Array scalable zero-bias far-IR detector with high sensitivity and dynamic range

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Program: Topic Area

Project Objective:

We develop an ultrasensitive far-IR detector based on the Zero-Bias (ZB) Hot-Electron Bolometer (HEB). Beside the advantage of high sensitivity, the ZBHEB does not require any dc or microwave bias, has a very large dynamic range of 60-100 dB and can be operated at arbitrary temperature in the 0.05-9 K range, depending on the radiation background. Johnson Noise Thermometry (JNT) allows for the FDM readout of up to 1,000 ZBHEBs using a single broadband quantum-limited (QL) parametric LNA and a filter-bank channelizer. The ZBHEB readout uses microwave noise power emitted by the bolometer as the measure of the sensor electron temperature, T_e. The thermal responsivity is determined by both the phonon (e-ph) cooling and microwave-photon mediated cooling (γ). The latter is critical at 50-100 mK. The ultimate detector NEP ≈ 2×10^{-21} W/Hz$^{1/2}$ @ 50 mK. This low NEP is required for the moderate resolution spectrometers ($\nu/\delta\nu$ ~ 1000) on a future space telescope (e.g., Origins Space Telescope – OST) with cold mirror (T_{mirror} ≈ 5 K).

FY19 Results:

We developed and built several essential components needed for implementation of the ZBHEB detector array and carried out electrical NEP measurements with a prototype ZBHEB device. In FY20, we will fabricate smaller ZBHEB devices (as in Fig. 2) and also employ a new Kinetic Inductance parametric amplifier.

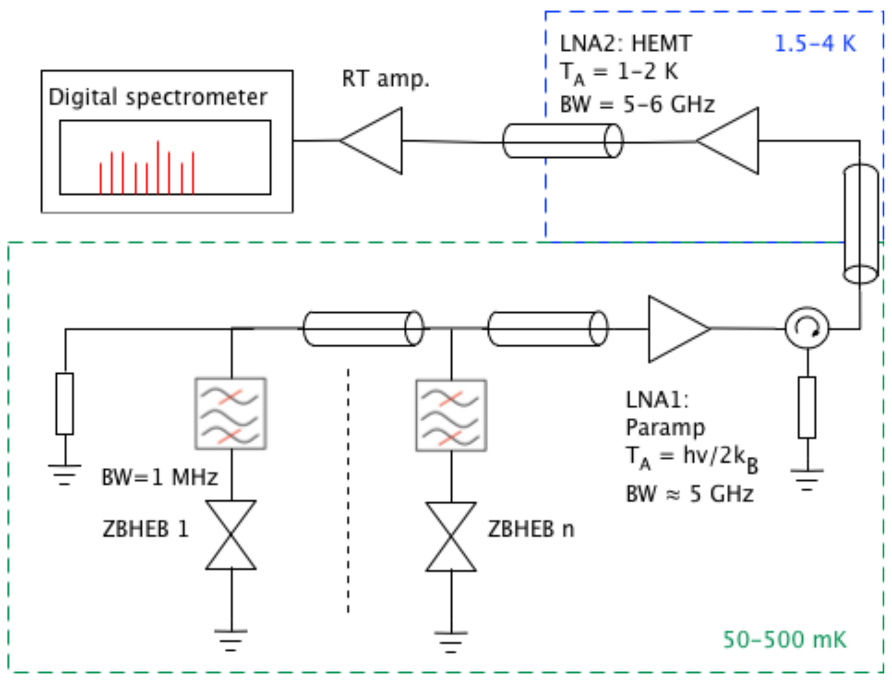

Figure 1. Block-diagram of a detector array utilizing ZHEB sensors. The Johnson noise outputs of all sensors are frequency multiplexed using a comb-filter with narrow (~ 1 MHz) passbands. All the output are read simultaneously using a superconducting QL parametric amplifier

