A frequency domain multiplexing system to readout the TES bolometers on the LSPE/SWIPE experiment

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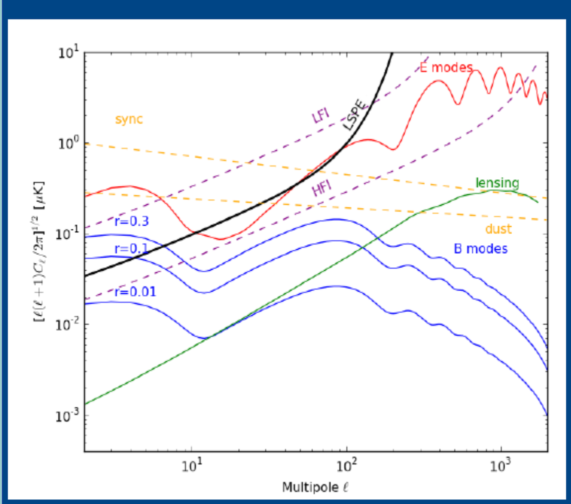
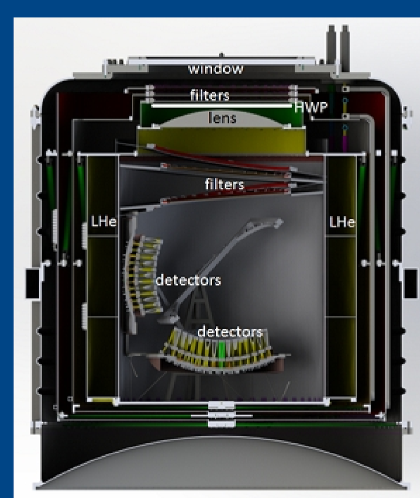
THE SWIPE/LSPE EXPERIMENT

The **Large Scale Polarization Explorer**[1] (LSPE) is:

- a mixed ground-based/balloon-borne mission aimed at measuring the B-mode polarization of cosmic microwave background (CMB) at large angular scales.
- designed to improve the tensor-to-scalar ratio down to r = 0.03 at 99.7% CL, exploiting the reionization peak at multipoles l < 10.
- composed of two experiments: STRIP (groun, Tenerife) and **SWIPE** (balloon, Arctic night flight).



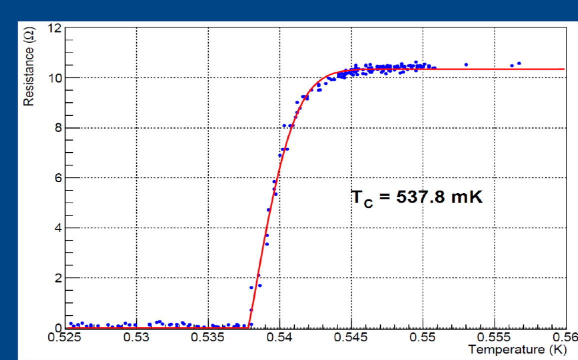


Left: *power spectrum of CMB polarization (E-modes and B-modes), foregrounds (synchrotron and dust), spurious B-modes due to lensing, actual limits set up by planck and expected sensitivity of LSPE.*

Right: *3D model of the cryostat of SWIPE, hosting the rotating HWP, the beam splitter and the two focal planes cooled at 300 mK.*

Up: *launch of a test payload during the polar night from Longyearbyen.*

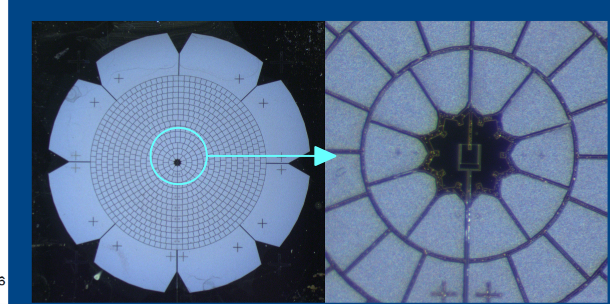
Down: *measured superconducting transition of the Ti TES for SWIPE[5].*



The **Short Wavelength Instrument for the Polarization Explorer**[2] (SWIPE):

- is a Stokes polarimeter designed to detect CMB in 3 frequency bands: 140 GHz, 220 GHz and 240 Ghz.
- will make use of 330 **spider-web TES bolometers**[3] hosted on 2 focal planes cooled downat 300 mK.
- will exploits multi-mode horns to couple the optical stages of the instruments with the detectors and efficiently collect incident power[4].
- is slated to launch from Longyearbyen (Svalbard Islands) in December 2019 for a 15 days long, circumpolar flight (h ≈ 40 km).

