A new SQUID controller unit for space-based TES sensor readout

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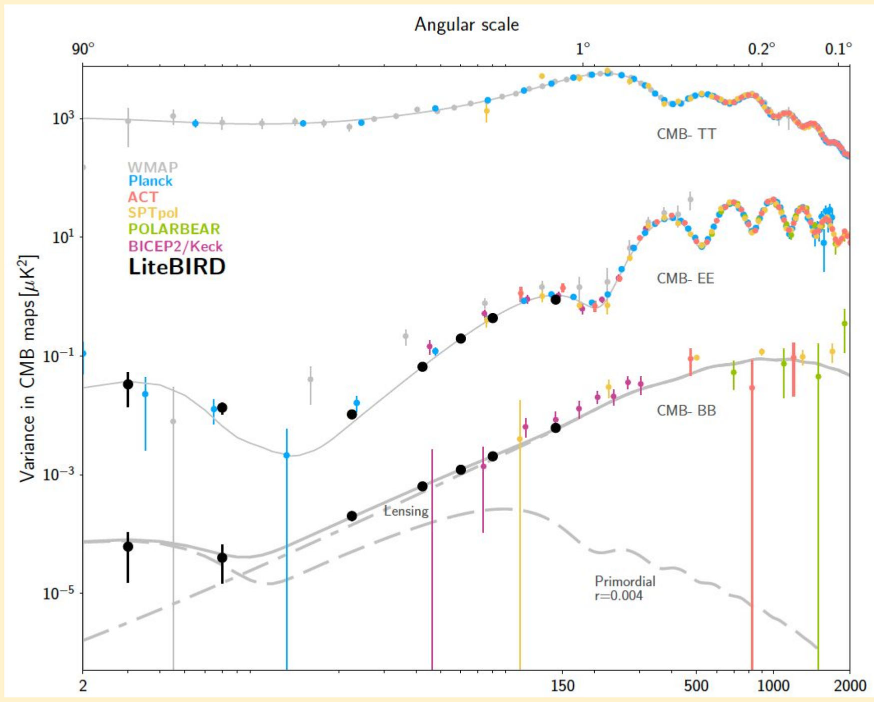
THE READOUT ELECTRONICS OF LITEBIRD EXPERIMENT: PHYSICS MOTIVATION AND OVERALL DESCRIPTION

The polarization anisotropy of the cosmic microwave background (CMB) contains crucial information on the very early stages of the Universe. The Cosmic Inflation paradigm predicts that primordial gravitational waves imprinted odd-parity (B-mode) polarization patterns on the large-angular-scale polarization structure of the CMB, in addition to even-parity (E-mode) ones. The amplitude of the inflationary B-mode polarization is parameterized by a tensor-to-scalar ratio r. The current best upper limit is $r<0.032$.

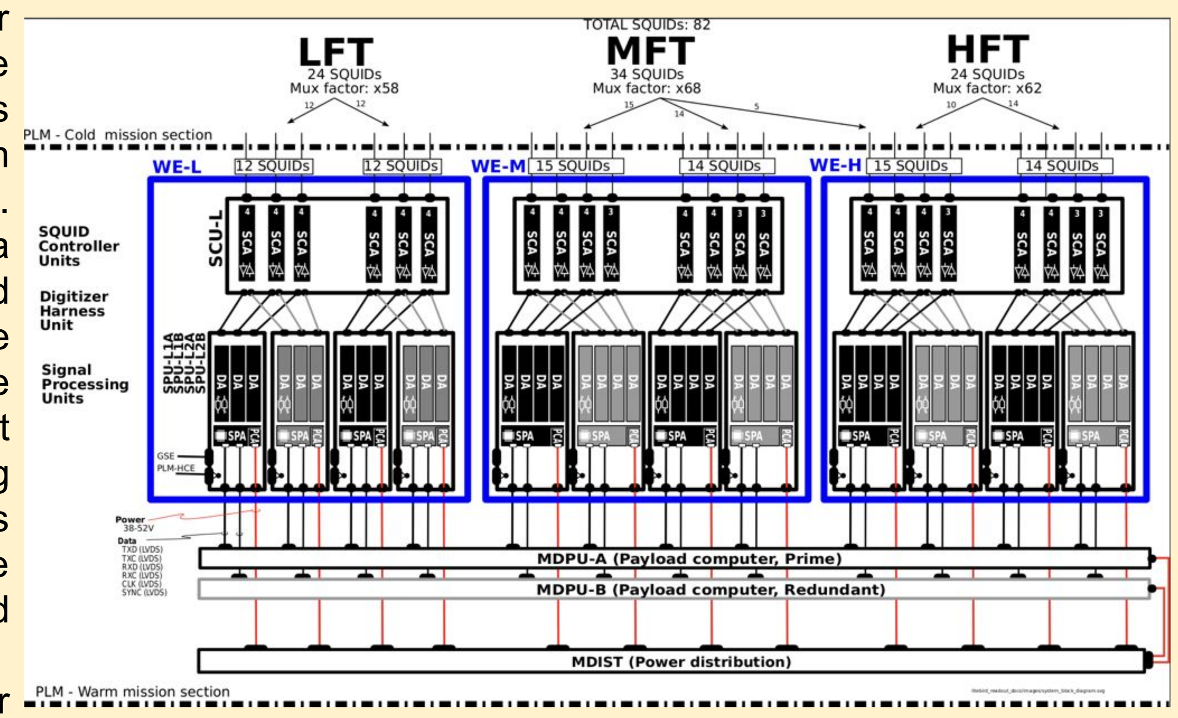
LiteBIRD, the Lite (Light) satellite for the study of B-mode polarization and Inflation from cosmic background Radiation Detection, aims to determine the tensor-to-scalar ratio r with a total uncertainty of $r<0.001$ after three years of all-sky observation from space. LiteBIRD was selected as a strategic large-class mission of the Japan Aerospace Exploration Agency and is planned to be launched in the late 2020s.



