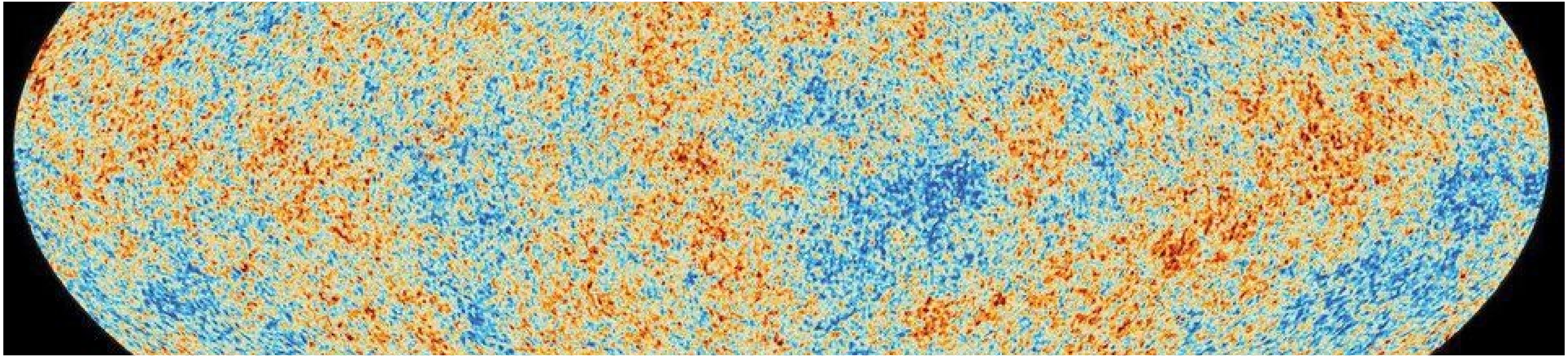
Backend Design of the Readout System for Cryogenic Particle Detectors

DDAp/DDEIT and HIRSAP Workshop 2023

Luciano Ferreyro | 21. November 2023

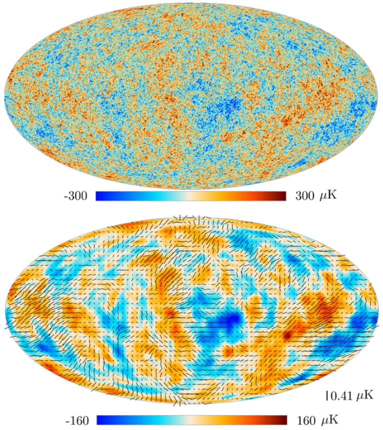
Supervisor at UNSAM: Prof. Manuel Platino | Supervisor at KIT: Prof. Marc Weber



Introduction

QUBIC – Q&U Bolometric Interferometer for Cosmology

QUBIC is an observational cosmology project and is dedicated to the exploration of the inflation era of the Universe. By detecting and characterizing the CMB B-mode polarization, QUBIC will contribute to finding the so called *smoking gun* of inflation.



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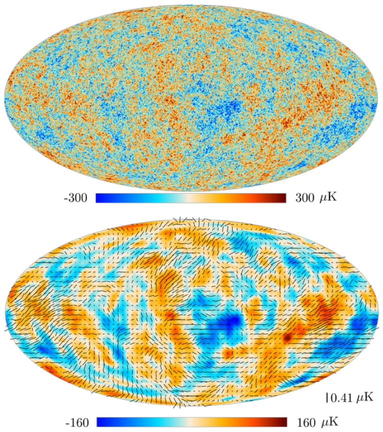
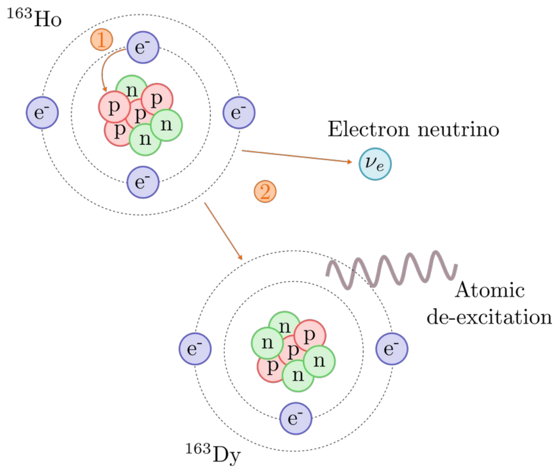


ECHo - Electron Capture in ^{163}Ho experiment

ECHo is designed to investigate the electron neutrino mass in the sub-eV region by the analysis of the calorimetrically measured electron capture spectrum of ^{163}Ho.



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Scalable

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Universidad Nacional de San Martín
Karlsruhe Institute of Technology

What is this work about?

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Capabilities to readout several sensors

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Highly configurable

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Design and implement a digital backend for a readout electronics for the aforementioned experiments →

- Capabilities to readout several sensors
- Scalable
- Hardware resource efficient
- Highly configurable

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Design and implement a digital backend for a readout electronics for the aforementioned experiments →

- Capabilities to readout several sensors
- Scalable
- Hardware resource efficient
- Highly configurable
- Bolometers and calorimeters applicable

- QUBIC Next Gen (with MMBs),
- ECHO (with MMCs)

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Design and implement a digital backend for a readout electronics for the aforementioned experiments

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Capabilities to readout several sensors

Scalable

Hardware resource efficient

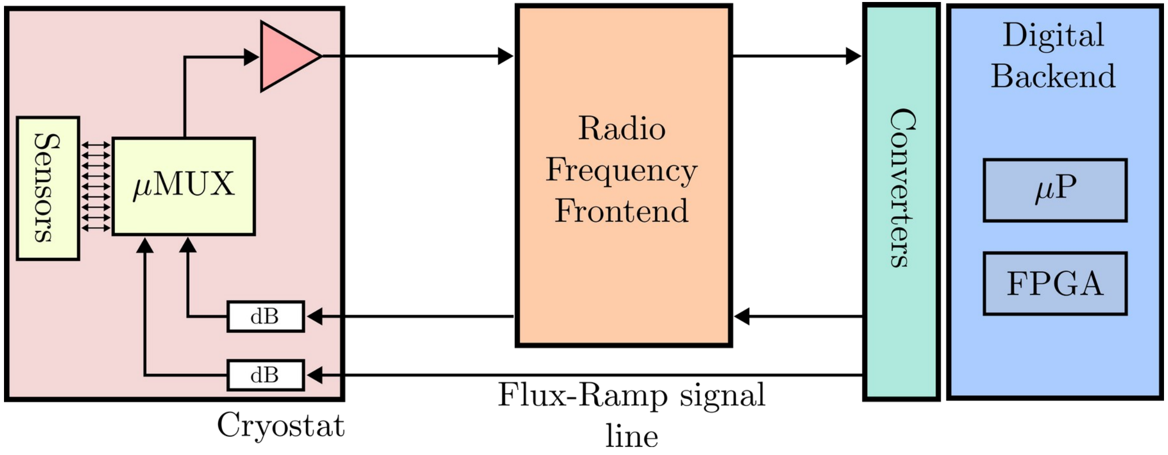
Highly configurable

Bolometers and calorimeters applicable

- QUBIC Next Gen (with MMBs),
- ECHO (with MMCs)

This work is focused in cryogenic sensors multiplexed in the frequency domain by means of a μMUX.

The Readout System



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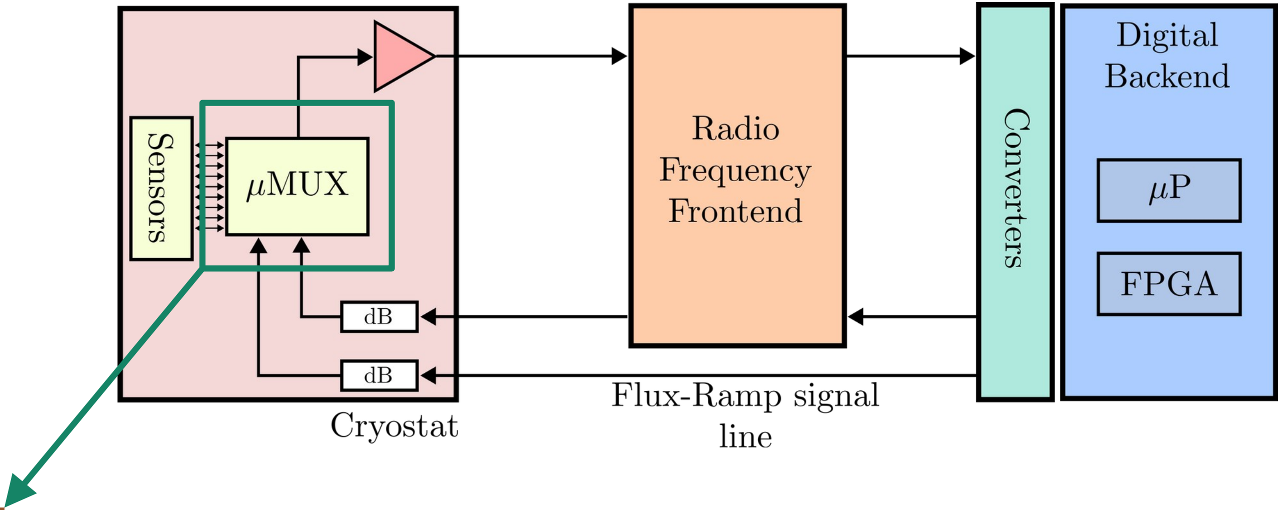

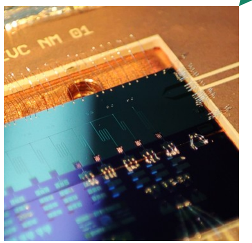

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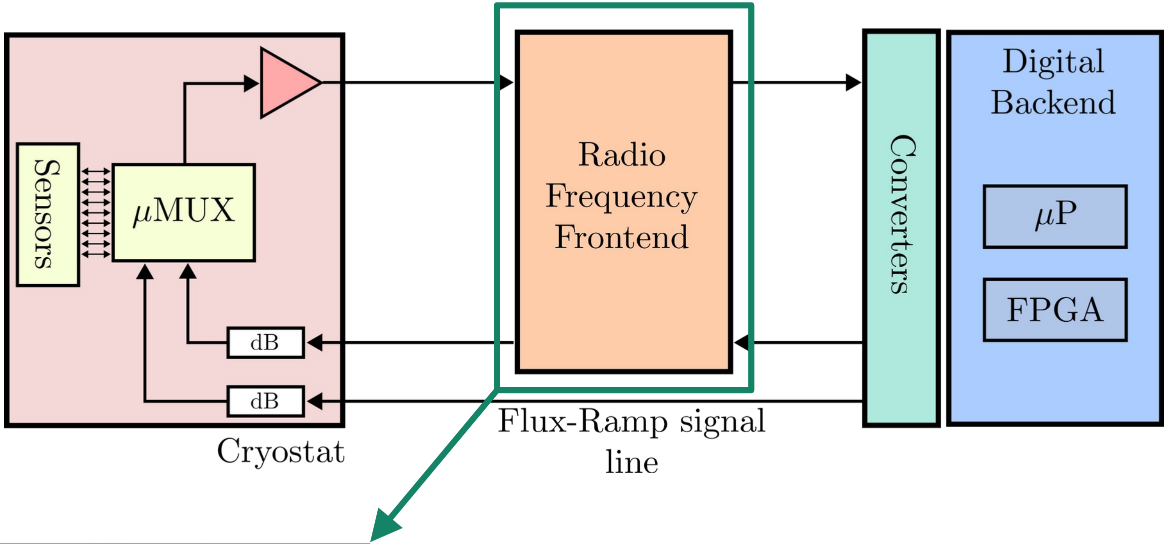

