# Demonstration and Stabilization of a 2x4 HEB Array Receiver at 1.4 THz Based on a Fourier Phase Grating Local Oscillator

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**Abstract— This paper is a report on the demonstration and stabilization of a 2x4 NbN hot electron bolometer (HEB) array receiver for GUSTO based on a multiple beam local oscillator (LO). Through the combination of a FIR Gas laser and a Fourier phase grating we were able to generate a 8 beam pattern at 1.4 THz. For the array demonstration, it used a 2x2 HEB mixer array which was translated vertically to match the full 2x4 LO beam pattern. Here two lens with a 60 mm were applied to reduce the beam pattern divergence, allowing for a 12 mm spacing between the beams to be achieved at 130 mm from the grating. To stabilize the array receiver, we introduced a new stabilization method, requiring only a voice coil PID controlled loop between the beam originated from the gas laser and a given pumped pixel. The total power Allan time measurements indicate a five times improvement on a two-pixel system stability.**

## INTRODUCTION

NbN hot electron bolometers (HEB) are currently the most suitable mixers for heterodyne terahertz astronomy ( > 1 THz). The reasons for this are its operating frequencies ranges, low noise temperature and low local oscillator (LO) requirements for operation, although somewhat limited in terms of the intermediate frequency (IF) bandwidth. Thus far, this devices have been used in different types of astronomic telescopes in order to map different lines of terahertz radiation.[1]–[3] Since the mapping process is inefficient for single pixel receivers, multi-pixel arrays are now demanded for airborne (SOFIA) and balloon borne THz observatories ( GUSTO), and future space telescopes (FIRSPEC, OST, TST). The use of multi-pixel arrays allows for an increase of the mapping speed while maintaining device performance.

GUSTO is a NASA balloon borne observatory, which will map three astronomic lines: [NI] at 1.4 THz, [CII] at 1.9 THz, and [OI] at 4.7 THz. All three lines will be measured simultaneously across the galactic plane of our Milky Way. This will be achieved using three independent 2x4 HEB array receivers. Until now some array receivers have been reported using different LO solutions: defocused LO[4], [5] or multiplexed LO[6]. Also, another possible solution would be the use of multiple LO sources as is being thought for the lower frequencies bands of GUSTO. In the case of the 4.7 THz array, it requires the use of quantum cascade lasers (QCL) as the LO source. This type of lasers are currently very limited regarding their power output and therefore using it as a divergent LO would require power levels not yet available. On the other hand, having multiple QCL's is also not an option because of the cooling footprint required to run them and the complex setup to frequency locking these devices. Due to these limitations, the best candidate solution is the multiplexing of the LO beam into sub beams, which can be achieved using a Fourier phase grating.

The Fourier phase grating,[7] is a reflective grating whose surface profile is based on the Fourier series expansion and can be tailored to transform a single incident LO beam into any desired beam pattern. In this work, two prototype gratings were designed to obtain a 2x2 and a 2x4 beam pattern respectively at an optimum angle of 25 degrees, for a central operation frequency of 1.4 THz. The simulations and experimental characterization have a good agreement, having the gratings measured efficiency of 66-73%. More details on these gratings can be found in other research.[8]

When dealing with heterodyne receivers, the IF time stability is a very important figure that determines the optimal observation strategy for an instrument.[9] To determine this figure it is employed the Allan variance method from which the Allan time is extracted.[10] The Allan time is defined as the optimum integration time of a given system, after which no improvement is achieved on the quality of the signal being measured. Some detailed studies using this method to characterize HEB heterodyne receivers can be found.[11]–[13] It has been found that HEB's suffer from poor stability performance mainly because of their sensitivity as direct detectors. Therefore, any fluctuations in the LO will be sensed by the device and is one of the main source of instability of the mixers. In this work we study the implementation of a HEB stabilization scheme introduced by Darren et al [13], with the goal of applying it to the stabilization of multi-pixel systems.

## Measurement Schemes

Our experiments can be divided into two parts. One is the 2x4 array demonstration, where it used a Fourier phase grating with a 2x4 beam pattern. The second is the stabilization scheme implementation where we used another grating with a 2x2 beam pattern, allowing for more power in each beam, and making it easier to study the stabilization. In terms of measurement setup both are very similar. The setup to measure the Allan time is represented in Fig. 1. A more detailed description of the optical path, IF circuit and PID control loop can be found elsewhere[13], [14]. Using this setup, we make use of the four-beam pattern grating to match the array receiver, while allowing to measure simultaneously the IF power of two HEB. Here a PID feedback loop between one of the pixel and the voice coil can be used. Using this setup, the total power Allan time is measured.