Angular power spectra of CMB anisotropy. Observed and predicted signals for TT, EE and BB. Low ℓ BB is sensitive to inflation.

We have developed a SQUID controller unit for TES sensors readout, to be used in a space mission. The unit is made of 8 boards and each board can condition four SQUID array amplifiers. The board design is inspired by a similar one developed for ground based experiments, but specific changes have been made to adopt COTS with space grade equivalents, to implement redundancy and cross-strapping capabilities. The design also includes the thermal path to lift the heat off the boards towards an in-house designed monolithic aluminum rack.

Three such units are planned, one for each of the three telescopes (L,M,HFT)



Warm readout electronics architecture. The Digital Process Units are redundant so each Squid COntroller Assembly has a double I/O.

THE SQUID CONTROLLER UNIT

ELECTRONICS

The SQUID controller electronics is a heritage of SPT-3G electronics developed at McGill University. A single board is designed to control four SQUIDs. For LiteBIRD we implemented some level of redundancy necessary for space application and a light weight communication protocol.

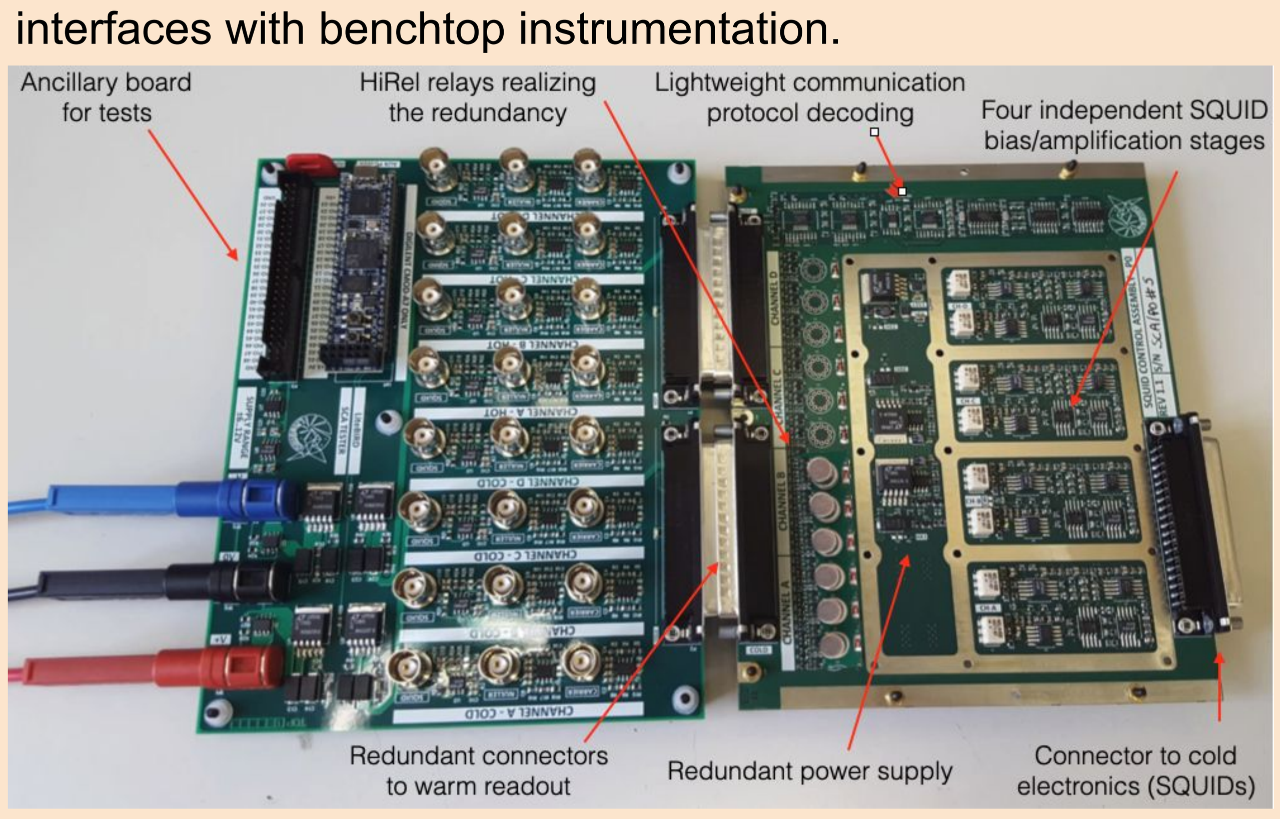
The redundancy consists in two identical power supply that are interconnected with the remaining system in such a way that either units can provide the power when the other fails (cross-strapping).

