Development of frequency-domain multiplexed readout of Transition Edge Sensor bolometers for the POLARBEAR-2 Cosmic Microwave Background experiment

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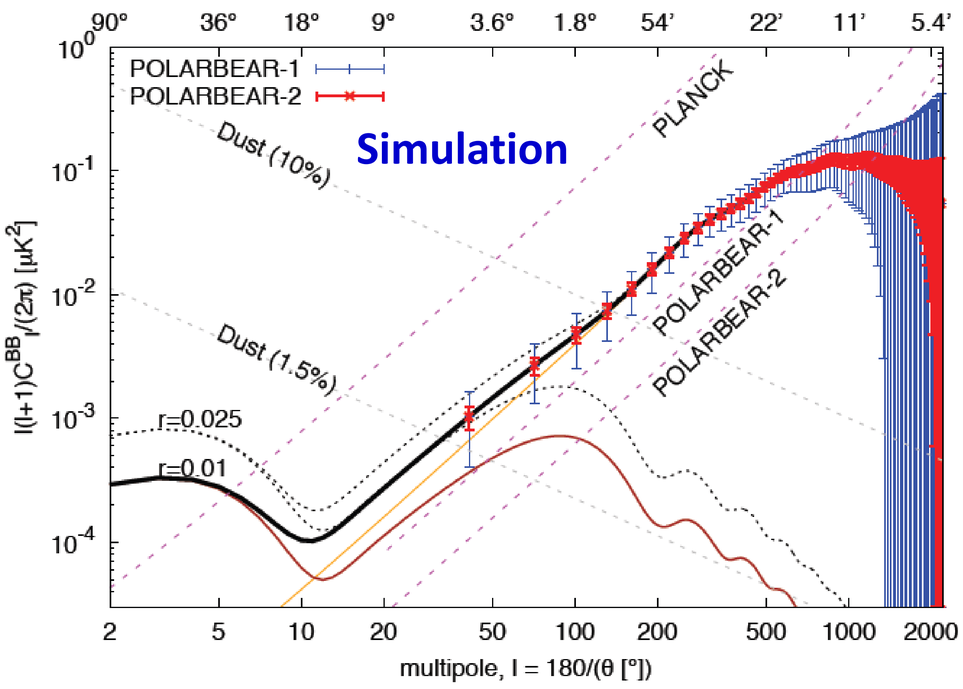
POLARBEAR-2 CMB experiment

The POLARBEAR-2 Cosmic Microwave Background (CMB) experiment aims to observe the polarization of the CMB to explore gravitational lensing of the CMB and inflationary gravitational waves. This experiment is an upgrade of the POLARBEAR-1, which located in Chile at an elevation of 5200 meters. POLARBEAR-1 had first light in January 2012, and finished its first observing season in December 2012.

