NBN PHONON–COOLED HOT ELECTRON BOLOMETER MIXER DEVELOPMENT AT IRAM

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Introduction :

NbN phonon cooled bolometric mixers offer very competitive performance up to the highest frequencies. Processing of NbN HEB's is relatively easy and reliable and due to microstructuring by Ebeam lithography LO power could be reduced to a level where pumping is possible with solid state sources and simple beam splitters up to around 1 THz. The typical sheet resistance for very thin NbN films is relatively well adapted to a variety of antennas or waveguide coupling structures. All these points make the NbN bolometric mixers very attractive for radio astronomical applications in the THz regime [8]. The main problem with the NbN devices however stays the limitation in IF bandwidth and contrary to predictions bandwidths beyond 2-3 GHz are hardly reached for NbN films on substrates which are suitable for high frequency applications. After establishing a reliable process [10], we have focused on the characterisation of the devices and improvements of antenna device coupling.

Bandwidth characterisation :

A variety of IF bandwidth characterisations for HEB's have been proposed in the past [1,2,3,4]. The IF bandwidth of a HEB mixer generally depends on the bias point which itself strongly influences noise and gain of the mixer. At heterodyne operation a global optimisation of all parameters is therefore required which is time consuming and often not straight forward.

For optimisation of film processing parameters, impedance measurements offer a more direct way to access the intrinsic characteristic time scales of the NbN films.

After having measured the bandwidth of a device with a 5 nm thick NbN film by a direct signal injection method [4], we investigated the possibilities of characterisation by an impedance measurement similar to the procedure, which was described by Karasik et al. [1].

In order to allow for rapid measurements we installed the set-up in a dipstick, which could be immersed in liquid He. The measurement was done with a HP8510 network analyser. The DC bias was directly fed over the internal bias input of the HP8510. The measurements were performed with a sweep between 200MHz and 5GHz and a power level of –60 dBm at the device. Using the available signal averaging option, we did not find any particular need for an additional cryogenic wide band amplifier. With a similar calibration scheme as described by [1] we obtained the complex impedance as plotted in Fig. 1. The solid lines show the results of a simultaneous fit to the real and imaginary part of the measured impedance to a theoretical model [9] :

$$Z(\omega) = R \cdot \frac{1+C}{1-C} \cdot \frac{1 + i\omega \frac{\tau_T}{1+C}}{1 - i\omega \frac{\tau_T}{1-C}}$$

Where R is the device resistance and τ_T (intrinsic electron temperature relaxation time) and C (self heating parameter) were the free fitting parameters. The fit is good for the real part of the impedance but only just acceptable for the imaginary part, a phenomenon that has been observed by other groups. The resulting IF bandwidth is 1.7 GHz, which is in reasonably good agreement with the bandwidth of 2GHz measured by the direct injection method.

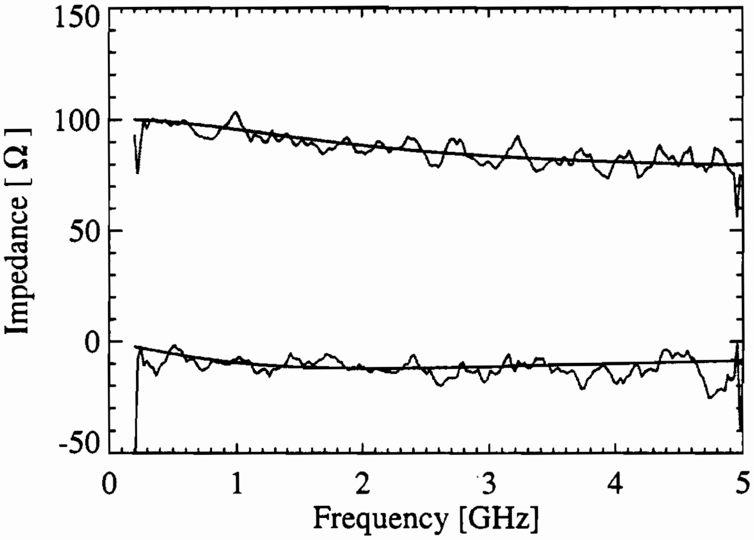

Fig. 1: Measured complex impedance for a HEB with a 5nm NbN film.

New Antenna Detector Structure for very high Frequencies :

Our first results on NbN HEB mixers were obtained with single lean bowtie dipoles in combination with elliptical or hyperhemispherical quartz lenses [4]. Such an antenna is largely sufficient to pass most of the radiation pattern through a dewar window of reasonable size and therefore allows for simple mixer tests. However the resulting beam is not well suited for coupling to practical antennas for radio astronomy. A variety of planar antenna structures have been proposed for HEB Mixers [1,4,5,6]. Here we investigated a double dipole structure with two different integration schemes of the HEB mixer elements.

