High speed microwave rf-SQUID multiplexing read-out for neutrino mass experiment

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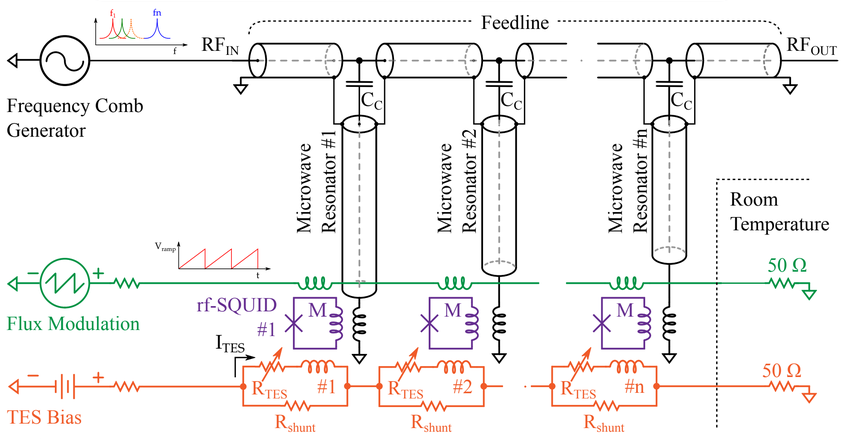
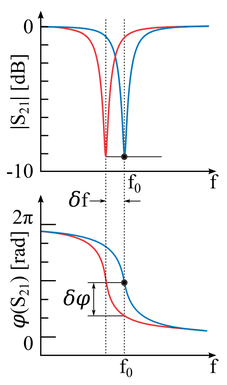
Overview

The baseline sensors for HOLMES are Mo/Cu TESs (Transition Edge Sensors) on SiN_x membrane with gold absorbers. Considering the large number of pixels and an event rate of about 300 Hz per pixel, a large multiplexing factor and a large bandwidth are needed. To fulfill this requirement, HOLMES will exploit recent advances on microwave multiplexing, techique that offers several gigahertz of readout bandwidth per pair of coaxial cables. In this contribution we present a fully scalable 32-channel readout system optimized to acquire high speed and high resolution TES detectors. This system is based on a ROACH2 board coupled to a remotely programmable semi-commercial up- and down-conversion circuitry, specifically designed for HOLMES.

B. Alpert et al. Eur. Phys. J. C75 (2015) 112

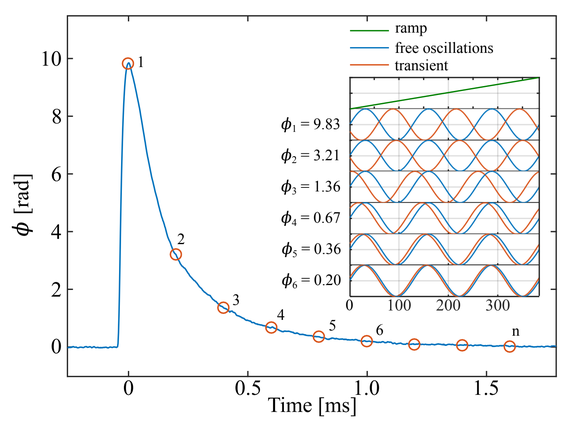
Microwave rf-SQUID multiplexing





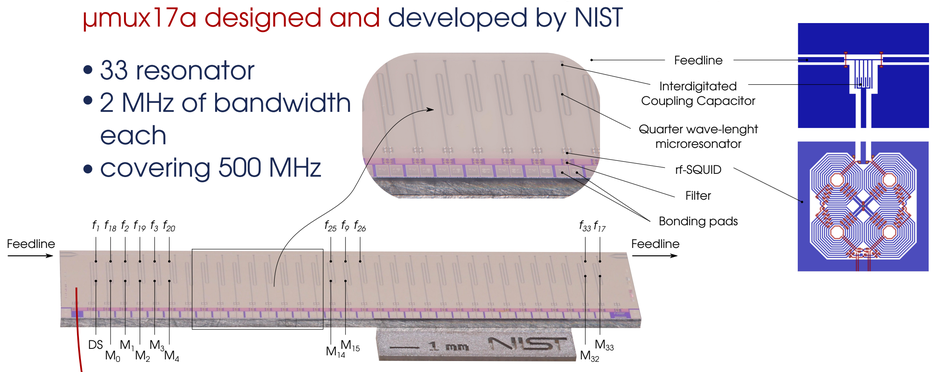
- dc-biased TES inductively coupled to a dissipationless -SQUID;
- rf-SQUID inductively coupled to a high-Q superconducting λ/4 resonator
- Change in TES current ⇒ change in the input flux to the SQUID
- Change in the input ux to the SQUID ⇒ change of resonance frequency and

