High speed microwave rf-SQUID multiplexing read-out for the HOLMES experiment

ERC-AdG-2013 no. 340321

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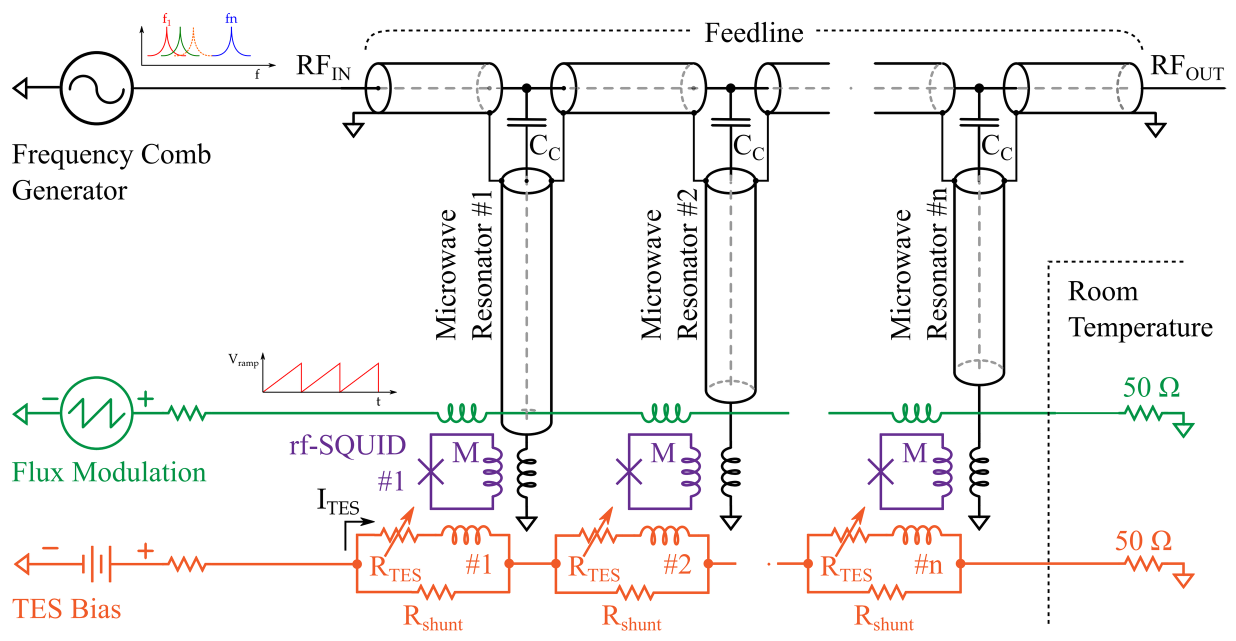
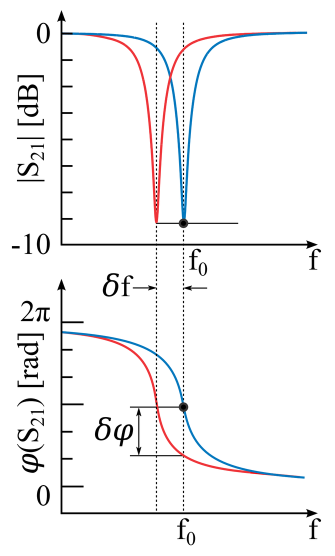
Overview

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. An emerging read out technique that can fulfill this requirement is the microwave multiplexing, which offers several gigahertz of readout bandwidth per pair of coaxial cables. TESs are coupled to rf-SQUIDs embedded in superconducting microwave resonators, which are probed via a common microwave feedline and read out at room temperature using GHz signals carried on coaxial cables. This form of multiplexing moves complexity from the cryogenic stages to room temperature hardware and digital signal processing firmware which must synthesize the microwave tones and process the information contained within them.