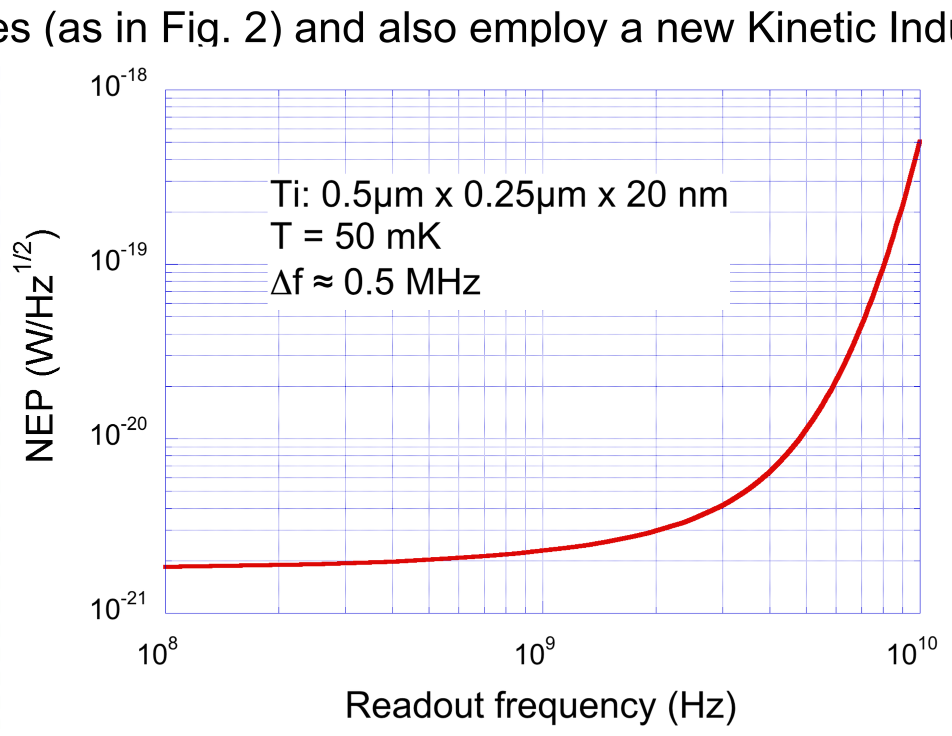

Figure 2. Ultimate NEP in ZBHEB according to the bolometric model. For a small-size sensor at 50 mK, the main cooling mechanism is emission of microwave (GHz) photons which occupies a bandwidth ~ k_BT/h ≈ 1 GHz. Even QL LNA is a major source of noise. For the above parameters, a half of the total noise contribution comes from it. Still the very low NEP is feasible.

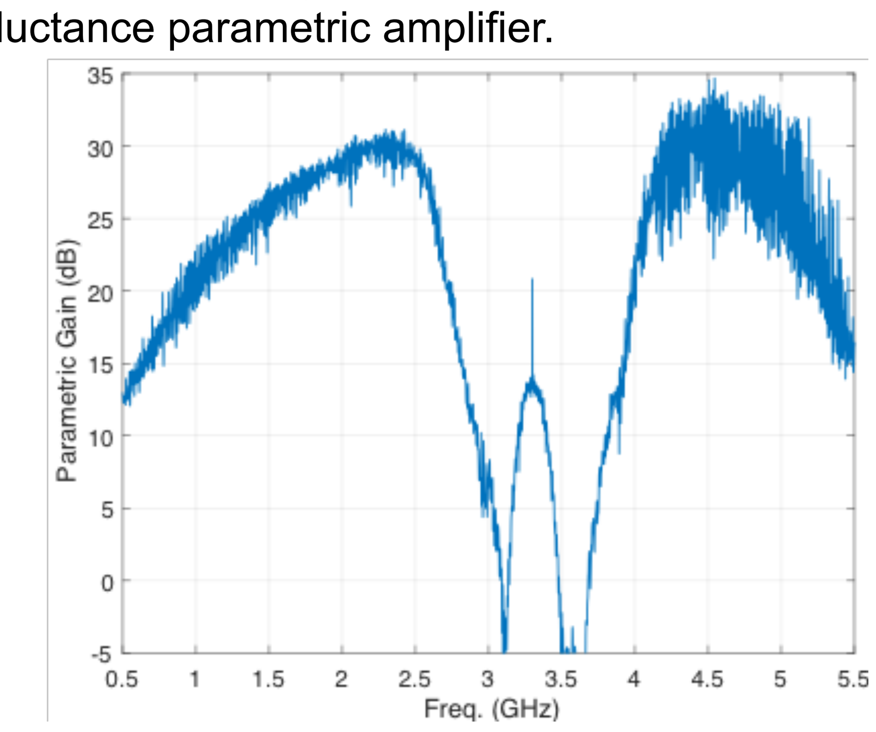

Figure 3. A dedicated L-band parametric amplifier based on the kinetic inductance in superconducting transmission line has been developed and demonstrated. The high gain of 25-30 dB is comparable to that in semiconductor HEMT amplifiers. The amplifier noise temperature has not been measured.