POLARBEAR1 telescope

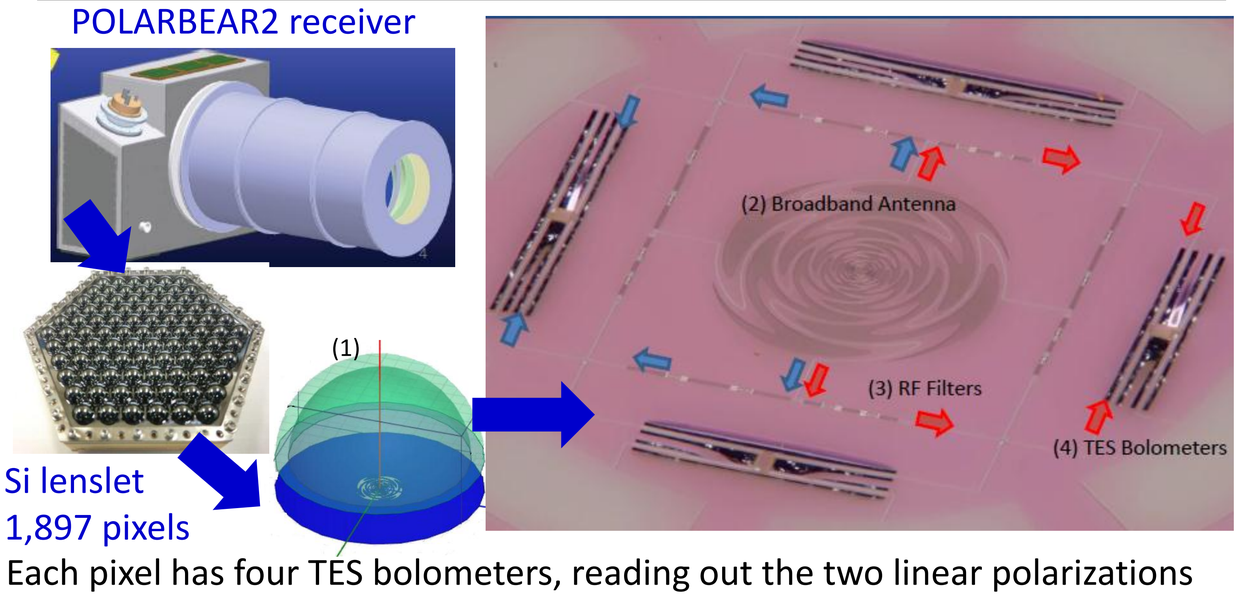


We will build a receiver that has 7,588 antenna-coupled, polarization sensitive Transition Edge Sensor (TES) bolometers to have sensitivity to the tensor-to-scalar ratio $r = 0.01$ (95 % confidence level). The kilopixel arrays of multi-band polarization-sensitive pixels are necessary to achieve the high sensitivity and stringent control of systematic errors required by these science goals.

	POLARBEAR-1	POLARBEAR-2
Science goal	$r = 0.025$	$r = 0.01$
Band	150 GHz	95 and 150 GHz
Number of TES bolometers	1,274	7,588
Multiplexing factor	8 bolos per SQUID	32 bolos per SQUID
Readout band width	0.3 – 1 MHz	0.3 – 3 MHz

Focal plane detectors

POLARBEAR2 receiver



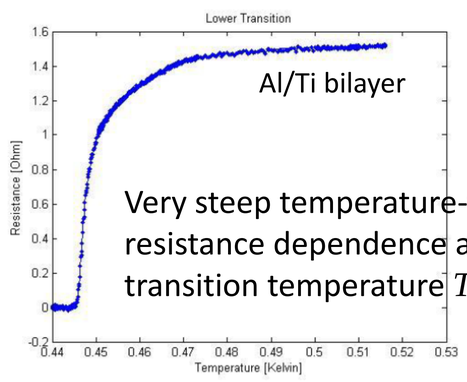
Each pixel has four TES bolometers, reading out the two linear polarizations in two frequency bands (95 and 150 GHz).

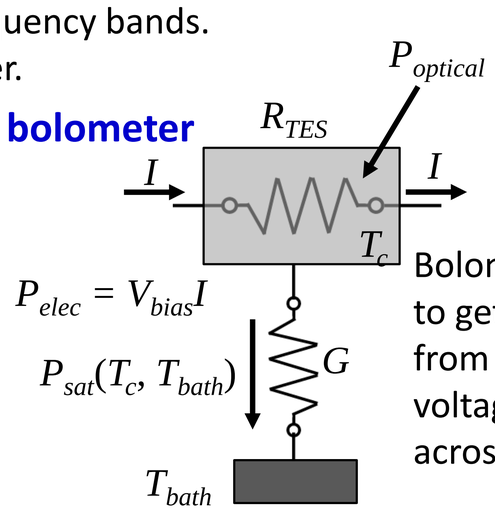
(1) Photons are focused by individual silicon lenses onto (2) a planar broadband sinuous antenna.

(3) RF filter splits signal into frequency bands.

(4) TES bolometers absorb power.

