An Array of Cold-Electron Bolometers with a JFET Readout for Cosmology Experiments

Master Thesis, Bachelor Diploma Project

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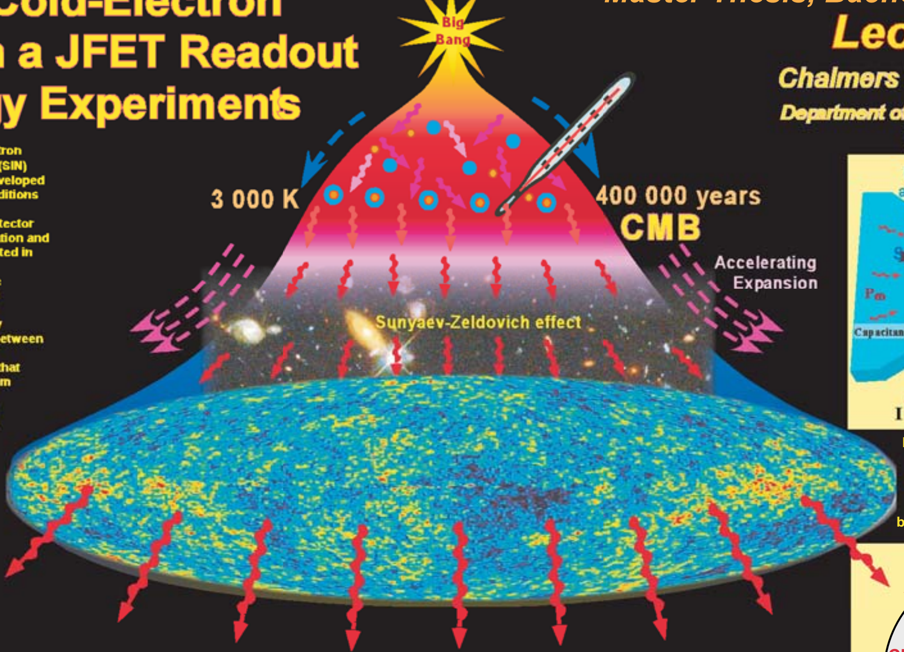
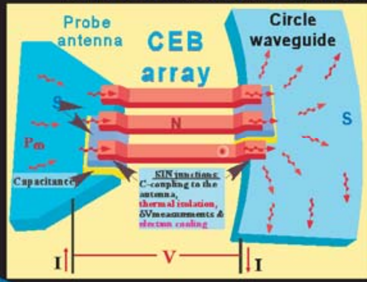
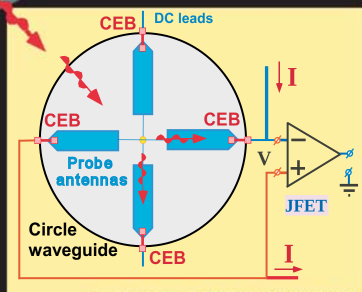
A novel concept of the parallel/series array of Cold-Electron Bolometers (CEB) with Superconductor-Insulator-Normal (SIN) Tunnel Junctions has been proposed. The concept was developed specially for matching the CEB with JFET amplifier at conditions of high optical power load.
The CEB is a planar antenna-coupled superconducting detector with high sensitivityFor combination of effective HF operation and low noise properties, the current-biased CEBs are connected in series for DC and in parallel for HF signal. A signal is concentrated from an antenna to the absorber through the capacitance of the tunnel junctions and through additional capacitance for coupling of superconducting islands.
Using array of CEBs the applications can be considerably extended to higher power load by distributing the power between N CEBs and decreasing the electron temperature. Due to increased responsivity the noise matching is so effective that photon NEP could be easily achieved at 300 mK with a room temperature JFET for wide range of optical power loads.
The concept of the CEB array has been developed for the BOOMERanG balloon telescope and for other Cosmology instruments.





Each probe is connected to a series CEB array for DC and to a parallel array for HF (schematically shown as a single CEB in the bottom figure). Connection in parallel for HF signal is realized by special capacitances between superconducting islands and antenna.