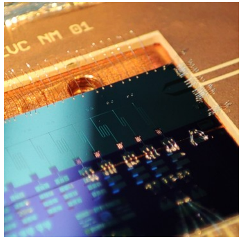

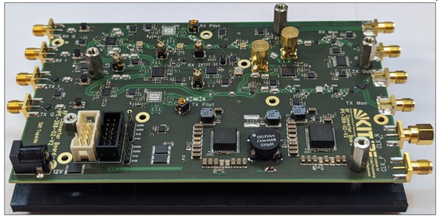

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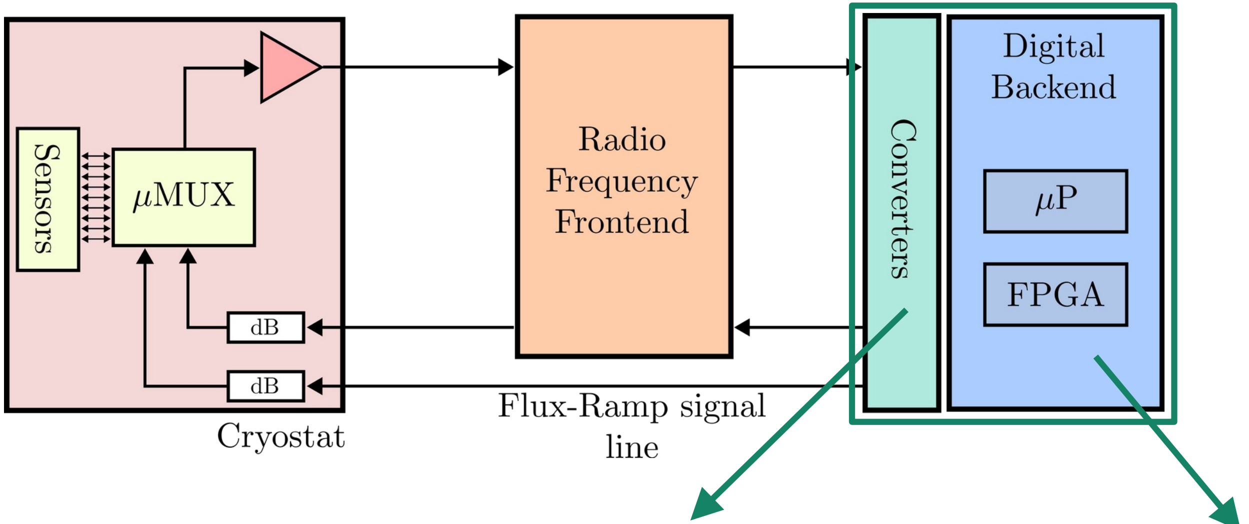

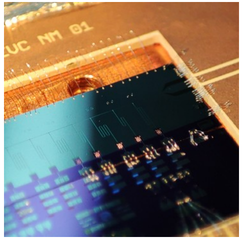
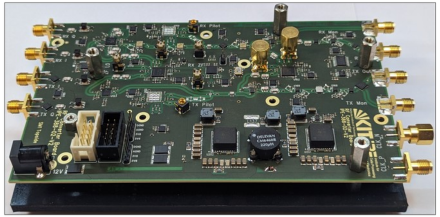

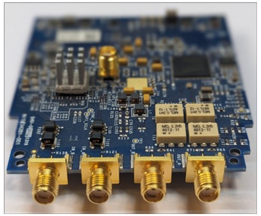

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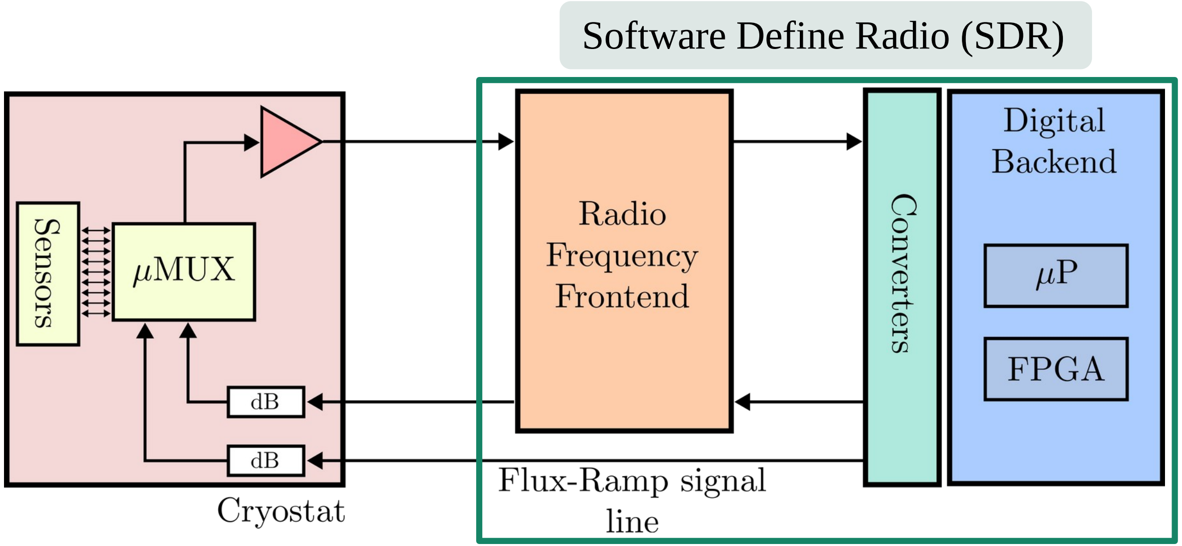
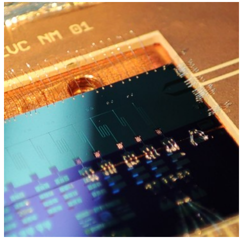
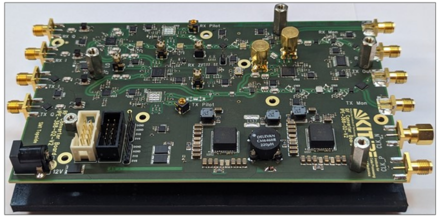
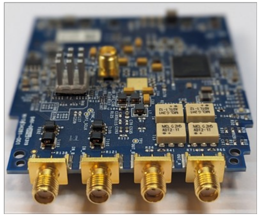
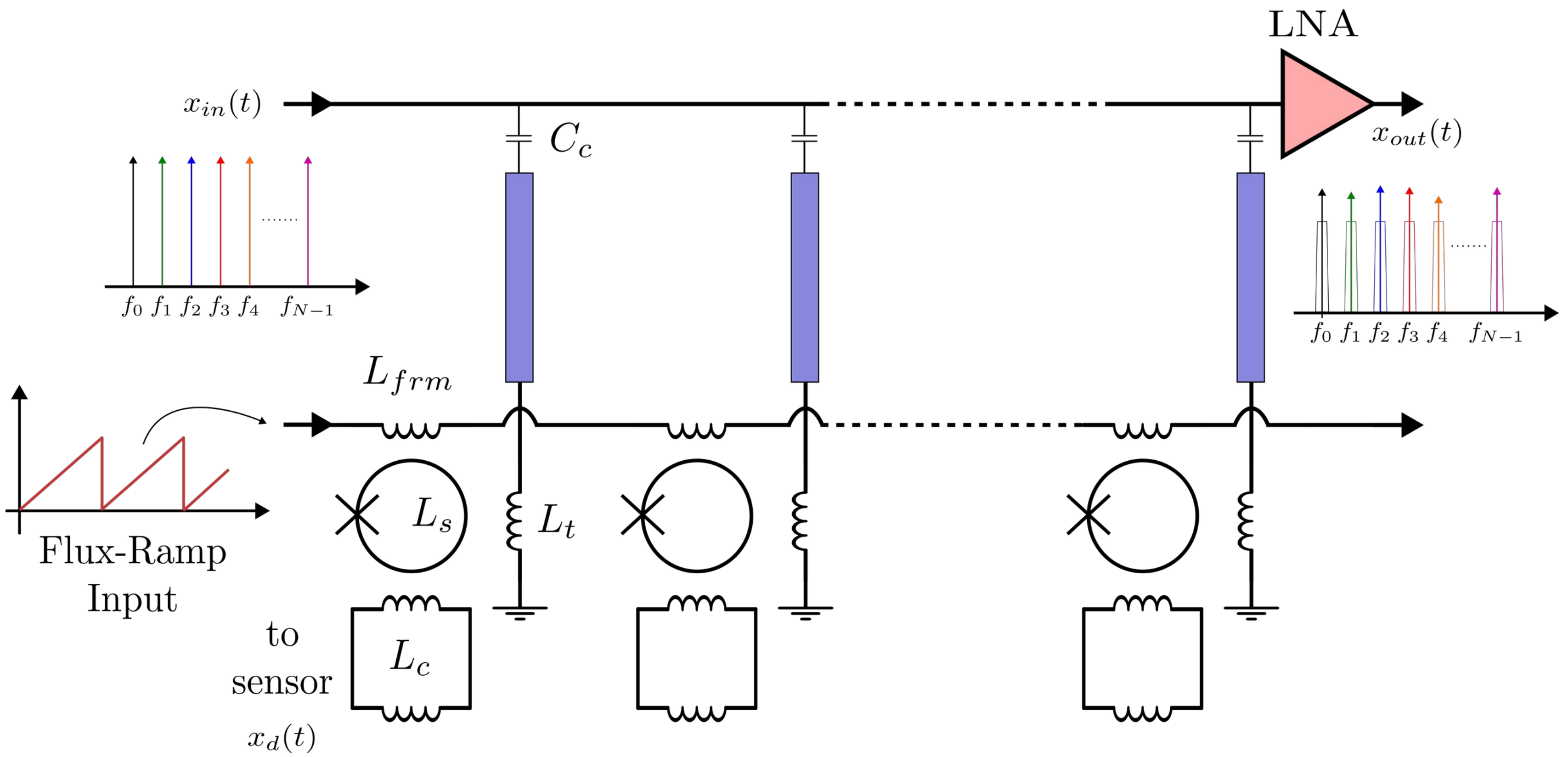


