Noise Temperature of a Wideband Superconducting HEB mixer

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***Abstract*—In this paper we report on the development of a log-spiral antenna coupled superconducting HEB mixer which has a RF bandwidth of 0.2-2 THz. The DSB receiver noise temperature (T_{rec}) has been measured from 0.2 THz to 1.4 THz with same measurement setup at 4 K bath temperature, the uncorrected T_{rec} shows good performance in the whole operating frequency and is 700 K at 0.2 THz, 700 K at 0.5 THz, 750 K at 0.6 THz, 750 K at 0.85 THz and 1000 K at 1.34 THz. The calibrated intrinsic noise temperature of HEB device shows a frequency independent performance across the gap frequency.**

***Index Terms*—Superconducting HEB mixer, receiver noise temperature, wide band, frequency dependence**

I. Introduction

Superconducting hot-electron bolometer mixers [1], with the advantages of high sensitivity and low LO power requirement, have been already used in ground-based [2] and space-based observatories [3]. Unlike superconducting SIS mixers, superconducting HEB mixers don't suffer from a cut-off frequency set by the superconductor's energy gap (gap frequency) [4], therefore they can be used in whole THz frequency range if integrating with different antenna feeds. A non-uniform absorption model of superconducting HEB mixer has been proposed recently [5], the frequency dependence of intrinsic noise temperature across the frequency gap has been theoretical investigated but hasn't been experimentally proved.

A planar log-spiral antenna [6] coupled superconducting HEB mixer can achieve very wide input bandwidth, making it good choice to study the noise temperature performance far below and beyond the gap frequency. In this paper, we report on the design and characterization of a spiral antenna coupled superconducting NbN HEB mixer whose frequency range is from 0.2 THz to 2 THz. The receiver noise temperatures across the gap frequency are studied in particular.

II. HEB Mixer Design

The 0.2-2 THz superconducting HEB mixer consists of a 2 μm wide, 0.2 μm long and 5.5 nm thick NbN microbridge based on a highly resistive and natively oxidized Si substrate, and a self-complementary log-spiral planar feed which couples the input RF and LO signal to the NbN microbridge.

A scanning electron microscope (SEM) micrograph of the measured device is shown in Fig. 1. The parameter $a = 0.32$ was chosen to build the log-spiral arms of the feed according to $r = ke^{a\phi}$ with ϕ being the azimuth angle and a being the distance from the geometric center of the spiral. The size of a spiral portion of the feed is defined by the outer and inner diameter. The outer diameter (D = 300 μm) is the diameter of the smallest circle that encompasses the spiral structure. The inner diameter (d = 8.4 μm) is the diameter of the smallest circle at which the arms still obey the spiral equation.

The superconducting HEB device was fabricated at LERMA based on an in-situ process. Unlike conventional processes [7] with a superconducting layer adopted to improve the contacting layer quality, the Au contact layer is directly deposited on the NbN film after an in-situ cleaning by the argon plasma. A 5 nm titanium layer is used as an adhesion layer. Then a lift-off process is performed on the Au layer to form the HEB's electrodes, the antenna, the transmission lines and the contact pads. The width of the microbridge is determined by reactive ion etching through a mask made of nickel. Finally, a dielectric SiN layer was deposited on the whole substrate for protection [8].

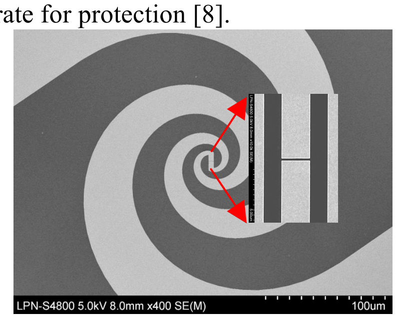

Fig. 1. SEM image of a log-spiral antenna integrated NbN HEB mixer on silicon. The light gray area is the gold antenna structure, while the dark area is the Si substrate. The close-up picture shows the structure of micro-bridge.