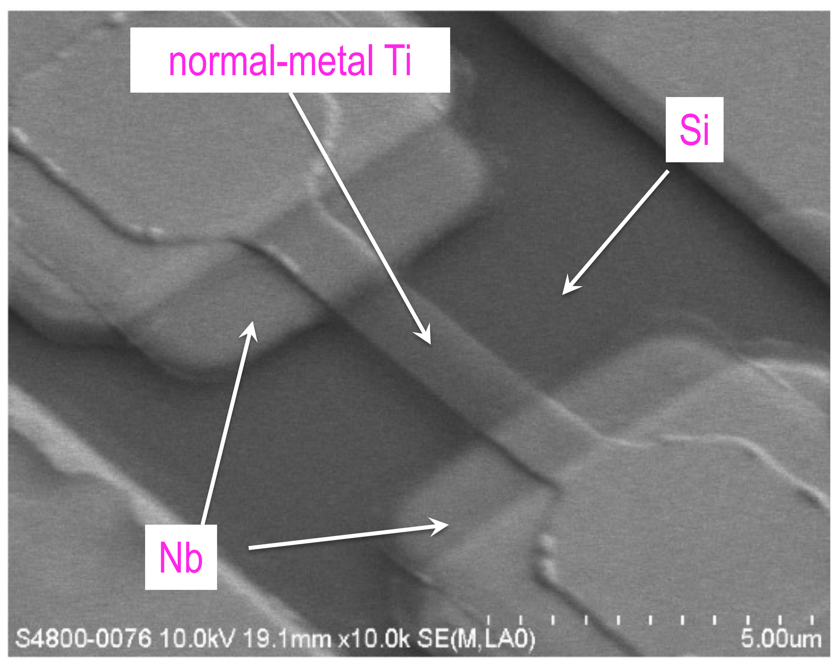

Figure 4. SEM image of a 2μm x 1μm x 25nm twin-slot antenna coupled ZBHEB used in the current experimental work. A non-superconducting Ti device was used as normal-metal sensor. The role of Nb contacts was to prevent the heat diffusion which would deteriorate the thermal conductance and NEP.

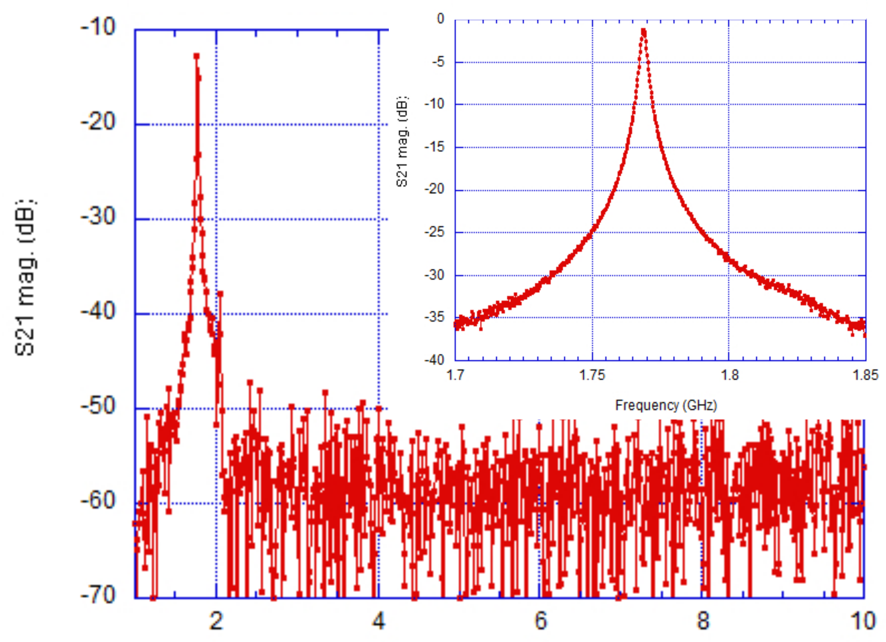

Figure 5. Transmission data for a resonant transmission line based superconducting (Nb) band-pass filters. An additional low-pass filter was used to suppress higher order harmonics. The role of the filter is to define the noise bandwidth of a channel and to control the cooling of the device by means of the emission of microwave photons.