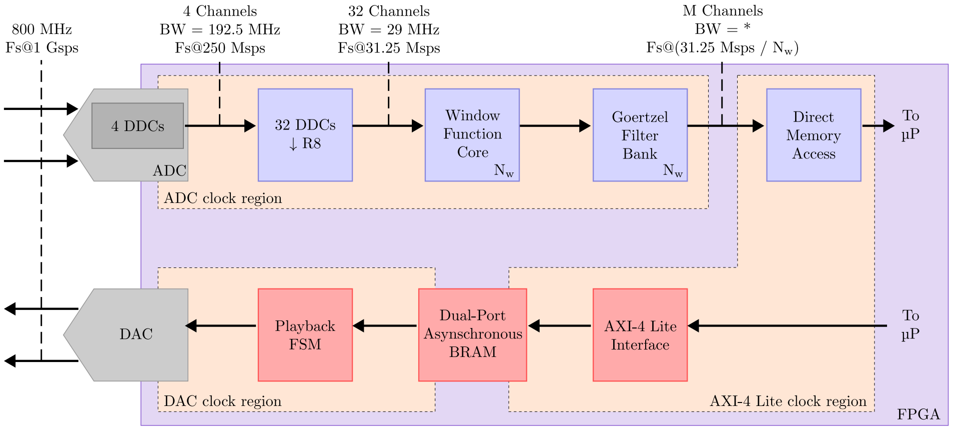





Microwave SQUID Multiplexing



A single-tone detection approach based on a Goertzel Filter Bank



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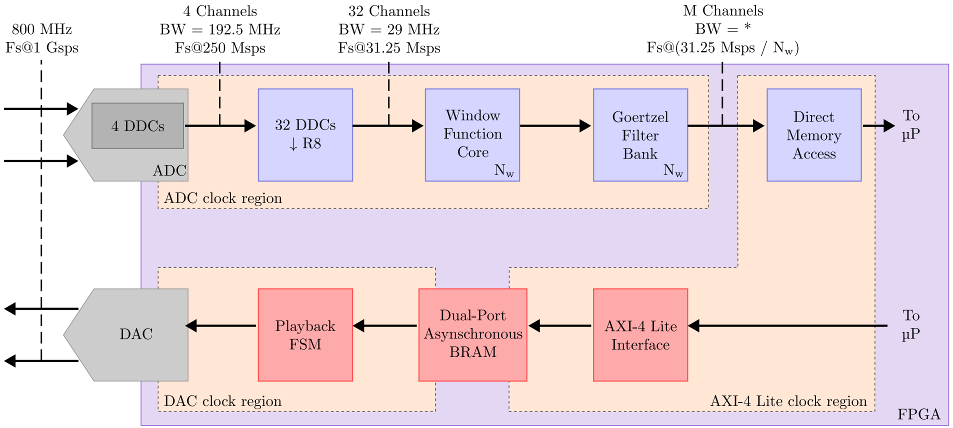

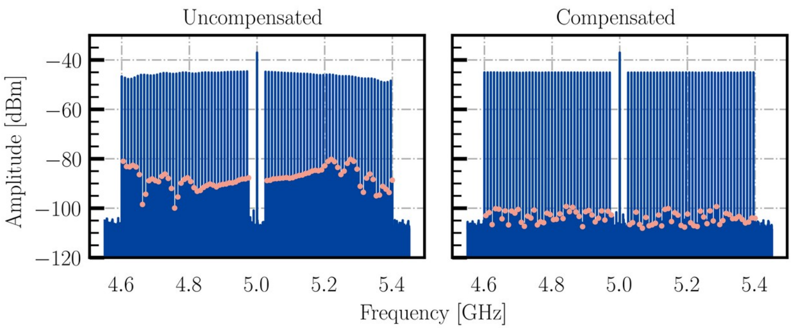

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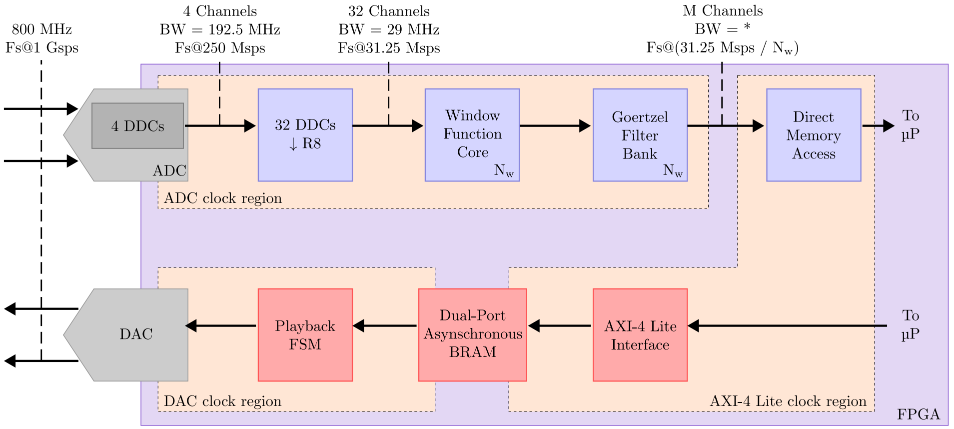
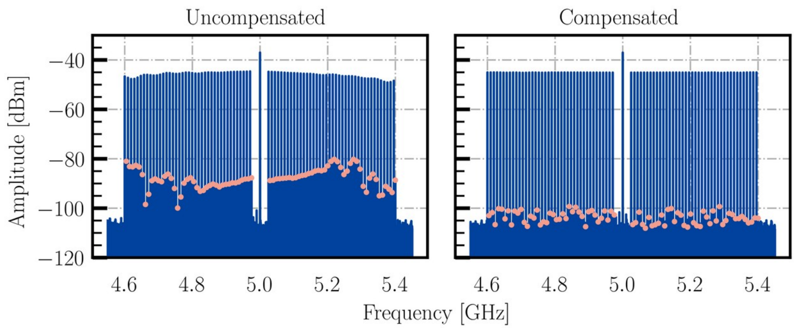


Towards RF - frontend



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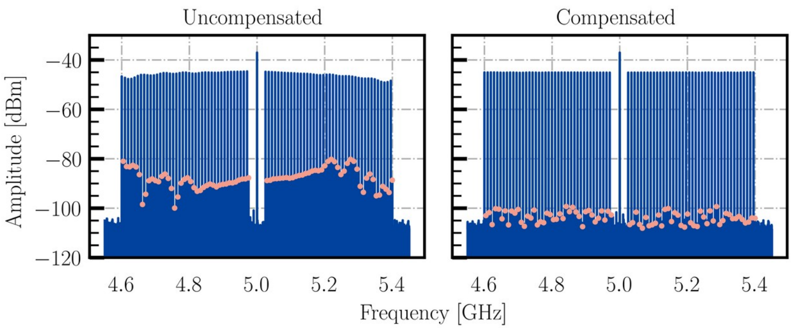
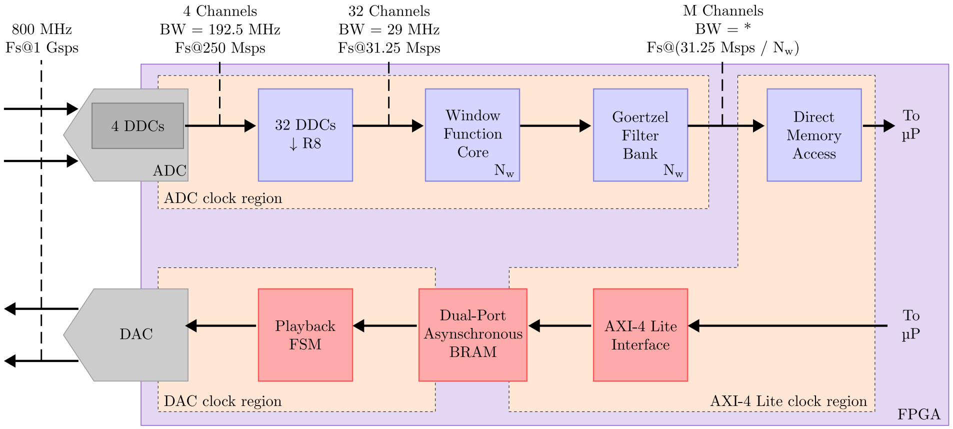
Towards cryo-setup

Towards RF - frontend





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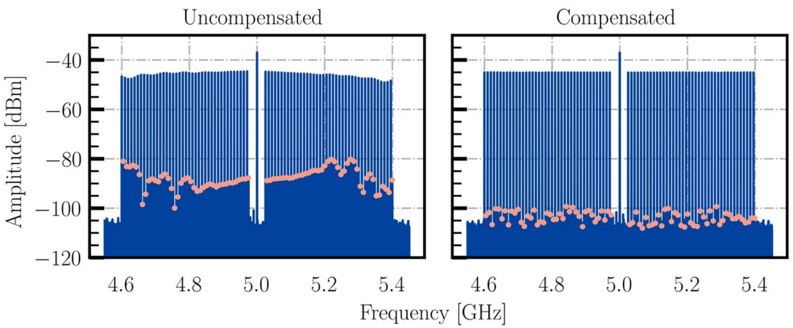
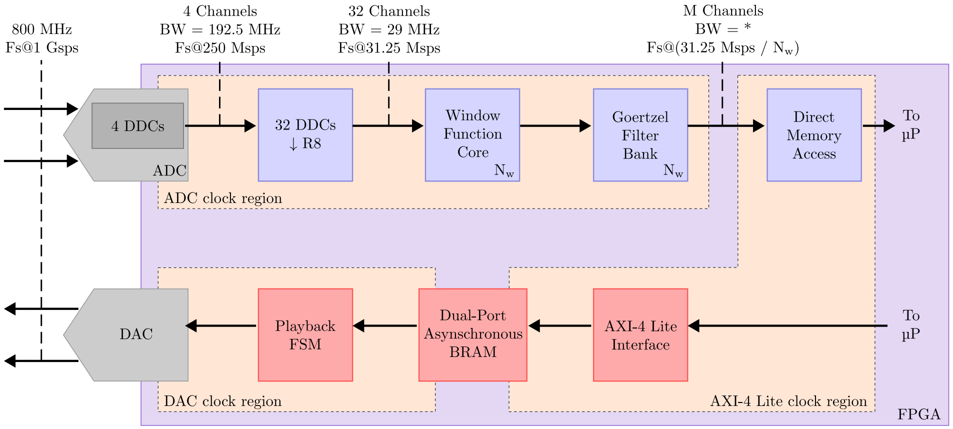
Back to RF - frontend

