CRYOGENIC TESTS OF ELECTRONIC COMPONENTS AND SENSORS FOR SUPERCONDUCTING MAGNET INSTRUMENTATION

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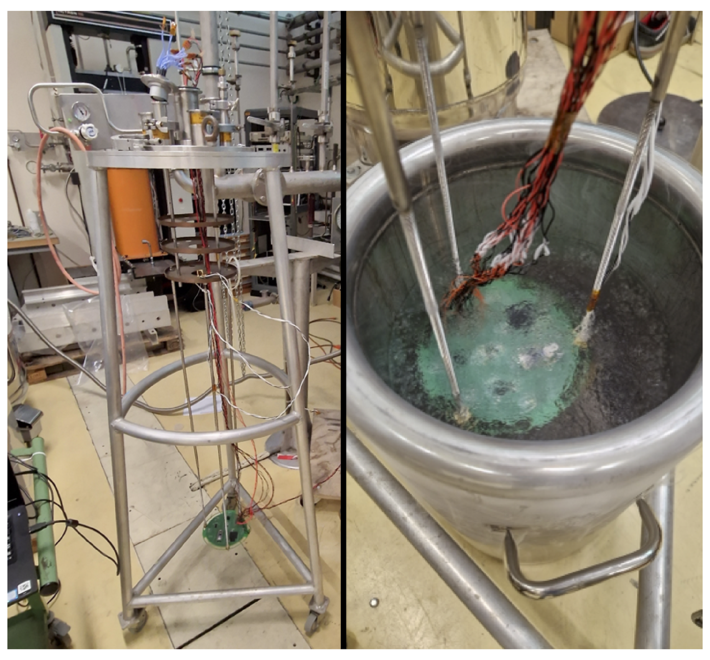
Introduction

Superconducting magnets are crucial for generating high magnetic fields used in diverse applications, including particle accelerators [1], nuclear fusion, and medical imaging (MRI). For a newly fabricated magnet, the **spontaneous quench** current increases gradually until stabilization during a process known as **"training"** [2]. Identifying the starting location of a quench is critical to drive the design of magnets and protection systems. **Traditional methods** (voltage taps [3] and quench antennas [4, 5]) are either **not accurate** or are **invasive**. One promising approach is detecting **acoustic emissions from quenches** using piezoelectric or **MEMS sensors** [6, 7, 8]. In all cases, a considerable number of cables with lengths up to several tens of meters are required to transport weak, millivolt-level signals. Moving the signals' **conditioning electronics inside the magnet cryostat could be beneficial for any magnet instrumentation.** Advancing the instrumentation further involves testing electronic components at cryogenic temperatures to be able to **integrate the conditioning electronics as close as possible to the sensors.**

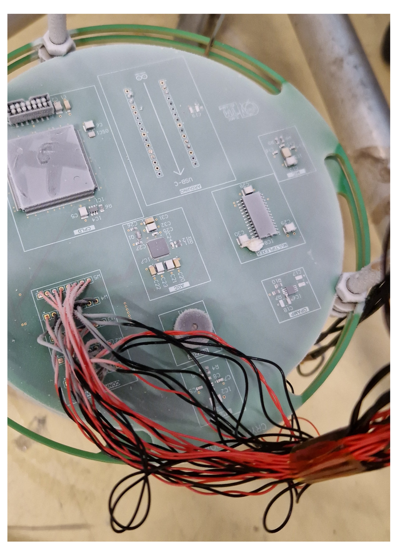
Setup

The setup is essentially the same for the tests at 77 K in liquid Nitrogen and the tests at 4.5 and 1.9 K in liquid Helium. The type of components to be tested was chosen to achieve a **complete acquisition chain**, deriving inspiration from existing literature. An **ad hoc PCB has been designed** to fit the existing support present in the cryostat and to allow an easy connection between the DUT and the 40 available feedthroughs. The **procedures are designed to optimize the number of tested devices and functionalities** while respecting at the same time the limitations of the feedthrough. The Setup includes a **NI USB-6361 DAQ** to acquire the analog signals with a **sampling rate of 50 kHz**, and a **Keysight 33500B frequency generator** to excite the piezoelectric transducer and to test the operational amplifier.