The readout electronics is based on a 16-channel **frequency domain multiplexing** (FDM) and is composed of a cold (300mK - 3K) component and a warm component.



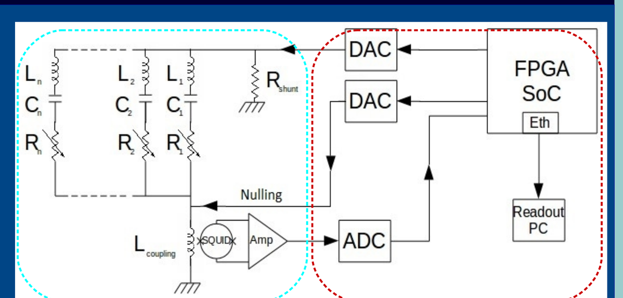
Left: *microscope view of a spider-web bolometer chip, with a particular on the TES.*

Right: *one of the multi-mode horns to be mounted on the focal plane. The dismounted backshort shows the housing for the bolometer chip.*

FREQUENCY DOMAIN MULTIPLEXING

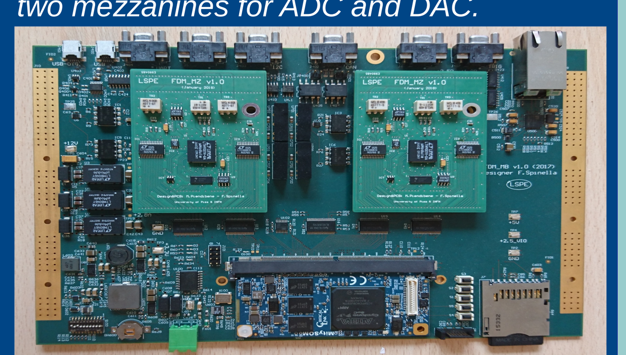
The FDM readout of the detectors is achieved by means of **superconducting LC filters** in series with each TES. The TESs are voltage biased in AC by an external carrier generator, so that the filters limit the current noise from the resistive TES bolometers and allow the 18 detectors to be biased with a single pair of wires. SWIPE will use a **16-channel multiplexing** from 200kHz to 1.6MHz.

The comb of bias carriers is generated by an FPGA and through a DAC is converted to analog and fed to the channels. A second DAC is used to send the comb directly to the SQUID to perform **active nulling**. In this way the full dynamic range of the SQUID is exploited to amplify only the physics signal, appearing in sidebands beside the carrier frequency. The output of the SQUID is fed to a first amplification stage of custom low-noise analog electronics. Finally, after conversion to digital through an ADC, the signals are demodulated by the FPGA and sent to the readout control computer via an Ethernet port.

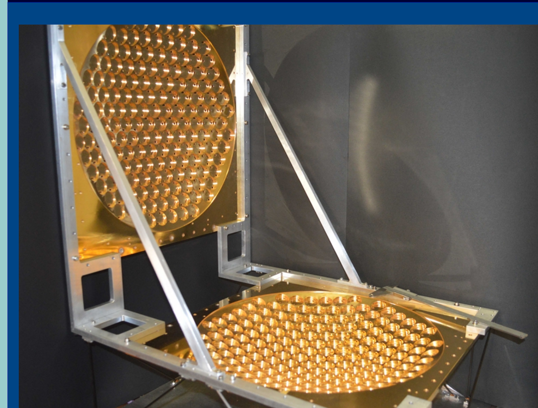


Up: *FDM readout schematics for SWIPE, with cold (light blue) and hot (red) electronics highlighted. The multiplexing frequencies will range from 200kHz to 1.6MHz, with 14-15 channels for biasing the TESs and 1 channel for calibration purposes.*

Down: *The custom board hosting the warm section of the readout electronics, with the two mezzanines for ADC and DAC.*

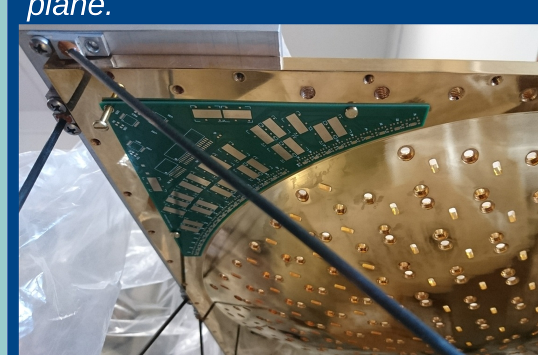


SUPERCONDUCTING ELECTRONICS



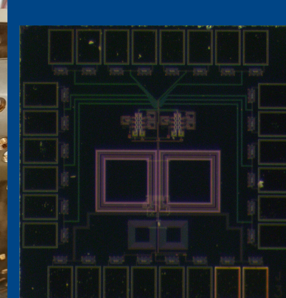
Up: *the two focal planes of the SWIPE insturment.*