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

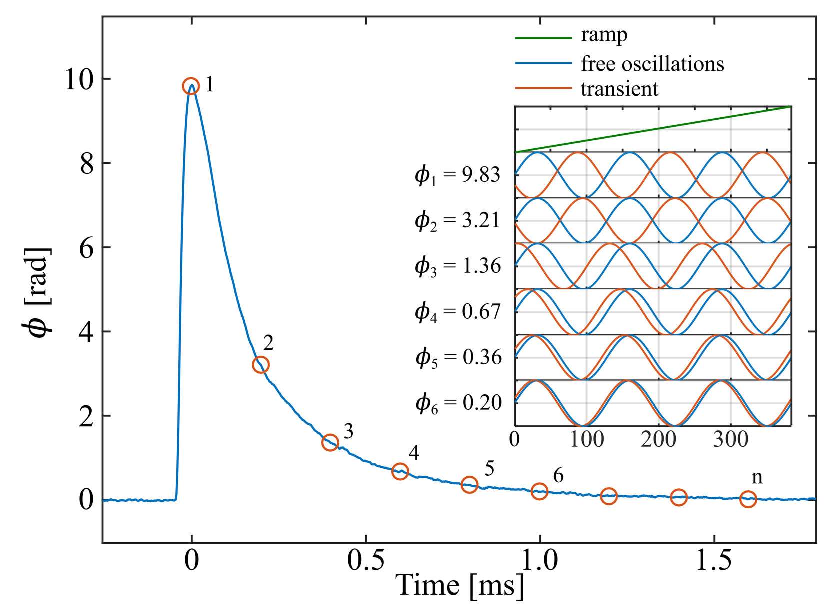
Microwave rf-SQUID multiplexing





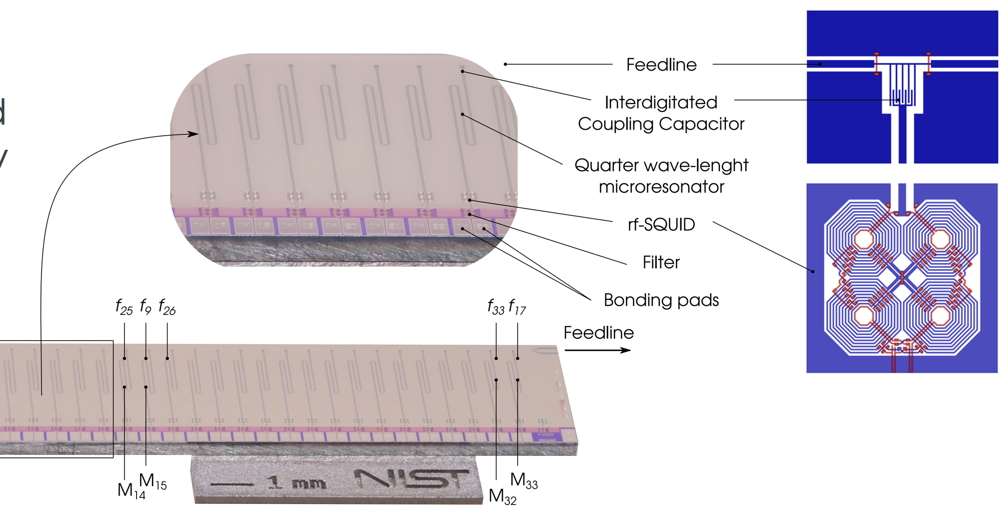
- dc-biased TES inductively coupled to a dissipationless -SQUID;
- rf-SQUID inductively coupled to a high-Q superconducting λ/4 resonator
- Change in TES current ⇒ change in the input flux to the SQUID
- Change in the input ux to the SQUID ⇒ change of resonance frequency and