In a first structure one central bolometric element is fed symmetrically over coplanar striplines (Fig 2). IF output and DC bias are connected over coplanar rf blocking filters on either side. Other groups [5] have successfully used the described double dipole structure with a central detector element with slight modifications. The structure was designed for a working frequency around 800 GHz assuming a fused quartz substrate.

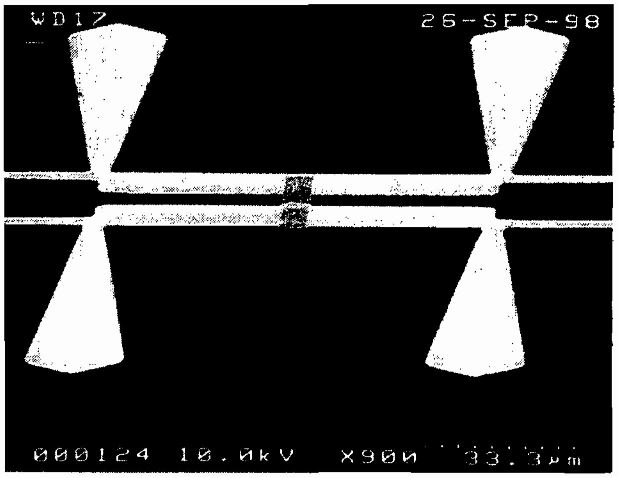

Fig 2 Double dipole with single central HEB element.

To control the frequency dependent response of this antenna detector structure we performed FTS measurements using the bolometer element in the direct detection mode. The FTS spectrometer consisted of a computer controlled Martin-Puplett Interferometer with a chopped liquid nitrogen cold load and a phaselock amplifier which is read out automatically. The response is plotted in Fig 3. The measured response is very wide band and shows that the structure is reasonably well tuned to 800 GHz. It should however be mentioned that the atmospheric absorption which is clearly present in our current set-up (typical pathlength is 1.5 m) does not allow to exclude a coupling maximum at higher frequencies. In this sense the measurement should be considered preliminary until we have installed a dry nitrogen container for the spectrometer.

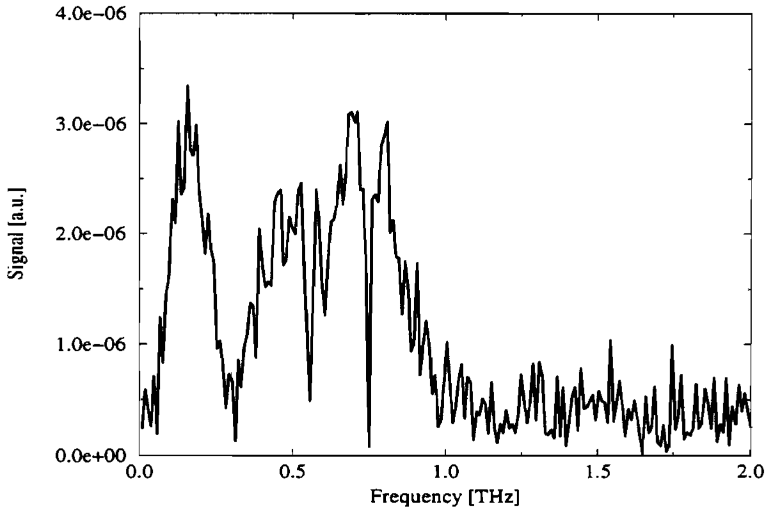

Fig.3: FTS measurement of a double dipole structure with central HEB element designed for 800 GHz .

The result for heterodyne mixing is given in figure Fig.4. The heterodyne mixing results for this structure are comparable to the results which were obtained with a simple dipole. Yet future beam measurements still have to show the desired improvement in the beam shape.

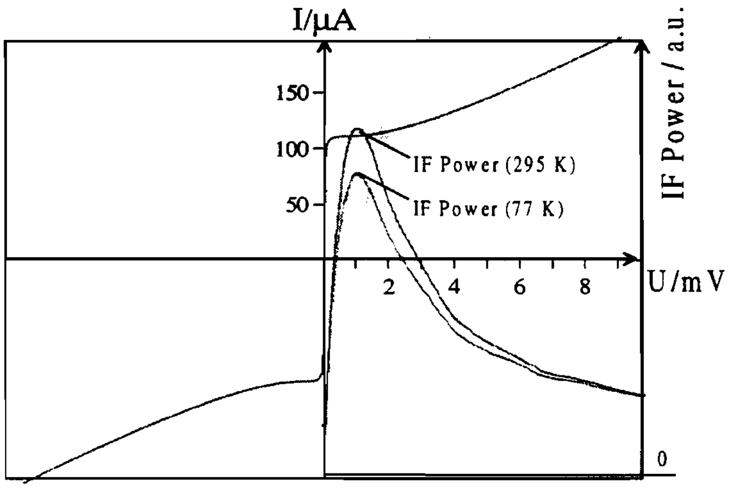

Fig. 4: Heterodyne measurement of a double dipole structure with central HEB element for 800 GHz . The best DSB receiver noise temperature is 1250 Kelvin (IF 1.5 GHz).