Towards cryo-setup

Towards RF - frontend





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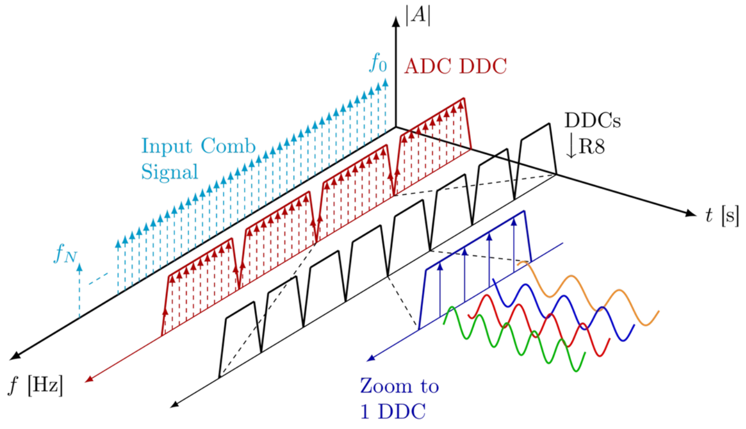
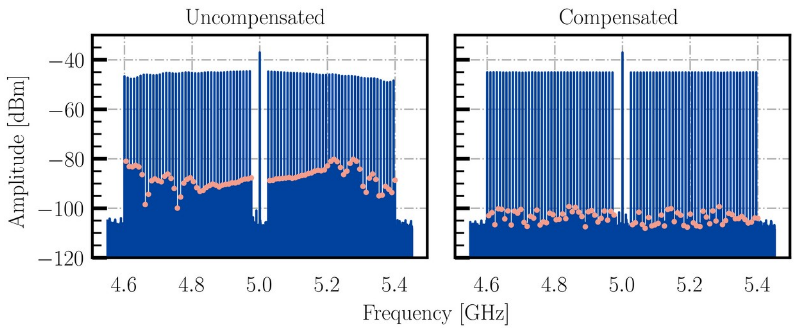
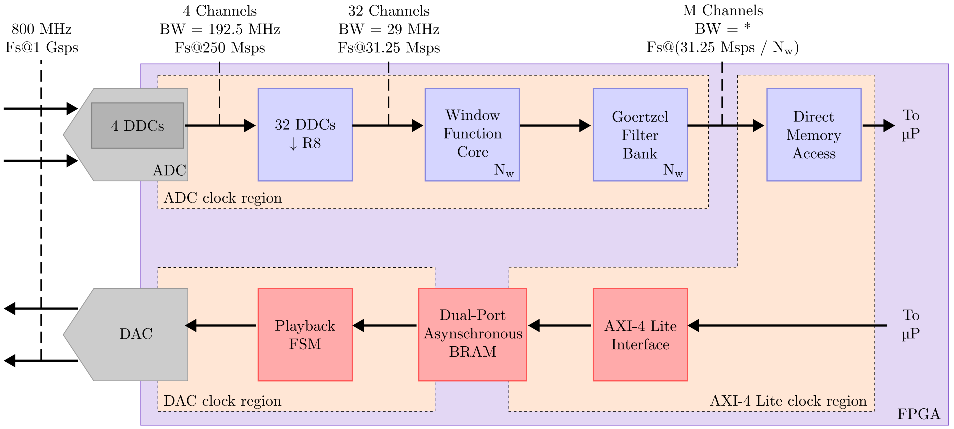
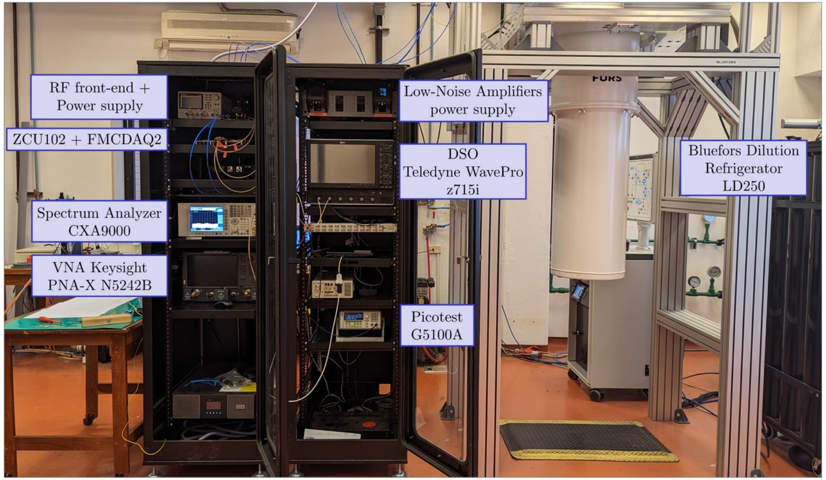
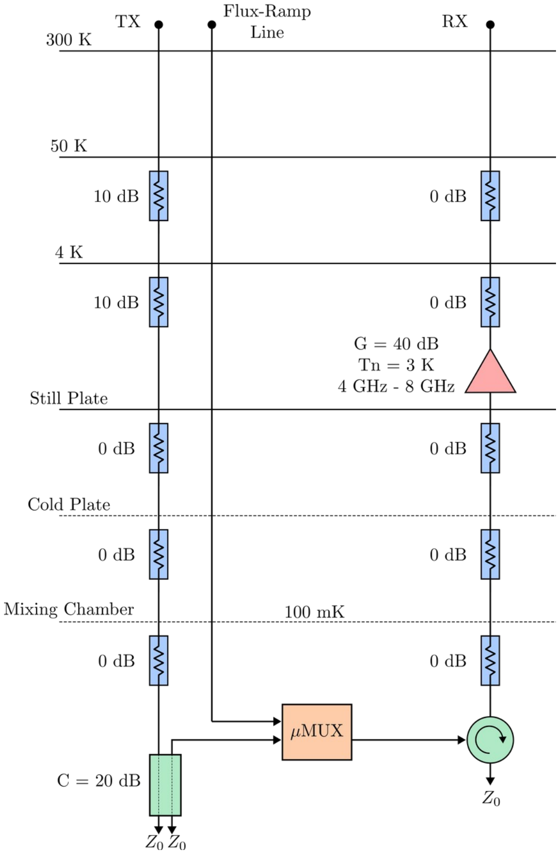






Readout electronics characterization





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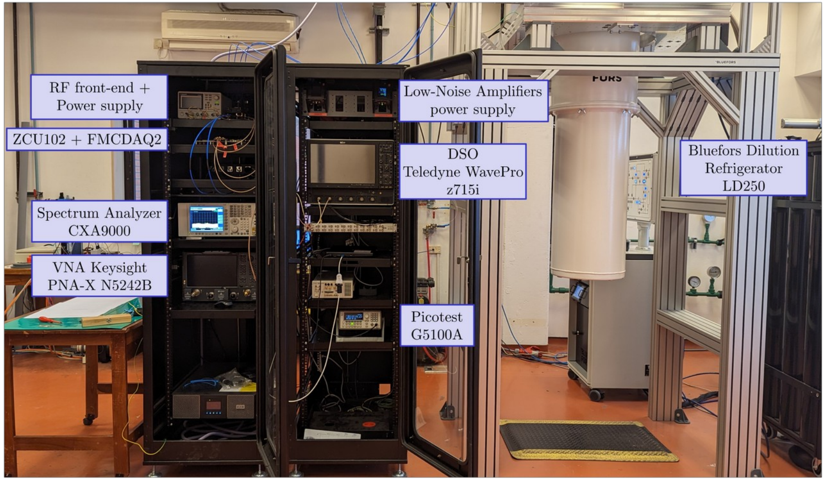
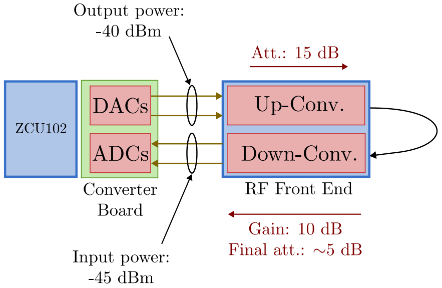
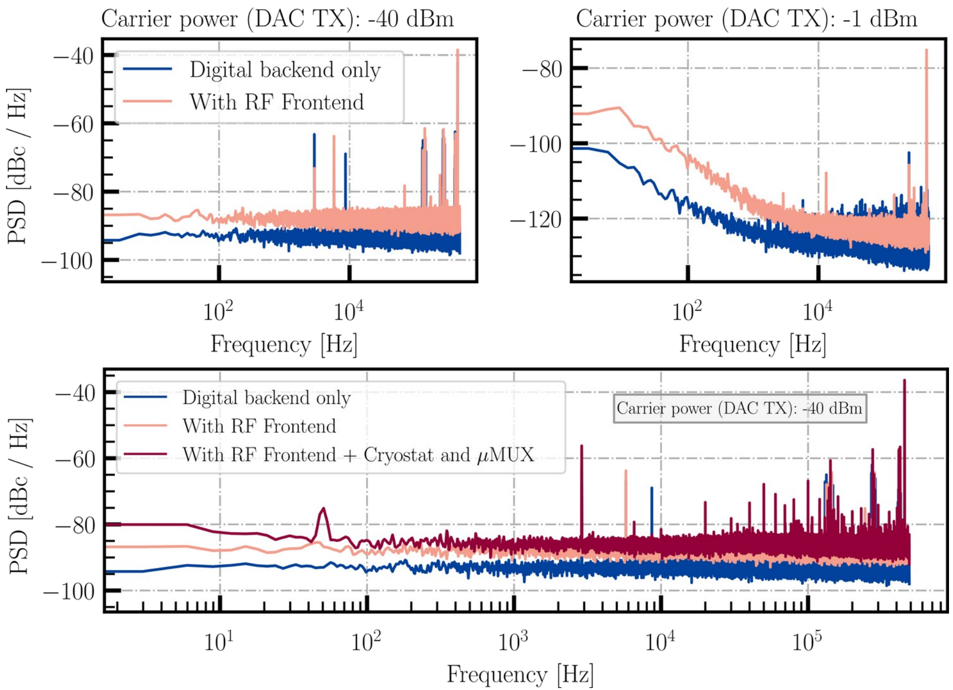