The signals from and to the Digital Assembly are also doubled because any SQUID controller is attached to two different digital boards, one hot and one cold. These signals are routed to the operative one by means of a set of Teledyne bistable relays (model 422K-5). These devices, available also as space grade, are extremely reliable and ideally noiseless. The noise performances of the SCA will be evaluated soon.

We also implemented the bias housekeeping which is sent to the digital assembly by means of an *ad hoc* communication system which:

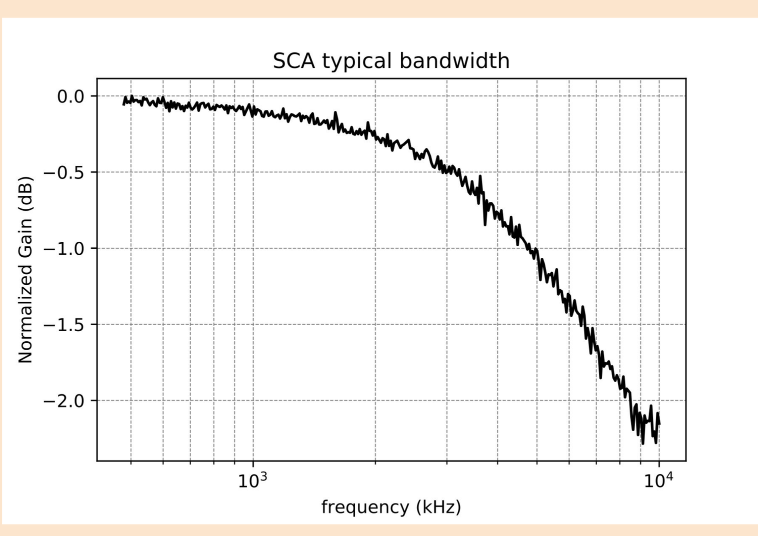
- is based on discrete components
- works without a system clock
- use only three wires.

An ancillary test board based on an Xilinx Artix 7 FPGA (Digilent Cmod A7) was also developed: (1) to communicate with the SCA board and route the SQUID signals and (2) to provide suitable interfaces with benchtop instrumentation.



TOP: The SCA board (right) connected to the test board (left)

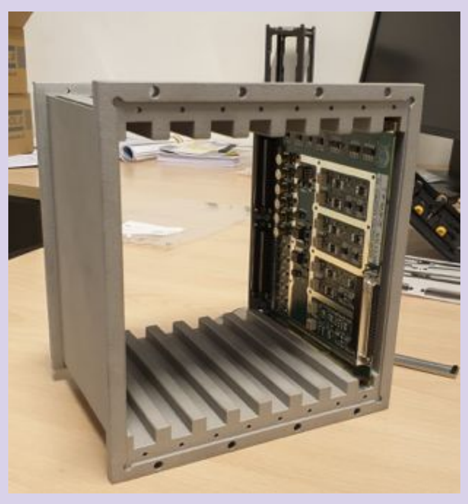
RIGHT: the bandwidth of the SCA obtained with a benchtop lock-in amplifier sweeping through the expected system bandwidth. The signal is injected and recovered through a series of differential-to-single-ended transitions.