Down: *placement of the PCB hosting the superconducting electronics underneath the focal plane.*



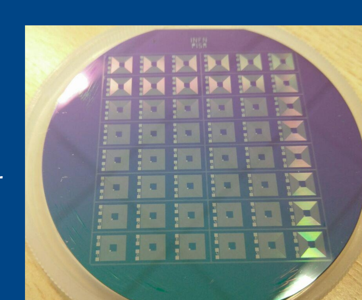
The **cold electronics** components are hosted on 8 boomerang-shaped PCBs to be mounted on the back of each quarter of the 2 focal planes. Each PCB hosts 3 readout chains of 18 channels, composed by a C0G/NP0 SMD capacitor and a superconducting inductor in series with each TES. Each chain is readout by a **6-series array SQUID** by VTT operated in a Flux Locked Loop (FLL) condition.

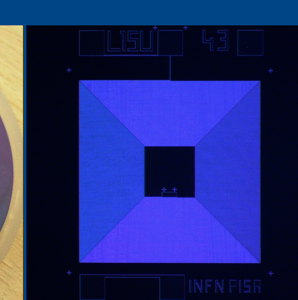
The 15 uH inductors are custom **Nb square spirals,** fabricated in matrices of 6x8. After niobium is DC sputtered on 2'' Si wafers, a positive photo-resist mask is patterned through optical lithography and then Nb is dry etched using a CF_4/O_2 gas mixture.



Left: *microscope view of the VTT 6-series array SQUID.*

Right: *Si wafer with the 6x8 array of spiral inductors after fabrication, and microscope view of a single device (old design).*





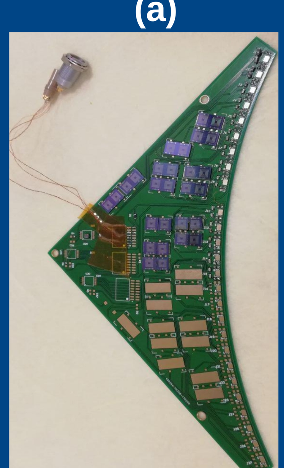
TESTS AND RESULTS

In Figure(a) a prototype PCB hosting a chain of **26 LC filters** readout by a SQUID is shown. The chips are glued with GE7430 cryogenic varnish degassed at 1 mbar. The PCB is mounted on the 3K plate of a **pulse-tube cryocooler** as shown in Figure(b). The 22 measured resonances, shown in Figure(c), have a bandwidth of 4 kHz, well beyond the requirements for SWIPE, so that **a multiplexing factor higher than the target one (16) is feasible**.

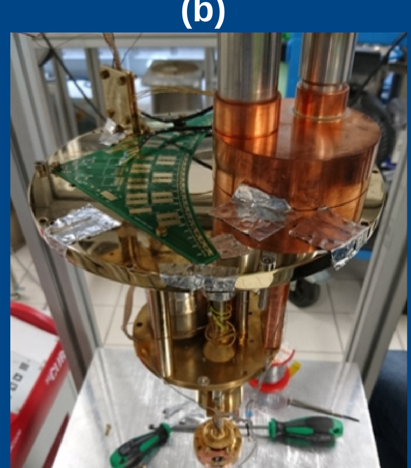
SQUID laboratory tests are done by means of a XXF-1 electronics system by Magnicon. The measured **I-V** and **V-Phi characteristics** are shown in Figure(d) and (e), respectively. The working point is adjusted choosing the bias current, bias voltage and flux bias corresponding to the V-Phi characteristic with maximum voltage swing. **Flux Locked Loop** is achieved through a 10kΩ resistor and selecting a Gain-Bandwidth Product of 7.20GHz, to obtain the maximum readout bandwidth available.

The **noise spectral density** at the SQUID output is shown in Figure(f), both in Open Loop (blue) and Flux Locked Loop (red) operation mode, when the input port is open (not connected to the carrier generator). In this case, the LCs filter out the **Johnson noise** of the resistors in series with the input coil and they are clearly visible in the noise spectrum (vertical dashed lines mark the position of each readout channel). FLL shows a **broader readout bandwidth** w.r.t. OL, as expected.