Direct connection of CEBs to a 4-probe antenna in a circle waveguide

Responsivity:

$$S_V = \frac{\delta V_\omega}{\delta P_\omega} = \frac{\partial V / \partial T}{G_{e-ph} + 2G_{SIN} + i\omega C_\Lambda}$$

$$G_{e-ph} = 5\Sigma\Lambda T_e^4$$

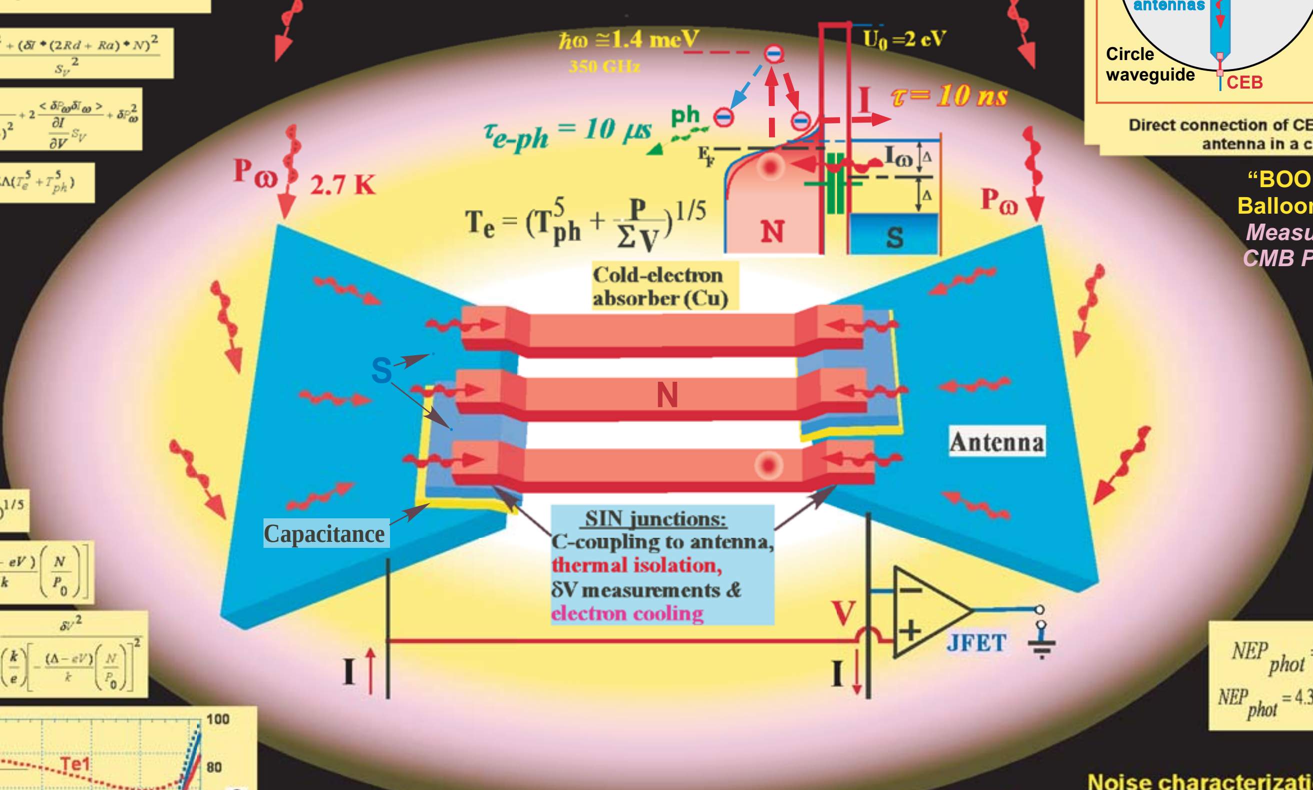
$$NEP_{tot}^2 = N * NEP_{e-ph}^2 + N * NEP_{SIN}^2 + NEP_{JFET}^2$$

$$NEP_{JFET}^2 = \frac{\delta V^2 + (\delta I * (2Rd + Ra) * N)^2}{S_V^2}$$

$$NEP_{SIN}^2 = \frac{\delta I_\omega^2}{(\frac{\partial I}{\partial V} S_V)^2} + 2\frac{<\delta P_\omega \delta I_\omega>}{\frac{\partial I}{\partial V} S_V} + \delta P_\omega^2$$

$$NEP_{e-ph}^2 = 10 k_B \Sigma\Lambda (T_e^5 + T_{ph}^5)$$

13.7 billion years



"BOOMERanG3" Balloon Telescope

Measurements of CMB Polarization

92 channels

350 GHz,

P_0=5 pW

$$NEP_{phot} = \sqrt{2P_0 * hf}$$

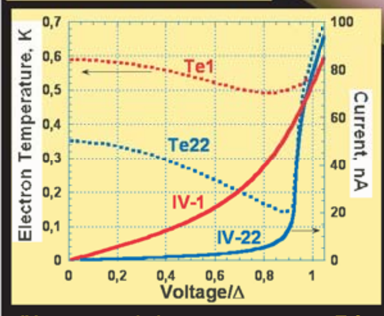
$$NEP_{phot} = 4.3*10^{-17} W/Hz^{1/2}$$