SDR noise characterization



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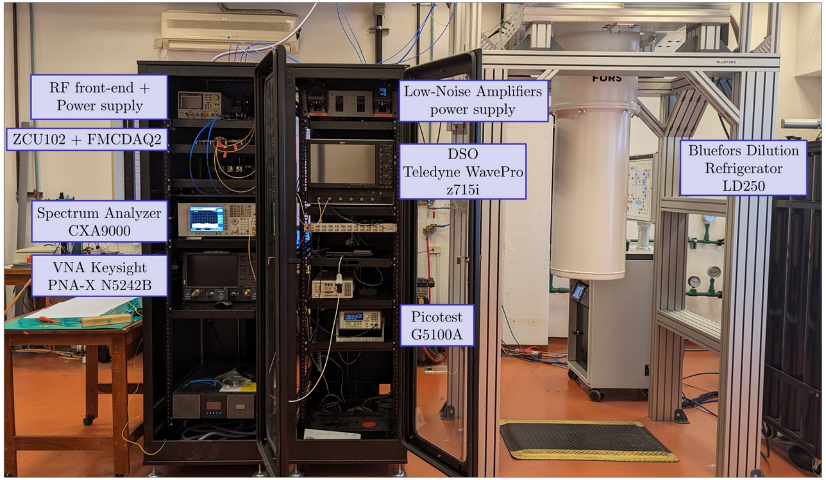
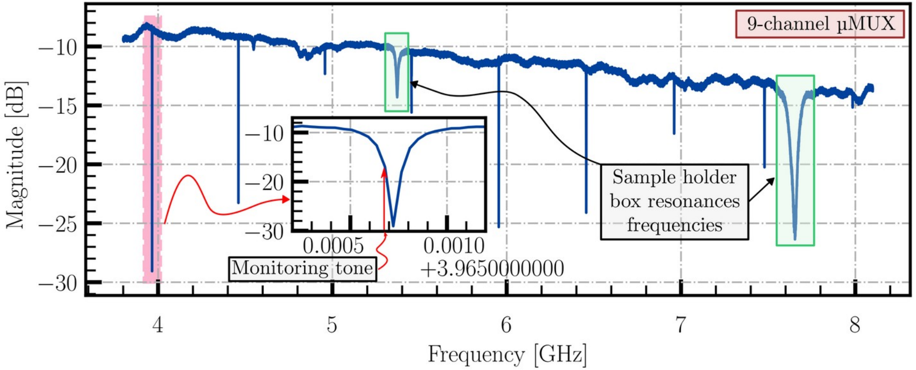


µMUX characterization (VNA)



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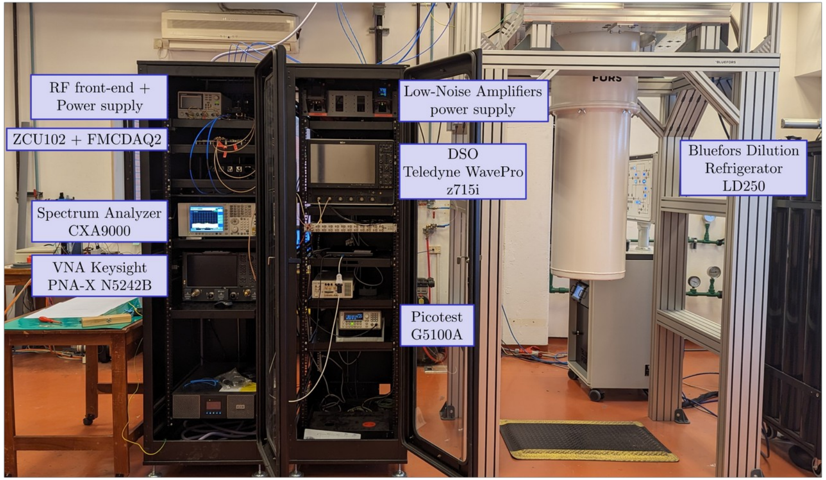

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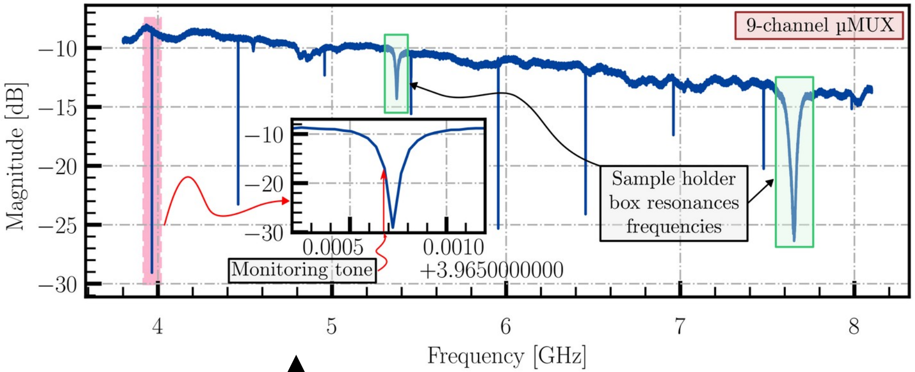

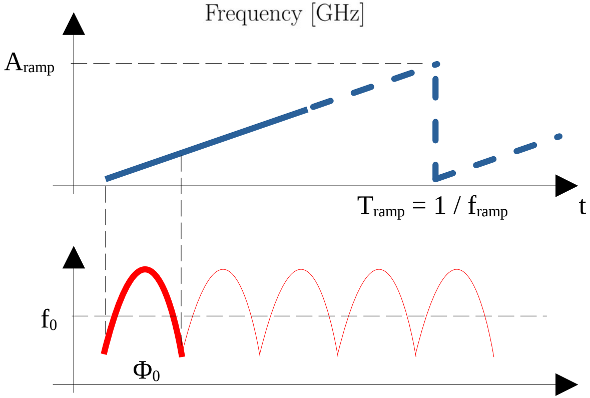

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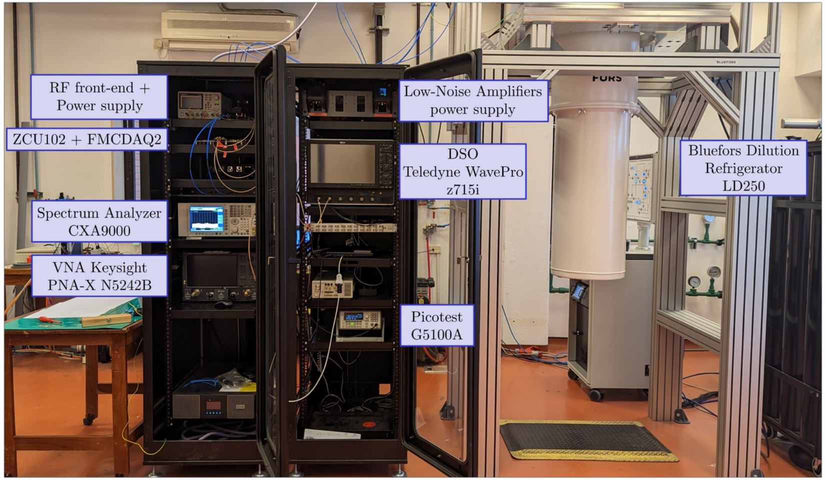

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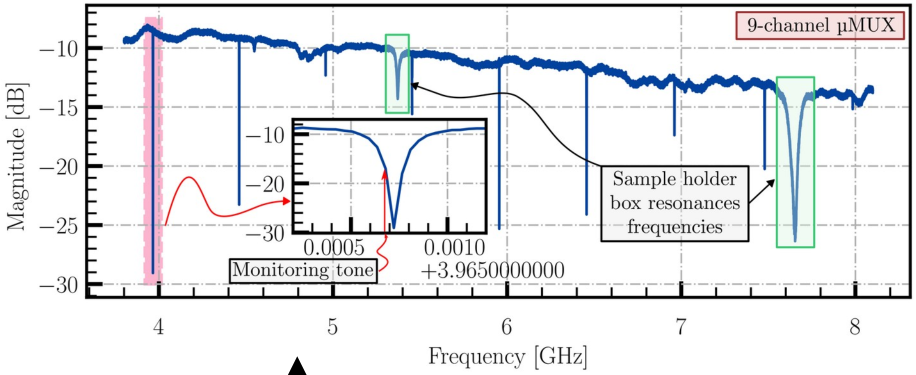
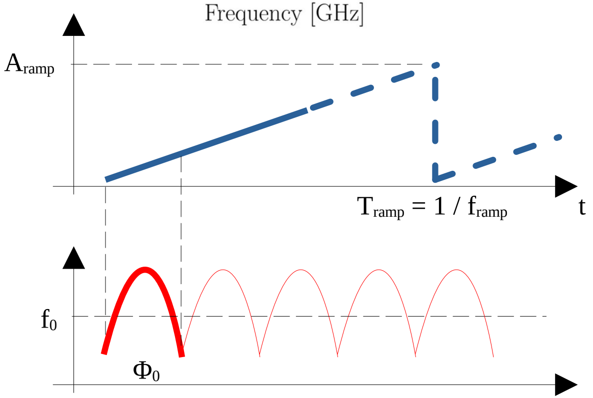


Rf-SQUID response: 1 Φ_0 / 186,8µA (lets call it “$k_{rf\text{-}squid}$”):

- If f_{ramp} = 1 kHz → $k_{rf\text{-}squid} * A_{ramp\ 1} = 1\ \Phi_0$ → f_{squid} = 1 kHz
- If f_{ramp} = 1 kHz → $k_{rf\text{-}squid} * A_{ramp\ 2} = 2\ \Phi_0$ → f_{squid} = 2 kHz
- If f_{ramp} = 1 kHz → $k_{rf\text{-}squid} * A_{ramp\ 4} = 4\ \Phi_0$ → f_{squid} = 4 kHz