A disadvantage of the described double dipole is that the coplanar connections to the central detector element perturb the antenna pattern and at very high frequencies cause also undesired ohmic losses. Furthermore control over the characteristic impedance of the connecting transmission lines becomes increasingly difficult for frequencies above 1 THz.

The wide range of achievable device impedance for NbN HEBs did suggest another antenna coupling solution for the double dipole. We propose a structure where each dipole is equipped with its own HEB element and the signals of both dipoles are combined in the IF path Fig. 5. With such a structure the losses in the connections to a central mixing element are avoided. This makes the structure especially interesting for the very high frequency region where ohmic losses are important.

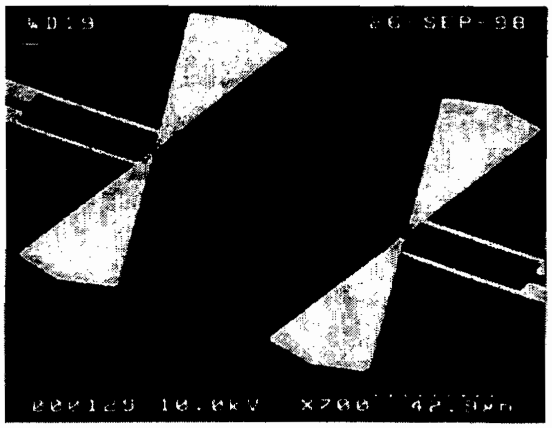

Fig 5 Double dipole with individual HEB elements for each dipole.

In a sense such a structure represents a miniature interferometer where the phase reference is given by the common local oscillator radiation field. Obviously such a structure requires identical mixer elements in order to conserve the symmetry of the antenna and therefore challenges processing of the devices. Gain imbalance would cause an increased sidelobe level and phase imbalance would lead to a beam deflection.

It should be mentioned that a simple FTS measurement does not anymore represent very well the frequency behaviour of the heterodyne mode because in the direct detection mode used for the FFT measurements one measures the incoherent sum of the response of the individual dipoles rather than the phased response.

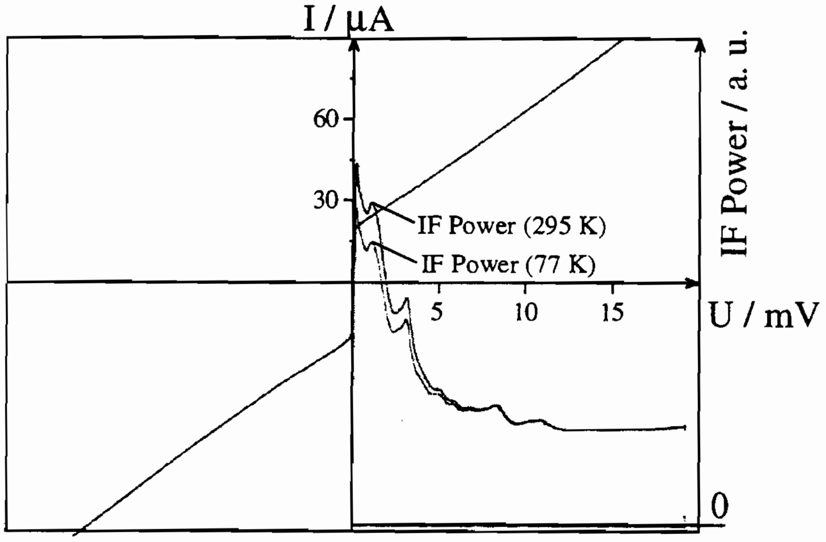

Fig. 6: First heterodyne measurement of a double dipole structure with individual HEB elements for each dipole. The best DSB receiver noise temperature is 1800 Kelvin at 810 GHz (IF 1.5 GHz).

First heterodyne results with the distributed mixing element structure at 800 GHz yielded receiver noise temperatures which were higher than our best results. However the conversion curve is cut off at the most sensitive area and we were clearly LO power starved in these measurements (Fig.6).

We do not yet really understand the particular structure of the conversion curves. As both of the HEB elements are connected with a common superconducting Nb film on either side of the elements we investigated possible SQUID effects but could not find any sensitivity to magnetic field. We suspect that the observed effect does origin from an instability which is due to the in parallel bias of the two elements.

Possible improvement of this problem could be obtained by completely separated IF branches for the two antenna elements with individual DC bias and cryogenic amplifiers. Although the effort seems high, such a solution would have other very interesting features as for example the possibility of very fast beam switching by a phase switch in the IF line.

The described antenna detector coupling scheme is not restricted to double dipoles but can also be applied for double slot antennas if the impedance level of the HEB elements can be made reasonable close to the feed point impedance of the slots.

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