A 2 × 2 Array Receiver at 1.4 THz based on HEB mixers and a Fourier Phase Grating Local Oscillator

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Abstract— **We report on realization of a 2 × 2 NbN hot electron bolometer (HEB) array receiver using multiple local oscillator (LO) beams that are obtained from a Fourier phase grating mirror. The grating splits a 1.4 THz single beam into four uniform sub-beams. Two 50mm lenses are applied to collimate each beam in order to achieve a spacing of 12mm between them. The LO power in each beam is shown to be enough to fully pump the HEB mixer elements. The IV curves, noise temperature and IF bandwidth for each pixel is then characterized.**

I. Introduction

For heterodyne radio astronomy receivers above 1 THz, the superconducting NbN HEB is the most suitable mixing detector due to its operating frequency range, near quantum noise limit performance, low local oscillator (LO) power consumption, and no needs for an external magnetic field. They have been used in several astronomic telescopes[1,2,3] for mapping fine structure lines. One of the structure lines is the ionized nitrogen line [NII] at 1.4 THz.

The mapping process, however, is inefficient for a single pixel receiver. Thus, an HEB array receiver is preferred to improve the mapping speed while retaining excellent performance. A number of studies[4,5] have demonstrated HEB arrays and characterized their performance. Despite the difference in array structure, all of these arrays use a divergent LO beam to pump the HEB mixers. A large percentage of LO power will be wasted in this way. In addition, each pixel may suffer from a non-uniform distribution of the LO power.

Based on the Fourier series expansion theory, a grating mirror that can transform a single 1.4 THz LO beam with an incident angle of 25 deg into a 2 × 2 pattern of four LO beams is designed[6]. We applied two identical lenses to achieve collimated far field beams at a spacing of 12mm between each beam, which is consistent with the HEB elements in our array mixer block (Fig 1b). Each pixel is then biased independently and has its own IF chain. The IV curve, LO power budget, noise temperature and IF bandwidth are determined for each pixel. Since only two ports are available in our measurement cryostat at the moment, we characterize our array in pairs of pixels, keeping one pixel as the reference and measure other three.

II. Measurement Scheme

The HEB mixer array block and measurement setup for our array receiver are shown in Fig 1.

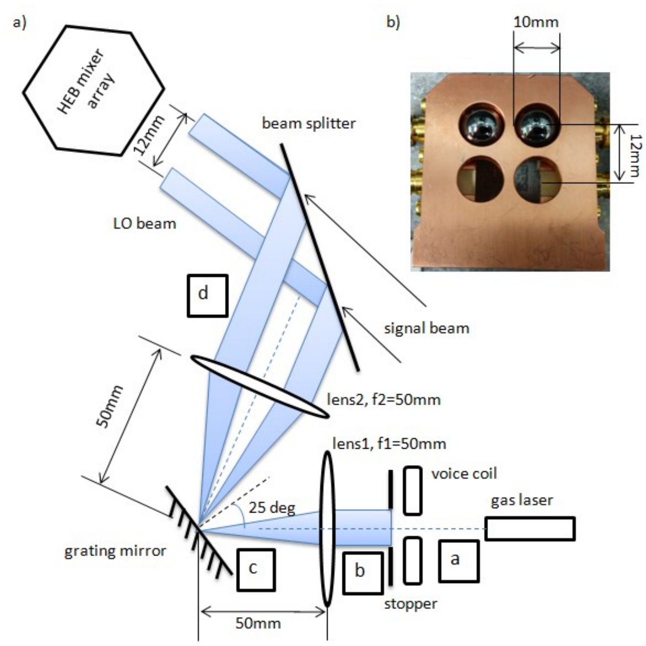

Fig 1. a) Optical part of the measurement setup. b) Layout of the block of four HEB mixers.

Our 1.4 THz LO is originated by an Far-Infrared gas laser with approximately 1mW emitted power. The LO power is stabilized using a voice coil based on optical attenuator that uses the HEB bias current to remove amplitude fluctuations in the laser[7]. A variable aperture stop is used to control the beam size in order to avoid overlapping between each beam.

It also helps to achieve a Gaussian beam by blocking the ring around the main beam. The grating mirror is placed at the focal point of two 50mm High Density Polyethylene (HDPE) lenses to achieve a desired peak-to-peak spacing between beams, and to collimate each beam.

Finally, the 4 beams are reflected from a 6 µm thick beam splitter so that they can be combined with a hot/cold load for characterization of the mixer sensitivity. The IF circuit of each pixel, LO budget calculation, noise temperature and IF bandwidth measurement techniques can be found elsewhere[8,9].

III. Results

A. 2 × 2 LO Beam Patterns

Fig 2 shows the beam pattern along the optical path (see Fig 1a). The beam patterns after lens2 indicate four, nearly collimated Gaussian beams. The peak to peak spacing is around 12mm, while the diameter of each beam is about 7mm. This pattern is perfectly matched to our array block in Fig 1b).