- 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

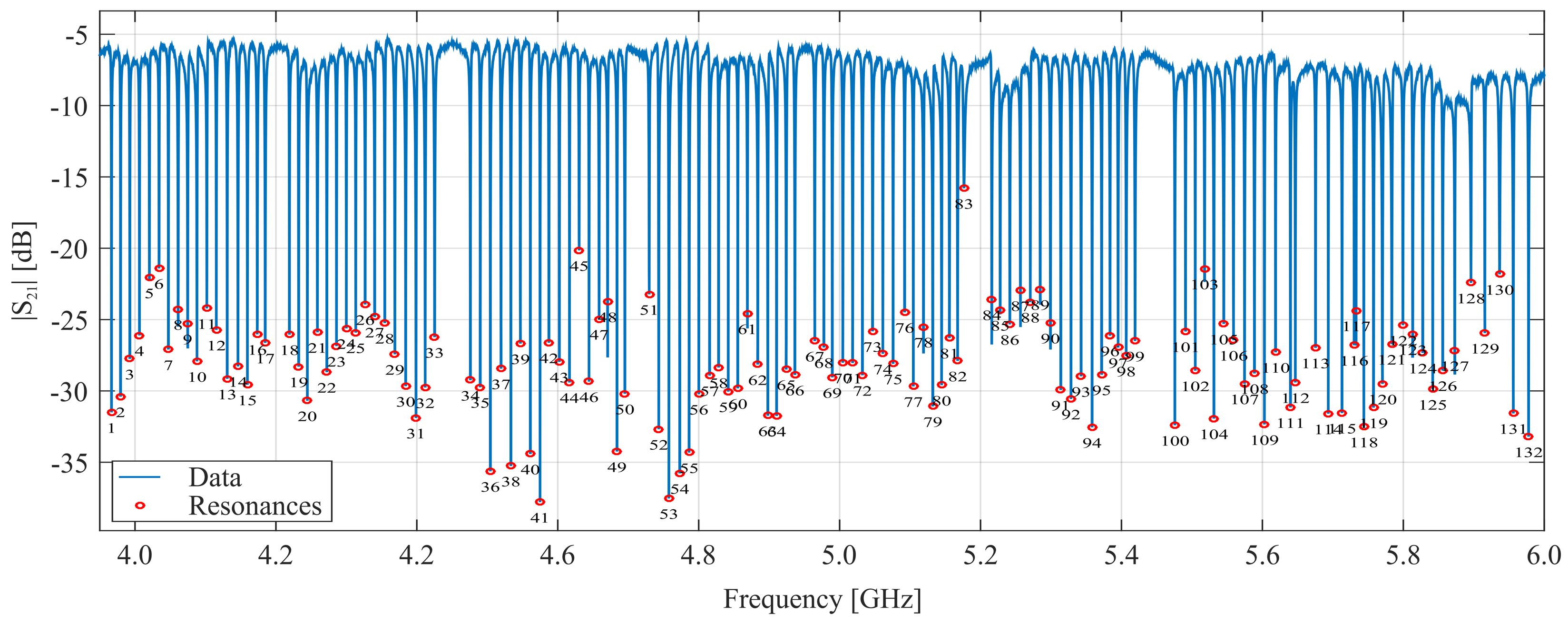
µmux17a
Designed and developed by NIST



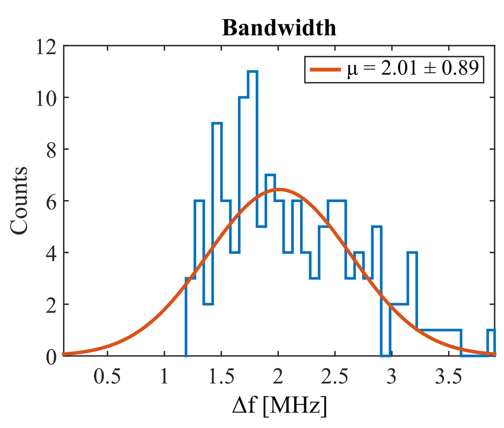
- Superconducting 33 quarter-wave coplanar waveguide (CPW)
- Each resonator has a trombone-like shape with slightly different
- The SQUID loop is a second order gradiometer consisting of four parallel lobes;
- Wiring in series di erent 33-channel chips with di erent frequency band allows to increase the multiplexing factor (daisy chain)
- Large multiplexing factor (> 100) and bandwidth, currently limited by the digitizer bandwidth

Multiplexer Characterization

Experimental characterization of 132 resonators (4 chips):