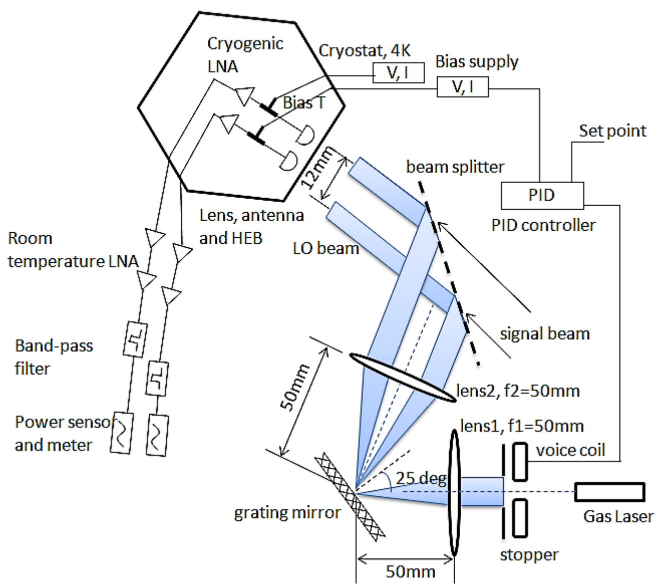


Fig. 1 Allan time measurement scheme. The optical path of the LO is similar for the 2x4 pixel array demonstration, with the devices being pumped directly from the grating instead of using a beam splitter.

A similar setup is used for the array demonstration. Since the beam pattern now is bigger (8 beams instead of 4), it requires an adaptation using lens with bigger diameter. In order to keep an acceptable F#, it was determined the best lenses required would have 60 mm focal length and 55 mm diameter. With this change, the distance from the gratings to the lenses changed to 60 mm. Besides this, the array is being pumped directly without the use of any beam splitter, and only de DC component is measured to obtain the IV curves.

## Results

### *A. 2x4 Array demonstration*

Since an eight-pixel array was unavailable, it was used a four-pixel array in a 2x2 configuration instead. This array receiver used for both experiments uses quasi-optical coupled HEBs with an optimum LO power requirement of 89±7 nW across the four pixels. The lenses are 10 mm diameter with a pitch size of 12 mm.

The beam pattern obtained at 130 mm from the grating can be seen in Fig. 2. It shows the two positions where the array was placed, by means of vertical translation of the cryostat. In the same figure, it also shows the IV curves obtained for such positions where it's possible to see an over pump of the devices, in both situations, effectively demonstrating the array. Although an over pumping is achieved, the mismatch of the array to the beam pattern at this position should also be noticed. This happens due to the design of angular offset of the out coming beams of the grating that was not optimized for the array block available, inducing some limits on the control of the beam pattern using optics, causing this mismatch to occur.

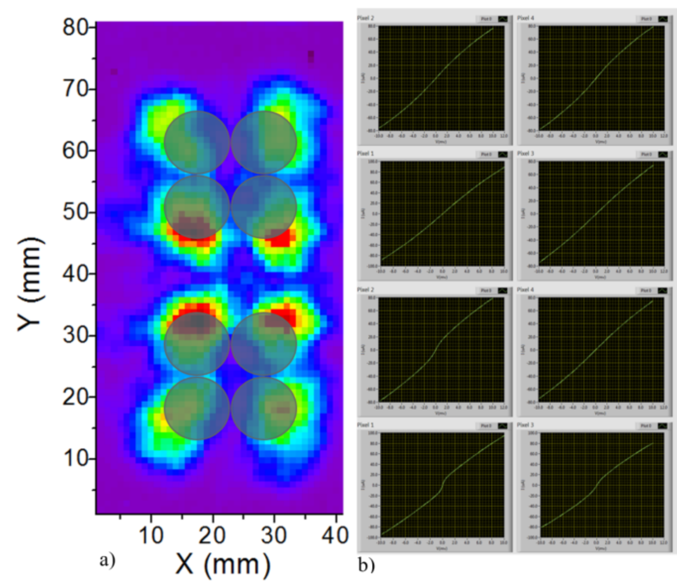


Fig. 2 Array demonstration results. a) Beam pattern at 13 cm from the grating with the placement position of the array to match the bottom and top four beams. The Y axis in the plot represents the Z dimension. b) Pumped IV curves obtained at the given arrays.