- Each micro-resonator can be continuously monitored by a probe tone
- By coupling many resonators to a single microwave feedline it is possible to perform the readout of multiple detectors
- Sensors are monitored by a set of sinusoidal probe tones (frequency comb)
- The ramp induces a controlled flux variation in the rf-SQUID, which is crucial for linearizing the response.

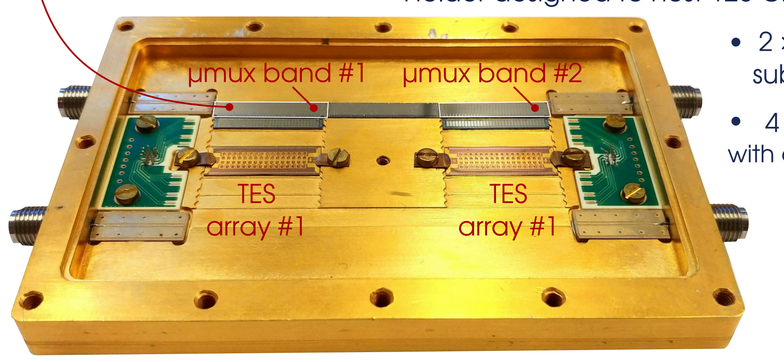


The core of the microwave multiplexing is the multiplexer chip μmux17a designed and developed by NIST

- 33 resonator
- 2 MHz of bandwidth each
- covering 500 MHz



Holder designed to host 128 Channels

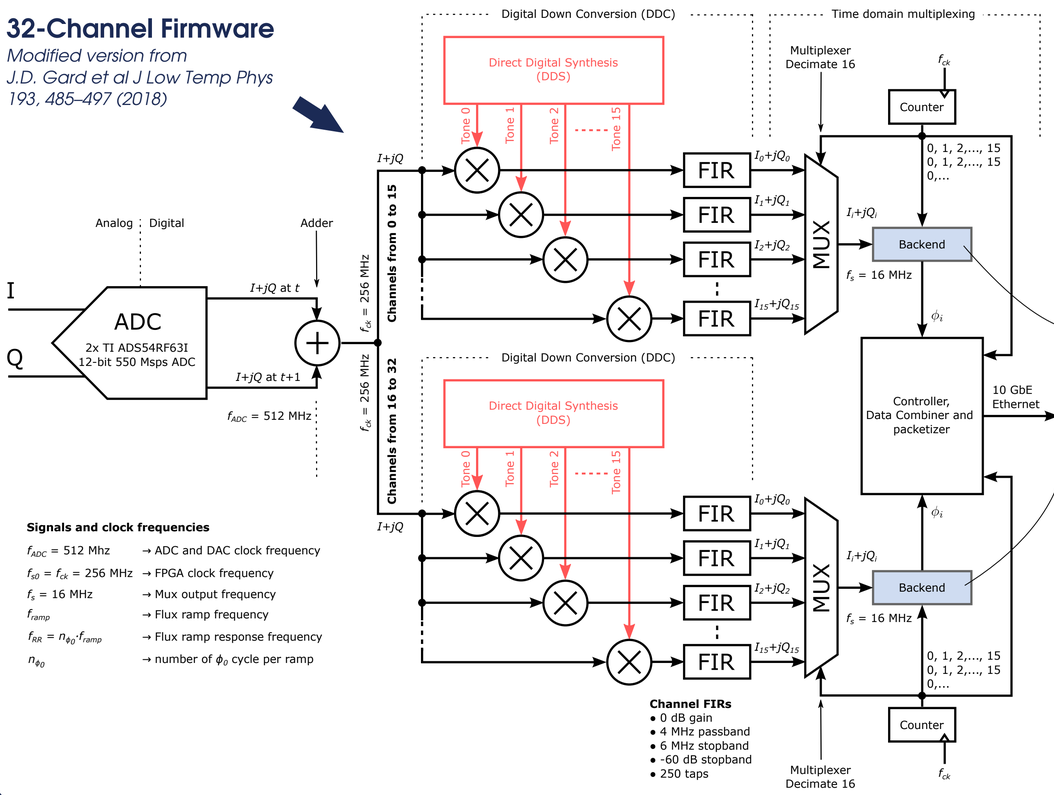


- 2 × 64-TES sub arrays
- 4 × μmux with different bands

Read-out Implementation

32-Channel Firmware

Modified version from J.D. Gard et al J Low Temp Phys 193, 485–497 (2018)