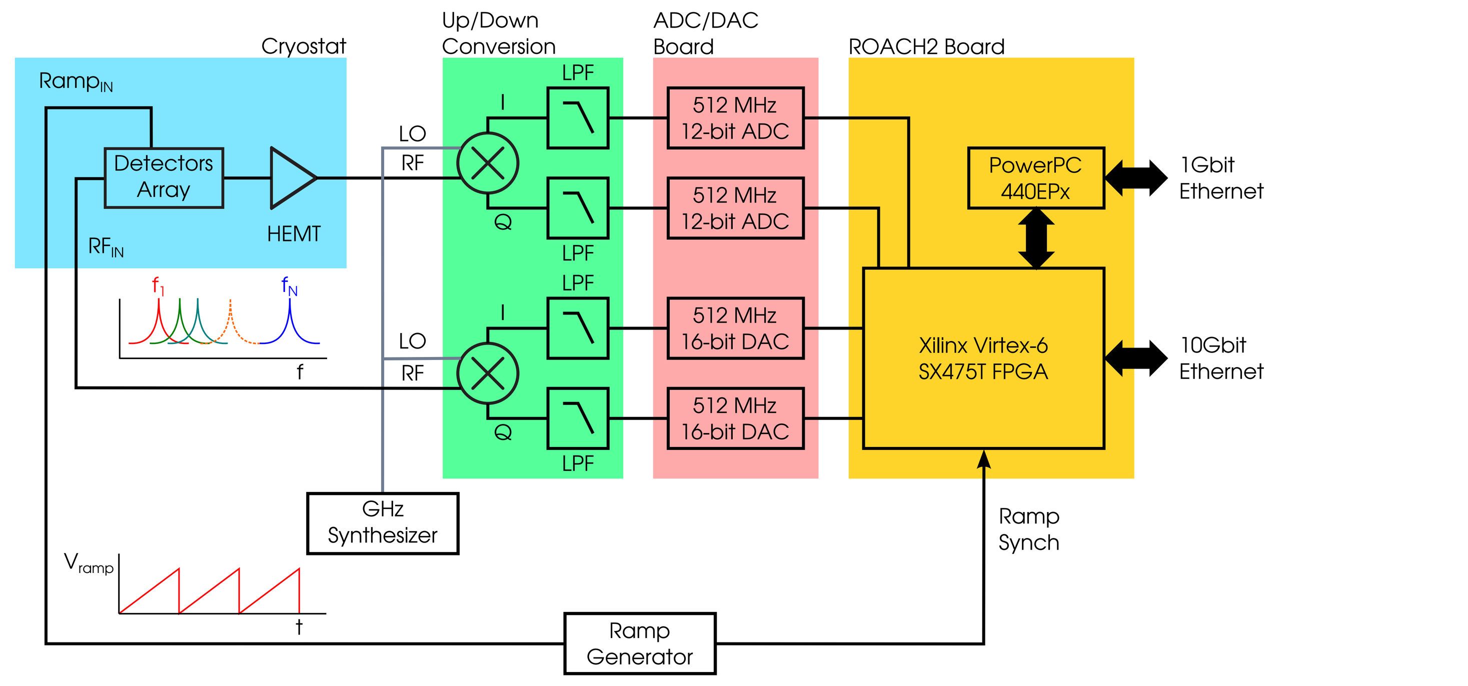


		Required	Measured
Resonators bandwidth	Δf_{BW} [MHz]	2	2 ± 1
Resonators spacing	Δf [MHz]	14	14 ± 1
Resonators depth	ΔS [dB]	> 10	29 ± 6



All the microresonator parameters match the HOLMES specification

Hardware implementation

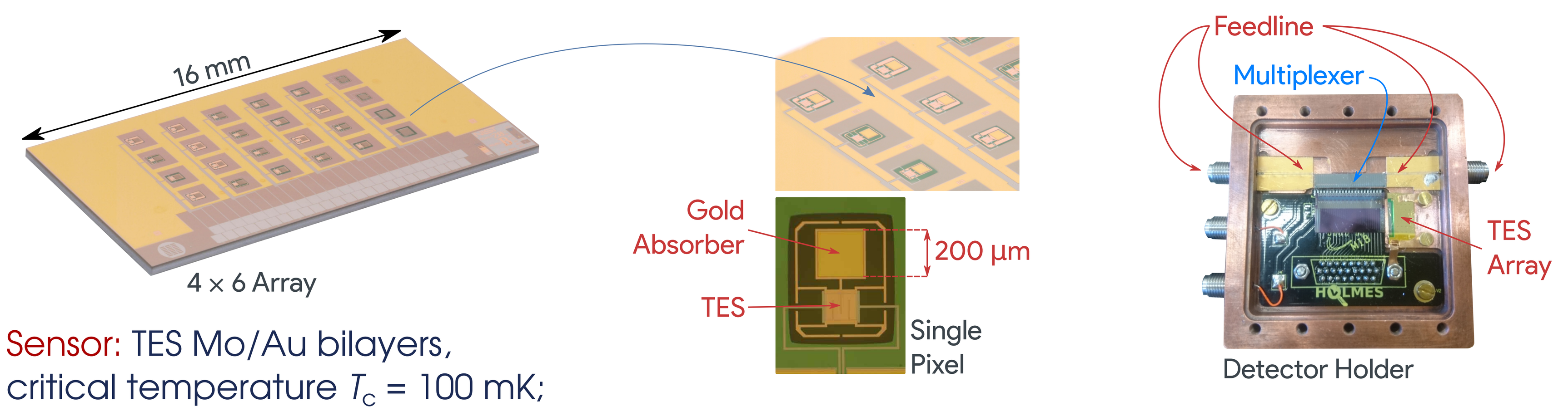


- The HOLMES multiplexing factor is 32 pixels per ADC board;
- In order to cover the total 1024 pixels, 1024/32 = 32 ADC boards are needed

Current Status
- ROACH2 board for tones generation/acquisition and for digital processing
- Custom intermediate frequency (IF) circuitry for up/down conversion;
- Working with: $n_{\Phi 0} = 2$, $f_{ramp} = 500$ kHz, $f_{ADC} = 512$ MHz
- Preliminary 16-channel firmware (uses only half of available ADC bandwidth)