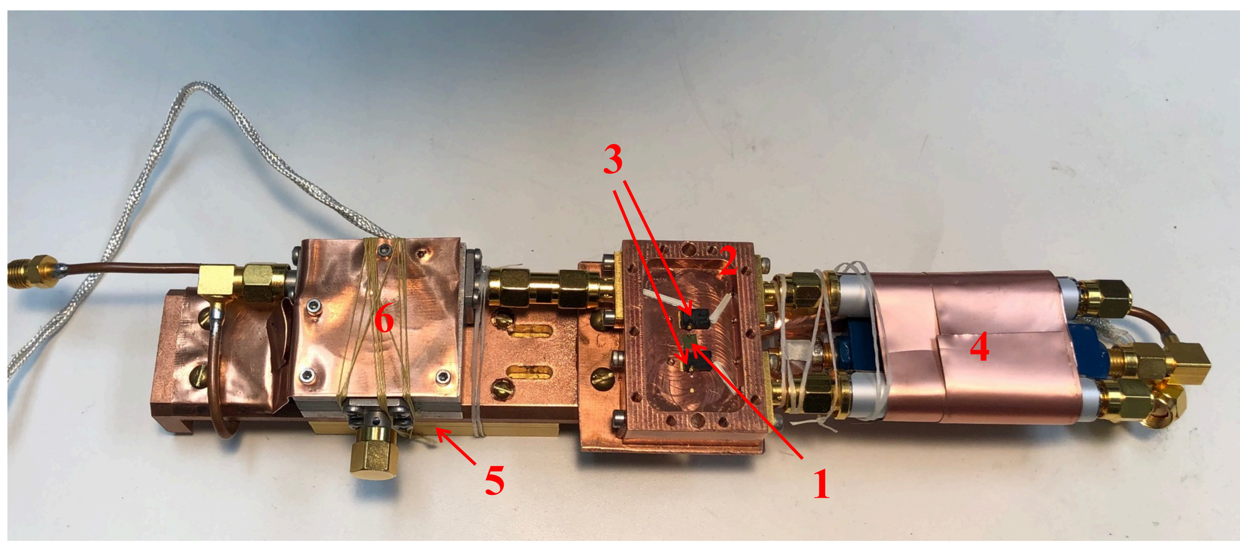

Figure 6. An experimental cryogenic assembly for electrical NEP tests. A 4mm x 4mm Si chip with a ZBHEB device (1) is mounted in an rf tight Cu box (2). In order to simulate the absorbed radiation power, a dc current is sent through the device using two chip bias-T's (3). The bias lines are filtered using two dc-80 MHz BPFs (4). The device output noise signal propagates through the Q=1000 BPF (on the back side of the assembly, (5)) and then through the cryogenic L-band isolator (6). A 1-K HEMT amplifier placed just above the LHe level is used for readout. In the future, the HEMT amplifier will be replaced by the KI parametric amplifier. The detector by itself does not require current bias. The bias is used only for electrical NEP tests.