### *B. Array stabilization*

When looking at the current of two pixels, both being pumped with a different beam originated at the grating, a similar drift structure together with other smaller effects were noticed. Cognizant of these effects, it was studied the current in frequency domain, to confirm the existence of a correlation. In Fig. **3** it can be seen the FFT for both currents. For higher frequencies, it can be seen some differences in the peaks intensity, but when looking at the first 20 Hz its clearly the existence of a correlation between both pixels.

Since the LO beams generated at the grating are all duplicated from the original, and the two current are found to be highly correlated, the possibility to stabilize both currents using a single PID controller was studied. In order to compare the differences between having both pixels running free (without stabilization) and the case where one is running free and the other being stabilized (using the PID feedback loop), the total power Allan variance was measured. In Fig. 4 the results obtained can be seen.

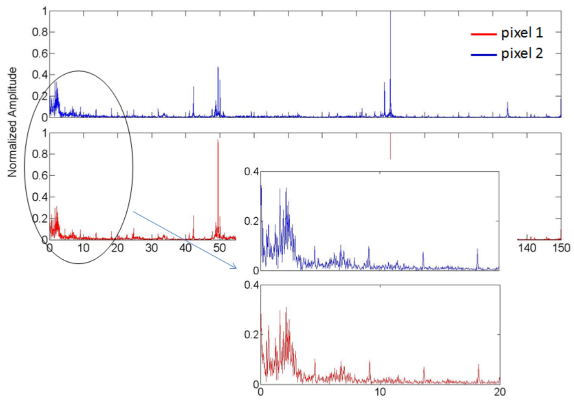


Fig. 3 Measured currents of two free running pixels in frequency domain.

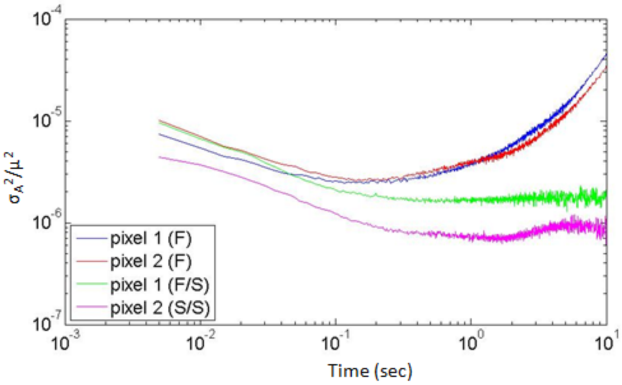


Fig. 4 Allan variance time for two IF chains when the HEB mixers are in optimal pumped stated. For the free running group, red and blue curve, the Allan time is 0.15s, while for the stabilization group, green and pink curves, the Allan time is 0.8s and 1.5 s respectively.

When letting both pixels to run free, without LO stabilization, the Allan time is very short, around 0.15 s. This result was expected since we are using a FIR gas laser, which amplitude is known to be highly unstable, which combined with the direct detection of HEB leads to low stability time. When applying the stabilization to pixel 2 however, there was an improvement of this pixel Allan time to 1.5 s. Although in this case pixel 1 is still running free, it also sees an Allan time improvement of around five times to 0.8 s. Based on this result, it seems the drift noise is highly reduced, but not the 1/f, resulting in a prolonged plateau on the Allan variance plot.

## CONCLUSIONS

We successfully demonstrated an eight beam LO based on a Fourier phase grating to pump an 2x4 HEB array receiver at 1.4 THz. We demonstrate that this approach can be an efficient way of multiplexing a single LO beam although the angular offset of the out coming beams must be carefully designed, in order to optimize the match between the beam pattern and the array dimensions while avoiding undesired constrains on the optical path design.

Moreover, we achieved a five times improvement on the Allan time of a two-pixel system through the implementation of a PID control feedback loop between one pixel and the original LO beam, while leaving the second pixel running free. This result is a good indicator of the possibilities of this technique to stabilize an array receiver based on multiple beam LO. The next steps on this work will be the stabilization of the entire four-pixel array in use, and a thorough analysis of factors that critically affect the multi pixel stabilization.

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