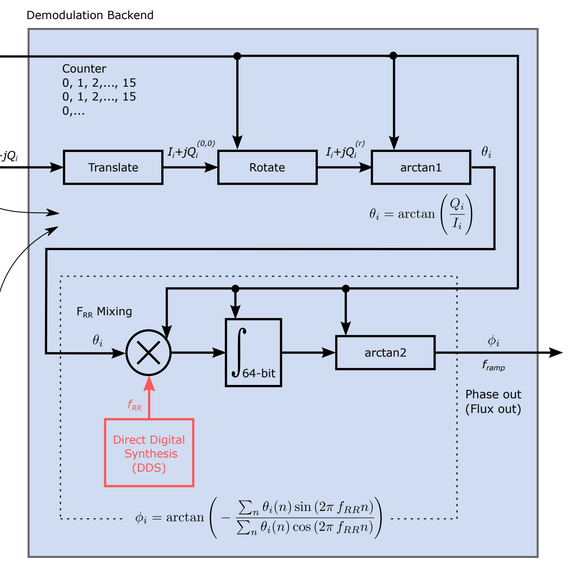
Signals and clock frequencies

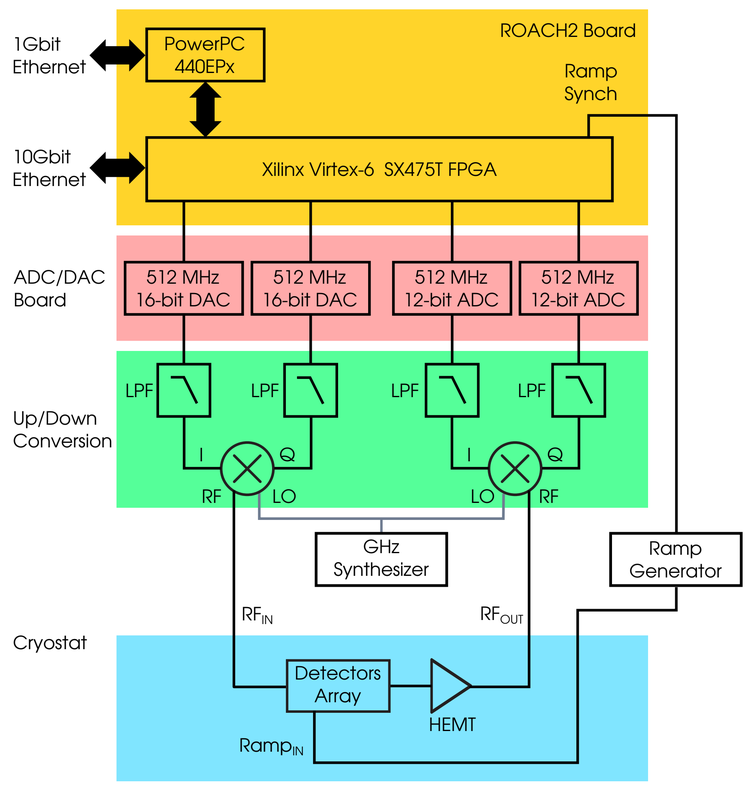
f_{ADC} = 512 Mhz	→ ADC and DAC clock frequency
$f_{s0} = f_{ck}$ = 256 MHz	→ FPGA clock frequency
f_s = 16 MHz	→ Mux output frequency
f_{ramp}	→ Flux ramp frequency
$f_{RR} = n_{\phi_0} \cdot f_{ramp}$	→ Flux ramp response frequency
n_{ϕ_0}	→ number of ϕ_0 cycle per ramp

Channel FIRs
- 0 dB gain
- 4 MHz passband
- 6 MHz stopband
- -60 dB stopband
- 250 taps