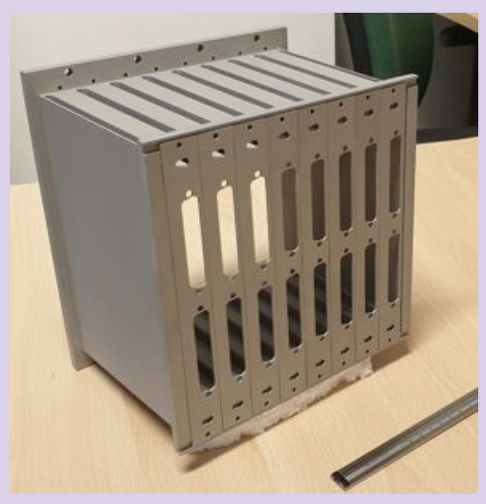


MECHANICS

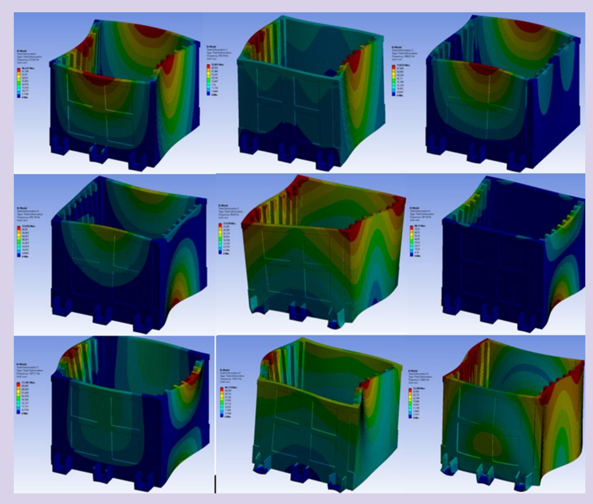
The Squid Control Enclosure, SCE, is an aluminum made crate where the SQUID boards are fixed using a space grade card-lok system. The mechanical design was based on dimension and weight constraints. The crate fits a 228x209x155 mm^3 volume and the overall weight, including electronic boards, is < 5 kg/unit. The manufacturing will be a mix of classic milling and EDM (electrical discharge machining) technology, in order to reduce the number of components and the number of their couplings (e.g. less EMI shields). The first mechanical prototype was made by aluminum printing in order to check the interfaces and the assembly procedure of the boards.

The structure was further optimized following a detailed vibrational analysis that confirmed that all eigenfrequencies are > 150 Hz, as required by the rules from the Space Agency.





# Mode	Frequency (Hz)	X-MASS (%)	Y-MASS (%)	Z-MASS (%)
2	719,595	31,3	0	0
3	856,134	0	26,35	0
8	1807,46	3,24	0	0
13	***2205,54***	***32,76***	0	0
17	2713,89	0	19,25	0
20	***2957***	0	***58,44***	0
26	3324,61	0	19,74	0
36	4519,82	0	0	4,21
37	***4582,88***	0	0	***52,71***
38	4589,57	3,07	0	0