Device	Description
OPA192IDGKT	Operational amplifier
IM73A135V01	MEMS microphone with analog differential output
ADG506AKR	CMOS 16-Channel Analog Multiplexers
KXG1205C	Piezoelectric transducer
SMD Thick Film Resistors	25 kΩ, 10 kΩ, 5.1 kΩ, 4.7 kΩ, 1.1 kΩ, 50 Ω
SMD PPS Film Capacitors	100 nF, 2.2 nF, 220 pF, 100 pF, 4.7 pF
SMD Tantalum Capacitors	10 μF

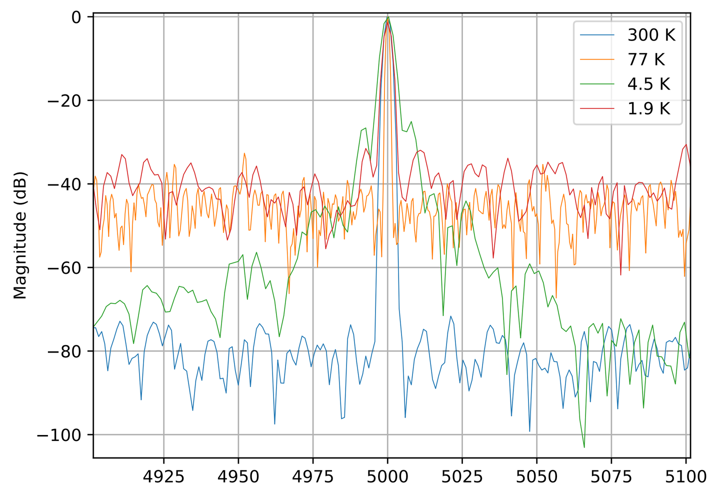
Analog Multiplexer

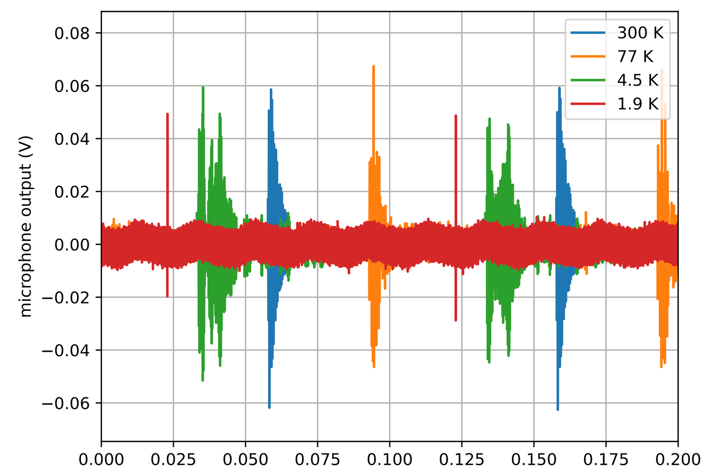


The input-output resistance has been measured at various temperatures for different outputs and for different control signals observing that it **drops in liquid Nitrogen** with respect to the test carried out at room temperature for both the tested inputs. On the other hand, the resistances **increase in liquid helium by a factor of about 2, with a negligible difference between 4.5 K and 1.9 K.** For all the tests the input-output resistances remain in the **same order of magnitude** making this **component suitable to operate at cryogenic temperatures** to switch the acquisition between different sensors, while **minimizing the number of connections to be extracted from the cryostat.**