Characterization with TESs

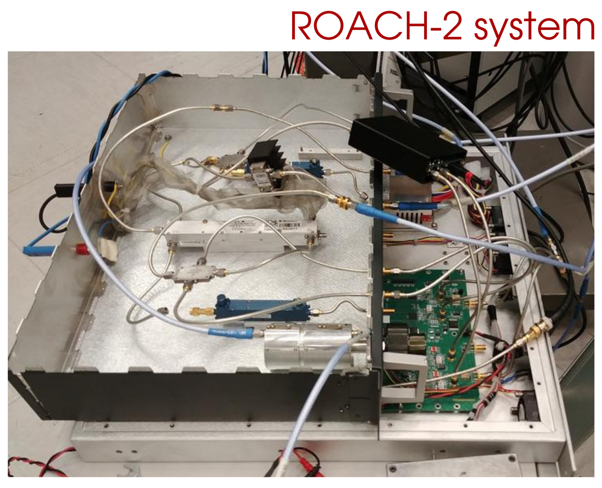
First HOLMES 4 × 6 array prototype measured with microwave multiplexing



Sensor: TES Mo/Au bilayers, critical temperature T_c = 100 mK;

Absorber: Gold, 2 µm thick for full e^- /γ absorption (sidecar design);

ROACH-2 system



4 pixels measurements ⇒ limited by available tone power;

Obtained performances

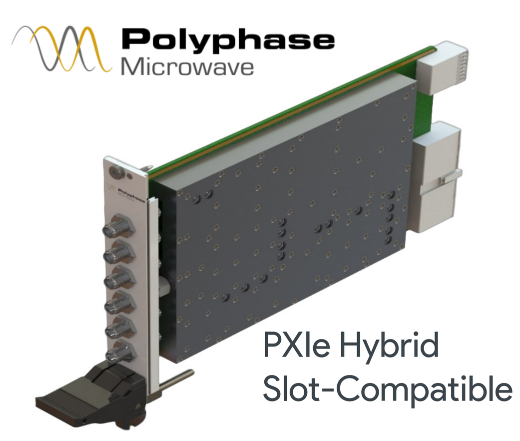
Read out noise ⇒ $n_S = (2-3)\,\mu\Phi_0/\sqrt{\mathrm{Hz}} \sim (23-35)\,\mathrm{pA}/\sqrt{\mathrm{Hz}}$

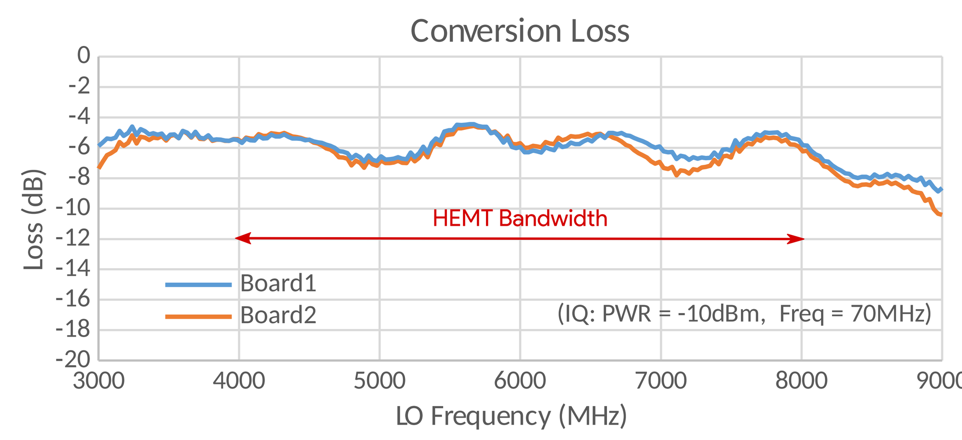
Resolution ⇒ $\Delta E_{\mathrm{Mn}} = 4.5 \pm 0.1\,\mathrm{eV}\,@\,5.9\,\mathrm{keV}$

B. Alpert et al. Eur. Phys. J. C79 (2019) no.4, 304

More details on the talks: #393, Monday 22, 11:10
#404, Tuesday 23, 15:45

New (semi) commercial up/down conversion boards





Commercial design but customized to match the HOLMES requirements;

Working in C-Band (4.0 to 8.0) GHz ⇒ fully compatible with the HEMT bandwidth

Total loss around -7 dBm ⇒ compatible with the power needed to drive 32 microresonators

Two boards delivered in Milano and currently under characterization

- Read-out system for the 64 channels currently in development
- Physics data from the first two 4 × 16 detector sub-arrays starting from 2020

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