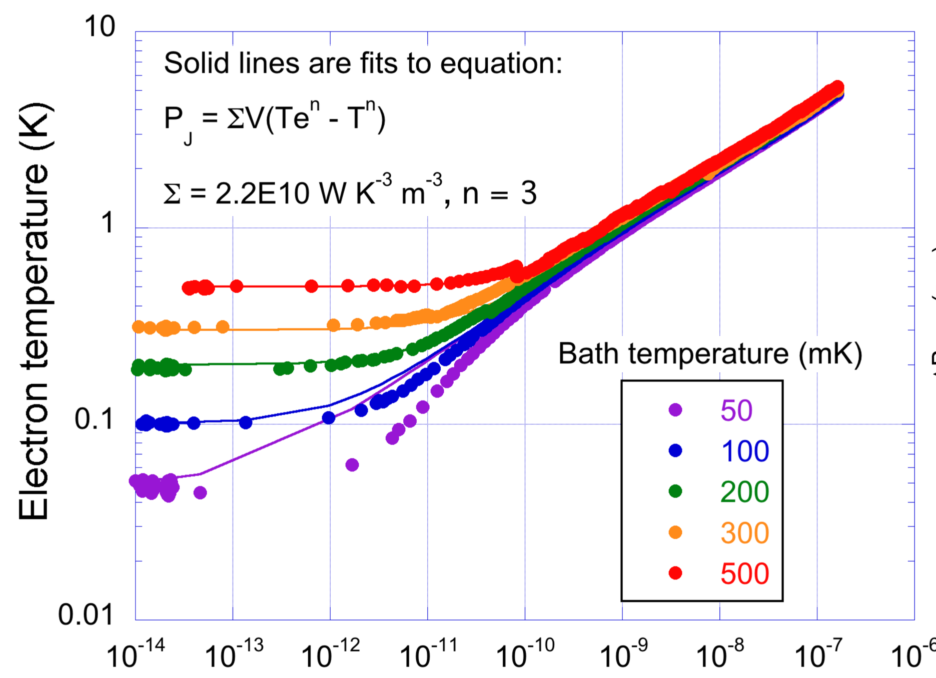

Figure 7. From the measurement of electron temperature as function of the Joule power due to the bias current dissipation, the thermal conductance was determined. In the current device, the thermal conductance is much higher than anticipated because of the potential heat leak in Nb Andreev contacts.

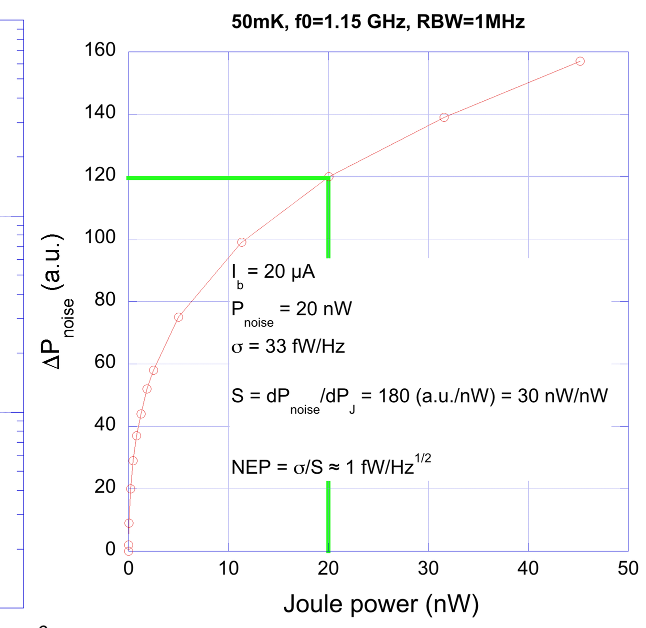

Figure 8. Electrical NEP was determined to be ≈ 1fW/Hz$^{1/2}$ @ 50 mK. The procedure involved measurement of the noise power vs Joule power and also the standard deviation of the noise power within a 1-Hz video bandwidth of the system.

Benefits to NASA and JPL (or significance of results):

Ultrasensitive far-IR array with NEP < 10^{18} W/Hz$^{1/2}$ are very hard to develop; this is yet another promising concept which may help to reach the ultimate detector array for OST spectrometers. This is a novel approach not pursued by others yet. Beside a number of technical advantages (very low ultimate NEP, large dynamic range, no bias lines, simple fabrication, only one coax readout line for a 10^3 pixels), ZBHEB detector can be deployed on a high-background platform (e.g., balloon instrument). The NEP will be higher but all the other characteristics of the system will be unchanged and can be tested. This is an important feature, helpful for advancing TRL.

Publications & Presentations:

- B. Karasik, P. Day, A. Skalare, "An array scalable zero-bias far-IR detector with noise thermometry readout," *presented at the 18th International Workshop on Low Temperature Detectors (LTD-18), 22-26 July 2019, Milan, Italy.*

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