Transition Edge Sensor (TES) bolometer



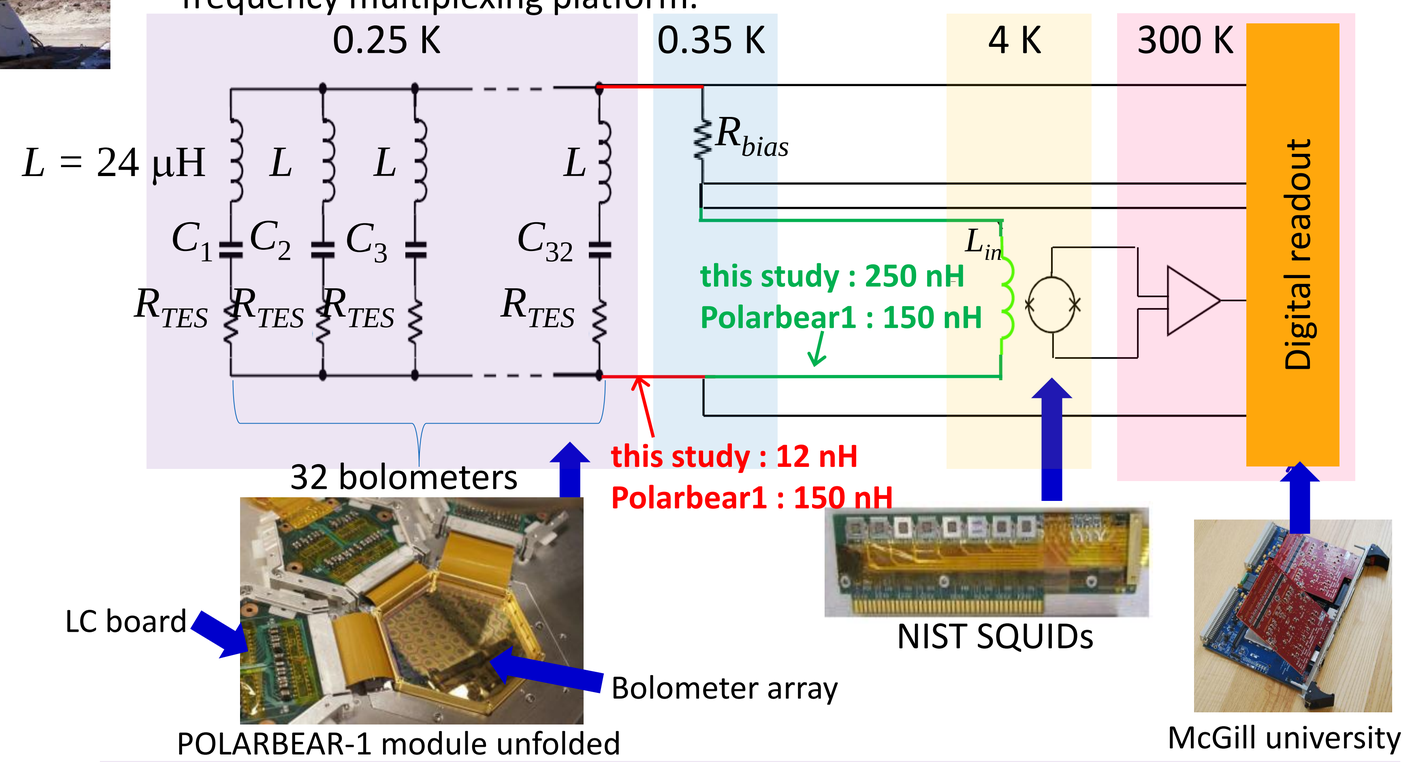


$$P_{sat} = P_{optical} + V_{bias}I$$

Bolometer current is measured to get absorbed power $P_{optical}$ from radiation. The constant voltage bias V_{bias} is applied across the bolometer.

Digital frequency-domain multiplexing

For the large array's readout, benefits of multiplexing bolometers through a single superconducting quantum interference device (SQUID) is (1) reduce the number of SQUIDs and thermal load from wiring (2) wide bandwidth of the SQUIDs can be used. We employ digital frequency-domain multiplexing and multiplex 32 bolometers. Extending that architecture to 32 bolometers requires an increase in the bandwidth of the SQUID electronics. To achieve this, we have implemented Digital Active Nulling (DAN) on the digital frequency multiplexing platform.