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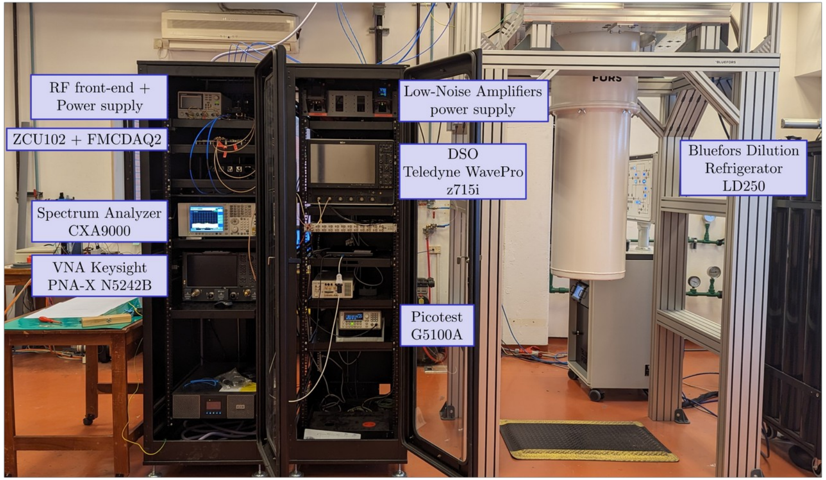
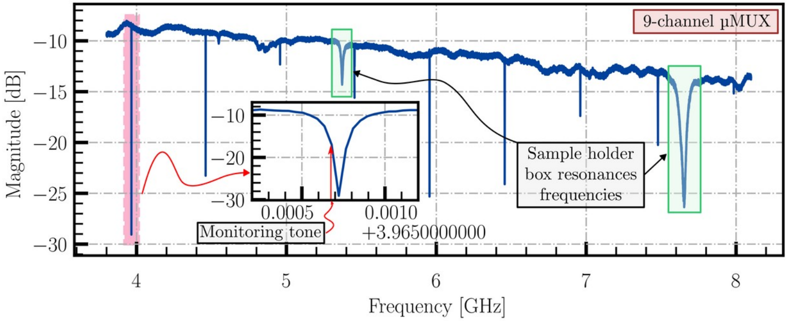
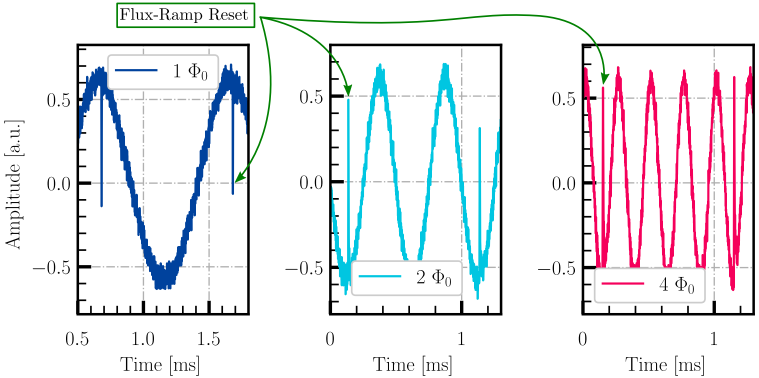
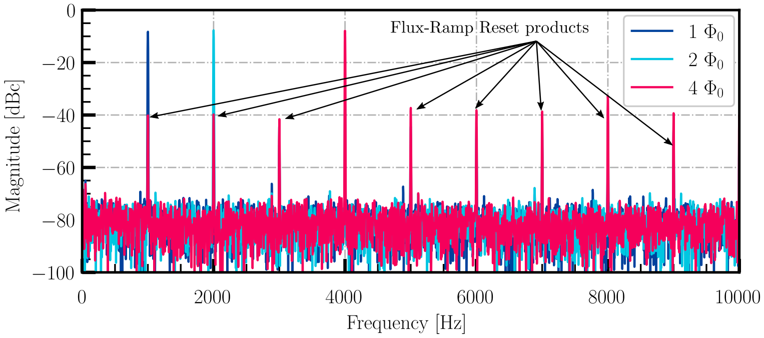




µMUX readout (SDR): Flux-Ramp only





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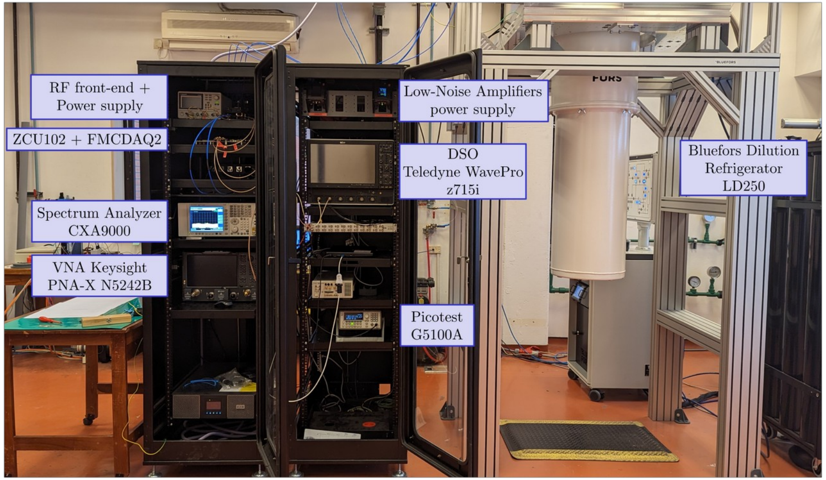
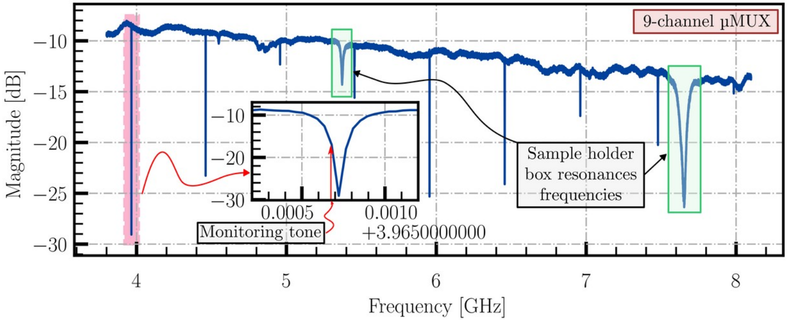
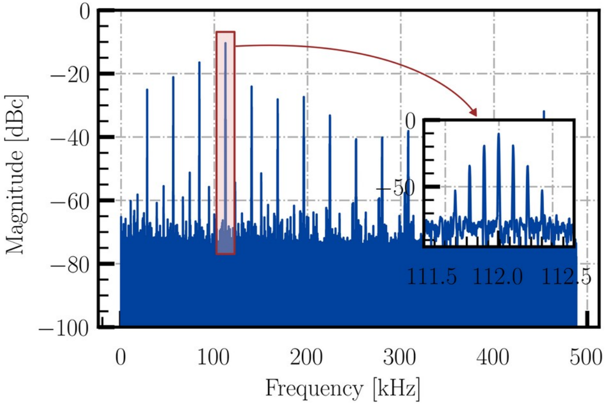
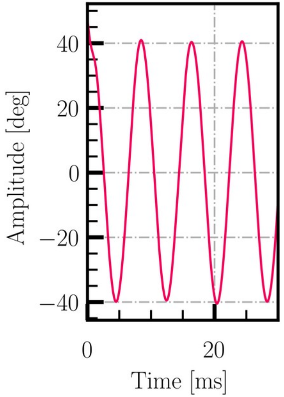




µMUX readout (SDR): Flux-Ramp with PM





f_{ramp} = 28 kHz → $k_{rf\text{-}squid}$ * $A_{ramp\ 4}$ = 4 Φ_0
→ f_{squid} = 112 kHz

$f_{detector}$ = 135 Hz with 40º (peak)

Summary and conclusions

Summary

- Several experimental setups where mounted,
- A first noise characterization of the complete system was carried out using the SDR electronics,
- The implemented Goertzel Filter Bank (GFB) channelizer presents a noise spectral density (NSD) within the state-of-the-art,
- The GFB channelizer demodulation capabilities were evaluated and validated.

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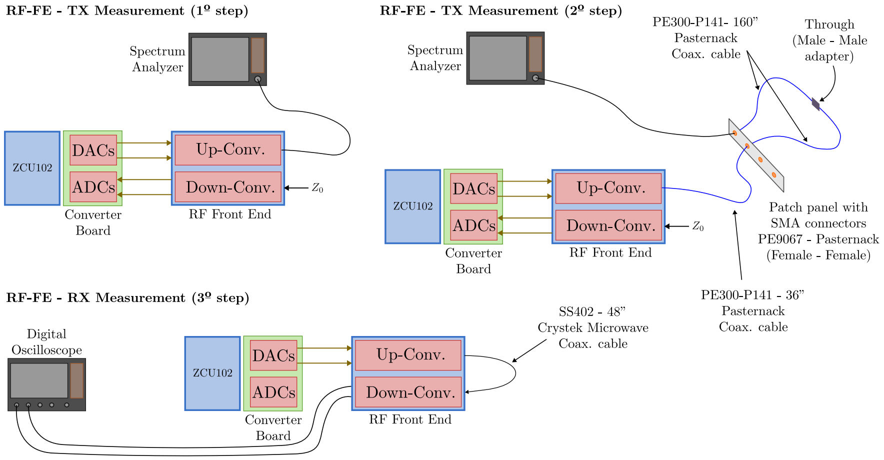
Conclusions

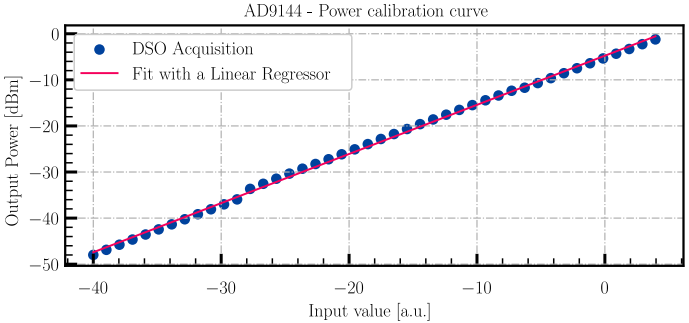
This work has demonstrated the suitability of the Goertzel Filter Bank as a tool for the channelization of multitonal signals with remarkable performance characteristics: NSD, configurability, low digital electronics resource requirements and low through-put; with applicability in cryogenic particle detectors readout.

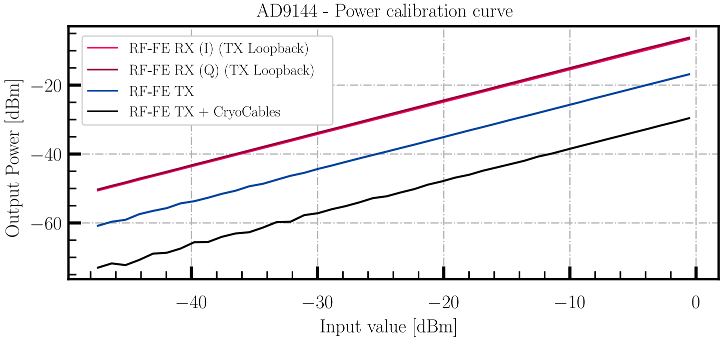
Thank you!
Vielen Danke!
¡Gracias!