III. Receiver Noise Temperature

The noise temperatures of this HEB mixer are characterized at 0.2 THz, 0.5 THz, 0.6 THz, 0.85 THz and 1.34 THz using the Y-factor method. The measurement setup is illustrated in Fig. 2. The HEB device is glued to the backside of an elliptical Si lens which has a diameter of 10 mm and an extension length of 1.149 mm, and is mounted into a copper mixer block anchored on the 4 K cold plate of a close-cycled cryostat. The LO signals are provided by different frequency multiplier chains. The beam from the LO source is collimated by an objective Teflon lens, and then coupled into the cryostat through a 25 μm Mylar beam splitter. The cryostat has a 1.5 mm thick high-density polyethylene (HDPE) window and a Zitex G104 infrared filter. The mixer intermediate frequency (IF) output signal goes through a bias-tee and an isolator, and is then amplified by a cryogenically cooled low-noise amplifier (LNA) of 35 dB gain and a room temperature amplifier of 40 dB gain. The IF output signal is filtered at 1.5 GHz within a bandwidth of 80 MHz and recorded by a square-law detector.

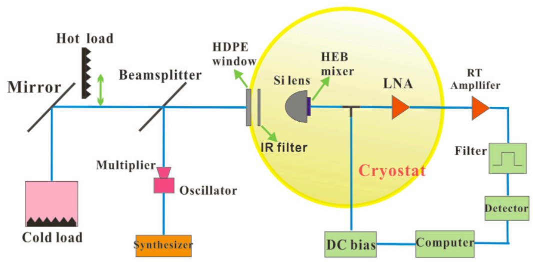

Fig. 2. Diagram of the experimental setup.

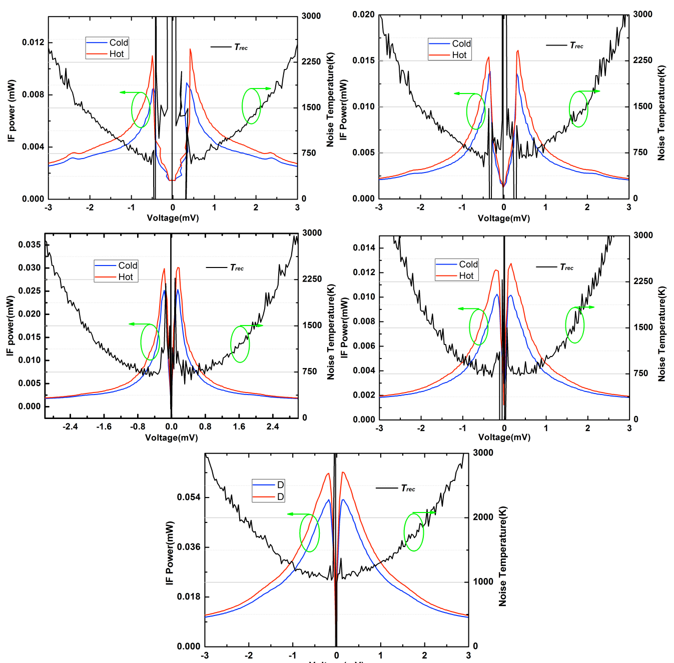

Fig. 3. Measured receiver IF output power (left axis) for the hot-and cold-load at an optimal LO power and the corresponding DSB receiver noise temperature (right axis) at 0.2 THz, 0.5 THz, 0.6 THz, 0.85 THz and 1.34 THz, shown as a function of the mixer dc-bias voltage.

Fig. 3 shows the measured receiver IF output powers at 295 K and 77 K and the corresponding receiver noise temperature as a function of the HEB dc-bias voltage. The temperatures of the hot and cold blackbody (295 K and 77 K) were calibrated to the effective radiation temperatures in terms of the Callen-Welton definition [9]. In addition, the direct detection effect was compensated by adjusting the LO power [10] to make the IV curves unchanged between the hot-load and cold-load measurement. The lowest uncorrected DSB receiver noise temperatures at these frequencies are listed in Table I. The result indicates that this HEB mixer has high performance in a broad frequency range. The calibrated intrinsic noise temperature of HEB device shows a frequency independency.

TABLE I

Lowest DSB receiver noise temperatures

Frequency (THz)	0.2	0.5	0.6	0.85	1.34
Uncorrected $T_{rec}(K)$	700	700	750	750	1000
Corrected $T_{heb}(K)$	290	295	290	295	300

IV. Conclusion

We have successfully developed a spiral antenna coupled superconducting NbN HEB mixer which has a high performance over a frequency range of 0.2-2 THz. The corrected intrinsic noise temperature shows a frequency independency over the whole frequency range across the frequency gap.

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