	300 K	77 K	4.5 K	1.9 K
in1-out (Ω)	166 ± 1	109 ± 1	315 ± 1	328 ± 1
in2-out (Ω)	167± 1	57 ± 1	282 ± 1	305 ± 1

MEMS Microphones



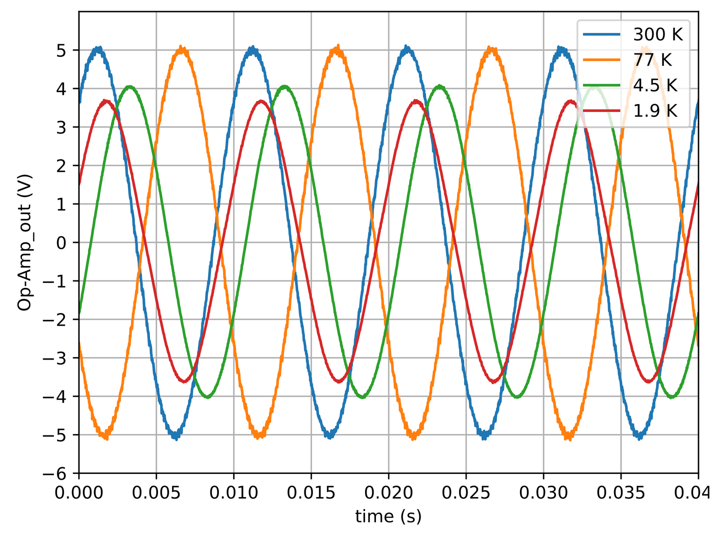


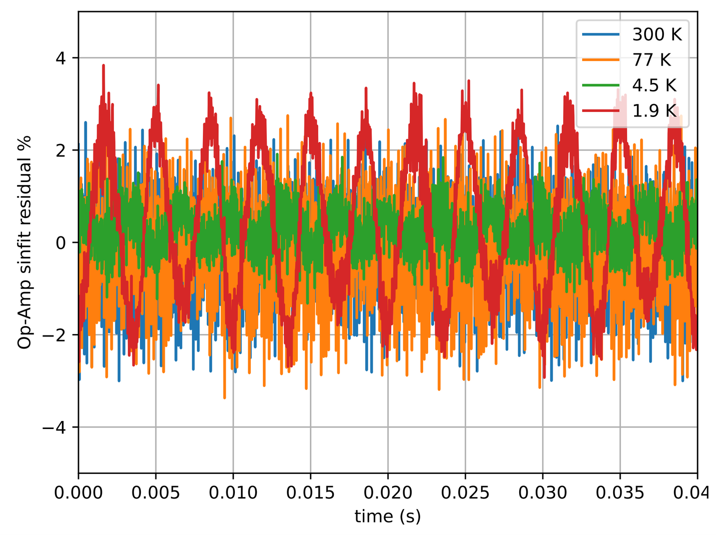
The source of acoustic vibrations was provided by a piezoelectric transducer excited with two external signals of amplitude 10 V, a 2 s train of 20 ms pulses with a 10 Hz period and a rising time of $20\,\mu\mathrm{s}$, and a sine wave of frequency varying from 1 to 20 kHz in 5 kHz steps. **The MEMS microphone exhibited an excellent capability to detect both the impulsive noise source and the sinusoidal signals** across the entire ranges of temperatures and frequencies, which validates the selection of this component as a **potential solution for detecting and localizing acoustic events generated by superconducting quenches.**

unit mV/V	300 K	77 K	4.5 K	1.9 K
Pulse train	2.1	6.7	5.6	4.9
1 kHz	3.3	0.6	0.7	0.5
5 kHz	1.5	0.5	0.4	0.5
10 kHz	1.9	0.5	0.6	0.6
15 kHz	2.4	0.5	1.5	0.5
20 kHz	1.5	0.5	0.5	0.5

Operational Amplifier

The sinusoidal signals have been used to compute the **Signal-to-Noise Ratio (SNR)** at different temperatures using the **sinfit method**. The **best performance is achieved at 4.5 K**, while in all other cases, it states the same order of magnitude. This **variations** might be **partly attributed to the discrete resistors**, which have a nominal temperature coefficient of $\pm 100\ \mathrm{ppm/K}$ at room temperature. However, this cannot explain the large **20 dB difference between the gains at 1.9 K and 4.5 K, which may be related to the internal semiconductor resistors.**

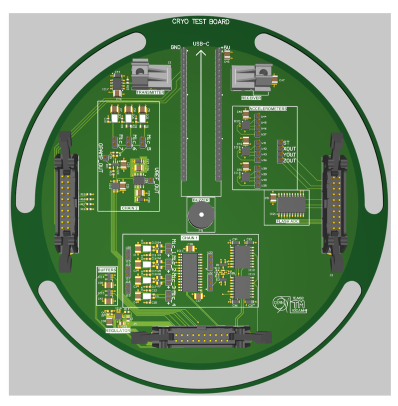




	300 K	77 K	4.5 K	1.9 K
SNR (dB)	74.58	73.66	85.7	65.74

Summary and Outlook

This experimental campaign has provided **insights into the behavior of electronic components and sensors at cryogenic temperatures**, particularly in the context of building a cryogenic acquisition chain. By leveraging non-intrusive sensors and moving conditioning electronics closer to the sensors' location, we can **enhance** the efficiency and accuracy of **quench detection and localization**, leading to improved performance and reliability of superconducting magnets. Future work may involve **deeper characterization** of these and other components (FPGA [9], ADC) in the presence of magnetic fields.



KEY REFERENCES

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MORE INFORMATION

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