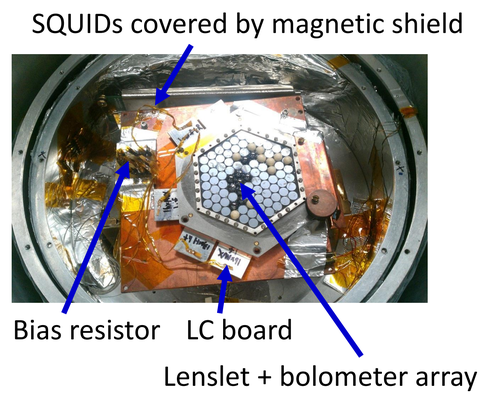


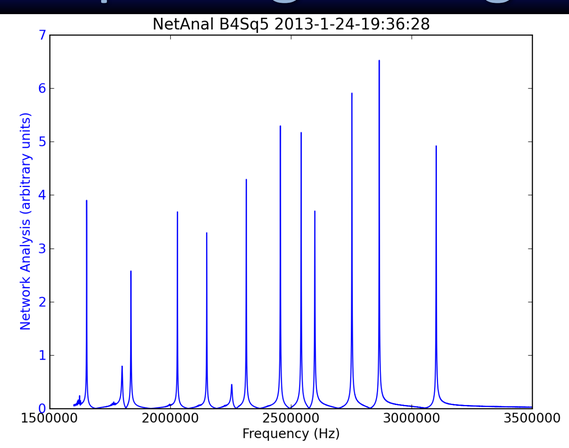
At 0.25 K : Each TES bolometer (R_{bolo}) is placed in series with an inductor and capacitor. Each LCR_{bolo} channel resonates at a unique frequency. The voltage bias is set to that frequency, and sky signals modulate R_{bolo} and thus the amplitude of the current flowing through the bolometer at the resonant frequency.

At 0.35 K : Current flows across a low impedance element (R_{bias}) here at all 32 frequencies, simultaneously setting all the voltage biases.

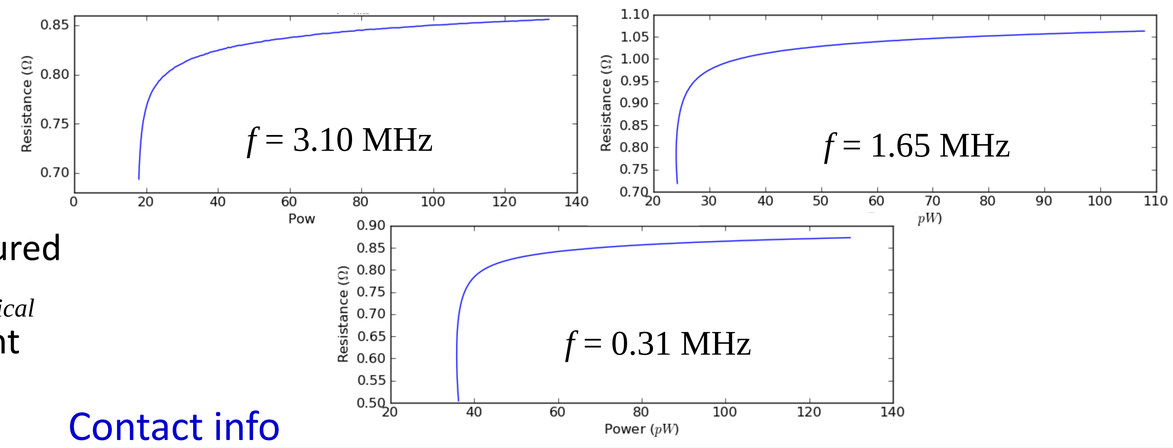
At 4 K : The signals from all TES are summed together as currents, transmitted to a SQUID and amplified. To extend the useful bandwidth of the SQUID amplifier, we use DAN instead of SQUID flux locked loop shunt feedback. Digital feedback is calculated for each bolometer and nulls the signals from the TES bolometers. With DAN, the loop shown in green in the top left figure can enclose a large impedance and this allows the bias element (R_{bias}) to be placed closer to the bolometers. This reduces the parasitic inductance enclosed in the red line, which affects the bolometer stability.

High frequency Multiplexing testing





Top right shows open-loop scan of frequency at 0.37 K where bolometers were superconducting, showing 13 resonances. Two low peaks were due to bad capacitors. Bottom figures are R_{bolo}-power curves. We haven't had bolometers deep in transition due to high equivalent series resistance (ESR) coming from small capacitance (< 1 nF) capacitors. The ESR of commercial ceramic capacitors we used was 0.3 – 0.4 Ω. We are trying to fabricate low ESR capacitors.



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