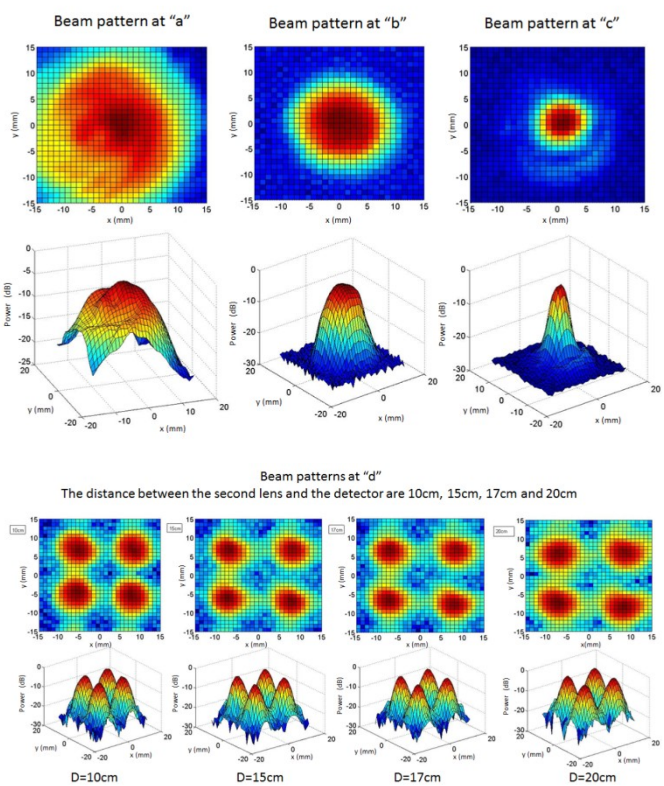

Fig 2. LO beam patterns along the optical path

B. IV Curves of Two Pixels Array

For the first time, we tried to pump a 1 x 2 mixer array due to the limitation of our cryostat window. Fig 1 b) is the layout of our array and each element is a twin slot antenna coupled NbN HEB mixer with the same HEB dimensions, as shown in the Table 1.

Table 1

Dimensions of the HEB mixers and the twin slot antenna

HEB mixer				
l (um)	w(um)	t (nm)	R (Ohm)	Tc (K)
0.19	1.5	7	130	9.45
Twin slot antenna				
L (um)	W (um)	S (um)	Frequency (THz)	
61	5	35	1.4	

Note: l and w are the length and width of the bolometer, t is the NbN thickness, R is the resistance in room temperature and Tc is the critical temperature. L, W and S are the length, width and separation of the twin slots. Frequency is the designed operational frequency for the twin slot antenna.

The IV curves of the pumped HEB mixer array are plotted in the Fig 3. We move the cryostat 12mm vertically and two mixers array is again fully pumped by the other two beams. This indicates that if we have four pixels, all of them would be fully pumped.

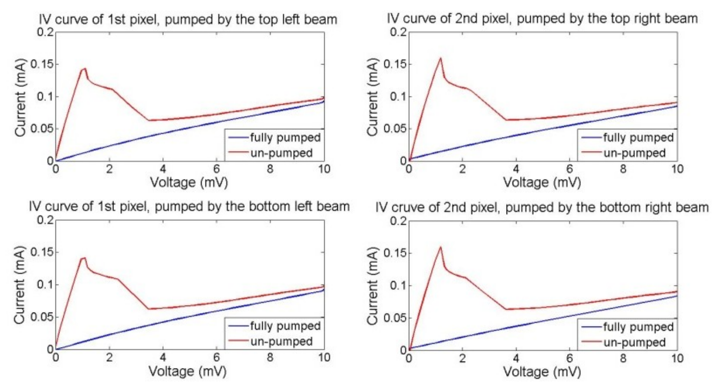

Fig 3. IV curves two HEB mixers: un-pumped and pumped state. The top two IV curves are pumped by the top two LO beams, while the bottom two are pumped by the bottom two LO beams.

C. Bias Currents of Two Pixels

The two bias currents of the HEB mixer array are measured simultaneously under fully pumped and optimal pumped (0.8mV, 0.028mA) situation without any stabilization, as shown in the Fig 4. The current scale is set to be the same in order to compare the fluctuations in currents under two pumping cases.

The Pearson product-moment correlation coefficient is defined as the measurement of linear dependence of two variables. The correlation coefficient between currents of two pixels in fully pumped case is 0.15, while the correlation coefficient in the optimally pumped case is 0.8, that indicates a very strong correlation between the two pixels' currents in this case. The very week correlation between the currents in fully pumped situation is because the two HEB mixers are already saturated. So the fluctuation in LO power has no significant influence on the current stability. The strong correlation in optimal pumped situation is due to the fact that two LO beams are duplicated from the same LO beam. This also suggests that the instability in current of the HEB mixer is mainly caused by the fluctuation in LO power.

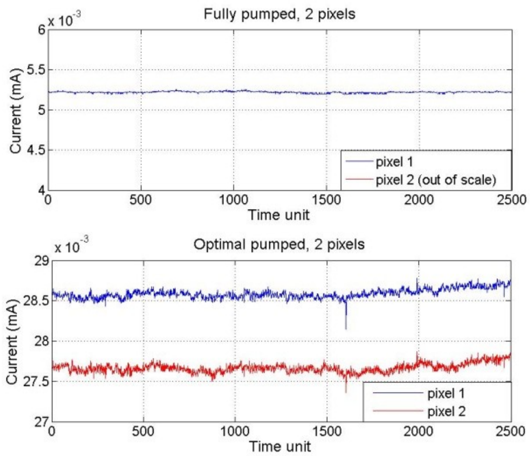

Fig 4. Currents of two HEB mixers under fully pumped and optimal pumped situations.

D. Expected Results

This measurement is being expanded to characterize all four mixers. Data will be presented for noise temperature and IF bandwidth of the full array. Moreover, the possibility of using one voice coil to stabilize the bias current of four HEB mixers will be investigated.

IV. Conclusions

We succeed in applying a designed Fourier phase grating mirror in our HEB array receiver at 1.4 THz. We demonstrate that our phase mirror provides an efficient and highly uniform distribution of the LO power that was not previously possible with the flood illumination approach. A beam pattern well matched to our array is formed using 2 lenses in combination with the Fourier phase grating. A 2 × 2 array is then fully pumped for the first time. Based on the correlation of two pixels' currents, we prove that the fluctuation in LO power is the main contributor to the instability of the bias currents.

Acknowledgement: We thank Chris Walker for many valuable discussions on the array.

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