32-Channel Hardware

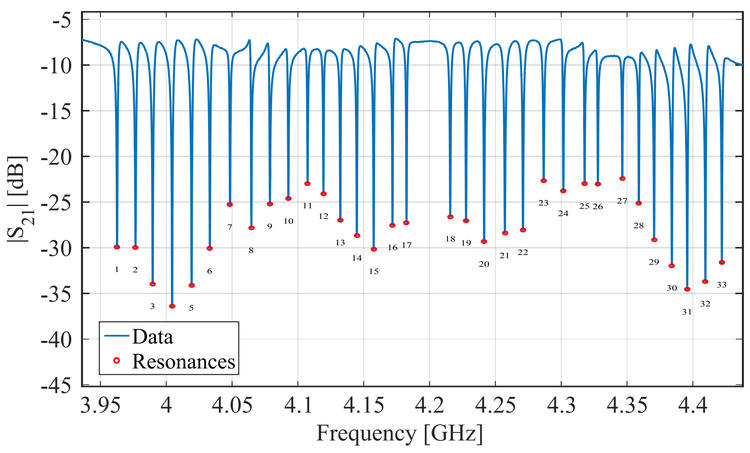
Based on ROACH2 board and PolyPhase up/down coversion system





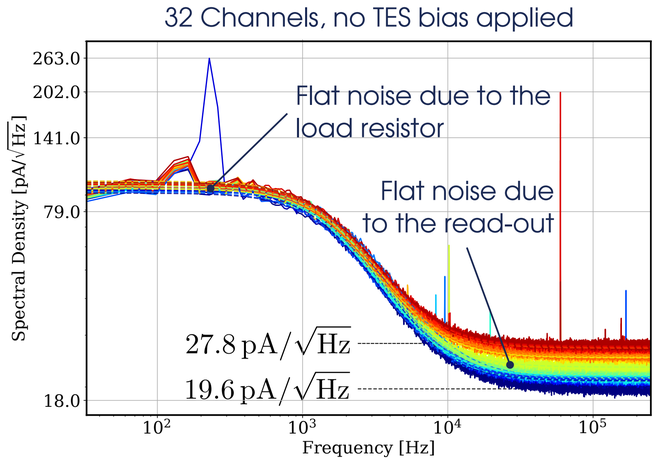
Characterization Results

Frequency Scan



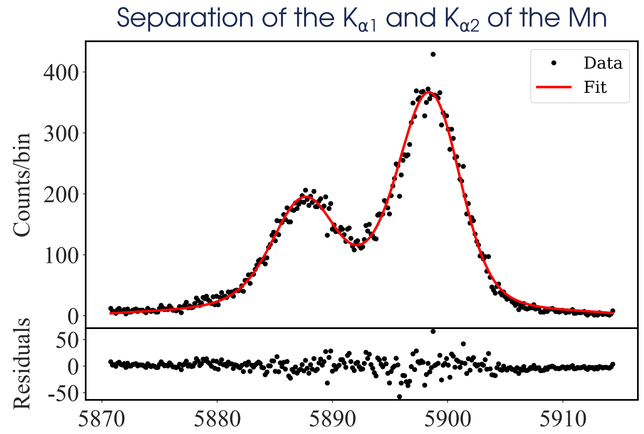
Read out noise

32 Channels, no TES bias applied



Test with x-ray fuorescence source

Separation of the $K_{\alpha 1}$ and $K_{\alpha 2}$ of the Mn



		Required	Measured
Resonators bandwidth	Δf_{BW} [MHz]	2	2 ± 1
Resonators spacing	Δf [MHz]	14	14 ± 1
Resonators depth	ΔS [dB]	> 10	29 ± 6

Improved read out noise ⇒ $n_S = (23.3 \pm 2.4)\,\mathrm{pA}/\sqrt{\mathrm{Hz}}$

Previous work ⇒ $n_S = (26 \pm 7)\,\mathrm{pA}/\sqrt{\mathrm{Hz}}$
IEEE TAS 31 (2021) 5, 2100205

Resolution ⇒ $\Delta E_{\mathrm{Mn}} = 4.90 \pm 0.06\,\mathrm{eV}\,@\,5.9\,\mathrm{keV}$
- not limited by the read-out noise
- compatible with previous works

Read-out system for the 64 channels currently in development ⇒ Physics data from the first two 4 × 16 detector sub-arrays starting from the end of 2021

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