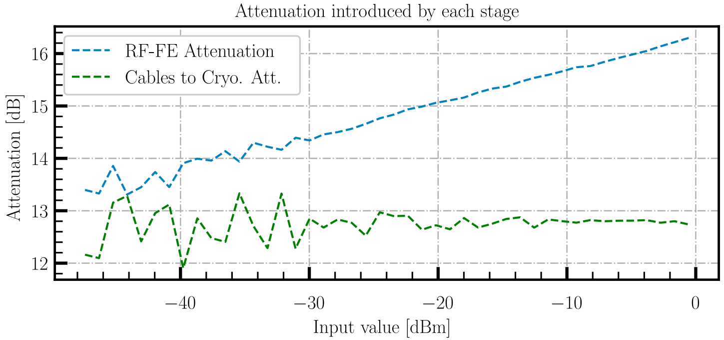
Back - Up

Power Calibration





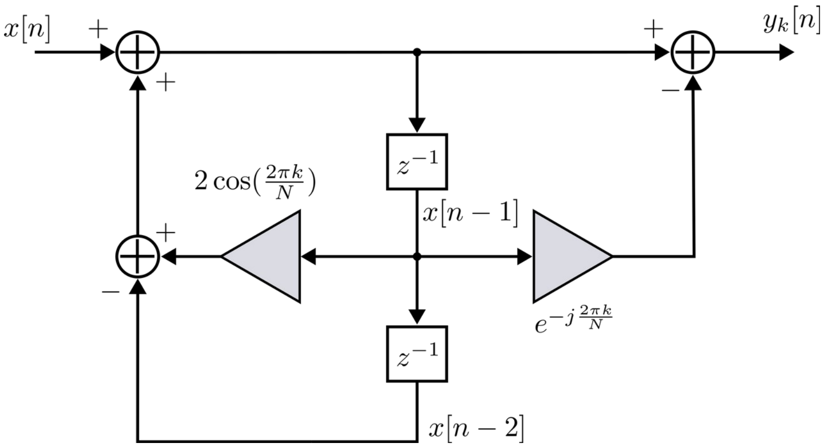


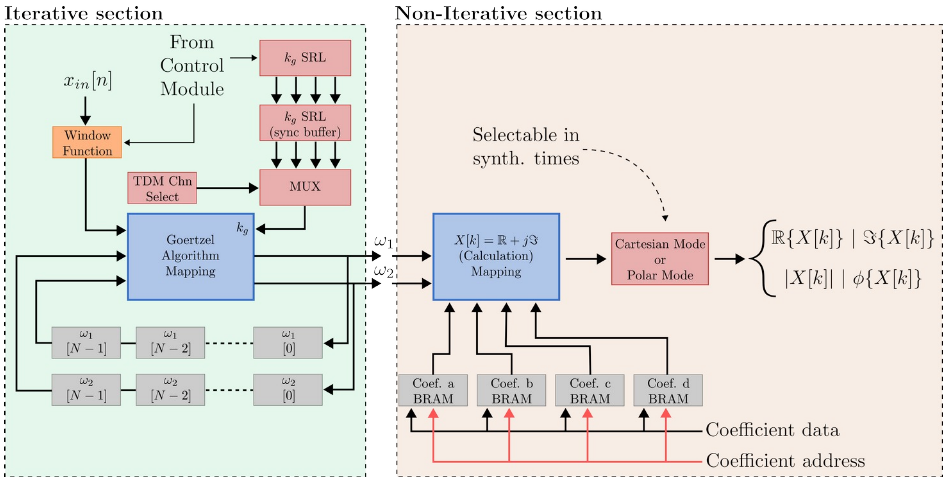


A single-tone detection approach

The Goertzel Filter

It allows the simultaneous calculation of the magnitude and phase of a single bin from a signal's Discrete Fourier Transform (DFT).





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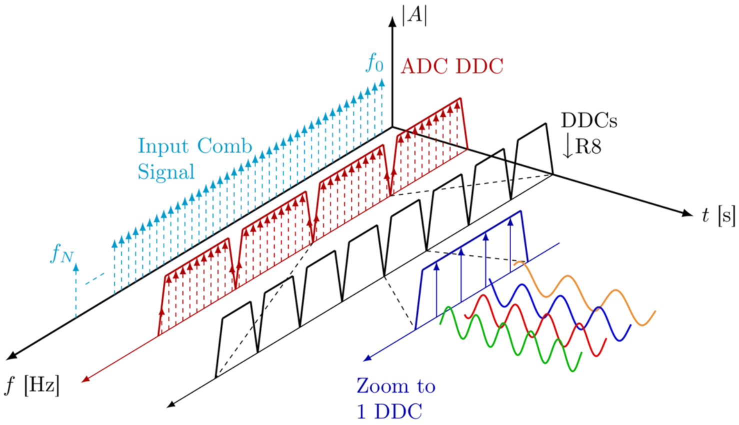
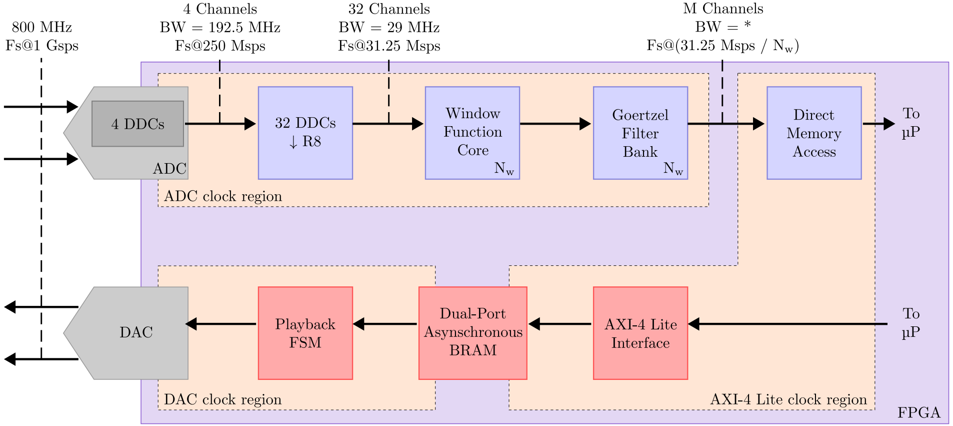
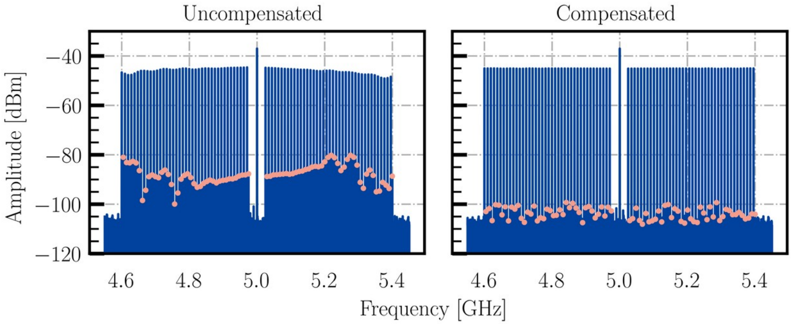
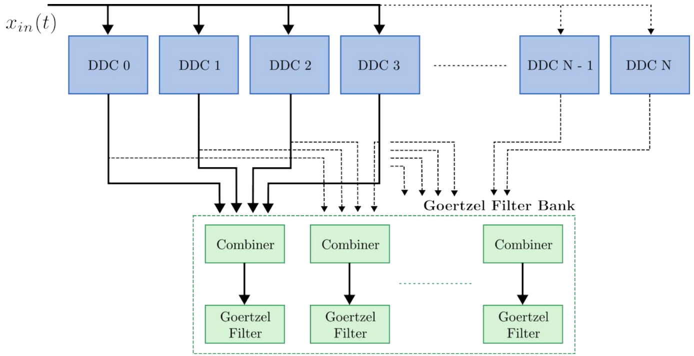
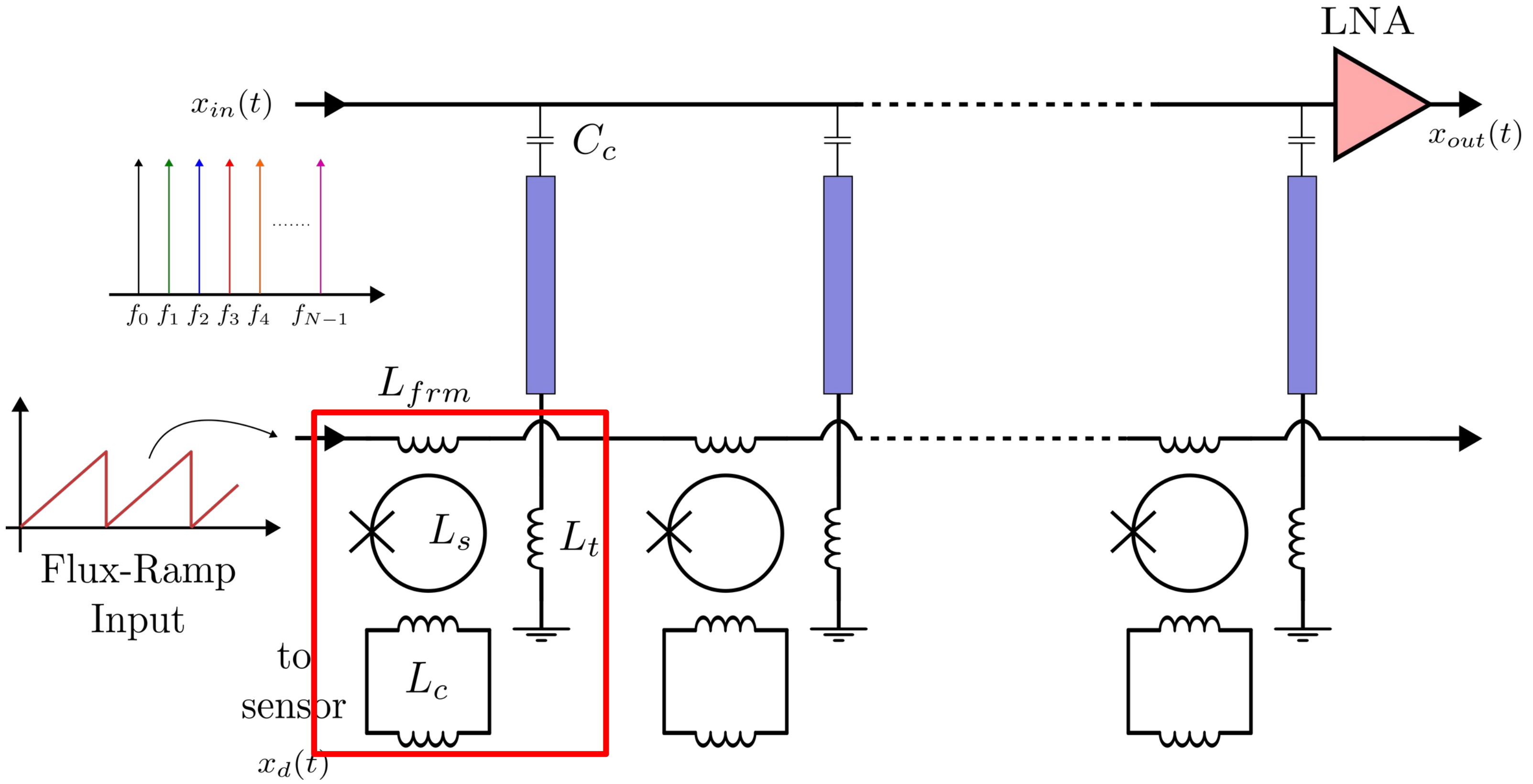