Analitical asymptotics:

$$T_e = (T_{ph}^5 + \frac{P_0}{N\Sigma\Lambda})^{1/5}$$

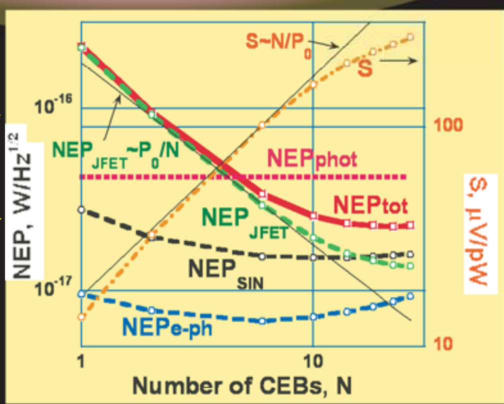
$$S_V = \frac{k}{e}\left[-\frac{(\Delta - eV)}{k}\left(\frac{N}{P_0}\right)\right]$$

$$NEP_{JFET}^2 = \frac{\delta V^2}{S_V^2} = \frac{\delta V^2}{\left(\frac{k}{e}\right)\left[-\frac{(\Delta - eV)}{k}\left(\frac{N}{P_0}\right)\right]^2}$$



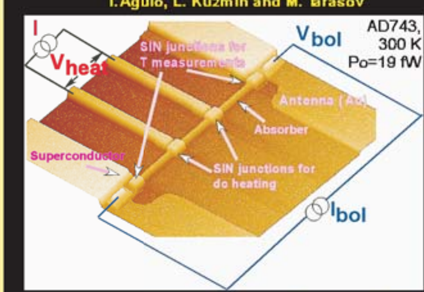
IV curves and electron temperature T for the array of 22 CEBs and a single CEB (P_0=5 pW)

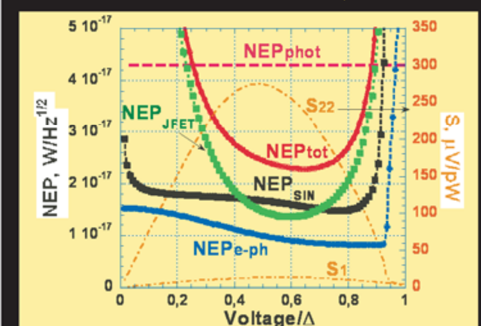
NEP components and photon NEP (for P_0=5 pW) in dependence on the number of CEBs in a series array. The responsivity S is shown for illustration of effect of the CEB number. Thin lines show asymptotics for S and NEP_{JFET}



Noise characterization of the single CEB

I. Agulo, L. Kuzmin and M. Tarasov





NEP components for the 22 CEB array (P_0=5 pW I_{JFET}=5 fA/Hz$^{1/2}$, V_{JFET}=3 nV/Hz$^{1/2}$, R=1 kOhm, Λ=0.01 µm^3). At the optimal point, the background limited mode is realized. Responsivity is shown for a 22 CEB array S22, and for a single CEB, S1, for comparison

Conclusions:

- Problem: No chance to achieve photon noise for high power load using a single current-biased CEB with JFET readout due to degradation of responsivity
- Decision: Series DC array of CEBs with parallel RF connection by additional capacitances for splitting a power load between CEBs
- Realization: Parallel/series array of bolometers could be used for any power load to achieve photon noise sensitivity with a JFET amplifier in current-biased mode
- Balloon project BOOMERanG: Power load = 5 pW per polarization, the photon noise NEPphot=4.3*10^{-17}W/Hz$^{1/2}$.
- CEB array: NEPtot=2.3*10^{-17}W/Hz$^{1/2}$ @ 300 mK with a room-temperature JFET amplifier used in current-biased mode as a voltmeter