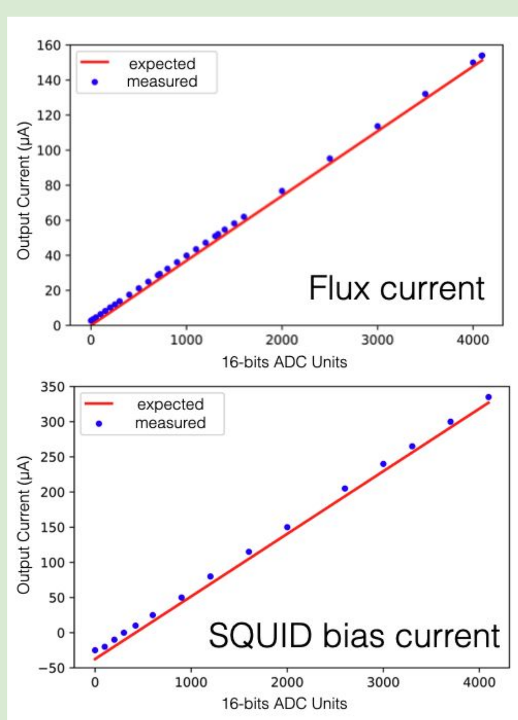


TESTS

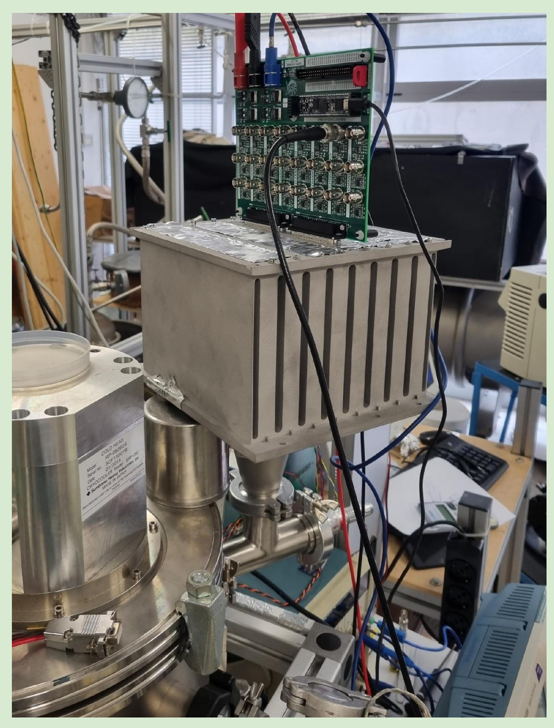
SQUID boards have been tested for electrical and functional performance. The value and linearity of bias and flux control currents are compliant to the expected values, as visible from the figures below.

One SCA board, inserted in the SCE prototype, has been used to successfully bias a 48x SQUID sereis array (StarCryo AR4825) with the cryogenic test facility at INFN Pisa and nominal SQUID parameters have been measured.

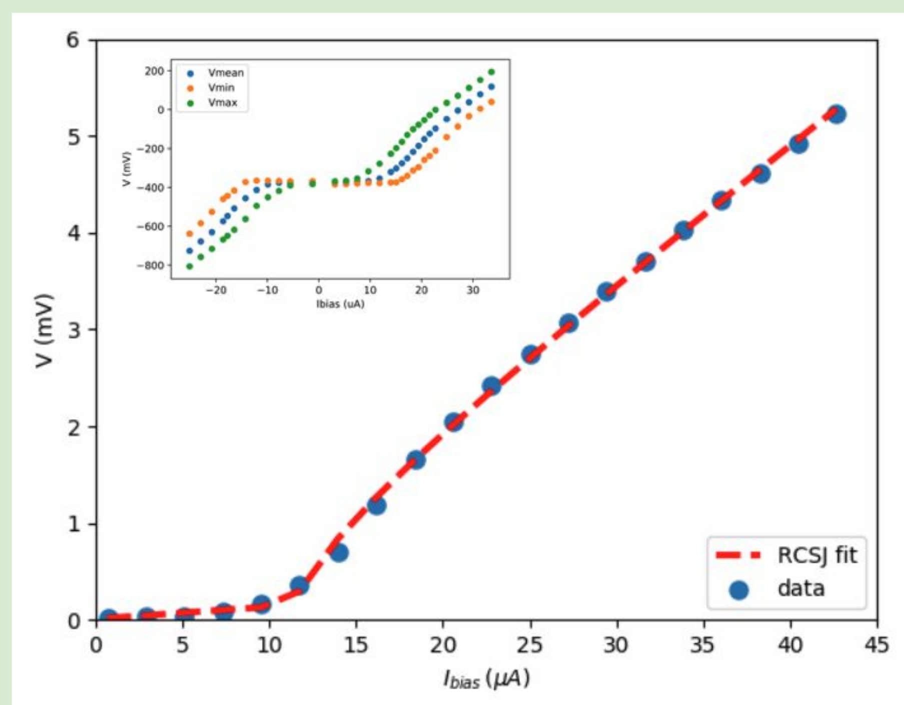
Performance tests of the complete SQUID readout + Digital Signal Processing system are planned later this year in McGill cryogenic test facility with representative cold electronics (TESs, LC filters) to fully characterize noise and bandwidth.



Measured vs expected output current to control SQUID flux (uppper panel) or bias (lower panel)



Picture of a portion of cryogenic test facility at INFN-Pisa. SCA is inside the box, the visible board is the control board.



I-V characteristics of a StarCryo AR4825 SQUID measured with the presented board. A fit with the RCSJ model to the $I_{bias}>0$ portion is superimposed. Inset: full measured characteristic at central and extremal flux values.

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