Microwave SQUID Multiplexing



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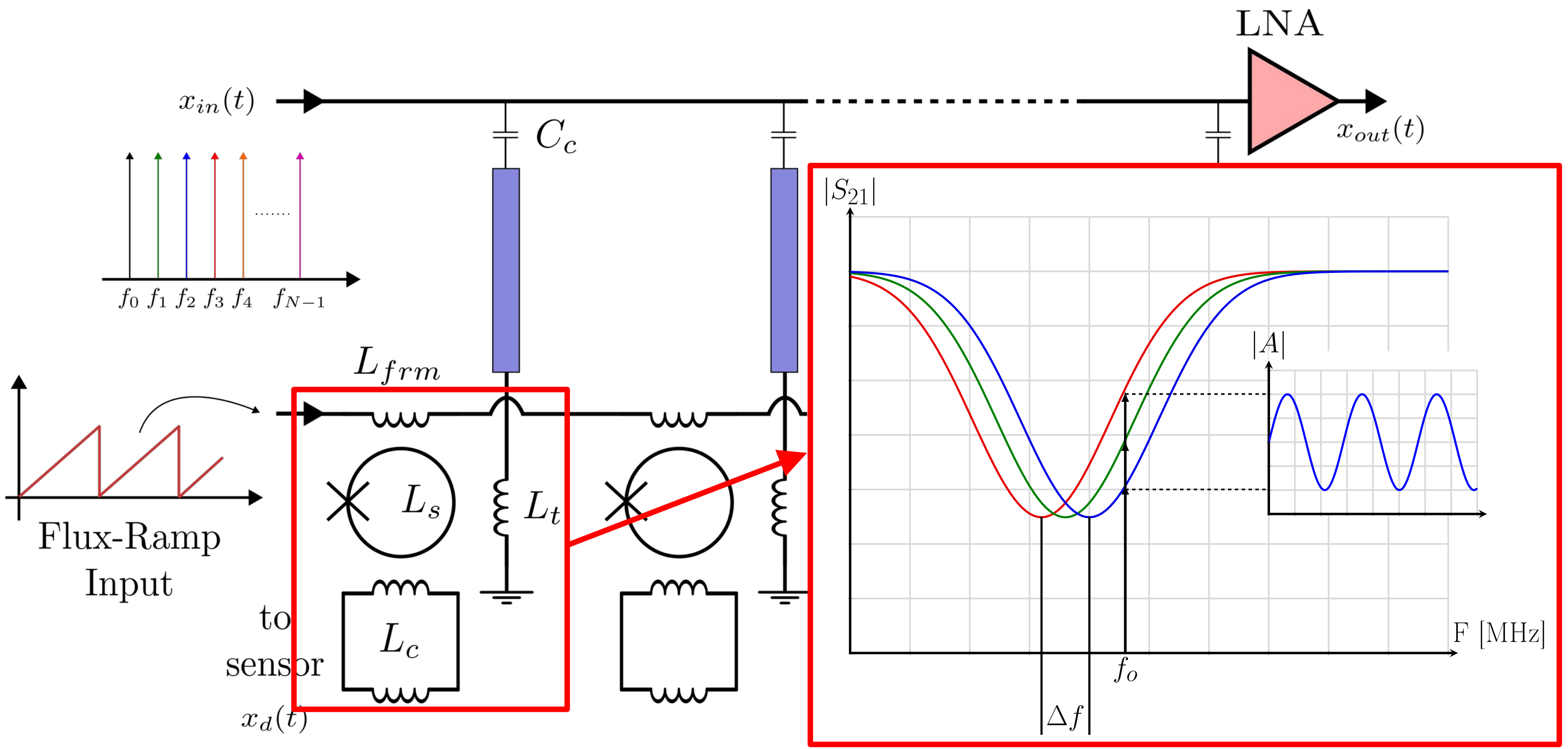

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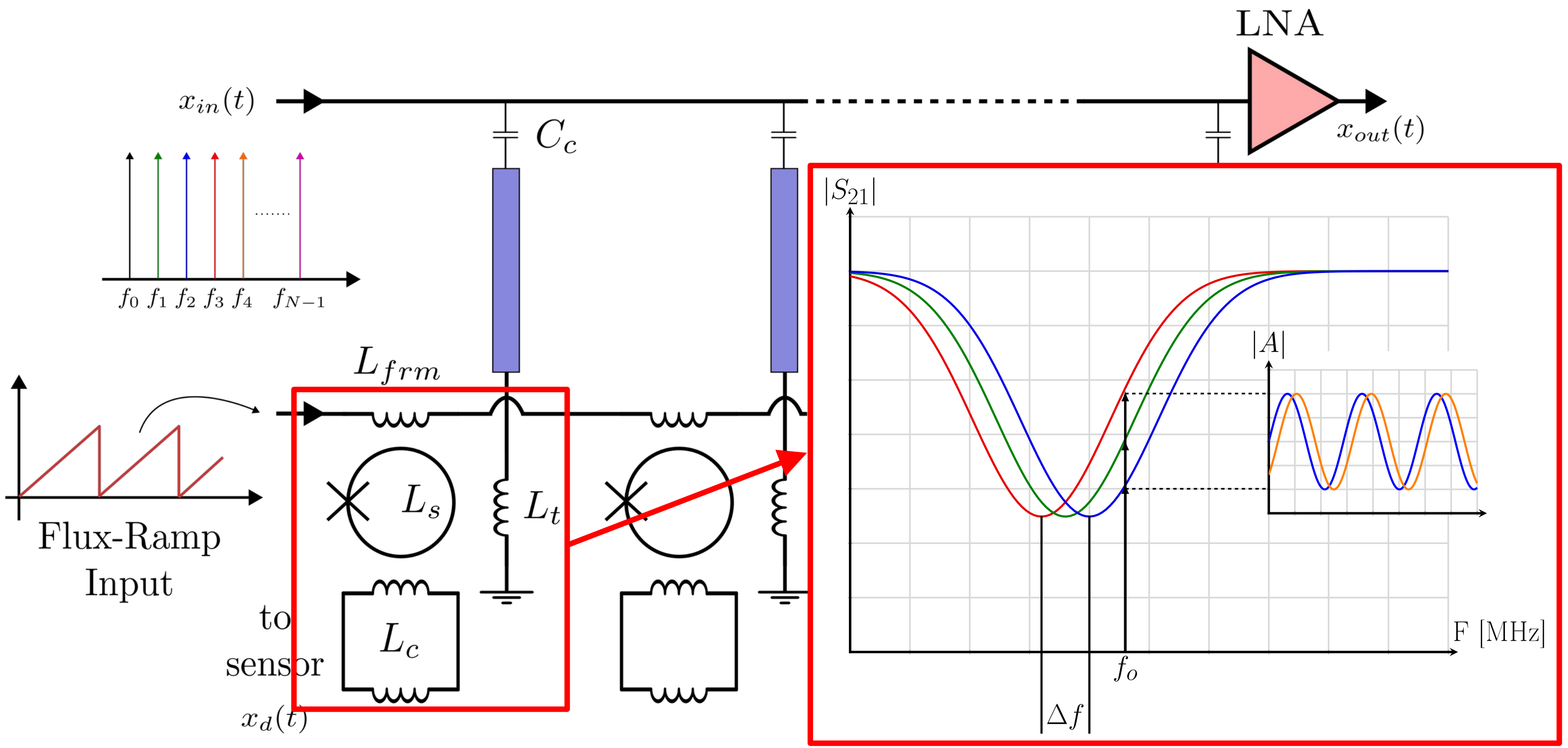

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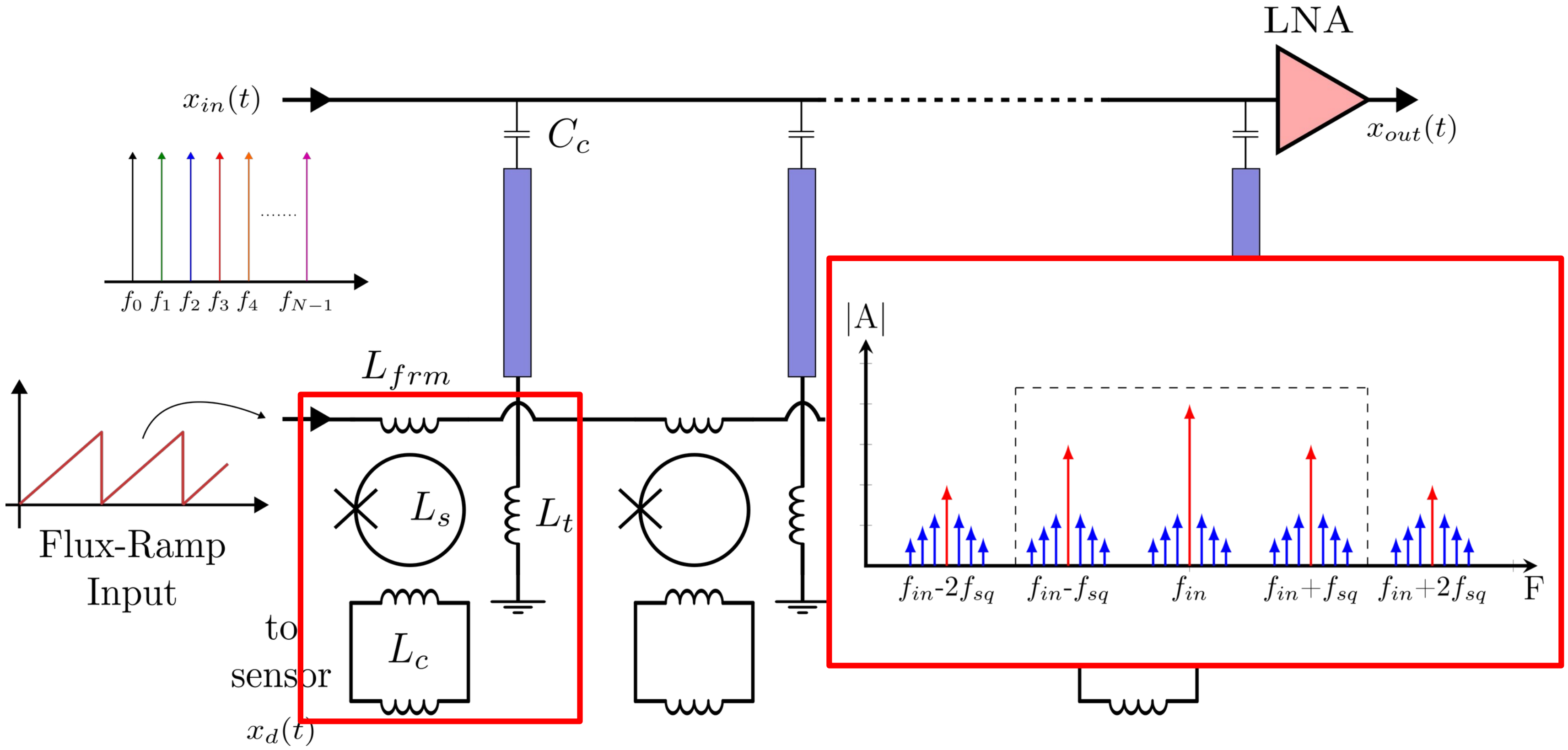

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