On the sensitivity limitation in the HEB mixers

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***Abstract*—While the superconducting HEB mixer remains the most sensitive heterodyne detector beyond 1.3 THz, its sensitivity is still well below the known quantum and thermal limits. We analyze possible limitations imposed by the biasing scheme as well as the parasitic effects distorting the noise temperature measurements.**

***Keywords*—hot-electron, mixer, terahertz.**

THE Hot-Electron Bolometer (HEB) introduced in [1] is the detector of choice for heterodyne spectroscopy in the THz range above the frequency where the SIS mixer stops working (≈ 1.3 THz). Still, a gap between the SOA noise temperature in HEB mixers and the quantum limit $T_{QL}^{DSB} = h\nu/2k_B$ is several times greater than that for the SIS mixers and there has been no good explanation of why this is the case.

Meanwhile, aggressive attempts to beat the sensitivity records sometimes led to reporting extraordinarily low noise temperature values that could not be reproduced by others (see, e.g., [2]. Another issue has been the use of the Y-factor technique in a way producing a receiver noise response not related to the mixing process. The latter issue is specific to the HEB which is a total power detector. Since most of the measurements have been done using HEB devices integrated with an ultra-broadband (several THz bandwidth) log-spiral antenna, the THz power from the 295K calibration target impinging an HEB detector can easily be several nW. This is a large power for a typical NbN HEB that causes the so-called "direct detection," a change of the output noise due to the shift of the bias point or of the standing wave between the mixer and the LNA (in the absence of the microwave isolator), or both.

By mixing two 2.5 THz monochromatic sources, we investigated the behavior of the mixer conversion gain in an NbN HEB device as a function of the LO power and dc bias. We found that the conversion gain increases as the LO power decreases. However, when the IVC develops an N-shape, the gain abruptly drops (Fig. 1). At the same time, the IF spectrum changes from the single tone into an intermodulation distorted spectrum thus indicating the presence of 10-20 MHz oscillations in the dc bias and/or IF circuit [3]. Even though the IVC appears to be continuous in this regime it is actually a superposition of the "real" dc N-shaped IVC and the time-averaged rectified contribution of fast MHz oscillations. Y-factor measurements performed under such conditions would have a contribution of the electrical noise associated with the oscillations triggered by the "direct detection."

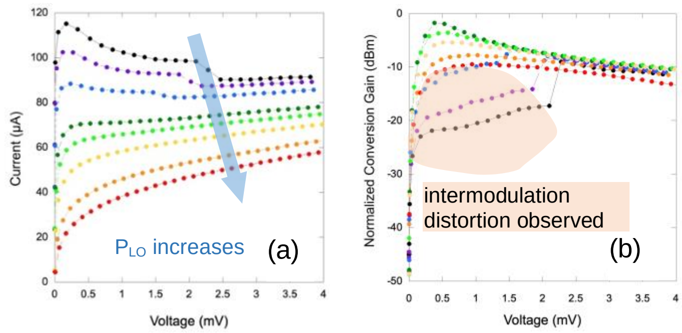

Fig. 1. (a) IVCs vs LO power in an NbN HEB at 4.3 K. (b) conversion gain vs LO power. The color of the symbols matches to that in Fig. 1a.

It is obvious that the regimes when the "direct detection" and/or the intermodulation distortion situations should be carefully avoided in the Y-factor measurements. The former regime can be mitigated by the use of a cold narrowband bandpass THz filter. On the other hand, the bolometric mixing model describes the transition to the N-shaped IVC with the decrease of the LO power continuously and predicts the gain under those hypothetical conditions to be much larger than that for the monotonic IVC. The operation of an HEB mixer in this regime has never been attempted. However, the counterpart direct detector TES always operates in this "voltage-biased" regime. The drastic difference in the approaches is due to the circuit instability issue which is much more severe in the case of the multi-GHz HEB IF circuit compared to the 10-100 kHz TES readout circuit. A solution allowing stable operation of the HEB mixer with the oscillations critically damped would lead to a much higher conversion gain followed by an improved noise temperature.

REFERENCES

[1] E. M. Gershenzon, G. N. Gol'tsman, I. G. Gogidze *et al.*, "Mixer of millimeter and submillimeter wave range based on heat-up of electrons in resistive state superconducting films," *Sverkhprovodimost': Fizika, Khimiya, Tekhnika*, vol. 3, pp. 2143-2160, 1990.

[2] I. Tretyakov, S. Ryabchun, M. Finkel *et al.*, "Low noise and wide bandwidth of NbN hot-electron bolometer mixers," *Appl. Phys. Lett.*, vol. 98, p. 033507, 2011.

[3] R. F. Su, Y. D. Zhang, X. C. Tu *et al.*, "Microwave probing of relaxation oscillations related to terahertz power detection in superconducting hot electron bolometers," *Supercond. Sci. Technol.*, vol. 32, p. 105002, 2019.

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