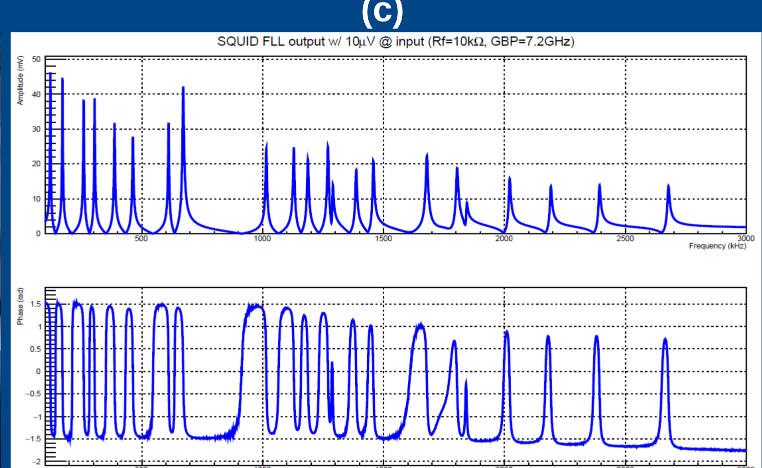
(a)



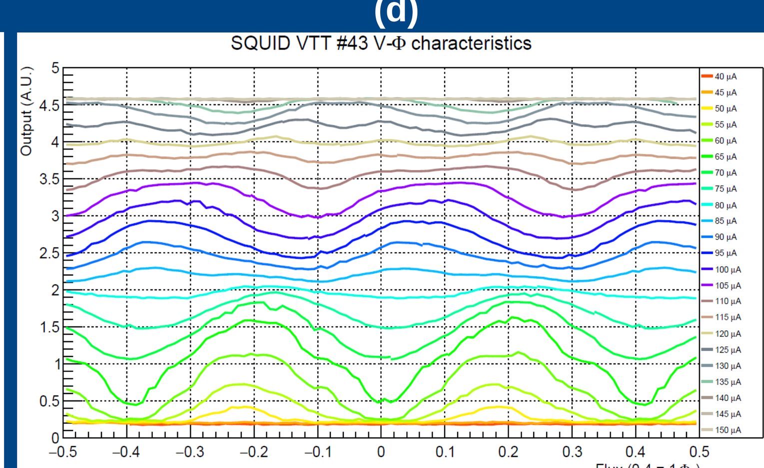
(b)



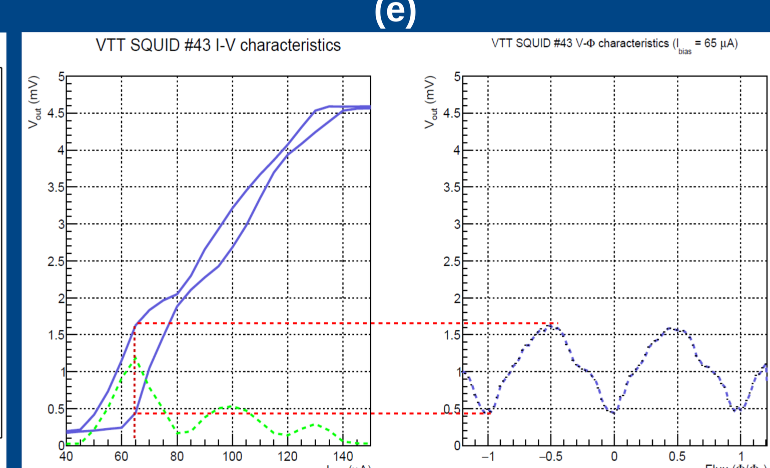
(c)



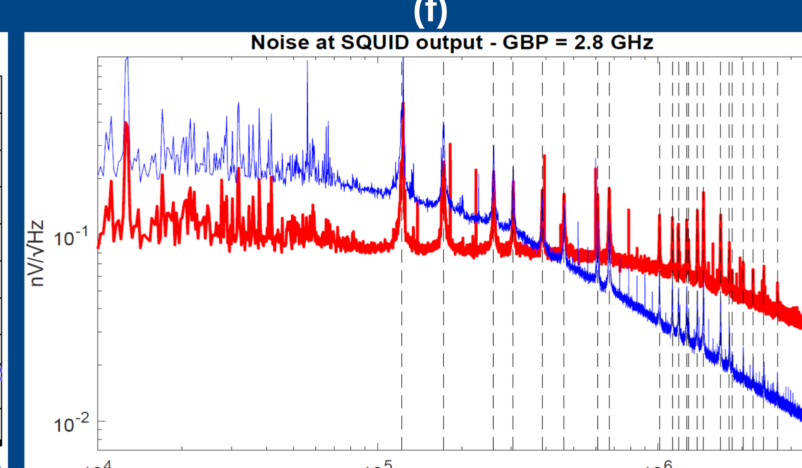
(d)



(e)



(f)



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(5) D. Vaccaro *et al.,* "Tuning the Tc of titanium thin films for transition-edge sensors by annealing in argon", J. Low Temp. Phys, 2018, proceedings submitted.