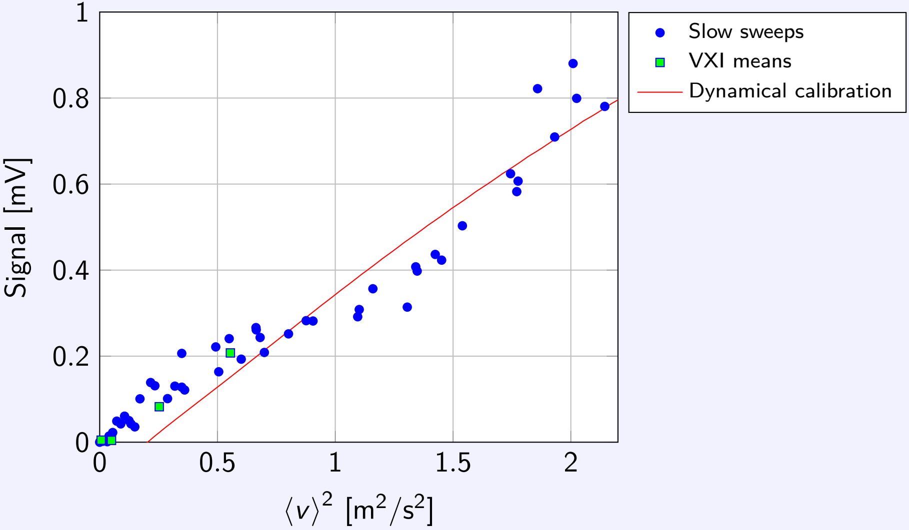
BUT

1. Quality factor very low
   ($\approx 10^3$ *versus* $10^5 - 10^6$ expected)
2. High low frequency noise
3. Many peaks for $f > 3\,\mathrm{kHz}$


RF source
FM in
RF out
Lock-in
Osc
X
A
Splitter
Mixer
I
LO
RF
$G = 10$
ADC
−20 dB
+20 dB
Room temperature
Cryostat
−20 dB
+30 dB
Nb


-5/3
0 m/s (1.66 K)
1 m/s (1.66 K)
1.1 m/s (1.82 K)
1.35 m/s (1.82 K)
P [au]
10^2
10^1
10^0
10^1
10^2
10^3
f [Hz]

Calibration *versus* Mean velocity



Conclusion

- Validation of the principle of cantilever anemometry He II
- Validation of the principle of a superconducting resonator sputtered on a cantilever to measure its deflection
- FM technique allows to get rid of phase noise problems

Perspectives

- Understand why Q is so low should greatly improve sensibility
  - Residual aluminum on the circuit ?
  - High temperature and gradients during plasma somehow changes niobium properties ?
  - Problems with Nordiko 2550 sputtering machine ?
- Replace Nb with NbN to get a higher T_c. Possible with Nordiko ?
- Improve resolution (at least down to 50 µm)
- Array of probes multiplexed on a single RF line

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